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Children With Chinese Dyslexia Acquiring English Literacy: Interaction Between Cognitive Subtypes of Dyslexia and Orthographies

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Abstract

This study investigated the impact of Chinese dyslexia subtypes on English literacy skills (i.e., reading fluency and dictation) in Hong Kong children. Eighty-four Cantonese-speaking children officially diagnosed with dyslexia (M_{age} = 103 months) and 48 age-matched typical developing (TD) children were tested. Cluster analysis with performances on Chinese syllable awareness (CSA), Chinese phonemic awareness (CPA), Chinese phonological memory (CPM), Chinese orthographic awareness (COA), and matrix reasoning (MR) yielded three cognitive subtypes: the phonological deficit (PD) subtype, the orthographic deficit (OD) subtype, and the global deficit (GD) subtype. After controlling for English language experience, age, and gender, all three dyslexia subtypes performed significantly worse in English word reading fluency and dictation than TD children. In addition, PD performed worse in English PA; OD performed worse in English OA; and GD performed worse in all English skills except English PM. We compared the level of impairment in literacy between languages and dyslexia subtypes. In word reading fluency, all subtypes experienced less impairment in English than Chinese, while OD showed the largest English advantage. In dictation, only OD showed a significant language effect favoring English. The findings suggest that different subtypes of Chinese dyslexia bear different risks for difficulties in English literacy.

Keywords

dyslexia, subtypes, Chinese-English bilingual, basic literacy

It is a long-existing question of whether having dyslexia poses extra burden to learning a second language. This pertains to not only spoken language but also literacy. Dyslexia, as defined in *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; American Psychiatric Association, 2013), is a decoding difficulty, specifically the difficulty of mastering the relationships between the spelling patterns of words and their pronunciations. This difficulty can manifest itself in both reading and writing activities. Substantial evidence from different societies has shown that dyslexia induces difficulty in reading and writing in a second language (alphabetic L1 and L2: Fazio et al., 2020; Lindgrén & Laine, 2011; Lallier et al., 2014; nonalphabetic L1 and alphabetic L2: Chung & Ho, 2010; C. S.-H. Ho & Fong, 2005), driven by the mechanism of "cross-linguistic transfer" (Cummins, 1991; Sparks & Ganschow, 1995). Interestingly, a few studies, conducted in the context where the two languages are linguistically and orthographically in contrast, for example, English and Chinese, have identified children who have Chinese dyslexia (CCD) but have no English reading difficulties (Kalindi et al., 2015; Li et al., 2018; McBride-Chang et al., 2012, 2013; Tong et al., 2015). The findings suggest complexities in the transfer of reading difficulties from Chinese to English. This study investigated cognitive subtypes in Chinese dyslexia as a contributing factor, and examined the impact of dyslexia subtype on English reading and writing difficulties. The relation between English and Chinese cognitive-linguistic skills was also examined to shed light on multiple aspects of cross-linguistic transfer. Understanding how cognitive types of Chinese dyslexia influence English language and literacy skills can inform the practice of assessing and instructing children with Chinese dyslexia to learn to read and write in English.

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Subtypes in Chinese Dyslexia

The dual-route model of word reading specifies that the lexical procedure and the sublexical procedure are two dissociated processes in word reading, underpinned by orthographic and phonological processing, respectively (Castles & Coltheart, 1993). Phonological processing could be reflected by phonological memory, the temporary storage of phonological information, and phonological awareness, the ability to consciously detect and manipulate linguistic units in speech (Gathercole et al., 1991). Orthographic processing refers to the ability to acquire, store, and use the knowledge of representing spoken language in given written form (Apel, 2011). The dual-route model predicts existence of phonological dyslexia and surface (orthographic) dyslexia, which are caused by phonological deficit and orthographic deficit, respectively (e.g., Castles & Coltheart, 1996; Hanley et al., 1992).

The dual-route model also received some support in Chinese dyslexia. Ho et al. (2004) identified that 25% of Chinese dyslexic children with specific cognitive deficits belonged to the phonological subtype marked by the single deficit in phonological memory, and all the rest as having orthographic deficits in combination with different problems such as rapid naming and visual memory. This is in contrast to a previous study with English-speaking children which showed that almost all poor readers had phonological deficits (Morris et al., 1998).

Another line of evidence for the dissociation between phonological and orthographic subtypes comes from performance profile of reading regular and irregular characters. Using a regression technique as in Castles and Coltheart (1993), F. Ho and Siegel (2012) identified 13% dyslexic children as having phonological dyslexia and 25% with orthographic dyslexia. Using a similar approach, L. C. Wang and Yang (2014) found that 20% of dyslexic children belonged to the phonological subtype, and 33% to the orthographic subtype. However, both studies found that around 50% of their samples did not show any discrepancy between reading regular and irregular characters. Zoubrinetzky et al. (2014) argued that this could be due to a limitation in analyzing reading profiles, which might not be sensitive enough to "reduce heterogeneity in the dyslexic population and define cognitively homogeneous subgroups" (p. 13). Instead, classification directly based on underlying cognitive skills is a better approach to identify subtypes in dyslexia that is somewhat homogeneous in underlying deficits.

The subtyping studies on English and Chinese dyslexia both identified a potential global deficit subtype, which showed deficits in every cognitive-linguistic domain. One prominent characteristic of the global deficit is a significantly lower nonverbal intelligence score in comparison with other subtypes (Ho et al., 2004; Morris et al., 1998). Therefore, we included nonverbal intelligence as a classification measure to distinguish the global subtype from subtypes with specific cognitive deficits.

