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In search of subtypes of Chinese developmental dyslexia

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Abstract

The dual-route model offers a popular way to classify developmental dyslexia into phonological and surface subtypes. The current study examined whether this dual-route model could provide a framework for understanding the varieties of Chinese developmental dyslexia. Three groups of Chinese children (dyslexics, chronological-age controls, and reading-level controls) were tested on Chinese exception character reading, pseudocharacter reading (analogous to English nonword reading), novel word learning, and some phonological and orthographic skills. It was found that Chinese exception character reading and pseudocharacter reading were highly correlated and that orthographic skills was a better predictor of both Chinese exception character and pseudocharacter reading than was phonological skills. More than half (62%) of the children in the dyslexia sample were classified as belonging to the surface subtype, but no children were classified as belonging to the phonological subtype. These results suggested that the lexical and sublexical routes in Chinese are highly interdependent or that there may be only one route from print to speech as suggested by the connectionist models. Chinese dyslexic children generally are characterized as having delays in various phonological and orthographic skills, but some, such as those identified as surface dyslexics in the current study, are more severely impaired.

Keywords: Chinese; Developmental dyslexia; Dual-route model; Subtyping

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Introduction

Research studies on individuals with developmental dyslexia or specific reading disability often have focused on examining cognitive deficits that might lead to such individuals' problems in reading and spelling. In general, there is a consensus that phonological deficit is a core cause of developmental dyslexia (e.g., Bradley & Bryant, 1978; Hulme & Snowling, 1992; Olson, Rack, & Forsberg, 1990; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). However, research findings also show that there are multiple causes of this disability apart from phonological problems, and the causes and manifestations may vary for speakers of different languages (e.g., Miles, 2000). Dyslexic populations often have been characterized as heterogeneous with varying degrees of impairment in different cognitive skills. Consequently, some researchers have devised different ways of classifying developmental dyslexia into different subtypes or subgroups (e.g., Castles & Coltheart, 1993; Lyon, Stewart, & Freedman, 1982; Lyon & Watson, 1981).

Frames of reference in subtyping studies

Dual-route model

The dual-route model is one of the common paradigms in subtyping studies. The idea of the dual-route model is that learning to read involves two main strategies: a grapheme–phoneme rule-based strategy for reading regular words and a lexical strategy for reading exception words (e.g., Aaron, Wilczynski, & Keetay, 1998). The former involves phonological skills, whereas the latter involves word-specific memory and orthographic knowledge.

Based on the dual-route model, Castles and Coltheart (1993) proposed two varieties of developmental dyslexia: surface and phonological. Surface dyslexics are those who have selective impairment in the lexical route and tend to have difficulty in reading exception words. Children with surface dyslexia were found to perform poorly in orthographic judgment (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996) and learn both regular and exception words more slowly than do chronological-age controls (Bailey, Manis, Pedersen, & Seidenberg, 2004). Stanovich, Siegel, and Gottardo (1997) suggested the causes of surface dyslexia to be mild phonological impairment coupled with inadequate reading experience. It appears that surface dyslexia is a delayed type of reading problem that displays a cognitive profile similar to that of younger average readers.

Phonological dyslexics, in contrast, are those who have selective impairment in the sublexical route and tend to have difficulty in reading nonwords. Children with phonological dyslexia tend to exhibit more severe reading and phonological impairment than do surface dyslexic readers. They were found to perform more poorly on phonemic analysis (Manis et al., 1996; Stanovich et al., 1997) and to learn regular and exception words more slowly than reading-level controls (Bailey et al., 2004). There is also a genetic basis for these two subtypes. As a group, phonological dyslexia is more genetically heritable (67%), whereas surface dyslexia depends more on environmental factors such as print exposure and reading instruction (Castles, Datta, Gayan, & Olson, 1999).

Connectionist models

In contrast to the dual-route model, connectionist models propose that nonword reading and exception word reading may be accomplished using a single mechanism operating over distributed representations of orthographic and phonological units (e.g., Seidenberg & McClelland, 1989). Although these models are not specifically designed for subtyping studies, they manage to simulate the two "subtypes" of dyslexia. Subsequent simulations demonstrate that the quality of underlying phonological representations and the efficiency of learning resources may lead to differential impairments of exception word and nonword reading (Harm & Seidenberg, 1999). It appears that both the dual-route model and the connectionist models may explain individual differences in dyslexia. The dual-route cascaded model (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and the connectionist dual-process model (Zorzi, Houghton, & Butterworth, 1998) are examples of combinations of the two models.

The hypothesis of granularity and transparency and the incidence of phonological dyslexia

Wydell and Butterworth (1999) proposed the hypothesis of granularity and transparency to predict the incidence of phonological dyslexia in different languages. According to this hypothesis, any orthography can be described on two dimensions: transparency of print-to-sound translation and the size of the smallest orthographic unit that represents sound (i.e., granularity). Wydell and Butterworth further suggested that orthographies with fine granularity and opaque print-to-sound translation (e.g., English, Danish) would have a high incidence of phonological dyslexia. In contrast, orthographies with coarse granularity (e.g., Japanese Kanji) or transparent print-to-sound translation (e.g., Italian, Spanish) would have a low incidence of phonological dyslexia.

Research generally supports the hypothesis of a higher incidence rate of phonological dyslexia in English (25–55%) than in Spanish (22%) or French (4%), where Spanish and French are transparent and fine-grained orthographies (Castles & Coltheart, 1993; Genard et al., 1998; Jimenez & Ramirez, 2002; Stanovich et al., 1997). The current study examined the incidence of phonological dyslexia and surface dyslexia in an opaque and coarse-grained orthography, namely Chinese. If the two dimensions of granularity and transparency are considered separately, the coarseness of Chinese would predict more cases of surface dyslexia, but the opacity of Chinese would make it more like English and predict the opposite (i.e., fewer cases of surface dyslexia). However, the two dimensions are not separable when we consider how children learn to read. We expect that Chinese children rely very little on the use of phonological cues in learning multicharacter words because Chinese is so coarse-grained (with each character representing a syllable) and the phonological cues are so unreliable (approximately 26% regularity, as discussed later). Phonological skills may be involved at the level of learning character-to-syllable mappings. Therefore, we expect more cases of surface dyslexia than of phonological dyslexia in Chinese.

Characteristics of the Chinese orthography

Because the reader might not be familiar with the Chinese language, we briefly describe the main characteristics of the Chinese orthography here.

