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The deficit profile of working memory, inhibition, and updating in Chinese children with reading difficulties

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ABSTRACT

This study investigated executive function deficits among Chinese children with reading difficulties. Verbal and numerical measures of working memory, inhibition, updating, and processing speed were examined among children with only reading difficulties (RD), children with reading and mathematics difficulties (RDMD), and typically developing peers (TD). Results showed that compared to the TD group, children with RD exhibited deficits in verbal working memory, inhibition, and processing speed, whereas children with RDMD had deficits in all these executive functions and processing speed in both the verbal and the numerical content. Processing speed mediated working memory and inhibition differences between the TD and the reading impaired groups, but processing speed could not explain the group differences in updating or the numerical working memory difference between children with RD and children with RDMD. The findings suggest that the executive function deficits of Chinese children with reading difficulties vary by task modality (verbal and numerical) and subtype (RD and RDMD). Implications of the findings for executive function training are also discussed.

Reading is critical for children's development, and yet about 8–15% of school-age children experience reading difficulties (Stevenson, Stigler, Lucker, & Lee, 1982; Velluntino & Fletcher, 2007). Many cognitive processing deficits are proposed for reading difficulties, and deficits in the executive function system are one contributing factor (e.g., Corina et al., 2001; van der Sluis, de Jong, & van der Leij, 2004). However, the executive function profile in children with reading difficulties is unclear, especially when it comes to complex, non-alphabetic languages like Chinese. Studies that address this issue can answer critical questions about how to differentiate among subgroups of reading difficulties and develop more fine-grained executive function interventions for each subgroup. The purpose of this study was to investigate the executive function deficits of Chinese children with reading difficulties. Working memory, inhibition, updating, and processing speed were systematically examined with paired verbal and numerical tasks among children with only reading difficulties (RD), children with reading and mathematics difficulties (RDMD), and typically developing peers (TD).

Executive functions refer to supervisory cognitive processes that are responsible for higher-level organization and execution of complex thoughts and behaviors (Alvarez & Emory, 2006). The most commonly proposed executive functions are working memory, inhibition, updating, and switching (Baddeley, 2003; Miyake et al., 2000). Working memory is the ability to concurrently store and manipulate information necessary to perform mental tasks. Inhibition refers to the ability to deliberately inhibit dominant responses when necessary. Updating is the ability to modify the content of memory to accommodate new input. Switching is the ability to shift attention or to shift between strategies or response sets. While switching is closely related to mathematics (e.g., Bull & Scerif, 2001), the others are more important for reading (Cain, Oakhill, & Bryant, 2004; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). More precisely, working memory plays a critical role in word decoding (Daneman & Carpenter, 1980; Ho, Chan, Lee, Tsang, & Luan, 2004) and reading comprehension (Cain et al., 2004). Inhibition and updating are both particularly important for reading comprehension (Carretti, Cornoldi, De Beni, & Romano, 2005; Palladino et al., 2001).

Deficits in working memory, inhibition, and updating are closely associated with poor reading performance. However, the deficit profile of these executive functions in children with reading difficulties remains unclear. While some studies have found poor readers to show deficits in working memory (e.g., Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005), inhibition (e.g., Altemeier, Abbott, & Berninger, 2007; Willcutt et al., 2005), and updating (e.g., Carretti et al., 2005; Swanson & Jerman, 2007), others did not find a link between these executive function deficits and reading difficulties (e.g., De Berni & Palladino, 2000; Jeffries & Everatt, 2004; Roodenrys, Koloski, & Grainger, 2001; Swanson, 1993; Swanson, Howard, & Saez, 2006).

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Several issues need to be considered when interpreting these conflicting results. One major issue is hidden co-morbidity. Reading difficulties often co-occur with math difficulties in learning disabled children (Light & DeFries, 1995). Many researchers postulate that children with RD are cognitively different from children with RDMD (e.g., van der Sluis et al., 2004). Because most previous studies did not distinguish between children with RD and children with RDMD (e.g., Carretti et al., 2005; De Berni & Palladino, 2000; Roodenrys et al., 2001; Willcutt et al., 2005), the discrepant findings may reflect a mixed pattern of executive function deficits for children with RD and children with RDMD.

Another issue is task modality (Booth, Boyle, & Kelly, 2010). Many previous studies used executive function tasks in either the verbal or the numerical content (e.g., Altemeier et al., 2007; Roodenrys et al., 2001), thus glossing over the possibility that executive function deficits may manifest only within a specific domain (i.e., verbal or numerical). This possibility is not only in line with neuropsychological evidence on the disassociation between numerical processing and verbal processing (e.g., Dehaene, Piazza, Pinel, & Cohen, 2003), but also is in support of domain-specific executive function theories. For example, the long-term working memory theory suggests that expertise of a domain greatly affects working memory capacity within that domain (Ericsson & Kintsch, 1995), and working memory deficits may simply reflect insufficient skills in a given domain. Research on mathematics difficulties (MD) supports the domain-specific executive function theories showing that children with MD show more numerical executive function deficits than their verbal executive function deficits (e.g., Peng, Sun, Li, & Tao, 2012). Thus, it is necessary to consider the possibility of domain specific executive function deficits by differentiating verbal from numerical materials. Given the potential task modality effect, we expect that children with RDMD show more numerical executive function deficits than children with RD. Children with RD may show more verbal executive function deficits than their numerical executive function deficits.