Cross-Linguistic Transfer of Cognitive-Linguistic Abilities

Cummins (1979) proposed the language interdependent hypothesis to account for the development of language abilities including reading and writing of bilingual children. The hypothesis states that the abilities in two languages are determined by a common underlying language proficiency, which enables the phenomenon of cross-linguistic transfer. Research studies have investigated cross-linguistic transfer from two perspectives. The first pertains to the correlational association between L1 and L2 skills. In respect of phonological skills, a large number of studies indicate that Chinese phonological awareness plays unique roles in English word reading (e.g., McBride-Chang et al., 2005) and writing abilities (e.g., Shum et al., 2016). The findings are equivocal regarding the transfer of orthographic skills, especially in the context where L1 and L2 are of linguistic contrast, that is, Chinese and English. Some researchers have found that orthographic skills are script specific and not transferable (Keung & Ho, 2009; Wang et al., 2009), in that Chinese orthographic skills did not predict English reading and writing abilities. In contrast, early experimental studies have demonstrated that Chinese children performed better than English-speaking children at English confrontational pseudo word spelling task, which requires visual memory (M. Wang & Geva, 2003). This suggests transfer of orthographic strategies, as visual-orthographic processes are largely involved in Chinese reading. In line with this finding, a few correlational studies have shown that Chinese orthographic awareness (COA) predicted English word reading (Cheung et al., 2007; Tong & McBride-Chang, 2010). The Chinese-English orthographic transfer could be attributed to analytical reading shared by Chinese and English, as well as mutually reinforced structure sensitivity across the two languages. Cheung et al. (2007) found that older Chinese children consciously extract structural regularities in writing systems, and use orthographic knowledge to read words in both languages. The correlational studies on cross-linguistic transfer were mostly conducted with typical developing (TD) children. It remains unknown whether children with dyslexia can transfer phonological and orthographic skills from Chinese to English same way as the TD children.

Apart from the correlational associations, another perspective of studying cross-linguistic transfer focuses on shared difficulties and cognitive deficits between two languages in bilingual children with dyslexia. Children with dyslexia who show phonological deficit in L1 also performed significantly lower in phonological skills in L2 compared with the TD children. Such evidence has been shown in the context where L1 and L2 are both alphabetic languages (e.g., Van Der Leij & Morfidi, 2006), as well as in children whose L1 and L2 are of linguistic contrast such as English-Chinese (e.g., Chung & Ho, 2010; C. S.-H. Ho & Fong, 2005). In respect of orthographic skills, Chung & Ho (2010) have found that Chinese children with dyslexia performed poorer in the task of English lexical decision. In contrast, Van Der Leij and Morfidi (2006) have identified children who have dyslexia in Dutch but have intact orthographic skills in English. The conflicting findings warrant further studies investigating the cross-linguistic transfer of orthographic processing.

Reading and Writing Problems in Bilingual Children With Dyslexia

It is established that cognitive demands of word reading and writing vary in function of orthographies (Geva & Wade-Woolley, 2013; McBride-Chang et al., 2005). This may result in different manifestations of reading problems in different languages. Many studies on this topic utilized the within-subject design involving bilingual dyslexic readers, such as Spanish-French (Lallier et al., 2014; Valdois et al., 2014), Dutch-English (Van Der Leij & Morfidi, 2006), and Hebrew-English (Oren & Breznitz, 2005). The results consistently showed that reading problems became more prominent in the opaque orthographies such as English and French, confirming the orthographic depth hypothesis (Katz & Frost, 1992). In respect of writing problems, it has been documented that dyslexic children and adults performed significantly worse than TD groups in spelling skills in a second language (Łockiewicz & Jaskulska, 2016; Fazio et al., 2020). Miller-Guron and Eundberg (2000) included parallel measures of students' spelling performances in L1 Swedish (L1) and English (L2), and found that the difficulties in English writing are more pronounced than those in Swedish writing. This finding is consistent with the pattern found in TD children (Caravolas, 2004), that is, learning to spell is easier in a consistent orthography than in an opaque one. Studies comparing reading and writing problems in a logographic versus an alphabetic system with bilingual children are very few. The orthographic depth framework can be extended to nonalphabetic writing systems such as Chinese. Chinese is often referred to as a deep orthography (e.g., M. Wang & Geva, 2003) and less consistent in comparison with English (Hu & Catts, 1998). It is expected that reading and writing difficulties would be less prominent in English than in Chinese.

The pioneering studies regarding bilingual CCD (Chung & Ho, 2010; C. S.-H. Ho & Fong, 2005) indicated that this group of children had lower performances on English reading and writing skills in comparison with age-matched TD children. Later, researchers have found dissociation between Chinese and English reading problems. Tong et al. (2015) identified that 57% Grade 5 children with Chinese reading difficulties do not suffer from difficulties in English reading. Li et al. (2018) screened a large sample of Chinese children for English dyslexia, and found that 43% of Children with English dyslexia did not have Chinese reading problems. The above studies explored the underlying causes of the dissociation by comparing different groups of children on their cognitive-linguistic skills. The results suggest that skills in the phonological domain, that is, phonological awareness and phonological memory, distinguish those with English difficulties from those without (Kalindi et al., 2015; Li et al, 2018), whereas nonphonological skills such as copying, morphological awareness, and rapid naming are markers of Chinese dyslexia (Kalindi et al., 2015; McBride-Chang et al., 2012, 2013; Tong et al., 2015). What remains unexplored is the link between dyslexia subtypes and the dissociation of writing difficulties across languages.

This study is an effort to understand the heterogeneity of Chinese dyslexia and its impact on acquiring literacy skills in English. The study has three aims. The first is to classify children with dyslexia into different cognitive subtypes. According to the dual-route model (Castles & Coltheart, 1993), we chose variables in the phonological and orthographic domains as clustering variables. In addition, nonverbal intelligence was also included as a clustering variable to distinguish a subtype with deficits across domains. The second aim is to examine the cross-linguistic transfer of cognitive-linguistic abilities. This was done from two perspectives. One was the contribution of Chinese skills to English basic literacy, that is, word reading fluency and dictation. We expected that orthographic and phonological processing each would independently explain the variances of the two literacy outcomes in both the TD and dyslexic sample. The other was the cognitive deficits shared across languages. Specifically, CCD with a phonological deficit would perform significantly worse in English phonological processing; CCD with an orthographic deficit would perform significantly worse in English orthographic processing. The third aim is to examine the modulation of language on the subtype differences on the level of impairment in basic literacy. The level of impairment is defined by the relative standing of the child with dyslexia against the TD group. Because Chinese orthography is deeper than English, CCD would have less severe English difficulties. Drawing on the phonological core hypothesis (Stanovich, 1998), we expected that CCD without phonological deficits would be the least impaired in English basic literacy.

