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The deficit profile of executive function in Chinese children with different types of reading difficulties

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Abstract
This study investigated executive function deficits among Chinese primary school children with word reading deficit and specific reading comprehension deficit. Working memory, inhibitory control, and cognitive flexibility were examined among children with Word Reading Deficit (WRD), children with Specific Reading Comprehension Deficit (S-RCD) and Typically Developing children (TD). Results showed that compared to the TD group, children with WRD showed deficits in working memory and inhibitory control, whereas children with S-RCD had deficits only in working memory. Further analyses suggested that the difference between WRD group and S-RCD group's poor performance on working memory was caused by different types of working memory tasks. The unique feature of the Chinese language may affect the difference between inhibitory control and cognitive flexibility.

Keywords Cognitive flexibility · Dyslexia · Executive function · Inhibitory control · Working memory

Introduction

Reading is a complex ability requiring the integration of several different cognitive and perceptual processes. To understand sentences, an individual must be able to visually process the words that s/he sees, match the words to stored phonological, orthographic, and semantic representations, and then combine these representations with context to form an understanding of the underlying meaning

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of the sentence and the larger passage (Christopher et al., 2012). Cognitive processing is considered an important factor for understanding reading difficulties, and executive function (EF) is one of such contributing factors (Butterfuss & Kendeou, 2018; García-Madruga et al., 2014; Nouwens et al., 2016). In alphabetic languages, a large body of evidence suggests that children who experience difficulties with reading show deficits in executive function (Bull & Scerif, 2001; Van Der Sluis et al., 2004). However, the executive function profile in children with reading difficulties is unclear in non-alphabetic languages such as Chinese (Peng et al., 2013). In particular, little research has been conducted to investigate EF between Chinese children with word reading difficulties and children with specific reading comprehension difficulties. The purpose of this study was to examine the executive function deficits of Chinese children with word reading difficulties and specific reading comprehension difficulties. Studying this issue can help develop more fine-grained executive function interventions for children with different types of reading difficulties.

The model of executive function

The current study draws from work on the unity and diversity of executive function (Miyake et al., 2000). Miyake et al. (2000) examined the separability of three executive functions—shifting, updating, and inhibition, and their roles in complex frontal lobe and executive tasks. Confirmatory factor analysis indicated that the three target executive functions are moderately correlated with one another, but are clearly separable. Later, Miyake and Friedman (2012) revisited this model and reconceptualized the unity and diversity among the components of EF. Unity was referred as common EF, which was described as the ability to both actively maintain task goals and relevant information, and to bias lower-level processing in favor of these goals. Although these components share considerable overlaps, they are also separable. Updating, inhibition, and shifting contribute differentially to performance on complex executive tasks, which showed diversity.

Executive Function refers to a set of cognitive processes utilized in the management of goal-directed behaviors and in the development and implementation of an approach to completing tasks that have not been habitually performed (Diamond, 2013; Locascio et al., 2010). There is a consensus that there are three core EF skills, including working memory, inhibitory control, and cognitive flexibility. Working memory is holding information in the mind and mentally working with it (Baddeley, 1996). Inhibitory control involves being able to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure, but instead, do what's more appropriate or needed (Borella et al., 2010; Garavan et al., 2002). Cognitive flexibility refers to the process in which an individual converts between different tasks or psychological fixes according to different rules, overcoming the effects of psychological fixation and maintaining the flexibility of thinking and movement (Davidson et al., 2006).

The role of EF in word reading and reading comprehension

There have been several studies examining the relationship between reading and EF. For example, in the active view of reading, Duke and Cartwright (2021) referred EF as a significant part of active self-regulation, which can influence word recognition (including phonological awareness, morphological, etc.), bridging process (including reading fluency, vocabulary knowledge, etc.), and language comprehension (including cultural and other content knowledge, etc.) and then influence reading. The process of reading requires the ability to direct attention to particular aspects of text (attentional control), build and maintain a model of text meaning while decoding the words in the text (working memory), suppress distracting information (inhibitory control), shift continuously between key processes (cognitive flexibility), and plan and manage one's progression toward the goal of a reading task (planning). In addition, the DIER model proposed by Kim (2020) also proved that language and cognitive skills (such as executive function) can predict word recognition and also have direct and indirect with reading comprehension. Furthermore, Spencer et al. (2019) used latent variable structural equation modeling to investigate relations between oral language, decoding, and two components of executive function (cognitive flexibility and working memory) and reading comprehension. Results showed that executive function is likely associated with reading comprehension through its relations with decoding and oral language and provide additional support for the role of executive function in reading comprehension as a potentially crucial precursor to skilled reading. Based on the above studies, we believed and hypothesized that executive function is an important role of executive function in reading processes.

