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Syntactic and discourse skills in Chinese adolescent readers with dyslexia: a profiling study

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Abstract This study aims to investigate the relation of syntactic and discourse skills to morphological skills, rapid naming, and working memory in Chinese adolescent readers with dyslexia and to examine their cognitive–linguistic profiles. Fifty-two dyslexic readers (mean age, 13;42) from grade 7 to 9 in Hong Kong high schools were compared with 52 typically developing readers of the same chronological age (mean age, 13;30) in the measures of word reading, 1-min word reading, reading comprehension, morpheme discrimination, morpheme production, morphosyntactic knowledge, sentence order knowledge, digit rapid naming, letter rapid naming, backward digit span, and non-word repetition. Results showed that dyslexic readers performed significantly worse than their peers on all the cognitive-linguistic tasks. Analyses of individual performance also revealed that over half of the dyslexic readers exhibited deficits in syntactic and discourse skills. Moreover, syntactic skills, morphological skills, and rapid naming best distinguished dyslexic from non-dyslexic readers. Findings underscore the significance of syntactic and discourse skills for understanding reading impairment in Chinese adolescent readers.

Keywords Adolescent readers · Chinese language · Discourse skills · Dyslexia · Syntactic skills

Developmental dyslexia is a specific and persistent learning difficulty despite average intelligence, normal schooling, and sufficient education, primarily affecting and impacting on the individual's reading performance (Chung & Ho, 2010; Rose, 2009; Shaywitz & Shaywitz, 2005). Much research on dyslexia has examined deficits in decoding skills, for example, phonological awareness and rapid automatized naming that may lead to difficulties with word reading (Goswami & Bryant, 1990; Storch & Whitehurst, 2002). Similarly, recent studies have

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found that the language-related skills, for instance, syntactic and discourse skills (e.g., inference making, use of context, and understanding story structure), have been shown to be important in word reading and reading comprehension (Nation & Snowling, 2000), with the implication that a deficit in these skills may be a factor in dyslexia. However, fewer attempts to date have been made to explore the relationships between decoding and language-related skills in explaining individual differences in reading in spite of the fact that reading has been broadly viewed as an execution and integration of multiple cognitive-linguistic components (Kendeou & Trevors, 2012; van den Broek & Espin, 2012; Ziegler & Goswami, 2005). This is in line with the simple view of reading (Gough & Tunmer, 1986; Hoover & Gough, 1990; Shaywitz, 2003), which posits that decoding, for example, phonological processing, is coupled with a broad range of language-related skills such as syntactic and discourse skills and other cognitive components (like working memory). In a similar vein, there has been recent emphasis on the interconnectedness of decoding and language skills for explaining individual differences in reading based on the extended version of the Triangle Model of Reading (Bishop & Snowling, 2004). This model incorporates connections between the cognitive-linguistic components of phonological, orthographic, and semantic processing and other language components, namely syntactic and discourse. It also suggests that efficient reading may depend on the individuals' ability to integrate and execute multiple cognitive-linguistic skills, for example, syntax, discourse, and morphology. Thus, all of these skills are likely to be essential for reading acquisition but all can also be possible sources of reading difficulties for readers with dyslexia. To better understand manifestations of dyslexia both theoretically and practically, it is important to clarify the extent to which cognitive-linguistic skills would distinguish readers with and without dyslexia and how these skills are related to reading difficulties.

Although there is considerable evidence showing that dyslexia is characterized by phonological processing deficits (e.g., Shu, McBride-Chang, Wu, & Liu, 2006), little attention has been devoted as to whether these children also have difficulties with morphological, syntactic and discourse skills (e.g., Cain, 2003, 2007; Cain & Oakhill, 1996). Furthermore, deficits in morphological, syntactic, and discourse skills and their relations to reading in adolescent readers with dyslexia, especially non-alphabetic speakers like Chinese-speaking readers, have remained even less explored. As suggested by Bishop and Snowling (2004), specific features of a given language might influence manifestations of cognitive and linguistic deficits associated with reading problems. Furthermore, certain cognitive and linguistic characteristics of dyslexia occurring in childhood may or may not evolve across time or be resolved with cognitive maturation. Possibly, both the quantity and the quality of problems in dyslexic readers may vary from childhood to adolescence. For example, the increasing complexity and challenges of academic subjects and their related texts may cause changes in the way dyslexia is manifested. Faced with this complexity, dyslexic adolescent readers who have limited working memory capacity and experience difficulties in rapid naming, making inference and analyzing and manipulating the syntactic and semantic structure of language may have severe reading problems. However, little attention has been paid to both proximal (e.g., syntactic skills, discourse skills, morphological skills, rapid naming) and distal (e.g., working memory) factors and how these five constructs of cognitive-linguistic skills are related to reading in adolescent readers, particularly in Chinese readers with dyslexia. Weakness in any of these skills is more likely to contribute to difficulties with reading. Thus, the present study is to investigate the contributions of syntactic skills, discourse skills, morphological skills, rapid naming, and working memory in distinguishing Hong Kong adolescent readers with and without dyslexia and to examine the cognitive-linguistic profile of adolescent readers with dyslexia. The following is a brief review of the five constructs: syntactic skills, discourse skills, morphological skills, rapid naming, and working memory referred to in the present study.

Syntactic skills

Syntactic skills include the ability to understand the grammatical structure of the language and reflect upon one's knowledge of grammatical rules (Cain, 2007; Gombert, 1992). Research studies in English have generally demonstrated that syntactic skills (as measured by cloze and judgment/error correction tasks) are strongly correlated both with word reading (Chiappe, Siegel, & Wade-Woolley, 2002; Jongejan, Verhoeven, & Siegel, 2007; Willows & Ryan, 1986) and reading comprehension (Cain, 2007; Muter, Hulme, Snowling, & Stevenson, 2004; Tunmer & Hoover, 1992). Syntactic skills tasks requiring children to detect and correct syntactic errors were also found to predict word reading and reading comprehension after controlling for vocabulary and IQ (e.g., Demont & Gombert, 1996; Mokhtari & Thompson, 2006), and for working memory (Cain, 2007). It is possible that syntactic skills influence reading through the parsing processes that entail assigning syntactic functions to the constituent words of sentences. Syntactic skills are therefore necessary for understanding and facilitating the role of each word in sentences and are helpful in comprehending the content. As such, syntactic skills are likely to be an important contributor to reading. Findings of these studies are consistent with tenets of the Triangle Model of Reading (Bishop & Snowling, 2004), which suggests that syntactic knowledge and skills play a significant role in facilitating individuals' understanding of the meanings embedded within particular sentence structures.

Syntactic skills have also emerged as a potential contributor to both typical reading development and dyslexia in Chinese. These skills may be even more important for Chinese than English due partly to the nature of the Chinese writing system and structure of the language. Chinese is often considered as a morphosyllabic writing system and referred to as an impoverished system of grammatical morphology (Li, Bates, & MacWhinney, 1993). Compared to English, Chinese lacks grammatical devices such as inflections and function words (e.g., case marking and subject–verb agreement, word class distinctions, and word boundaries), and sentence boundaries are often unclear (Li, 1996; Li & Thompson, 1981). Consequently, morphosyntax is often used to show tense, number, and degree, whereas morphological transformation is employed in English. In Chinese, a category of words known as function, or empty words (similar to prepositions in English), is used in conjunction with the main verbs indicating tense expression. For instance, listened is represented by 聽/ting 1/(listen) 了/liu 5/(–ed, past action) and listening by 聽/ting 1/(listen) 着/zoek 6/(-ing, continuous action). Chinese has in general no plural form. Characters like 筆、波、杯 can be interpreted as either singular or plural—pen/pens, ball/balls, cap/caps. These characters can also combine with the quantifiers showing their plurality, for example, 很多 (a lot of), 幾個 (some), 大量 (plenty of). Such connectives, which take up specific positions and linguistic functions in sentences, are used extensively in Chinese. Particles can be used to form questions so that a statement can be converted into a question, for example, He is angry 生氣/sang 1 hei 3/(angry) to Is he angry by the addition of the quantifier (function word?) 嗎/maa 1/(asking a question).

