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Reading comprehension, working memory and higher-level language skills in children with SLI and/or dyslexia

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Abstract This study examined (1) whether working memory and higher-level languages skills—inferencing and comprehension monitoring—accounted for individual differences among Chinese children in Chinese reading comprehension, after controlling for age, Chinese word reading and oral language skills, and (2) whether children with specific language impairment (SLI) or dyslexia showed deficits in these skills. Eighty-two Cantonese Chinese-speaking children between the age of 7; 8–9; 5 were assessed. Regression analyses on the full sample offered support for the first question. The children were also classified into four groups: Typically-developing (TD; $N = 34$), specific language impairment-only (SLI-only; $N = 18$), SLI-dyslexia comorbid (SLI-D; $N = 22$) and dyslexia-only (D-only; $N = 8$). Pair-wise comparisons focusing on the second question revealed that both the SLI-only and the D-only group performed worse than the TD group in reading comprehension after controlling for age and nonverbal intelligence. The SLI-only and the D-only group showed a different profile of deficits: only the SLI-only group performed worse than the TD group in working memory, comprehension monitoring, and inferencing. The SLI-D comorbid group did worse than the SLI-only, but not the D-only group, in reading comprehension. The SLI-D comorbid group did not do worse than either single diagnosis group in the higher-level language skills associated with reading comprehension. These findings suggested adopting different intervention approaches for reading comprehension difficulties in children with SLI versus children with dyslexia.

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Introduction

To understand the skills involved in reading comprehension, the simple view of reading (Hoover & Gough, 1990) makes a good starting point. The simple view of reading describes reading comprehension as the joint product of oral language comprehension and word decoding—each has been found to explain unique and a good amount of variance in reading comprehension (e.g., Chen & Vellutino, 1997; Gough, Hoover, & Peterson, 1996). Some studies, however, have shown that a fair amount of variance remains unexplained (e.g., Cutting & Scarborough, 2006; Keenan, Betjemann, & Olson, 2008). While it can be argued that the unexplained variance can be attributed to the poor alignment between the oral language and reading comprehension tests used in these studies, additional skills have nevertheless been proposed: reading fluency (Adolf, Catts, & Little, 2006; Cain, Catts, Hogan, & Lomax, 2015) and verbal working memory (Cain, 2006). There has also been a debate on how the components of oral language comprehension should be examined. Traditional measures of listening comprehension and vocabulary may not adequately tap the full range of oral language skills involved in the comprehension of text, which is often embedded with multiple themes and levels of meanings. Some higher-level language skills such as inferencing and comprehension monitoring may also be essential.

Verbal working memory

Verbal working memory is required for processing and integration of meanings to construct a reasonable mental model during reading comprehension (Kintsch & Rawson, 2005). Indeed, verbal working memory significantly predicts reading comprehension in typically developing children (Oakhill, Cain, & Bryant Oakhill et al., 2003; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000; Swanson & Howell, 2001). It explains variance in reading comprehension even after word decoding, vocabulary and general cognitive ability have been controlled for (Cain, Oakhill & Bryant, 2004). Moreover, poor comprehenders (i.e., children who have reading comprehension difficulties despite adequate word decoding) have deficits in verbal working memory (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Yuill, Oakhill, & Parkin, 1989).

There are two views on the role of verbal working memory in reading comprehension impairments (Ricketts, 2011). On the one hand, Cain (2006) proposed that verbal working memory deficits undermine higher-level language skills of inferencing and comprehension monitoring, leading to poor reading comprehension. On the other hand, Nation et al. (1999) proposed that poor oral language causes problems in both verbal working memory and reading comprehension. Hulme and Snowling (2011) elaborated that oral language comprehension could involve vocabulary, syntax and discourse knowledge and skills. Indeed, after training on a broad range of oral language skills, poor comprehenders improved in reading comprehension at immediate posttest and 11 months later (Clarke, Snowling, Truelove, & Hulme, 2010). These two views contrast in where they put verbal working memory in the causal chain, but they do not have to be mutually exclusive. For example, poor oral language can cause problems in verbal working memory (Nation et al., 1999), which then can lead to difficulties in inferencing and comprehension monitoring, resulting in poor reading comprehension (Cain, 2006). To evaluate these views, we examined two groups of children with reading comprehension impairments: children with oral language impairments versus children with word decoding problems and normal oral language abilities. According to Nation et al. (1999), the former group of children, but not the latter, should have problems in verbal working memory, inferencing and comprehension monitoring.

Higher-level language skills: inferencing and comprehension monitoring

Inferencing refers to the process of going beyond what is explicitly written in the text to fill in details by connecting ideas in different parts of the text, and by connecting ideas within the text with background knowledge (Kintsch, 1994). Inferencing predicts reading comprehension in elementary children above and beyond word reading, vocabulary, and general cognitive ability (e.g., Cain et al., 2004; Pike, Barnes, & Barron, 2010). Poor comprehenders have problems in inferencing. In general, inadequate inferencing occurs when one does not realize that inferencing is needed or when one does not possess the background knowledge, or when one's verbal working memory is insufficient (Yuill & Oakhill, 1991). Even with the first two possibilities controlled for (Cain & Oakhill, 1999; Cain, Oakhill, Barnes, & Bryant, 2001), poor comprehenders continued to perform worse than their age peers in inferencing, suggesting a role for verbal working memory.

Comprehension monitoring enables the reader to assess whether comprehension has been successful, identify instances of comprehension difficulties and resolve anomalies in the text. Like inferencing, comprehension monitoring predicts reading comprehension in elementary children even after controlling for word reading, vocabulary, and general cognitive ability (Cain et al., 2004). Children with poor comprehension have monitoring problems (Oakhill, Hartt, & Samols, 2005; de Sousa & Oakhill, 1996; Yuill & Oakhill, 1991). However, it remains unclear whether poor comprehension monitoring is a cause of reading comprehension problems (Cain & Oakhill, 1999) or is a reading problem itself (Perfetti, 1994).

Cain et al. (2004) also examined the relationships between the higher-level language skills and working memory in predicting reading comprehension; they found that neither inferencing nor comprehension monitoring was fully mediated by verbal working memory.

