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The impact of visual-spatial attention on reading and spelling in Chinese children

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Abstract The present study investigated the associations of visual-spatial attention with word reading fluency and spelling in 92 third grade Hong Kong Chinese children. Word reading fluency was measured with a timed reading task whereas spelling was measured with a dictation task. Results showed that visual-spatial attention was a unique predictor of speeded reading accuracy (i.e., the total number of words read correctly divided by the total number of words read in a timed reading task) but not reading speed (i.e., the number of words read correctly in the same task) after controlling for age, non-verbal intelligence, morphological awareness, phonological awareness, orthographic knowledge, and rapid automatized naming. Visual-spatial attention also explained unique variance in word spelling measured with a dictation task after the same control variables. The findings of the present study suggest that visual-spatial attention is important for literacy development in Chinese children.

Keywords Visual-spatial attention · Reading fluency · Spelling · Chinese

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Introduction

Visual-spatial attention refers to attention to the spatial location of a visually presented stimulus (e.g., Vecera & Rizzo, 2003). Studies have shown that visual-spatial attention is related to reading and spelling in learners of alphabetic languages (e.g. Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Ferretti, Mazzotti, & Brizzolara, 2008; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Pammer, Lavis, Hansen, & Cornelissen, 2004). However, with the exception of Liu, Chen, and Chung (2015), no previous studies have investigated the association of visual-spatial attention with literacy skills in Chinese children. Liu et al. (2015) showed that visual-spatial attention was related to word reading and reading comprehension in third grade Hong Kong Chinese children. Building on this earlier study, we examined the role of visual-spatial attention in word reading fluency and spelling among the same children in the present study.

Both word reading and spelling require processing of visual information (Vidyasagar & Pammer, 2010). Word reading involves visual scanning and decoding of printed words (Facoetti, et al., 2000). The reader needs to disengage from the previous unit, shift attention to the current unit and focus on it long enough so that further processing can be conducted. At the same time, distraction from surrounding stimuli must be inhibited. Thus, visual-spatial attention is important for both reading accuracy and reading fluency. Word spelling involves retrieving visual-orthographic information stored in memory. As such, the quality of orthographic representation is critical for spelling success (e.g., Ehri, 1980). Visual-spatial attention helps children identify and store visual details of a word, such as the contour, positioning of letters (e.g., "*r*" appears at the end of the word "*center*"), and whether the word contains a specific letter (e.g., whether there is a letter "*h*" in the word "*wheel*") and enables them to retrieve the information accurately and efficiently.

There is evidence that for children who speak alphabetic languages, visual-spatial attention is related to success in word reading as well as spelling, although the relationship with spelling has been less examined (e.g., Plaza & Cohen, 2007). For example, in a three-year longitudinal study, Franceschini et al. (2012) demonstrated that visual-spatial attention measured in kindergarten was predictive of reading skills including letter naming, pseudo-word and real word reading and text reading measured in grades 1 and 2 among Italian children. The longitudinal design of this study highlighted the potential causal relationship between visual-spatial attention and reading development. In another study, Plaza and Cohen (2007) showed that visual-spatial attention uniquely predicted word and pseudoword reading in 6-year-old French children after controlling for phonological awareness and rapid naming. Notably, this study also reported a significant association between visual-spatial attention and spelling. Building on Plaza and Cohen (2007), we examined the contribution of visual-spatial attention to word spelling among third grade Hong Kong children.

Aside from reading accuracy and spelling, a small number of studies examined the relationship between visual-spatial attention and reading fluency. Plaza and

Cohen (2007) included a 1-min reading task in their reading measures, but the correlation between visual-spatial attention and this measure was not significant. However, all the words in the 1-min reading task were of high-frequency. Studies have shown that high-frequency words tend to be processed holistically (e.g., Wong, et al., 2011). That is, reading high-frequency words in a timed measure requires fast mapping of orthographic to phonological information, thereby minimizing the effect of visual-spatial attention. This notion is confirmed by the significant correlation between the 1-min reading task and rapid naming observed in Plaza and Cohen (2007). In comparison, reading low-frequency words involve processing detailed information, which likely places a higher demand on visual-spatial attention. To further examine the relationship between visual-spatial attention and reading fluency, reading fluency was measured with a time-limited word reading task including both high- and low-frequency words in the present study.