Another difference between Chinese and English is the word order of subject and/or object in sentence structures. In English, a subject is usually required for each verb but Chinese allows the same subject to run on over many verbs, even over several sentences. For instance, 小文是一個好市民,履行義務,也熱心參與公益善事。 (Siu Man [the subject] is a good citizen. (The subject, i.e., He) fulfills his obligation. [The subject, i.e., He] is also zealous in doing voluntary work. This run-on effect is also possible with the object. Furthermore, in English, a word usually changes its form according to whether it is a noun or a verb, but this is not true in Chinese. For example, 溫習/wan 1 zaap6/(revision) or 溫習/wan 1 zaap6/(revise) (e.g., 小明已完成溫習明天的考試。 Siu Ming has done the revision for his exam tomorrow; 小明正在溫習明天

的考試。Siu Ming is revising for the exam tomorrow.) Despite the canonical word order in Chinese being subject–verb–object as found in English, the subject noun/phases can be left out given that a topic word or phrase has been established in a sentence. For example, 约翰我見過了。很英俊。也很能幹。John [the topic] I have just met. [The topic, i.e., John is] Very handsome. [The topic, i.e., John is] Very talented as well. Given the lack of syntactic devices of inflections, function words, and unclear sentence boundaries in Chinese, understanding of the context of the written text may require syntactic information from the linguistic constituents and their semantic relationships in order to monitor the semantic relations of character sequence in sentences. Thus, a good command of skills such as syntax and morphosyntax may assist readers to understand the role of the words in sentences and to comprehend or construct meaning from the text efficiently.

In Chinese, syntactic skills are typically assessed by tasks that tap into individuals' morphosyntactic knowledge and skills. For example, in the morphosyntactic task (e.g., Chik et al., 2012b; Chung, Ho, Chan, Tsang, & Lee, 2013; Tong, Chan, McBride-Chang, Tong, & Shu, 2013), individuals are required to detect and correct syntactic errors in a sentence or passage given. Indeed, recent studies with Chinese readers investigating the role of syntactic awareness in reading showed that syntactic skills, particularly in morphosyntactic detection/correction task were strongly correlated with Chinese reading and significantly predicted reading comprehension after controlling word reading, orthographic knowledge, and phonological and morphological awareness (e.g., Chik et al., 2012a, b; Yeung et al., 2011). In addition, Chik et al. (2012b) reported that dyslexic children performed worse on the morphosyntax tasks than did their typically developing peers. Given the complexity of syntactic structures, Chinese dyslexic readers may have difficulty in detecting and correcting morphosyntactic errors and syntactically anomalous sentences partly due to the fact that they have not yet mastered the knowledge and rules of syntax, e.g., word order, appropriate word use, the double object sentence, and the existential sentence. Such poor morphosyntactic skills may also prevent the readers from comprehending and using certain syntactic structures thus contributing to failures in reading Chinese. Although syntactic skills are found to be related to reading ability among Chinese elementary grade students (Chen & Chen, 2008; Chik et al., 2012a; Xiao & Ho, 2013), little attention has been devoted to the extent to which syntactic skills are associated with reading as children with dyslexia mature into adolescence (Chung et al., 2013). Given these previous findings, we therefore expected to find that syntactic skills would distinguish adolescent readers with dyslexia from those without dyslexia. In the present study, we also extended previous research into syntactic skills in relation to other cognitive-linguistic skills.

Discourse skills

Discourse skills are often defined as the ability to consciously focus on text coherence and to understand and use cohesive devices and discourse markers in order to develop coherent stretches of language (Cain, 2003; Cain & Oakhill, 1996; Chik et al., 2012b; Griffin, Hemphill, Camp, & Wolf, 2004). Coherence and cohesion are related to conceptual and linguistic properties of text as follows: Coherence is usually viewed as a logical flow of meanings and sequences of ideas linked with each other within a text as founding a conceptual unity, and cohesion can be thought of as the grammatical features and lexical links making connection between sentences that manifest the conceptual unity (Graesser, McNamara, Louwerse, & Cai, 2004; Oakhill, Cain, & Bryant, 2003). Consistent with Shapiro and Hudson (1991), coherence refers to "the degree to which the overall structure of a narrative satisfies the requirements of

story well-formedness, whereas cohesion is viewed as the degree to which the propositions and character references within a narrative are linguistically connected" (p. 960).

Recent studies of English and Chinese have shown that discourse skills contribute to word reading and reading comprehension (e.g., Cain, 2003; Cain & Oakhill, 1996; Chik et al., 2012b). As proposed by Triangle Model of Reading (Bishop & Snowling, 2004), syntactic skills and discourse skills are probably among the most important linguistic skills enabling individuals to comprehend a passage and to understand different meanings embedded within sentence structures. Particularly, for a text to be understood as a coherent whole, it is important that individuals have developed their discourse skills in drawing inferences between sentences that together provide a meaningful discourse. Frequently, tasks used to measure discourse skills require readers to manipulate and arrange sentences in sequence to test readers' ability to focus on the cohesive devices, for example, causal connectives and certain device-specific story features, such as time and sequence markers. An individual's ability to identify these devices and features may be a good indicator of his ability to comprehend the meaning and logic of a given text. Indeed, studies have suggested that discourse skills are linked with reading acquisition (Cain, 2003; Cain & Oakhill, 1996; Griffin et al., 2004).

Studies of poor readers and children with dyslexia have demonstrated a significant lag in the development of their discourse skills (e.g., Cain, 2003). These readers tend to display deficits in two aspects of discourse skills, namely, the structural coherence (event structure) and the linguistic cohesion (the use of cohesive devices to show the semantic and logical relations between clauses and sentences) of story organization. As mentioned earlier, Chinese is characterized by the extensive use of connectives (Liu, 1999) and allows omissions of subject nouns/phrases across succeeding sentences (Chao, 1968; Li & Thompson, 1981). Without an understanding of the significance of specific linguistic devices such as pairs of connectives, comprehension of Chinese text becomes very difficult. Subsequent study in Chinese reading acquisition and impairment reported that dyslexic children scored significantly lower on the discourse skills measures than the typically developing readers (e.g., Chik et al., 2012a, b). Discourse skills were also particularly important in explaining the difference in reading ability of typically developing children and dyslexic children (e.g., Chik et al., 2012b). Therefore, an awareness of cohesion and coherence in text plays an important role in reading acquisition because they indicate how sentences are connected within a text and how they convey the message (e.g., Cain, 2003; Graesser et al., 2004). In the present study, we therefore included a measure of discourse skills as these skills could be used to distinguish adolescent readers with dyslexia from those without dyslexia.

Morphological skills

Distinct from syntactic and discourse skills, morphological skills are defined as the ability to reflect upon and manipulate morphemes as well as employ word formation rules (Carlisle, 1995). Across languages morphological skills have been shown to play an important part in reading and impairment (e.g., Carlisle, 2000; Kuo & Anderson, 2006). Morphological skills have been consistently shown to contribute to word reading and reading comprehension in English (e.g. Carlisle, 2000; Deacon & Kirby, 2004; Nagy, Berninger, Abbott, Vaughan, & Vermeulen, 2003; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009) and in Chinese (e.g. McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Wang, Yang, & Chen, 2009). In Chinese, morphological skills can be viewed as the ability to distinguish meanings among morpheme homophones or as the ability to manipulate and access morphemes in words with two or more morphemes. Conceivably morphological skills are particularly important for

reading in Chinese because of the lack of inflections and less transparency in terms of print to sound correspondences. Compared to English, Chinese is a morphosyllabic writing system as each character is associated with a morpheme (meaning unit) and represents a syllable of spoken Chinese (DeFrancis, 1989; Mattingly, 1984). Chinese morphology is mainly made up of two or more morphemes. As stated by Kuo and Anderson (2006), over 75 % of Chinese words are formed through compounding, which is a very vital way of forming complex words. Many words therefore share the same morpheme. For example, 電話/din6 waa6/(tele-phone), 電報/din6 bou3/(tele-graph), 電視/din6 si6/(tele-vision). All of these words sharing the morpheme 電/din6/(tele) are semantically related as indicated by this morpheme. Additionally, there are a vast number of syllables that may have more than one sound or homophone, each with a different meaning (e.g., Packard, 2000; Zhou, Zhuang, & Yu, 2002). For example, the simple syllable "san" has multiple meanings, e.g., [san1] 'new' (新), [san1] 'stretch' (伸), [san1] 'body' (身) and [san1] 'hard' (辛). Therefore, the ability to understand and deploy morphologically complex forms or their morphological competence may be particularly important for reading in Chinese.