SLI and dyslexia

According to the simple view of reading, both children with SLI and those with dyslexia should show difficulties in reading comprehension, but their profiles or causes may be different. SLI and dyslexia are developmental disorders in children with typical sensory, cognitive and social development. Children with SLI, typically diagnosed at age four or above, show deficits across domains of oral language: linguistic expression and comprehension, vocabulary, grammar and/or discourse. Dyslexia refers to impairment in literacy development, with marked word decoding problems. Children with dyslexia are typically diagnosed after at least 1 year of formal reading instruction at about the age of seven.

SLI and dyslexia often co-occur, in between 17 % (Catts, Aldof, Hogan, & Weismer, 2005) to 75 % (McArthur, Hogben, Edwards, Heath, & Mengler, 2000) of school-age children in English-speaking countries according to different studies. Catts et al. (2005) summarized three major hypotheses about the relationship between SLI and dyslexia in English-speaking children on the basis of their performance in phonological processing (phonological awareness and phonological memory) tasks. The 'Severity' hypothesis posits that both children with SLI and children with dyslexia have a phonological processing deficit, but children with SLI are more severely affected by the deficit (Kamhi & Catts, 1986; Tallal, Allard, Miller, & Curtiss, 1997; Snowling, Bishop, & Stothard, 2000). The 'Dyslexia-plus' hypothesis posits that children with SLI and children with dyslexia share a similar level of phonological processing deficit, but children with SLI are affected by additional cognitive deficit(s) that leads to their oral language difficulties (Bishop & Snowling, 2004). The 'Distinct' hypothesis posits that children with SLI and children with dyslexia have different underlying cognitive deficits (Catts et al., 2005): children with dyslexia showing deficits in phonological processing, and children with SLI showing deficits in non-phonological aspects of language, including vocabulary and syntax. A comparison of 21 children with dyslexia only, 43 children with SLI only, 18 children with SLI and dyslexia, and 165 children with typical language/reading development on a phonological awareness and a nonword repetition task (a putative measure of phonological short-term memory) provided evidence in support of the 'Distinct' hypothesis (Catts et al., 2005).

Separate bodies of research that tested children with SLI and children with dyslexia on areas other than phonological processing have however shown that SLI and dyslexia might not be distinct disorders. Children with SLI performed worse than their typically-developing peers on verbal working memory tasks (e.g., Archibald & Gathercole, 2006; Ellis Weismer, Evans, & Hasketh, 1999). Children with SLI were subpar in the listening comprehension of complex sentences (e.g., Montogemery & Evans, 2009) and sentences which required them to retain and process critical details despite adequate lexical and syntactic knowledge (Leonard, Deevy, Fey, & Bredin-Oja, 2013), suggesting a verbal working memory deficit. Verbal working memory deficits were also evident in children with dyslexia (Berninger et al., 2006; Pickering, 2006; Swanson, 2006; Vellutino, Fletcher, Snowling, & Scanlon, 2004). When processing demands exceeded their limited capacity verbal working memory, their reading comprehension became even worse. These pieces of evidence suggest that SLI and dyslexia might both in part be caused by subpar verbal working memory. Given the high comorbidity rates of SLI and dyslexia, is this shared-deficit view justified? A double-dissociation study including children with SLI but no dyslexia and children with dyslexia but no SLI would be necessary to answer this question.

Reading in Chinese

Different writing systems pose different challenges to their readers. In Chinese, the basic units of writing are characters. Chinese characters (e.g., 媽) map onto syllables (e.g., maa1) and morphemes (e.g., mother), which are typically composed of stroke-patterns called radicals (e.g., semantic radical 女 meaning "female" and phonetic radical 馬, pronounced as maa3). Although the phonetic radical provides some clues to the character's pronunciation, there is a general lack of correspondence between the phonemic structure of spoken words and orthographic units as observed in alphabetic languages such as English. This difference may result in different profiles of deficits in children who have word reading difficulties. While phonological processing, and phonological awareness in particular, is the predominant deficit in English-speaking children with dyslexia (e.g., Vellutino et al., 2004), more Chinese children with dyslexia are found to have problems in orthographic skills than in phonological awareness (Ho, Chan, Tsang, & Lee, 2002; Ho, Chan, Lee, Tsang, & Luan, 2004).

Differences in writing systems do not however seem to result in differences in the linguistic and cognitive correlates of reading comprehension. Findings from research on Chinese-speaking children are largely consistent with those from children learning alphabetic writing systems. Leong, Tse, Loh and Hau (2008) reported that verbal working memory explained the largest portion of unique variance in Grade 3–5 children's text reading comprehension, and that pseudoword reading explained only a small amount of additional variance. Other reading related skills, including rapid automatic naming and onset-rhyme segmentation, made almost no additional contribution.

Chik et al. (2012) extended Leong et al.'s (2008) study and examined the role of different levels of language in reading comprehension. Chik et al. (2012) reported that for typically developing students from Grade 1 to Grade 5—as well as Grade 4 students with dyslexia—verbal working memory, word level skills (as measured by two different tasks tapping word meanings), syntactic skills (as measured by a sentence correction task and a word order task) and discourse skills (as measured by a task in which the child re-ordered several sentences into a coherent text) accounted for a significant portion of variance in reading comprehension after taking into account of word reading, age, and nonverbal intelligence. For typically developing students from Grades 1 to 3, as well as the Grade 4 students with dyslexia, the significant correlates were word level and discourse skills; and for typically developing Grades 4 and 5 students, the significant correlates were syntactic and discourse skills.

Using similar tasks, Yeung, Ho, Chan, Chung and Wong (2013) reported comparable results in that verbal working memory, syntactic and discourse skills contributed significant variance to reading comprehension after word reading was taken into account. Path analysis further suggested that their effects on reading comprehension were direct, whereas the effects of rapid naming and morphological awareness were indirect via word reading. In both Chik et al. (2012) and Yeung et al.'s (2013) research, however, syntactic and discourse skills were sometimes tested using print materials. In those tasks, although the materials were read aloud, the children still had to read the written words, thus confounding language knowledge with word reading and verbal working memory. Moreover, these tasks only examined the children's manipulation of word and sentence order, and they did not test the children's use of linguistic knowledge as in typical tests of receptive and expressive grammar. Indeed, Yeung et al. (2013) acknowledged that better oral measures for syntactic and discourse skills were needed. While providing support for the simple view of reading (i.e., word decoding and oral language comprehension contributing significantly and independently to reading comprehension), Ho, Chow, Wong, Wayne and Bishop (2012) also acknowledged that it was inadequate to have only vocabulary as in the case of their study, instead of a range of oral language skills and knowledge, to assess the oral language comprehension component of the simple view of reading.

