Reading and Writing
https://doi.org/10.1007/s11145-024-10623-7

The effectiveness of phonological training and morphological training in Chinese children with reading difficulty

Linling Shen[1] · Guoyan Feng[2] · Liping Shi[3] · Yu Wu[4,5] · Fan Cao[4,5]

Accepted: 30 November 2024

Abstract
Purpose: Reading difficulty (RD) affects 5–10% of the population across languages (Wagner in J Learn Disabil 53(5), 354–365, 2020). However, only a few studies have focused on developing effective interventions for Chinese children with RD. Both the phonological deficit and morphological deficit hypotheses have been proposed to explain the underlying cognitive cores of RD in Chinese, with limited research directly comparing the interventions targeting these skills. Method: In the current study, we designed and directly compared a phonological and a morphological training program in improving reading for Chinese children with RD. The phonological training program addressed phonological awareness and conversion from orthography to phonology, while the morphological training addressed morphological awareness and conversion from orthography to meaning. Sixty-two fifth-grade students with RD were randomly assigned to the phonological, morphological intervention, or a business-as-usual (BAU) group. Results: Both the phonological training (PT) and the morphological training (MT) improved sentence reading fluency, character naming, one-minute irregular character naming, and phonological awareness compared to the BAU group. Furthermore, we found that responsiveness to the PT was negatively correlated with phonological awareness and maternal education, while responsiveness to the MT was positively correlated with rapid automatized naming (RAN) skills. Conclusion: The phonological training and the morphological training had similar effectiveness in promoting reading in Chinese children with RD, which provides important insights into reading intervention for Chinese RD.

Keywords Phonological intervention · Morphological intervention · Reading disability · Chinese

Linling Shen and Guoyan Feng have contributed to the study equally.

Extended author information available on the last page of the article

Published online: 14 December 2024

Introduction

Reading difficulty in Chinese

Reading is a primary way for people to acquire knowledge. However, around 5–10% of the population, across languages, struggles to achieve fluent reading, despite adequate intelligence, learning opportunities, and motivation (Wagner et al., 2020). Individuals with RD show significant impairments in word recognition and reading fluency, as well as in various cognitive-linguistic processes such as phonological awareness, morphological awareness, visual-orthographic processing, working memory, and rapid naming (see Peng et al., 2017, for a meta-analysis). Fortunately, research has shown that early and effective interventions can make a significant difference in reading development in individuals with RD (Carlisle, 2010; Gustafson et al., 2007; Snowling & Hulme, 2012; Vaughn et al., 2010; Wanzek et al., 2018). However, previous interventions have been developed in English or other alphabetic languages, and very few have targeted Chinese children with RD. Therefore, it is sorely needed to understand what training would be the most effective for Chinese children with RD.

Phonological deficits and phonological training

The phonological deficit hypothesis is one of the most influential theories about RD both in alphabetic languages (Goswami, 2000; Snowling, 1998; Vellutino et al., 2004), and in non-alphabetic languages such as Chinese (Cheng et al., 2021; Ho et al., 2000; Wang et al., 2021). In this hypothesis, deficits in representing, accessing, or manipulating sound cause difficulties in developing print-sound correspondence (Anthony & Francis, 2005; Castles & Friedmann, 2014). The phonological deficit hypothesis also has a great impact on reading intervention studies, and most reading intervention programs have an emphasis on phonological skills in alphabetic languages. These intervention programs typically include training on letter-sound knowledge, grapheme-phoneme correspondence rules, in addition to phonemic awareness, such as blending, segmenting, and phoneme manipulation (Schuele & Boudreau, 2008). There is evidence that English-speaking children who have RD or are at risk of RD benefit from phonologically-based training, especially in phonological decoding and phonological awareness (Lovett et al., 2000; Snowling & Hulme, 2012). However, phonologically-based training appears to have a mild effectiveness on more difficult reading tasks such as exception word reading, vocabulary, reading fluency, and reading comprehension (Lovett et al., 1994; O'Shaughnessy & Swanson, 2000; Suggate, 2016). There is also great variability in the responsiveness to phonologically-based interventions in individuals with RD (Romeo et al., 2018).

In Chinese, phonological awareness is also strongly correlated with Chinese character reading (Shu et al., 2008). Chinese children with RD show poor phonological skills, such as categorical perception of speech sounds (Zhang et al., 2012), lexical tone identification and rime detection (Li & Ho, 2011; Wang et al., 2017). In

addition, children with RD show reduced use of phonetic radicals as a cue in orthography-to-pronunciation mapping (Ho et al., 2006; Li et al., 2022).

However, studies also suggest language differences in terms of the role that phonological skills play in reading acquisition. For example, a longitudinal study suggests that phonological skill only plays an essential role in the early years of reading and spelling in Chinese, while morphological skills are more critical for higher-level literacy skills, such as reading comprehension and reading fluency (Pan et al., 2016). The reduced importance of phonological skills in Chinese reading compared to alphabetic reading may be due to some special characteristics of the Chinese writing system. Chinese is a morpho-syllabic system rather than an alphabetic system, in which a character represents a morpheme and a syllable. There is no part of a character that corresponds to a phoneme; instead, the whole character maps to the whole syllable. Therefore, the morpho-syllabic nature and the fact that there are many homophones in Chinese encourage the direct mapping between orthography and semantics during Chinese reading. This may be why morphological skills play a bigger role in later reading development than phonological skills.

Reading intervention studies have been sparse in Chinese. There have been a few studies that have examined the effectiveness of phonological intervention in Chinese children (Ho & Ma, 1999; Li et al., 2020; Wang, 2017; Wang et al., 2021), most of which have found a positive effect. However, in these studies, phonological intervention is often combined with other interventions, which makes it hard to disentangle the unique effectiveness of phonological intervention. For example, Wang et al. (2017) conducted a three-week training which combined phonological awareness training and character instruction in third- to sixth-grade Chinese children with dyslexia or at risk of dyslexia. During phonological awareness training, children learned to separate the onset and rime in a syllable (syllable analysis) and to combine an onset and a rime to form a new syllable (phoneme synthesis). Character instruction was conducted by using famous songs to teach target characters. The results showed that children who received training improved more than controls on character reading, onset awareness, rime awareness, and rapid naming (Wang et al., 2017). In another study, researchers found that meta-linguistic training, but not working memory training improved syllable representations in addition to word reading in second and third-grade elementary school children with dyslexia (Wang et al., 2021). In the meta-linguistic training, radicals were highlighted with different colors, and children learned the function of phonetic and semantic radicals in relation to the pronunciation and meaning. Therefore, both phonological training and morphological training were included in the meta-lingusitic training. In addition, Li et al. (2020) examined the effect of a 3-week Pinyin GraphoGame delivered via tablet to first-grade poor Pinyin readers from disadvantaged migrant families in China. The training group significantly outperformed a control group in Pinyin reading accuracy and fluency, phonological awareness (e.g. rime and phoneme deletion) and Chinese character recognition. Pinyin is a regular alphabetic system that indicates the sound of a character. Pinyin serves as the bridge between speech and written characters. Previous research has suggested that Pinyin knowledge is closely related to phonological awareness and learning Pinyin facilitates phonological awareness and character recognition (Lin et al., 2020; Ping et al., 2006; Shu et al., 2008). Taken together, the

study by Lin et al. (2020) seems to suggest that Pinyin learning is a plausible way of improving phonological awareness and character reading.

Morphological deficits and morphological training

Reading is a complex task involving multifaceted processes. The phonological deficit hypothesis alone cannot fully explain the causes of RD in all cases (Carroll et al., 2016; Castles & Friedmann, 2014; Pennington et al., 2012), especially considering the language differences. Research suggested that deficits in morphological awareness, rather than phonological awareness, consititue the core deficits in Chinese dyslexic children (McBride et al., 2018; Shu et al., 2006), probably because of the non-alphabetic nature of the Chinese writing system. Several studies have directly compared the predictive power of phonological and morphological awareness for reading outcomes in Chinese and English. A meta-analysis by Ruan et al. (2018) found that morphological awareness had a stronger effect on reading in Chinese than in English, while phonological awareness showed the opposite pattern. Similarly, some longitudinal studies have shown that early morphological awareness is a better predictor than phonological awareness of later Chinese character reading, spelling, and vocabulary knowledge (Lin et al., 2019; McBride-Chang et al., 2006; Tong et al., 2017).

Morphological awareness is the ability to analyze and manipulate morphemes, the smallest semantic units in a language. As children start to learn the mapping between word form and meaning, their morphological awareness develops (Carlisle, 2010). Unlike English, Chinese does not employ inflectional or derivational morphemes to mark grammatical and semantic changes. Both grammatical and semantic information are conveyed by single characters because each character represents a morpheme in Chinese (Taft & Zhu, 1995).

Chinese morphological processing takes place at both the character level and the sub-character (radical) level. At the character level, morphological awareness can be tested in homophonic morpheme awareness, homographic morpheme awareness, and word compounding. There are many homophones in Chinese, which are different characters sharing the same sound with different meanings (Liu et al., 2013). For example, eyebrow (眉), coal (煤), without (没), media (媒), rose (玫), and berry (莓) share the same sound /méi/, but they are different characters and have different meanings. When hearing the sound /méi/, Chinese speakers must use context to decide which morpheme it is. Moreover, the same morpheme may have different meanings in different contexts, and this is called homographic morpheme awareness (Cheng et al., 2016). For instance, the character "亲" (/qīn/) means "parent", "dear", "kiss", "intimate", or "close" depending on the context. Lastly, morphemes can be combined to make up compounding words (McBride-Chang et al., 2008). Compounding is a productive and common way to create new words. For example, "zebra" (斑马/bān mǎ/) is formed by combining "stripe" (斑/bān/) and "horse" (马/mǎ/).

At the radical level, morphological awareness refers to the awareness of semantic radicals, which provide clues to the meaning of the character to some degree.