A growing number of studies has accentuated that morphological awareness is a good predictor of reading ability in Chinese (e.g., McBride-Chang et al., 2003; Tong, McBride-Chang, Shu, & Wong, 2009) and a reliable discriminator for Chinese children with and without reading difficulties (e.g., McBride-Chang, Lam, Lam, Doo, Wong, & Chow, 2008; Shu et al., 2006). In Chinese, morphological skills are frequently measured by tasks such as the morpheme discrimination that requires the selection of the odd words out from 4 two-morpheme words (Packard et al., 2006) and morpheme production that requires producing a morpheme orally to fit in a target morpheme word given in a sentence (Chung, Ho, Chan, Tsang, & Lee, 2010). Although studies of the development of morphological skills in adolescent readers with dyslexia are relatively rare, emerging research has shown that dyslexic adolescent readers tend to perform less well than the typical adolescent readers of the same age on morphological tasks involving morpheme discrimination and morpheme production (Chung et al., 2010). In the present study, we therefore expected on the basis of previous research that morphological skills would be useful in distinguishing adolescent readers with reading impairment from those without such a problem.

Rapid naming

Rapid naming has emerged as a relatively strong correlate of reading development and impairment both in English (e.g., Berninger, Abbott, Thomson, & Raskind, 2001; Manis, Seidenberg, & Doi, 1999) and Chinese (e.g., Jones, Branigan, Hatzidaki, & Obregón, 2010; Liao, Georgiou, & Parrila, 2008; Shu, Peng, & McBride-Chang, 2008). Studies of Chinese individuals with dyslexia have generally found that rapid naming, a measure of fluency, is associated with reading difficulties in children and adolescent readers (e.g., Chung et al., 2010; Ho, Chan, Tsang, & Lee, 2002; Ho, Chan, Lee, Tsang, & Luan 2004). Typically, rapid naming tasks require individuals to name orally a series of numbers or letters as quickly as possible. Perhaps, these tasks tap into readers' general speed of processing, visual–verbal learning and processing, and phonological retrieval. If readers take much longer than the average to name all the stimuli, they may have problems in operating and integrating these processes smoothly and efficiently. Consequently, these readers may be considered as having deficits in rapid naming, making reading a laborious task (Bowers & Newby-Clark, 2002; Bowers & Wolf, 1993). In Hong Kong, dyslexic Chinese children and adolescents tended to be particularly

slow in rapid naming measures relative to their typically developing peers (e.g., Chung et al., 2010; Ho et al., 2002, 2004). Subsequent profiling studies of dyslexia in Chinese also revealed that deficient rapid naming was found to be one of the main problems for dyslexic child and adolescents readers (see Chung et al., 2010; Ho et al., 2002, 2004 for more comprehensive review). Given the fact that Chinese dyslexics experience difficulties in rapid naming, this measure was included in the present study as well.

Working memory

Previous studies have examined the relationship between working memory, particularly verbal working memory and short-term memory, and reading performance across orthographies (e.g., Chik et al., 2012b; Kormos & Sáfár, 2008; Leong, Tse, Loh, & Hau, 2008; Savage & Frederickson, 2006; Seigneuric & Ehrlich, 2005). Working memory is defined as the capacity to simultaneously store and manipulate complex cognitive information (Baddeley, 2000; Savage & Frederickson, 2006). Referring to one commonly used model, working memory has been viewed as a multicomponent system consisting of two slave systems: a visuo-spatial sketch pad and phonological loop for dealing with visuo-spatial input and verbal speech input, respectively, and an episodic buffer that connects the two slave systems with the long-term memory and central executive (e.g., Baddeley, 2000). In most studies on dyslexia (e.g., Ramus & Szenkovits, 2008; Martinez Perez, Majerus, & Poncelet, 2013), deficits in verbal working memory and short-term memory have been highlighted using measures tapping into phonological processing and phonological memory storage, for example, backward digit span and non-word repetition, in which participants are required to recall sequences of material (i.e., digit or word span). The backward digit span requires one to store and process phonological information in working memory, whereas the non-word repetition is used to measure the storage of phonological information in short-term memory (e.g., Alloway & Passolunghi, 2011; Wang & Gathercole, 2013).

Studies on dyslexia have reported that the majority of readers with dyslexia often exhibit significant problems in verbal working memory and short-term memory maybe because they make inefficient use of the phonological loop component in working memory (e.g., Ramus & Szenkovits, 2008; Sela, Izzetoglu, Izzetoglu, & Onaral 2012; Smith-Spark, Fisk, Fawcett, & Nicolson, 2003). Consequently, inadequate verbal memory may cause difficulties in readers' ability to retain verbal information and acquire the sound patterns of words and to develop the skill of mapping sound to meaning (e.g., Sela et al., 2012; Smith-Spark et al., 2003). As far as Chinese readers are concerned, a few studies have examined the relation between working memory and reading performance (e.g., Chik et al., 2012b; Chung et al., 2010). These studies have found that poor Chinese readers performed worse on the verbal memory tasks such as backward digit span and memory for words than the average readers, suggesting that individuals with inadequate working memory capacity may experience difficulties in reading (e.g., Chung, McBride-Chang, Cheung, & Wong, 2013; Stevenson, Stigler, Lucker, Lee, Hsu, & Kitamura, 1982). At the same time, however, working memory is not always associated with reading ability once other cognitive-linguistic skills are statistically controlled (e.g., Cain, Oakhill, & Lemmon, 2004; Chik et al., 2012b). The existing findings concerning working memory have been less consistent. Thus, in the present study, we extended our investigation to examine working memory in relation to syntactic skills, discourse skills, morphological skills, and rapid naming, in order to obtain a fuller picture of the importance of working memory for adolescent readers with dyslexia.

Research aim and hypotheses

To date, few studies from the aforementioned research concerning reading failure in adolescent readers with dyslexia have specifically focused on cognitive-linguistic markers of reading difficulties in Chinese. Moreover, even fewer studies have done so when including the five constructs of syntactic skills, discourse skills, morphological skills, rapid naming, and working memory together as correlates of reading difficulties in adolescent readers with dyslexia. In the present study, we aimed to examine: (1) the extent to which syntactic skills, discourse skills, morphological skills, rapid naming, and working memory distinguish adolescent readers with dyslexia from those without reading difficulties; (2) what distinct cognitive-linguistic profiles exist in a sample of adolescent readers with dyslexia; and (3) the role of syntactic and discourse skills along with measures of morphological skills, rapid naming, and working memory in the classification of readers with dyslexia and typically developing readers. Because of the linguistic and grammatical structures of Chinese, we expected that adolescent readers would show deficits in syntactic skills, morphological skills, and discourse skills. It was also anticipated that adolescent readers would manifest deficits in rapid naming and working memory relative to their typically developing peers given that previous studies demonstrating these deficits are associated with reading impairment (e.g., Chik et al., 2012b; Chung et al., 2010). Perhaps, deficits in syntactic skills in dyslexic readers may stem from weakness in morphological skills, rapid naming, and working memory. Presumably, if readers have particular difficulties in discriminating subtle meaning among morphemes in the text and rapid-automatic manipulating and retrieving these morphemes in a working memory, they are likely to have difficulty with processing complex syntactic information and making inferences to provide a cohesive discourse. We therefore hypothesized that syntactic skills could play a pivotal role in distinguishing Chinese adolescent readers with and without dyslexia. Similarly, we expected that dyslexic readers would have particular difficulties in discourse and morphological skills, which might also reflect their different degrees of difficulties with underlying problems in syntactic skills, rapid naming, and working memory, and subsequent reading difficulties. Furthermore, we anticipated that adolescent readers with difficulties across a broader range of cognitive-linguistic skills would probably show greater reading difficulties because some previous studies of Chinese dyslexic readers have suggested multiple causes for reading difficulties (Chung et al., 2010; Ho et al., 2002, 2004).

