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REVIEW ARTICLE

The Deficit Profiles of Chinese Children with Reading Difficulties: a Meta-analysis

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Abstract The current meta-analysis synthesized findings from profiling research on Chinese children with reading difficulties (RD). We reviewed a total of 81 studies published between 1964 and May 2015, representing a total of 9735 Chinese children. There are 982 effect sizes for the comparison between children with RD and age-matched typically developing (A-TD) children and 152 effect sizes for the comparison between children with RD and reading-level-matched typically developing (R-TD) children on multiple linguistic and cognitive skills. Results showed that compared to A-TD children, children with RD have severe deficits in morphological awareness, orthographic knowledge, phonological awareness, rapid naming, working memory, and visual skills and moderate deficits in short-term memory and motor skills. Compared to R-TD children, children with RD only have moderate deficits in rapid naming and mild deficits in orthographic knowledge. Moderation analyses for the comparison between RD and A-TD children revealed that children with more severe RD show more severe deficits in morphological awareness, phonological awareness, rapid naming, and visual skills. However, neither location (Mainland vs. Hong Kong) nor type of reading screening (character recognition vs. character recognition combined with reading comprehension) emerged as a moderator of the deficit profiles. These findings indicate that Chinese children with RD have deficits on a wide range of cognitive and linguistic skills. Deficits in rapid naming and orthographic knowledge may be

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potential causal factors for RD in Chinese based on existing evidence. Implications for the diagnosis and instructions of Chinese children with RD were discussed.

Keywords Chinese reading difficulties · Rapid naming · Phonological awareness · Orthographic knowledge · Morphological awareness · Working memory

Reading is critical for children's development, and yet about 5~8 % of school-aged Chinese children have difficulties in reading Chinese (e.g., Sun et al. 2003; Stevenson et al. 1982; Zhang et al. 1996). A wide range of linguistic and cognitive deficits are proposed for Chinese reading difficulties (RD) (e.g., Chung et al. 2013; Ho et al. 2002; Peng et al. 2013; Shu et al. 2006), and research on the deficit profiles of these linguistic and cognitive skills can help us better understand RD in Chinese and provide implications for diagnosis of and instruction for Chinese children with RD.

There are two types of deficit profiling research that have examined skills associated with RD in Chinese. The first focuses on within-subject variance, investigating questions such as whether individual children with reading disabilities, for example, child A or child B, show similar or different patterns of deficits compared to a typically developing peer on a full range of linguistic and cognitive skills (e.g., Ramus et al. 2013). The second type focuses on between-subject variance, investigating whether a group of children with RD, compared to a typically developing group, shows one or more deficits on a full range of linguistic and cognitive skills (e.g., Shu et al. 2006). Both types of profiling research contribute to our understanding of theories for RD in Chinese. In this study, we focused on the deficit profiles of children with RD using the group comparison approach, since most previous studies reported group comparison results and far fewer reported individual deficit results.

Our current research is also driven by the gap in previous studies that the deficit profiles for Chinese children with RD remain unclear despite that a number of studies have advanced our understanding of RD in Chinese. Mixed findings exist from previous research regarding (1) whether Chinese children with RD have deficits in specific skills such as orthographic knowledge, morphological awareness, visual skills, and motor skills (e.g., Chung et al. 2008; Yeung et al. 2014); (2) the deficit severity of different skills (e.g., Ho et al. 2007; Hoosain 1991); and (3) the domain effects on the deficit profiles (e.g., is syllable awareness deficit the most salient phonological awareness deficit). In the following sections, we discuss the feature of Chinese language and script, theories, and empirical findings about each skill investigated in this study.

The Feature of Chinese Language and Script

Chinese is a morphosyllabic script used by the largest population in the world (DeFrancis 1984). It contrasts sharply with English in the visual complexity and the mapping relationships among orthography, phonology, and meaning. In Chinese, the basic unit of writing is the character. Each character corresponds to a single syllable and a single morpheme (DeFrancis 1984; Wang 1973). As both conjugation and declension are negligible in Chinese language, characters always remain the same in various contexts. Characters consist of strokes in a square-shaped form and are complex visually. Moreover, there are extensive homophones, and the phonological information is insufficient to help access semantics of a character (Chou et al. 2009). Current models of Chinese reading emphasize the importance of a fully specified orthographic representation prior to the activation of phonological and meaning information in reading Chinese (e.g., Perfetti et al. 2005; Taft et al. 1999).

Most characters are compound characters made up of phonetic radicals and semantic radicals. For example, the compound character 盯[ding1] "stare" contains [目] "eye," a semantic radical providing a cue to the meaning of the character (use eyes to stare), and 丁[ding1] is the phonetic radical giving a cue to the pronunciation of the compound character. Unlike alphabetic writing systems, in which graphic units are mapped to the segmental structure of speech, the structure of Chinese orthography typically does not correspond to their phonemic sequences. Although the phonetic radical of the Chinese character can indicate its phonology, fewer than 50 % of Chinese characters have a pronunciation that corresponds to the pronunciation of the phonetic radical in that character (e.g., Shu 2003). Nevertheless, previous studies repeatedly showed that Chinese reading entails phonological activation (e.g., Ho et al. 2000).

Compared to the unsystematic mapping between orthography and phonology, the orthography to semantics mapping is relatively systematic (Ho et al. 2000), and the meanings of Chinese characters are often suggested by their semantic radicals. Moreover, because characters are monosyllabic and a single syllable can be written in many different ways with different meanings, accessing semantics from phonology is unreliable without contextual cues. The direct connection between orthography and semantics is, therefore, more reliable for accessing meaning in Chinese (Cao et al. 2010).

Given these distinctive features of Chinese script, the profiling research on RD in Chinese usually involves many cognitive and linguistic skills. In the current meta-analysis, we focused on the following: phonological awareness, rapid naming, orthographic knowledge, morphological awareness, short-term memory, working memory, visual skills, and motor skills. We chose these skills because they are all theoretically associated with reading difficulties (e.g., Badian 1997; Stein 2001; Shu et al. 2006; Snowling 2000; Swanson et al. 1996; Wolf and Bowers 1999) including Chinese reading difficulties (e.g., Ho et al. 2000; Peng et al. 2013; Shu et al. 2006), and they were studied most in previous RD in Chinese profiling research.

Phonological Awareness

Phonological awareness refers to the ability to manipulate the characteristics of spoken sound that does not necessarily involve print (Wagner et al. 1993). According to the phonological deficit theory, RD are mostly likely caused by an impairment in the cognitive presentation of speech sounds (Snowling 2000). Some research on Chinese reading supports this theory (Huang and Hanley 1994; McBride-Chang and Chen 2003; McBride-Chang and Ho 2000; Ho et al. 2000, 2004). However, researchers have debated whether deficits in phonological awareness are the most salient deficits among Chinese children with RD.

One reason for this debate may lie in the different domains measured by different studies. Specifically, phonological awareness measured in Chinese usually includes syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing skills (e.g., Ho et al. 2000; Li and Ho 2011; Zhou et al. 2014). Chinese character corresponds to a morpheme and syllable, the basic speech unit in Chinese is the syllable; Chinese is basically morphosyllabic (e.g., Leong 1999; McBride-Chang et al. 2004). Also, as mentioned earlier, most characters are compound characters made up of phonetic radicals and semantic radicals. While the phonetic radical of a Chinese character may suggest syllable or onset/rime information of the whole character, none of the parts in a Chinese character represents any phoneme. In contrast, a word in English can be pronounced by assembling phonemes represented by letters or letter combinations. Thus, syllable awareness is more closely related to Chinese character recognition than is phonemic awareness, as suggested by some research (e.g., McBride-Chang et al. 2004). Moreover, Chinese is a tonal language, and tonal processing skills play an important role in character learning (So and Siegel 1997). Specifically, researchers have hypothesized that tone awareness influences the learning of Chinese characters through the orthography-phonology correspondence (OPC) rules. Many Chinese characters with the same phonetic components are often homophones or partial homophones, and therefore, good tone discrimination is essential in applying the OPC rules effectively to learning words. Eventually this process helps one learn orthographic regularities in Chinese and facilitates both phonological and phonetic processing (Li and Ho 2011). Given these linguistic features of Chinese, it is reasonable to assume that deficits in syllable awareness, onset-rime awareness, and tonal processing skills may be more likely than deficits in phonemic awareness to differentiate Chinese children with and without RD.

Rapid Naming

According to the double-deficit hypothesis, naming speed deficit may be another core deficit in RD (Wolf and Bowers 1999). Rapid naming refers to the ability to name as fast as possible highly familiar stimuli such as digits, letters, characters, objects/pictures, and colors. Research shows that rapid naming is a very strong predictor of Chinese reading development (e.g., Song et al. 2016) and that rapid naming deficits differentiate Chinese children with and without RD (e.g., Chung et al. 2008, 2010; Ho et al. 2004).

Still, it is unclear whether deficits in rapid naming differ by domain (e.g., digits, letters, characters, objects/pictures, and colors). For example, some studies have found that children with RD have rapid naming deficits to a similar degree in most of the aforementioned domains, which suggests that children have generalized difficulties in speed of access to the lexicon (Huang et al. 2007). Other studies have found that deficits of rapid naming are more salient in digits or letters than in other domains (e.g., Liao et al. 2015; Yeh 2012). Because digit/letter rapid naming is often found to be more predictive of reading than are object/picture and color rapid naming (Bowey et al. 2005; Cardoso-Martins and Pennington 2004), one would expect deficits in rapid digit/letter naming to be more related to RD than naming in other domains.

Orthographic Knowledge

According to the triple-deficit hypothesis proposed by Badian (1997), orthographic deficits are another major source for RD in addition to phonological and rapid naming deficits. Orthographic knowledge in Chinese refers to children's knowledge of the positions, structuring, and functions of radicals; children's awareness of conventional rules in characters; and their ability to identify or distinguish real characters from a pool of pseudocharacters and visual symbols (e.g., Ho et al. 2007; Leung and Ho 2009). Given the features of Chinese script, orthographic knowledge is speculated as an important skill in Chinese reading development and this has received evidence from research among typically developing children (e.g., Li et al. 2012; Siok and Fletcher 2001; Tong et al. 2009).

There is controversy, however, about whether Chinese children with RD have deficits in orthographic knowledge. While some research shows that a deficit in orthographic knowledge is among the most dominant linguistic deficits in Chinese children and adolescents with dyslexia (Ho et al. 2002, 2004; Chung et al. 2010), other research indicates that children with RD do not perform worse than age-matched typically developing peers on orthographic knowledge tasks (Yeung et al. 2014; Chung et al. 2008).

Morphological Awareness

Morphological awareness refers to the ability to reflect on and manipulate morphemes and employ word formation rules in one's language (Kuo and Anderson 2006; Shu et al. 2006). It influences Chinese reading in three ways. First, in 80 % of characters, the semantic radical is directly linked to meaning (Shu et al. 2003). Thus, morphological and phonological print information can be more clearly distinguished in Chinese than in alphabetic scripts like English. Second, Chinese is relatively transparent semantically, so that a complex vocabulary can often be built by compounding morphemes. Third, because there are many homophones in Chinese, children become better at understanding how morphemes are related to one another as their reading experience increases.

Indeed, research shows that morphological awareness contributes to Chinese character recognition (e.g., McBride-Chang et al. 2003, 2005), that morphological awareness can be used to differentiate between good and poor Chinese readers (e.g., Chung et al. 2011; Shu et al. 2006), and that Chinese children's inability to distinguish among meanings of homophones and to discriminate morphemes contributes to their reading failure (e.g., Chung et al. 2011; Shu et al. 2006). However, some research also suggests that although Chinese children with RD have deficits in morphological awareness, these deficits are not as salient for children with persistent/severe RD as for those with mild RD (Yeung et al. 2014). Thus, although prior research has consistently shown that Chinese children with RD have deficits in morphological awareness, further investigation is needed to determine whether these deficits are important features for Chinese children with RD, when the severity of RD is considered.

Short-Term Memory and Working Memory

Memory deficits also contribute to RD (Gathercole et al. 2004; Swanson et al. 1996). Deficits in short-term memory and working memory, in particular, are two most commonly suggested memory deficits associated with RD in Chinese (e.g., Ho et al. 2000; Peng et al. 2013). Specifically, short-term memory refers to one's ability to temporarily retain information. It has been suggested that short-term memory, especially verbal short-term memory (i.e., phonological memory), is likely to affect children's acquisition of verbal vocabulary and their development of stable graphic-sound associations; in turn, short-term memory deficits hinder normal reading development (e.g., Ho et al. 2000; Gathercole et al. 1991). Working memory refers to the ability to process and store information simultaneously (Baddeley 1986). It is related to one's reading ability, especially to reading comprehension. Thus, it has often been suggested that working memory deficits are associated with deficits in reading comprehension (Cain et al. 2004).