We also included English language experience as an explanatory factor of English basic literacy in Chinese-speaking children. Previous studies have shown that language experience is the most prominent factor explaining individual differences in second language learning (e.g., Hu & Schuele, 2015). However, English language experience was often overlooked in studies on second language reading and writing difficulties. McBride-Chang et al. (2012) have found Chinese poor readers with English reading difficulties were from homes with mothers of lower education levels, which may co-occur with less English language experience for the children.

Participants

Eighty-six children with dyslexia and 51 TD children participated in the study. Study information was sent to 144 randomly selected primary schools in Hong Kong, among which 11 schools responded and distributed the study information to potential participants. The children with dyslexia have been diagnosed by either educational or clinical psychologists using the tool of the Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students—Third Edition (HKT-SpLD [III]) (2015). The assessment battery covers domains including formal literacy (Chinese word reading, 1-min reading, Chinese word dictation), fluency (digit-naming), phonological awareness (rhyme detection and onset detection), phonological memory (word repetition and nonword repetition), and orthographic knowledge (lexical decision). One has to meet all the following criteria to be diagnostic with dyslexia: (a) IQ score higher than 1 *SD* below the population mean; (b) score 1 *SD* below the population mean in at least one skill in the formal literacy domain; and (c) score 1 *SD* below the population mean in at least one cognitive domain. The TD children have never been referred for a diagnosis of learning disabilities. They have no difficulties in reading or writing based on parents' and teachers' report. All children were in Grade 3 or 2 (G3-to-G2 ratio: 1.97) when recruited, speak Cantonese at home, and were not diagnosed with any other kinds of special education needs (including visual or hearing impairment, attention-deficit/hyperactivity disorder, autism spectrum disorder, speech impairment, intellectual disability). Five children dropped out the study due to distraction and tiredness, and their data were excluded from the analysis. This leaves 84 children with dyslexia (M_{age} = 100.7 months, SD_{age} = 9.1) and 48 TD children (M_{age} = 103.0 months, SD_{age} = 7.6) in the sample. Despite the unequal group size, the two groups did not differ in age $t(135) = 1.50$, $p > .05$, male-to-female ratio, χ^2 (1) = .023, $p > .05$, G2-to-G3 ratio, χ^2 (1) = .002, $p > .05$, or English language experiences $t(135) = 2.10$, $p > .05$.

Measures

Nonverbal intelligence was assessed by Raven's Standard Progressive Matrix (RSPM; Raven, 2000), Sets A to C. Each set consisted of 12 visual geometrics with a missing piece. The children were required to choose the best among six (Sets A and B) or eight (Set C) options to fill the missing part.

Chinese and English orthographic awareness was measured by a lexical decision task. The task in each language contained 24 infrequent real characters/words and 24 noncharacters/words. The items were presented to the children in a quasi-randomized order, and the children were asked to indicate whether an item was a real Chinese character (or an English word). The number of items correctly judged per minute was used as the index of the children's orthographic awareness. In the Chinese task, all characters have the left-right structure. For example, the character 嗖/sou/(meaning the sound of wind) has the semantic radical "口" on the left and the phonetic radical "叟" on the right. Each noncharacter was created by one of the following means: (a) combining two semantic radicals (e.g., 口亻), (b) combining two phonetic radicals (e.g., 亥柔), or (c) reversing the positions of two radicals in a real character (e.g., 易犭). In the English task, each nonword violates the orthographic rules in one of the three ways: illegal vowel combination (e.g., baaet), illegal consonant combination (e.g., cqink), or vowel omission (e.g., cnlts).

Chinese and English syllable awareness was measured with a shortened version of the phonological awareness test used in Siu et al. (2018). Children listened to a recording of a trisyllabic word and needed to delete one syllable and pronounce the remaining two syllables. The test had 12 items and a maximum score of 24, with one mark given to each correct syllable.

Chinese and English phonemic awareness was measured with an onset deletion task adopted from Siu et al. (2018). A monosyllabic word or monosyllabic nonword was presented, and the children were asked to delete the first phoneme of the word. The test had 12 items with one mark given to each correct answer.

Chinese and English phonological memory was measured with a nonword repetition task. Children were required to remember a sequence of nonwords from a recording and verbally reproduce all the nonwords they heard. The nonwords were monosyllabic and followed the Cantonese phonology in the Chinese set or the English phonology in the English set. The memory span of Chinese and English nonwords was determined by the maximum length of sequence the children could remember. There were two items for each length level, and the length increased by one if a child got at least one of the two items correct.

Word reading fluency was measured with a 1-min word reading task (Siu et al., 2018). In both Chinese and English tasks, children were required to read aloud two types of words, that is, consistent and inconsistent, as two subtests. In English, the consistent words contained rime spelling patterns that only have one pronunciation; the inconsistent words contained rime spelling patterns that have more than two pronunciations. All English words were monosyllabic. In Chinese, consistency refers to the token consistency of the character at each grade. The Grade 1 and 2 database was used to select the one-character words for this study. The consistent words contained phonetic radicals, the sound of which on average occurred in 96% of the family members; the number was 35% for the inconsistent words. In each subtest, the children were asked to name correctly as many words as possible from a list of 80 items in 1 min. The performance in two subtests of each language was calculated and averaged into a reading fluency index.

In Chinese and English dictation task, children listened to a sentence and needed to write down the last character/word of the sentence. The length of the Chinese sentences was 5 to 11 syllables, and that of the English sentences was four to seven words. In the Chinese task, a child was accredited 2 points if a character was written correctly, and 1 score if they produced one radical correctly. In the English task, a child was given 2 scores for a fully correct response, and 1 score if at least two letters were spelled correctly in the right order. Each task contained 16 items.

English language experience was measured by a questionnaire. The parents were asked to indicate how often family members were using English with the children, the frequency the children used English at home, and parents' English proficiency in a five-point Likert-type scale. Information about the onset age of English language learning, and the length of English learning (in years) was also obtained. Following Hu and Schuele (2015), we calculated a composite score as an index of English language experience by transforming participants' responses to each question to a z score and then averaging them across questions.

