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Contributions of executive functioning to Chinese and English reading comprehension in Chinese adolescent readers with dyslexia

Kevin Kien Hoa Chung[1] · Chun Bun Lam[1] · Chloe Oi Ying Leung[1]

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Abstract
The present study investigated the executive functioning of working memory, inhibition, shifting, and planning in Chinese adolescent readers with dyslexia and how they related to Chinese (L1) and English (L2) reading comprehension. Fifty-seven Hong Kong Chinese students at Grade 7 were compared with 57 typically developing readers of chronological-age-matched controls on their performance on working memory, inhibition, shifting, planning, vocabulary knowledge, rapid naming, and reading comprehension in Chinese and English. Results from the multivariate analysis of variance showed that readers with dyslexia performed worse than the typical readers in executive functioning, vocabulary knowledge, rapid naming, and reading comprehension. Hierarchical regressions indicated that working memory, inhibition, and vocabulary knowledge were significant predictors of reading comprehension in L1 after controlling for age, IQ, and group membership. Furthermore, working memory, inhibition, shifting, vocabulary knowledge, and rapid naming contributed uniquely to reading comprehension in L2. Taken together, these findings suggest executive functioning difficulties in Chinese readers with dyslexia and highlight the differential contributions of executive functioning to Chinese and English reading comprehension; working memory and inhibition appear to play an important role in reading comprehension across different languages.

Keywords Dyslexia · Executive functioning · Chinese · English · Reading comprehension · Adolescent readers

✉ Kevin Kien Hoa Chung
kevin@eduhk.hk

[1] Department of Early Childhood Education and Centre for Child and Family Science, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, New Territories, Hong Kong, SAR, China

Introduction

Dyslexia is a specific learning disability that adversely affects accurate and fluent word reading (Chung, 2017; Chung & Ho, 2010a, b; Lyon, Shaywitz, & Shaywitz, 2003; Rose, 2009). Although reading comprehension difficulties do not have to stem from word reading problems (Nation, 2019), inaccurate and slow word reading may limit sentence and text processing, resulting in reading comprehension difficulties (Snowling & Hulme, 2013). Indeed, a handful of studies have indicated that readers with dyslexia may experience difficulties in reading comprehension, partly due to their poorer phonological awareness skills and compromised word reading abilities (Catts, Fey, Zhang, & Tomblin, 1999; Snowling, Gallagher, & Frith, 2003). Evidence also exists that executive functioning (EF) problems may be implicated in reading comprehension difficulties among readers who learn English as the first language (L1; Follmer, 2018; Reiter, Tucha, & Lange, 2005; van Reybroeck & De Rom, 2019). However, the interrelationship between EF and reading comprehension has rarely been examined among adolescent readers with dyslexia who learn English as a second language (L2). In a bilingual society like Hong Kong, China, children are expected to learn both Chinese and English at an early age and become efficient biliterate readers. Therefore, in the present study, we investigated the contributions of four key components of EF, namely working memory, inhibition, shifting, and planning, to reading comprehension in both Chinese (L1) and English (L2) among adolescent readers with and without dyslexia in Chinese.

Executive functioning and reading comprehension

Reading comprehension is a complex linguistic and cognitive process involving the execution and integration of a range from lower to higher order language and cognitive processing skills (Kendeou, Broek, Helder, & Karlsson, 2014). Reading comprehension can be viewed as the process of constructing and extracting the meaning from written text, integrating the meaning with knowledge derived previously from other sources (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). This process could involve, for example, accessing word meanings, remembering words, parsing sentences, drawing inferences, and collecting facts from multiple sentences to form a coherent mental model. The interplay of these processes may require processing speed, lexical retrieval, and executive functioning (Kintsch, 1998). In the light of these findings, Kendeou et al. (2014) expanded the Simple View of Reading model proposed by Gough and Tunmer (1986) to include EF as a key mechanism that coordinates and integrates the iterative processes of construct representation while reading. This model has been supported by empirical studies showing that executive functioning contributes to reading comprehension beyond the skills of decoding and listening comprehension (e.g., Locascio, Mahone, Eason, & Cutting, 2010).

EF broadly refers to a set of abilities that involve the coordination of multiple processes for individuals in order to take conscious control of their thoughts and actions, planning and problem solving, and other goal-directed behaviors, particularly in response to complex stimuli and/or stimulating environments (Blair, 2016; Miyake et al., 2000). EF has been conceptualized as a multicomponent construct that consists of four core components: (a) working memory (the ability to manipulate or update, revise and monitor incoming information in memory), (b) inhibition (the ability to focus attention and suppress inappropriate responses), (c) shifting (the capacity to switch attention between mental sets, strategies, tasks, and goals), and (d) planning (the ability to perform multistep tasks, select information, and execute a response) (Butterfuss & Kendeou, 2018; Follmer, 2018). The importance of the relationship of the EF of working memory, inhibition, shifting, and planning to reading comprehension has been increasingly stressed in studies (Kieffer, Vukovic, & Berry, 2013; Potocki, Sanchez, Ecalle, & Magnan, 2017), as these EF components are necessary to understand the features of the text (e.g., letters, words, phrases, and sentences) while actively engaging with the text structure, making inferences, monitoring comprehension, and acquiring oral language skills to read and comprehend the text (e.g., Oakhill, Hartt, & Samols, 2005; Perfetti, Landi & Oakhill, 2005).