Several studies have found that poor Chinese readers performed worse than average readers on tasks requiring short-term memory (Ho et al. 2000; Chung et al. 2013) and working memory (Wang and Liu 2007; Cheng and Gong 1998; Lu 1994). What remains unclear is whether there are differences by domain in the short-term memory and working memory deficit profiles among RD in Chinese. While some studies have suggested that deficits in verbal short-term/working memory are more apparent than deficits in nonverbal domains among children with RD (e.g., Cheng and Gong 1998; Shu et al. 2006; Lu 1994; Li 2006), others have not found such domain differences (e.g., Chung et al. 2011; Han and Maihepulaiti 2012; Wang and Liu 2007).

Visual and Motor Skills

The magnocellular theory and cerebellar theory of RD propose that visual and motor skills may also be important factors that contribute to RD (Stein 2001; Stein and Walsh 1997). Visual skills refer to children's ability to perceive and integrate visual information in general (not necessarily involving reading materials) (Lovegrove 1991; Lovegrove and Slaghuis 1989). Since Chinese is heavily visual (e.g., Chen and Kao 2002; Hsiao and Shillcock 2006; Shu et al. 2003), visual skills are likely to contribute to Chinese reading ability, but the relationship between visual skills and Chinese reading acquisition is unclear. Some research shows that visual skills predict Chinese reading (e.g., Yang et al. 2013; Chung et al. 2008; McBride-Chang and Chang 1995) and that a large proportion (i.e., 30 %) of dyslexic Chinese children have visual processing problems (Ho et al. 2002, 2004). Other studies suggest that visual skills are not important in learning to read Chinese (e.g., Hu and Catts 1998; Huang and Hanley 1997) and that visual processing cannot differentiate poor readers from good readers (Li 2006; Li-Tsang et al. 2012).

Motor skills here are defined as intentional movement with a motor or muscular component. Motor skills are theoretically important for learning Chinese, which requires a lot of practice (e.g., copying and dictation) involving motor skills such as handwriting (e.g., Lam et al. 2011). That is, writing in Chinese involves making complex geometric figures and arranging strokes within a squared area (Chow et al. 2003; Tan et al. 2001). Some research indicated that Chinese children with RD write more slowly and are less competent in motor skills than typical children (Feder and Majnemer 2007; Tseng and Murray 1994). Still, compared to the other skills mentioned above, deficits in motor skills have been less studied among Chinese children with RD. We investigated the severity of motor skills deficits based on the limited number of studies available.

Factors That Influence the Deficit Profiles

Differences in sample and methodological characteristics may account for some of the variant findings on the deficit profiles of Chinese children with RD. In this study, we focused on sample characteristics including age, location, and severity of RD and methodological issues such as type of reading screening.

Age

Research indicates that Chinese children with RD at different ages may show different deficit profiles. For example, in a longitudinal study, Lei et al. (2011)) found that the deficit profiles of RD were affected by age. For some children at risk for RD, deficits in phonological awareness skills emerged as early as 4 years old but disappeared 2 years later. For other at-risk children, deficits in morphological awareness did not emerge until 5 years old. Some at-risk children showed consistent deficits in phonological awareness skills and rapid naming, but the severity of these deficits changed as a function of age: from 4 to 6 years, deficits in phonological awareness became more severe while deficits in rapid naming became less severe. Although it is still unclear whether the age effects reflect children's maturation or increased reading-related experiences, findings from Lei et al. (2011)) indicate that age may be an important factor to consider in RD profiling research.

Location

The present study included studies from Mainland China, Hong Kong, and Taiwan. Because we did not expect sufficient number of studies conducted in Taiwan, we only focused on children from Mainland and Hong Kong for the location effect analysis. Mainland and Hong Kong differ in a variety of ways that might impact reading development, including languages spoken (Mandarin vs. Cantonese), Chinese script (simplified vs. traditional characters), and methods of early reading instruction. Specifically, Mandarin spoken in Mainland has five tones, whereas Cantonese spoken in Hong Kong has nine tones (Bauer and Benedict 1997; Li and Ho 2011). The Chinese writing system currently has two scripts. Mainland uses the simplified script, while Hong Kong uses the traditional script (McBride-Chang et al. 2005). The simplified characters in Mainland have approximately 22.5 % fewer strokes than the more orthographically complicated characters of Hong Kong (Gao and Kao 2002). Another difference between Mainland and Hong Kong is the use of Pinyin for early Chinese instructions. Pinyin is a phonological coding system that uses the Roman alphabet to introduce pronunciations of new Chinese characters. Pinyin is systematically taught and used in Mainland starting at elementary school. Hong Kong does not systematically use such a "phonics" system but focuses instead on the whole word approach, or "look and say method," starting as early as 3.5 years old (Holm and Dodd 1996). All of these differences between Mainland and Hong Kong may influence deficit profiles of orthographic knowledge and phonological awareness, visual, and motor skills among Chinese children with RD. Because of the instructional differences, in particular, it may be reasonable to assume an interaction between age and location on the deficit profiles. Specifically, young children with RD in Mainland China may tend to show more salient deficits in phonological awareness skills, while their peers in Hong Kong may show more salient deficits in orthographic knowledge and memory.

However, some recent studies indicated that the education environment in Mainland tend to become more similar to that of Hong Kong. Specifically, reading instruction without Pinyin instruction for Mainland children tends to start early before formal schooling (e.g., Lau et al. 2011; Li et al. 2011). Children tend to have similar early experiences with learning English in both Hong Kong and Mainland. Thus, the increasingly homogeneous biscriptal (Pinyin characters; English characters) nature of education in both Mainland and Hong Kong may actually reduce the effect of spoken language and Chinese script effect on the deficit profiles of RD in Chinese.

Severity of RD

Low-achievement identification is a widely adopted approach in RD research (e.g., Andersson and Lyxell 2007; Geary et al. 2007; Murphy et al. 2007). With this approach, children are identified as having RD if their IQs are at a normal range but their performance is below a cutoff point on reading screening measures (Fuchs et al. 2003). However, one major problem associated with this approach is inconsistency in the cutoff criterion used on the reading screening measure, which usually varies across studies from the 35th percentile to less than the 5th percentile (e.g., Geary et al. 2000; Landerl et al. 2004). Different cutoff scores lead to different degrees of severity in RD (e.g., Fuchs et al. 2004), which may affect cognitive profiles of RD.

Specifically, through simulations, Branum-Martin et al. (2013) found that the patterns of cognitive profiles are a product of the cut points and the correlational structure of the data in reading and cognitive skills, indicating that there are relations between the cognitive profiles of children with learning difficulties and the achievement cutoff criterion. Similarly, Murphy et al. (2007) found qualitative differences in the profiles of math-related cognitive skills across groups defined by different cutoff scores (11th percentile and 25th percentile on math measures). Children with less severe mathematics difficulties appeared to show less severe cognitive deficits than children with more severe mathematics difficulties. Moreover, as mentioned earlier, research shows that deficits in morphological awareness are not as salient for Chinese children with persistent/severe RD as for children with mild RD (Yeung et al. 2014). Together, these results suggest that the severity of cognitive deficits among Chinese children with RD may vary as a function of the severity of RD.

Type of Reading Screening

The type of reading screening measure also varies across relevant studies. To identify RD in Chinese, many investigators used measures assessing character recognition (e.g., Wong and Ho 2010; Yeung et al. 2014; Goswami et al. 2010) or character recognition combined with reading comprehension (e.g., Chung et al. 2011; Huang et al. 2007; Leung and Ho 2009). Research shows that different reading skills involve different cognitive skills to varying degrees. For example, it is a general finding that reading comprehension is more closely related to working memory (e.g., Cain et al. 2004; Savage et al. 2007), whereas decoding skills such as character recognition are more closely related to morphological awareness, orthographic knowledge, and phonological awareness skills (e.g., Ho et al. 2000; Shu et al. 2006). Thus, the type of reading screening measures used to identify RD in Chinese may influence the deficit profiles; in particular, poor readers identified by character recognition measures may have less severe deficits in working memory than those identified by comprehension measures. Moreover, as mentioned earlier, Lei et al. (2011)) found that the influence of age on deficit profiles may vary according to different types of RD (identified by different reading measures). We therefore investigated whether there was an interaction between age and type of reading screening.

Type of Control Group

Although the majority of profiling research used age-matched typically developing (A-TD) children as controls, some researchers argue that it is also necessary to compare children with

RD to reading-level-matched typically developing children (R-TD) to further confirm whether children with RD really have certain deficits (e.g., Cheung et al. 2009; Goswami and Bryant 1989; Zhang et al. 1996). The rationale is that the difference between the RD and A-TD groups on a cognitive/linguistic skill may only indicate that RD has deficits in that skill, which is associated with reading problems. In contrast, the difference between the RD and R-TD groups on a cognitive skill cannot be a consequence of differences in reading skills and is therefore more likely to represent causal effects (Goswami and Bryant 1989). In profiling research, the strongest evidence for causal effects of a cognitive skill on reading is that the RD group shows inferior performance on that skill to both the A-TD group and the R-TD group (e.g., Cheung et al. 2009; Goswami and Bryant 1989).

However, findings are mixed from studies that compare the RD and A-TD groups. For example, some studies have found that children with RD performed significantly worse than the A-TD and R-TD controls in phonological awareness, rapid naming, visual-orthographic knowledge, and verbal short-term memory (e.g., Zhang et al. 1996), suggesting that RD is caused by deficits in these skills. In contrast, other research has shown that children with RD did not differ from their R-TD controls in performance levels on rapid naming, phonological awareness, visual skills, orthographic knowledge, or morphological awareness (e.g., Chung et al. 2010; Ho et al. 2002). Thus, in this study, we coded R-TD controls to further investigate the deficit profiles of Chinese children with RD.

Research Questions

In sum, a number of studies have advanced our understanding of the deficit profiles of Chinese children with RD. However, it is still unclear (1) whether Chinese children with RD have deficits in orthographic knowledge, morphological awareness, visual skills, and motor skills; (2) the deficit severity of different skills; and (3) whether the deficit profile differs by domain. To address these issues, we examined three major questions in the current meta-analysis.

> Question 1: Compared to A-TD and R-TD children, do Chinese children with RD perform significantly worse on phonological awareness, rapid naming, orthographic knowledge, morphological awareness, short-term memory, working memory, visual skills, and motor skills? Based on theories mentioned and the majority findings of previous research, we hypothesized that Chinese children with RD may have deficits in all those skills.
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> Question 2: Based on the comparison between A-TD and children with RD, are deficit profiles influenced by age, location, type of reading screening, severity of RD, the interaction between age and location, and the interaction between age and type of reading screening? Based on the difference on oral language, Chinese script, and early reading instructions between Mainland and Hong Kong, we hypothesized that young children with RD from Hong Kong may have more severe deficits in character recognition-related skills (e.g., visual skills and orthographic knowledge), whereas young children with RD in Mainland may have more severe deficits in Pinyin-related skills (e.g., phonological awareness). Children with RD identified by character recognition and comprehension measures may have more comprehensive and severe deficits than those identified by character recognition measures only. The severity of RD may be related to more comprehensive and severe deficits.

Question 3: Compared to A-TD children, do the deficits of children with RD differ by domain? In particular, we investigate whether deficits in phonological awareness of children with RD differ among syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing; whether the deficit profiles for rapid naming differ among digits, letters, colors, objects/pictures, and characters; and whether memory deficits differ between verbal and nonverbal tasks. Based on the features of Chinese language and script, we hypothesized that children with RD may have more deficits in severe syllable awareness, onset-rime awareness, and tonal processing than in phonemic awareness and may have domain-general deficits in both short-term memory and rapid naming.

Because we may not obtain enough effect sizes, we did not examine moderation effects on the comparison children with RD and R-TD children or the domain effects on the comparison between children with RD and R-TD children.