Visual-spatial attention may be particularly important for literacy acquisition in Chinese due to the characteristics of the Chinese writing system. Chinese characters are visually complex. Each character is composed of multiple strokes within a two-dimensional space. Thus, visual-spatial attention is needed to process character configuration accurately and efficiently. There are a large number of characters that differ only by one stroke or a couple of strokes, e.g., 土/tou2/(earth) and 士/si6/ (soldier). In order to process visually similar characters, children must direct their visual-spatial attention to recognize subtle stroke differences. Compared to character reading, character spelling is a cognitively more demanding task because it requires knowledge of the exact spatial positioning of the strokes. As such, we anticipate that visual-spatial attention is related to both character reading fluency and spelling. This may be particularly true for Hong Kong Chinese children, who learn to read and write traditional characters[1] and receive character instruction with an emphasis on rote memorization (e.g., Cheung & Ng, 2003; Tzeng & Wang, 1983).

Although a number of previous studies examined the role of visual processing in Chinese reading, these studies focused on visual discrimination and memory and did not produce consistent results (e.g., Ho & Bryant, 1999; Huang and Hanley, 1995; Luo, Chen, Deacon, Zhang, & Yin, 2013; McBride-Chang, Chow, Zhong, Burgess, & Hayward, 2005; McBride-Chang & Kail, 2002). In comparison, few studies have explored the relationship between visual-spatial attention and the literacy performance of Chinese children. Wang, Bi, Gao, and Wydell (2010) found that Chinese children with developmental dyslexia had deficits in the visual magnocellular system. Because the magnocellular system is thought to be the biological basis of visual-spatial attention (e.g., Vidyasagar & Pammer, 2010), this finding suggests a potential link between visual-spatial attention and Chinese reading. To our knowledge, Liu et al. (2015) was the first study to directly address the contribution of visual-spatial attention to Chinese reading. The researchers found that visual-spatial attention measured by a visual search task predicted unique variance in both character reading and reading comprehension in third grade Hong Kong Chinese

[1] Traditional Chinese is currently used in Taiwan and Hong Kong. Traditional characters have more strokes on average than simplified characters, which are currently used in Mainland China and Singapore.

children, after substantive controls including age, non-verbal IQ, phonological awareness, morphological awareness, orthographic knowledge, and vocabulary. This study provided preliminary evidence supporting the role of visual spatial attention in Chinese reading.

The present study

While Liu et al. (2015) established the association of visual-spatial attention with word reading and reading comprehension in Chinese, the present study aimed to extend the findings to two new literacy outcomes, word reading fluency and spelling, in an attempt to provide a comprehensive picture of the role of visual-spatial attention in Chinese children's literacy development. We adopted the visual search paradigm to measure visual-spatial attention. In this paradigm, participants are asked to identify the target from a matrix composed of the target and distracters (e.g., searching "*E*" from "*F*"), and both search time and accuracy are used as indices of visual-spatial attention (e.g., Casco, Tressoldi, & Dellantonio 1998; Plaza & Cohen, 2007). We chose the visual search paradigm because it can be administered as a paper and pencil task in the classroom setting.

With respect to the outcome variables, an experimental measure parallel to TOWRE was adopted to assess word reading fluency in Chinese (Pasquarella, Chen, Gottardo, & Geva, 2015). Word reading speed was calculated as the total number of words read correctly within the 45-s time limit. Following Vaessen and Blomert (2010), we also recorded speeded reading accuracy (the total number of words read correctly divided by the total number of words read) for this task. We anticipated that visual-spatial attention would contribute to both outcome variables, because, as we argued earlier, visual-spatial attention is important for both reading precisely and fluently. Word spelling was measured with a dictation task. Visual-spatial attention was also expected to be associated with the performance on the dictation task.