Two studies (Chik et al., 2012; Chung, Ho, Chan, Tsang, & Lee, 2011) have compared a dyslexia group with an age-matched group and a (word) reading-level matched group on reading comprehension. While the dyslexia group performed worse than the age-matched group in both studies, it performed similarly to the reading matched group in the case of elementary children (Chik et al., 2012) but worse than the reading-matched group in the case of adolescents (Chung et al., 2011). Such a discrepancy can be due to better verbal working memory and/or higher-level language skills (i.e., inferencing, comprehension monitoring) of the adolescents, who were matched primarily on (word) reading level. In other words, such skills for reading comprehension can be dissociated from word reading skills.

The current study

This review has revealed three important research gaps. One is heterogeneity in the participant groups. In all of the Chinese reading comprehension studies reviewed here, children with dyslexia were not tested for SLI, hence their reported weakness in reading comprehension could have reflected a combined problem in oral language comprehension and word reading. Second, there have not been any investigations on reading comprehension in Chinese children with SLI (Ho, 2010). And as is the case with English-speaking children (Ricketts, 2011), children with SLI and children with dyslexia have yet to be compared directly in working memory and higher-level language skills, against the benchmark of typically developing peers. Such a comparison will offer an assessment of how verbal working memory may be related to reading comprehension impairment. Third, many reading comprehension studies used vocabulary as the only measure of oral language comprehension, hence failing to take into account of the roles of syntax, listening comprehension of text, and higher-level language skills in the ability to understand written passages.

In this study, we tested Chinese reading skills in a group of Cantonese-Chinese speaking Grade 2 children. There were two goals. One was to examine the relationship between reading comprehension, working memory, comprehension monitoring and inferencing in these children. Two was to compare these children's working memory, reading comprehension, and higher-level language skills in four groups: with dyslexia and no SLI (D-only), with SLI no word reading problems (SLI-only), with both impairments (SLI-D), typically-developing (TD) age controls.

These Grade 2 children had participated in another study one year prior that focused on cognitive deficits differentiating children with dyslexia and children with SLI (Wong et al., 2015). Orthographic skills and lexical access and retrieval skills were found to be associated with dyslexia. Phonological memory and morphological awareness were associated with SLI. Phonological awareness was associated with both SLI and dyslexia. Results of that study suggest that SLI and dyslexia in Chinese are not exactly distinct disorders as they are both characterized by a deficit in phonological awareness. Bishop and Snowling's (2004) two-dimensional model of reading and language impairments—classic SLI has problems in both phonological and non-phonological skills, whereas dyslexia has problems in only the phonological skills—then might not apply to Chinese. Do children with dyslexia and children with SLI share other deficits, such as verbal working memory? In this study, we therefore aimed to address these questions:

1. Do verbal working memory and the higher-level language skills (namely, inferencing and comprehension monitoring) contribute significantly and uniquely to reading comprehension?

   Prediction Following Cain et al. (2004) findings, the answer should be yes. The reason is that these higher-level language skills help the reader develop a coherent and integrated mental model for the interpretation of a text.

2. Is the relation between the higher-level language skills and reading comprehension mediated by verbal working memory?

   Prediction Following Cain et al. (2004) findings, the answer should be no. Despite the fact that the higher-level language skills and reading comprehension require the reader to store and process information simultaneously, performance on tasks that tap these skills is not totally determined by working memory.

3. Do children with SLI and D have problems with verbal working memory and the higher-level language skills?

   Prediction According to Nation et al. (1999), poor oral language causes problems in both verbal working memory and reading comprehension. Children with SLI, but not children with dyslexia, should have subpar verbal working memory and reading comprehension. According to Cain et al. (2004), subpar verbal working memory would hurt higher level language skills, so jointly with Nation et al. (1999), children with SLI—but not children with dyslexia—should also have problems with the higher level language skills.

4. Does the SLI-group, the D-group and SLI-D group have problems with reading comprehension?

   According to the simple view of reading, the answer to this question would be yes for all three groups.

5. Does the SLI-TD group demonstrate a more severe deficit than the single diagnosis of SLI and D group on working memory and the higher-level language skills?

   Predictions Given the absence of studies on working memory, comprehension monitoring and inferencing in children with comorbid SLI and dyslexia, a prediction on the SLI-D group's performance could not be made.

Results from this study can help identify the different barriers to success in reading comprehension in the children with SLI versus children with dyslexia and hence inform, if necessary, how to tailor effective intervention for each group.

Method

Participants

Participants in this study were part of a longitudinal project on reading development. One hundred and twenty-five children were first recruited at the third and last year of kindergarten between the age of 5 and 6. Sixty of them were subsequently classified as SLI while the other 65 were later confirmed as typically developing. One year later at the end of Grade 1, 111 children returned for testing on their word reading and related skills. Based on their performance on a battery of tests, these children were classified into four groups: children with dyslexia, children with SLI, children with co-morbid SLI and dyslexia and typically-developing children. Group differences on word reading and reading-related cognitive skills were examined and the results were reported in Wong et al. (2015). At the end of Grade 2, 82 children returned and participated in the present study. In the subsequent paragraphs, we will first review the procedure for participant recruitment in the last year of kindergarten and in Grade 1. For details, please refer to Wong et al. (2015).