Methods

Literature Search

Articles for this meta-analysis were identified in two ways. First, a computer search of the ERIC, Google Scholar, and ProQuest for literature was conducted. Journals from Chinese databases wanfangdata (万方数据), CNKI (中国知网), and CQVIP (维普资讯) databases were also searched. We used the earliest possible start date (1964) through May 2015. Titles, abstracts, and keywords were searched for the following terms: *Chinese* AND *read**, *reading di**, *poor read**, or *dyslexi**. The terms *read**, *di**, and *dyslexi** allowed for inclusion of reading/readers, difficulties/difficulty/disability/disabilities, dyslexia/dyslexic, and so forth. Second, we searched unpublished literature through Dissertation and Masters Abstract indexes in ProQuest, Cochrane Database of Systematic Reviews, relevant conference programs (e.g., conference of Society for the Scientific Study of Reading; Conference of Society for Research in Child Development), and emailing some researchers likely to have conducted work in this area. We also contacted several researchers to check the appropriateness of certain studies in terms of our selection criteria (e.g., we contacted authors to clarify the specific skills their tasks measure if this information was not clearly described in the study). The initial search yielded 3683 studies. The first author and one doctoral student majored in Psychology then reviewed all studies by titles and abstracts. After excluding 3505 non-relevant and duplicate studies, the remaining 178 studies were carefully reviewed based on the specific criteria described below.

1. The study must include a group of native Chinese-speaking (i.e., Mandarin or Cantonese) children (up to 16 years old) with RD and a group of TD children (A-TD or R-TD). The study must report information showing that children with RD scored lower than A-TD children on reading screening measures, or children with RD score comparably to R-TD children on reading screening measures, or information showing that children with RD were identified by school/district psychologists, classroom teachers, or researchers. Also, the study must provide information that all children's IQ scores were in the normal range (standardized score 80–120).

2. The study compared children with RD to TD children on non-screening measures that tap at least one of the following categories: phonological awareness, rapid naming, orthographic knowledge, morphological awareness, short-term memory, working memory, visual skills, and motor skills.

Coding Procedure and Interrater Reliability

Based on the above-mentioned criteria, 81 studies were included in the review (i.e., 5 dissertations, 1 unpublished manuscript, and 75 peer-reviewed articles). These studies were coded according to the characteristics of participants, reading screening tasks, tasks used to measure phonological awareness skills, rapid naming, orthographic knowledge, morphological awareness, short-term memory, working memory, visual skills, and motor skills. Not all studies provided sufficient information on the variables of interest for the present study. In case of insufficient information, authors were contacted to obtain the missing information. The important features of individual studies are provided in Appendix Table 4.

Variables were discussed until a consensus was reached between the first and the second author. Then, the second author used this coding system to conduct the final coding of all studies. To assess inter-rater reliability, the fourth author independently coded 32 % of the studies (26 studies). Across the total variable matrix, the mean inter-rater agreement coefficient was 0.97, with the coefficient above 0.95 for age, location, type of control, and all skills investigated in this study, and 0.91 for reading screening measures. Any disagreements between raters were resolved by consulting the original article or by discussion. The examples of measures for different skills are presented in Appendix Table 5.

Analytic Strategies

Hedges *g*, corrected for sample size bias, was used as the measure of effect size. We chose Hedges *g* as it provides better estimate of effect sizes than Cohen's *d* on small sample sizes (most studies in this review had small sample sizes) (Grissom and Kim 2005). For studies reporting means, standard deviations, and sample size, the following formulae were used:

$$g^{\mathrm{u}} = g\left(1 - \frac{3}{4(N_{\mathrm{RD}} + N_{\mathrm{TD}} - 2) - 1}\right)$$

$$\text{With } g = \frac{\overline{X}_{\mathrm{RD}} - \overline{X}_{\mathrm{TD}}}{S} \quad \text{and} \quad g = \sqrt{\frac{(N_{\mathrm{RD}} - 1)S_{\mathrm{RD}}^2 + (N_{\mathrm{TD}} - 1)S_{\mathrm{TD}}^2}{N_{\mathrm{RD}} + N_{\mathrm{TD}} - 2}}$$

in which g^{u} is the unbiased estimate of Hedge's *g*, *g* is Hedges *g* as traditionally defined, N_{RD} is the number of participants in the RD group, N_{TD} is the number of participants in the TD group, $\overline{X}_{\mathrm{RD}}$ is the mean of the target skill (e.g., working memory) scores for participants in the RD group, $\overline{X}_{\mathrm{TD}}$ is the mean of the target skill scores for participants in the TD group, *S* is the pooled standard deviation, S_{RD}^2 is the variance of target skill scores for the participants in the RD group, and S_{TD}^2 is the variance of target skill scores for the participants in the TD group. According to Cohen (2013), the absolute value of the negative effect size (RD vs. TD) ranging

0.02~0.05 means small effects (light deficits), 0.50~0.80 means medium effects (moderate deficits), and >0.80 means large effects (severe deficits).

We first estimated the effect sizes of deficits on phonological awareness skill, rapid naming, orthographic knowledge, morphological awareness, short-term memory, working memory, visual skills, and motor skills for children with RD in comparison to TD children. Next, meta-regression analyses were used to examine the moderation effects of age, location, type of reading screening, and severity of RD on the deficit profiles for each skill based on the comparison between children with RD and A-TD children. For the moderation analyses, each moderator was examined with other moderators controlled in one meta-regression model. For moderators that were dichotomous, we entered them directly into the meta-regression model (Cohen et al. 2013).

We considered all eligible effect sizes in each study. That is, studies can contribute multiple effect sizes as long as the sample for each effect size is independent. For studies that reported multiple effect sizes from the same sample (e.g., two effect sizes based on two working memory measures are calculated for RD vs. A-TD in one study), we accounted for the statistical dependencies using the random-effects robust standard error estimation technique developed by Hedges et al. (2010). This analysis allowed for the clustered data (i.e., effect sizes nested within samples) by correcting the study standard errors to take into account the correlations between effect sizes from the same sample. The robust standard error technique requires that an estimate of the mean correlation (ρ) between all the pairs of effect sizes within a cluster be estimated for calculation of the between-study sampling variance estimate, τ^2. In all analyses, we estimated τ^2 with $\rho = 0.80$; sensitivity analyses showed that the findings were robust across different reasonable estimates of ρ.

Because we hypothesized that the research body is reporting a distribution of effect sizes with significant between-studies variance, as opposed to a group of studies attempting to estimate one true effect size, a random-effects model was appropriate for the current study (Lipsey and Wilson 2001). Weighted, random-effects meta-regression models using the corrections of Hedges et al. (2010) were conducted with ROBUMETA in Stata (Hedberg 2011) to summarize effect sizes and examine potential moderators.

Moreover, publication bias (the problem of selective publication, in which the decision to publish a study is influenced by its results) was examined using the method of Egger et al. (1997) and funnel plot. Publication bias is suggested when the Egger et al. publication bias statistic is significantly greater than zero ($p < 0.05$), and the funnel plot was further examined for potential publication bias. Specifically, in the absence of publication bias, the studies will be distributed symmetrically around the mean effect size. In the presence of publication bias, it is possible that studies with large-medium sample size may be missing if a few studies are missing in the top and middle of the funnel plot. It is possible that small studies may be missing if a few studies are missing near the bottom (Borenstein et al. 2009). The funnel plot was also used to detect possible outliers. Sensitivity analyses were conducted to examine adjusted overall effect size and adjusted moderation effects after removing observed outliers.

Results

The 81 studies included in the meta-analysis represent a total of 9735 Chinese children (4402 for RD, 4685 for A-TD, and for 648 R-TD) obtained from 120 independent samples. There are 982 effect sizes that indicate the comparison between RD and A-TD on phonological awareness (247 effect sizes), rapid naming (148 effect sizes), orthographic knowledge (82 effect sizes), morphological awareness (91 effect sizes), short-term memory (87 effect sizes), working memory (48 effect sizes), visual skills (158 effect sizes), and motor skills (133 effect sizes). There are 152 effect sizes that indicate the comparison between RD and R-TD on phonological awareness (38 effect sizes), rapid naming (29 effect sizes), orthographic knowledge (30 effect sizes), morphological awareness (11 effect sizes), short-term memory (9 effect sizes), working memory (5 effect sizes), visual skills (25 effect sizes), and motor skills (5 effect sizes).

The Deficit Profiles of RD as Compared to A-TD and R-TD

The estimated average effect size indicating the deficits of RD as compared to A-TD is as follows (see Fig. 1): phonological awareness: Hedges $g = -1.06$, 95 % CI [−1.31, −0.82], rapid naming: Hedges $g = -1.17$, 95 % CI [−1.44, −0.91], orthographic knowledge: Hedges $g = -1.03$, 95 % CI [−1.55, −0.51], morphological awareness: Hedges $g = -1.20$, 95 % CI [−1.56, −0.84], short-term memory: Hedges $g = -0.71$, 95 % CI [−0.84, −0.59], working memory: Hedges $g = -1.18$, 95 % CI [−1.46, −0.91], visual skills: Hedges $g = -0.86$, 95 % CI [−1.14, −0.59], and motor skills: Hedges $g = -0.54$, 95 % CI [−0.67, −0.41]. The estimated average effect size indicating the deficits of RD as compared to R-TD is as follows (see Fig. 1): phonological awareness: Hedges $g = -0.44$, 95 % CI [−1.09, 0.20], rapid naming: Hedges $g = -0.79$, 95 % CI [−0.99, −0.60], orthographic knowledge: Hedges $g = -0.25$, 95 % CI [−0.43, −0.07], morphological awareness: Hedges $g = 0.11$, 95 % CI [−0.27, 0.48], short-term memory: Hedges $g = -0.35$, 95 % CI [−0.74, 0.05], working memory: Hedges $g = -0.24$, 95 % CI [−0.84, 0.37], visual skills: Hedges $g = -0.30$, 95 % CI [−0.82, 0.21], and motor skills: Hedges $g = 0.08$, 95 % CI [−1.12, 1.28]. To sum, compared to A-TD children, children with RD showed severe deficits in morphological awareness, orthographic knowledge, phonological awareness, rapid naming, working memory, and visual skills and moderate deficits in short-term memory and motor skills. Compared to R-TD children, children with RD only showed moderate deficits in rapid naming and mild deficits in orthographic knowledge.

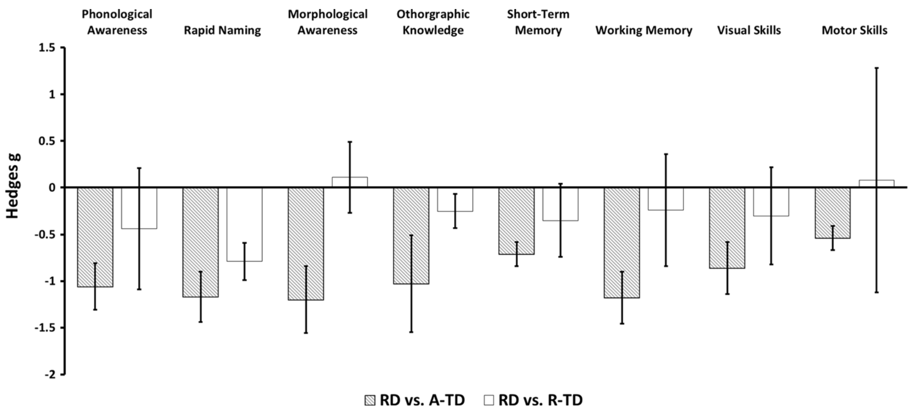

Fig. 1 Bar graph showing the comparison between Chinese children with RD and typically developing children on different skills. *Error bars* represent 95 % confidence interval. *Note*: RD vs. A-TD: comparison between children with reading difficulties and age-matched typically developing controls; RD vs. R-TD: comparison between children with reading difficulties and reading-level-matched typically developing controls

Factors That Influence the Deficit Profiles of RD as Compared to A-TD

Next, we examined whether age, location, type of reading screening, or severity of RD influenced the deficit profiles of each skill of RD as compared to A-TD children. As hypothesized, we also examined the interaction between age and location and the interaction between age and type of reading screening. Specifically, for each skill, we entered all those moderators, the interaction between age and location, and the interaction between age and type of reading screening in the model simultaneously. Because we did not obtain many effect sizes from Mainland, on reading screening type, and severity of RD for motor skills (see Table 1), we did not conduct the moderation analysis for motor skills.