Working memory

Working memory is well recognized to play an important role in both word reading and reading comprehension, especially in alphabet languages (Butterfuss & Kendeou, 2018; Cain et al., 2004). Through the relationship between working memory and word reading, working memory plays a key role in the early reading process, serves as the role of acquiring voice-based information in word reading (Gathercole & Baddeley, 1993; Mcdougall et al., 1994), and establishes a strong connection between speech and text (Ehri, 1998).

Working memory is also a well-established predictor of reading comprehension (Christopher et al., 2012; Seigneuric & Ehrlich, 2005). The relationship between working memory and reading comprehension requires one to be able to match up, retain, and manipulate words and their meanings to form a coherent gist of what is being read (Christopher et al., 2012). Many studies supported the relationship between reading comprehension and working memory. For example, Cain et al. (2004) addressed the relations between working memory and reading comprehension skills in children aged 8, 9, and 11 years and found that at each age point, working memory predicted unique variance in reading comprehension after word reading ability, vocabulary, and verbal ability were controlled. Nouwens et al. (2016) also found that after controlling vocabulary and word recognition, working memory contributed to reading comprehension indirectly.

Working memory was shown to become crucial for reading comprehension once a general level of reading ability has been met (Christopher et al., 2012; Seigneuric & Ehrlich, 2005). Seigneuric and Ehrlich (2005) examined the contribution of working memory to the development of children's reading comprehension and reported that word recognition became automated throughout the early grade levels while working memory became an important determinant of reading comprehension. There was a potential reciprocal relation between word reading and reading comprehension, which was mediated by working memory (Christopher et al., 2012). The individual's word reading ability was proportional to the reading comprehension ability, and the improvement of the reading comprehension ability, in turn, promoted the improvement of the word reading ability (Christopher et al., 2012; Nation et al., 1999; Seigneuric & Ehrlich, 2005).

The relationship between reading and working memory was also supported by research on reading disabilities. Poor readers were found to have deficits in working memory (Swanson et al., 2009; Willcutt et al., 2005). Besides, they were disadvantaged on working memory tests requiring the simultaneous and storage of digits with sentence sequences (Swanson et al., 2009) and also showed less accurate recall and more intrusion errors than good comprehenders on updating working memory tasks (Carretti et al., 2005).

In the existing research with English-speaking children, both word reading deficit group and specific reading comprehension deficit group performed more poorly than TD group on working memory measures (Locascio et al., 2010; Swanson & Berninger, 1995). However, very limited research focused on the relationship between EF and Chinese children with word reading deficit and with specific reading comprehension.

Inhibitory control

The links between inhibitory control and word reading showed in emergent literacy (Blair & Razza, 2007). After controlling intelligence and other cognitive ability, inhibitory control significantly predicted phoneme awareness and character knowledge (Blair & Razza, 2007; Gernsbacher, 1997). Altemeier et al. (2008) found that growth in inhibition from first to fourth grade significantly predicted fourth-grade word reading and spelling. The results also posited the significance of suppressing the distracting information, because decoding is effortful at the early reading stage.

In fact, there is an open question about the relationship between inhibitory control and reading comprehension (Barnes et al., 2004; Kieffer et al., 2013). On the one hand, some of the research supported that inhibitory control demonstrated a unique direct association with reading comprehension. For example, Kieffer et al. (2013) used the number-quantity Stroop task to examine the direct and indirect effects of attention shifting and inhibitory control to reading comprehension through decoding and oral language in 120 fourth graders. Results showed that after accounting for working memory and processing speed, attention shifting and inhibitory control were directly related to reading comprehension. On the other hand, there are still arguments about the role of inhibitory control in reading comprehension in activating the relevant meaning for a polysemous word while inhibiting other meanings (Barnes et al., 2004) and in ignoring irrelevant information when building a coherent mental representation of a complete text (Barnes et al., 2004; Beni & Palladino, 2000).