Method

Participants

One hundred four Hong Kong Chinese secondary school students were included in the present study: 52 dyslexic group (DD) and 52 chronological age (CA) control group. The 52 dyslexic readers, recruited through the local education authority, were students from grades 7 to 9 (mean age=161.00 months, SD=9.35), with 40 boys and 12 girls. All nominated students had previously been assessed by the professional psychologists on an intelligence test from Hong Kong Wechsler Intelligence Scale for Children (HKWISC: Hong Kong Education Department, & Hong Kong Psychological Society, 1981) and Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD) (Ho, Chan, Tsang, & Lee, 2000). This test battery consists of literacy skills, rapid naming, phonological awareness, phonological memory, and orthographic skills. The HKT-SpLD is a standardized test for diagnosis of developmental dyslexia with norms in Hong Kong primary school students. The DD group's

literacy composite scores and at least one of their cognitive-linguistic composite scores in the HKT-SpLD were at least 1 standard deviation below their respective age. A normal intelligence of IQ of 85 or above was also required. These are the diagnostic criteria of developmental dyslexia in Hong Kong. All participants 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.

In the chronological age (CA), 52 typically developing readers were recruited from two secondary representative schools in Hong Kong. Of these, 28 boys and 24 girls (mean age= 159.62 months, SD=10.60) were matched to the dyslexic students in age (see Table 1). These students, who were relatively average performers, were nominated by their class teachers based on the previous grade average for one school year. This grade point average was at the 50–75 percentile in the students' Chinese language/literature. None of these students had any history of developmental dyslexia or any other types of learning difficulty or psychopathology in childhood.

Procedures

The students were administered a battery of 11 measures: three reading tests, two morphological tests, two rapid naming tests, one syntactic test, one discourse test, and two working memory tests. All tests were administered individually to each participant. Two practice items were given to the participants before formal testing. The parents' or guardians' consents for students' participation were obtained before testing. All assessments were conducted by trained experimenters.

Measures

Reading skills We used the three reading subtests from The Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Junior Secondary School Students (HKT-JS)

Table 1 Descriptive statistics and *t* test results for all measures

Task	Typically developing readers (n=52)			Dyslexic readers (n=52)				
	M	SD	Range	*M*	SD	Range	*t* (102)*	Effect size (Cohen's *d*)
Chinese word reading	111.54	12.00	79–135	64.40	21.84	14–106	13.64	2.68
One-minute reading	79.02	13.57	45–119	50.19	12.04	23–76	11.46	2.25
Reading comprehension	14.63	1.79	11–18	9.46	3.08	2–15	10.47	2.05
Morphosyntactic knowledge	20.69	3.98	12–30	12.08	5.15	2–24	9.55	1.87
Sentence order knowledge	13.21	3.69	6–21	7.13	4.63	0–17	7.40	1.45
Morpheme discrimination	12.98	1.89	8–16	9.56	3.01	1–16	6.94	1.36
Morpheme production	12.58	1.24	9–14	9.69	1.86	4–13	9.29	1.82
Digit rapid naming	26.70	5.55	17.18–40.35	38.30	7.91	24.56–57.28	−8.65	−1.70
Letter rapid naming	30.43	5.74	21.23–46.76	48.31	10.15	29.07–71.71	−11.06	−2.17
Backward digit span	8.96	2.94	3–14	5.54	2.34	2–12	6.57	1.29
Non-word repetition	72.21	13.56	39–102	60.88	17.87	9–108	3.64	0.71

*All p<0.001

(Chung, Ho, Chan, Tsang, & Lee, 2007). The HKT-JS is a standardized test for diagnosis of developmental dyslexia with norms in Hong Kong. The Chinese Word Reading, One-Minute Reading, and Reading Comprehension subtests were used to assess students' reading ability. For the Chinese Word Reading, participants were asked to read aloud 143 Chinese two-character words in order of difficulty. The test was discontinued when students failed to read 20 words consecutively. In responding to the One-Minute Word Reading, students were asked to read aloud each of the 120 simple two-character words as quickly and as accurately as possible within 1 min. The Reading Comprehension consisted of one narrative, one descriptive, and one expository passage each of which was followed by multiple-choice questions. The passages and questions were designed in ascending order of difficulty. Participants were asked to read the passages and answer six multiple-choice questions. For students with ages ranging from 11:7 to 14:6, the publisher reports reliability estimates of (r=0.94 to 0.95), (r=0.97 to 0.97), and (r=0.64 to 0.75) for the Chinese Word Reading, One-Minute Reading, and Reading Comprehension.

Syntactic skills We used the Morphosyntactic Knowledge test, which included both syntactic detection/correction and a conjunction cloze task. This test, like the one used in the studies of Chik et al. (2012b) and Tong et al. (2013), was to assess participants' understanding of the basic knowledge and parts of speech (e.g., multi-attributive, singularity and plurality, prepositions, and adverb), and the rules of Chinese syntax [e.g., subject–verb–object (SVO), subject–object–verb (SOV), and object–subject–verb (OSV) sentence]. We focused on the aforementioned syntactic knowledge covering a considerable amount of the basic knowledge and rules of Chinese syntax and reflecting aspects of syntax that readers should have mastered in the junior high school level. In this task, there were two parts, both with two practice trials given. To minimize the impact of word recognition ability in this measure, students were asked to listen to the test items that were read aloud by the experimenters. For the items used, the classes of morphosyntactic errors selected were varied and linked to appropriate word order, missing verbs, word repetition, a missing agent, and inappropriate word use. Part 1 comprised 12 items, which were selected based on the reading materials and texts recommended from the Education Bureau. In this test, participants were requested to identify and correct morphosyntactic errors. They were asked to (a) circle the errors, (b) delete the extra and inappropriate words used, (c) insert the missing words, (d) indicate the incorrect word order used, and (e) provide correct words at the appropriate place of sentences given. For example, 她在吵架。 She is quarreling. The correct answer should be 她和他/她在吵架。/她們在吵架。She is quarreling [^with him/her]./ They are quarreling. Take another example, 他在聚餐。He is having a dinner party. The correct answer should be 他和她在聚餐。/他們在聚餐。He is having a dinner party [^with him/her]./ They are having a dinner party.) The answers were scored with two points: one point for correct identification and syntactically proper correction and two points for completely correct answers.

As mentioned earlier, Chinese writing system makes extensive use of connectives and allows omissions of subject nouns/phrases across succeeding sentences. Therefore, mastery of the linguistic devices (such as pairs of connectives) is of particular importance for building text coherence and understanding Chinese texts. The conjunction cloze task was used to investigate individual's skills in using connective words. In this task, participants were required to provide pairs of conjunctions (including the coordinating and subordinating conjunctions) that were likely to make the given sentences syntactically and semantically correct. There were four items in part 2, each with sentences that required participants to use paired conjunctions to link the sentences presented. (For example, __下雨了,我__會帶我的傘子。__ it is going to rain, __ I will take my umbrella. The correct answer should be 如果下雨了,我就會帶我的傘子。*If* it is going to rain, *then* I will take my umbrella. This example illustrates the use of conditional connectives, which asserts that the truth of the antecedent guarantees the truth of consequent. Take another example, ___媽媽

抱恙在身,___今天未能上班。___my mother was not feeling well, ___she did not go to work today. The correct answer should be 因為媽媽抱恙在身,所以她今天未能上班。*Since* my mother was not feeling well, *therefore* she did not go to work today. The connectives in this example indicate a causal relationship between the two events. That is, the antecedent leads to a particular consequence. The use of connectives in the above two examples generate a more fluent and meaningful sentences. Participants' answers were scored with two points: one point for correct identification with either syntactically proper correction or semantically appropriate, and two points for completely correct answers. A total score of the morphosyntactic knowledge was calculated by summing the *z*-scores from the part 1 to 2.