Recruitment of children with SLI at the last year of kindergarten

Among the 60 children in the SLI group, 52 were referred by speech-language therapists in several local government-funded child assessment centers. These children were diagnosed by their speech-language therapist as having a oral language impairment based on formal testing and clinical judgments. The other eight children, recruited from kindergartens with the other children in the language normal group to be described in the next paragraph, failed a short version of the Hong Kong Cantonese Oral Language Assessment Scale (HKCOLAS; T'sou et al., 2006) at intake, that is, scoring below 1.25 SD of age-norm on one or both of these subtests: Nominal Expressive Vocabulary and Cantonese Grammar. These two subtests were recommended by the test developers to be used with children between age 5 and 6 if time does not allow administration of the entire subtest (T'sou et al., n.d.). These eight and the other 52 children in the SLI group eventually received the entire HKCOLAS and met the criterion for language impairment, which is a score of 1.25 SD below the age-normed mean in two or more of the six subtests. Based on this criterion, HKCOLAS was found to have sensitivity equaled to 94.6 % (53/56), indicationg very strong accuracy in the diagnosis of specific language impairment, and specificity equaled to 98.2 % (55/56), indicating very strong accuracy in the diagnosis of children with normal language. Among the 60 children, 13 failed 2 subtests, 17 failed 3 subtests, 13 failed 4 subtests, 10 failed 5 subtests, and 7 failed 6 subtests, indicating a fair distribution of severity of impairment in the group. Among the 60 children, 44 failed Cantonese Grammar, 50 failed Nominal Expressive Vocabulary, 37 failed Story Retell, 29 failed Textual Comprehension, 19 failed Word Definition, and 18 failed Lexical Semantics. The children in the SLI group also met the other conventional criteria for SLI (Leonard, 2014). They passed a hearing screening and had no report of psychosocial impairment. All but three children scored 85 or above on the Raven's Standard Progressive Matrices (Raven, 1986) and hence considered within the normal range in nonverbal reasoning. The lowest score of the three remaining children was 79, which was slightly below the cut-off. To ensure that we had an adequate number of children with comorbid SLI and dyslexia at Grade 1, parents also filled out the Hong Kong Learning Behavior Checklist for Preschool Children (HKLBC; Wong, Ho, Chung, Chan, & Tsang, 2006)-a standardized screening tool for identifying kindergarten children at risk for learning disabilities in Hong Kong. Among the 60 children, half were identified as at risk for dyslexia according to the HKLBC.

Recruitment of the normal language group at the last year of kindergarten

Kindergartens from the 18 different adminstrative districts in Hong Kong, representing different social economic backgrounds, were asked to help in the recruitment of participants for this study. Seventeen kindergartens responded positively to the request and all children from the 5–6 year old class in these kindergartens were screened with the HKLBC. All children who failed the screening were invited, and 35 participated in the study. Thirty children who passed the screening and who were matched with those at risk for dyslexia by age, gender and school were also recruited. All 65 children received the short version of the HKCOLAS. All of the 54 children who had no history of language impairment passed both subtests in the short version of the HKCOLAS, confirming their normal language status. The remaining 11 children, who were reported to have an early history of oral language impairment by their parents in the case history form, failed one of the two subtests in the short version of the HKCOLAS. They were subsequently confirmed not meeting the diagnostic criteria for SLI upon completion of the six subtests in HKCOLAS. In the literature, these children are commonly known as "late-talkers". Between 50 and 75 % of late-talkers moved into the normal range for vocabulary by 5 years and scored within normal limits on standardized tests of language skills by 6 years (Paul, 1996; Rescorla, Mirak, & Singh, 2000; Whitehurst & Fischel, 1994). In sum, these 65 children could be considered as having normal language at the time of the study based on results from formal testing. All but three of these 65 children scored 85 or better on the Raven's Standard Progressive Matrices; the remaining three scored 80.

Recruitment of participants at Grade 1

One year later, at the end of Grade 1, 111 children returned to complete the study reported in Wong et al. (2015). The children were re-tested on their oral language. Given time constraints, the children were given only four HKCOLAS subtests: Cantonese Grammar, Nominal Expressive Vocabulary, Textual Comprehension, and Narrative Retell. The SLI status was considered confirmed if children in the SLI group scored more than 1.25 SD below the age-normed mean in at least two of these subtests, and status of the typically-developing children was considered confirmed if they did not fail in more than one of these subtests. Among the 111 children, the language status of 17 children (15 from the SLI group and 2 from the TD group) could not be confirmed by the HKCOLAS, a test with very strong diagnostic accuracy, and hence were excluded from further assessment and data analysis.

Eventually, 94 children were included in the Wong et al. (2015) study, with 44 children meeting the criteria for SLI, and 50 children with typically-developing oral language. The 94 children were then given the Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students-Second Edition (HKT-P [II]; Ho et al., 2007). The HKT-P [II] makes up of the literacy composite (with subtests on Chinese word reading, spelling, and one-minute word reading), phonological awareness composite, phonological memory composite, rapid automatic naming and orthographic skills composite. In the present study, dyslexia was defined as a scaled score of 7 or lower in the literacy composite score in HKT-P [II] and with nonverbal intelligence within the normal range. Based on their performance on the HKCOLAS and on the HKT-P [II] in Grade 1, each child was classified into one of these four groups: SLI-only ($n = 19$), Dyslexia-only ($n = 10$), co-morbid SLI-D ($n = 25$), and typically-developing (TD) ($n = 40$). Children in the SLI-only group failed the HKCOLAS, and did not meet the criteria for dyslexia. Children in the Dyslexia group passed the HKCOLAS and failed the Literacy composite of the HKT-P [II]. Children in the SLI-D group met the criteria for both SLI and dyslexia. Children in the TD group passed the HKCOLAS and the HK-P [II] literacy composite. The TD group and the D-group scored better than the SLI and the SLI-D group on all four measures from the HKCOLAS (Wong et al., 2015).

Grade 2 participants for the present study

At the end of Grade 2, 82 of the 94 children from the Wong et al. (2015) study returned for the present study on reading comprehension. Twelve children decided to withdraw for personal reasons. The 82 children included 18 from the SLI-only group, 8 from the Dyslexia-only group, 22 from the SLI-D group, and 34 from the TD group. These children did not receive testing on oral language or word reading for confirmation of their current language or reading status. The mean age of these children at the time was 8;1 with a range of 7; 8–9; 5, and there was no difference in mean age between the four groups.

Procedures

The children were seen individually and completed all tasks in about an hour in a quiet room. The tasks were given in a random and counterbalanced order across the children.