In Chinese, transparent characters have semantic overlap with the semantic radical, whether it be the same meaning (e.g., 孩 /hái/, children and 子 /zǐ/, children), belonging to the same category (e.g., 雷 /léi/ thunder and 雨/yǔ/, rain), or carrying a directly related meaning (e.g., 湖 /hú/, lake and "氵" /shuǐ/, water). Conversely, opaque characters have unrelated meanings to their semantic radicals (e.g., 默 /mò/ silent and 黑/hēi/, black). Less than one-tenth of characters taught in elementary school are opaque in Chinese (Shu et al., 2003). Therefore, children benefit from transparent semantic radicals in deriving the meaning of characters.

Previous research on morphological intervention in English speakers with RD has shown a significant effect on phonological and morphological awareness, as well as on literacy outcomes including vocabulary, reading comprehension, and spelling but not reading fluency and decoding (see Goodwin & Ahn, 2010 for a meta-analysis). In Chinese, a few studies have demonstrated the effectiveness of morphological training in typically developing Chinese readers (Packard et al., 2006; Wu et al., 2009; Zhou et al., 2012) but no research has been conducted on Chinese children with RD. In the study by Zhou et al. (2012), morphological instruction was conducted at the character level, and it was found that compound word training improved character recognition and vocabulary comprehension, and homophone training was related to vocabulary comprehension enhancement. Packard et al. (2006) conducted a morphological instruction study at the sub-character level, and they found that 144 Chinese first graders whose reading was in a normal range showed improvement in character writing and copying after receiving orthographic and morphological structure training and compound word awareness instruction. Another study that delivered morphological training at both the character and sub-character level further suggests the effectiveness of morphological training by showing that children who received a 2-year morphological enhanced curriculum in first and second grade (6–7 years) outperformed children who received a standard curriculum in morphological awareness and various literacy measures, including vocabulary, reading fluency, pseudocharacter correction, reading comprehension, and new word interpretation (Wu et al., 2009).

There is only one Chinese study that has directly compared the effectiveness of phonological intervention and morphological intervention among typically developing children. Zhou et al. (2012) found that phonological awareness training did improve children's phonological awareness, but it was less effective in facilitating children's character recognition and vocabulary knowledge than morphological training in 88 kindergarteners in Hong Kong. There are two key differences in pedagogy and language/script between the studies conducted in Hong Kong and the current study. First, in Hong Kong, Pinyin is not used as a phonetic system, whereas in mainland China, children learn characters with the aid of Pinyin in early grades. This difference may lead to the expectation that in Hong Kong, a phonological training may be less effective for reading than it is in Mainland China, because Pinyin is actually an effective visual aid in phonological training. The second difference between Hong Kong and mainland China is the use of traditional versus simplified Chinese characters. Traditional Chinese characters, used in Hong Kong, are more complex in their visual configuration than the simplified characters used in mainland China. This difference may encourage greater emphasis on spelling and orthography

for intervention programs in Hong Kong. Moreover, the traditional Chinese characters maintain a more complete and systematic mapping between orthography and semantics; therefore, they may also benefit more from morphological intervention.

It is important to note that no morphological intervention studies to date have targeted Chinese children with RD. Moreover, the existing reading intervention studies in Chinese were mostly conducted in Hong Kong (Ho & Ma, 1999; Wang, 2017; Zhou et al., 2012), where children learn traditional Chinese characters through the look-and-say method (Wang, 2017). In mainland China, however, children learn simplified Chinese characters with the help of Pinyin; therefore, one might expect different influences of phonological training on reading when Pinyin is taught for children from mainland China than those from Hong Kong. In sum, research on reading intervention in Chinese RD is still sparse, and more research is needed to understand what phonological and morphological training can improve, respectively.

Responsiveness to reading interventions

There is variability in the responsiveness to reading intervention, and it is important for researchers and educators to understand what factors influence responsiveness to different kinds of interventions. However, few studies have addressed this issue in Chinese children with RD. Previous studies in alphabetical languages have not reached a consensus either.

Some studies suggest that children with better baseline skills show greater improvement following intervention. For example, Saine et al. (2010) found that higher pre-training phonological awareness, letter knowledge and RAN ability predicted better word-level reading fluency following intervention. Similarly, Torgesen et al. (1999) found that higher phonological naming, parents' education and occupations, and behavior rating predicted higher growth of word identification. A recent study also found that higher phonological memory in pretest predicts greater growth of reading and spelling outcomes (Uyar et al., 2023). On the other hand, children who do not respond to interventions tend to be those with low socioeconomic status (SES), poor attention, poor behavior control, or severe phonological deficits (Al Otaiba & Fuchs, 2006; Snowling & Hulme, 2011; Torgesen et al., 2001). Therefore, some researchers concluded that intervention should focus on strengths rather than weakness (Simos et al., 2002). For instance, children with poor phonological processing recognize words based on semantics or orthographic cues (Fiorello et al., 2006). In this case, the intervention should focus on children's strengths such as orthographic ability, rather than weakness (i.e. phonological ability).

However, evidence also suggests the opposite. Foorman et al. (1998) found that children with poor phonological ability before training had the most improvement in word recognition following direct instruction. There is also evidence that phonological intervention is helpful for Chinese dyslexic children with poor phonological skills (Ho & Ma, 1999; Wang, 2017). A recent study further found that lower SES and phonological awareness before the intervention predicted greater responsiveness in a phonologically-based intervention (Romeo et al., 2018). In the present study, we measured multiple home background, linguistic and cognitive skills in the

pretest in order to examine what variables predict responsiveness to different kinds of interventions.

Research aims and hypothesis

There is an on-going theoretical debate regarding the importance of phonological and morphological skills in Chinese reading acquisition and disorders. Intervention studies would help understand the roles each of them plays in Chinese reading, but no rigorous studies have examined this issue in Chinese children with RD. Therefore, our study aims to fill the gap in understanding how phonological and morphological interventions might contribute differently to reading improvement among Chinese children with RD. We expected that both types of training would be effective in improving character reading, but phonological and morphological training would have different effects on meta-linguistic skills.

We also planned to examine what variables would predict responsiveness to different interventions. We expected that low SES would predict greater responsiveness in general, because children from low SES families have limited opportunities to develop reading. With our interventions, they should show a relatively large improvement. We hypothesized that different skills may predict responsiveness to the phonological intervention and morphological intervention.

Method

This study is under a parent study investigating changes in the brain and behavior following reading intervention in Chinese children with RD. The parent study aims to understand the neural plasticity associated with specific reading interventions.

Participants

We recruited fifth-grade children in three public elementary schools in urban areas of Guangdong Province, China. Children with RD met the following three criteria: (1) scored above 80 on Raven's Standard Progressive Matrices (Raven, 1958), indicating no intellectual disability; (2) scored below 1.5 standard deviations on either a Sentence Reading Fluency test or a Character Naming test (norms of these tests were developed in previous studies; Song et al., 2015; Xue et al., 2013); (3) did not have Autism Spectrum Disorder, Attention Deficit Hyperactivity Disorder, stuttering or other psychiatric and neurological conditions. Typically developing (TD) children met the following criteria: (1) scored above 80 on Raven and (2) scored above -1 standard deviation on both the Sentence Reading Fluency test and Character Naming test. Sixty-two children with RD and 52 typical children were qualified and participated in the study. All participants were native Chinese speakers, and none of them had received reading interventions before. Parents signed written

consent before children participated in the screening tests. The IRB committee at the local university approved the current study.

After the pre-test, the 62 fifth-graders with RD (M = 11.12 years, SD = 0.45; 18 girls and 44 boys) were then randomly allocated to one of the three groups: a phonological training group (N = 22; M = 11.27 years, SD = 0.42; 5 girls and 17 boys), a morphological training group (N = 22; M = 11.05 years, SD = 0.36; 7 girls and 15 boys) and a business-as-usual group (BAU; N = 18; M = 11.04 years, SD = 0.54, 6 girls and 12 boys). The 52 age-matched TD children (M = 11.34 years, SD = 0.37; 34 girls and 18 boys) only participated in the pretest of the current study. The BAU group received intervention after the completion of the study.

Measures

The screening was conducted at the end of the school year. Chinese reading and metalinguistic skills were measured in pretest and post-test. The pretest was conducted one month before the intervention, and the post-test was conducted three months after the intervention. All test were administered face-to-face in schools. Nonverbal intelligence and cognitive skills, which do not change within a short period of time, were measured only before the intervention. Trained graduate research assistants who were blind to the treatment conditions administered the assessments.

Nonverbal intelligence

Raven's standard progressive matrices (II) (Raven, 1958) was used to assess children's nonverbal intelligence. This test was measured in a group format in the screening phase.

Chinese reading and writing

Sentence reading fluency. Participants were asked to read and judge whether sentences were true or false in meaning within 3 min. There were 100 sentences altogether, sorted from short to long in length. Each sentence described a commonsense scenario using familiar characters. For example, "太阳从西边升起" (Sun rises from the west) was a false statement, and "燕子会飞" (Sparrows can fly) was a true one. The final score was obtained by counting the number of characters in the correctly judged sentences. This test was administered in a group format in students' classroom (split-half reliability r = 0.97, Song et al., 2015; test–retest reliability r = 0.79). Test–retest reliability was assessed for each test by administering the tests to typically developing children in the parent study with 3 months apart. The Pearson correlation coefficient between pretest and post-test scores served as a measure of test–retest reliability.

Character naming: This test was used to measure character decoding accuracy. Participants were asked to name 150 Chinese characters ranging from easy to difficult without time limit. The total number of correctly recognized characters was

counted. The split-half reliability of this test was 0.97 (Song et al., 2015). This test was administered individually (test–retest reliability = 0.98).