The basic graphic unit in Chinese is a character. Each Chinese character represents the smallest unit of meaning (i.e., morpheme), and characters are monosyllabic. There are many homophones at the character level. To avoid the problem of homophones, the majority of words are multisyllabic, and approximately two thirds of them are bisyllabic (Taylor & Taylor, 1995). Chinese is not as logographic as people believe it to be. Only a small percentage of Chinese characters convey meaning by pictographic or ideographic representation (Hoosain, 1991). According to Kang (1993), approximately 80–90% of Chinese characters are ideophonetic compounds, each composed of a semantic component and a phonetic component (also known as *radicals*). Many semantic and phonetic radicals are themselves integrated characters with independent sound and meaning, and some of them are bound forms that appear as components only in compound characters. The semantic radical provides cues about the semantic category of a Chinese character and often occupies a habitual position in a character.

Unlike the assembled phonology in English, the pronunciation of a Chinese character may be derived directly from its phonetic radical (e.g., deriving the sound of 碼 [ma5][1] "yard" from its phonetic 馬 [ma5]) or indirectly by making an analogy with another character having the same phonetic radical (e.g., associating the sound of 碼 [ma5] "yard" with that of 螞 [ma5] "ant"). The former is analogous to the regularity effect in English, whereas the latter reflects a consistency effect. These script–sound regularities/consistencies are called orthography–phonology correspondence rules (Ho & Bryant, 1997; Tzeng, Lin, Hung, & Lee, 1995) or the phonetic principle (Anderson, Li, Ku, Shu, & Wu, 2003) in Chinese. According to some statistical analyses, the predictive accuracy of the pronunciation of an ideophonetic compound character from its phonetic radical is approximately 40% (Shu, Chen, Anderson, Wu, & Xuan, 2003; Zhou, 1980; Zhu, 1987). This drops to 23–26% if tone is taken into consideration (Fan, 1986; Shu et al., 2003; Zhou, 1980). Thus, Chinese is a relatively opaque and coarse-grained orthography.

Developmental dyslexia in Chinese

Reading-related cognitive deficits

Ho and her colleagues identified seven subtypes of developmental dyslexia in Chinese, and rapid naming and orthographic deficits were found to be the most dominant (Ho, Chan, Lee, Tsang, & Luan, 2004; Ho, Chan, Tsang, & Lee, 2002). They suggested that such cognitive deficits may reflect poor orthographic representations and weak linkage between orthographic and phonological processors of Chinese dyslexic readers. The orthographic rules in Chinese are rather complicated (e.g., large number of orthographic units; different degrees of positional, semantic, and phonological regularities for radicals), and this may become a hurdle for some Chinese dyslexic children.

[1] All pronunciation notes for Chinese characters in this article are Cantonese pronunciations. The Linguistic Society of Hong Kong numerical convention for Cantonese tone is used. For instance, in the syllable [ma5], 5 means that the syllable is in the fifth tone, that is, a low rising tone.

Paired-associate and word learning problems

As suggested by Manis, Seidenberg, and Doi (1999), rapid naming deficit may also reflect the difficulty in learning arbitrary associations. This may especially be the case for learning Chinese, a system with rather arbitrary associations between script and sound. Chow and Ho (2005) reported supporting evidence that Chinese dyslexic children learned some visual–verbal pairs even worse than did reading-level controls.

Other research findings also show that both alphabetic readers (e.g., Messbauer & de Jong, 2003; Messbauer, de Jong, & van der Leij, 2002; Vellutino, Scanlon, & Spearing, 1995) and Chinese dyslexic readers (Ho, Chan, Tsang, & Lee, 2000) tend to have word learning problems, a specific instance of visual–verbal paired-associate learning. Ho and her colleagues (2006) reported that Chinese dyslexic children performed significantly less well than reading-level controls in learning exception words but not regular words. Their result suggests that Chinese dyslexic children have difficulty in remembering the sound of new words when no phonological cues are available. Consequently, in the current study, we examined whether Chinese children of different dyslexia subtypes would learn regular and exception words differently.

Is there a sublexical route in Chinese?

It is debatable whether there is a sublexical route in Chinese. We argue that not all Chinese characters are learned holistically. Apart from the lexical route, readers may also pronounce a Chinese character via the phonetic principle, that is, using the phonetic radical to help reading an unknown Chinese character (Anderson et al., 2003). The finding of a significant regularity effect in reading Chinese characters supports the presence of the sublexical route in Chinese (e.g., Ho & Bryant, 1997). There are also cases reported to have selective impairment of the sublexical route in Chinese adults with acquired dyslexia (Yin & Butterworth, 1992).

Analogous to the nonword reading in English, pseudocharacter reading is considered a good measure of the sublexical route in Chinese (Yin & Butterworth, 1992). A Chinese pseudocharacter is made up of a phonetic radical and a semantic radical in their legal positions but with the combination being a nonsense character. A Chinese pseudocharacter may be pronounced by direct derivation from the sound of its phonetic radical or by making an analogy through the sound of other characters having the same phonetic radical.

Research aims and expectations

Given the different linguistic features of Chinese and other alphabetic languages, the current study aimed at classifying Chinese developmental dyslexia into subtypes according to the dual-route model. Specifically, our first aim was to examine the relation between the lexical and sublexical routes in Chinese. We expected the two routes to be more closely related in Chinese than in alphabetic languages. Our second aim was to examine the incidence rates of surface and phonological dyslexia in Chinese. According to the hypothesis of granularity and transparency reviewed previously, the incidence rate of phonological dyslexia in Chinese should be low. Our third aim was to examine whether different subtypes of Chinese dyslexia have differential impairments in orthographic and phonological skills. In the case of English, phonological dyslexic readers are more impaired in phonological skills, whereas surface dyslexic readers are weak in orthographic skills (Manis et al., 1996). Our final aim was to examine whether different subtypes of Chinese dyslexia have different difficulties in learning regular and exception words in a word learning task.

A few recent studies have also examined subtyping in Chinese developmental dyslexia. For instance, Shu, Meng, Chen, Luan, and Cao (2005) identified one child with characteristics of surface dyslexia and two children with deep dyslexia. The child with surface dyslexia was found to be strongly affected by phonetic regularity in character naming and to show difficulty in semantic processing rather than phonological processing. However, this child was compared with only five chronological-age controls and with no reading-level controls. The use of better comparison groups would be desirable to examine the extent of the problems of Chinese dyslexic children.