Discourse skills The Sentence Order Knowledge test was used. This test adapted from the discourse skill task used in the study by Chik et al. (2012b) aimed at measuring participants' skills in drawing inferences between sentences that form together a coherent and meaningful discourse in a text. Therefore, individuals' performance in the discourse skills task could reflect their sensitivity of text coherence and knowledge about cohesive devices and discourse markers. The Sentence Order Knowledge test consisted of four items that included narrative, expository and argumentative text (see Examples 1 and 2 below). These passages were selected based on the reading materials and texts recommended from the Education Bureau. Participants were asked to arrange from five to eight sentences of 10–25 words into a coherent and meaningful discourse for each passage presented. In doing so, they were required to focus on the cohesive devices, e.g., causal connectives and certain story features, e.g., time and sequence markers. How sensitive readers are in detecting those devices and features then forms a good index of their ability in reading to comprehend the meaning and logic of a given text. In this test, the items were read aloud by the experimenters in order to minimize the impact of word recognition ability on the performance. The items were also printed in an answer book to help reduce the memory load of the participants. The maximum score for each item made up of five sentences was 3. Three points were awarded to the participants for an answer representing a complete and semantically coherent discourse. One or two points were given when the participants' answer was partially correct, and zero was given for a completely wrong answer. For eight-sentence items, six points were given to the participants for an answer representing a complete and semantically coherent discourse. One, two, three, four, or five points were given when the participants' answers were partially correct, and zero for a completely wrong answer. The internal consistency reliability was 0.62.

Example 1:

A. 人們只好叫這位臉上長了麻子的婦女為麻婆,
   People could only call this woman whose face was pockmarked as 'Ma Po',
B. 她燒的豆腐清香嫩滑, 贏得了客人們的讚譽,
   The bean curd she cooked was fresh and soft, which won praise of many of her customers.
C. 相在清代同治年間, 四川有一名婦女, 能燒得一手好菜。
   In the Tongzhi era of Qing Dynasty, there was a Sichuan woman who could cook well.
D. 而她燒的這道菜就名為麻婆豆腐。
   and the bean curd dish she cooked as 'Ma Po Tofu'.
E. 但是她毫無名氣, 而且那道菜也沒有特別的名堂,
   However, the woman was not famous at all. Moreover, the bean curd dish she cooked did not have any special features,
   Answer: CBEAD

Example 2:

A. 但如果有計畫地加以重複,
   but if it is systematically rehearsed,
B. 大腦皮層的痕跡就會逐漸加深, 記憶就會得到加強。
   the memory trace at the cortex will then be gradually strengthened, memory will later become consolidated.
C. 不僅記憶的痕跡很淡薄,
   not only the memory trace will be very weak,
D. 心理學的研究證明,
   Psychological research shows that,
E. 而且遺忘率也很高,
   the rate of memory decay will also be quite high,
F. 人們學到的知識,
   when the knowledge obtained by individuals,
G. 如果只經過一次大腦,
   is encoded only once in the brain,
H. 只有百分之五以下的信息能較長期地保留下來,
   only five percent of the information can be retained in the long-term,
   Answer: DFGCEHAB

Morphological skills Two subtests of the HKT-JS, namely, Morpheme Discrimination and Morpheme Production test, were used. The Morpheme Discrimination test was to assess students' knowledge of Chinese morphological structure. This test included 17 items each consisting of 4 two-character words presented visually and orally. In each of the set, there was a character that shared the same sound and written form but with a different meaning when combined with the other characters. For example, a character 安,/on1/is common character in the words 安靜,/on1 zing6/, quiet, 安排,/on1 paai4/, arrange, 安祥,/on1 coeng4/, peaceful, and 安定,/on1 deng6/, stable. For each set, students were asked to identify the "odd" word. The correct response is 安排/on1 paai4/, arrange because the character/on1/in the word/on1 paai4/ represents a different meaning (set) from the character/on1/in the other three words (calm at ease). One point was awarded for each correct response.

The Morpheme Production test was used to measure participants' ability to apply and integrate the morphological and contextual information in given contexts. In this test, a total of 14 sentences with missing words were orally presented to participants. Students were told that they would hear some sentences with a word missing and they would have to replace the "blank." An example of a sentence would be "今天沒有同學缺 _____。" "There is no one _____ from class today." One of the possible correct response for this was 缺席, absent as "席", seat was combined to the word "缺", lack. One point was given if the response was semantically correct under its position constraint. The publisher reports reliability estimates (r=0.49 to 0.55) and (r=0.56 to 0.69) for the Morpheme Discrimination and Morpheme Production among students with ages ranging from 11:7 to 14:6.

Rapid naming The two Rapid Naming subtests of the HKT-JS used were the Digit Rapid Naming and Letter Rapid Naming test. With the Digit Rapid Naming test, five Arabic digits (2, 4, 6, 7, and 9) arranged in ten rows of eight were printed on a piece of A4 paper in a random order. Participants were asked to name the digits as fast and as accurately as possible from left to right row by row. Each student named each list

twice, and the mean score was based on the average time taken across the two trials. In the Letter Rapid Naming test, similar to the Digit Rapid Naming test, English letters were used because these stimuli were familiar to students who were taught them in kindergarten. Students were asked to read a series of lowercase letters (a, u, y, p, t, b, i, and o) as quickly as they could. They were also asked to name the list twice and the average of these responses was calculated for two trials. The publisher reports reliability estimates (r=0.87–0.93) and (r=0.83–0.92) for the Digit Rapid Naming and Letter Rapid Naming test among participants with ages ranging from 11:7 to 14:6.

Working memory We used the Backward Digit Span and Non-word Repetition subtests from the HKT-JS. With the Backward Digit Span test, there were 14 sequences in lists starting from two digits to a maximum of eight digits. Two sequences were presented at each string length and the list length was increased by one. Students were asked to listen to a series of digits through a CD player. They were then required to repeat the list of numbers in the reverse order from which they were originally presented. For the Non-word Repetition test, there were 14 trials with three to eight Chinese syllables that were presented to participants. Individual syllables were phonetically legal syllables in Cantonese but were monosyllabic non-words in Cantonese (e.g./bei5/備,/tan5/吞, and/daai5/帶). The stimuli were presented through a CD player. Students were asked to repeat orally the syllables in the presented order. One point was given for each correctly reproduced syllable in a trial. The publisher reports reliability estimates for the Non-word Repetition and Backward Digit Span test among participants with ages ranging from 11:7 to 14:6 (r=0.73–0.74) and (r=0.74–0.74) respectively.

Results

Group comparisons of reading and cognitive-linguistic measures

SPSS statistical software package was used to conduct all the statistical analysis presented. Table 1 presents the means, standard deviations, ranges, t, and Cohen's d values for all tests for reading and cognitive-linguistic measures. As shown in Table 1, the performance of the dyslexic group was significantly lower than the performance of the control group on all the reading measures: word reading [$t(102)=13.64$, $p<0.001$], 1-min word reading [$t(102)=11.46$, $p<0.001$], and reading comprehension [$t(102)=10.47$, $p<0.001$]. The dyslexic group performed worse than the control group on all the cognitive-linguistic measures: morphosyntactic knowledge [$t(102)=9.55$, $p<0.001$], sentence order knowledge [$t(102)=7.40$, $p<0.001$], backward digit span [$t(102)=6.57$, $p<0.001$], non-word repetition [$t(102)=3.64$, $p<0.001$], digit rapid naming [$t(102)=-8.65$, $p<0.001$], letter rapid naming [$t(102)=-11.06$, $p<0.001$], morpheme discrimination [$t(102)=6.94$, $p<0.001$], and morpheme production [$t(102)=9.29$, $p<0.001$].