One-minute character reading: This test was used to measure character decoding fluency. It contained two subsets: regular character naming (test–retest reliability r = 0.85) and irregular character naming (test–retest reliability r = 0.89). Regular characters are those that share the pronunciation of their phonetic radicals, including onset, rime and tone. Irregular characters are those that have different pronunciations from their phonetic radicals, for instance, 猜/cāi/ (guess). Participants were asked to read characters aloud as accurately and quickly as they could within one minute for each subset. The final scores were the number of characters correctly named. This test was administered individually.

One-minute sentence reading fluency: This test was a shortened version of the Sentence Reading Fluency assessment designed to monitor students' weekly progress. The test employed parallel forms with equivalent difficulty levels to ensure consistent measurement across administrations. During the intervention period, participants in both the PT and MT groups completed this test every Friday. The task required students to read a series of sentences and judge whether they are true or false within a one-minute time limit. The final score was obtained by counting the number of characters in the correctly judged sentences. Different materials were used in each week's test.

Meta-linguistic awareness

Phonological awareness*: Initial sound deletion* (test–retest reliability r = 0.81). Participants listened to a word first and then were instructed to delete the first consonant of the word and say the rest of the word. For example, "table" /teibl/ should be /eibl/ after deleting the initial sound. This task consisted of 30 items. *Rhyming Judgment* (test–retest reliability r = 0.56). Participants listened to a pair of pseudowords first and then judged whether they rhymed or not. This task consisted of 40 items. These two tests were administered individually, and students needed to complete all items.

Morphological awareness: *Homophonic Morpheme* (test–retest reliability r = 0.65). Participants were asked to choose the correct character among four homophones to make a compound word. For example, the participant should choose "A 慕 (/mù/ admire)" from "A慕 (/mù/ admire), B幕 (/mù/ curtain), C 暮 (/mù/ dusk), D 募 (/mù/ collect)" to fill in the blank of the compound word "羡 ()" which means envy. *Homographic morpheme* (test–retest reliability r = 0.62). Participants were asked to judge whether the same character has different meanings in different compound words. For example, participants were asked to tell whether "理 (/lǐ/)" in "道理 (/dào lǐ/ principle)" and "理会 (/lǐ huì/ pay attention to)" have the same meaning or not. These two tests were administered in a group format. Each task consisted of 30 items, and students needed to complete all items.

Cognitive tests

Working memory: *Verbal Digit Span*. This test was adapted from the Wechsler Adult Intelligence Scale version IV (Wechsler, 2008). Participants were required to

repeat the sequence of digits they just heard, forward or backward. The test stopped when a participant answered incorrectly three times in a row at a certain sequence length. The test–retest reliability for the forward digit span was 0.769 and for the backward digit spanwas 0.642.

Rapid automatized naming (RAN): *Digit Rapid Naming* (test–retest reliability r = 0.93). In this test, participants were required to name numbers printed on an A4 sheet as fast as they could. The time used to name all numbers was documented. *Picture Rapid Naming* (test–retest reliability r = 0.83). In this test, 50 pictures of everyday items were presented on an A4 sheet. The procedure was identical to number naming. These two tests were administered individually.

Intervention

The training lasted for four consecutive weeks during summer break, with a 45-min training session every day, five days a week. This dosage was chosen to strike a balance between several key factors: (1) Intervention efficacy: The daily sessions over a month-long period were intended to provide sufficient exposure and practice to effect meaningful change in reading skills. (2) Practical constraints: The 4-week duration fit within a typical school summer schedule, minimizing disruption to participants' regular academic routines. (3) Student engagement: The daily, focused sessions were designed to maintain student interest and motivation throughout the intervention period. (4) Content coverage: The chosen duration allowed us to adequately address all key components of each intervention type (phonological and morphological), ensuring comprehensive coverage of the intended material. By considering these factors, we aimed to maximize the potential impact of the intervention while ensuring its feasibility within the constraints of the educational setting.

The intervention was executed by four highly-trained graduate research assistants, each receiving two days of preparatory training. The intervention was conducted virtually using the Voov meeting platform during the COVID-19 pandemic in a classroom setting. Each classroom had around 20 students and two teachers. The lead teacher delivered lectures while a teacher assistant managed the online setting and addressed students' inquiries. At least one parent was required to sit next to the child during the intervention to ensure fidelity. Children were required to do homework after each day's training, which lasted for about 20 min, and individual feedback was provided. One-on-one and small-group supplemental instruction was provided based on students' performance in class and homework quality. A review session took place every Friday. Materials in the intervention programs were different from the testing materials. The BAU group received reading instruction after the completion of the study.

Phonological training

The phonological training included phoneme discrimination, phonological awareness, and phonetic radicals in every session. An example lesson plan is presented in Supplementary Material 1.

Phoneme discrimination: Several activities were designed for this part of training. For example, children listened to two sounds (consonants or vowels) and judged whether they were the same or not. Another activity was to listen to a sound and select it from two phonemes they heard afterward.

Phoneme manipulation: Activities included phoneme blending, segmentation, and manipulation. The phonemes selected for training were all frequent onsets and rimes in elementary Chinese language arts class. For example, in phoneme blending, children were asked to combine /ch/ and /ūn/ and then say /chūn/. In phoneme segmentation, when children were asked to delete the initial consonant of /xiàng/, they should say /iang4/. In phoneme manipulation, children were asked to switch the initial consonant of two characters. For instance, /cuì/ and /dài/ should be converted to /duì/and /cài/. We used Pinyin as a visual aid in teaching phonological awareness.

Chinese phonetic radicals and phonetic knowledge: This section was designed to explicitly teach the connection between phonology and orthography. There are regular, semiregular, and irregular characters in Chinese. Phonetic radicals provide full or partial clues to the pronunciation of the characters. Children learned two to three phonetic radical families every day. They were taught that characters sharing a phonetic radical might have similar or different pronunciations. Here are some examples of characters that share the phonetic radical "青 /qīng/ (teal)", illustrating various degrees of phonetic regularity in Chinese characters. Regular characters maintain identical pronunciation to their phonetic radical. For instance, "清/qīng/ (clear)" is pronounced exactly the same as "青". Semi-regular characters partially resemble the pronunciation of their phonetic radical. This partial similarity can manifest in three ways: they may share the same onset and rime but differ in tone, as in "晴/qíng/(sunny)"; they may share the same onset but have a different rime, as in "倩 /qiàn/ (pretty)"; or they may share the same rime but have a different onset, as in "睛/jīng/(eye)". Irregular characters, on the other hand, have pronunciations that completely diverge from their phonetic radical, as in "猜/cāi/ (guess)".

Morphological training

The morphological training included four parts in the daily session: homophones, homographs, compound word structure, and semantic radicals. An example lesson plan is presented in Supplementary Material 2.

Homophones. For instance, “晨 (morning)”, “陈 (old)“, “沉(heavy)”, and “尘 :ash)” are all pronounced /chén/. Children were taught the orthography and meaning of each character in a homophone family. Children were asked to write down more characters with the same pronunciation and to make a word using each homophone.

Homographs: One Chinese character usually conveys multiple meanings depending on which compound word it is in. In our training, first, children needed to think about whether a character has the same meaning in two different words. For example, “放 /fàng/” in “释放 /shì fàng/ (be set free)” and “存放 /cún fàng/ (store)”. Second, the trainer explained the meaning of the character in these two words. “放 /fàng/” means “let go” in “释放” and “place something somewhere” in “存放”. After that, children were asked to form new words for each meaning, for example, “放手 /fàng shǒu/(let go)” for “let go”, and “放置 /fang zhì/(put)” for “place something

somewhere". Then children were encouraged to think about all possible different meanings of this character.

Compound word structure: Children learned how compound words are composed in different ways. They first learned the rules of composing compound words and then learned to create compound words following those rules. For example, subject-predicate compounds (年 (age) 轻 (young) /nián qīng/, young), verb-object compounds (吃(eat) 饭 (meal) /chī fàn/, eat), modifier-head compounds (大(big) 海 (sea) /dà hǎi/, ocean), verb-resultative compounds (推 (push)翻 (upside down) /tuī fān/, overturn), and parallel compounds (开(on) 关(off) /kāI guān/, switch). Children had chances **to learn** all these different kinds of compound words.

Chinese semantic radicals and semantic knowledge: Children learned characters with a shared semantic radical and the overlap of their meanings. For instance, characters containing "讠" such as "读 (/dú/read), 评 (/píng/ comment), 议 (/yì/ discuss), 论 (/lùn/ argue), 谦 (/qiān/ modest), 词 (/cí/ word), 计 (/jì/ calculate)" are mostly related to speaking and verbal-related behaviors. These characters are transparent characters because their meanings are related to the semantic radical. Children were also asked to find exceptions—opaque characters – that have meanings unrelated to the semantic radical. For example, "谁 (/shuí/ who), 试 (/shì/ try)" are not related to verbal behaviors. Children were encouraged to remember the meaning of those semantic radicals and compare the radicals' meaning to the characters' meaning.

Results

Pre-intervention results

We first performed one-way ANOVAs to compare reading and cognitive abilities in the TD and the RD group before the intervention. We found that the TD group was higher than the RD groups on all behavioral tests (Table 1). Then we compared the three training groups on the tests. We found that all three groups of children with RD performed equally well on all tests, and there were no significant differences in age, parent education, and family income either. The results are presented in Table 2.

Intervention effects

Table 3 presents results on all measures in the three groups of children with RD for the pretest and post-test. To mitigate Type I error, a Multivariate Analysis of Variance (MANOVA) was conducted before univariate tests to assess the impact of group membership on post-test dependent variables. A significant effect was found ($F(14, 102) = 2.713$, Pillai's trace $= 0.54$, $p = 0.002$), suggesting that there is a statistically significant difference in the multivariate combination of the dependent variables on the post-test among the groups.