In another study, Ho (2004) claimed to have found 26% of surface dyslexic cases and 13% of phonological dyslexic cases in a Chinese sample using the dual-route method. However, the participants in that study were not Chinese dyslexic readers with formal diagnosis but rather poor readers or underachievers based on a general Chinese language attainment test. Therefore, in the current study, we carefully screened Chinese dyslexic participants to adequately address the research questions mentioned previously.

Method

Participants

Participants in this study were 87 Hong Kong Chinese primary school children divided into three groups of 29 children each. The dyslexia group consisted of those diagnosed with developmental dyslexia using the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD) (Ho et al., 2000) and referred by the local education authority. The HKT-SpLD is a standardized test for diagnosis of developmental dyslexia with norms in Hong Kong. All children in the dyslexia group had normal intelligence (i.e., IQ $\geqslant$ 85). Their literacy composite scores and at least one of their cognitive composite scores were at least 1 standard deviation below their respective age means in the HKT-SpLD. These were the diagnostic criteria of developmental dyslexia in Hong Kong. The children were also carefully screened to ensure that they had sufficient learning opportunities (e.g., new immigrants were excluded) and that they did not have any suspected brain damage, uncorrected sensory impairment, or serious emotional or behavioral problems.

The remaining 58 participants were normally achieving children recruited from three representative primary schools and one kindergarten in Hong Kong. They matched on either chronological age (CA control group) or reading level (RL control group) with those in the dyslexia group. On average, the RL control group members were 1.6 years younger than the dyslexia group members. These 58 children had grade-appropriate reading achievement and normal intelligence. These controls were carefully selected to match on age, IQ, and reading level with those in the dyslexia group (Table 1).

It is noteworthy that most schools in Hong Kong adopt the whole word look-and-say approach of reading instruction. Very little emphasis or training has been put on sublexical strategies such as the use of phonetic radicals to aid character reading.

Table 1
Characteristics of the three groups of participants

Characteristic/Task	Dyslexia ($n = 29$)	CA control ($n = 29$)	RL control ($n = 29$)	Group comparison
Age (years)	9.0 (1.1)	9.1 (1.0)	7.4 (1.2)	D = CA D > RL
IQ	102.9 (10.8)	103.7 (10.1)	104.6 (10.2)	D = CA D = RL
Chinese word reading (maximum: 150)	63.9 (29.1)	121.6 (18.4)	65.6 (32.1)	D < CA D = RL

Note. Standard deviations are in parentheses. D, dyslexia; CA, chronological age; RL, reading level.

Materials and procedures

Children were assessed on an intelligence test, four literacy tasks, two phonological tasks, two orthographic tasks, and a word learning task. The intelligence test was administered to the control children in groups, whereas all other tests were administered individually.

Raven's standard progressive matrices

This is a standardized test of nonverbal intelligence. There are five sets (Sets A–E) of 12 items each. Kindergartners, first graders, and second graders were given the short form (Sets A–C), whereas the older children were given the full form (Sets A–E). Each item consisted of a target visual matrix with one missing part. Children were asked to select, from six to eight alternatives, the part that best completed the matrix. Scoring procedures were based on the local norm established by the former Hong Kong Education Department in 1986.

Literacy tasks

Chinese word reading

In this subtest of the HKT-SpLD, children were asked to read aloud 150 Chinese two-character words in the order of graded difficulty. The test was discontinued when children failed to read 15 words consecutively.

Chinese pseudocharacter reading

This was a test of the sublexical route in reading Chinese. The task consisted of 54 Chinese pseudocharacters, each made up of a semantic radical and a phonetic radical in their legal positions but with the character not signifying a meaningful word. Half of the pseudocharacters contained lexical phonetics (i.e., phonetic radicals were also stand-alone characters such as 爭 and 常). The other half of the pseudocharacters contained nonlexical phonetics (i.e., phonetic radicals were bound forms such as 咼 and 艮) or very rare phonetics that were unknown to the children but could be read by making analogy to other characters containing the nonlexical phonetics. All of the phonetic radicals were carefully selected, with 94% of them being of medium to high frequency for first graders (around 6 years of age) based on the Hong Kong Corpus of Primary School Chinese

(Leung & Lee, 2002), and should be familiar for the participants of the current study (8–10 years of age).

An IBM-compatible notebook computer, running the DMDX stimulus presentation software developed at Monash University and the University of Arizona by K. I. Forster and J. C. Forster, was used to present pseudocharacters with millisecond accuracy and to record reaction time. An external Philips microphone was connected to the notebook computer to detect the vocal response. The experiment began with 10 practice items, which were followed by 54 test items. The test items were divided into six blocks of 9 items each, and presentation was randomized in block. Each item began with the presentation of a white fixation plus sign (+) at the center of the computer screen for 298.8 ms. It was then replaced immediately by a white-printed character on a black background at the center of the screen. The stimuli were presented one at a time, and each stimulus remained on the computer screen until children named the character. The DMDX defaulted to a "time out" of 3000 ms. Children were told that the presented stimuli were some funny characters, and they were asked to guess their pronunciations. No corrective feedback was given to participants. A pseudocharacter was considered to be read correctly if it was pronounced by its phonetic radical (for those with lexical phonetics) or by another character having the same phonetic radical as the pseudocharacter (for those with nonlexical phonetics).

Chinese exception character reading

This was a test of the lexical route in reading Chinese. Exception characters were phonologically irregular and inconsistent characters. They were those characters whose phonetic radicals did not provide any sound cues about the pronunciation of the whole characters. A total of 60 Chinese exception characters were selected from the Hong Kong Corpus of Primary School Chinese at Grade 1 to Grade 3 levels of medium frequency. The pronunciations of all the characters were different (in both onset and rhyme) from those of their phonetic radicals. The computer setup and test procedures were the same as those of the Chinese pseudocharacter reading task.

Chinese exception character dictation

The stimuli of this task were 25 Chinese exception characters selected from the Hong Kong Corpus of Primary School Chinese at Grade 1 to Grade 3 levels of medium frequency. The pronunciations of these exception characters were different (in both onset and rhyme) from those of their phonetic radicals. The characters were presented orally through a minidisc player, and children were asked to write down the characters they heard. Each target character was presented in a word context for easy reference. For example, for the character 苗 "shoot," the children would hear 菜苗個苗字 "shoot, as in vegetable shoot." Two practice items were given before the 25 test items.