Data Analyses

Multivariate multiple regression (MMR) was adopted to predict word reading fluency and dictation in two languages from Chinese phonological and orthographic processing, nonverbal intelligence, and English language experience. One model was built for the CCD and TD sample each. MMR can estimate a single regression model with multiple predictor and multiple outcome variables, thus lowering the Type I error rate compared with a series of univariate multiple regressions. The parameters of the models were estimated using full information maximum likelihood (FIML). Notably, the multiple regression models were saturated, so their goodness-of-fit indices were perfect and cannot be used to evaluate the model-data fit. However, interpretation of parameters is allowed (Muthén & Muthén, 1998–2012).

Hierarchical clustering analysis (HCA) was used to explore the cognitive subtype in the dyslexic sample. Ward's method was chosen because of the tendency to generate clusters that are homogeneous and relatively equal in size. The squared Euclidean distance was employed to indicate the similarities between clusters. The standardized score of general and Chinese-specific cognitive measures was entered in the model for the clustering: RSPM, COA, Chinese syllable awareness (CSA), Chinese phonemic awareness (CPA), and Chinese phonological memory (CPM). The number of clusters was determined by the agglomeration schedule as well as the level of stability (Hair et al., 2013). A clustering solution should be considered when there is a remarkable increase in heterogeneity within a cluster indicated by percent change of agglomeration coefficient (i.e., the distance between two combined clusters). Regarding stability, which can be assessed by the number of cases assigned to the same cluster across different methods (Hair et al., 2013), a clustering solution is preferred when it is the most stable. To assess stability of different clustering solutions, two methods were adopted. The first was to follow the previous study of Chinese dyslexia subtypes (Ho et al., 2004), and replicate the clustering procedures in the combined sample comprising both CCD and TD children. The second was to randomly split the dyslexic sample into two subsets, and perform the clustering procedures on each subset (Hair et al., 2013). The results were then compared against the original memberships. Cross-tabulation was used because the members of any specific cluster in one solution should stay together in a cluster in another solution.

Pairwise discriminant analysis was conducted to characterize the clusters among themselves and against the control group. The Bonferroni procedure was applied to correct for alpha inflation. The variables were entered step wise with an inclusion criterion of $p < .01$ and an exclusion criterion of $p > .10$. All priors were set equal. Wilks' lambda was calculated for each step.

General linear model was employed to compare dyslexic subtype groups against the control group on English skills. Linear mixed-effect model was employed to examine the effects of language and cognitive subtypes, as well as the interaction between the two variables, on the level of impairment in basic literacy outcomes, that is, word reading fluency and dictation. English language experience was included as a control variable in the analyses.

Results

Table 1 shows the raw scores of Chinese and English cognitive-linguistic and literacy measures. The results of t tests indicated that the CCD performed significantly worse on all measures than TD children (all $p < .01$) except Chinese and English phonological memory.

Do Chinese Cognitive-Linguistic Skills Contribute to English Reading and Writing Abilities?

Partial correlation coefficients between cognitive-linguistic skills and literacy outcomes controlling for English language experience in children with dyslexia and TD children are displayed in Table 2. The literacy outcomes were shown

Table 1. Descriptive and Reliability Statistics of Cognitive and Language Measures of Dyslexia and TD Children.

			Typical developing			Dyslexia			
Variables (raw score)	Range (min–max)	Cronbach's α	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*
RSPM	1–35	0.86	48	28.15	3.46	84	24.6	6.17	4.24***
COA	7–41	0.71	48	25.54	6.73	84	22.02	6.19	3.04**
CSA	16–24	0.51	48	22.58	1.47	84	21.63	1.97	3.15**
CPA	0–12	0.94	48	9.1	3.96	84	5.24	5.02	4.88***
CPM	3–8	0.63	48	4.65	1	84	4.46	0.88	1.08
CRF	0–95	0.95	48	50.14	17.04	83	20.62	13.19	10.34***
CWD	4–31	0.86	44	21.02	6.76	72	12.91	4.99	5.34***
EOA	5–34	0.66	46	20.02	6.64	81	16.23	5.37	3.50**
ESA	4–24	0.89	48	21.29	2.99	84	16.7	5.58	6.15***
EPA	0–12	0.96	48	7.81	4.02	84	4.62	4.87	4.03***
EPM	2–5	0.59	46	3.65	0.71	81	3.51	0.81	1.02
ERF	0–113	0.98	48	38.72	27.22	83	15.13	18.74	5.32***
EWD	1–32	0.9	42	23.36	7.24	78	15.17	8.4	6.92***

Note. RSPM = Raven's Standard Progressive Matrix; CRF = Chinese reading fluency; CWD = Chinese word dictation; COA = Chinese orthographic awareness; CSA = Chinese syllable awareness; CPA = Chinese phonemic awareness; CPM = Chinese phonological memory; EOA = English orthographic awareness; ESA = English syllable awareness; EPA = English phonemic awareness; EPM = English phonological memory; ERF = English reading fluency; EWD = English word dictation.
**$p < .01$. ***$p < .001$.

Table 2. Partial Correlation Coefficients Controlling for English Language Experience in Dyslexia (Upper Panel) and TD Children (Lower Panel).