Correlations between reading and cognitive-linguistic measures

Correlations among performance on the syntactic skills, discourse skills, morphological skills, rapid naming, working memory, and reading measures for the whole sample (n=104) are shown in Table 2. Most of the cognitive-linguistic measures (morphosyntactic knowledge, sentence order knowledge, morpheme discrimination, morpheme production, backward digit span, non-word repetition, digit rapid naming, and letter rapid naming) were significantly

Table 2 Correlations among all measures

	1	2	3	4	5	6	7	8	9	10
1. Word reading	–									
2. One-minute reading	0.76***	–								
3. Reading comprehension	0.70***	0.66***	–							
4. Backward digit span	0.48***	0.44***	0.45***	–						
5. Non-word repetition	0.30**	0.33***	0.33***	0.16	–					
6. Digit rapid naming	0.55***	0.64***	0.44***	0.50***	0.12	–				
7. Letter rapid naming	0.61***	0.70***	0.52***	0.56***	0.24*	0.92***	–			
8. Morpheme discrimination	0.54***	0.47***	0.56***	0.46***	0.19	0.31**	0.42***	–		
9. Morpheme production	0.69***	0.61***	0.69***	0.36***	0.35***	0.41***	0.48***	0.55***	–	
10. Morphosyntactic knowledge	0.66***	0.53***	0.56***	0.46***	0.38***	0.42***	0.47***	0.58***	0.61***	–
11. Sentence order knowledge	0.60***	0.51***	0.64***	0.37***	0.24*	0.27**	0.36***	0.48***	0.53***	0.57***

*$p<0.05$; **$p<0.01$; ***$p<0.001$

correlated with each other. Among the reading-related measures, the non-word repetition was not significantly correlated with the backward digit span and morpheme discrimination, possibly due to our relatively small sample size. The reading word reading, 1-min word reading, and reading comprehension measures were also significantly correlated with all the cognitive-linguistic tasks.

Analyses of individual performance

Since the group comparisons might not reflect clusters of dyslexic readers with specific deficits, the performance of each reader and their profiles were examined and analyzed. The performance of the dyslexic and the control group was transformed into *z*-scores with reference to the control group. The cut-off criterion was set to at least 1.5 standard deviations below the average score by the CA controls. This operational criterion was similar to the cut-off definition used for classifying individuals with dyslexia (e.g., Birch & Chase, 2004; Chung et al., 2010). Table 3 shows the number and percentage of dyslexic readers in each measure. On average, 69, 61, and 67 % of the dyslexic individuals exhibited deficits in syntactic skills, rapid naming, and morphological skills, respectively. A further 58 and 33 % of dyslexic readers also showed deficits in discourse skills and working memory.

Table 4 presents the number of individuals exhibiting deficits on each measure. Seven dyslexic readers showed a single deficit. The majority of dyslexic readers exhibited multiple deficits. Twelve dyslexic readers had deficits on two measures. Fifteen readers also had deficits on three measures. Furthermore, 12 and five dyslexic readers showed deficits on the four and five measures. As shown in Table 4, none of the dyslexic readers displayed a deficit in working memory alone. Of those readers exhibiting deficits in two areas, the combined syntactic and morphological deficits (6 %), discourse and rapid naming deficit (4 %), syntactic and rapid naming deficit (4 %), morphological and rapid naming deficit (4 %), and morphological and discourse deficits (4 %) were the most common, followed by working memory and rapid naming deficits (2 %). For three or more cognitive-linguistic areas, the most prominent types were the combined syntactic,

Table 3 Number of dyslexic readers exhibiting deficits in various cognitive-linguistic areas

Task	*n*	Percent	Average (%)
Syntactic skills			–
Morphosyntactic knowledge	36	69	
Discourse skills			–
Sentence order knowledge	30	58	
Morphological skills			67
Morpheme discrimination	34	65	
Morpheme production	36	69	
Rapid naming			61
Digit rapid naming	21	40	
Letter rapid naming	42	81	
Verbal working memory			33
Backward digit span	17	33	
Non-word repetition	17	33	

Table 4 Number of dyslexic readers with deficits in each cognitive-linguistic area and their corresponding mean age, and reading skills

Cognitive deficits	Subtotal *n* (%)	Total *n* (%)	Age (months)	Word reading		One-minute reading		Reading comprehension	
				Raw score	*z*-score	Raw score	*z*-score	Raw score	*z*-score
No deficit		1 (2 %)	176.00	103.00	−0.71	61.00	−1.33	10.00	−2.58
Single		7 (14 %)	162.71	77.57	−2.83	56.14	−1.69	10.43	−2.35
Rapid naming (*R*)	3 (6 %)		153.00	76.00	−2.96	55.00	−1.77	9.67	−2.77
Morphological skills (*M*)	2 (4 %)		171.00	83.00	−2.38	55.50	−1.73	9.50	−2.86
Syntactic skills (*S*)	1 (2 %)		171.00	91.00	−1.71	61.00	−1.33	13.00	−0.91
Discourse skills (*D*)	1 (2 %)		167.00	58.00	−4.46	56.00	−1.70	12.00	−1.47
Verbal working memory (*W*)	0 (0 %)		–	–	–	–	–	–	–
Double		12 (23 %)	160.25	58.83	−4.39	48.67	−2.24	9.08	−3.10
M+*S*	3 (6 %)		161.67	50.67	−5.07	52.33	−1.97	8.00	−3.70
M+*D*	2 (4 %)		163.50	34.50	−6.42	48.00	−2.29	7.50	−3.98
R+*M*	2 (4 %)		159.50	75.50	−3.00	43.00	−2.65	11.00	−2.03
R+*S*	2 (4 %)		159.50	66.00	−3.79	61.50	−1.29	12.00	−1.47
R+*D*	2 (4 %)		151.50	82.50	−2.42	46.00	−2.43	7.50	−3.98
W+*R*	1 (2 %)		170.00	37.00	−6.21	30.00	−3.61	9.00	−3.14
Triple		15 (29 %)	162.87	66.47	−3.76	56.47	−1.66	11.00	−2.03
R+*M*+*S*	6 (12 %)		157.33	64.83	−3.89	51.50	−2.03	11.67	−1.65
M+*S*+*D*	3 (6 %)		170.33	63.67	−3.99	62.00	−1.25	9.67	−2.77
W+*S*+*D*	2 (4 %)		165.50	72.50	−3.25	56.50	−1.66	9.50	−2.86
W+*R*+*D*	1 (2 %)		168.00	90.00	−1.79	65.00	−1.03	13.00	−0.91
W+*R*+*S*	1 (2 %)		152.00	70.00	−3.46	64.00	−1.11	14.00	−0.35
R+*M*+*D*	1 (2 %)		167.00	51.00	−5.04	53.00	−1.92	10.00	−2.58
R+*S*+*D*	1 (2 %)		170.00	61.00	−4.21	57.00	−1.62	10.00	−2.58
Quatriple		12 (23 %)	158.33	59.08	−4.37	44.50	−2.54	8.83	−3.23
R+*M*+*S*+*D*	10 (19 %)		159.60	58.30	−4.44	44.90	−2.51	8.20	−3.59
W+*R*+*S*+*D*	1 (2 %)		154.00	70.00	−3.46	37.00	−3.10	10.00	−2.58
W+*M*+*S*+*D*	1 (2 %)		150.00	56.00	−4.63	48.00	−2.29	14.00	−0.35
Quintuple		5 (10 %)	158.20	58.20	−4.44	38.20	−3.01	5.80	−4.93

morphological and rapid naming deficits (12 %) and syntactic, discourse, and morphological and rapid naming deficits (19 %).

Table 4 also indicates that those who had more cognitive-linguistic deficits appeared to have lower scores of word reading, 1-min word reading, and reading comprehension than those who had fewer deficits. This observation was further verified by the results of correlation analyses. The correlation coefficients showed that the number of areas in which a dyslexic individual had a deficit was significantly correlated with his or her word reading score (r=−0.32, p<0.05), 1-min word reading score (r=−0.41, p<0.01), and reading comprehension score (r=−0.32, p<0.05) after controlling for age.

Distinguishing adolescent readers with dyslexia from readers without dyslexia

To examine the extent to which cognitive-linguistic measures could best distinguish the dyslexic and non-dyslexic readers, logistic regression analyses were used to investigate the five cognitive-linguistic domains, taking each linguistic-cognitive area into consideration once. The first step of analysis was to identify the best predictors of linguistic-cognitive deficits across each domain by using a backward stepwise selection (Elbro, Borstrøm, & Petersen, 1998). For the second step, the remaining significant predictors of each cognitive domain from the first step were entered together in a logistic regression analysis by employing a backward stepwise selection. The measures of cognitive-linguistic variables were then entered in the second block, respectively.