Following the significant MANOVA result, we performed an Analysis of Covariance (ANCOVA) of group on post-tests with pretest scores on the same test included

Table 1 Differences between TD and RD on pretest: independent samples *T*-Test Results

	RD			TD			*t*	*df*	*p*	Cohen's d
	M	*SD*	*N*	*M*	*SD*	*N*				
Age	11.12	0.45	62	11.35	0.37	52	− 2.89	112	0.005	− 0.54
Raven	97.74	9.08	62	113.39	11.93	52	− 7.94	112	< .001	− 1.49
Sentence reading fluency (3505)	506.87	202.94	62	1285.73	405.67	52	− 13.27	112	< .001	− 2.50
Character naming (150)	85.57	19.90	62	132.15	7.11	52	− 16.04	112	< .001	− 3.02
One-minute regular character reading (150)	37.92	17.29	61	79.44	16.46	50	− 12.86	109	< .001	− 2.45
One-minute irregular character reading (150)	20.64	11.73	61	60.67	17.09	51	− 14.64	110	< .001	− 2.78
Initial sound deletion (30)	8.67	7.72	62	23.34	7.67	52	− 10.14	112	< .001	− 1.91
Rhyming judgement (40)	28.36	4.53	62	33.40	4.55	52	− 5.91	112	< .001	− 1.11
Homographic morpheme (30)	17.66	3.32	62	25.54	2.09	52	− 14.80	112	< .001	− 2.78
Homophonic morpheme (30)	20.86	4.99	62	28.67	1.12	52	− 11.06	112	< .001	− 2.08

The number in parentheses is the maximum possible score of each test

Table 2 Participant Demographics

	PT (n = 22)		MT (n = 22)		BAU (n = 18)		One-way ANOVA		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2_p
Age	11.27	0.42	11.04	0.36	11.04	0.54	1.96	0.15	0.06
Raven	98.23	9.45	96.55	9.89	98.61	7.84	0.30	0.743	0.01
Years of education (Father)	10.23	3.68	10.23	3.02	10.89	3.20	0.25	0.777	0.01
Years of education (Mother)	10.09	2.96	9.41	3.11	10.33	2.35	0.58	0.563	0.02
Family annual income (10,000 RMB)	13.05	5.63	14.95	10.28	13.03	9.98	0.33	0.719	0.01

PT = phonological traing; MT = morphological training; BAU = business as usual

as a covariate for each measurement. The results are presented in Table 3. We found significant group differences in four tests, namely, sentence reading fluency ($F = 4.05$, $\eta^2_p = 0.12$, $p = 0.023$), character naming ($F = 7.11$, $\eta^2_p = 0.20$, $p = 0.002$), one-minute irregular character reading ($F = 6.25$, $\eta^2_p = 0.18$, $p = 0.004$) and initial sound deletion ($F = 10.55$, $\eta^2_p = 0.27$, $p < 0.001$). For these four tests, both the phonological training and the morphological training groups outperformed the BAU group, while the two training groups did not have a significant difference. However, neither intervention group outperformed BAU in pseudoeword rhyming or morphological awareness tasks. Figure 1 presents the results of the three groups on these four tests (Fig. 2).

Progress monitoring

Students in both the PT and MT groups were administered alternate forms of the One-minute sentence reading fluency test weekly for four weeks to track their progress. As shown in Table 4 and Fig. 3, both groups started and ended at similar levels and they showed improvement over the four-week period. A 2 X 4 repeated measure ANOVA (Intervention group X Time) revealed a significant time effect ($F(3, 149) = 5.63$, $p = 0.001$) but no significant intervention group effect or interaction. Post hoc analysis using Tukey's HSD showed that Week 3 had a higher score than Week 1 ($p = 0.02$) among the PT group, while other pairwise comparisons were not significant.

Responsiveness to intervention

The responsiveness to intervention in the present study was defined as the change in scores on sentence reading fluency and character naming from the pretest to the post-test because these two tests are our standard of reading ability. We examined whether SES or pretraining skills could predict responsiveness. We conducted partial correlation analyses for each group separately (Table 5).

We calculated partial correlations between parental education (i.e. father's and mother's education separately) and the change scores for the sentence reading fluency and the character naming tests, while controlling for family income and

Table 3 Mean, standard deviation of the three groups in Pre- and Post test and the ANCOVA results on the change score

		PT		MT		BAU		ANCOVA				
		M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η^2_p	*p*	Post Hoc	Power
Sentence reading fluency (3505)	pre	534.5	193.75	531.23	238.24	443.33	158.96					
	post	879.32	212.88	884.91	274.02	670.83	226.42	4.05	0.12	.023	PT > BAU, MT > BAU	0.72
Character naming (150)	pre	89.41	16.39	85	21.63	81.56	21.79					
	post	107.73	12.75	103.57	24.08	90.28	21.28	7.11	0.2	.002	PT > BAU, MT > BAU	0.94
One-minute regular character reading (150)	pre	40.64	16.68	40.05	18.42	32.11	16.16					
	post	61	14.68	55.68	22.45	47	19.73	1.81	0.06	.173		0.39
One-minute irregular character reading (150)	pre	21.86	12.11	20.67	9.69	19.11	13.75					
	post	32.86	10.8	33.32	15.15	23.22	13.77	6.25	0.18	.004	PT > BAU, MT > BAU	0.91
Initial sound deletion (30)	pre	9.96	8.03	6.64	6.89	9.58	8.18					
	post	20.25	7.87	20.64	6.34	13.58	7.14	10.55	0.27	< .001	PT > BAU, MT > BAU	0.99
Rhyming judgement (40)	pre	28.09	5.13	27.82	3.96	29.33	4.52					
	post	32.36	4.32	30.55	5.76	30.28	4.40	1.30	0.04	.279		0.35
Homographic morpheme (30)	pre	18.27	4.11	17	3.07	17.72	2.47					
	post	20.91	2.37	19.77	3.01	20.67	2.25	0.96	0.03	.389		0.21
Homophonic morpheme (30)	pre	22.05	3.57	19.18	5.91	21.44	4.97					
	post	24.68	2.21	23.5	3.67	24.17	3.59	0.14	0.01	.867		0.10
WM (forward digit span)	pre	7.68	1.52	6.82	1.01	7.44	1.2					
WM (backward digit span)	pre	3.27	1.2	3.41	1.14	3.56	1.15					
RAN (digits) (Response time in seconds)	pre	43.45	9.83	44.92	10.67	46.21	10.42					
RAN (pictures) (Response time in seconds)	pre	60.08	15.84	65.5	19.83	71.39	17.99					

PT = phonological traing; MT = morphological training; BAU = business as usual; WM = working memory; RAN = rapid automatized naming; The number in parentheses is the maximum possible score of each test; A post hoc power analysis was conducted using G*Power to determine the achieved power of our ANCOVA tests

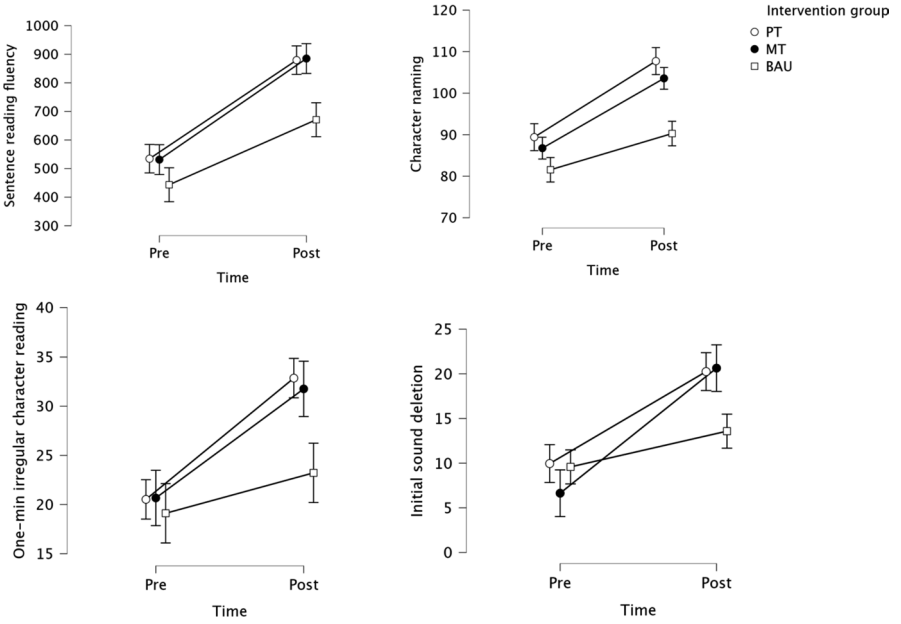

Fig. 1 Line charts showing performance in each group of participants at the pretest and posttest, for sentence reading fluency, character naming, one- minute irregular character reading, and initial sound deletion

RAVEN scores. We found a significant negative correlation between mother's education and change score on the sentence reading fluency test (Pearson's r = -0.475, p = 0.034) in the phonological training group. This correlation was not significant in the MT (Pearson's r = 0.126, $p > 0.05$) or BAU groups (Pearson's r = 0.21, $p > 0.05$). Fisher's z-transformation was used to determine if two correlation coefficients were significantly different from each other. The results showed that the correlation coefficient in the PT group was significantly different from that in the MT group (z = 1.983, $p = 0.047$) and the BAU group (z = − 2.064, $p = 0.039$).