As Table 2 shows, regarding phonological awareness, age, location, and reading screening type did not moderate the group differences on phonological awareness, $\beta = -.75$–0.07, $ps > 0.30$. There was no interaction between age and location or between age and type of reading screening, $\beta = 0.06$–0.17, $ps > 0.37$. However, severity of RD significantly moderated the group differences, $\beta = -0.33$, $p = 0.03$. That is, children with more severe RD demonstrated more severe deficits in phonological awareness. With respect to rapid naming, age, severity of RD, and type of reading screening were significant moderators such that younger children, children with more severe RD, and children with RD identified by character recognition plus comprehension showed more severe rapid naming deficits, $\beta = -0.51$–21.90, $ps < 0.001$. There was also a significant interaction between age and type of reading screening, $\beta = -1.64$, $p < 0.001$. The interaction pattern reveals that young children with RD identified by character recognition and comprehension show more severe rapid naming deficits than those identified by character recognition only, whereas older children with RD identified by character recognition and comprehension show comparable rapid naming deficits to those identified by character recognition only. However, location and the interaction between age and location were not significantly moderators, $\beta = -.53$–7.17, $ps > 0.05$.

Age, location, and reading screening type did not moderate the group differences on morphological awareness, $\beta = -0.36$–4.26, $ps > 0.20$. Also, we did not find the interaction between age and location, $\beta = -0.35$, $p = 0.28$, or the interaction between age and type of reading screening, $\beta = 0.02$, $p = 0.89$. However, severity of RD significantly moderated the group differences such that children with more severe RD seemed to demonstrate more severe deficits in morphological awareness, $\beta = -0.46$, $p < 0.001$. Regarding orthographic knowledge, none of those factors significantly moderated the group differences. There was no interaction between age and location or between age and type of reading screening, $\beta = -1.78-20.66$, $ps > 0.10$.

For short-term memory, working memory, and visual skills, we did not find any moderation effects, $\beta = -3.01$–33.06, $ps > 0.10$, except that severity of RD significantly moderated the group differences on visual skills such that children with more severe RD seemed to show more severe visual skills, $\beta = -0.35$, $p = 0.003$.

To sum, moderation analyses for the comparison between RD and A-TD children revealed that children with more severe RD tend to show more severe deficits in morphological awareness, phonological awareness, rapid naming, and visual skills. Neither location (Mainland vs. Hong Kong) nor type of reading screening (character recognition vs. character recognition combined with reading comprehension) emerged as a moderator of the deficit profiles. However, for rapid naming deficits, young children with RD identified by character recognition and comprehension show more severe rapid naming deficits than those identified by character recognition only.

Table 1 The number of effects sizes across moderators for the comparison between RD and A-TD children

	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual Skills	Motor Skills
Location								
Mainland	30	39	85	67	47	42	113	0
Hong Kong	56	38	105	56	37	5	41	132
Reading screening								
Character recognition	52	59	156	106	57	11	126	22
Character recognition + comprehension	39	29	72	38	29	37	29	1
Severity of reading difficulties	59	77	177	89	56	42	126	8
Age[a]	3.4–13.87	6.66–13.66	4.4–13.66	4.4–13.66	3.4–13.65	9.76–14.6	5.07–14.6	7.76–11.76

[a] It shows the range of age

Table 2 Meta-regression of the moderation analysis for the comparison between RD and A-TD children

	Morphological awareness					Orthographic knowledge				
	β	SE	t	95 %CI	p value	β	SE	t	95 % CI	p value
Age	0.04	0.07	0.50	[−0.11, 0.17]	0.62	1.19	0.75	1.60	[−0.39, 2.78]	0.13
Location (Mainland vs. Hong Kong)	4.26	3.56	1.20	[−3.21, 11.73]	0.25	0.50	8.19	0.06	[−16.86, 17.88]	0.95
Age × Location	−0.36	0.32	−1.11	[−1.03, 0.32]	0.28	0.31	0.70	0.45	[−1.17, 1.79]	0.66
Severity of RD	*−0.46****	*0.06*	*−7.90*	*[−0.58, −0.34]*	*<0.001*	−0.70	0.65	−1.08	[−2.07, 0.68]	0.30
Character recognition vs. Character recognition + comprehension	0.09	1.20	0.08	[−2.44, 2.62]	0.94	20.66	12.36	1.67	[−5.55, 46.86]	0.11
Age × Character recognition vs. character recognition + comprehension	0.02	0.11	0.14	[−0.22, 0.26]	0.89	−1.78	1.06	−1.68	[−4.03, 0.47]	0.11
	Phonological Awareness					Rapid Naming				
	β	SE	t	95 % CI	p value	β	SE	t	95 % CI	p value
Age	−0.04	0.15	−0.23	[−0.34, 0.27]	0.82	*1.53****	*0.27*	*5.62*	*[0.97, 2.10]*	*<0.001*
Location (Mainland vs. Hong Kong)	−0.43	1.98	−0.22	[−4.47, 3.62]	0.83	7.17	3.97	1.81	[−1.06, 15.40]	0.09
Age × Location	0.07	0.18	0.39	[−0.30, 0.44]	0.71	−0.53	0.35	−1.53	[−1.24, 0.19]	0.14
Severity of RD	*−0.33***	*0.14*	*−2.31*	*[−0.62, −0.04]*	*0.03*	*−0.52****	*0.11*	*−4.63*	*[−0.76, −0.29]*	*<0.001*
Character recognition vs. Character recognition + comprehension	−0.75	0.80	−0.94	[−2.37, 0.87]	0.36	*21.68****	*3.62*	*5.99*	*[14.17, 29.19]*	*<0.001*
Age × Character recognition vs. Character recognition + comprehension	0.06	0.07	0.82	[−0.09, 0.21]	0.42	*−1.62****	*0.27*	*−6.00*	*[−2.18, −1.06]*	*<0.001*
	Short-term Memory					Working Memory				
	β	SE	t	95 % CI	p value	β	SE	t	95 % CI	p value
Age	−0.03	0.12	−0.24	[−0.29, 0.23]	0.82	0.28	0.70	0.40	[−1.52, 2.08]	0.70
Location (Mainland vs. Hong Kong)	−2.36	2.67	−0.88	[−7.97, 3.26]	0.39	7.43	11.04	0.67	[−20.95, 35.81]	0.53
Age × Location	0.23	0.24	0.95	[−0.28, 0.73]	0.36	−0.60	0.85	−0.70	[−2.79, 1.59]	0.51
Severity of RD	−0.07	0.10	−0.71	[−0.29, 0.15]	0.49	0.09	0.25	0.37	[−0.56, 0.74]	0.73
Character recognition vs. Character recognition + comprehension	−0.20	2.26	−0.09	[−4.94, 4.54]	0.93	33.06	64.82	0.51	[−133.56, 199.67]	0.63
Age × Character recognition vs. Character recognition + comprehension	−0.01	0.20	−0.03	[−0.43, 0.41]	0.97	−3.01	5.97	−0.50	[−18.36, 12.33]	0.64
	Visual Skills					Motor Skills				
	β	SE	t	95 % CI	p value	β	SE	t	95 % CI	p value
Age	−0.01	0.19	−0.06	[−0.42, 0.40]	0.96	–	–	–	–	–

Table 2 (continued)

Location (Mainland vs. Hong Kong)	0.45	2.11	0.21	[−3.96, 4.86]	0.83	–	–	–	–	–
Age × Location	−0.01	0.17	−0.03	[−0.37, 0.36]	0.98	–	–	–	–	–
Severity of RD	*−0.35***	*0.11*	*−3.34*	*[−0.57, − 0.13]*	*0.003*	–	–	–	–	–
Character recognition vs. Character recognition + comprehension	0.66	2.93	0.02	[−5.47, 6.79]	0.82					
Age × Character recognition vs. Character recognition + comprehension	−0.05	0.26	−0.17	[−0.59, 0.50]	0.86	–	–	–	–	–

All moderators were entered in one model simultaneously. Between-study sampling variance (τ^2) ranges 0.02~1.65 for all models. Moderation analyses were not conduct for motor skills, because there were not many effect sizes for location (Mainland) and type of reading screening (character recognition vs. character recognition + comprehension) for motor skills

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

Domain Effects on Phonological Awareness, Memory, and Rapid Naming

Next, we examined compared to A-TD children, whether RD children's deficits in phonological awareness, memory, and rapid naming differ by domain. As Table 3 shows, for phonological awareness, there is no difference among measurements of syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing. For short-term memory and working memory, there was no difference between verbal and nonverbal tasks. However, for rapid naming, tasks that use digits or letters seem to show stronger relation with RD in Chinese than tasks on characters. In other words, Chinese children with RD have more severe rapid digit/letter naming deficits than rapid character naming deficits. To sum, we did not find that domain effects on phonological awareness, short-term memory, or working memory. For rapid naming, the RD group demonstrate more severe rapid digit/letter naming deficits than rapid character naming deficits.

Publication Bias and Sensitivity Analysis

As mentioned, we used the method of Egger et al. (1997) to examine publication bias for the comparison between RD and TD groups (i.e., publication bias may exist, if the standard errors of effect sizes significantly predict effect sizes among studies with ROBUMETA in Stata). Results on the comparison between RD and A-TD showed that there was no publication bias for the analysis on short-term memory, morphological awareness, and motor skills, $t = -1.85$–1.50, $ps > 0.07$. However, publication bias may exist for the analysis on orthographic knowledge, phonological awareness, working memory, visual skills, and rapid naming, $\beta = -8.34$–2.17, $ps < 0.05$. Funnel plots were further used to detect the possible bias pattern. As Fig. 2

Table 3 The analysis on the domain effects within phonological awareness, rapid naming, short-term memory, and working memory for the comparison between RD and A-TD children

	k	ES	ES/coeff 95 % CI	τ^2	Subgroup comparison on deficits severity
Phonological Awareness					
1. Syllable	46	−1.12	[−1.83, −0.42]	1.42	1 = 2 = 3 = 4
2. Onset-rime	70	−1.10	[−1.41, −0.79]	0.43	
3. Tone	25	−1.36	[−1.98, −0.73]	1.65	
4. Phoneme	21	−0.80	[−1.03, −0.57]	0.06	
Rapid Naming					
1. Digits	71	−1.22	[−1.52, −0.92]	0.52	1, 5 > 4
2. Pictures/objects	33	−0.72	[−0.96, −0.48]	0.13	
3. Colors	11	−1.10	[−1.60, −0.60]	0.14	
4. Characters	13	−0.81	[−1.02, −0.60]	0.07	
5. Letters	16	−1.30	[−1.99, −0.61]	0.28	
Short-term Memory					
1. Verbal	61	−0.78	[−0.95, −0.61]	0.25	1 = 2
2. Nonverbal	26	−0.61	[−0.88, −0.35]	0.11	
Working Memory					
1. Verbal	34	−1.27	[−1.64, −0.89]	0.34	1 = 2
2. Nonverbal	14	−1.11	[−2.10, −0.11]	0.51	

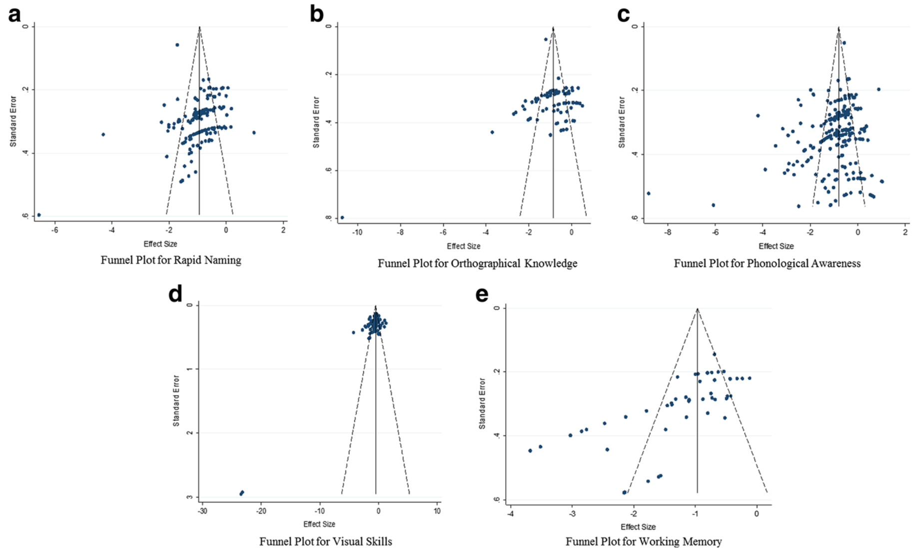

Fig. 2 Funnel plots for the comparison between children with reading difficulties and age-matched typically developing controls: **a** funnel plot for rapid naming, **b** funnel plot for orthographical knowledge, **c** funnel plot for phonological awareness, **d** funnel plot for visual skills, and **e** funnel plot for working memory

shows, the funnel plots indicate that we may lack small-scale studies that reported Chinese children with RD outperformed A-TD children on rapid naming and working memory. The funnel plots also indicate that outliers existed for orthographic knowledge (Hedges $g < -3.00$), phonological awareness (Hedges $g < -3.00$), visual skills (Hedges $g < -20.00$), working memory (Hedges $g < -2.00$), and rapid naming (Hedges $g < -4.00$). After excluding all those outliers, the test of publication bias was no longer significant for those skills except for rapid naming. Furthermore, sensitivity analysis showed that after excluding all those outliers, the pattern results stayed the same.