Although EF has been linked to reading comprehension in alphabetic languages as L1 (Dilworth-Bart, 2012; Ober, Brooks, Plass, & Homer, 2019; Potocki et al., 2017), whether specific components of EF are linked to reading comprehension among typically developing adolescent readers remains unclear. For example, Kieffer et al. (2013) found that inhibition and shifting, but not working memory, were uniquely associated with reading comprehension in English among 4th graders, controlling for vocabulary knowledge, word reading, and sentence comprehension. However, Christopher et al. (2012) found that working memory and inhibition were uniquely associated with reading comprehension in English among children (8–10-year-olds) and adolescents (11–16-year-olds), controlling for processing speed and rapid naming. Meanwhile, Potocki et al. (2017) found that working, inhibition, shifting, and planning were all uniquely associated with reading comprehension in French among 5th graders, controlling for phonological awareness, processing speed, word reading, and language comprehension. Some additional studies found that working memory and planning were uniquely predictive of reading comprehension in English among 9–15-year-olds (Locascio, Mahone, Eason, & Cutting, 2010; Sesma, Mahone, Levine, Eason, & Cutting, 2009), although Georgiou and Das (2014) did not find planning to be a unique predictor of reading comprehension in English among college students.

Findings are also mixed as to whether readers with dyslexia have poorer EF skills, and whether specific components of EF are linked to reading comprehension among readers with dyslexia. Specifically, some studies found that readers with dyslexia showed deficits in working memory (Smith-Spark & Fisk, 2007; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005), inhibition (Altemeier et al., 2008; Willcutt et al., 2005), shifting (Helland, & Asbjørnsen, 2000; Poljac et al., 2010), and planning (Soriano-Ferrer, Piedra-Martínez, Arteaga, 2018; Smith-Spark, Henry, Messer, Edvardsdottir, & Zięcik, 2016), but other studies did not find such patterns (Jeffries & Everatt, 2004; Swanson, Howard, & Saez, 2006). Moreover, some studies showed that deficits in working memory and inhibition (Doyle et al., 2018) and planning (Altemeier et al., 2008) were linked to reading comprehension problems among readers with dyslexia, whereas other studies did not find such links (Sesma et al., 2009). Potential reasons for these inconsistent findings may include discrepancies in sample characteristics and measurement tools, as well as inclusion of different control variables. Moreover, studies that reported null findings tended to have relatively small sample sizes ($N=87$ in Jeffries & Everatt, 2004; $N=66$ in Swanson et al., 2006; $N=60$ in Sesma et al., 2009), highlighting the importance of having enough statistical power to detect the relationships of different EF components with reading comprehension.

Executive functioning and Chinese reading

Reading comprehension in Chinese may differ from that in English. Chinese language is a morphosyllabic writing system in which each character represents a spoken sound and meaning at the syllable and morpheme level respectively. In comparison, English uses letters and letter combinations to stand for units of sounds. Each unit represents sound at the phonemic level. Such letter-phoneme mapping is central to English reading. Unlike English, each Chinese character has a noticeable perceptual unit that differs from thousands of other characters. Most Chinese words are made up of two or more characters (Taylor & Taylor, 1995). It is estimated that there are over 50,000 characters in Chinese, around 4500 of which are frequently used characters (Gao et al., 2019). Furthermore, many characters look alike and sound similar. Reading Chinese or English passages, readers have to use working memory to process and retrieve units (e.g., sound and meaning information, characters or letters in words, and words in passages) from long-term memory, inhibit irrelevant information, shift attention between information clues (e.g., sound information, word and text meanings), and be involved in comprehension monitoring and identifying key ideas in the passages. Despite the linguistic and structural differences between Chinese and English, EF is likely to play a crucial role in both word reading and reading comprehension in these two language systems.

Recent studies have investigated the impact of EF on Chinese reading with typically developing children (e.g., Chung, Lam, & Cheung, 2018; Chung & McBride-Chang, 2011), but similar research involving adolescent readers with dyslexia is sparse. The few available studies showed that EF such as working memory and inhibition were significant contributions to Chinese word reading among Chinese typically developing children (Chung, Lo, & McBride, 2018; Chung & McBride-Chang, 2011; Lan, Legare, Ponitz, Li, & Morrison, 2011), and Chinese children with poor reading skills show weakness in EF (e.g., Chung, 2015; Peng, Sha, & Li, 2013). A recent study (Liu et al., 2018) found that inhibition was predictive of Chinese sentence reading comprehension in Chinese children beyond word reading and other reading-related processes. Another longitudinal study conducted by Liu, Chung and Fung (2019) also revealed that EF including working memory and inhibition and word reading in Chinese or English reciprocally predicted each other in Chinese children during the transition from kindergarten to primary school. To date, EF has been shown to impact reading in Chinese word reading and sentence comprehension, but not much is known about its role in reading comprehension for readers learning English as L2. Yet few attempts have been made to assess multiple components of EF which simultaneously include working memory, shifting, inhibition, and planning in relation to Chinese reading comprehension and even fewer have examined these relations with other reading-related processes in adolescent readers. Given the different linguistic and structural features of Chinese and English and readers' language learning exposure and proficiency, it is as yet unclear which four components of EF would affect reading in Chinese and English and how these skills would relate to reading comprehension in Chinese adolescent readers with and without dyslexia.

The present study: context and purpose

In Hong Kong, China, formal education begins at the age of 3.5 years. Children begin to read and write concurrently in Chinese and English. Most children speak Cantonese, which is the dialect of Chinese spoken in Hong Kong. Reading instruction in Cantonese usually proceeds with the memorization of characters or the "look-and-say" method (McBride-Chang, 2016). Cantonese and traditional characters are most commonly used in Hong Kong society, although English is one of Hong Kong's official languages. Most children receive reading instruction in both Chinese and English. Many universities and higher education institutions use English as a medium of instruction and the Government increasingly encourages the use of English language skills in primary and secondary schools. Thus, the Hong Kong context may provide an opportunity to investigate individuals' reading development and difficulties in both Chinese and English. It would be particularly interesting to understand whether EF including working memory, inhibition, shifting, and planning would play different roles in supporting Chinese (L1) and English (2) reading comprehension among Chinese adolescent readers with and without dyslexia.