Furthermore, the correlation between metalinguistic/cognitive skills at the pretest and changes on the two reading tests was calculated within each group. In the phonological training group, a negative correlation was found between the pretest score of the initial sound deletion test and the change score of the character naming test (Pearson's r = -0.566, $p = 0.009$), indicating that children with lower phonological awareness at the baseline were more responsive to the phonological training. There was no such relationship in the MT (Pearson's r = 0.024, $p > 0.05$) or BAU group (Pearson's r =—0.009, $p > 0.05$). By comparing the correlation coefficients among the groups, we found that the coefficient of the PT group was significantly different from that of the MT group (z = − 2.052, $p = 0.040$) but not the BAU group (z = − 1.84, $p = 0.066$). In the MT group, a negative correlation was found between the pretest response time on the picture RAN and the change score of the character naming test (Pearson's r = − 0.455, $p = 0.038$), indicating that children with better RAN skills were more responsive to the morphological

A. Negative Correlation Between Initial Sound Deletion and Improvement on Character Naming in the Phonological Training Group. B. Negative Correlation Between Maternal Education and Improvement on Sentence Reading Fluency in the Phonological Training Group. C. Negative Correlation Between Response Time in the RAN Test and Improvement on Character Naming in the Morphological Training Group.

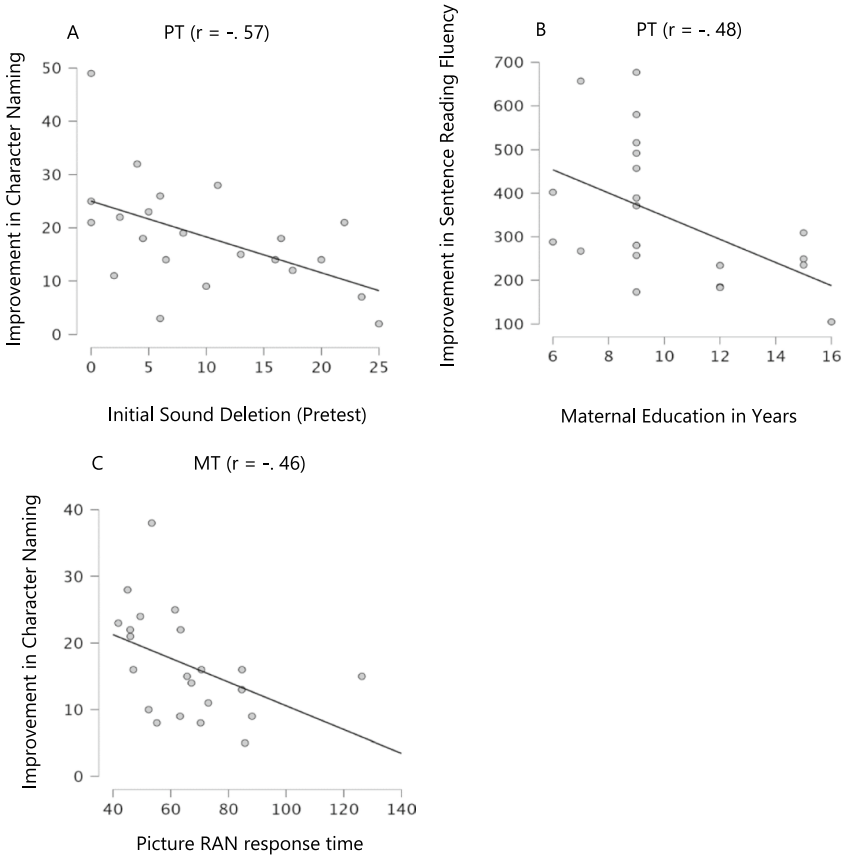

Fig. 2 Scatterplots of significant correlations suggesting predictions of responsiveness A. negative correlation between initial sound deletion and improvement on character naming in the phonological training Group. B. Negative correlation between maternal education and improvement on sentence reading fluency in the phonological training Group. C. Negative correlation between response time in the RAN test and improvement on character naming in the morphological training Group

intervention. There was no such relationship in the PT (Pearson's $r = -0.128$, $p > 0.05$) or the BAU group (Pearson's $r = 0.11$, $p > 0.05$). However, the comparison among the three groups showed that the correlation coefficients were not different from one another. Additionally, we found no correlations between any pretest measures or parent education and the change scores of reading measures in the BAU group.

The Benjamini–Hochberg method (Benjamini & Hochberg, 1995) was employed to control the false discovery rate. After this correction, only the

Table 4 Mean, standard deviation, and *T*-test results on the one-minute sentence Reading fluency test during intervnetion for the PT and MT Group

	Week 1			Week 2			Week 3			Week 4		
	M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
PT	194.24	110.59	21	284.71	152.95	21	346.25	150.49	20	252.14	154.54	21
MT	204.37	137.44	19	213.75	118.82	20	313.6	156.19	15	250.8	154.32	20
Repeated measure ANOVA												
Week	F (3, 149) = 5.63, $p = .001$											
Intervention group	F (1, 149) = 1.00, $p = .32$											
Interaction: Week X Intervention group	F (3, 149) = .69, $p = .56$											

PT = phonological traing; MT = morphological training

Trajectory of Phonological Training Group (PT) and Morphological Training Group (MT) from Week 1 to Week 4 on a one-minute senence reading fluency test

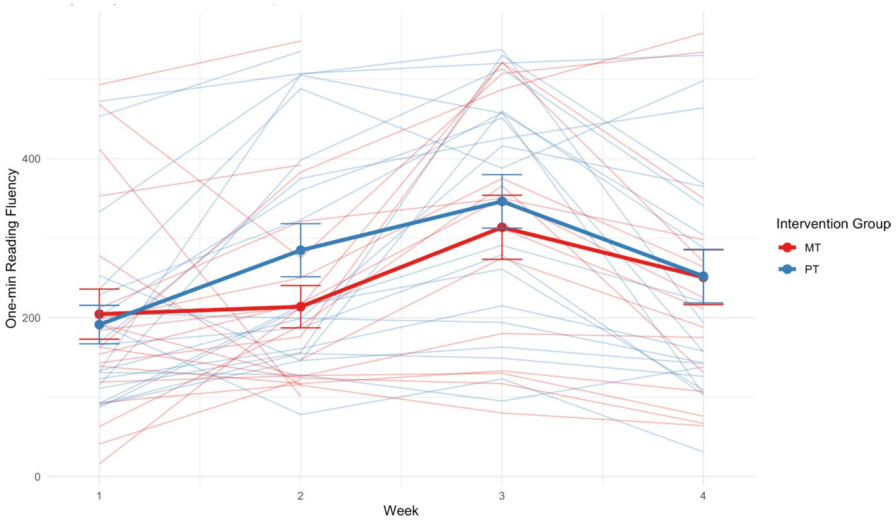

Fig. 3 Trajectory of phonological training group (PT) and morphological training group (MT) from Week 1 to Week 4 on a one-minute senence reading fluency test

correlation between initial sound deletion and character naming in the PT group remained statistically significant.

Discussion

In this study, we directly compared the effectiveness of phonological training and morphological training in Chinese children with RD, and examined what variables predict responsiveness. Our findings suggest that both types of training are effective in improving sentence reading fluency, character naming, one-minute irregular character reading, and initial sound deletion in the three-month post-test. No significant differences were found in the effectiveness of the two types of training. Moreover, we found that maternal education and initial phonological awareness negatively predicted responsiveness to phonological intervention, and initial RAN ability positively predicted responsiveness to morphological intervention. These findings shed new light on the nuanced relationship between SES variables, cognitive abilities, and intervention outcomes in Chinese RD.

The effectiveness of the phonological training

Our phonological training included both phonological awareness training and phonetic radical training. Children were trained to discriminate similar phonemes

Table 5 Partial correlations between meta-cognitive skills and changes in sentence reading fluency and character naming, controlling for family income and Raven's progressive matrices

	PT		MT		BAU	
	sentence reading fluency	Character naming	sentence reading fluency	Character naming	sentence reading fluency	Character naming
Father education	-0.39	−0.21	0.23	−0.20	0.01	0.27
Mother education	−0.475*	−0.30	0.13	−0.34	0.21	0.25
Initial sound deletion	−0.17	−0.566**	0.02	0.02	−0.44	0.01
Homographic morpheme	0.20	−0.04	0.19	−0.26	0.13	−0.13
Homophonic morpheme	−0.40	−0.07	0.23	0.12	0.34	−0.08
Rhyming judgement	−0.12	0.19	0.15	0.15	0.04	−0.08
WM (forward digit span)	0.11	−0.16	0.10	0.44	−0.25	−0.25
WM (backward digit span)	0.00	0.04	0.31	−0.10	−0.31	−0.10
RAN (digits)	−0.09	−0.06	−0.17	−0.25	0.18	−0.23
RAN (pictures)	−0.27	−0.15	−0.25	−0.457*	−0.20	−0.09

PT = phonological traing; MT = morphological training; BAU = business as usual; WM = working memory; RAN = rapid automatized naming

Critical p-value after Benjamini–Hochberg correction for false discovery rate control: $p = 0.009$

** significant after false disvovery rate control

* significant before false disvovery rate control, but not after

and to combine phonemes or break up syllables for the phonological awareness training. Accurate phonological representation at the phoneme level is vital for readers to decode words (Snowling, 1998). Even though there is no grapheme-phoneme-correspondence in Chinese reading, a more accurate and elaborated phonological representation also facilitates the mapping between print and sound, as suggested in a previous study (McBride-Chang et al., 2004). In the current study, children who received phonological training showed improvement in phonological awareness and reading.

It is worth mentioning that Pinyin was incorporated as a visual aid in our phonological awareness training, potentially supporting children's understanding of phoneme-level tasks. Pinyin is taught in the first two years of elementary school in Mainland China. Still, some children with RD in our study could barely use Pinyin at the beginning of the intervention according to our observation, although they were already in 5th grade. After they learned to use the Pinyin system as an aid to complete phoneme blending or segmentation tasks during our phonological intervention, they performed much better in the initial sound deletion task in the post-test. This is consistent with the previous finding that children who learn to read through the Pinyin system perform better in phonological awareness tasks than those who do not learn Pinyin (Huang & Hanley, 1995). It is also consistent with findings from English studies that when reading instruction starts, it also facilitates the development of phonological awareness (Duff et al., 2014), suggesting a reciprocal relationship between reading and phonological awareness. However, while we hypothesize that Pinyin might facilitate students' phonological awareness development, we did not include a Pinyin measure in the current study to isolate its specific effects. This statement was based on our observations during the intervention and theoretical considerations. Future studies could investigate the role of Pinyin in phonological awareness training for Chinese children with RD.