Phonological tasks

Rhyme detection

To economize the overall test administration time, only one phonological awareness subtest of the standardized HKT-SpLD was administered. The rhyme detection test, rather than onset detection, was selected because rhyme awareness tended to discriminate between Chinese average and dyslexic readers better than did onset awareness

(Ho, Law, & Ng, 2000) and the reported reliability of the rhyme detection subtest (.73) was higher than that of the onset detection subtest (.64) in the HKT-SpLD. In each of the 18 trials of the rhyme detection subtest, children heard three Chinese syllables presented through a cassette player. The Chinese syllables were names of common objects. To ease memory load, pictures of these objects were presented together with the auditory stimuli. Children were asked to indicate, among the three syllables, which two syllables sounded similar in rhyme (e.g., [gaam]1, [bing]1, [daam]1).

Nonword repetition

Only one phonological working memory test was administered. The nonword repetition subtest of the HKT-SpLD was chosen because Chinese word reading was found to have a higher correlation with nonword repetition (.50) than with digit repetition (.36) or word repetition (.38) in Chinese primary school children (Ho & Lai, 1999). There were 14 trials with three to six Chinese syllables each. The stimuli were presented through a cassette player, and the children were asked to orally repeat the syllables in the presented order. These syllables were phonetically legal syllables in Cantonese but were nonsense syllables. The stimuli were presented at the rate of two syllables per second.

Orthographic tasks

Lexical decision

This was an orthographic subtest of the HKT-SpLD and was used to assess children's knowledge of Chinese character structure. There were 30 rare characters and 30 noncharacters. Radicals of noncharacters were placed in illegal positions. The characters were printed in a fixed random order on two pieces of A4 paper. Children were asked to cross out all noncharacters.

Orthographic choice

This task was similar to Olson, Kliegl, Davidson, and Foltz (1985) and Manis et al.'s (1996) orthographic choice task. The test materials consisted of 54 real character–pseudocharacter pairs, with each sharing the same phonetic radical. A total of 54 Chinese regular characters (with character pronunciations the same as those of their phonetic radicals in both onset and rhyme) were first selected from the Hong Kong Corpus of Primary School Chinese at Grade 1 to Grade 3 levels of medium frequency. Also, 54 pseudocharacters were created using the same phonetic radicals of the 54 selected real characters combined with other semantic radicals. Sample character–pseudocharacter pairs included 獅 and  as well as 披 and . All of the phonetic radicals were of high frequencies. The computer setup was the same as that used in other tasks. The task began with 10 practice trials, which were followed by 54 test trials. In each trial, children heard the sound of a character and were asked to choose the correct word from a real Chinese character and a pseudocharacter presented on the computer screen by pressing a key. The order of the 54 test pairs was randomized.

Chinese word learning

This task was similar to the Chinese word learning task in Ho, Chan, Tsang, Lee, and Chung (2006) study. In this task, the children were asked to learn the pronunciations of eight unfamiliar Chinese two-character words of senior elementary levels. Half of the words had phonetic radicals providing reliable sound cues (regular words), and half did not (exception words). Regular words were defined as those whose phonetic radicals and the corresponding characters were homophones (i.e., identical syllables with the same tones, e.g., the phonetic 丁 [ding1] in the character 酊 [ding1]) or partial homophones (i.e., identical syllables with different tones, e.g., the phonetic 名 [ming4] in the character 酩 [ming5]). Ho and Bryant (1997) demonstrated that children as young as Grade 2 showed a significant regularity effect in reading Chinese characters with these two types of phonetics. Exception words in the task were defined as those whose phonetic radicals differed in onsets and rhymes from the corresponding characters (e.g., the phonetic 田 [tin4] in the character 累 [loey5]).

Each word was printed on a separate card. There were three parts in this learning task: pretraining, training, and delayed recall. In the pretraining part, children were asked to name all of the words before training so as to measure their baseline levels. In the training part, children were first taught the pronunciation and meaning of each word. The cards were then shuffled, and children were asked to recall the name of each word. Immediate feedback and corrective training were given for each word. There were 10 trials in this part, and the order of words for naming was randomized in each trial. Without giving children prior notice, a surprise delayed recall took place approximately 1 h after the training part. Children were asked to name each word again.

Results

Table 2 shows the means and standard deviations of the three groups of participants on the various tasks. Results of analyses of variance (ANOVAs) and post hoc comparisons with least significant difference (LSD) show that the dyslexia group performed significantly less well than the CA control group and similarly to the RL control group on all measures except rhyme detection ($p < .05$). Although not statistically significant, there was a trend for the dyslexia group to perform less well than the RL control group on the latency measure of pseudocharacter reading ($p = .06$) and exception character reading ($p = .07$). The dyslexia group was found to detect rhymes less well and to name pseudocharacters and exception characters somewhat slower than the RL control group. Consistent with previous findings, these results suggest that Chinese dyslexic children have a deficit in rhyme awareness (Ho et al., 2000) and are generally slow in naming Chinese characters.

Correlation and regression analyses for exception character and pseudocharacter reading

To examine the relation between the lexical and sublexical routes, the partial correlation coefficient between exception character reading and pseudocharacter reading was calculated for the whole sample, controlling for differences in age and IQ. The two reading scores were highly correlated, $r = .83$, $p < .001$, and the correlation was much higher than that in English (approximately .48 in Manis et al.'s (1996) study). This suggests that reading exception characters and pseudocharacters may be highly similar in Chinese.

To further examine this hypothesis, hierarchical multiple regression analyses were performed for the whole sample with exception character and pseudocharacter reading accuracy scores as the dependent variables. Table 3 shows that orthographic skills had a

Table 2
Mean scores and standard deviations of the various tasks for the three groups of participants

Task	Dyslexia ($n = 29$)	CA control ($n = 29$)	RL control ($n = 29$)	Group comparison
Pseudocharacter reading				
Accuracy (maximum: 54)	27.0 (10.1)	43.4 (6.3)	30.2 (12.6)	D < CA D = RL
Latency (ms)[a]	1311.6 (273.9)	991.5 (295.2)	1174.5 (255.4)	D > CA D > RL[b]
Exception character reading				
Accuracy (maximum: 60)	25.6 (12.8)	52.1 (6.7)	29.7 (15.1)	D < CA D = RL
Latency (ms)[a]	1191.1 (351.7)	779.1 (119.8)	1060.1 (297.4)	D > CA D > RL[c]
Exception character dictation (maximum: 25)	4.6 (4.8)	18.4 (5.4)	6.7 (6.3)	D < CA D = RL
Rhyme detection (maximum: 18)	1.0 (3.2)	14.4 (3.7)	12.8 (3.4)	D < CA D < RL
Nonword repetition (maximum: 112)	67.7 (24.8)	83.8 (11.6)	73.6 (15.2)	D < CA D = RL
Lexical decision (maximum: 60)	50.3 (4.9)	55.6 (3.6)	49.7 (6.0)	D < CA D = RL
Orthographic choice				
Accuracy (maximum: 54)	40.8 (7.5)	51.1 (2.5)	41.7 (8.1)	D < CA D = RL
Latency (ms)[a]	1332.4 (269.1)	1117.2 (170.9)	1349.7 (318.6)	D > CA D = RL

Note. Standard deviations are in parentheses. All significance levels were $p < .05$ unless otherwise indicated. D, dyslexia; CA, chronological age; RL, reading level.
[a] For correct items only.
[b] $p = .06$.
[c] $p = 07$.