Previous studies have mainly examined the role of EF in learning alphabetic languages, particularly English (Georgiou & Das, 2018; Ober et al., 2019; Potocki et al., 2017). Though important, these studies have seldom considered the contributions of other well-established, reading-related processes, especially vocabulary knowledge and rapid naming (Best, Miller, & Naglieri, 2011). Indeed, research has indicated that readers with dyslexia have deficits in vocabulary knowledge as well as rapid naming (Chung, Ho, Chan, Tsang, & Lee, 2013; Chung & Lam, 2020; Li, Tao, Joshi, & Xu, 2018). Associations of vocabulary knowledge (Chung & Lam, 2020; Gottardo, Koh, Chen, & Jia, 2017) and rapid naming (McBride-Chang & Wang, 2015; Chung et al., 2008) with word reading in Chinese and English have also been documented in studies with readers with dyslexia and typically developing readers. Therefore, we examined the potential differences in vocabulary knowledge in both Chinese and English and rapid naming between readers with and without dyslexia, and controlled for these variables when examining the unique impact of EF on reading comprehension in Chinese and English.

The present study focused on the extent to which adolescent readers with dyslexia would have difficulties in their working memory, inhibition, shifting, planning, vocabulary knowledge, and rapid naming as compared with their typical peers. It also examined the relationships between these EF and reading-related processes with reading comprehension on narrative text in Chinese and English. This study was among the first to examine all these variables simultaneously in Chinese and English reading comprehension for the dyslexic and typical group. In order to control the effects of text types, only narrative text was selected for this study. Narrative and expository texts are the commonly used types of texts in school textbooks and reading materials (e.g., Heller & Greenleaf, 2007; Shanahan & Shanahan, 2008). Two groups of students at Grade 7, with readers with dyslexia and typical readers (refer to age-matched typically developing readers) were recruited in Hong Kong, China.

The aims of this study were twofold. First, we examined whether readers with dyslexia would show difficulties in EF of working memory, inhibition, shifting, planning, vocabulary knowledge, and rapid naming compared to the typical readers. Evidence from previous research on the co-occurrence of Chinese (L1) and English (L2) reading difficulties has shown associations between poor reading skills in L1 and L2 (Chung & Lam, 2020; Chung & Ho, 2010a, b; Ho & Fong, 2005). These studies found a high overlap of L1 and L2 reading difficulty in Chinese children with dyslexia. The cross-linguistic hypotheses (Cummins, 1979; Geva & Siegel, 2000; Sparks & Ganschow, 1995) have also suggested that cognitive and reading-related processes in L1 and L2 are interrelated and that some common skills acquired in L1 could affect and ease the development of L2 reading. Based on previous studies on readers with dyslexia (e.g., Chung et al., 2018a, b; Peng et al., 2013; Potocki et al., 2017) and cross-linguistic hypotheses, we expected that readers with dyslexia would have more difficulties in working memory, inhibition, shifting, planning, vocabulary knowledge, and rapid naming when compared to their typical peers. Second, we investigated whether, for the dyslexic and typical group, EF, vocabulary knowledge, and rapid naming would be related to reading comprehension in L1 and L2. In light of previous studies of multiple components of EF and reading comprehension (e.g., Doyle et al., 2018; Georgiou & Das, 2018; Liu et al., 2019; Potocki et al., 2017), we hypothesized that EF in particular working memory and inhibition would predict reading comprehension in both languages beyond vocabulary knowledge and rapid naming.

Methods

Participants

Participants were 114 of 7th graders, including 57 students with dyslexia in Chinese (29 boys and 28 girls; mean age = 152.28 months, *SD* = 3.71) and 57 typically developing students (31 boys and 26 girls; mean age = 152.12 months, *SD* = 4.53), from three secondary schools in Hong Kong, China. All students were Chinese native speakers who had been learnng both Chinese and English in local primary and secondary schools for at least 9 years.

The 57 students with dyslexia were assessed at Grade 3 by educational psychologists using the Hong Kong Test of Specific Learning Difficulties in Reading and Writing for

Primary School Students (2nd ed.) [HKT-P(II); Ho et al., 2007]. The HKT-P(II) is a locally normed, age-specific assessment tool for diagnosing dyslexia in Chinese among primary school students. It taps onto such reading-related skills as rapid naming, phonological awareness, orthographic awareness, and verbal working memory. To be diagnosed as dyslexic, students need to meet the HKT-P(II)'s criteria, including scoring at least one standard deviation below the mean of their same-age peers in the target reading-related skills, though enjoying sufficient learning opportunities, having an IQ of 85 or above, and having no prior diagnoses of attention disorders, language difficulties, mental and cognitive impairments, behavioural problems, brain damage, or visual or hearing impairment.

To reassess the dyslexic status of these 57 students, we invited their school teachers to complete The Hong Kong Behaviour Checklist of Specific Learning Difficulties in Reading and Writing for Junior Secondary School Students (BCL-JS; Ho et al., 2009) at Grade 7. The BCL-JS taps onto Chinese reading, writing, and composition, and is proven effective in differentiating between adolescents with and without dyslexia. The cutoff point of BCL-JC is 2.6. All the 57 students diagnosed to have with dyslexia at Grade 3 and had teacher ratings above the cutoff score of the BCL-JS ranging from 3.4 to 4.6. In other words, these students were classified as dyslexic based on educational psychologists' judgement (at Grade 3) and school teachers' ratings (at Grade 7).