Results on the comparison between RD and R-TD showed that there was no publication bias for the analysis on morphological awareness, motor skills, orthographic skills, and working memory, $t = -1.95$–2.19, $ps > 0.06$. However, publication bias may exist for the analysis on phonological awareness, rapid naming, short-term memory, and visual skills, $t = -7.32$–2.54, $ps < 0.05$. Funnel plots were further used to detect the possible bias pattern. The funnel plots indicate that we may lack large-scale studies that reported on phonological awareness, rapid naming, and short-term memory. The funnel plots also indicate that outliers existed for phonological awareness (Hedges $g < -1.00$), rapid naming (Hedges $g > 0$), visual skills (Hedges $g < -20.00$), and short-term memory (Hedges $g < -1.00$). After excluding all those outliers, the test of publication bias was no longer significant for those skills except for visual skills and short-term memory. Furthermore, sensitivity analysis showed that after excluding all those outliers, the pattern results stayed the same (Fig. 3).

Moreover, we noticed that two studies had a large difference in sample size between groups (i.e., the number of children in one group is below 30 and the number of children in the comparison group is above 140) (i.e., Lei et al. 2011; Lam et al. 2011). Group comparisons based on unequal sample size tend to produce large standard errors and thus decrease the power to detect significant group differences. We ran the sensitive analysis by excluding those two studies, and our pattern results stayed unchanged.

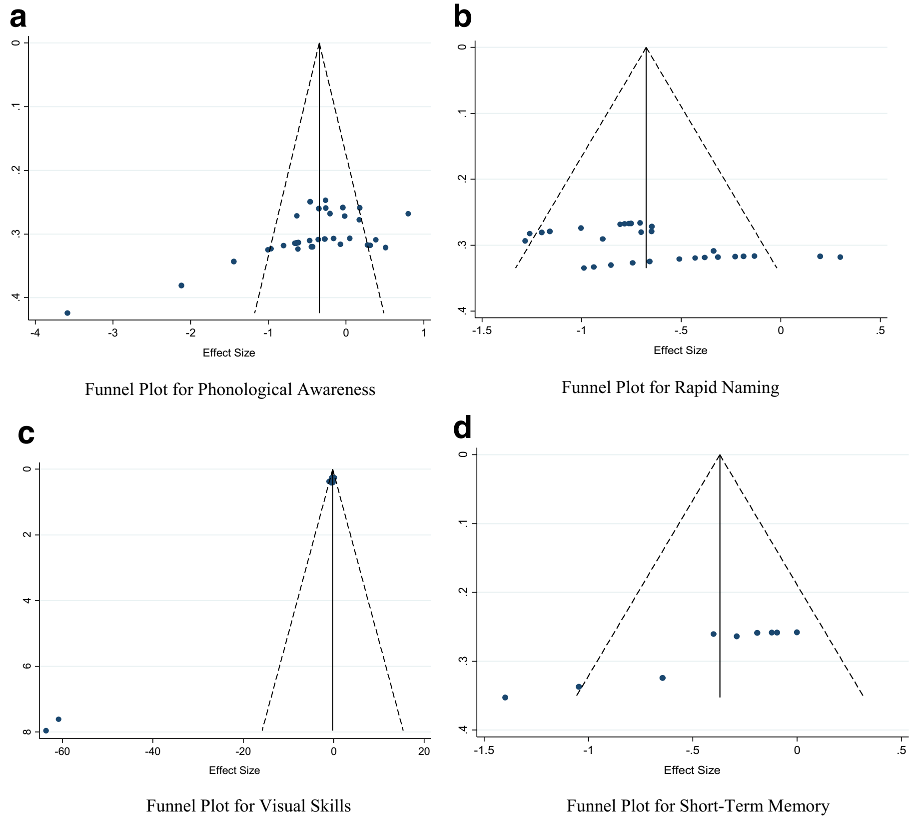

Fig. 3 Funnel plots for the comparison between children with reading difficulties and reading-level-matched typically developing controls: **a** funnel plot for phonological awareness, **b** funnel plot for rapid naming, **c** funnel plot for visual skills, and **d** funnel plot for short-term memory

Discussion

The present meta-analysis investigated the deficit profiles of Chinese children with RD. Compared to A-TD children, Chinese children with RD had severe deficits in phonological awareness, rapid naming, working memory, orthographic knowledge, morphological awareness, and visual skills and moderate deficits in short-term memory and motor skills. However, when compared to R-TD children, the children with RD had only moderate deficits in rapid naming and mild deficits in orthographic knowledge. For the comparison between the RD and A-TD groups, the presence of more severe RD was related to more severe deficits in morphological awareness, phonological awareness, rapid naming, and visual skills. Rapid digit/letter naming deficits were more salient than rapid character naming deficits. There were no differences in the severity of deficits in syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing, nor were there any differences in severity between verbal and nonverbal short-term memory/working memory deficits.

Ho et al. (2002) suggest that Chinese children with RD have deficits in multiple linguistic and cognitive domains such as rapid naming, visual processing, phonological awareness, and orthographic knowledge. The rapid naming deficit was the most dominant. Our findings are in line with Ho et al. (2002). We extend their findings by suggesting that Chinese children with RD also have very severe deficits in morphological awareness and working memory, which is also consistent with more recent profiling studies among Chinese children with RD (e.g., Shu et al. 2006; Peng et al. 2013). Moreover, our findings indicate that deficits in morphological awareness, orthographic knowledge, visual skills, and working memory are also salient among Chinese children with RD.

Type of Control

The difference between the RD and A-TD groups on a cognitive skill may indicate that RD have deficits in that skill, which is associated with reading problems. The difference between the RD and R-TD groups on a cognitive skill could rule out the explanation that better reading skills and more reading experience are responsible for the observed differences in that cognitive skill (Goswami and Bryant 1989). The deficits in cognitive skills as suggested by the comparison between RD and R-TD may be potential causal factors in poor reading (Goswami and Bryant 1989). In this study, we included both A-TD and R-TD groups as controls. We found that although children with RD show comprehensive deficits compared to A-TD children, they only show selective deficits in rapid naming and orthographic knowledge compared to R-TD children. This finding suggests that RD in Chinese are associated with deficits in phonological awareness, rapid naming, working memory, orthographic knowledge, morphological awareness, short-term memory, and motor skills and that the deficits in rapid naming and orthographic knowledge could be causal factors for RD in Chinese. One possible explanation for this finding is that low naming speed may be an indication of the disruption of the automatic processes involved in the extraction and induction of orthographic patterns (e.g., Wolf 1991; Wolf et al. 1986; Yap and Van der Leij 1993), which may directly cause RD as suggested by some researchers (Badian 1997).

Domain Effects

For the deficit profiles of rapid naming, phonological awareness, short-term memory, and working memory, we also investigated whether there were domain effects. For rapid naming, we found that Chinese poor readers, compared to their A-TD peers, have difficulties in the domains of speed-naming digits, letters, pictures/objects, colors, and characters. This finding may indicate that Chinese children with RD have domain-general deficits in naming speed, which may reflect their deficits in orthographic pattern process and retrieval (e.g., Wolf 1991; Wolf et al. 1986; Yap and Van der Leij 1993). However, there is also research showing that rapid naming continues to predict reading over and above the effects of orthographic knowledge (Ho et al. 2004; Liao et al. 2008; Li et al. 2012). Taken together, these findings suggest that Chinese children with RD may have domain-general retrieval deficits that relate to their reading problems.

We also found that the rapid digit and letter naming deficits are more related to RD than character naming deficits. This finding is consistent with the majority of rapid naming studies, which show that alphanumeric (digit and letter) rapid naming has a stronger relationship with reading than nonalphanumeric rapid naming (Bowey et al. 2005; Cardoso-Martins and

Pennington 2004). One possible explanation is that the major share of reading tapped by the rapid naming tasks may be the degree of automaticity in print-to-sound conversion for various materials (i.e., the relative ease of directly accessing phonological representations from print), and alphanumeric rapid naming tasks predict reading better than nonalphanumeric rapid naming tasks because alphanumeric stimuli are more likely automatically processed (Meyer et al. 1998; Wolf et al. 1986).

However, in a recent meta-analysis on the relation between rapid naming and Chinese reading among typically developing children, Song et al. (2016) found that graphological (i.e., digits and characters) rapid naming showed a stronger relation with Chinese reading accuracy than did nongraphological (i.e., objects and colors) rapid naming. Thus, our findings are not completely in line with Song et al. (2016). There are several possible reasons. One may be that Song et al. (2016) combined rapid digit naming and rapid character naming tasks into one graphological rapid naming task, and thus, their findings cannot reveal fine-grained differences in the relations between reading and rapid naming of digits and of characters. Second, Song et al. (2016) selected only those studies that measured both phonological awareness and rapid naming, and thus, their findings based on this selective pool may not reflect the whole picture of the relation between Chinese reading and rapid digit/rapid character naming.

Another possible reason may be that character learning is a more difficult task than digit/letter learning and lasts during the entire childhood. Thus, children may process characters less automatically than they do for digits and letters. That is, rapid character naming may capture less of the variation in automaticity on the access from print to phonological presentation than does rapid digits/letters naming. If this hypothesis is true, then age/reading experience would moderate differences between digits/letters and characters in the correlation of rapid naming skills with reading. Unfortunately, we could not address this issue due to a small number of effect sizes for rapid character naming in this study ($n = 13$). Thus, future studies should systematically investigate the graphological material differences (digits, letters, and characters) on rapid naming for Chinese reading and whether age/reading experience moderates these differences.

Regarding phonological awareness, we investigated whether the deficit profiles for phonological awareness were influenced by different domains, including syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing. Because syllable awareness, onset-rime awareness, and tonal processing skills are theoretically important for Chinese word recognition (Ho et al. 2000; Li and Ho 2011; Zhou et al. 2014), we hypothesized that Chinese poor readers may have more severe deficits in these areas than in phonemic awareness. However, we found that Chinese children with RD show deficits in syllable awareness, onset-rime, tonal processing, and phonemic awareness to a similar extent. This finding indicates that poor Chinese readers have domain-general deficits in phonological awareness and further suggests that phonological awareness deficits are not greatly influenced by the structure of the Chinese language.

This finding is partly in line with the findings from studies that showed children's sensitivity to different linguistic units may be best conceptualized as a single underlying ability (e.g., Anthony and Lonigan 2004; Anthony et al. 2002; Branum-Martin et al. 2015). For example, based on a meta-analysis with structural equational modeling, Branum-Martin et al. (2015) studied the structure of phonological awareness in English, Spanish, Korean, and Chinese, including syllable awareness, onset-rime awareness, phonemic awareness, and tonal processing. Their models indicated that phonological awareness is a unitary construct across Chinese and other languages. Their findings, together with ours, indicate that poor reading among Chinese children with RD may be associated with a domain-general deficit in constructing phonological representations of linguistic materials. However, our findings and those from Branum-Martin et al. (2015) may not be able to reveal the relative importance of and interactions between each domain in phonological awareness for RD in Chinese. Specifically, Li and Ho (2011) found that Chinese children with RD have deficits in rhyming awareness and tone awareness to a similar degree. However, when performing learning tasks that involved associating verbal names with visual figures, children with RD actually grasped the rhymes faster than they did for the tonal information. Li and Ho (2011) argued that tonal information may act as supplementary information, building upon the existing segmental information (e.g., onset and rhymes) to enrich the phonological representation of newly learned characters. Following this logic, more studies are needed to further investigate how the domains of Chinese phonological awareness interact with each other and how these interactions contribute to RD in Chinese and Chinese reading development.