In addition to the phonological awareness training, we also provided explicit instruction on mapping characters with sounds using phonetic radicals. We did this by teaching phonetic radicals and explaining how they are related to the pronunciation of characters, highlighting both similarities and differences. Therefore, the improvement in character naming, one-minute irregular character reading, and sentence reading fluency might be due to the training on phonetic radicals. A previous phonological training study yielded better performance in regular character reading than irregular character reading (Ho & Ma, 1999). In our study, we emphasized the orthography regularity and both regular and irregular phonetic radicals during our training, and therefore, irregular character reading showed a significant improvement in our study.

We did not observe a significant effect in the pseudo-word rhyming judgment task, which may be attributed to the low reliability of this measure in our sample. The possible reason for low reliability in the pseudoword rhyming judgment task may be because participants's unfamiliarity with the stimuli, potentially leading to a high rate of guessing. Future studies may consider changing the stimuli to Chinese words/pseudo-words.

The effectiveness of the morphological training

During the morphological training, children learned the function of semantic radicals in Chinese characters, and thus, they developed a deeper understanding of the orthographic structure of characters (Tong et al., 2009). Homophonic and homographic morpheme training help to strengthen the whole word reading pathway, including a direct connection between orthography and semantics. These types of training are helpful in improving character naming, especially irregular character reading, because irregular character decoding relies more on the lexical pathway for the whole character mapping to sound and meaning (Coltheart & Rastle, 1994) while regular character naming relies more on the sub-lexical (phonetic radical) processing (Yang et al., 2009). Regarding the differential improvement in irregular versus regular character reading, we propose that this may be due to the complex nature of irregular characters and the design of our intervention. Irregular characters, by definition, have pronunciations that cannot be directly derived from their phonetic radicals. This complexity may make them more susceptible to explicit instruction (Conway, 2020; Tong et al., 2023). Our intervention emphasized both regular and irregular radicals, potentially providing more benefit to the more challenging irregular characters. Furthermore, the compound word structure training helps with word comprehension, which facilitates sentence reading fluency. Improvement on character naming also generalizes to sentence reading fluency (Shinn et al., 1992).

We found that morphological training also improved phonological awareness. This is consistent with a previous study that found that homophone training can significantly improve phonological awareness in typically developing children (Zhou et al., 2012). The homophone training in Zhou et al. (2012) is actually the same as our homophonic morpheme training in the current study. We speculate that morphological training increased the quality of representations of morphemes, including orthographic, phonological, and semantic representations (Zhou & Marslen-Wilson, 1994). Therefore, a high-quality representation of a morpheme, including phonological representation, in turn, improves phonological awareness.

However, the morphological training did not significantly improve awareness of homographic and homophonic morphemes compared to the other two groups. We speculate that this may be due to the limited duration of the intervention or the need for more targeted training specifically focused on these aspects of morphological awareness. In addition, the tools used to assess morphological awareness might not have been sensitive enough to detect subtle improvements, or the assessments might not have aligned well with the training content.

Taken together, phonological training and morphological training had a similar effect in promoting reading in the current study, probably because in Chinese, each character is an integration of orthography, phonology and semantics (Zhou & Marslen-Wilson, 1999), and learning one representation actually improves all three together.

Responsiveness to intervention

In the present study, within children who received the phonological training, those with lower phonological ability showed greater improvement. Children who had poorer phonological awareness initially had more room to improve in phonological awareness (Pfost et al., 2019). When phonological ability is improved, it facilitates word decoding (Hulme et al., 2012). This finding provides important insights for developing individualized interventions: when children with RD have low phonological ability, phonological intervention is more effective in improving phonological skills and enhancing word reading ability. This is consistent with a previous study which found that children with phonological problems improved more if they received phonological training than orthographic training, and that children with orthographic problems benefited more from orthographic training than phonological training (Gustafson et al., 2007), suggesting that reading intervention should focus on the weakness of each individual. This finding is also consistent with a recent study that showed greater responsiveness to a phonologically-based intervention in children with lower phonological awareness before the intervention (Romeo et al., 2018).

Despite our study supporting the "training the weak skills" model, we believe that weakness-based and strength-based interventions should not be mutually exclusive. Their efficacy may vary depending on the stage of intervention and students' characteristics. Our participants had never received any intervention before this study, therefore, they tended to benefit from explicit training targeting their areas of weakness. However, for individuals with extensive intervention experience, strength-based interventions might be more beneficial (Gustafson et al., 2007). The severity of skill deficits is another crucial factor to consider. For instance, children with severe phonological deficits may not respond effectively to phonological training at all (Al Otaiba & Fuchs, 2006), but might instead benefit from strength-based training (Gustafson et al., 2007; O'Brien et al., 2011). Conversely, children with milder phonological deficits typically show improvement with explicit training on phonological skills.

Our findings also underscore the impact of maternal education on intervention outcomes within the phonological training group. The significant negative correlation observed between maternal education and sentence reading fluency improvement with family income regressed out, suggests that children with mothers having lower educational levels exhibit a greater responsiveness to the phonological intervention. A previous study has found that the heritability of RD is lower in children from low SES families than high SES families (Friend et al., 2008), suggesting that environment modulates how genetics impact RD. When the environment is optimal in high SES families, RD is mostly determined by genetics, whereas the unideal environment in low SES families hinders reading development, and children develop RD even without genetic risks. Our finding further suggests that the negative impact of low SES on reading can be mediated by intervention, and it is especially essential for these children to receive phonological intervention, presumably because phonological skills are more affected by the unideal home environment than morphological skills.

For the morphological training, we observed a positive correlation between picture RAN performance before the intervention and improved character naming. However, the correlation did not persist after controlling for false discovery rate. Therefore, we offer only a preliminary explanation here, and readers should interpret these findings with caution. This potential relationship could be explained by several factors: First, picture RAN shares some commonality with Chinese character naming: the rapid mapping of a whole visual stimulus (picture or character) to a whole syllable. Our morphological training placed an emphasis on developing whole word reading ability. Consequently, we observed that children with better RAN skills benefited more from this training approach. Second, RAN tasks measure the automaticity of phonological retrieval. Greater automaticity in phonological retrieval may indicate greater connection between semantics and phonology, which is essential in morphological training. The aim of the morphological training is to estabilish stronger connections between orthography, phonology, and semantics. Therefore, children with strong RAN skills may have advantages in quickly associating morphemes with their meanings and pronunciations.

Education implications

An important aspect of the reading intervention programs in the current study lies in their explicit instructions on phonological and morphological knowledge in Chinese characters and sub-characters. Therefore, our training programs can be seamlessly integrated into the curriculum, facilitating a holistic approach to character reading during regular classroom instruction. Teachers can also incorporate these training programs as supplementary after-school tutorials for students encountering challenges in decoding. The flexibility of these programs allows for personalized instruction, which can be delivered either through one-on-one sessions or in small group settings. Future reading interventions should consider combining the phonological training and morphological training since we found them both to be effective.

Limitation and future directions

Our study employed an online intervention mode during the Covid-19 pandemic when schools in China were temporarily closed. It is important to acknowledge that the relatively modest effects observed on most measures could be attributed to the online format and the relatively short duration of the intervention. Research has suggested that small-group, in-person tutorials may yield more substantial and immediate effects (Slavin et al., 2011). Therefore, while our findings offer valuable insights, it is essential to recognize that the choice of an online platform and the abbreviated intervention timeframe may have influenced the outcomes observed. Future research should explore the effect of face-to-face interventions.

Another limitation of our study is the relatively small sample size, which precluded the execution of more complex statistical modeling aimed at predicting responsiveness. Consequently, future research should aim to address these limitations through the implementation of a larger-scale randomized controlled trial. The

expanded sample size would allow for advanced statistical techniques to enhance our understanding of the factors influencing responsiveness and offer more insights into the effectiveness of different interventions.

In addition, the present study reveals the efficacy of both interventions in enhancing character recognition ability among fifth-grade children with RD. Given the distinctive roles that phonological awareness and morphological awareness play in the context of Chinese reading development, future research should investigate whether the two interventions have distinct effectiveness in younger or older children.

Conclusions

Our study demonstrated the effectiveness of both a phonological and a morphological intervention for Chinese children with RD, with both interventions being equally effective in improving phonological awareness, sentence reading fluency, character naming, and one-minute irregular character naming. The correlation results underscore the importance of providing timely phonological intervention to children with lower SES and lower phonological ability. In contrast, morphological intervention seems to be more beneficial to children with better RAN skills. Our study suggested that even though the two interventions had similar effectiveness, they may have different mechanisms and paths to promote reading.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11145-024-10623-7.

Acknowledgements This research was supported by Science and Technology Program of Guangzhou, China, Key Area Research and Development Program (202007030011).

Funding Science and Technology Program of Guangzhou, China, Key Area Research and Development Program, 202007030011, Fan Cao.

Declarations

Conflict of interest The authors report that there are no conflicts of interest.

References

Al Otaiba, S., & Fuchs, D. (2006). Who are the young children for whom best practices in reading are ineffective?: An experimental and longitudinal study. *Journal of Learning Disabilities, 39*(5), 414–431. https://doi.org/10.1177/00222194060390050401

Anthony, J. L., & Francis, D. J. (2005). Development of phonological awareness. *Current Directions in Psychological Science, 14*(5), 255–259. https://doi.org/10.1111/j.0963-7214.2005.00376.x

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological), 57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Carlisle, J. F. (2010). Effects of instruction in morphological awareness on literacy achievement: An integrative review. *Reading Research Quarterly, 45*(4), 464–487.