Fifty-seven typically developing students were recruited from the same secondary school as the students with dyslexia. These students, consisting of 31 boys and 26 girls (mean age = 152.12 months, SD = 4.53), were matched to the dyslexic group as a control group. They were nominated by their class teachers according to their grade point average for the previous school term. Their grade point average was at the 50–75th percentile in Chinese language and literature. These students had no history of dyslexia or other types of learning difficulty, according to reports from their class teachers. The Test of Nonverbal Intelligence 4th edition (TONI-4) was administered to both groups as a proxy for students' nonverbal intelligence (Brown, Sherbenou & Johnsen, 2010).

Materials and procedures

Students were administered assessment measures: working memory, inhibition, shifting, planning, vocabulary knowledge, rapid naming, and reading comprehension. Two practice assessments for all the measures were administered to students before formal testing. The measures were administered to students individually and conducted by trained experimenters. This study was approved by the University's Human Research Ethics Committee.

Assessment measures

Nonverbal intelligence test

The Test of Nonverbal Intelligence 4th edition (TONI-4) was used to assess students' nonverbal reasoning ability (Brown et al., 2010). It was composed of 60 items of increasing difficulty. Students were required to identify and discriminate various visual features and patterns (i.e., shape, position, direction, rotation, contiguity, shading, size, and/or movement) in a visual matrix. Next, they were provided a visual matrix with a missing part and asked to complete it by selecting one of the four to six response options given. The Cronbach's α of this task was .83.

Reading comprehension

Constructed in line with the measure of Chinese reading comprehension used in previous studies (Chung, Ho, Chan, Tsang, & Lee, 2010; Chung et al., 2018a, b) and English reading comprehension (Ransby & Swanson, 2003), a total of four narrative passages, with two passages of Chinese and two of English, were selected and modified based on the reference materials and texts recommended by the Education Bureau. Each of these passages was followed by 8 multiple-choice questions with five answer choices. The questions were designed in ascending order of difficulty. Both literal and inferential questions were used to assess students' comprehension skills. A pilot study with 51 students was carried out to try out the measures of these four passages. For reading comprehension, students were given 2 booklets comprising 2 passages for Chinese and English, respectively. They were asked to read each passage carefully and answer the multiple-choice questions for each passage. The maximum time limit was 15 min for each passage. Students' scores were the total number of correct answers. The Cronbach's alpha reliability coefficient was .71.

Vocabulary knowledge

The Chinese vocabulary knowledge test was used to tap into depth understanding of students' vocabulary knowledge (Chung et al., 2013). Twenty-five words including adjectives, verbs, and nouns, were familiar to students in junior secondary grades and were orally presented to students. Students were asked to explain or define the given target words and then use the target words to construct sentences to illustrate their meaning. For example, given the target word (silence), an explanation or definition would be "quiet", "mute", "voiceless", "noiseless", and "absence of sound". An example of a sentence would be the following: "The only sounds breaking the silence of the night were our footsteps". Students' answers were scored on a three-point scale (0–2). Two points were given for a proper answer that expressed the meaning of the word, one point was awarded to a partial answer that expressed the meaning of the word, and zero points were given to an unrelated answer. The Cronbach's α of this test was .92.

The English vocabulary knowledge test is modelled on the Stanford–Binet Intelligence Scale Vocabulary subtest (Throndike, Hagen, & Sattler, 1986) and the aforementioned Chinese Definitions Knowledge test. This measure consists of 22 English words selected from the four secondary school textbooks. Students were presented with a word representing an object or concept and asked to explain or define the word. They were then asked to use the target words to construct sentences to demonstrate their meaning. What is the meaning of "considered"? An explanation or definition could be the following: "take something into account", "decided", "think", "think carefully", or "premeditate". An example of a sentence would be the following: "Ian considered all options before making the decision." Similar to the Chinese Definitions Knowledge test, sample answers for scores of 2, 1, and 0 per question were included in the scoring scheme. The Cronbach's α of this test was .90.

Rapid naming

Similar to the measure of rapid digit naming used in previous studies (e.g., Chung, Lo, Ho, Xiao, & Chan, 2014), the rapid digit naming measure was composed of five digits (2, 4, 6, 7 and 9) printed in random order on A4 paper in rows of 10 × 8. With the rapid letter naming measure, eight English letters (a, u, y, p, t, b, i, and o) were selected and printed on a 10 × 8 matrix. Students were asked to name the digits or letters as quickly and accurately as possible. For both measures, students were also required to name each list twice. The average naming latency across the two trials was calculated. The test–retest coefficient of rapid digit naming and rapid letter naming was .92 and .95, respectively. A composite Z-score was calculated by averaging the scores across the two measures.

Working memory

The letter memory task was used to measure students' updating of their working memory representations (Miyake et al., 2000; Morris & Jones, 1990). Students were provided lists of letters, presented one at a time, each for two seconds. The number of letters per trial was between 5 and 11, randomly varied across 16 trials. Students were then asked to rehearse the letters in memory and remember the last four letters of each trial. For example, if the letters ''B, H, I, G, P, S, and L'' were given, students were requested to recall the letters ''G, P, S, and L". One point was awarded to each correct letter given. The Cronbach's alpha reliability coefficient in this sample was .89.