For the first analysis, the predictive value of the measures, including syntactic skills, discourse skills, morphological skills, rapid naming, and working memory, was analyzed. For both syntactic and discourse skills, morphosyntactic knowledge and sentence order knowledge measures were entered into a logistic regression analysis separately. The measures of morphosyntactic knowledge $\chi^2(1, N=104)=63.79$, $p<0.001$ and sentence order knowledge $\chi^2(1, N=104)=42.91$, $p<0.001$ were found to be significant predictors. Regarding the morphological skills, rapid naming, and working memory, the measures including backward digit span $\chi^2(1, N=104)=35.98$, $p<0.001$ and non-word repetition $\chi^2(1, N=104)=12.84$, $p<0.01$, digit rapid naming $\chi^2(1, N=104)=59.39$, $p<0.001$ and letter rapid naming $\chi^2(1, N=104)=80.17$, $p<0.001$, morpheme discrimination $\chi^2(1, N=104)=40.93$, $p<0.001$ and morpheme production $\chi^2(1, N=104)=62.16$, $p<0.001$ were the significant predictors. Hence, the eight measures were then carried over to the second step of the analysis. When the eight measures were entered simultaneously into a logistic regression analysis, the three final significant predictors were morphosyntactic knowledge $\chi^2(1, N=104)=4.73$, $p<0.05$, morpheme discrimination $\chi^2(1, N=104)=5.04$, $p<0.05$, and digit letter naming $\chi^2(1, N=104)=6.26$, $p<0.05$ (see Table 5). With these three measures included in the analysis, an overall hit rate was 97 %, with accuracy rates of both the dyslexic group (98 %) and control group (96 %) being very similar to one another.

Discussion

In the present study, syntactic and discourse skills in addition to morphological skills, rapid naming, and working memory distinguished Chinese adolescent readers with dyslexia as compared to those without such difficulties. We observed syntactic and discourse deficits in the readers with dyslexia. Morphological skills, rapid naming, and working memory were also impaired. These results seem to generally coincide with the prior research reporting poor syntactic skills, discourse skills, morphological skills, rapid naming, and working memory abilities among Chinese children with dyslexia (e.g., Chik et al., 2012a, b; Xiao & Ho, 2013). Our results showed that more than half of the readers with dyslexia in our sample exhibited deficits in syntactic and discourse skills, and these deficits frequently appeared to be in association with other cognitive-linguistic deficits. In particular, we found that readers with more severe dyslexia were particularly impaired in syntactic skills, morphological skills, and rapid naming compared to the readers with less severe dyslexia, suggesting that these deficits are the major factors contributing to reading impairment in Chinese. Furthermore, morphosyntactic knowledge along with measures of morpheme discrimination and letter rapid naming significantly distinguished Chinese adolescent readers with and without dyslexia in the logistic regression analyses. The current study has also shown that the syntactic skills, discourse skills, morphological skills, rapid naming, and working

Table 5 Logistic regression analyses predicting dyslexia in Chinese

Model no.	Model/predictor	χ^2	Hosmer–Lemeshow test	p value	Nagelkerke R^2	Correctly identified typically developing reader (%)	Correctly identified dyslexic reader (%)	Overall accuracy (%)	β	Odds ratio	Wald
1	Backward digit span	35.98	5.59	0.59	0.39	67	81	74	−1.42	0.24	22.43***
2	Non-word repetition	12.84	9.69	0.29	0.15	65	69	67	−0.63	0.53	10.64**
3	Digit rapid naming	59.39	16.30	0.04	0.58	81	87	84	−2.25	0.11	25.93***
4	Letter rapid naming	80.17	11.10	0.20	0.72	89	89	89	−2.45	0.09	28.10***
5	Morpheme discrimination	40.93	5.32	0.50	0.43	77	83	80	−1.08	0.34	24.95***
6	Morpheme production	62.16	1.40	0.92	0.60	85	79	82	−1.40	0.25	29.51***
7	Morphosyntactic knowledge	63.79	2.13	0.98	0.61	85	79	82	−1.59	0.20	27.78***
8	Sentence order knowledge	42.91	7.16	0.52	0.45	73	73	73	−1.22	0.30	25.48***
9	Backward stepwise	131.68	0.86	1.00	0.96	98	96	97			
	Letter rapid naming								−6.97	0.00	6.26*
	Morpheme discrimination								−2.04	0.13	5.04*
	Morphosyntactic knowledge								−3.99	0.02	4.73*

*p<0.05; **p<0.01; ***p<0.001

memory of readers with dyslexia are critical both for word reading and reading comprehension abilities. These findings are in line with the simple view of reading (Hoover & Gough, 1990) and the Triangle Model of Reading (Bishop & Snowling, 2004), which suggest that reading development and impairment may depend on the orchestration of interconnected, cognitive-linguistic components. Thus, difficulties in any of syntactic skills, discourse skills, morphological skills, rapid naming, and working memory may in turn entail weakened reading and reading comprehension skills. We further elaborate on these results below.

Our findings indicated that, on average, readers with dyslexia performed worse in syntactic skills than readers of the same age. Approximately 69 % of dyslexic readers demonstrated syntactic deficits that frequently appeared in association with deficits in morphological skills and rapid naming. Syntactic deficits could have different causes. It may be that readers with dyslexia have not fully mastered their syntactic skills particularly those of morphosyntax, which in turn may produce a vast number of grammatical mistakes and morphosyntax errors. Because of the lack of inflections and word boundaries in Chinese, the ability to reflect on and manipulate morphosyntax information may be particularly important for comprehending Chinese texts. Morphosyntax has been viewed as a vital skill for reading Chinese texts given the intertwining nature of semantic and syntactic properties of Chinese words, and thus, poor morphosyntax may contribute to reading impairment. Syntactic deficits may also be caused by underlying weaknesses in both morphological skills and rapid naming, perhaps because readers with dyslexia have not attained and utilized morphological knowledge and the ability to efficiently access lexical information. Such deficits in morphological skills and rapid naming could hinder one's syntactic processing. It may also be true that many dyslexic readers have been limited to simple texts containing fewer syntactically complex structures and types of intricate sentences as a result of poor reading experience and/or low reading level, thus further inhibiting the attainment of syntactic processing. Further investigation is needed to investigate the extent to which syntactic skills underlie reading difficulties in Chinese readers. Nonetheless, these results are compatible with the previous findings of studies with Chinese dyslexic readers (Chik et al., 2012a, b; Chung et al., 2013) reporting that individuals with dyslexia performed less well in syntactic skills than the typically developing readers. Taken together, our data show that syntactic skills remain problematic for readers with dyslexia and support the view that syntactic deficits characterize adolescent readers with dyslexia.

Apart from syntactic deficits, deficient discourse skills were identified in 58 % of the dyslexic readers in our sample. Discourse deficits were also commonly found in conjunction with additional impairments of rapid naming and working memory. It may be that readers with dyslexia have difficulty in detecting cohesive devices and particular story features and in understanding the relationships among sentences, thereby hindering the forming a mental schema of the passage. Thus, readers' performance in the discourse skills measure appears to be less sensitive to their text coherence, and knowledge about cohesive devices and discourse markers. As in the measure of discourse skills, the readers are required to rearrange various sentences into a coherent discourse. Therefore, these readers need to pay attention to the cohesive devices and certain story features including connectives, time and sequence markers, and semantic hints in order to compose a meaningful and logical passage. Consistent with the research study on Chinese children (Chik et al., 2012b), which found that discourse deficits contribute significantly to reading failure, a similar result was found in our sample of adolescent readers with dyslexia.

Our present data showed that 67 % of adolescent readers with dyslexia exhibited deficits in morphological skills. The majority of these readers also tended to show deficits in the

combination of morphological skills along with the syntactic skills, discourse skills, and rapid naming. It seems that the individuals with dyslexia may have difficulties in morphological skills given that many homophones and words are formed with multi-morphemes in Chinese. These readers may have problems in identifying and discriminating morphemes, manipulating the morphemic structure, and generalizing morpheme meaning. Perhaps, the readers with dyslexia are unaware of the role of morphological relations, storing words in isolation rather than network forms. Therefore, difficulties in morphological skills may hinder adolescents with dyslexia in establishing semantic representations of morphemes and multimorphemic network. Such difficulties can in turn lead to reading difficulties. The present findings concur with prior work (e.g., Chung et al., 2010, 2013; Shu et al., 2008) reporting that deficits in morphological skills may be a problem for Chinese adolescent readers with dyslexia thus constituting a persistent problem.