Given that metalinguistic skills such as morphological awareness, phonological awareness, and orthographic knowledge have been found to predict both reading and writing in Chinese children (e.g., McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Shu, Peng, & McBride-Chang, 2008; Tong, McBride-Chang, Shu, & Wong, 2009), these measures were included as control variables in the present study. A homograph identification task and a compound production task were administered to measure morphological awareness. Orthographic knowledge was evaluated with a character identification task tapping the knowledge of legal positions of radicals in compound characters. Phonological awareness was measured with syllable deletion and onset deletion tasks. Considering the robust power of rapid automatized naming (RAN) in predicting literacy outcomes in both alphabetic languages (for a review see Lervåg & Hulme, 2009) and Chinese (e.g., Liao, et al., 2015), it was also included as a control variable. Finally, non-verbal intelligence was further controlled to rule out the possibility that any relationship observed was due to spurious third variables.

Method

Participants

A total of 92 third grade Hong Kong Chinese children (60 boys and 32 girls, mean age = 9.03, *SD* = .32) participated in this study. All children were native speakers of Cantonese, and came from families of low-to-middle SES backgrounds. No physical or cognitive delays were reported by teachers or parents for these children. Parents of all children provided written informed consent for their children's participation in this study.

Measures

Visual-spatial attention

The visual search paradigm (e.g., Casco et al., 1998; Plaza & Cohen, 2007) was adopted for measuring the visual-spatial attention. Participants were required to circle out the target items from a 20 (items) × 5 (lines) matrix composed of both target items and background distracters. The target items were randomly distributed in the matrix. The number of targets ranged from 19 to 21, to avoid any expectation effect. Participants were given two lines of items to familiarize them with targets and distracters prior to the formal testing. Three types of stimuli were involved, including alphabetic letters, symbols, and Chinese characters (see Table 1). Only one type of stimuli was used in each trial. There were totally 12 trials, 4 for each type of stimuli. All stimuli were in Microsoft Jheng Hei font, with the font size of 11. The visual complexity and visual similarity of the stimuli were balanced across the three types of stimuli. The visual complexity of the stimuli was calculated using the perimetric complexity measure[2] described by Pelli, Burns, Farell, and Moor-Page (2006). The visual similarity of the target and distracter within each trial was rated by 30 undergraduate students on a 7-point scale (1 = very different, and 7 = very similar). Both completion time and error were recorded. The coefficient of internal consistency (Cronbach's α) of this task was .87.

Reading fluency

This measure required children to read as many Chinese words as possible within 45 s (Pasquarella et al., 2015). There were 104 Chinese words in total, including 21 single-character words, 76 two-character words, 5 three-character words, and 2 four-character words. Children were also given eight practice words. One error was recorded if a child pronounced a word incorrectly, missed a word, or paused for over 3 s. If a child completed the task less than 45 s, the time of completion was recorded. Two kinds of scores were obtained in this reading fluency task, namely

[2] Perimetric complexity is calculated by the squared perimeter of the stimulus divided by its ink area. The ink area is measured with the number of inked pixels on the computer screen times the area of a pixel.

Table 1 The description of the visual search task

	Example	Complexity		Similarity	
Letter	C–G	17.02 (2.53)	F(2, 9) = .39	.53 (.37)	F(2, 9) = .00
Symbol	◇–▽	16.48 (7.46)		.53 (.36)	
Character	人–入	19.46 (3.84)		.53 (.35)	

reading speed and speeded reading accuracy. Reading speed was indicated by the total number of correctly read words (Vaessen, Gerretsen, & Blomert, 2009). Following Vaessen and Blomert (2010), speeded reading accuracy was calculated by dividing the number of words read correctly by the total number of words read.

Chinese word spelling

A word dictation task (e.g., Wang, McBride-Chang, & Chan, 2014) adopted from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (Ho, Chan, Tsang, & Lee, 2002) was used for testing children's word spelling skills. The tester read aloud the words and asked children to write them down on a blank sheet. The task consisted of 3 trials and 20 formal items presented in order of increasing difficulty. All items were two-character Chinese words. One point was allotted to each correctly spelled Chinese character and thus the maximum score of this task was 40. The coefficient of internal consistency (Cronbach's α) of this task was .84.