Inhibition

The inhibition test (NEPSY II; Korkman, Kirk, & Kemp 2007) was used as a measure of students' ability to inhibit spontaneous responses in accordance with novel instructions. This timed test consisted of three tasks measuring the individual's ability to denominate, inhibit, and change. Students were asked to look at a series of black and white arrows or shapes. They were also instructed to name the shape, the direction or an alternative response according to the color of the shape or arrow given. In the first test, students were asked to name the shape and direction of the arrow according to what they saw. In the second task, they had to name the shape and direction that was the opposite of what they saw. For the last test, they were asked to name the correct shape and direction when the arrow was black and the opposite shape and direction when the arrow was white. The Cronbach's alpha reliability coefficient in this sample was calculated as .77. A composite Z-score was computed by averaging the scores across the three tasks.

Shifting

The animal sorting test of NEPSY II (Korkman et al., 2007) was used to measure a student's ability to produce categories, transfer those categories to actions, and shift from one category to another. In this timed test, a set of eight drawing cards, representing animals in various contexts, was presented to students. These cards contained different features, for example, the color and number of animals on a card. Students were instructed to sort these cards into two groups of four cards each according to the prescribed sorting criteria. They were subsequently asked to apply a new classification to form two new four-card categories. Students were given 60 s to form as many categories as possible. One point was given for each correct category. The Cronbach's alpha reliability coefficient in the present sample was .81.

Planning

Tower of London (TOL; Shallice, 1982) was used to tap into students' ability in planning, rule learning, and inhibitory control. A computerized version of TOL was used to measure students' planning skills. It consisted of three disks with varying color (blue, red, and green) and a board featuring three vertical pegs. Students were required to move a set of colored disks, one by one, from an original state to a goal state, using the fewest number of moves possible while following the prescribed rules for how the disks could be moved across the three pegs (e.g., only one disk could be moved at a time, and a larger disk was not allowed to be placed on a smaller disk). In the TOL task, students were shown a goal configuration of the disks on the computer screen and subsequently asked to move the disks to match that configuration in the fewest number of moves. The students' problem-solving accuracy was recorded. The split-half reliability coefficient for accuracy was .71.

Results

Three types of statistical analyses were carried out. First, multivariate analysis of variance (MANOVA) was used to examine the group differences between the readers with dyslexia and typical readers. Second, partial correlation analysis was employed to examine the associations among the EF of working memory, inhibition, shifting, planning, vocabulary knowledge, rapid naming, and reading comprehension. Finally, regression analyses were conducted to examine the contributions of EF to reading comprehension in L1 and L2.

The means, standard deviations and F-statistics of EF, vocabulary knowledge, rapid naming, and reading comprehension across the dyslexic and control groups are presented in Table 1. The reliabilities for all the measures in English and Chinese were above .70. As shown in Table 1, the dyslexic group performed significantly worse than the control group in the measures of reading comprehension (F $(1, 112) = 140.54$, $p < .001$ for Chinese; $F(1, 112) = 88.22$, $p < .001$ for English), vocabulary knowledge (F $(1, 112) = 9.93$, $p < .01$ for Chinese; F $(1, 112) = 13.58$, $p < .001$ for English), rapid naming (F $(1, 112) = 232.59$, $p < .001$); working memory

Table 1 Group comparisons on ages and measures for the two groups

	Dyslexic group ($n=57$)		Control group ($n=57$)		$F(1, 112)$	η^2
	M	*SD*	*M*	*SD*		
Age in months	152.28	3.71	152.12	4.53	.04	.000
IQ	30.96	2.51	31.07	2.72	.05	.000
Chinese reading comprehension	5.18	1.89	9.51	2.01	140.54***	.557
English reading comprehension	6.16	1.99	9.58	1.90	88.22***	.441
Chinese vocabulary knowledge	9.84	3.85	12.16	3.99	9.93**	.081
English vocabulary knowledge	10.37	4.34	13.09	3.50	13.58***	.108
Rapid naming	.78	.65	−.78	.42	232.59***	.675
Working memory	27.04	2.98	29.95	2.64	30.46***	.214
Inhibition	−.12	.37	.12	.23	17.98***	.138
Shifting	4.86	2.04	7.53	2.31	42.74***	.276
Planning	18.81	5.75	25.16	8.09	23.34***	.172

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

(F (1, 112) = 30.46, $p<.001$); inhibition (F (1, 112) = 17.98, $p<.001$); shifting (F (1, 112) = 42.74, $p<.001$); and planning (F (1, 112) = 23.34, $p<.001$). Large effect sizes were found for Chinese reading comprehension ($\eta^2=.557$), English reading comprehension ($\eta^2=.441$), and rapid naming ($\eta^2=.675$).

A partial correlational analysis, as shown in Table 2, was carried out on the reading comprehension, EF, vocabulary knowledge, and rapid naming for the dyslexic and control groups. For both groups, after controlling for IQ and age, Chinese reading comprehension and English reading comprehension were significantly

Table 2 Correlations among measures in adolescent readers with dyslexia (lower left) and typical readers (upper right) after controlling for age and IQ

	1	2	3	4	5	6	7	8	9
1. Chinese reading comprehension	–	.30*	.44**	.30*	−.16	.40**	.16	.35**	.38**
2. English reading comprehension	.27*	–	.34*	.50***	−.15	.36**	.32*	.54***	.44**
3. Chinese vocabulary knowledge	.29*	.28*	–	.18	−.15	.40**	−.10	.18	.49***
4. English vocabulary knowledge	.28*	.33*	.38**	–	−.26	.26	.17	.28*	.30*
5. Rapid naming	−.33*	−.13	−.36**	−.41**	–	−.33*	−.05	−.20	−.40**
6. Working memory	.35**	.35**	.11	.27*	−.39**	–	.12	.41**	.46***
7. Inhibition	.49***	.39**	.35**	.45**	−.58***	.44**	–	.11	.18
8. Shifting	.31*	.37**	.36**	.40**	−.27*	.13	.48***	–	.37**
9. Planning	.39**	.38**	.27*	.36**	−.23	.18	.36**	.47***	–