Evidence supporting the role of inhibition for reading comprehension comes from studies showing deficits in inhibition can be found in children who struggle with reading (Cain, 2006; Palladino & Cornold, 2001). For instance, Cain (2006) found that both adults and children with weak reading comprehension had inhibitory control deficit and they were slower to suppress the irrelevant meaning of ambiguous words (Barnes et al., 2004; Gernsbacher & Faust, 1991). They were more likely to recall materials that should have been forgotten when they are dealing with implicit memory sentence completed test. However, Locascio et al. (2010) pointed out that after controlling social-economic status, ADHD, and age, the WRD group had poorer performance on conflicting/contralateral motor response than controls in response inhibition factor, nevertheless children with specific reading comprehension deficit showed no significant difference with the controls. But the authors contributed this difference to the unequal sample size among WRD and S-RCD children; besides, when examined effect sizes versus statistical significance for group contrasts among the latent EF factors, the two groups had essentially equal relative deficits on response inhibition.

Cognitive flexibility

The relationship between cognitive flexibility and word reading is shown in the following aspects: First, elementary school-aged children with a tendency to focus primarily on phonological information instead of semantic features showed cognitive flexibility difficulties (e.g., Bialystok & Niccols, 1989). Second, meta-linguistic awareness entailed the switching of attention from the word meaning to consider other properties of language such as phonology, which needs cognitive flexibility (Cole et al., 2014). Third, there is also evidence showing that cognitive flexibility made an independent contribution to fluent word identification when other EF factors were controlled (Cartwright et al., 2019). Specifically, executive functions, including cognitive flexibility, are associated with production of miscues and may underlie students' behavior of self-corrections (Nguyen et al., 2020a, 2020b).

As in the relationship between cognitive flexibility and reading comprehension, evidence indicated that reading comprehension gave a central role to the recognition of the written words that made up the sentences, paragraphs, and text to be understood (Berninger & Nagy, 2008). Moreover, Kieffer et al. (2013) used Wisconsin Card Sorting Test to claim that cognitive flexibility played a direct role in reading comprehension because in the process of reading, individuals need to encode both the phonetic and semantic information of a written text. Further evidence showed that cognitive flexibility supported comprehension by allowing readers to consider multiple aspects of the text simultaneously; compared to this, cognitive inflexibility may affect reading comprehension processes (Butterfuss & Kendeou, 2018; Guajardo & Cartwright, 2016). The relationship between cognitive flexibility and reading comprehension may be influenced by language orthographies (Monette et al., 2011; Sluis, Jong, & Leij, 2007). Compared to readers of English, readers of shallow orthographies displayed more exhaustive letter-by-letter decoding (e.g., Landerl, 2000; Thaler et al., 2004).

Compared to typically-developing children, struggling children tended to consider only one aspect of print, usually, graphophonological information, while not attending to other important aspects such as meaning (Cartwright, 2009). According to Kieffer et al. (2013) and Cartwright et al. (2010), cognitive flexibility could significantly predict reading comprehension among reading comprehension difficulties children. With the development of cognitive flexibility, more research focused on cognitive flexibility in a particular domain—reading (Israel & Duffy 2014). Cartwright (2002) demonstrated that training with a reading-specific flexibility task produced significant improvements in reading comprehension, while training with a general flexibility task did not. Cartwright et al. (2017) assessed the contribution of cognitive flexibility to S-RCD children and found that children with S-RCD were significantly lower in reading-specific cognitive flexibility than their typically developing peers, even when decoding, verbal ability, nonverbal matrix reasoning ability, and vocabulary were controlled.

The executive function deficits in Chinese children

Considering the variety of Chinese characters, there are 4000–5000 characters used in modern Chinese society. Among them, 3500 are frequently used, but these characters are presented by only about 400 distinct syllables and 1277 tonal syllables (Defrancis, 1986). Semantic-phonetic compounds make up 72% of approximately 2570 character that students in Mainland China are expected to learn during 6 years of primary school. Compared to English, Chinese did not show systematic grapheme-phoneme correspondences (Shu et al., 2003). Besides, there are a lot of characters with different meanings that sound the same and look alike (Peng et al., 2013). 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 et al., 2006), which requires working memory and inhibitory control. Specifically, working memory need to hold information in working memory while encoding and retrieving information from long-term memory. While, during this process inhibitory control were asked to suppress irrelevant information while engaging in the rapid search and recall of relevant information (Chung & Mcbride-Chang, 2011). At the same time, the series of processing and understanding of reading would also involve to constantly refresh the information (Kintsch et al. 1998).

Chinese studies mostly focused on the relationship between EF and reading on typically developing children. Kong et al. (2018) found that working memory affected middle school students' prose reading comprehension grades, moderated by mind wandering. Chung and Mcbride-Chang (2011) indicated that after controlling age, vocabulary knowledge, and metalinguistic skills, the combination of working memory and inhibitory control together independently explained approximately 14–16% of the variance in word reading at 4–5 ages Chinese children. Li et al. (2007) examined the development of cognitive flexibility of primary school students in different grades. The findings indicated that students' cognitive flexibility had a positive correlation with their academic achievements in Chinese. Gao et al. (2018) also used the Wisconsin card sorting test to intervene primary school students. Results showed experimental class students' reading speed, and the effective reading rate displayed higher scores than those in the control class. It indicated cognitive flexibility enhanced gain in the Chinese reading area.