Measures at Grade 2

Word reading and reading comprehension The children completed the word reading subtest in the HKT-P[II]. They read 150 Chinese two-character words. The total score is 150. The computer-administered reading comprehension subtest from The Hong Kong Chinese Literacy Assessment for Junior Primary School Students (CLA-P) (Ho et al., 2011) was used in this study. The CLA-P is standardized and normed on Hong Kong Chinese children from Primary 1 to Primary 3 between 6 and 9 years of age. The Reading Comprehension subtest contains 9 passages. There are a total of 32 multiple-choice questions with 3–4 questions for each passage. Each passage contains between 130 and 180 characters. The passages are of different genres, including narrative and expository texts, fables, and practical writings. The questions require literal or inferred understanding of the text, logical reasoning of given information, or ask for a summary or the theme of the text. The words used in the passages were designed to be appropriate for children from Primary 1 to Primary 3. They were selected from The Hong Kong Corpus of Primary School Chinese (Leung & Lee, 2002) and the Key Stage 1 lexical items of Fundamental Chinese Learning in primary schools recommended by the Hong Kong Education Bureau. Each child was asked to choose the right answer from one of the four choices on the computer.

Comprehension monitoring For comprehension monitoring, an inconsistency detection task was used. Each child read six different stories. The stories contained between 108 and 144 characters that should be familiar to kindergarten or Grade 1 children. In each story, there were one to three anomalies, with 14 anomalies in all stories combined. The anomalies violated the internal consistency of the text, which could involve conflicting (contradictory) actions or inconsistent semantics for the same referent. For instance, “Mom is afraid of cats and every time she sees one, she screams…When mom sees the kitten, she picks it up and says, ‘oh, how cute!’”. A score between 1 and 4 were given, depending on the level of support the child needed to succeed. A full score of 4 marks was given if the conflicts or the inconsistencies were adequately explained. If the child failed to give a response, s/he would be asked to read the story again; the child would then receive 3 marks upon spotting an inconsistency. The child would receive 2 marks if the investigator pointed out the sentences where the inconsistencies lay. The child would receive only 1 mark if s/he required the investigator to ask her a question that would lead to the answer. The child received zero point if s/he gave no response or an irrelevant answer. The distance between the two inconsistent sentences varies between 1 and 6 sentences. The total number of score is 56 points. Cronbach's alpha for this task was .86 in our sample.

Inferencing The inferencing task was modeled after Barnes, Dennis and Haefele-Kalvaitis (1996) and Cain et al. (2001). After a demonstration trial of the testing procedure, we taught the child 12 pieces of information about people, places and events in an imaginary planet with support from colored illustrations. For example, "in the Ball planet, the leaves are mirrors". The information was used for making inferences as required in the questions. The child read the experimental story in two halves, which contain characters that should be familiar to kindergarten or Grade 1 children. Before the child proceeded with the first three pages of the story, we tested him/her on the 6 pieces of relevant information to ensure that the child had the knowledge needed for making inferences. The child read the story in silence and then was asked several questions with the colored illustrations present to remind him/her of the information about the planet. For example, "how does the prince find out what he looks like?" and the answer was "by looking at the leaves, which are mirrors in the Ball planet." After a short break the child was tested on another 6 facts about the planet. The child then read the remaining half of the story and was asked the remaining inferential questions in the same fashion.

There were altogether 11 questions, which amount to 44 points in total. For each item, the child received two points if his/her answer could be directly extracted from the text. The child received additional two points if his/her answer included information that was integrated from the knowledge provided to him/her earlier. In the sample answer given, the child received two points for the first part (i.e., "by looking at the leaves,") and another two for the second part (i.e., "…which are mirrors in the Ball planet"). One to two points would be deducted if the child needed cues from the examiner. Item reliability in this sample as measured by Cronbach's alpha was .67, slightly below the acceptable level of .7 (Kline, 2000).

Working memory The listening span task was modeled after Gaulin and Campbell (1994). The child was asked to listen to two sets of one to six sentences that were unrelated in meaning. They were asked to do two tasks: first to give a true or false response at the end of each sentence, and then recall the last word of the sentence (s) at the end of each set. The sentences were constructed to be simple and common sense, and children were expected to be correct on most if not all of them. A translated example in English of a two-sentence set is: "Birds can drive. Giraffes are tall." The answer was No and Yes; drive, tall". One mark was given for each sentence correctly responded to and one mark for each sentence-final word recalled. The total score for true/false response was 42 and for word recall was also 42. Cronbach's alpha in this sample for the yes–no answers was .78 and for word recall it was .70.

Results

Two of the children in the SLI-D group did not participate in the inferencing task because of fatigue. The scores of these two children were replaced by the mean of the remaining 20 children in the group in the regression analysis. In the comparison of group means, the two children were not included in the analysis and hence the degree of freedom was smaller than that of the other tasks.

Interrelations between reading comprehension, working memory and the higher-level language skills

Table 1 shows the zero order correlations (two-tailed) of the standardized assessment and the experimental measures. Because of the large number of correlations, a significant level of .01 was adopted. Reading comprehension was not significantly correlated with age ($r = -.040$) nor the Raven's score ($r = .170$). As predicted, reading comprehension correlated significantly with word reading ($r = .767$), various measures of oral language (rs ranging from .408 to .546), verbal working memory ($r = .434$), and the two higher-level language skills of reading comprehension (with comprehension monitoring, $r = .672$; and with inferencing, $r = .563$). Verbal working memory was moderately correlated with comprehension monitoring ($r = .456$) and inferencing ($r = .449$). These two higher-level language skills associated with reading comprehension were strongly correlated ($r = .617$).

A set of three fixed-order hierarchical multiple regression analyses was run with reading comprehension as the dependent variable. The variables were entered in an order determined a priori to test our predictions. To control for the relation between age, nonverbal IQ, word reading and reading comprehension, the child's age in months, Raven's raw score, and Chinese word reading score from the HKT-P [II] were first entered step by step. To control for the relationship between oral language and reading comprehension, the Cantonese grammar, story retell, story comprehension, and expressive vocabulary score from the HKCOLAS were entered together at the fourth step. As it turned out, these variables altogether explained a substantial amount of 66.7 % of the variance in reading comprehension F (7, 74) = 21.078, $p = .000$.