Variables (raw score)	1	2	3	4	5	6	7	8	9
1. MR	1	.143	.111	.186	.294**	.321**	.096	.086	.272*
2. CRF	−.036	1	.546**	.179	.219*	.053	.203	.281**	.285*
3. CWD	.128	.672**	1	.089	.418**	.024	.103	−.109	.184
4. COA	.286*	.350**	.501**	1	.182	.066	−.048	−.015	−.061
5. CSA	−.009	.002	.241	.004	1	.213*	.109	.042	.046
6. CPA	.255	.048	.307*	.180	.343*	1	−.039	.372**	.402**
7. CPM	.174	.096	−.171	−.012	−.041	.034	1	−.004	.065
8. ERF	.358	.503**	.588**	.460**	.026	.413**	.104	1	.633**
9. EWD	.066	.409**	.503**	.321*	.199	.529**	−.085	.687**	1

Note. TD = typical developing; MR = matrix reasoning; CRF = Chinese reading fluency; CWD = Chinese word dictation; COA = Chinese orthographic awareness; CSA = Chinese syllable awareness; CPA = Chinese phonemic awareness; CPM = Chinese phonological memory; ERF = English reading fluency; EWD = English word dictation.
**$p < .01$. *$p < .05$.

correlated with numerous Chinese cognitive-linguistic skills for both groups (r = .24~.51). The full correlational matrices are provided in Supplemental Materials. Results of multivariate regressions are shown in Table 3. English and Chinese reading fluency and dictation was predicted by multiple Chinese cognitive-linguistic skills, and that the pattern of prediction was somewhat different across the two groups. For typically developing children, COA independently predicted word reading fluency and dictation in both languages; CPA predicted English word reading fluency and dictation. For children with dyslexia, CPA was the independent predictor of English word reading fluency and dictation; CSA and CPA were independent predictors of Chinese and English dictation, respectively. CPM predicted Chinese word reading fluency.

Are There Dissociated Phonological and Orthographic Subtypes in Chinese Dyslexia?

The agglomeration schedule indicated that at most five clusters should be considered for the data set, as a remarkable inflation (8%) of the agglomeration coefficient occurred at Stage 79 (the last fifth stage), which is twice the amount as in previous stages (4%). The dendrogram is shown in Supplemental Figure S1. The four- and three-cluster solutions were also considered because they were

Table 3. Standardized Regression Coefficients and Standard Errors in the Multivariate Regression Models.

Variables (raw score)	Chinese WRF	English WRF	Chinese WD	English WD
Typical developing children				
EngExp	0.11 (0.14)	0.37*** (0.10)	0.26* (0.12)	0.28* (0.13)
MR	−0.17 (0.14)	0.14 (0.12)	−0.05 (0.14)	0.04 (0.14)
COA	0.37*** (0.13)	0.28*** (0.11)	0.40*** (0.11)	0.27* (0.12)
CSA	−0.03 (0.14)	−0.15 (0.12)	0.14 (0.14)	0.02 (0.14)
CPA	0.03 (0.14)	0.33*** (0.11)	0.19 (0.13)	0.36* (0.14)
CPM	0.13 (0.13)	0.08 (0.10)	−0.11 (0.12)	0.02 (0.12)
Children with dyslexia				
EngExp	0.17 (0.10)	0.39*** (0.09)	0.18 (0.10)	0.49*** (0.10)
MR	0.07 (0.11)	−0.06 (0.11)	0.05 (0.12)	0.11 (0.11)
COA	0.14 (0.10)	0.05 (0.10)	−0.02 (0.11)	−0.06 (0.10)
CSA	0.14 (0.11)	−0.10 (0.10)	0.40*** (0.10)	−0.04 (0.11)
CPA	0.02 (0.11)	0.36*** (0.09)	−0.05 (0.11)	0.32*** (0.09)
CPM	0.20* (0.10)	0.02 (0.09)	0.09 (0.10)	0.06 (0.08)

Note. EngExp = English language experience; MR = matrix reasoning; WRF = word reading fluency; WD = word dictation; COA = Chinese orthographic awareness; CSA = Chinese syllable awareness; CPA = Chinese phonemic awareness; CPM = Chinese phonological memory.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

yielded from the five-cluster solution by combining clusters. The pairwise comparisons between the five clusters are displayed in Table S2 in Supplemental Material. To validate the three clustering solutions, the same clustering solution was applied on the combined sample with the TD children included, as well as with the two subsamples randomly generated from the dyslexic sample. The cluster membership yielded from the new sample was cross-tabulated with that yielded from the original dyslexic sample. The tabulated tables were shown in Table S3 to S5 in the Supplemental Material. The stability calculated for each solution was shown in Table S6. The results indicated that the three-cluster solution had the highest stability across the two methods, in that 79% of the cases retained the original cluster membership across methods, and thus was selected as the final solution.

Following Heim et al.' s (2008) practice of subtyping children with dyslexia, the absolute cognitive profiles characterizing each cluster were identified in pairwise discriminant analyses of each cluster versus the control group (all $p < .001$). Cluster 1 ($n = 36$) performed worse than the control group in phonemic awareness (Wilks' $\lambda = 0.840$, $F_{1,82} = 15.60$). Cluster 2 ($n = 20$) performed worse than the control group in lexical decision (Wilks' $\lambda = 0.732$, $F_{1,66} = 24.20$) and performed better than the control group in phonemic awareness (Wilks' $\lambda = 0.683$, $F_{2,65} = 15.07$). Cluster 3 ($n = 28$) performed worse than the control group in phonemic awareness (Wilks' $\lambda = 0.459$, $F_{1,74} = 87.31$), matrices reasoning (Wilks' $\lambda = 0.330$, $F_{2,73} = 74.23$), syllable awareness (Wilks' $\lambda = 0.284$, $F_{3,72} = 60.39$), and lexical decision (Wilks' $\lambda = 0.267$, $F_{4,71} = 48.68$).

The absolute cognitive profile of each cluster indicated that Cluster 1 only had deficits in the phonological domain, Cluster 2 only have deficit in the orthographic domain, and Cluster 3 has deficits in orthographic processing, phonological processing, and nonverbal intelligence. Guided by the dual-route model, we labeled Cluster 1 as phonological deficit subtype (PD; $n = 36$, 42.9% of the dyslexic sample), Cluster 2 as the orthographic subtype (OD; $n = 20$, 23.8% of the dyslexic sample), and Cluster 3 as the global subtype (GD; $n = 28$, 33.3% of the dyslexic sample). The relative cognitive profiles between the three subtypes were shown by the discriminant analysis. PD performed better in lexical decision (Wilks' $\lambda = 0.395$, $F_{1,54} = 82.76$) and worse in phonemic awareness (Wilks' $\lambda = 0.298$, $F_{1,53} = 52.45$) than OD. PD performed better in lexical decision (Wilks' $\lambda = 0.476$, $F_{1,62} = 68.16$), matrix reasoning (Wilks' $\lambda = 0.303$, $F_{1,61} = 70.169$), and syllable awareness (Wilks' $\lambda = 0.238$, $F_{1,60} = 63.92$) than GD. OD performed better in phonemic awareness (Wilks' $\lambda = 0.173$, $F_{1,46} = 220.29$), syllable awareness (Wilks' $\lambda = 0.102$, $F_{1,44} = 129.20$), and matrices reasoning than GD (Wilks' $\lambda = 0.121$, $F_{1,45} = 162.69$). The cognitive profiles for the three subtypes as well as the control group were shown in Figure S2 in Supplemental Material. The means and standard deviations on all the cognitive and linguistic measures for each subtype were displayed in Table S7.