Control measures

Morphological awareness A homograph awareness task and a compound production task (Liu & McBride-Chang, 2010) were used for testing children's morphological awareness. In the homophone awareness task, children were first presented with a target word, and then asked to select from three words the one that shared "a character that had the same meaning" (i.e., the same morpheme) as the target word. For example, 商量 (soeng1 loeng4, consult) was the target word, and 商店 (soeng1 dim3, store), 商定 (soeng1 ding6, agree), and 商人 (soeng1 jan4, merchant) were the three options. The correct answer was商定. There were totally 40 items in this task and all of them were presented orally. One point was given to a correct answer; and thus the maximum score was 40. The coefficient of internal consistency (Cronbach's α) of the task was .66.

In the compounding production task, children were first presented with a scenario, and asked to create a novel word to properly represent the scenario. One item in this task was "我們把專門吃鐵的怪獸叫做什麼?(What should we call a monster that can only eat iron?)" The answer for this item was 吃鐵怪 (iron-eating monster). Children's answers were rated based on a five-point scale (0–4). There were totally 31 items in this task, and thus the maximum score was 124. All the items were orally presented. The coefficient of internal consistency (Cronbach's α) of the task was .85.

Phonological awareness Children's phonological awareness was measured with a task consisting of 9 syllable deletion and 22 onset deletion items (McBride-Chang et al., 2003). In a syllable deletion item, children were asked to remove a syllable from a three-syllable word For example, say "he6 kou1 peng2" without "kou1," the answer was "he6 peng2." In an onset deletion item, children were asked to remove the onset of a syllable. For example, say "gut3" without "g," the answer was "ut3." One point was given to each correct answer, and thus the maximum score was 31. The coefficient of internal consistency (Cronbach's α) of this task was .95.

Orthographic knowledge Orthographic knowledge was measured with a Chinese character identification task (Tong et al., 2009). Children were required to judge whether an item was a real Chinese character or not. There were 30 real Chinese characters, 9 pseudo-characters, 21 non-characters, and 10 visual symbols in this task, which were randomly arranged in 14 sets of 5 items each. The pseudo-characters were created by combining real Chinese radicals following orthographic conventions in Chinese (e.g., 木米). The non-characters were also created with real Chinese radicals; however, they were in illegal positons (e.g., 也土). Some unfamiliar Chinese characters were included in the task to reduce the overlap between this task and the Chinese character reading task. The maximum score of this task was 30. The coefficient of internal consistency (Cronbach's α) of this task was .77.

Rapid automatized naming (RAN) The RAN digit task was adapted from a task used in previous studies (e.g., Tong et al., 2009). Children were required to read aloud single-digit numbers arranged on a single page of paper in a 5 (row) by 5 (column) array as quickly as possible. All five numbers (i.e., 1, 2, 5, 6, 8) were shown in each row in a randomized order. Children were asked to complete the task twice, and the average completion time was calculated as the score.

Procedure

All measures were administered individually by trained student helpers in quiet classrooms of the children's school during school hours. It took about one hour for each participant to complete the testing.

Results

The descriptive results are shown in Table 2. In order to reduce the number of variables included in the regression analyses, a composite score was calculated for the homograph awareness and compounding production tasks to represent morphological awareness. No severe violation of normal distribution was observed in any of the measures. One outlier (4 SD away from the mean) was found in the completion time of the visual search task and was subsequently replaced by the serial mean.

The Zero-order correlations among all measures are shown in Table 3. The number of errors in the visual search task was significantly correlated with all three

Table 2 The descriptive statistics of all measures ($N = 92$)

Measure	Range	Mean	SD
Age	8.50–10.17	9.03	.32
Visual-spatial attention_Time	22.53–54.54	33.12	5.07
Visual-spatial attention_Error	0–19	3.53	4.16
Reading speed	32–80	55.36	10.95
Speeded reading accuracy	.86–1	.98	.03
Word spelling	2–35	22.77	6.14
Morphological awareness	10–104	67.61	19.32
Phonological awareness	5–31	15.75	7.59
Orthographic knowledge	35–65	53.88	6.18
Vocabulary	2–59	42.14	9.92
RAN	11.05–34.72	18.96	6.14
Non-verbal IQ	2–23	16.20	4.82