Moreover, most previous research on executive functions in reading difficulties was conducted among children of alphabetic languages (e.g., English). Evidence from children of non-alphabetic languages, such as Chinese, is relatively scarce.

In Chinese, character recognition is the primary skill learned by early readers and the skill with which most poor readers struggle (Ho et al., 2004; Shu, Meng, & Lai, 2003). There are 4000–5000 characters used in modern Chinese society, 3500 of which are frequently used, but these characters are presented by only about 400 distinct syllables and 1277 tonal syllables (DeFrancis, 1984). Moreover, it is common to see characters with different meanings that sound the same and look alike. Thus, learning Chinese characters relies heavily on semantics and children must memorize a large number of characters to build a strong character-semantic route for fluent reading (Shu, McBride-Chang, Wu, & Liu, 2006). Executive functions, such as working memory, inhibition, and updating, likely play an important role in Chinese reading development. Children must use working memory to read and learn many characters (e.g., Ho et al., 2004), inhibit irrelevant information when encountering homophones, and update meanings of visually confusable characters when reading passages.

Actually, working memory and inhibition are significant predictors of Chinese word reading among typically developing Chinese children (Chung & McBride-Chang, 2011), and Chinese children with poor reading skills show poor verbal working memory (e.g., Ho et al., 2004). However, none of the previous studies on Chinese children with reading difficulties studied updating, or compared working memory and inhibition across the verbal and numerical domain, and no study has compared these executive functions between children with RD and children with RDMD. Considering the important role of semantics in Chinese reading, we expect that the executive function deficits may vary across subtypes of reading difficulties and task modality such that children with RD may suffer from deficits in the verbal domain, and children with RDMD may suffer from deficits in both the verbal and the numerical domain.

One more issue that needs to be addressed is the mechanism of executive function deficits. That is, whether executive function deficits among children with reading difficulties are relatively independent cognitive deficits or whether they are a function of more fundamental deficits of cognitive functioning, such as processing speed deficits. Processing speed refers to the efficiency with which information is processed (Salthouse, 1996). According to processing speed theory, processing speed is a fundamental mechanism that allows for higher-level cognition because it greatly influences the availability of information for advanced cognitive processing (Salthouse, 1996). Among typically developing individuals, processing speed explains all or a majority of variance in age-related differences in working memory and inhibition (e.g., Christ, White, Mandernach, & Keys, 2001; Fry & Hale, 1996). However, it is unknown whether this theory holds for children with reading difficulties. Almost all previous research focused only on identifying differences in executive functions. Without controlling for processing speed, the extent to which executive function deficits among children with reading difficulties can be attributed to their processing speed abilities is unclear.

To summarize, the purpose of this study was to investigate the executive function profile in Chinese children with reading difficulties. By comparing children with RD, RDMD, and TD peers, we examined (a) whether Chinese children with RD and children with RDMD had working memory, inhibition, updating, and processing speed deficits, and whether these deficits were similar when processing verbal and numerical information, and (b) whether the group differences on verbal and numerical executive functions could be explained by the verbal and the numerical processing speed, respectively.

1. Method

1.1. Participants

We administered three screening tests including non-verbal IQ (RAVEN), reading (CMRA), and math (WRAT) (see Screening Measures below) to 805 fifth graders from 5 average-performing public elementary schools in one county of Beijing, China. Using 25th and 35th percentile cut-off scores (e.g., Velluntino & Fletcher, 2007) on achievement measures, we identified 22 children with RD (< the 25th percentile on CRMA; > the 35th percentile on WRAT-math), 24 children with RDMD (< the 25th percentile on CRMA and WRAT-math), and 31 TD children (> the 35th percentile on CRMA and WRAT-math, with a mean around the 76th percentile on the CRMA and WRAT-math). Children with low non-verbal IQ (<35th on RAVEN), neurological deficits, or ADHD were excluded.

As Table 1 shows, all groups were comparable in terms of age, $F\ (2, 72) = .60$, $p = .55$, gender, $\chi^2\ (2) = 1.00$, $p = .61$, non-verbal IQ, $F\ (2, 72) = .81$, $p = .45$, and mother's education level, $\chi^2\ (6) = 11.00$, $p = .08$. With respect to reading, the RD and RDMD groups were comparable, and they were both significantly worse than the TD. Regarding mathematics, the TD and RD groups were comparable, and they were both significantly better than the RDMD group.

1.2. Screening measures

1.2.1. Reading

We used the Chinese Character Recognition Measure and Assessment Scale for Primary School Children (CRMA; Shu et al., 2003, 2006; Wang & Tao, 1993). In this test, the children had about 1 h to identify194 characters by using each character in a phrase or a word. The sum of the weighted score of each character used correctly was the final score of this test. The Cronbach's alpha of this test was .98.

1.2.2. Math

Adapted from the computation subtests of the Wide Range Achievement Test-4 (WRAT-math; Wilkinson & Robertson, 2006), this test