Table 3
Hierarchical regression equations predicting the accuracy scores of Chinese exception character reading and pseudocharacter reading

Step	Exception character reading (R^2 change)	Pseudocharacter reading (R^2 change)
Model 1		
1. Age, IQ	.322***	.228***
2. Orthographic skills	.370***	.341***
3. Phonological skills	.017	.009
Model 2		
3. Rhyme detection	.006	.005
4. Nonword repetition	.011[a]	.004
Model 3		
3. Nonword repetition	.010	.003
4. Rhyme detection	.007	.005
Model 4		
2. Phonological skills	.139***	.108**
3. Orthographic skills	.248***	.241***
Model 5		
3. Lexical decision	.090***	.076**
4. Orthographic choice	.159***	.165***
Model 6		
3. Orthographic choice	.218***	.219***
4. Lexical decision	.030**	.022*

Note. Age and IQ were entered as the first step in all of the models of regression analyses. The predictor in the second step was orthographic skills for Models 1–3 and phonological skills for Models 4–6. Orthographic skills included lexical decision and orthographic choice, whereas phonological skills included rhyme detection and nonword repetition.
[a] $p = .08$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

greater unique contribution to reading both Chinese exception characters and pseudocharacters than did phonological skills. Of the two orthographic skills tested in the current study, orthographic choice had a greater unique contribution to reading both types of Chinese characters than did lexical decision. The patterns of prediction to exception character and pseudocharacter reading were very similar.

Identifying subgroups of dyslexia based on the CA controls

We used Castles and Coltheart's (1993) regression method to identify surface and phonological dyslexia. With this method, surface dyslexia in Chinese was defined as having a greater than expected deficit in exception character reading as predicted by pseudocharacter reading based on the linear relation between these two reading scores of the CA control group. Similarly, phonological dyslexia was defined by having a greater than expected deficit in pseudocharacter reading. Similar to Manis et al.'s (1996) study, a confidence interval of 95%, instead of 90%, was used. Fig. 1 shows that 18 Chinese dyslexic children (i.e., 62%

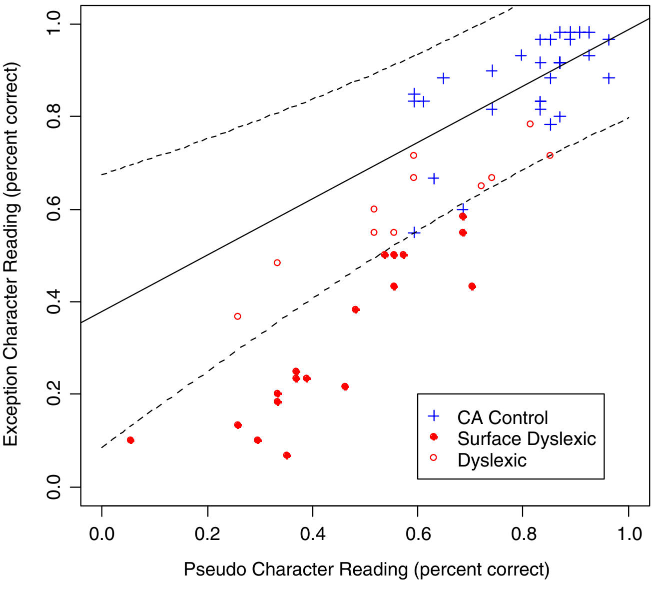

Fig. 1. Exception character reading by pseudocharacter reading for the CA control and dyslexia groups, with regression line and 95% confidence limits. Cases of surface dyslexia are represented by filled circles.

of the sample) with exception character performance fell short of that predicted by pseudocharacter reading. In other words, these children were classified as surface dyslexic and had selective impairment in exception character reading (i.e., the lexical route). In contrast, Fig. 2 shows that no Chinese dyslexic children in our sample had greater than

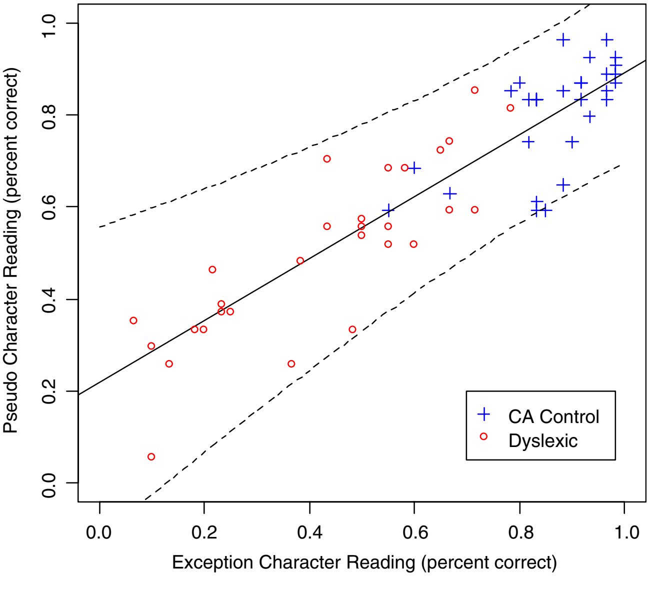

Fig. 2. Pseudocharacter reading by exception character reading for the CA control and dyslexia groups, with regression line and 95% confidence limits.

expected impairment in pseudocharacter reading. To summarize, using CA controls as a comparison group, 62% of this Chinese sample were cases of surface dyslexia, and there were no cases of phonological dyslexia.