Table 3 Zero order correlations among all measures

		1	2	3	4	5	6	7	8	9	10
1	Age	–									
2	Raven	.03	–								
3	RT_VS	−.13	.05	–							
4	ER_VS	−.01	−.28**	−.15	–						
5	MA	−.07	.16	−.09	−.12	–					
6	PA	−.07	.16	−.06	−.03	.51***	–				
7	OK	−.06	.08	.16	.08	.19	.20	–			
8	RAN	.02	−.09	.14	.19	−.18	−.10	−.05	–		
9	Read_Speed	−.01	.12	−.21*	−.22*	.31**	.19	.17	−.67***	–	
10	Read_Accuracy	−.07	.04	−.09	−.25*	.26*	.18	.19	−.44***	.54***	–
11	Word Spelling	.04	.10	.12	−.29**	.11	.21*	.12	−.40***	.39***	.40***

N = 92

Raven non-verbal IQ, *RT_VS* average completion time in visual search, *ER_VS* the total number of errors made in visual search, *MA* morphological awareness, *PA* phonological awareness, *OK* orthographic knowledge

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

literacy measures ($r = .21$, $p < .05$ for reading speed, $r = -.25$, $p < .05$ for speeded reading accuracy, and $r = -.29$, $p < .01$ for spelling). The completion time of the visual search task was correlated with reading speed ($r = .21$, $p < .05$), but not any of other measures. Morphological awareness was significantly correlated with both reading speed ($r = .31$, $p < .01$) and speeded reading accuracy ($r = .26$, $p < .05$), but not word writing. Phonological awareness was significantly correlated with word spelling ($r = .21$, $p < .05$), but neither reading speed nor speeded reading accuracy. Orthographic knowledge did not show significant correlation with any of the three literacy measures. The associations of RAN with the reading and spelling

Table 4 Hierarchical regressions explaining both Reading fluency and word spelling measures

Block and variable	Reading speed			Speeded reading accuracy			Word spelling		
	R^2	R^2 change	Final beta	R^2	R^2 change	Final beta	R^2	R^2 change	Final beta
1. Age	.02	.02	.03	.01	.01	−.04	.01	.01	.06
Non-verbal IQ			−.01			−.09			−.02
2. Morphological awareness	.12	.10*	.14	.09	.09 (p = .052)	.11	.06	.05	−.13
Phonological awareness			.03			.06			.22
Orthographic knowledge			.11			.16			.09
3. RAN	.50	.38***	−.57***	.25	.16***	−.38***	.20	.14***	−.34**
4. Visual-spatial attention	.51	.01	−.07	.29	.03*	−.20*	.25	.05*	−.24*

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

measures were moderate (rs ranged from −.40 to −.67, ps $< .001$). Finally, the reading and spelling measures were found to be correlated with each other (rs ranged from .39 to .49, ps $< .001$).

Multiple regressions were conducted to further explore the associations of visual-spatial attention with word reading (both word reading speed and speeded reading accuracy) and spelling. The total number of errors of the visual search task was used as an index of visual-spatial attention in the regression analyses. The completion time of the visual search task was not used because it was only weakly correlated with word reading speed and was not correlated with any other measures. In all three regression models, age and non-verbal intelligence were entered in the first block, morphological awareness, phonological awareness, and orthographic knowledge in the second block, RAN in the third block, and the total number of errors in the visual search task in the fourth and final block. Visual-spatial attention accounted for unique variance in both speeded reading accuracy (5 %, $p < .05$) and word spelling (5 %, $p < .05$), after controlling for age, non-verbal intelligence, morphological awareness, phonological awareness, orthographic knowledge, and RAN. However, it was not a unique predictor of word reading speed (1 %, $p = .29$). The results of the regression analyses are shown in Table 4.

Discussion

To our knowledge, this was the first study exploring the associations of visual-spatial attention with word reading fluency and spelling in Chinese children. Consistent with our hypotheses, visual-spatial attention was a unique predictor of speeded word reading accuracy and word spelling after controlling for age, non-verbal intelligence, morphological awareness, phonological awareness, orthographic knowledge, and RAN in third grade Hong Kong Chinese children.

However, visual-spatial attention did not explain unique variance in word reading speed after the same controls, although the two variables were found to be significantly correlated with each other.