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

correlated, with $r = .27$, $p < .05$ for the dyslexic group and $r = .30$, $p < .05$ for the control group. Chinese vocabulary knowledge was also significantly correlated with reading comprehension in each language ($r = .29$, $p < .05$ for Chinese, $r = .28$, $p < .05$ for English) for the dyslexic group and ($r = .44$, $p < .01$ for Chinese, $r = .34$, $p < .05$ for English) for the control group. English vocabulary knowledge was significantly correlated with Chinese reading comprehension and English reading comprehension ($r = .28$, $p < .05$, $r = .33$, $p < .05$ for the dyslexic group and $r = .30$, $p < .05$, $r = .50$, $p < .001$ for the control group). For both groups, EF was positively associated with reading comprehension in both languages (rs ranging from .31 to .49, ps < .05, for the dyslexic group, and rs ranging from .32 to .54, ps < .05, for the control group).

To examine the relationships among EF, vocabulary knowledge, rapid naming, and reading comprehension of L1 and L2, a series of four-stage hierarchical regression analyses was performed for each language separately. In step 1, age and IQ were entered into the regression models. A group variable was created, with the control group as the reference group (control group = 0, dyslexic group = 1), and entered as a categorical variable at step 2. The EF of working memory, inhibition, shifting, planning, vocabulary knowledge, and rapid naming were entered as independent variables at step 3, after controlling for age, IQ, and group membership at steps 1 and 2, respectively. The EF, vocabulary knowledge, rapid naming, and the group interaction term were then entered at step 4. Given that the interactions between group effects, EF, vocabulary knowledge, and rapid naming were not significant for Chinese and English reading comprehension, step 4 of the regression analysis is not reported in Tables 3 and 4.

For the regressions explaining Chinese reading comprehension for the dyslexic group and control group (see Table 3), Chinese vocabulary knowledge ($\beta = .15$, $p < .05$), working memory ($\beta = .15$, $p < .05$), and inhibition ($\beta = .14$, $p < .05$) uniquely predicted Chinese reading comprehension. For the regressions explaining English reading comprehension for the two groups, as shown in Table 4, English vocabulary knowledge ($\beta = .16$, $p < .05$), rapid naming ($\beta = .30$, $p < .05$), working memory ($\beta = .17$, $p < .05$), inhibition ($\beta = .15$, $p < .05$), and shifting ($\beta = .21$, $p < .01$) uniquely predicted English reading comprehension for both groups after controlling for age, IQ, and group membership. Overall, the regression model explained the substantial variance between Chinese reading comprehension ($R^2 = .70$) and English reading comprehension ($R^2 = .67$).

Discussion

The present study examined the executive functioning of working memory, inhibition, shifting, and planning in Chinese adolescent readers with dyslexia and how they related to Chinese (L1) and English (L2) reading comprehension. This study was the first to examine simultaneously the relationships among these EF, vocabulary knowledge, and rapid naming in the Grade 7 students with and without dyslexia. Although the associations of EF with word reading and reading comprehension have been studied with readers with dyslexia and typical readers across languages (e.g., Chung & McBride-Chang, 2011; Locascio et al., 2010;

Table 3 Hierarchical regressions explaining Chinese reading comprehension for both adolescent readers with dyslexia and typical readers

	R^2	ΔR^2	*F* change	β	*t*
Step 1	.02	.02	1.09		
Age in months				−.09	−.89
IQ				.13	1.32
Step 2	.57	.55***	140.92		
Age in months				−.07	−1.06
IQ				.11	1.70
Group				−.74	−11.87***
Step 3	.70	.13***	6.21		
Age in months				−.07	−1.14
IQ				.073	1.31
Group				−.54	−5.39***
Chinese vocabulary knowledge				.15	2.29*
English vocabulary knowledge				.01	.21
Rapid naming				.06	.49
Working memory				.15	2.14*
Inhibition				.14	2.12*
Shifting				.08	1.03
Planning				.10	1.36

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

Ober et al., 2019; Sesma et al., 2009), the relationships, particularly regarding which four components of EF are linked to reading comprehension in L1 and L2, have not yet been examined in Chinese adolescent readers with dyslexia and typical readers.

Our results indicated that the performance of readers with dyslexia was below that of the age-matched typical readers on the measures of working memory, inhibition, shifting, planning, vocabulary knowledge, and rapid naming in L1 and L2. EF was also correlated with L1 and L2 reading comprehension, suggesting that difficulties in these EF and reading-related processes may result in reading comprehension difficulties for both languages. Furthermore, EF in particular working memory and inhibition contributed to L1 and L2 reading comprehension after controlling for age, IQ, and group membership. To comprehend a passage, readers have to process and retrieve sound and meaning of words, extract and construct meaning information from text, and disengage irrelevant information. Consequently, working memory and inhibition appear to play an important role in support of reading comprehension. The findings of this study further add to the existing research on reading comprehension difficulties (e.g., Georgiou & Das, 2016; Potocki et al., 2017) by showing that Chinese adolescents with dyslexia having difficulties in L1 tend to have difficulties in L2 and EF may play a specific role in reading comprehension for Chinese adolescent readers. These results are further elaborated below.