Carroll, J. M., Solity, J., & Shapiro, L. R. (2016). Predicting dyslexia using prereading skills: The role of sensorimotor and cognitive abilities. *Journal of Child Psychology and Psychiatry, 57*(6), 750–758. https://doi.org/10.1111/jcpp.12488

Castles, A., & Friedmann, N. (2014). Developmental dyslexia and the phonological deficit hypothesis. *Mind & Language, 29*(3), 270–285. https://doi.org/10.1111/mila.12050

Cheng, C., Yao, Y., Wang, Z., & Zhao, J. (2021). Visual attention span and phonological skills in Chinese developmental dyslexia. *Research in Developmental Disabilities, 116*, 104015. https://doi.org/10.1016/j.ridd.2021.104015

Cheng, Y., Zhang, J., Wu, X., Liu, H., & Li, H. (2016). Cross-lagged relationships between morphological awareness and reading comprehension among Chinese children. *Frontiers in Psychology, 7*, 1379.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*(6), 1197.

Conway, C. M. (2020). How does the brain learn environmental structure? Ten core principles for understanding the neurocognitive mechanisms of statistical learning. *Neuroscience & Biobehavioral Reviews, 112*, 279–299. https://doi.org/10.1016/j.neubiorev.2020.01.032

Duff, F. J., Hulme, C., Grainger, K., Hardwick, S. J., Miles, J. N. V., & Snowling, M. J. (2014). Reading and language intervention for children at risk of dyslexia: A randomized controlled trial. *Journal of Child Psychology and Psychiatry, 55*(11), 1234–1243. https://doi.org/10.1111/jcpp.12257

Fiorello, C. A., Hale, J. B., & Snyder, L. E. (2006). Cognitive hypothesis testing and response to intervention for children with reading problems. *Psychology in the Schools, 43*(8), 835–853. https://doi.org/10.1002/pits.20192

Foorman, B. R., Francis, D. J., Fletcher, J. M., Schatschneider, C., & Mehta, P. (1998). The role of instruction in learning to read: Preventing reading failure in at-risk children. *Journal of Educational Psychology, 90*(1), 37–55. https://doi.org/10.1037/0022-0663.90.1.37

Friend, A., DeFries, J. C., & Olson, R. K. (2008). Parental education moderates genetic influences on reading disability. *Psychological Science, 19*(11), 1124–1130. https://doi.org/10.1111/j.1467-9280.2008.02213.x

Goodwin, A. P., & Ahn, S. (2010). A meta-analysis of morphological interventions: Effects on literacy achievement of children with literacy difficulties. *Annals of Dyslexia, 60*(2), 183–208. https://doi.org/10.1007/s11881-010-0041-x

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia, 6*(2), 133–151.

Gustafson, S., Ferreira, J., & Rönnberg, J. (2007). Phonological or orthographic training for children with phonological or orthographic decoding deficits. *Dyslexia, 13*(3), 211–229.

Ho, C.S.-H., Chan, D. W., Tsang, S.-M., Lee, S.-H., & Chung, K. K. H. (2006). Word learning deficit among Chinese dyslexic children. *Journal of Child Language, 33*(1), 145–161. https://doi.org/10.1017/s0305000905007154

Ho, C.S.-H., Law, T.P.-S., & Ng, P. M. (2000). The phonological deficit hypothesis in Chinese developmental dyslexia. *Reading and Writing, 13*(1), 57–79.

Ho, C. S., & Ma, R. N. (1999). Training in phonological strategies improves Chinese dyslexic children's character reading skills. *Journal of Research in Reading, 22*(2), 131–142.

Huang, H. S., & Hanley, J. R. (1995). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition, 54*(1), 73–98. https://doi.org/10.1016/0010-0277(94)00641-W

Hulme, C., Bowyer-Crane, C., Carroll, J. M., Duff, F. J., & Snowling, M. J. (2012). The causal role of phoneme awareness and letter-sound knowledge in learning to read: Combining intervention studies with mediation analyses. *Psychological Science, 23*(6), 572–577.

Li, W.-S., & Ho, C.S.-H. (2011). Lexical tone awareness among Chinese children with developmental dyslexia. *Journal of Child Language, 38*(4), 793–808.

Li, Y., Chen, X., Li, H., Sheng, X., Chen, L., Richardson, U., & Lyytinen, H. (2020). A computer-based Pinyin intervention for disadvantaged children in China: Effects on Pinyin skills, phonological awareness, and character reading. *Dyslexia, 26*(4), 377–393. https://doi.org/10.1002/dys.1654

Li, Y., Hui, Y., Li, H., & Liu, X. (2022). The use of phonological and semantic strategies in written word learning among Chinese children with dyslexia. *Journal of Learning Disabilities, 55*(6), 482–498. https://doi.org/10.1177/00222194221077685

Lin, D., Sun, H., & McBride, C. (2019). Morphological awareness predicts the growth rate of Chinese character reading. *Developmental Science, 22*(4), e12793. https://doi.org/10.1111/desc.12793

Lin, Y., Lin, Y.-J., Wang, F., Wu, X., & Kong, J. (2020). The development of phonological awareness and Pinyin knowledge in Mandarin-speaking school-aged children. *International Journal of Speech-Language Pathology, 22*(6), 660–668. https://doi.org/10.1080/17549507.2020.1819417

Liu, P. D., McBride-Chang, C., Wong, T.T.-Y., Shu, H., & Wong, A.M.-Y. (2013). Morphological awareness in Chinese: Unique associations of homophone awareness and lexical compounding to word reading and vocabulary knowledge in Chinese children. *Applied Psycholinguistics, 34*(4), 755–775.

Lovett, M. W., Borden, S. L., DeLuca, T., Lacerenza, L., Benson, N. J., & Brackstone, D. (1994). Treating the core deficits of developmental dyslexia: Evidence of transfer of learning after phonologically- and strategy-based reading training programs. *Developmental Psychology, 30*(6), 805–822. https://doi.org/10.1037/0012-1649.30.6.805

Lovett, M. W., Steinbach, K. A., & Frijters, J. C. (2000). Remediating the core deficits of developmental reading disability: A double-deficit perspective. *Journal of Learning Disabilities, 33*(4), 334–358.

McBride, C., Wang, Y., & Cheang, L.M.-L. (2018). Dyslexia in Chinese. *Current Developmental Disorders Reports, 5*(4), 217–225.

McBride-Chang, C., Bialystok, E., Chong, K. K. Y., & Li, Y. (2004). Levels of phonological awareness in three cultures. *Journal of Experimental Child Psychology, 89*(2), 93–111. https://doi.org/10.1016/j.jecp.2004.05.001

McBride-Chang, C., Cheung, H., Chow, B.W.-Y., Chow, C.S.-L., & Choi, L. (2006). Metalinguistic skills and vocabulary knowledge in Chinese (L1) and English (L2). *Reading and Writing, 19*(7), 695–716. https://doi.org/10.1007/s11145-005-5742-x

McBride-Chang, C., Tardif, T., Cho, J.-R., Shu, H., Fletcher, P., Stokes, S. F., Wong, A., & Leung, K. (2008). What's in a word? Morphological awareness and vocabulary knowledge in three languages. *Applied Psycholinguistics, 29*(3), 437–462.

O'Brien, B. A., Wolf, M., Miller, L. T., Lovett, M. W., & Morris, R. (2011). Orthographic processing efficiency in developmental dyslexia: An investigation of age and treatment factors at the sublexical level. *Annals of Dyslexia, 61*(1), 111–135. https://doi.org/10.1007/s11881-010-0050-9

O'Shaughnessy, T. E., & Lee Swanson, H. (2000). A comparison of two reading interventions for children with reading disabilities. *Journal of Learning Disabilities, 33*(3), 257–277. https://doi.org/10.1177/002221940003300304

Packard, J. L., Chen, X., Li, W., Wu, X., Gaffney, J. S., Li, H., & Anderson, R. C. (2006). Explicit instruction in orthographic structure and word morphology helps Chinese children learn to write characters. *Reading and Writing, 19*(5), 457–487.

Pan, J., Song, S., Su, M., McBride, C., Liu, H., Zhang, Y., Li, H., & Shu, H. (2016). On the relationship between phonological awareness, morphological awareness and Chinese literacy skills: Evidence from an 8-year longitudinal study. *Developmental Science, 19*(6), 982–991.

Peng, P., Wang, C., Tao, S., & Sun, C. (2017). The deficit profiles of Chinese children with reading difficulties: A meta-analysis. *Educational Psychology Review, 29*(3), 513–564.

Pennington, B. F., Santerre-Lemmon, L., Rosenberg, J., MacDonald, B., Boada, R., Friend, A., Leopold, D., Samuelsson, S., Byrne, B., Willcutt, E. G., & Olson, R. K. (2012). Individual prediction of dyslexia by single vs multiple deficit models. *Journal of Abnormal Psychology, 121*(1), 212–224.

Pfost, M., Blatter, K., Artelt, C., Stanat, P., & Schneider, W. (2019). Effects of training phonological awareness on children's reading skills. *Journal of Applied Developmental Psychology, 65*, 101067.

Ping, R., Fen, X., & Ruiping, Z. (2006). Effects of Pinyin learning on development of phonological awareness in kindergarten. *Acta Psychologica Sinica, 38*(1), 41–46.

Raven, J. C. (1958). Guide to using the coloured progressive matrices.