To examine whether verbal working memory explained additional variance in reading comprehension, we entered the working memory score at the next and fifth step. As can be seen in Table 2, the change in R square was 2.3 % (F (1, 73) = 5.517, $p = .022$), the standard beta coefficient was .179 ($t = 2.349, p = .022$), and both values were statistically significant. The other two fixed-order hierarchical multiple regression analyses were identical to the first, except that performance on a particular higher-level language skills of reading comprehension, rather than the working memory score, was entered at the fifth step after the control variables. When comprehension monitoring was the fifth step, the change in R square was 3.3 % (F (1,73) = 7.872, $p = .006$), the standardized beta coefficient was .281 ($t = 2.806$, $p = .006$), and both values were statistically significant. When inferencing was the fifth

Table 1 Zero-order Correlations between Measures

	1	2	3	4	5	6	7	8	9	10	11
1. Reading comprehension (G2)	1	−0.040	0.17	.767**	.525**	.408**	.546**	.508**	.672**	.563**	.434**
2. Age (G2)		1	#	−0.010	−0.085	0.136	−0.132	0.035	0.060	−0.08	0.125
3. Raven's (KG)			1	.224*	.357**	0.152	.266*	0.144	.364**	.326**	0.169
4. Word Reading (G2)				1	.459**	.382**	.433**	.563**	.624**	.435**	.296**
5. Grammar (G1)					1	.720**	.757**	.738**	.619**	.508**	.466**
6. Listening comprehension (G1)						1	.668**	.698**	.566**	.476**	.415**
7. Narrative retell (G1)							1	.737**	.576**	.630**	.441**
8. Expressive vocabulary (G1)								1	.559**	.468**	.454**
9. Comprehension monitoring (G2)									1	.617**	.456**
10. Inferencing (G2)										1	.449**
11. Working memory (G2)											1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Since the Raven was measured in standard scores, its correlation with age was uninterpretable

Table 2 Summary of fixed-order hierarchical multiple regression analyses (R sqaure and R square change) with reading comprehension as the dependent variable and working memory and higher-level language skills as criteria, controlling for age, nonverbal IQ, word reading, and oral language

Step	Variable	Standardized beta	*R* Square	*R* Square Change
1	Age	−.071	0.005	0.005
2	Nonverbal IQ	.162	0.030	0.03
3	Word reading	.770***	0.591	0.562***
4	Oral language		0.666	0.075**
	Cantonese grammar	.193		
	Textual comprehension	−.042		
	Narrative retell	.309*		
	Nominal expressive vocabulary	−.215		
5	Working memory	.179*	0.689	0.023*
5	Comprehension monitoring	.281**	0.698	0.033**
5	Inferencing	.221*	0.692	0.026*

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

step, the change in R square was 2.6 % ($F\,(1, 73) = 6.156, p = .015$), the standardized beta coefficient was .221 ($t = 2.481$, $p = .015$) and both values were statistically significant. These results suggest that verbal working memory, comprehension monitoring, and inferencing each made a unique and significant contribution to the variance of reading comprehension, after controlling for age, nonverbal IQ, word reading and various aspects of oral language. Of note is that comprehension monitoring received the highest standandized beta value, suggesting that it was the most important of the three variables.

To examine whether individual differences in children's working memory explained the relationship between reading comprehension and its two higher-level language skills, we conducted another set of two fixed-order hierarchical multiple regression analyses, with reading comprehension as the dependent variable. The child's age, Raven's raw score, Chinese word reading score, and oral language scores sequentially were entered as the first steps, followed by working memory as the fifth step. After these control variables, at the final and sixth step, the score of one of the higher-level language skills was entered. If working memory fully mediated the relationship between reading comprehension and the process being examined, then the process should not explain additional variance in the reading comprehension scores after working memory has been accounted for. As can be seen in Table 3, when comprehension monitoring was entered after working memory, the change in R square was 2.4 % (F (1, 72) = 6.046, p = .016), the standardized beta value was .246 (t = 2.459, p = .016), and both values were still statistically significant. When inferencing was entered after working memory, the change in R square was 1.7 % (F (1, 72) = 4.196, p = .044), the standardized beta coefficient was .184 (t = 2.048, p = .044), and both values were still statistically significant. These results suggested that comprehension monitoring and inferencing

Table 3 Summary of fixed-order hierarchical multiple regression analyses (R sqaure and R sqaure change) with reading comprehension as the dependent variable and higher-level language skills as criteria, controlling for age, nonverbal IQ, word reading, and oral language, and working memory

Step	Variable	Standardized beta	*R* square	*R* square change
1	Age	−.071	0.005	0.005
2	Nonverbal IQ	.162	0.030	0.03
3	Word reading	.770***	0.591	0.562***
4	Oral language		0.666	0.075**
	Cantonese grammar	.193		
	Textual comprehension	−.042		
	Narrative retell	.309*		
	Nominal expressive vocabulary	−.215		
5	Working memory	.179*	0.689	0.023*
6	Comprehension monitoring	.246*	0.714	0.024*
6	Inferencing	.184*	0.707	0.017*

each had a unique role in accounting for variance in reading comprehension, above and beyond working memory. In other words, performance on these tasks was not wholely determined by working memory.

Noted also that among the four oral language scores, the standaradized beta coefficient for narrative retell was .309, and it was statistically significant ($t = 2.626$, $p = .010$). The coefficients for the other three oral language scores were not significant.

Group comparisons on reading comprehension, working memory and the higher-level language skills

The mean and standard deviation scores obtained on each standardized and experimental measures are presented in Table 4. The distribution of the reading comprehension, working memory, comprehension monitoring and inferencing scores was examined by group. All distributions were normal except for that of the comprehension monitoring scores for the SLI-D and TD group. To address our research questions, pair-wise comparisons were completed on reading comprehension, working memory, comprehension monitoring, and inferencing, with Bonferroni adjustments made .05/4 = .012. In situations where the distribution was normal, ANOVA with age and nonverbal IQ as covariates were used. In situations where the distribution was not normal, the Mann–Whitney test was used. Table 5 reports details of results on the statistical analyses.