Table 4 Hierarchical regressions explaining English reading comprehension for both adolescent readers with dyslexia and typical readers

	R^2	ΔR^2	*F* change	*β*	*t*
Step 1	.00	.00	.18		
Age in months				.05	.46
IQ				– .05	– .46
Step 2	.45	.44***	88.14		
Age in months				.06	.84
IQ				– .06	– .85
Group				– .67	– 9.39***
Step 3	.67	.22***	9.61		
Age in months				.04	.63
IQ				– .12	– 1.89
Group				– .54	– 5.13***
Chinese vocabulary knowledge				.08	1.22
English vocabulary knowledge				.16	2.20*
Rapid naming				.30	2.52*
Working memory				.17	2.23*
Inhibition				.15	2.07*
Shifting				.21	2.67**
Planning				.14	1.86

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

Co-occurrence between reading difficulties in L1 and L2

Our analyses showed that readers with dyslexia performed worse than the typical readers on measures of working memory, inhibition, shifting, planning, rapid naming, vocabulary knowledge, and reading comprehension, indicating that readers with dyslexia may have difficulties in EF, general reading-related processes, and reading comprehension in both L1 and L2. Difficulties in EF may imply problems in encoding, monitoring, and updating of working memory representations, inhibiting irrelevant linguistic information, switching between information presented in text, and performing multiple tasks at the same time (e.g., Doyle et al., 2018). On the other hand, difficulties in rapid naming may imply problems in reading text quickly and accurately (e.g., Chung et al., 2018a, b).

Readers with dyslexia were less knowledgeable about vocabularies and performed worse on reading comprehension tasks in both Chinese (L1) and English (L2). These findings were consistent with prior studies showing that, compared with the typically developing readers, readers with dyslexia show poorer vocabulary knowledge in L1, even when it is measured through oral exchanges rather than text reading (Chik et al., 2012; Chung et al., 2013; Kalindi & Chung, 2018; Hulme, Nash, Gooch, Lervåg, & Snowling, 2015). Readers with dyslexia also show poorer reading abilities in comprehension tests in L1 (Ransby & Swanson, 2003). Although dyslexia is a reading disability characterized by reading-related problems (Chung, 2017; Chung & Ho, 2010a, b; Lyon et al., 2003; Rose, 2009), individuals with dyslexia also tend to have delayed language development beginning from infancy and toddlerhood, suggesting that dyslexia may be related to deficiencies in broader language skills (Snowling & Melby-Lervåg, 2016). Difficulties in reading may further reduce individuals' opportunities to play with the meanings of words in general (Adolf & Hogan, 2018). Future researchers should use more differentiated measures to examine the functioning of dyslexic individuals in oral exchanges versus text reading.

It is worth noting that efficient word reading is necessary, but not sufficient, for success in reading comprehension (Nation, 2019; Snowling & Hulme, 2013). Therefore, dyslexia (a specific learning disability characterized by problems in word reading) and reading comprehension difficulty (a specific learning disability characterized by problems in reading comprehension but not necessarily in word reading) may show similarities as well as differences in reading-related processes (Fong & Ho, 2019; Snowling & Hulme, 2013)—readers with dyslexia may have problems at the vocabulary and the text levels (as in the case in our study), whereas readers with reading comprehension difficulty may have problems at the text but not the vocabulary level. An important direction for future research is to examine potential differences in EF, reading related processes, and reading comprehension among readers with dyslexia, readers with reading comprehension difficulties (but not dyslexia), and typically developing readers to clarify their profiles in different language systems.

Correlational analyses showed that EF and vocabulary knowledge were associated with reading comprehension in L1 and L2, suggesting that readers with dyslexia in L1 could have a high risk of reading difficulty for L2. It is worth noting that rapid naming was more associated with reading comprehension in Chinese than in English. Because the link between orthography and phonology mapping is more arbitrary in Chinese than in English, rapid naming has consistently shown a stronger relationship with word reading and reading comprehension in Chinese than in English (Chung & Ho, 2010a, b; McBride-Chang, 2016). Taken together, these findings are in line with those of prior studies, suggesting the co-occurrence of L1 and L2 reading difficulties in Chinese–English bilingual children (Chung & Ho, 2010a, b; McBride-Chang, Liu, Wong, Wong, & Shu, 2012; Tong, Tong, & McBride-Chang, 2015), and supported by the cross-linguistic hypotheses proposing that cognitive and reading-related processes are interrelated in L1 and L2. As a result, for adolescent readers with dyslexia, difficulties in L1 could affect their L2 due to under development of their cognitive and reading-related processes in L1 and L2, subsequently hampering their reading processes for both languages.

Contributions of executive functioning, vocabulary knowledge, and rapid naming to reading comprehension in L1 and L2

Our regression analyses also indicated that for the dyslexic and typical group, working memory and inhibition were predictors of reading comprehension in Chinese and English after controlling for age, IQ, and group membership. In contrast with

Chinese reading comprehension, shifting in addition to working memory and inhibition were predictive of English reading comprehension. Furthermore, planning did not make contribution to reading comprehension for either L1 or L2. These findings could be explained by reference to readers' experience in language exposure and proficiency, the type of reading comprehension task used, and procedural issues for administering the reading comprehension task.

Although both Chinese and English are considered official languages in Hong Kong, Chinese (Cantonese) is used in everyday life whereas English is more often used in formal settings and official events. In Hong Kong, students probably have fewer opportunities to be exposed to and practice English than Chinese both in school and at home. They may also have fewer literacy-related activities (reading) and limited availability of literacy text types and purposes in English than in Chinese. Reading English as L2 seems to make greater demands on readers' shifting from letter sound to word meaning and argument analysis in text than reading in L1. In this circumstance, readers may be actively involved in shifting so as to meet the demands of retrieving and applying different types of linguistic information such as orthography and phonology associations, semantics, and concepts as well as interpreting this information at the word and sentence level. Given that English involves a deep orthographic system in which the relationship between letters and sounds is often inconsistent and that it has complex syllables, it is likely to place very high demands on different components of EF over a period of time for readers of L2. The findings of this study suggest that shifting along with working memory and inhibition appear to have an influential role in reading L2 for Chinese readers.