With respect to short-term memory and working memory, we found that deficits in these skills are comparable in both verbal and nonverbal domains, suggesting that Chinese children with RD have domain-general deficits in their memory abilities. The deficits in both short-term memory and working memory may disturb the process of building strong associations among orthography, sound, and meaning of characters (e.g., Ho et al. 2000; Gathercole et al. 1991) and may also likely contribute to reading comprehension difficulties among Chinese poor readers (e.g., Peng et al. 2013). The domain-general deficits in working memory, in particular, may also indicate that Chinese children with RD have problems in high-level cognitive skills such as executive functions, which are often considered the core of working memory (e.g., Baddeley 1986; Peng et al. 2013). In future research, it would be interesting to determine whether different components of executive functions in working memory are impaired among Chinese children with RD.

Age, Location, Severity of RD, and Type of Reading Screening

Lei et al. (2011) found that age may affect deficit profiles for different types of children who are at risk for RD. However, in this study, we did not find that age was a significant moderator for the deficit profiles of most skills, except for rapid naming. One possible reason is that unlike Lei et al. (2011), which only included children from age 3.4 to 8.4, we included children from a much wider span of 3–14 years old. However, we found that age significantly influenced the deficit profiles of rapid naming and that age interacted with the type of reading screening. In particular, we found that young children who were identified for RD based on character recognition and comprehension skills showed more severe deficits in rapid naming than children identified by character recognition only. These findings suggest that deficits in rapid naming skills are age-sensitive (e.g., Meyer et al. 1998; Wolf et al. 1986) such that young children with RD in Chinese show more severe deficits in rapid naming than their older peers. Moreover, if young children with RD have more comprehensive reading problems (identified by reading comprehension and character recognition), they are more likely to show more severe rapid naming deficits. That said, studies are needed to investigate whether this interaction between age and rapid naming is caused by maturation or reading-related experiences.

Mainland and Hong Kong differ in spoken language, writing scripts, and early reading instructions. Thus, we think location (Mainland vs. Hong Kong) may be an important factor contributing to the deficit profiles of RD in Chinese. However, we did not find that location affected the deficit profiles of Chinese children with RD. One possible explanation is the increasing homogeneity of the early reading environment in those two locations. We noticed that the majority of the RD in Chinese studies from Mainland China were conducted in recent years (2009~2014). In recent years, reading instruction for Mainland children tends to start early at home and in kindergartens, preschools, and private early childhood education institutions. It is quite common for children 3–5 years old in Mainland to spend time learning to read/write characters without systematically learning Pinyin (e.g., Lau et al. 2011; Li et al. 2011). Thus, early reading practice in Mainland has become increasingly similar to the whole word approach for early reading instructions in Hong Kong, and this may decrease the influence of writing scripts on the deficit profiles among RD children. Moreover, both Hong Kong and Mainland emphasize English education early on (Cheung and Ng 2003). Previous research has clearly demonstrated "transfer" in phonological processing across languages (Comeau et al. 1999), including Chinese (Gottardo et al. 2001). Thus, early experiences with learning English in both Hong Kong and Mainland may decrease the influence of oral language differences on the deficit profiles among RD children. That being said, our hypothesis for this effect of a more homogeneous early reading environment in Mainland and Hong Kong should be further investigated in future studies.

Based on the characteristics of the reading screening measures used in the majority of studies we reviewed, we focused on comparing studies that used character recognition as the screening measure and those that used character recognition combined with comprehension. We found that the type of reading screening did not influence the deficit profiles except for rapid naming. One plausible reason for the null findings on the majority of skills relates to the character recognition measure used by most studies. Specifically, most of the studies we reviewed from Mainland China used the Character Recognition Measure and Assessment Scale for Primary School Children (CRM) (Wang and Tao 1993) as a reading screening measure. This measure requires children to compose a word with a given character and therefore also involves comprehension at the character level. It is likely that the comprehension of character in the CRM may tap comprehension to some extent. Conversely, it may also be true that the comprehension tasks draw a lot on character recognition or vocabulary but not on higher level cognitive skills such as inference generation (e.g., Kendeou et al. 2012). However, among all reviewed studies that provided information on their reading comprehension screening measures, few clearly explained what those reading comprehension measures look like or what aspects of comprehension abilities were tapped. Thus, whether different Chinese reading comprehension measures may affect deficit profiles of RD in Chinese still warrant further research.

Another possible reason is that most studies that used character recognition as a reading screening measure did not provide information about the comprehension ability of their RD sample. It is likely that the poor "decoders" identified by those studies may have comprehension deficits as well. To sum, research is still needed to examine whether the deficit profiles of Chinese children with RD differ among RD subtypes (children with only character recognition problems vs. children with only comprehension problems).

As expected, almost all the studies reviewed identified children as having RD if their IQs were within a normal range but their performance was below a cutoff point on reading screening measures. Although this low-achievement identification approach has been widely adopted in the area of learning difficulties, it has one major problem—the inconsistent cutoff criteria on the academic screening measures (Fuchs et al. 2003). Indeed, the cutoff criterion used to establish RD in the studies we reviewed varied from the 35th percentile to less than the 5th percentile (e.g., Peng et al. 2013; Liu et al. 2014; Huang et al. 2007). Branum-Martin et al. (2013) found that the patterns of cognitive profiles are a product of the cut points and the correlational structure of the data in reading and cognitive skills, indicating relations between the cognitive profiles of children with learning difficulties and the achievement cutoff criterion. Similarly, Murphy et al. (2007) found that there were qualitative group differences in the profiles of math-related cognitive skills across groups defined by different cutoff scores (11th percentile and 25th percentile on math measures). Children with less severe mathematics difficulties appeared to show less severe cognitive deficits than children with more severe mathematics difficulties. Our findings are consistent with Branum-Martin et al. (2013) and Murphy et al. (2007), indicating that different cutoff points may lead to different degrees of RD, which influences the deficit profiles of Chinese children with RD. In this study, the severity of deficits in morphological awareness, phonological awareness, rapid naming, and visual skills is related to the severity of RD, whereas deficits in orthographic knowledge, short-term memory, working memory, and motor skills are relatively independent of RD severity.

Limitations

Our findings are based on the combined results of 81 studies conducted with more than 9000 Chinese children. Despite the scale of our literature search and the sample size, we note several limitations when interpreting our findings. First, due to the small number of studies that reported comparisons between the RD and R-TD groups, we could not run moderation analyses on these comparisons. We may also be underpowered for some comparisons between RD and R-TD on skills such as morphological awareness (11 effect sizes), short-term memory (9 effect sizes), working memory (5 effect sizes), and motor skills (5 effect sizes). Thus, the profiles comparing RD to R-TD in this study would be regarded as exploratory in nature and warrant further investigation.

Likewise, because only six studies conducted in Taiwan met our inclusion criteria, we did not include Taiwan as a subcategory of location for the moderation analysis. The Chinese language and reading instruction in Taiwan are different from those in Hong Kong and Mainland. Most children in Taiwan can speak both Minnan and Mandarin, which are not mutually intelligible despite their few phonological similarities (Luo 2005). Also, Taiwan has adopted a supplemental phonetic and semi-alphabetic writing system (Zhuyin Fuhao, ZF) in all textbooks of the first four grades in elementary schools. ZF provides a simple phonetic spelling system to help children retrieve lexical information about Chinese characters. Thus, the unique feature of language and instruction in Taiwan may contribute to the deficit profiles of Chinese children with RD (Yeh 2012). Moreover, because children from Taiwan read traditional Chinese characters with the phonetic system, while children from Hong Kong read traditional Chinese characters without the phonetic system and children from Mainland read simplified Chinese characters with the phonetic system, there may be interaction effects of phonetic system and written script on Chinese reading for children from different regions (Chen and Yuen 1991). Thus, more research should be done in Taiwan to examine this instruction-by-script interaction effect on deficit profiles of RD in Chinese.

Second, it is very common that RD co-occur with other disabilities such as language impairment, mathematics difficulties, and attention deficits (e.g., Fuchs and Fuchs 2002; Tomblin et al. 2000; Willcutt and Pennington 2000). Compared to children with RD only, children who have RD and other disabilities tend to demonstrate more comprehensive and severe cognitive deficits (e.g., Cirino et al. 2015). Among the studies reviewed, only two specifically mentioned including RD children who also have specific language impairment (i.e., Wong et al. 2010, 2015), seven mentioned including children with RD only (i.e., Cheng and Gong 1998, 1999; Chen et al. 2001; Lu 1994; Peng et al. 2013; Qian and Bi 2014; Wang and Liu 2007), and four mentioned including children with RD and mathematics difficulties (i.e., Cheng and Gong 1998, 1999; Peng et al. 2013; Wang and Liu 2007). The majority of studies reviewed did not provide very specific information about whether their RD sample has disabilities in other areas (Most studies claimed that their RD sample did not have medical or physical disabilities or have obvious attention deficits). Thus, it is likely that unreported comorbidity from reviewed studies may affect our findings. In particular, the deficit severity of different cognitive and linguistic skills may be related to comorbidity or a specific comorbidity type (e.g., RD children with attention deficit may demonstrate more severe deficits in working memory than RD-only children). This hypothesis should be investigated in future studies.

Third, we found that almost all studies included in this review stated that RD and TD groups have IQ in the normal range, with a handful of studies ($n = 53$) providing information that the RD group and the A-TD group have comparable IQ scores. Among those 53 studies, the IQ tests used varied substantially (e.g., verbal IQ, nonverbal IQ, or verbal and nonverbal IQ combined). Thus, although all children in our review were reported to have normal IQs, we cannot strictly control for the effect of IQ, especially the effect of verbal IQ, which may affect the deficit profiles of RD in Chinese, especially for RD identified with reading comprehension measures.

Fourth, although we searched for unpublished studies (e.g., dissertation and conference articles), most studies that met the inclusion criteria for this review were peer-reviewed journal articles. Although our publication bias test was majorly influenced by outliers, our funnel plots may indicate that we still lack large-scale studies that reported comparisons between poor readers and good readers on the skills investigated. Last, the profiling research is just one step in delineating the causal factors in RD.

Synthesis of studies from longitudinal, intervention, and neuroscience research could help better shape the pictures of deficit profiles that lead to RD (e.g., Goswami and Bryant 1989; Hoeft et al. 2006).

Implications for Education

With these limitations in mind, the present study is the first meta-analysis to systematically investigate the deficit profiles among Chinese children with RD. These findings may have implications for improving the accuracy of diagnosing RD in Chinese in general. That is, in addition to giving the traditional reading screening focused on character recognition and comprehension, the accuracy of diagnosis might be improved by conducting reading screenings of skills with salient deficits among RD in Chinese children such as morphological awareness, orthographic knowledge, rapid naming, phonological awareness, and working memory.

Our findings may have implications for interventions for Chinese children with RD. Specifically, Chinese reading instruction should emphasize phonological awareness, orthographic knowledge, and morphological awareness. Given the salient deficits in rapid naming and orthographic knowledge, reading intervention for Chinese children with RD may consider the drill-and-practice approach. Repeated practice on character learning may help children retrieve character information faster and may strengthen their mental presentation of orthographic knowledge.

In the meanwhile, we should consider different instructional strategies to compensate for RD children's domain-general deficits in visual processing, motor skills, and memory. For example, a multimedia and multisensory approach of instruction may help reduce the learning load on visual, motor, and memory. Alternatively, we can directly address domain-general deficits among children with RD to improve their reading performance. For example, working memory training has recently received a lot of attention in the area of special education (e.g., Jacob and Parkinson 2015). Although few studies of working memory training have found that the training effects transfer to academic skills, researchers believe that training academic skills together with training working memory can improve the academic performance of children with severe learning difficulties (e.g., Peng and Fuchs 2015). We found that Chinese children with RD have severe deficits not only in linguistic skills but also in working memory, which suggest that training reading-related skills and working memory skills together may be an effective instructional approach. This "hybrid" approach may be especially important for children with RD who do not respond to evidence-based skill training because of their limited working memory capacity. That said, more intervention research is needed to investigate whether cognitive-linguistic training would produce synergistic effects on reading among Chinese children with RD.