While Liu et al. (2015) established a connection between visual-spatial attention and Chinese word reading accuracy, the present study extended the effect of visual-spatial attention to word reading fluency. Visual-spatial attention was found to predict speeded reading accuracy, calculated as the ratio of the number of words read correctly to the total number of words read, after substantive controls. As mentioned earlier, Chinese characters are visually complex. Although there are only five basic strokes in Chinese (i.e., 一, 丨, 丿, 丶, and 乙), they combine in many different ways to form thousands of characters. A slight change in stroke configuration may result in an entirely different character, e.g., 士 (soldier) and 土 (earth). Thus, visual-spatial attention is important for developing word reading fluency in Chinese because it enables the reader to process visual details of a Chinese character both precisely and efficiently.

Contrary to our hypothesis, visual-spatial attention was not a unique predictor of reading speed in the present study. A possible explanation for the lack of unique prediction is that RAN was a very strong predictor of reading speed, accounting for about 40 % of the variance. Thus, the overlap between the RAN and reading speed decreased the predicting power of visual-spatial attention. Nevertheless, speeded reading accuracy and reading speed were highly correlated with each other and both were correlated with visual-spatial attention, suggesting that visual-spatial attention is important for overall reading fluency. The relationship between visual-spatial attention and reading speed needs to be further investigated by future studies.

Visual-spatial attention was also found to explain unique variance in word spelling in a dictation task in the present study. In order to perform successfully on a spelling task, children need to be able to store detailed orthographic information in the mental lexicon and later retrieve it from memory. Both storing and retrieving of orthographic information require good visual-spatial attention. Because Chinese characters are visually complex, children with poor visual-spatial attention are likely to memorize Chinese characters incorrectly or confuse visually similar characters, leading to poor performance on spelling tasks. These findings are consistent with the findings of previous studies involving children who are speakers of alphabetic languages (e.g., Plaza & Cohen, 2007). Thus, our study extended the relationship between visual-spatial attention and spelling to Chinese, a non-alphabetic language.

Previous study observed that visual-spatial attention was independent of metalinguistic measures such as phonological awareness, morphological awareness, and orthographic processing (Liu et al., 2015). In the present study, visual-spatial attention was also found to be independent of rapid naming. Although the exact processing nature of rapid naming remains unclear, it is believed to measure the speed of mapping orthographic information to phonological code and orally producing retrieved phonological information. (e.g., Georgiou, Parrila, Cui, & Papadopoulos, 2013; Lervåg & Hulme, 2009; Vaessen, et al., 2009). Thus, rapid naming may also require attentional resources. However, research findings have been mixed. There is evidence that children with attentional deficits did not show difficulties in rapid naming (e.g., Semrud-Clikeman, Guy, Griffin, & Hynd, 2000). Moreover, efficient processing of visual-orthographic information, which is the underlying mechanism of visual-spatial attention, was not related to rapid naming (e.g., Moll, Fussenegger, Willburger, & Landerl, 2009). While these findings support the observation of the present study, the nature of the relationship needs to be further investigated.

The present study had at least three limitations. First, only third grade children were included, limiting the generalizability of the findings. Future studies should include children of different age groups. Second, while we included a large number of control variables to test the strength of the relationship between visual-spatial attention and literacy outcomes, the concurrent design did not speak to the directionality of the relationship. Longitudinal and intervention studies need to be conducted to reveal the causality of the relationship. Finally, visual-spatial attention was only measured with a single task of the visual search paradigm in the present study. Multiple measures of different paradigms, including both the visual search paradigm used in the present study and the cueing paradigm (e.g., Facoetti, et al., 2000), need to be adopted to increase the validity of the construct.

In sum, the present study demonstrated that third grade Hong Kong Chinese children's visual-spatial attention measured with the visual-search task significantly predicted speeded reading accuracy and word spelling even after controlling for age, non-verbal intelligence, morphological awareness, phonological awareness, orthographic awareness, and RAN. Currently, most studies on Chinese children's literacy development have focused on the contributions of different aspects of metalinguistic awareness (such as morphological awareness and phonological awareness). The findings in the present study, together with the previous one (Liu et al., 2015) are among the first to provide empirical evidence for the importance of visual-spatial attention in the literacy development of Chinese children. These findings not only provide a new direction for studying visual processing in Chinese reading, but also enrich our understanding of the underlying mechanism of literacy development in Chinese by considering both cognitive and linguistic factors.

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