Examining the literacy and cognitive skills of the surface dyslexia subgroup

Children in the surface dyslexia subgroup were those with more severe reading difficulties. On average, they were slightly younger (8.8 vs. 9.0 years), but with a much lower Chinese word reading score (49.3 vs. 63.9), compared with the original dyslexic sample. Subgroups of the CA and RL controls were selected to match the surface dyslexia subgroup in age, IQ, and Chinese word reading score (Table 4). On average, children with surface dyslexia were 1.9 years older than the RL controls. Table 4 shows the means and standard deviations of the various tasks for the surface dyslexia subgroup and the two control subgroups. Results of ANOVAs show that all of the group differences on literacy and cognitive measures were significant, $F\text{s} > 3.4$, $p\text{s} < .05$. Post hoc comparisons by LSD revealed that the surface dyslexia subgroup performed significantly less well than the CA control group on all of the literacy and cognitive measures. Although not statistically significant, there was a trend for the surface dyslexia subgroup to perform less well than the RL control group in nonword repetition ($p = .08$) and the naming speed of Chinese exception characters ($p = .06$) and pseudocharacters ($p = .09$) This suggests that Chinese children with surface dyslexia may have some delays in naming speed and phonological working memory.

Word learning performance of the surface dyslexia subgroup

To further examine whether the surface dyslexia subgroup had selective impairment in the lexical route, we compared the performance of the three matched subgroups in the word learning task. A three-way ANOVA, Group (3) × Word Type (2) × Trials (12), was conducted. With the exception of Group × Word Type, all of the main effects and interaction effects were significant, $F\text{s} > 2.03$, $p\text{s} < .01$. Post hoc comparisons by Tukey's HSD show that, on average, the children with surface dyslexia performed significantly less well than the CA controls but comparably to the RL controls. The children generally learned regular words better than they learned exception words.

The learning curves of the three subgroups on regular and exception words are shown in Fig. 3. The CA control group outperformed the other two groups in both regular and exception word learning. We were most interested to know whether the surface dyslexia and RL control subgroups learned the two types of words differently. Two two-way ANOVAs (Group × Trials) were conducted on regular and exception words separately. The main effect of group and the interaction effect for regular words were not significant, but the main effect of group for exception words was significant, $F(1,37) = 4.78$, $p < .05$, and the interaction effect was marginally significant, $F(11,407) = 1.64$, $p = .085$. The results suggest that Chinese children with surface dyslexia learn regular words in a similar way as do RL controls but tend to learn exception words less well than do RL controls.

Identifying subgroups of dyslexia based on the RL controls

To examine the extent to which the surface dyslexia subgroup resembled the subgroup of younger readers, we followed Manis et al.'s (1996) practice of repeating the analyses

Table 4
Mean scores of the various tasks for the surface dyslexia subgroup and matched subgroups of the two control groups

Task	Surface Dyslexia ($n = 18$)	CA control ($n = 25$)	RL control ($n = 21$)	Group comparison
Age (years)	8.8 (1.2)	8.9 (0.9)	6.9 (0.9)	SD = CA SD > RL
IQ	103.2 (11.3)	104.1 (10.8)	104.0 (9.1)	SD = CA SD = RL
Chinese word reading (maximum: 150)	49.3 (24.8)	119.0 (18.2)	52.2 (26.7)	SD < CA SD = RL
Pseudocharacter reading				
Accuracy (maximum: 54)	24.0 (9.2)	43.2 (6.3)	26.7 (12.1)	SD < CA SD = RL
Latency (ms)[a]	1319.3 (278.9)	1003.8 (312.9)	1161.5 (260.5)	SD > CA SD > RL[b]
Exception character reading				
Accuracy (maximum: 60)	18.7 (10.4)	51.3 (6.8)	23.9 (13.4)	SD < CA SD = RL
Latency (ms)[a]	1296.8 (385.1)	781.6 (128.0)	1119.7 (318.3)	SD > CA SD > RL[c]
Exception character dictation (maximum: 25)	3.6 (4.9)	17.7 (5.4)	3.8 (4.3)	SD < CA SD = RL
Rhyme detection (maximum: 18)	11.4 (3.6)	14.2 (4.0)	12.0 (3.4)	SD < CA SD = RL
Nonword repetition (maximum: 112)	60.3 (24.9)	84.4 (10.6)	69.8 (13.9)	SD < CA SD < RL[d]
Lexical decision (maximum: 60)	49.5 (4.8)	55.4 (3.7)	48.2 (6.2)	SD < CA SD = RL
Orthographic choice				
Accuracy (maximum: 54)	40.1 (6.6)	51.1 (2.4)	39.3 (7.9)	SD < CA SD = RL
Latency (ms)[a]	1366.0 (308.4)	1140.3 (161.2)	1417.1 (302.4)	SD > CA SD = RL

Note. Standard deviations are in parentheses. All significance levels were $p < .05$ unless otherwise indicated. SD, surface dyslexia; CA, chronological age; RL, reading level.

[a] For correct items only.

[b] $p = 09$.

[c] $p = 06$.

[d] $p = 08$.