On word reading and reading comprehension, the TD group did significantly better than the D-only, the SLI-only group and the SLI-D group, and the SLI-D group did significantly worse than the SLI group. There was no statistical significance between the SLI-D and the D group on either one of these measures.

Table 4 Mean (and standard deviation) of the Grade 1 oral language and Grade 2 reading measures of the SLI-D, The TD, the SLI-only and the dyslexia-only Group

	TD	SLI	SLI-D	D
Sample size	34	18	22	8
Ravens K3	110.76 (8.26)	110.00 (10.94)	101.41 (13.80)	107.00 (13.84)
Age G2	96.68 (2.93)	95.83 (4.05)	99.36 (4.95)	98.88 (3.68)
Grade 1 measures				
Grammar	59.62 (6.30)	39.89 (5.55)	39.86 (10.15)	59.38 (6.21)
Listening comprehension	15.88 (2.91)	10.28 (1.93)	10.59 (3.51)	18.75 (4.95)
Narrative retell	101.65 (16.78)	64.78 (18.75)	59.55 (14.78)	98.00 (13.36)
Expressive vocabulary	59.18 (11.05)	33.39 (8.15)	33.41 (8.02)	58.50 (10.25)
Grade 2 measures				
Word reading	107.85 (15.68)	88.67 (15.07)	59.00 (26.06)	69.75 (29.17)
Reading comprehension	23.03 (4.99)	15.56 (5.49)	10.91 (4.90)	12.12 (5.69)
Monitoring	47.59 (3.99)	34.78 (10.57)	32.36 (11.59)	39.63 (11.50)
Inferential comprehension	34.24 (4.18)	27.72 (6.09)	26.20 (8.36)	30.25 (4.59)
Listening span: true–false	40.85 (1.23)	39.44 (3.62)	40.09 (2.07)	39.25 (1.75)
Listening span: word recall	22.88 (3.79)	18.28 (4.18)	18.36 (4.67)	22.25 (6.48)

The patterns of group-comparison results were identical for working memory and the two higher-level language skills associated with reading comprehension. That is for working memory, comprehension monitoring, and inferencing, the typically-developing (TD) group did significantly better than the SLI-only group and the SLI-D group. There were no other significant differences between the groups.

Discussion

In this study, 82 Cantonese Chinese-speaking Grade 2 children were assessed on their ability to read words, to comprehend and infer meanings from written texts, to monitor comprehension breakdowns while reading, and to simultaneously store and process verbal information in working memory. The five research questions were addressed by two sets of analyses. Hierarchical multiple regression analyses showed that working memory, comprehension monitoring and inferencing made independent contributions to individual differences in reading comprehension (first research question), and that working memory did not mediate the relationship between reading comprehension and the two higher-level language skills (second research question).

Pairwise comparisons revealed that the D-only and the SLI-only group showed a different profile of deficits. The SLI-only group, but not the D-only group, showed problems in verbal working memory and the two higher-level language skills associated with reading comprehension (third research question). The answer to the fourth research question was yes. The SLI group, the D-group and the SLI-D group

Table 5 Results of pair-wise comparisons on word reading, reading comprehension, working memory, comprehension monitoring and inferencing

	SLI-D vs. SLI	SLI-D vs. D	TD vs. SLI	TD vs. D	TD vs. SLI-D
Word reading	F (1, 36) = 25.285	F (1, 26) = 1.224	F (1, 48) = 17.413	F (1, 38) = 26.505	F (1, 52) = 80.034
	p = .000	p = .279	p = .000	p = .000	p = .000
	Partial η^2 = .413	Partial η^2 = .045	Partial η^2 = .266	Partial η^2 = .411	Partial η^2 = .606
Reading comprehension	F (1, 36) = 9.789	F (1, 26) = .406	F (1, 48) = 23.856	F (1, 38) = 29.572	F (1, 52) = 73.972
	p = .003	p = .529	p = .000	p = .000	p = .000
	Partial η^2 = .214	Partial η^2 = .015	Partial η^2 = .332	Partial η^2 = .438	Partial η^2 = .587
Working memory	F (1, 36) = .001	F (1, 26) = 2.726	F (1, 48) = 15.799	F (1, 38) = .388	F (1, 52) = 11.513
	p = .973	p = .111	p = .000	p = .537	p = .001
	Partial η^2 = .000	Partial η^2 = .095	Partial η^2 = .248	Partial η^2 = .010	Partial η^2 = .181
Comprehension monitoring	U = 183.00	U = 59.00	U = 83.00	U = 86.00	U = 63.5
	p = .683,	p = .173	p = .000	p = .108	p = .000
	r = −.065	r = −.249	r = −.596	r = −.248	r = −.697
Inferencing	F (1, 34) = .052	F (1, 24) = 1.173	F (1, 48) = 19.836	F (1, 38) = 6.539	F (1, 50) = 16.587
	p = .821	p = .290	p = .000	p = .015	p = .000
	Partial η^2 = .002	Partial η^2 = .047	Partial η^2 = .292	Partial η^2 = .147	Partial η^2 = .249

all did worse than the TD group on reading comprehension. The SLI-D group, however, did not do worse than either the SLI-only or the D-only group on working memory and the two higher-level language skills (fifth research question). In other words, the SLI-D group did not show a more severe deficit as the single diagnosis groups on these skills.

Relationship between reading comprehension, working memory and higher-level language skills

In this study, reading comprehension correlated strongly and positively with working memory, comprehension monitoring and inferencing (.434–.672). Its relationship with the oral language measures was not as strong (.408–.546). These findings offered some support to Cain's (2006) but not Nation et al.'s (1999) proposal. After controlling for age, word reading, nonverbal cognitive skills and a comprehensive range of oral language skills, this study replicated Cain et al. (2004) findings that working memory and the two higher-level language skills are important for reading success because each made a unique contribution to individual differences in reading comprehension.

One might argue however that the oral language measures are not robust enough to detect individual differences in working memory and higher-level language skills. It is plausible that if more robust measures were used, working memory and higher-level language skills would no longer make a contribution to variance in reading comprehension. This remains a question to be investigated.