Romeo, R. R., Christodoulou, J. A., Halverson, K. K., Murtagh, J., Cyr, A. B., Schimmel, C., Chang, P., Hook, P. E., & Gabrieli, J. D. E. (2018). Socioeconomic status and reading disability: Neuroanatomy and plasticity in response to intervention. *Cerebral Cortex, 28*(7), 2297–2312. https://doi.org/10.1093/cercor/bhx131

Ruan, Y., Georgiou, G. K., Song, S., Li, Y., & Shu, H. (2018). Does writing system influence the associations between phonological awareness, morphological awareness, and reading? *A Meta-Analysis. Journal of Educational Psychology, 110*(2), 180–202. https://doi.org/10.1037/edu0000216

Saine, N. L., Lerkkanen, M. K., Ahonen, T., Tolvanen, A., & Lyytinen, H. (2010). Predicting word-level reading fluency outcomes in three contrastive groups: Remedial and computer-assisted remedial reading intervention, and mainstream instruction. *Learning and Individual Differences, 20*(5), 402–414. https://doi.org/10.1016/j.lindif.2010.06.004

Schuele, C. M., & Boudreau, D. (2008). Phonological awareness intervention: Beyond the basics. *Language, Speech, and Hearing Services in Schools, 39*(1), 3–20.

Shinn, M. R., Knutson, N., Good, R. H., Tilly, W. D., & Collins, V. L. (1992). Curriculum-based measurement of oral reading fluency: A confirmatory analysis of its relation to reading. *School Psychology Review, 21*(3), 459–479. https://doi.org/10.1080/02796015.1992.12085629

Shu, H., Chen, X., Anderson, R. C., Wu, N., & Xuan, Y. (2003). Properties of school Chinese: Implications for learning to read. *Child Development, 74*(1), 27–47.

Shu, H., McBride-Chang, C., Wu, S., & Liu, H. (2006). Understanding Chinese developmental dyslexia: Morphological awareness as a core cognitive construct. *Journal of Educational Psychology, 98*(1), 122–133.

Shu, H., Peng, H., & McBride-Chang, C. (2008). Phonological awareness in young Chinese children. *Developmental Science, 11*(1), 171–181.

Simos, P. G., Fletcher, J. M., Bergman, E., Breier, J. I., Foorman, B. R., Castillo, E. M., Davis, R. N., Fitzgerald, M., & Papanicolaou, A. C. (2002). Dyslexia-specific brain activation profile becomes normal following successful remedial training. *Neurology, 58*(8), 1203–1213. https://doi.org/10.1212/WNL.58.8.1203

Slavin, R. E., Lake, C., Davis, S., & Madden, N. A. (2011). Effective programs for struggling readers: A best-evidence synthesis. *Educational Research Review, 6*(1), 1–26.

Snowling, M. (1998). Dyslexia as a phonological deficit: Evidence and implications. *Child and Adolescent Mental Health, 3*(1), 4–11. https://doi.org/10.1111/1475-3588.00201

Snowling, M. J., & Hulme, C. (2011). Evidence-based interventions for reading and language difficulties: Creating a virtuous circle. *British Journal of Educational Psychology, 81*(1), 1–23. https://doi.org/10.1111/j.2044-8279.2010.02014.x

Snowling, M. J., & Hulme, C. (2012). Interventions for children's language and literacy difficulties. *International Journal of Language & Communication Disorders, 47*(1), 27–34.

Song, S., Su, M., Kang, C., Liu, H., Zhang, Y., McBride-Chang, C., Tardif, T., Li, H., Liang, W., & Zhang, Z. (2015). Tracing children's vocabulary development from preschool through the school-age years: An 8-year longitudinal study. *Developmental Science, 18*(1), 119–131. https://doi.org/10.1111/desc.12190

Suggate, S. P. (2016). A meta-analysis of the long-term effects of phonemic awareness, phonics, fluency, and reading comprehension interventions. *Journal of Learning Disabilities, 49*(1), 77–96. https://doi.org/10.1177/0022219414528540

Taft, M., & Zhu, X. (1995). The representation of bound morphemes in the lexicon: A Chinese study. *Morphological Aspects of Language Processing*, 293–316.

Tong, X., McBride, C., Lo, J. C. M., & Shu, H. (2017). A three-year longitudinal study of reading and spelling difficulty in Chinese developmental dyslexia: The matter of morphological awareness. *Dyslexia, 23*(4), 372–386.

Tong, X., McBride-Chang, C., Shu, H., & Wong, A.M.-Y. (2009). Morphological awareness, orthographic knowledge, and spelling errors: Keys to understanding early Chinese literacy acquisition. *Scientific Studies of Reading, 13*(5), 426–452.

Tong, S.X., Duan, R., Shen, W., Yu, Y., & Tong, X. (2023). Multiple mechanisms regulate statistical learning of orthographic regularities in school-age children: Neurophysiological evidence. *Dev Cogn Neurosci. 59*, 101190. https://doi.org/10.1016/j.dcn.2022.101190. Erratum in 2023. *Dev Cogn Neurosci. 61*, 101208. https://doi.org/10.1016/j.dcn.2023.101208.

Torgesen, J. K., Alexander, A. W., Wagner, R. K., Rashotte, C. A., Voeller, K. K. S., & Conway, T. (2001). Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes from two instructional approaches. *Journal of Learning Disabilities, 34*(1), 33–58. https://doi.org/10.1177/002221940103400104

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Rose, E., Lindamood, P., Conway, T., & Garvan, C. (1999). Preventing reading failure in young children with phonological processing disabilities:

Group and individual responses to instruction. *Journal of Educational Psychology, 91*(4), 579–593. https://doi.org/10.1037/0022-0663.91.4.579

Uyar, M., Kirby, J. R., Maclean, J. J., & Eriksen, J. L. (2023). Phonological memory and naming speed predict response to intervention in elementary school-aged children with word-level reading difficulties. *Global Journal of Intellectual & Developmental Disabilities, 11*(2), 1–10.

Vaughn, S., Denton, C. A., & Fletcher, J. M. (2010). Why intensive interventions are necessary for students with severe reading difficulties. *Psychology in the Schools, 47*(5), 432–444. https://doi.org/10.1002/pits.20481

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*(1), 2–40.

Wagner, R. K., Zirps, F. A., Edwards, A. A., Wood, S. G., Joyner, R. E., Becker, B. J., Liu, G., & Beal, B. (2020). The prevalence of dyslexia: A new approach to its estimation. *Journal of Learning Disabilities, 53*(5), 354–365.

Wang, J., Wu, K. C., Mo, J., Wong, W. L., Siu, T. S. C., McBride, C., Chung, K. K. H., Wong, P. C. M., & Maurer, U. (2021). Remediation of a phonological representation deficit in Chinese children with dyslexia: A comparison between metalinguistic training and working memory training. *Developmental Science, 24*(3), e13065.

Wang, L.-C. (2017). Effects of phonological training on the reading and reading-related abilities of Hong Kong children with dyslexia. *Frontiers in Psychology, 8*, 1904.

Wang, L.-C., Liu, D., Chung, K.K.-H., & Yang, H.-M. (2017). Development of lexical tone awareness in Chinese children with and without dyslexia. *Contemporary Educational Psychology, 49*, 203–214. https://doi.org/10.1016/j.cedpsych.2017.02.002

Wanzek, J., Stevens, E. A., Williams, K. J., Scammacca, N., Vaughn, S., & Sargent, K. (2018). Current evidence on the effects of intensive early reading interventions. *Journal of Learning Disabilities, 51*(6), 612–624. https://doi.org/10.1177/0022219418775110

Wechsler, D. (2008). Wechsler Adult Intelligence Scale-Fourth Edition.

Wu, X., Anderson, R. C., Li, W., Wu, X., Li, H., Zhang, J., Zheng, Q., Zhu, J., Shu, H., Jiang, W., Chen, X., Wang, Q., Yin, L., He, Y., Packard, J., & Gaffney, J. S. (2009). Morphological awareness and Chinese children's literacy development: An intervention study. *Scientific Studies of Reading, 13*(1), 26–52.

Xue, J., Shu, H., Li, H., Li, W., & Tian, X. (2013). The stability of literacy-related cognitive contributions to Chinese character naming and reading fluency. *Journal of Psycholinguistic Research, 42*(5), 433–450. https://doi.org/10.1007/s10936-012-9228-0

Yang, J., McCandliss, B. D., Shu, H., & Zevin, J. D. (2009). Simulating language-specific and language-general effects in a statistical learning model of Chinese reading. *Journal of Memory and Language, 61*(2), 238–257. https://doi.org/10.1016/j.jml.2009.05.001

Zhang, Y., Zhang, L., Shu, H., Xi, J., Wu, H., Zhang, Y., & Li, P. (2012). Universality of categorical perception deficit in developmental dyslexia: An investigation of Mandarin Chinese tones: Categorical perception deficit in lexical tones. *Journal of Child Psychology and Psychiatry, 53*(8), 874–882.

Zhou, X., & Marslen-Wilson, W. (1994). Words, morphemes and syllables in the Chinese mental lexicon. *Language and Cognitive Processes, 9*(3), 393–422. https://doi.org/10.1080/01690969408402125

Zhou, X., & Marslen-Wilson, W. (1999). Phonology, orthography, and semantic activation in reading Chinese. *Journal of Memory and Language, 41*(4), 579–606. https://doi.org/10.1006/jmla.1999.2663

Zhou, Y.-L., McBride-Chang, C., Fong, C.Y.-C., Wong, T.T.-Y., & Cheung, S. K. (2012). A comparison of phonological awareness, lexical compounding, and homophone training for Chinese word reading in Hong Kong kindergartners. *Early Education & Development, 23*(4), 475–492.

Authors and Affiliations

Linling Shen[1] · Guoyan Feng[2] · Liping Shi[3] · Yu Wu[4,5] · Fan Cao[4,5]

✉ Fan Cao
fancao@hku.hk

1 Department of Special Education, The University of Texas, Austin, TX, USA

2 School of Management, Guangzhou Xinhua University, Dongguan, China

3 School of Psychology, Third Military Medical University, Chongqing, China

4 Department of Psychology, The University of Hong Kong, Hong Kong, China

5 State Key Lab of Brain and Cognitive Sciences, The University of Hong Kong, Hong Kong, China