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Appendix

Table 4 Study characteristics

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
Bai et al. (2011)	Journal	Mainland	11.8	11	Insufficient info	15	13	Character recognition vs. character recognition + comprehension	−2.00
Chan et al. (2004)	Journal	Hong Kong	8.33	102	Insufficient info	148		Character recognition	N/A
Chan et al. (2006)	Journal	Hong Kong	8.14	1235	Insufficient info	591		Character recognition	N/A
Chang (1989)	Dissertation	Mainland	N/A	16	RD only	16		Character recognition vs. character recognition + comprehension	N/A
Cheng and Gong (1998)	Journal	Mainland	10.72	31	RD only	63		Character recognition vs. character recognition + comprehension	−3.21
			10.55	45	RD only	63		Character recognition vs. character recognition + comprehension	−3.07
Cheng and Gong (1999)	Journal	Mainland	10.72	31	RD only	63		Character recognition vs. character recognition + comprehension	N/A
			10.55	45	With mathematics difficulties	63		Character recognition vs. character recognition + comprehension	N/A
Chen et al. (2001)	Journal	Mainland	10	172	RD only	61		Character recognition vs. character recognition + comprehension	N/A
Cheng et al. (2011)	Journal	Taiwan	7.9	37	With developmental coordination disorder	93		Character recognition vs. character recognition + comprehension	−1.79
Cheung et al. (2009)	Journal	Hong Kong	10.42	30	Insufficient info	30	30	Character recognition	−1.31
Chik et al. (2012)	Journal	Hong Kong	9.76	101	Insufficient info	101	101	Character recognition	−1.73

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
Chung and Ho (2010)	Journal	Hong Kong	9.75	28	Insufficient info	28	28	Character recognition	−2.06
Chung et al. (2008)	Journal	Hong Kong	8.91	26	RD only	26	28	Character recognition	−1.25
Chung et al. (2010)	Journal	Hong Kong	13.66	27	Insufficient info	27	27	Character recognition vs. character recognition + comprehension	−1.65
Chung et al. (2011)	Journal	Hong Kong	13.65	30	Insufficient info	30	30	Character recognition vs. character recognition + comprehension	−1.68
Chung et al. (2013)	Journal	Hong Kong	13.87	26	Insufficient info	26	26	Character recognition vs. character recognition + comprehension	−1.82
Chung et al. (2014)	Journal	Hong Kong	13.36	52	Insufficient info	52		Character recognition vs. character recognition + comprehension	−2.31
Deng et al. (2011)	Journal	Mainland	10.45	18	With ADHD	18		Character recognition	N/A
Ding et al. (2011)	Journal	Mainland	10.77	18	Insufficient info	64		Character recognition	N/A
	Journal	Mainland	10.77	18	Insufficient info	20		Character recognition	N/A
Dong et al. (2012)	Journal	Mainland	10.31	47	RD only	43		Character recognition	−2.54
Goswami et al. (2010)	Journal	Taiwan	10.02	26	RD only	29	18	Character recognition	−1.93
Han and Maihepulaiti (2012)	Journal	Mainland	10.44	35	RD only	27		Character recognition	−5.79
	Journal	Mainland	10.22	28	RD only	27		Character recognition	−4.34
Ho and Fong (2005)	Journal	Hong Kong	9.4	25	RD only	25		Character recognition	N/A
Ho and Lai (1999)	Journal	Hong Kong	8.77	20	RD only	20	20	Character recognition	−0.89
Ho and Yan (2014)	Journal	Hong Kong	9.07	53	Insufficient info	44		Character recognition	−4.41
Ho et al. (2000)	Journal	Hong Kong	8.3	33	RD only	33	33	Character recognition	−2.33

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
Ho et al. (2002)	Journal	Hong Kong	8.67	30	RD only	30	30	Character recognition	−2.55
Ho et al. (2004)	Journal	Hong Kong	8.28	147	RD only	78		Character recognition	−1.22
			8.29	78		78		Character recognition	−1.30
Ho et al. (2007)	Journal	Hong Kong	9.05	29	RD only	29	29	Character recognition	−2.34
Huang et al. (2007)	Journal	Mainland	10.15	20	RD only	20		Character recognition vs. character recognition + comprehension	N/A
Jiang et al. (2008)	Journal	Mainland	11.49	9	Insufficient info	10		Character recognition	N/A
Lam et al. (2011)	Journal	Hong Kong	7.76	24	RD only	147		N/A	N/A
			8.81	34	RD only	153		N/A	N/A
			9.78	30	RD only	156		N/A	N/A
			10.76	31	RD only	159		N/A	N/A
			11.76	18	RD only	141		N/A	N/A
Lei et al. (2011)	Journal	Mainland	3.4	14	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			4.4	14	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			5.4	14	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			6.4	14	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			3.4	32	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			4.4	32	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
			5.4	32	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			6.4	32	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			3.4	31	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			4.4	31	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			5.4	31	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
			6.4	31	Insufficient info	184		Character recognition vs. character recognition + comprehension	N/A
Leung and Ho (2009)	Journal	Hong Kong	10.05	20	Insufficient info	20	20	Character recognition	−2.23
Li and Cao (2014)	Journal	Taiwan	8.44	20	RD only	20		Character recognition vs. character recognition + comprehension	−1.95
Li and Ho (2011)	Journal	Hong Kong	8.92	20	Insufficient info	20	20	Character recognition	−1.72
Li et al. (2009)	Journal	Mainland	11.68	41	RD only	41		Character recognition	−2.33
Li et al. (2011)	Journal	Mainland	9.7	19	RD only	19		Character recognition vs. character recognition + comprehension	N/A
Li (2006)	Unpublished Manuscript	Mainland	11.69	41	Insufficient info	41	28	Character recognition	−2.31
Liao et al. (2015)	Journal	Taiwan	10.23	30	Insufficient info	30		Character recognition	−3.09
Li-Tsang et al. (2012)	Journal	Hong Kong	9.51	10	RD only	10		Character recognition	N/A

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
Liu et al. (2012)	Journal	Mainland	11.9	11	RD only	11		Character recognition	−3.47
Liu et al. (2014)	Journal	Mainland	N/A	21	RD only	21		Character recognition	N/A
Liu et al. (2006)	Journal	Mainland	10.43	29	RD only	26		Character recognition	−4.32
Lu (1994)	Dissertation	Taiwan	10.77	27	Insufficient info	29		Character recognition vs. character recognition + comprehension	−2.04
			10.79	20	Insufficient info	20		Character recognition vs. character recognition + comprehension	−1.09
			11.01	15	Insufficient info	21		Character recognition vs. character recognition + comprehension	−2.86
Lu and Wu (2007)	Journal	Mainland	N/A	55	Insufficient info	110		Character recognition vs. character recognition + comprehension	N/A
McBride-Chang et al. (2008)	Journal	Hong Kong	5.1	36	Insufficient info	36		Character recognition vs. character recognition + comprehension	−9.36
			5.1	36	Insufficient info	36			−5.78
McBride-Chang et al. (2011b)	Journal	Hong Kong	9.22	21	Insufficient info	33		Character recognition	−1.42
McBride-Chang et al. (2011a)	Journal	Hong Kong	5.07	26	RD only	47		Character recognition	−2.30
	Journal	Hong Kong	5.07	21	RD only	47		Character recognition	−0.65
McBride-Chang et al. (2012)	Journal	Hong Kong	5.05	16	Insufficient info	16		Character recognition	−2.24
			6.05	16	Insufficient info	16		Character recognition	−2.24
			7.05	16	Insufficient info	16		Character recognition	−2.24
			8.05	16	Insufficient info	16		Character recognition	−2.24
			9.05	16	Insufficient info	16		Character recognition	−2.24
			5.05	8	Insufficient info	16		Character recognition	−2.24

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
			6.05	8	Insufficient info	16		Character recognition	−2.24
			7.05	8	Insufficient info	16		Character recognition	−2.24
			8.05	8	Insufficient info	16		Character recognition	−2.24
			9.05	8	Insufficient info	16		Character recognition	−2.24
McBride-Chang et al. (2013)	Journal	Mainland + Hong Kong + Taiwan	4.44	44	Insufficient info	44		Character recognition	−1.34
			5.39	44	Insufficient info	44		Character recognition	−1.34
			6.4	44	Insufficient info	44		Character recognition	−1.34
			7.42	44	Insufficient info	44		Character recognition	−1.34
			8.44	44	Insufficient info	44		Character recognition	−1.34
Meng et al. (2011)	Journal	Mainland	10.32	27	Insufficient info	27		Character recognition	−2.33
Pan et al. (2013)	Journal	Mainland	10.65	30	Insufficient info	26		Character recognition	−4.24
Pan et al. (2014)	Journal	Mainland	10.65	33	Insufficient info	29		Character recognition	−4.25
Peng et al. (2013)	Journal	Mainland	11.05	22	RD only	31		Character recognition	−6.99
			11.05	24	With mathematics difficulties	31		Character recognition	−6.54
Penney et al. (2005)	Journal	Hong Kong	N/A	20	Insufficient info	18		Comprehension	N/A
Qian and Bi (2014)	Journal	Mainland	10.2	26	Insufficient info	27		Character recognition	−1.79
Shu et al. (2006)	Journal	Mainland	11.71	75	Insufficient info	77		Character recognition	−2.40
So and Siegel (1997)	Journal	Hong Kong	6.69	12	Insufficient info	26		Character recognition	−2.17
			7.52	12	Insufficient info	26		Character recognition	−2.59
			8.54	12	Insufficient info	26		Character recognition	−3.43
			9.62	12	Insufficient info	26		Character recognition	−3.45

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
			6.69	14	Insufficient info	36		Character recognition	−2.17
			7.52	14	Insufficient info	36		Character recognition	−2.59
			8.54	14	Insufficient info	36		Character recognition	−3.43
			9.62	14	Insufficient info	36		Character recognition	−3.45
Song et al. (2013)	Journal	Mainland	10.25	20	Insufficient info	20		Character recognition	−3.04
Song (2006)	Dissertation	Mainland	N/A	20	Insufficient info	20		Character recognition vs. character recognition + comprehension	N/A
Tong et al. (2014)	Journal	Hong Kong	9.56	15	Insufficient info	10		Character recognition	N/A
Wang and Liu (2007)	Journal	Mainland	14.55	26	RD only	28		Character recognition vs. character recognition + comprehension	−4.18
			14.55	26	With mathematics difficulties	28		Character recognition vs. character recognition + comprehension	−4.40
Wang et al. (2010)	Journal	Mainland	11.37	16	Insufficient info	16	16	Character recognition	−3.87
Wang et al. (2012)	Journal	Taiwan	10.02	26	RD only	29	18	Character recognition vs. character recognition + comprehension	−1.43
Wang et al. (2012a)	Journal	Mainland	10.05	27	RD only	27		Character recognition	−5.20
*Wong, S. W and Ho (2010)	Journal	Hong Kong	10.5	30	Insufficient info	30	30	Character recognition	N/A
Wong et al. (2010)	Journal	Hong Kong	9.11	12	With specific language problems	8		Character recognition	−1.47
			9.1	7	With specific language problems	8		Character recognition	−0.81
			8.15	10	With specific language problems	8		Character recognition	−0.49

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (*n*)	RD comorbidity[a]	A-TD (*n*)	R-TD (*n*)	Type of reading screening	Severity of reading difficulties (Hedges *g*)
Wong et al. (2012)	Journal	Hong Kong	7.3	57	RD only	57		Character recognition	−7.36
Wong et al. (2015)	Journal	Hong Kong	7.17	10	RD only	40		Character recognition	−0.84
			7.07	19	With specific language problems	40		Character recognition	−1.49
			7.17	25	With specific language problems	40		Character recognition	−2.22
Wong (2005)	Dissertation	Hong Kong	10.5	30	Insufficient info	30	30	Character recognition	−1.37
Woo and Hoosain (1984)	Journal	Hong Kong	8.38	13	RD only	13		Character recognition	N/A
Wu and Zou (2008)	Journal	Mainland	10.95	25	RD only	25	25	Character recognition vs. character recognition + comprehension	−1.54
Xiao and Ho (2014)	Journal	Hong Kong	10	30	RD only	30	30	Character recognition	−2.34
Yan et al. (2013)	Journal	Mainland	10.7	35	RD only	28		Character recognition	−3.12
Yang et al. (2009)	Journal	Mainland	11.46	20	Insufficient info	20		Character recognition	−3.51
Yeh (2012)	Dissertation	Taiwan	6.59	16	Insufficient info	25		Character recognition	N/A
			6.59	12	Insufficient info	25		Character recognition	N/A
			6.59	12	Insufficient info	37		Character recognition vs. character recognition + comprehension	N/A
Yeung et al. (2014)	Journal	Hong Kong	6.68	23	Insufficient info	46		Character recognition	N/A
			7.68	23	Insufficient info	46		Character recognition	N/A
			6.68	23	Insufficient info	46		Character recognition	N/A
			7.68	23	Insufficient info	46		Character recognition	N/A
Zhang et al. (2014)	Journal	Mainland	10.25	30	Insufficient info	30			−1.24

Table 4 (continued)