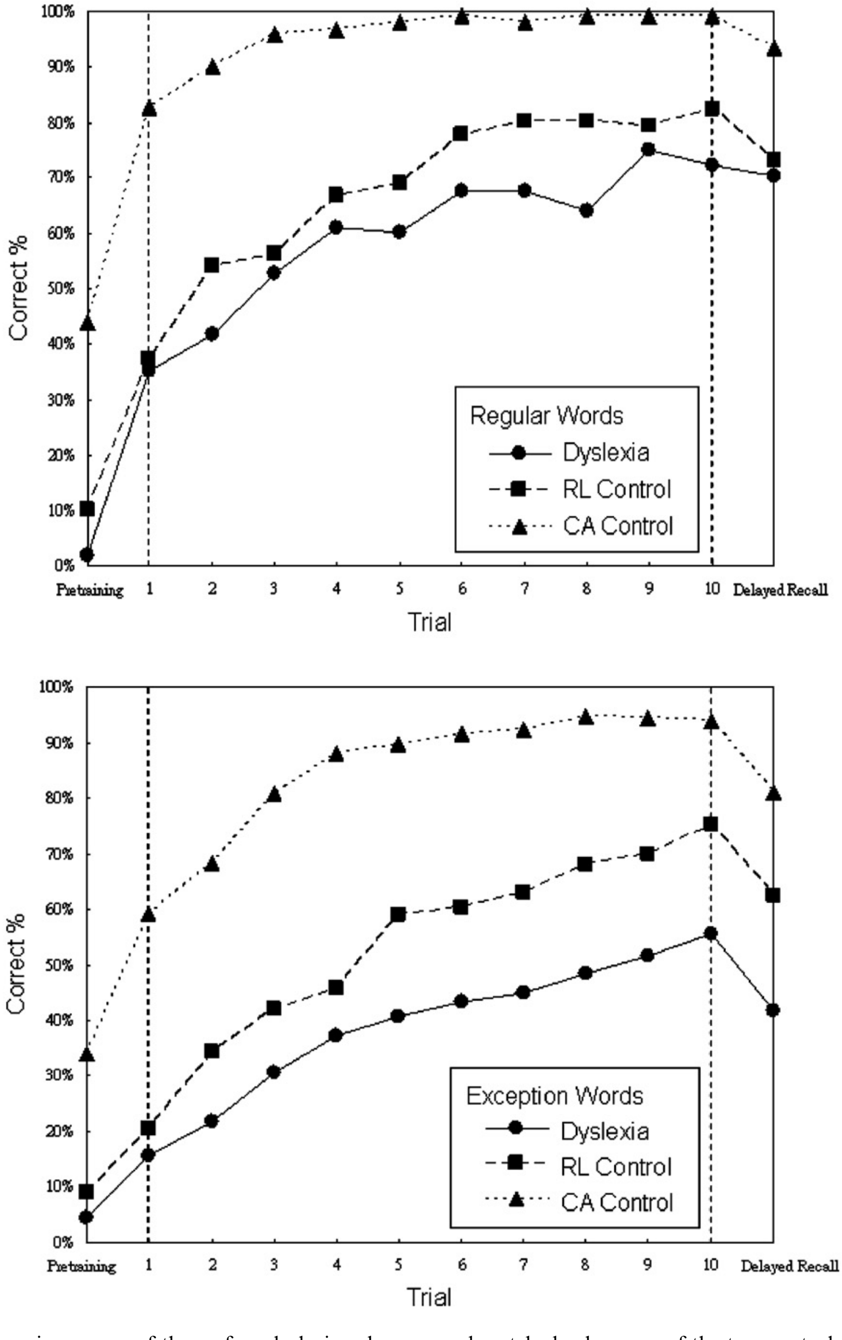

Fig. 3. Learning curves of the surface dyslexia subgroup and matched subgroups of the two control groups on regular words (left panel) and exception words (right panel) in the word learning task.

using regression equations for the RL control group. Fig. 4 shows that all of the surface dyslexic cases disappeared when RL controls were used to define processing trade-off. This

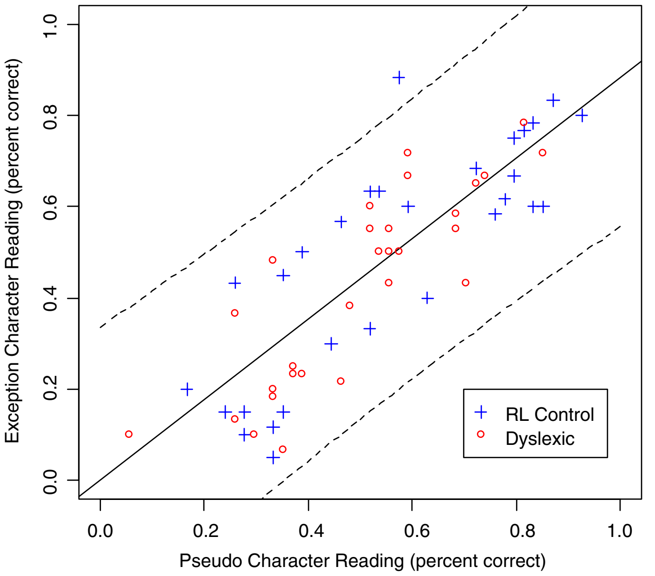

Fig. 4. Exception character reading by pseudocharacter reading for the RL control and dyslexia groups, with regression line and 95% confidence limits.

suggests that the surface dyslexia subgroup overlaps with the younger average readers, implying that their problems could be more a delay in nature than a deficit. Fig. 5 shows that there were no cases of phonological dyslexia based on the RL controls.

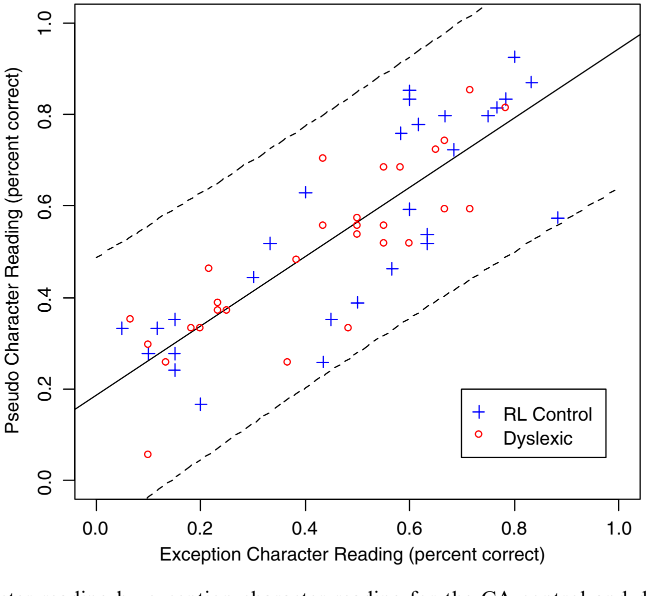

Fig. 5. Pseudocharacter reading by exception character reading for the CA control and dyslexia groups, with regression line and 95% confidence limits.

Discussion

In the current study, we set out to examine subtyping in Chinese developmental dyslexia with the dual-route model. Although the findings show that there is a high incidence of surface dyslexia in Chinese, the applicability of the dual-route model for classifying Chinese dyslexia remains a debatable issue, as we discuss later.

Relation between the lexical and sublexical routes in Chinese: one route or two routes?

Manis et al. (1996) and Griffiths and Snowling (2002) pointed out that the dual-route model does not explain well that most dyslexic children are mixed (with delays in reading both exception words and pseudowords). To account for this observation, many researchers, including Jackson and Coltheart (2001), Griffiths and Snowling (2002), and Share and colleagues (Jorm & Share, 1983; Share, 1995), have argued that the lexical and sublexical routes are interdependent during the course of reading acquisition. For instance, Share's self-teaching hypothesis suggests that phonological recoding (the sublexical route) performs a self-teaching function that enables a reader to learn the detailed orthographic representations that will help rapid word recognition (the lexical route). However, some connectionist models propose that there is only one route from print to speech and that reading exception words also depends on having access to segmental phonological representations (Seidenberg & McClelland, 1989, 1990).