One-way analyses of variance (ANOVAs) were conducted on the background information and English learning experience of the three subtypes and the TD group. The results are displayed in Supplemental Table S8. The four groups showed no significant differences on parents' education levels, household income, English usage with parents, mothers' English proficiency, English usage frequency at home, and onset age of learning English, and overall English experience (all ps $> .05$). However, there were significant group differences in terms of gender, $\chi^2(2) = 10.84$, $p < .01$; age $F(3, 81) = 5.40$, $p < .01$, partial

$\eta^2 = .13$; father's level of English proficiency, $F(3, 78) = 4.23$, $p < .01$, partial $\eta^2 = .09$; and length of English learning $F(3, 78) = 3.42$, $p < .05$, partial $\eta^2 = .08$. OD had significantly more females, and GD had significantly more males, than expected. The GD group was significantly younger than the control and PD group, both ps < .05, and OD group was significantly younger than the PD group, $p < .05$. Fathers of children in the PD group had lower English proficiency than those of the OD group and the control, both ps < .05. Children in the OD group had learned English for longer time than GD, $p < .05$.

Do Phonological and Orthographic Deficits Transfer from Chinese to English?

Table 4 displays the contrasts between the dyslexic groups and the TD group controlling for English language experience, age, and gender on six English measures. All three dyslexia subtypes performed significantly lower than TD children on English word reading fluency and dictation, all ps < .01. PD performed lower than TD on English phonemic and syllable awareness skills, both ps < .001, but not on English orthographic awareness or English phonological memory. OD performed lower than TD on English orthographic awareness, $p < .001$, and syllable awareness, $p < .05$, but not on English phonemic awareness or English phonological memory. GD performed lower than TD on all English skills, all $p < .001$, except English phonological memory.

Does Language Modulate the Relation of Cognitive Subtypes in Basic Literacy Impairment?

Another aim of this study was to examine whether language modulates differences of cognitive subtypes in the level of impairment in word reading fluency and dictation. We calculated standardized scores of children with dyslexia using means and standard deviations of the TD group. Because the performance of all the subtype groups was below the means of the TD group (i.e., negative z scores), absolute value of the z score was used to indicate the degree of impairment. As shown in Figure 1, a higher score means more severe impairment.

The estimated model of word reading fluency impairment indicated a significant fixed effect of language, $\beta = .64$, $t(80) = 4.99$, $p < .001$. The children's word reading fluency was more severely impaired in Chinese than in English. The fixed contrast between GD and PD was also significant, $\beta = .43$, $t(137) = 2.46$, $p < .05$, indicating that the GD subtype was significantly more impaired than PD in Chinese reading fluency. A significant subtype by language interaction was obtained, $\beta = .65$, $t(80) = 3.08$, $p < .01$, indicating that the effect of subtype on reading impairment was modulated by language. As shown in Figure 1, OD subtype exhibited the least impairment in English word reading fluency, whereas the PD subtype exhibited the least impairment in Chinese word reading fluency. In addition, the fixed effect of English language experience was significant, $\beta = .07$, $t(79) = 3.44$, $p < .001$.

In the estimated model of dictation impairment, the interaction between language and subtype was significant, $\beta = .75$, $t(71) = 2.41$, $p < .05$. As shown in Figure 1, the OD subtype showed the least impairment in English dictation. The fixed effect of English language experience was also significant, $\beta = .12$, $t(70) = 4.96$, $p < .001$.

Discussion

This study is an effort to investigate the heterogeneity of Chinese dyslexia in terms of cognitive origins, and its role in explaining the variance in basic English literacy, that is, word reading fluency and dictation. Cluster analysis yielded three subtypes with distinct cognitive profiles labeled as OD subtype, PD subtype, and GD subtype, which showed different English cognitive-linguistic profiles demonstrating cross-linguistic transfer of cognitive deficits from Chinese to English. Furthermore, the CCD experienced less difficulty in word reading fluency in English. The OD subtype showed the largest English advantage, in that they had the least impairment in English word reading fluency and dictation.

Cognitive Subtypes in Chinese Dyslexia

Consistent with previous findings, we found two subtypes dissociated in phonological and orthographic processing, that is, each had a deficit in one domain but was intact in the other. We also found a global deficit subtype which showed deficits in both domains. The results provide evidence for the dual-route model of word reading in Chinese. The proportion across subtypes, however, is somewhat different from previous studies. In our sample, 43% of the children with dyslexia were classified as phonological deficit subtype, which is a lot higher than 16% as shown in Ho et al.'s (2002, 2004) studies. A possible explanation could be that the classification measures adopted in this study cover few domains, which result in relatively coarse classification. Ho et al.'s (2004) study showed that rapid naming was the most dominant deficit in Chinese children with dyslexia. Because rapid naming was shown to be closely related to phonological processing (Wagner & Torgesen, 1987), the PD subtype in our study may comprise cases of both pure phonological subtype and some of rapid naming–related subtype.

Phonological awareness at different linguistic levels played different roles in classifying CCD. Phonological deficit subtype in this study only showed a deficit in phonological awareness at the onset-rime level. Although Chinese writing system

Table 4. Fix Effects Between Three Cognitive Subtypes and Control Group on English Skills Controlling for English Language Experience, Gender, and Age.