Study ID	Publication type	Location	Age (years)	RD (n)	RD comorbidity[a]	A-TD (n)	R-TD (n)	Type of reading screening	Severity of reading difficulties (Hedges g)
								Character recognition vs. character recognition + comprehension	
			9.02	22	Insufficient info	22		Character recognition vs. character recognition + comprehension	−1.38
Zhao et al. (2012)	Journal	Mainland	9.85	20	Insufficient info	20	20	Character recognition	−7.15
Zheng et al. (2007)	Journal	Mainland	10.55	13	RD only	13		Character recognition vs. character recognition + comprehension	N/A
Zhou et al. (2014)	Journal	Hong Kong	6.26	15	Insufficient info	15		Character recognition	−2.58
			7.52	15	Insufficient info	15		Character recognition	−2.58
			8.24	15	Insufficient info	15		Character recognition	−2.58

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
Bai et al. (2011)							○	
Chan et al. (2004)					○		○	○
Chan et al. (2006)		○	○	○	○			
Chang (1989)							○	
Cheng and Gong (1998)					○	○		
					○	○		
Cheng and Gong (1999)				○				
				○				
Chen et al. (2001)					○			

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
Cheng et al. (2011)								○
Cheung et al. (2009)			○	○				
Chik et al. (2012)						○		
Chung and Ho (2010)	○	○	○	○				
Chung et al. (2008)	○	○	○	○				
Chung et al. (2010)	○	○	○	○		○		
Chung et al. (2011)	○	○		○	○	○	○	
Chung et al. (2013)	○							
Chung et al. (2014)	○			○	○	○		
Deng et al. (2011)					○		○	
Ding et al. (2011)				○	○		○	
				○	○		○	
Dong et al. (2012)	○	○	○	○				
Goswami et al. (2010)								
Han and Maihepulaiti					○		○	
(2012)					○		○	
Ho and Fong (2005)			○	○	○			
Ho and Lai (1999)				○	○			
Ho and Yan (2014)		○			○			
Ho et al. (2000)		○	○					
Ho et al. (2002)		○	○	○	○		○	
Ho et al. (2004)					○		○	
Ho et al. (2007)		○	○		○			

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
Huang et al. (2007)				○			○	
Jiang et al. (2008)						○		
Lam et al. (2011)								○
								○
								○
								○
								○
Lei et al. (2011)	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
	○		○	○	○			
Leung and Ho (2009)		○						
Li and Cao (2014)			○					
Li and Ho (2011)			○				○	
Li et al. (2009)	○		○	○	○		○	
Li et al. (2011)								

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
Li (2006)	○		○	○	○		○	
Liao et al. (2015)		○	○	○			○	
Li-Tsang et al. (2012)							○	○
Liu et al. (2012)		○	○					
Liu et al. (2014)			○				○	
Liu et al. (2006)	○	○	○	○				
Lu (1994)		○	○		○	○		
		○	○		○	○	○	
		○	○		○	○	○	
Lu and Wu (2007)			○				○	
McBride-Chang et al. (2008)	○		○	○			○	
	○		○	○			○	
McBride-Chang et al. (2011b)	○	○		○				○
McBride-Chang et al. (2011a)	○		○	○			○	
	○		○	○			○	
McBride-Chang et al. (2012)	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
McBride-Chang et al. (2013)	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
	○		○	○				
Meng et al. (2011)							○	
Pan et al. (2013)				○			○	
Pan et al. (2014)							○	
Peng et al. (2013)						○		
						○		
Penney et al. (2005)		○	○	○				
Qian and Bi (2014)		○					○	
Shu et al. (2006)	○		○	○	○		○	
So and Siegel (1997)			○		○			
			○		○			
			○		○			
			○		○			
			○		○			
			○		○			
			○		○			
			○		○			
Song et al. (2013)			○					

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
Song (2006)			○					
Tong et al. (2014)	○							
Wang and Liu (2007)						○	○	
						○	○	
Wang et al. (2010)							○	
Wang et al. (2012)	○	○	○	○		○		
Wang et al. (2012a)		○	○	○	○			
*Wong, S. W and Ho (2010)							○	○
Wong et al. (2010)			○					
			○					
			○					
Wong et al. (2012)	○		○	○			○	
Wong et al. (2015)	○	○	○	○	○			
	○	○	○	○	○			
	○	○	○	○	○			
Wong (2005)			○	○	○	○	○	○
Woo and Hoosain (1984)					○		○	○
Wu and Zou (2008)								
Xiao and Ho (2014)	○							
Yan et al. (2013)				○				
Yang et al. (2009)		○						
Yeh (2012)			○	○	○			
			○	○	○			

Table 4 (continued)

Study ID	Morphological Awareness	Orthographic Knowledge	Phonological Awareness	Rapid Naming	Short-term Memory	Working Memory	Visual/spatial Skills	Motor Skills
			○	○	○			
Yeung et al. (2014)	○	○	○	○	○			
	○	○	○	○	○			
	○	○	○	○	○			
	○	○	○	○	○			
Zhang et al. (2014)	○		○					
	○		○					
Zhao et al. (2012)		○		○				
Zheng et al. (2007)		○	○	○	○			
Zhou et al. (2014)	○		○	○			○	
	○		○	○			○	
	○		○	○			○	

N/A data were not reported, *RD* children with reading difficulties, *A-TD* age-matched typically developing children, *R-TD* reading-level-matched typically developing young children

[a] Insufficient info: studies only provided screening information about IQ and reading, thus insufficient information about comorbidity; RD only: studies mentioned that their RD sample is specific RD, or the RD sample did not have other known disabilities, or provided screening information on other skills (e.g., mathematics, attention, specific language impairment) and showed that the RD sample did not have disabilities on these skills; with other disabilities: studies mentioned that the RD sample had other disabilities (e.g., mathematics difficulties, ADHD, or specific language impairment)

Table 5 Examples of measures for different skills

Skills	Examples of measures
Phonological awareness skills	• Three Chinese syllables (names of common objects) were presented to children using an audiocassette player together with pictures of these objects to ease memory load. Children were asked to indicate which two among the three syllables sounded similar. • Children were asked to say aloud the word with either the first, second, or third syllable dropped.
Rapid naming	• There are five types of rapid naming tasks, the materials are as follows: digits (2, 4, 6, 7, and 9), letters (a, u, y, p, t, b, i, and o), colors (red, blue, yellow, green, and black), characters ("尺," "衣," "风," "也," and "出"), and pictures (flower, shoe, hand, book, and dog). The names of all of these test items were single syllables in Chinese. For each type of material, the items were repeated seven times in random orders and were arranged in 7 rows of 5 each on an A4 paper. The children were asked to name the 35 items in each task as fast and as accurately as possible from left to right row by row. Naming latencies were recorded with a stopwatch to the nearest millisecond. The children named each list twice, and the score was the average naming latency across the two trials.
Orthographic knowledge	• In responding to the 70 simple Chinese characters and numbers, half of which were left-right reversed, children were asked to cross out all items with an incorrect orientation. • In responding to the 30 rare characters and the 30 noncharacters with their radicals placed in illegal positions, children were requested to cross out all noncharacters. • In responding to the 20 semantic and phonetic radicals in the test, children were asked to indicate from the 4 options (left, right, top, and bottom) the legal position of each radical. • There were 24 two-character words. Each word consisted of one missing character. The missing character was of a low frequency and unfamiliar to the children, according to the Hong Kong Corpus of Primary School Chinese. This was not a measure of sight vocabulary as the words were unknown to the children in print. The whole word was read orally by the experimenter so that the children could get the meaning of the word. The children were then asked to select the best answer from 4-character alternatives in each item. The distracters were characters with the same phonetic components but with different semantic radicals. Among the 24 target semantic radicals, half were semantically transparent and half were opaque radicals. Since the task consisted of multiple-choice items, no writing or spelling was required. • There were 8 target semantic radicals. The children were asked to write down as many characters as possible that contained the target semantic radicals.
Morphological awareness	• The experimenter initially orally presented a 2-character Chinese word to each child. Within this 2-morpheme word, 1 of the 2 morphemes was identified for the child. The child was then asked to produce 2 words containing the target morpheme. One of the morphemes was required to have the same meaning as the target morpheme. The other morpheme was required to have a meaning different from its original meaning. However, both morphemes were identical in pronunciation and written form. • Children were asked to combine morphemes in new ways to produce novel words. All of this was done orally. This test was modified across years to increase the numbers of items on it. • Children were orally presented with a scenario describing one object or concept. Children were asked to produce a newly described object or concept based on a description. • 19 items each consisting of four 2-character words presented visually and orally. In each of the sets, there was a character that shared the same sound and written form but with a different meaning when combined with the other characters. This task was to measure the students' understanding of the morpheme having different meanings in 2 morphemic words.

Table 5 (continued)

Skills	Examples of measures
	• 18 sentences in which word(s) was missing were presented orally. The participants were told that they would hear some sentences with a word missing and they would have to replace the "blank."
Short-term memory	• There were 16 trials with sequences that ranged from 2 digits (Chinese syllables, symbols) to 8 digits (Chinese syllables, symbols). The children heard these sequences presented orally through a tape player. The interdigit interval was 1 s. The children were asked to repeat each sequence clearly in the presented order.
Working memory	• In the task, 5 items consisting of 1 to 5 prerecorded sentences, all unrelated in meaning, were played to individual participants one by one. The participants were asked to first listen to the sentence(s), then answer a comprehension question about those sentence(s), and finally, repeat the last word in each sentence aloud. • Three phonological memory tasks: a digit repetition task, a word repetition task, and a nonword repetition task of 10 trials each. These were immediate recall tasks. In each trial of these tasks, the children heard 5 digits/Chinese syllables presented through a cassette player. They were asked to repeat orally the digits/Chinese syllables in the presented order.
Visual skills	• Six pictures and 1 question are on each page. The children are required to choose the 1 picture among the 6 that demonstrates the spatial relationship raised by the question. • Children to look at a target symbol and find an identical one from a pool of 5 alternatives. • Five visual forms were presented simultaneously, and children were to identify the one that was facing the wrong way. • Children to select a matching geometric figure from a set that differed in size or orientation from the given target. • Children to select from 4 uncompleted geometric figures the one that was identical to the target when completed. • Five abstract visual figures were developed. Each figure was a combination of 4 elements of either straight lines, dots, or curves. The figures were clearly distinguishable from one another and did not resemble any real objects or symbols. Five gap words were paired with these visual figures for learning. In the learning part, the 5 visual-verbal pairs were presented twice and followed by the children repeating the names of the visual figures. This was to ensure that the children heard the names correctly. There were 4 trials in the testing part. In each testing trial, the children were shown the visual figures one by one in a random order and were asked to produce the name of each figure. • Each of the 60 rows in the task contained 6 digits, 2 of which were identical (e.g., 8 9 5 2 9 7), and children were asked to circle the identical digits in each row.
Motor skills	• Each participant was required to copy a standardized template of 90 characters displayed on the computer screen as quickly and as accurately as possible. • It consisted of a digitized writing board to be used with an ink pen, which could capture the handwriting data such as pressure exerted on the writing board while a user is writing on the grid paper. Each participant was instructed to sit in front of the computer screen at a distance of 50 cm. A template consisted of 90 common Chinese characters selected from a list of Chinese Characters recommended for the subject of Chinese Language in primary schools in Hong Kong (Li-Tsang et al. 2012). The display sequence of the columns was randomized each time when the system was operated. Each participant was instructed to copy the 90 characters as fast and accurately as possible on a piece of paper with a 9 × 10 grid pasted on the handwriting digitizer. They were asked not to correct their writing if they wrote the character wrongly. • In the single-task motor automaticity condition, the finger-tapping task was adopted from a digital finger-tapping test. The participants were instructed to tap as many times as possible with their index finger of the preferred hand within 50 s; a digital counter recorded the total number of finger taps. In the dual-task condition, the children were asked to continuously count backward from 50 every 2 s, while

Table 5 (continued)

Skills	Examples of measures
	simultaneously finger tapping. Before the experiment, the counting speed was calibrated to ensure that the children counted at a rate of 1 number per 2 s. If the children counted down to 0 before the time limit, they had to start again at 50. The score was the total number of taps. • The task consisted of 20 blue pegs located onto a wooden board. Each of the 5 rows consisted of 4 pegs. The children were asked to displace one peg to the above row at a time, from left to right, row by row. The children were required to do the task twice. Latencies were recorded with a stopwatch to the nearest millisecond. The average latencies were analyzed.

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