The readers with dyslexia in our sample also experienced rapid naming deficits. Our findings show that 61 % of adolescents had deficits in rapid naming that often emerged in association with accompanying deficits in syntactic, discourse, and morphological skills. Readers with dyslexia appeared to be slower in the measures requiring the rapid naming of numbers and letters than their typically developing readers. Thus, slow performance in the rapid naming measures are likely to reflect weakness in the individual's phonological representations, difficulties in learning arbitrary associations, and slowness in the speed of access to the lexicon (e.g., Bowers & Newby-Clark, 2002; Georgiou, Protopapas, Papadopoulos, Skaloumbakas, & Parrila., 2010; Liao et al., 2008). Perhaps, because the mapping between orthographic and phonological forms is relatively arbitrary in Chinese, it is reasonable to suggest that the relationship between deficient rapid naming and reading problem is particularly strong in Chinese, and deficits in rapid naming are often considered as one of the major underlying causes of poor reading in Chinese readers. Similar findings have been reported in previous studies (Chung et al., 2010; Ho et al., 2002, 2004) who found that a high proportion of children and adolescent readers with dyslexia displayed rapid naming deficits. Such deficits might remain major problem for adolescent readers with dyslexia.

Working memory appeared to be another weakness for dyslexic readers with 33 % of the dyslexic readers demonstrating working memory deficits. It is possible that the readers with dyslexia may have weakness in the phonological loop component of working memory that may affect individuals' ability to acquire the sound patterns of words and develop the mapping sound to meaning connections. Arguably, such difficulty may hinder the development of graphic–sound associations, multi-morpheme words, morphosyntax, and discourse skills, thus adversely affecting the acquisition of reading Chinese. Consistent with the previous studies (Archibald & Gathercole, 2006; Chik et al., 2012a, b; Gathercole, Pickering, Knight, & Stegmann, 2004; Sela et al., 2012), readers with dyslexia seem to have difficulties in processing, storage, and retrieval of information and performing concurrent cognitive activities. Consequently, reading difficulties may be caused by verbal working memory deficits. The present findings from this study add to the growing evidence of an association between poor working memory capacity and reading impairment (e.g., Chik et al., 2012a, b; Chung et al., 2010; Gathercole et al., 2004).

The findings also revealed a striking heterogeneity of cognitive-linguistic profiles in dyslexic readers, suggesting multiple causes for reading impairment in Chinese. Our results indicated that around 85 % of the present sample had double or more cognitive-linguistic deficits, which suggests that the adolescent readers with dyslexia have impairments across multiple cognitive-linguistic domains. Of the 52 readers with dyslexia in the sample, 23 % had double deficits and over 61 % had three or more cognitive-linguistic deficits. It is noteworthy that syntactic deficits commonly appear in connection with morphological and rapid naming

deficits and these three deficits occur when the readers exhibited more than three types of deficits. Similarly, deficits in discourse skills were often found in association with additional syntactic and morphological deficits. These results suggest that when the rapid naming, syntactic, discourse, and morphological deficits occur jointly, these deficits could possibly cause severe problems in reading for readers with dyslexia. The association between the number of deficits and the degree of reading impairment was also observed. In essence, we found that reading performance deteriorated as the number of deficits increased. The results, in general, suggest that the dyslexic readers' problems may have been caused by different underlying cognitive-linguistic deficits. These findings support results reported in the previous studies conducted with Korean and Chinese readers with dyslexia (e.g., Cho & Ji, 2011; Chung et al., 2010; Ho et al., 2002).

In addition, logistic regression analyses revealed that syntactic skills, morphological skills, and rapid naming were found to be the strongest factors distinguishing Chinese adolescent readers identified as dyslexic from non-dyslexic readers. The importance of the syntactic skills, morphological skills, and rapid naming has been demonstrated in previous work on Chinese readers with dyslexia (e.g., Chik et al., 2012b; Chung et al., 2013; Li, Shu, McBride-Chang, Liu, & Xue, 2009; Shu et al., 2006). Our findings further extended this work by reporting that the measure of morphosyntactic knowledge, morpheme discrimination, and letter rapid naming uniquely distinguish adolescent readers with dyslexia and without dyslexia. Syntactic skills in addition to both morphological skills and rapid naming could adequately be used to predict group membership of dyslexic and typically developing readers with an overall correct classification rate of 97 %. Therefore, perhaps, measures of morphosyntactic knowledge, morpheme discrimination, and letter rapid naming should be considered to be used for screening adolescent readers at risk of dyslexia.

Several limitations of the present study are worthy of note. First, the current study only examined a specific set of cognitive-linguistic abilities as underlying causes of dyslexia in Chinese. The measures of visual-orthographic knowledge, pragmatic skills, and executive functioning were not included in the present investigation despite some evidence showing their relevance to dyslexia. Future research should consider a wider arrange of other cognitive-linguistic skills including visual-orthographic knowledge (Chung et al., 2010), pragmatic skills (Griffiths, 2007), and executive functioning (Booth, Boyle, & Kelly, 2010). Second, given that in the present study the dyslexic group was matched with the chronological-age control group only, future studies should include a reading-level matched control group (RL) that provides a better comparison in determining the underlying reading deficits with further causal factors of dyslexia than just the chronological-age control group pinpointed. Including the RL group may allow assessing the degree to which various cognitive-linguistic skills are potentially affected by an individual's reading achievement. Thus, it can be argued that the RL group could be used to counterbalance any effects of reading skills that are likely to affect the degree of various cognitive-linguistic skills being measured. Third, the study was limited to assessing the discourse skills, namely, the structural coherence and the linguistic cohesion of story organization. Future studies should investigate other related skills such as inference processing, reader prior knowledge, use of context, comprehension monitoring ability, and understanding story structure (e.g., Cain & Oakhill, 2006; Kintsch, 1994; van den Broek, 1994). Fourth, this investigation focused on the syntactic aspects of morphosyntactic knowledge; further investigation may consider examining other possible linguistic devices and characteristics, for example, anaphoric references, causal references, instrumental inferences, elaborative inferences, backward inferences, and temporal terms with sequencing problems. Fifth, future work should redevelop the measures of morpheme discrimination and sentence order knowledge to improve the reliability of the tasks. One possible way is to increase the length of the tests and

improve the discriminating quality of items in order to reduce the chances of students guessing the correct answer. Sixth, the present data showed a variety of heterogeneous cognitive-linguistic profiles of Chinese readers with dyslexia and thus fairly low frequency of some deficits, which could make it difficult to establish a causal link between the less frequently appearing deficits and reading skills. Seventh, future studies should include screening measures [e.g., van der Lely, Gardner, Froud, and McClelland's (2007) Grammar and Phonology Screening (GAPS) test] that could be used to screen out readers with speech language impairment. These measures may further assist to examine varying different degrees of difficulties in syntactic, discourse, and semantic skills among readers with dyslexia. Future studies, ideally based on a larger sample with an equal split of boys and girls for dyslexic and chronological-age control group, are needed to disentangle the causal link between different cognitive-linguistic skills, such as morphological skills, syntactic skills, discourse skills, and pragmatic skills, and different degrees of reading difficulties. Lastly, longitudinal research of individuals with a familial risk of dyslexia from birth to young adulthood could provide further insight to different subtypes of dyslexia with different underlying multiple causes of reading difficulties in Chinese adolescent readers.

Despite these limitations, our findings add to a growing body of research investigating developmental dyslexia in Chinese and highlight the importance of syntactic skills, discourse skills, morphological skills, rapid naming, and working memory in distinguishing between the readers with dyslexia and typically developing readers. In addition, deficits in syntactic and discourse skills appear not only in isolation but also in conjunction with other cognitive-linguistic deficits, suggesting multiple deficits in the Chinese readers. In particular, syntactic skills in addition to morphological skills and rapid naming are found to be significant in distinguishing dyslexic from non-dyslexic readers partly because of the features of the Chinese language. Taken together, these findings suggest that syntactic and discourse skills might emerge to be particularly vital in understanding developmental dyslexia in Chinese.

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