	ERF		EWD		EOA		ESA		EPA		EPM	
Fixed effects	Est	*t*	Est	*t*	Est	*t*	Est	*t*	Est	*t*	Est	*t*
Intercept	17.84 (22.02)	−0.81	4.86 (7.74)	0.63	8.64 (6.48)	1.33	26.86 (5.83)	4.61***	4.22 (4.46)	0.95	3.42 (0.89)	32.21***
PD vs. TD	−24.49 (4.33)	−5.98***	−9.46 (1.50)	−6.29***	−2.13 (1.25)	−1.68	−4.20 (1.12)	−3.77***	−2.91 (0.86)	−3.37***	−0.17 (0.17)	−0.96
OD vs. TD	−17.13 (5.23)	−2.84***	−4.64 (1.83)	−2.53*	−5.55 (1.56)	−3.57***	−3.10 (1.36)	−2.38*	1.11 (1.07)	1.03	−0.29 (0.22)	−1.44
GD vs. TD	−27.24 (4.66)	−5.05***	−9.97 (1.74)	−5.71***	−4.25 (1.43)	−2.97***	−4.88 (1.21)	−4.12***	−6.10 (0.96)	−6.31***	0.05 (0.20)	0.21
Age	0.53 (0.21)	2.58	0.17 (0.07)	2.32*	0.12 (0.02)	1.91	−0.06 (0.06)	−1.04	0.03 (0.04)	0.77	0.01 (0.01)	0.24
Gender	2.26 (3.56)	0.63	2.01 (1.27)	1.58	−1.07 (1.05)	−1.02	−0.12 (0.94)	−0.13	0.72 (0.40)	0.4	0.02 (0.15)	0.14
EngExp	3.02 (0.53)	5.73***	1.10 (0.19)	5.75***	0.32 (0.16)	1.87	0.17 (0.14)	1.36	0.29 (0.10)	2.81**	0.01 (0.02)	0.53

Note. Gender, female was coded 1 and male 0. EngExp = English language experience; TD = typical developing; PD = phonological deficit; OD = orthographic deficit; GD = global deficit; ERF = English reading fluency; EWD = English word dictation; EOA = English orthographic awareness; ESA = English syllable awareness; EPA = English phonemic awareness; EPM = English phonological memory.
*$p < .05$. **$p < .01$. ***$p < .001$.

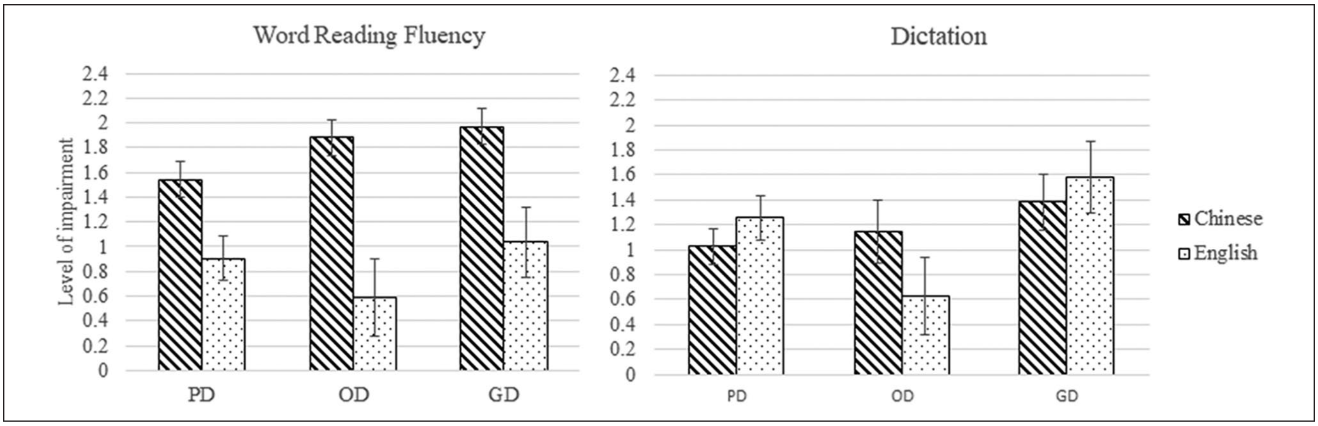

Figure 1. Level of impairment (absolute value of z score) on reading fluency (left) and dictation (right) across languages in phonological deficit (PD), orthographic deficit (OD), and global deficit (GD) groups corrected for English language experience.

is morphosyllabic, segmenting a syllable into phonemes was shown to discriminate CCD from age-matched TD children in previous studies (Shu et al., 2006). One explanation may be that the segmental phonological awareness contributes to word reading in Chinese via the covariance with phonological processing of suprasegmental features such as lexical tone (Zhang & McBride-Chang, 2014). Further studies investigating the subtypes of Chinese dyslexia may include phonological processing at the suprasegmental level.

Phonological awareness at the syllable level specifically differentiated the GD subtype from the rest of the sample but did not further contribute to the identification of the PD subtype. This may reflect that syllable awareness is relatively easy to develop even for the PD subtype. However, our finding suggests that the syllable segmentation task is particularly sensitive in identifying children with dyslexia who have deficits in a broad range of cognitive functioning including severe reading problems. This is in line with the view that phonological deficit, at least at the syllabic level, can reflect executive dysfunction (Ramus & Szenkovits, 2008).

Phonological memory did not discriminate between TD children and CCD, nor did it between the subtypes. This result is inconsistent with previous findings that a subgroup of CCD were particularly poor in phonological memory (e.g., Ho et al., 2004). The reason for this discrepancy could be that the phonological memory was measured by the task of nonword repetition, which the nonwords were constructed at the syllable level in this study. The task puts load on phonological encoding beyond memory, which may have rendered the task more difficult for both TD children and CCD. Previous studies using the nonword repetition task also failed to show group differences (e.g., Ho et al., 2002).