Unexpectedly, our results for planning conflict with some other reports of how it was a predictor of reading comprehension (Georgiou & Das, 2015; Kieffer et al., 2013). In particular, planning did not contribute to reading comprehension in L1 and L2 for either group of readers. One explanation for this conflict might be the type of reading comprehension task used in this study for assessing readers' reading abilities. Planning may indeed play an important role in reading comprehension (Cartwright, 2015; Kendeou, Papadopoulos, & Spanoudis, 2015; Naglieri & Rojahn, 2004) when such comprehension requires readers to consider multiple perspectives of stories while processing texts, a process that involves shifting between stories and the actively monitoring strategies and plans. The passage comprehension task in our study consisted of narrative texts which often require readers to concentrate on events and arrange parts chronologically. Such narrative texts may not require these skills. An alternative explanation may be the fact that in the pen-and-paper test, readers were allowed to go back and forth between the four passages and the questions presented thereby reducing the demands on their planning ability. Consequently, planning may not have any effect on reading comprehension. Further studies are needed to examine the relationships among shifting, planning, and reading comprehension in L1 and L2.

Vocabulary knowledge was related to reading comprehension in L1 and L2. These results are similar to those findings obtained in previous studies (Chung et al., 2013; Chung & Lam, 2020; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003), showing that vocabulary knowledge is associated with Chinese and English reading. Rapid naming was also found to be predictive of reading comprehension in L2 but not in L1. Compared to reading in L1, reading in L2 is more difficult and may need an extended period to reach fluency. During reading in L2, readers probably need to process different sources of letter sound and meaning information and then consciously integrate them to form a coherent mental representation of each word of text. Therefore, rapid naming may still be helpful and more involved in reading in L2 than L1. Nevertheless, the role of rapid naming, shifting, and planning in reading comprehension merits more comprehensive work in future research.

Limitations and suggestions for future research

Several limitations of the present study are worth mentioning. First, our study involved only narrative text for L1 and L2. The effects of EF, particularly planning, on reading comprehension may be affected by the type of text used in reading comprehension tasks (Butterfuss & Kendeou, 2018; Follmer, 2018). Future studies should therefore replicate our findings by using a variety of text types, such as expository and argumentative texts and online reading comprehension tests across different time points. Second, this study did not investigate the differences between readers with dyslexia and readers with specific reading comprehension difficulties (i.e., readers with average word reading skills and poor comprehension skills). Further research is needed to examine the profile of these two groups of readers to offer a comprehensive perspective on EF and its contribution to reading comprehension across time. Additional measures such as oral discourse skills for story comprehension and comprehension monitoring, receptive and expressive vocabulary knowledge, and word reading should be included to examine these two groups of readers. Third, further research should include some reading measures such as English word reading to establish a baseline performance of the readers with dyslexia and typical readers.

Fourth, this study sought to examine potential reading-related problems in both Chinese and English among Chinese adolescent readers with dyslexia, with its findings indicating that readers with dyslexia in Chinese showed problems in both languages. However, despite evidence suggesting that the co-occurrence of reading difficulties in Chinese (L1) and English (L2) is high among readers with dyslexia (Chung & Ho, 2010a, b; Tong & McBride, 2017), readers with dyslexia in Chinese in this study did not necessarily have dyslexia in English. Indeed, dyslexia in L1 and L2 do not always co-occur. Ho and Fong (2005), for example, presented the case of a Hong Kong boy with dyslexia in Chinese (L1) who scored above average in his word reading in English (L2). Wydell and Butterworth (1999) also presented the case of a Japanese adult who had no problems in reading Japanese (L1), but experienced marked difficulties in reading English (L2). More research is needed, especially on under which circumstances L1 and L2 difficulties may co-occur and, relatedly, under which circumstances dyslexia in L1 and L2 may occur at the same time.

Fifth, this study used only one measure to assess each construct of interest, meaning that we might not be able to capture the multidimensional nature of reading-related processes. Future researchers should use multiple measures to respectively assess EF, vocabulary knowledge, rapid naming, and reading comprehension, model these constructs using structural equational modelling, and retest the interrelationships among these constructs. Finally, our study used a cross-sectional design, and the observed effects did not imply causation. Longitudinal and experimental studies are needed to replicate our results to further verify the direction of the effects of EF on reading comprehension.

Conclusion

Despite these limitations, the present study has focused on a new area and yielded some notable findings given that the role of EF, particularly working memory, inhibition, shifting, and planning in Chinese and English reading comprehension, has rarely been investigated in Chinese adolescent readers. This study has demonstrated that readers with dyslexia show difficulties in multiple components of EF as well as in vocabulary knowledge and rapid naming and EF provides unique contributions to reading comprehension in readers with and without dyslexia. Among the four components of EF, working memory and inhibition appear to be more involved in reading comprehension for both L1 and L2. These findings and future work should be of both theoretical and practical interest to researchers and educators. Theoretically, these results highlight the important role of EF in supporting reading comprehension and imply that it could be incorporated into models of reading comprehension in Chinese and English (e.g., Yeung, Ho, Chan, Chung, & Wong, 2013). Practically, instructors and teachers targeting readers' literacy achievement should consider incorporating executive functioning skills and strategies into their literacy curriculum and across content areas in the school-based curriculum.

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