The current findings show a high correlation between Chinese exception character and pseudocharacter reading ($r = .83$). Does this result support one route or two routes in Chinese? Reading nonwords in English requires phonological sensitivity and knowledge of grapheme–phoneme correspondence rules, whereas reading Chinese pseudocharacters requires knowledge of the phonetic principle. The reader may derive the pronunciation of a Chinese pseudocharacter either directly from the sound of the phonetic radical if it is a standalone character (i.e., the direct derivation strategy) or indirectly from the sound of other characters containing the same phonetic radical if it is a bound form (i.e., the analogy strategy). In other words, reading Chinese pseudocharacters depends on knowing many other characters that may serve directly as phonetic radicals or indirectly as sound cues through other same-phonetic characters. In this sense, one may argue that reading Chinese pseudocharacters is achieved mainly through the lexical route. This means that the dual-route model might not be entirely applicable for Chinese as it is in alphabetic languages. The connectionist models that propose one route or a single mechanism for processing both regular and exception words, or other models that suggest the integration of visual analysis with phonological and semantic word forms in reading (Perfetti, Liu, & Tan, 2005; Perfetti, Tan, & Siok, 2006; Siok, Perfetti, Jin, & Tan, 2004), may be more relevant in the case of Chinese. However, the adequacy of these models in explaining reading development and failure in Chinese warrants further examination.

With one route or two routes, the heavy reliance of reading both Chinese pseudocharacters and exception characters on lexical knowledge may explain why orthographic skills, rather than phonological skills, were found to be a better predictor of reading both types of characters.

Subtypes in chinese developmental dyslexia: surface subtype or no subtypes?

It was not unexpected that the majority (62%) of our sample was classified as surface dyslexic readers and that no participants were classified as phonological dyslexics given that delays in orthographic processing is the core problem in Chinese dyslexia. This finding supports the prediction of a low incidence (none in the current study) of phonological dyslexia for orthographies with coarse granularity, such as Chinese, based on the hypothesis of granularity and transparency (Wydell & Butterworth, 1999). However, the issue about the applicability of the dual-route model for Chinese remains unresolved, as discussed previously. Coupled with the finding of no phonological dyslexic cases in Chinese, one may argue against the existence of subgroups in Chinese dyslexia.

Cognitive and word learning problems of chinese dyslexic children

There may be no obvious subgroups in Chinese developmental dyslexia. Chinese dyslexic children generally are characterized as having delays in various phonological skills (phonological awareness and phonological working memory) and orthographic skills, but some, such as those identified as surface dyslexics in the current study, are more severely impaired. Chinese children with surface dyslexia tend to have special difficulty in learning new exception words that may have contributed to their more severe reading problems.

Specific problems in the lexical route

By definition, children with surface dyslexia have selective impairment in the lexical route. As a group, the surface dyslexic children in the current study read Chinese exception characters at a level of accuracy similar to that of younger average readers. They might have achieved this through the use of some compensatory strategies and repeated practices. Their specific problem in the lexical route may be more apparent in a new learning situation. In the novel word learning task of the current study, the Chinese children with surface dyslexia learned exception words much worse than did younger average readers, but this was not the case in learning regular words. Ho et al. (2006) reported similar findings, but there was no classification of subtypes in their study.

The fact that Chinese surface dyslexic children are less impaired in reading and learning regular words and pseudocharacters suggests that they understand the application of orthography–phonology correspondence rules (i.e., the phonetic principle). However, they have specific difficulty in learning and remembering exceptions to the rules. What could be the underlying causes of their difficulty in learning exception words in Chinese? We hypothesize that poor associate learning skill, especially that of visual–verbal pairs as reported by Chow and Ho (2005), may be one possibility. Mayringer and Wimmer (2000) also suggested that the poor performance of dyslexic readers in visual–verbal learning tasks may be due to their difficulty in acquiring new phonological forms and retaining them in long-term memory. Poor phonological working memory may be another possible and related cause of difficulty in learning Chinese exception words. This conjecture is consistent with our findings that phonological working memory skill has a slightly more unique contribution to Chinese exception character reading and that Chinese surface dyslexic children have somewhat greater impairments in phonological working memory.

The deviance/delay issue in developmental dyslexia

Regarding the issue of whether the subtypes of developmental dyslexia represent a developmental deviance or delay, findings with English-speaking samples generally support the hypothesis that phonological dyslexia reflects some persistent deficits, whereas surface dyslexia resembles a form of developmental delay (e.g., Sprenger-Charolles & Serniclaes, 2003; Stanovich et al., 1997). In the current study, all surface dyslexic readers disappeared when the RL controls were used for classification, and their reading and cognitive profile resembled that of the RL controls. This suggests that the reading problem of Chinese children with surface dyslexia could represent some general developmental delay. Even though the difficulties of the current surface dyslexia subgroup were a delay type, the delay was in fact quite significant clinically and educationally (nearly 2 years behind in reading attainment) and would require intensive educational intervention.

Conclusion and suggestions for future research

Chinese dyslexic children generally are characterized as having delays in various phonological and orthographic skills, but some, such as those identified as surface dyslexics in the current study, are more severely impaired. Chinese children with surface dyslexia tend to have special difficulty in learning new Chinese exception words. Our findings appear to support Ziegler and Goswami's (2005) claim that a phonemic awareness deficit might not be the primary proximal cause of dyslexia across languages but rather is mainly a result of experience with irregular orthographies such as English. A more generally applicable hypothesis regarding the proximal cause of most cases of dyslexia might be one involving more basic skills such as phonological working memory and long-term representations of phonology. This hypothesis is highly applicable for Chinese in that problems in phonological working memory and in remembering orthographic–phonological associations lead to general delays in learning to read Chinese characters.

There are still other areas that may require further investigation. For instance, Stanovich et al. (1997) proposed that surface dyslexics have a mild phonological impairment coupled with inadequate reading experience. Future studies may include measures such as print exposure to test whether Chinese children with surface dyslexia are experientially deprived. A more complete set of phonological measures (e.g., with the addition of onset and tone processing tasks) may be considered in future research to provide further evidence of the low incidence of phonological dyslexia in Chinese.

Finally, with the addition of the lexical semantic pathway to the direct lexical and nonlexical grapheme-to-phoneme pathways, the "multiroute" model of reading proposed by Coltheart and colleagues (2001) may also be tested with the case of Chinese developmental dyslexia because reading in Chinese always is considered to be mediated by semantics (e.g., Yin & Rohsenow, 1994).

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