Cross-Linguistic Transfer

In respect of transfer of deficits, all three subtypes were significantly poorer in English word reading fluency and dictation than TD children, consistent with previous findings that CCD also experience difficulties in English reading and writing (Chung & Ho, 2010; C. S.-H. Ho & Fong, 2005). Specifically, PD children, who only showed deficits in Chinese phonological processing, showed lower English phonemic awareness and English basic literacy outcomes compared with TD children. This is in agreement with our hypothesis that phonological processing is transferable across languages. Together with previous studies in alphabetic languages (Łockiewicz & Jaskulska, 2016; Palladino & Ferrari, 2008), this study provides evidence to the linguistic coding difference hypothesis (Sparks & Ganschow, 1995) stating that deficits in phonological processing in one's first language can hinder the word reading and spelling process in another language.

The OD subtype showed a deficit in English orthographic processing. Because this subtype has intact phonological skills, the deficit in English orthographic processing cannot be attributed to phonological deficits. Thus, this finding suggests a true cross-linguistic transfer of orthographic deficit from Chinese to English. The OD subtype, who did not experience phonological deficit, also showed lower English word reading fluency and dictation, suggesting that phonological deficit alone cannot fully account for why CCD experience difficulty in English literacy. As previous studies have suggested, the OD subtype may have difficulty extracting visual-orthographic regularities in the writing system across different languages (Cheung et al., 2007; Tong & McBride-Chang, 2010). This deficit may lead to problems processing letter groups in reading and spelling in English, which do not follow the grapheme-phoneme corresponding rule but have statistical regularities in print-sound mapping.

Results of the multivariate regression indicate transfer of phonological processing, consistent with the results of group comparisons. CPA predicted English outcomes in CCD as well as TD children. The findings altogether suggest that CPA is an important skill for learning English literacy for children of all ability levels.

Regarding the transfer of orthographic processing, the results, however, are mixed. COA significantly predicted English word reading and spelling in TD children, controlling for phonological skills, nonverbal IQ, and English language experience. The finding fell in line with previous studies that showed the association between Chinese orthographic skills and English reading abilities (Cheung et al., 2007; Tong & McBride-Chang, 2010). This finding also provides novel evidence that Chinese orthographic processing explains individual differences in English dictation. Together with the finding that OD dyslexia performed more poorly in English basic literacy, the hypothesis of cross-linguistic transfer of orthographic processing was confirmed. However, orthographic processing cannot explain individual differences in English basic literacy within the CCD group. The different findings between TD children and CCD suggest that the two groups might use different strategies to read and spell English words. CCD possibly primarily rely on the grapheme-phoneme corresponding patterns to decode English words while having difficulties processing letter groups. TD children may have multiple strategies at hand to do so.

COA, however, was associated with English orthographic awareness in CCD. We infer that the ability to extract visual-orthographic regularities in Chinese can facilitate detecting orthographic regularities in English for CCD. However, CCD may not be able to apply the visual-orthographic skill in timed word reading or spelling. This further suggests that the construct of cross-linguistic transfer comprises many aspects. Transference of linguistic skills in L1 to its parallel form in L2 is different from transference from L1 skills to L2 literacy outcomes. The different aspects of transfer should be analyzed separately, especially for CCD. This finding has educational implications: Training CCD the regularities in the writing system may promote their ability to extract regularities in the English writing system, but the effects might not extend to their English reading and writing skills. Efforts explicitly targeted at applying the orthographic regularities in reading and writing processes (e.g., Lovett et al., 1994) may be necessary in the setting of second language literacy acquisition for CCD.

Cognitive Subtype Differences in Literacy Impairment and Modulation of Language

The present findings suggest dyslexia manifests differently in Chinese and English. The OD showed the least impairment in English word reading and dictation, but not so in the Chinese outcomes. This is consistent with our hypothesis. Because orthographic processing is less important than phonological processing in reading English (Stanovich, 1998), deficits in orthographic processing may not heavily affect English reading and spelling skills. In contrast, orthographic processing is particularly important in Chinese reading and writing (Perfetti et al., 2013); thus, the deficit leads to relatively severe Chinese dyslexia.

In terms of the language difference in the severity of dyslexia, the orthographic depth hypothesis (Katz & Frost, 1992) was only supported in word reading fluency, in that the CCD in general may experience less difficulty in reading English. This finding fell in line with the studies that extend the framework of orthographic depth to compare Chinese with alphabetic languages (Hu & Catts, 1998; Wang & Geva, 2003). However, the participants, both TD children and CCD, were not balanced bilinguals, in that their Chinese language proficiency was better than that in English. So, an alternative explanation is that CCD who are unbalanced bilinguals are less impaired in L2, not because it is English (a relatively transparent orthography), but because it is the weaker language. Future studies which involve CCD who are balanced Chinese-English bilinguals are needed to shed light on this issue.

Limitations

This study bears several limitations. First of all, several cognitive skills important to word-level reading and spelling such as rapid naming (Wagner & Torgesen, 1987) and morphological awareness (Shu et al., 2006) were not included in this study. This led to a coarse classification of subtypes in Chinese dyslexia, and limited insight to the cross-linguistic transfer of cognitive-linguistic skills. Second, this study used the observed variable methods to classify and characterize children with dyslexia. This approach cannot separate measurement error from the actual value of the attributes. Future studies could measure each attribute with multiple tasks, and adopt latent variable approaches to directly test the usefulness of the dual-route model in accounting for heterogeneity in the dyslexic population. Third, the present findings can only inform limited aspects of literacy, that is, word reading fluency and spelling. Other outcomes, for example, reading comprehension and word reading accuracy, were not included in this study.

Educational Implications and Conclusion

Our findings have practical implications for assessment and instruction of Chinese children with dyslexia who learn English as a second language. Chinese children with different subtypes of dyslexia bear different risks in learning English literacy skills. Teachers and clinicians could evaluate the risks based on children's cognitive-linguistic profiles in Chinese. The possibility that some Chinese children with dyslexia have less difficulty reading and spelling in English because of transfer of intact phonological skills should be explored. Our findings suggest that assessment batteries for evaluating English difficulties of Chinese children should include at least syllable awareness, phonemic awareness, and orthographic awareness to identify subtypes that have an impact on English basic literacy.

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Supplemental Material

Supplemental material for this article is available online.

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