Verbal working memory, comprehension monitoring and inferencing in SLI and dyslexia

Consistent with Nation et al.'s (1999) proposal, only the children with SLI, but not the children with dyslexia, were found to have problems in verbal working memory. In the listening span task, the children with SLI demonstrated adequate comprehension of simple sentences, but poor recall of the last word of the sentences. Problems in verbal working memory have been documented in English-speaking children with SLI (e.g., Archibald & Gathercole, 2006). Attempts to invoke working memory problems as an explanation of SLI notwithstanding (e.g., Montogmery, Magimairaj, & Finney, 2010), the listening span task is probably not independent of language knowledge. Indeed, children with SLI have more problems recalling low frequency words, words with many lexical competitors and words they did not know much about (Mainela-Arnold & Evans, 2005; Mainela-Arnold, Evans, & Coady, 2010). The relationship between oral language and verbal working memory appeared bidirectional.

Findings from this study were also consistent with Cain's (2006) prediction. Only the children with SLI, who had deficits in verbal working memory, had problems with inferencing and comprehension monitoring. Prior research using oral tasks also reported problems with both inferencing (Bishop & Adams, 1990) and comprehension monitoring (Skarakis-Doyle & Dempsey, 2008) in children with SLI. In contrast, without working memory deficits, the children with dyslexia did not show problems with these two higher-level language skills. Given that problems in verbal working memory, inferencing and comprehension monitoring were only found in children with SLI, such problems may well have more to do with oral language impairment than dyslexia, as Hulme and Snowling (2011) suggested. Our findings are consistent with the hypothesis that poor oral language causes problems in verbal working memory, which then leads to difficulties in inferencing and comprehension monitoring, resulting in poor reading comprehension in children with SLI. Our findings are however inconsistent with earlier reports of difficulties in verbal working memory, inferencing and comprehension monitoring in children with dyslexia. One explanation to this consistency is methodological. In these studies, children with dyslexia were not tested for a probable co-morbid impairment in oral language.

Word reading in children with SLI

Recall that the SLI-only group was defined by an impairment in oral language and the D-only group was defined by an impairment in word reading. Although not meeting the criteria for dyslexia, the SLI-only group also did worse than the TD group in word reading. There are three plausible explanations. First, morphological awareness bootstraps the learning of new characters in word compounds. Given that the SLI-only children did not have problems with orthographic skills and rapid automatic naming (Wong et al., 2015), the two core cognitive skills involved in the reading of Chinese, their poor word reading could be a result of their poor morphological skills. Second, the SLI-only group's poor language also could have prevented them from making use of the semantic (Plaut, McClelland, Seidenberg, & Patterson, 1996), and discourse context (Bishop & Snowling, 2004) in trying to decode a novel word through the semantic pathway that maps between orthography and phonology via meaning. Third, poor language could also make them less interested in a language-based activity such as reading, leading to slower learning and poorer word reading.

Implications: early identification and intervention

Compared with dyslexia, SLI was said to have a "Cinderella status" (Bishop, 2009, p. 163) and a "lack of visibility of the impairment" (Conti-Ramsden, 2009, p. 167) in affected individuals. Compared with dyslexia, reading comprehension impairment was also said to be a "hidden disability" (Hulme & Snowling, 2011, p. 139). Reading comprehension impairment in children with SLI, then, means a double dose of neglect in research and clinical service. According to a large-scale epidemiological study, only 29 % of the 5-year-old kindergarten children with SLI were clinically referred (Tomblin et al., 1997), and many children's language learning difficulties went unnoticed until they were formally tested. Given the role of oral language comprehension in reading comprehension, many of these non-referred children could have surfaced as poor comprehenders later on in elementary school. Research has shown that children could be effectively screened for reading difficulties in the preschool years (Wilson & Lonigan, 2010). Such screening however should go beyond a screening for word reading. It should include other aspects of language skills such as listening comprehension, vocabulary and narrative production to identify children at risk with reading comprehension difficulties due to poor language skills.

Our findings on children with dyslexia and/or SLI echo Cain & Oakhill's (2006) suggestion that there can be different routes to reading comprehension difficulties, hence different intervention approaches are warranted for these two clinical populations of children. For children with SLI, in addition to oral language, intervention should include the use of questions to facilitate children's identification of gaps in understanding—i.e., comprehension monitoring—and the need to make inferences for successful comprehension. It can focus on improving their comprehension monitoring through summarizing and questioning. To reduce working memory demand for comprehension, children with SLI can first pre-read the text with a purpose to identify words, phrases, clauses or sentences that they have problems with and then seek help for their understanding. For children with dyslexia, intervention can focus more on improving their processing of orthographic structures.

This study constitutes a first-ever comparison between Chinese children with SLI and those with dyslexia using the same assessment tools on their reading comprehension, working memory and higher-level language skills. Despite vastly different writing systems, skills involved in reading comprehension—verbal working memory, comprehension monitoring, and inferencing—should be similar for English-speaking and Cantonese-speaking children. Our results should therefore have implications beyond Cantonese Chinese.

Limitations

We are mindful of the following limitations in the present study. First is the modest sample size (especially for the dyslexia-only group) and hence relatively limited statistical power. Second is that use of a comprehension monitoring and an inferencing task that required reading. Such tasks are not pure tasks of their associated constructs and given their reading nature, will naturally make contributions to reading comprehension beyond word reading and oral language comprehension. Third, the oral and the reading measures used in the multiple regression were obtained at different time points, with the former obtained at Grade 1 and the latter at Grade 2. It is plausible that if Grade 2 oral language measures were included, comprehension monitoring, inferencing and working memory would not add additional variance to reading comprehension. Forth, results from this study should be interpreted in light of the fact that reading comprehension was examined at the end of Grade 2 when word reading skills are still yet to fully develop. Children's developing word reading skills placed a constraint on their reading comprehension. Once these skills are more automatized, comprehension monitoring, inferencing, and working memory might contribute a larger variance to reading comprehension. Fifth, only a single test at a single time point at Grade 1 was used to define the D-group. The implication is that it might have overdiagnosed children who were poor in word reading due to inadequate exposure. Future cross-sectional research with a larger and more evenly distributed group size using a more robust multiple regression design is needed to replicate these promising findings on the relationships between working memory, higher-level language skills, and reading comprehension.

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