Few studies have paid attention to the executive function of Chinese children with reading disabilities. Tan et al. (2018) investigated Chinese developmental dyslexic children with both phonological awareness and rapid automatized naming deficit. They found that developmental dyslexic children showed a significant lower span of digit than the chronological age children, as well as a deficit in working memory. Peng et al. (2013) tended to focus on executive function deficits among Chinese children with reading difficulties and their results showed that compared to the TD group, children with RD exhibited deficits in verbal working memory and inhibition. Zhang et al. (2021) further discovered through meta-analysis that inhibitory control and working memory showed both domain generality and domain specificity, undergirded by the multiple-demand network, as well as different brain regions in response to verbal and nonverbal task materials in neuroscience research. Peng et al. (2017) found that Chinese reading difficulties children showed working memory deficits, compared to age matched typically developing children. Zhao et al. (2018) further found that inhibitory control and independent of linguistic processing skills can be used to predict children's Chinese-language reading difficulties. The research on the relation between cognitive flexibility and reading is inconsiderable, especially in Chinese. Yan and Yu (2006) used domain- general multiple classification test to provide empirical evidence for clinical intervention of reading disabilities by investigating and comparing developmental characteristics of cognitive flexibility between the RD and Non-RD children. The results showed that mutual enhancing effects exist between reading skills and cognitive flexibility. Hung and Loh (2020) used the Wisconsin card sorting test and found that cognitive flexibility was significantly associated with Chinese children's reading comprehension. However, none of the previous research studied working memory, inhibitory control, and cognitive flexibility across Chinese children with subtypes of reading difficulties.

The present study

Due to the lack of research on the roles of EF in Chinese children with reading difficulties, the goal of present study was to investigate the executive function profiles in Chinese children with word reading deficit and specific reading comprehension deficit. By comparing children with WRD, S-RCD, and TD peers, we examined (a) whether Chinese children with WRD and S-RCD had working memory, inhibitory control, and cognitive flexibility deficits, compared to controls, and (b) whether the differences between children with different types of reading difficulties existed.

Compared to the TD group, it was hypothesized that both levels of reading difficulties children show executive function deficits were observed. We expected the difference between Chinese WRD children and S-RCD children on one or more particular EF factor.

Considering the components of the executive function are relatively independent and interconnected when completing most tasks, the coordination and cooperation of each component is required (Miyake et al., 2000). For example, when a child needs to switch between two rules (red cards are placed here, and blue card is placed here), it involves cognitive flexibility that focuses on the rules when interference occurs (inhibitory control) and keeps the rules in mind simultaneously (working memory). We used N-back tasks to measure working memory. Redick and Lindsey (2013) found that n-back tasks are frequently used in cognitive neuroscience studies, compared with complex span tasks. However, this task was found to be useful for experimental research in working memory and well predicted inter-individual differences in other higher cognitive functions (Deng et al., 2020; Jaeggi et al., 2010). Two Go/No go tasks were administered to assess inhibitory control. They required students to press a button when a stimulus appears, but when a certain stimulus appears, the button should not be pressed (Diamond, 2013). The cognitive flexibility was measured using multiple classification tasks, including a general color-shape flexibility task and a specific graphophonological-semantic flexibility task (Cartwright et al., 2010, 2017). These measures were selected as children showed significantly lower in these measures than typically developing peers (Cartwright et al., 2017). We were interested in whether Chinese children with different types of reading difficulties showed the same deficits in cognitive flexibility.

Methods

Participants

In order to identify children with word reading deficit and reading comprehension deficit, we administered three screening tests including non-verbal IQ (RAVEN), word recognition (Character Recognition Measure and Assessment scale for primary school children, CRMA), and reading comprehension test to 551 third to fifth graders in a public elementary school in a city in central China. Based on prior work (Griffiths & Snowling, 2002; Nation, 2005; Nation et al., 2004), we identified 35 children with word recognition deficit ($<$ 1.5 *SD* on the Chinese Character Recognition Measure), including 11 grade 3 students, 9 grade 4 students, and 15 grade 5 students; 20 children with specific reading comprehension deficit ($>$ grade average 1.5 *SD* on CRMA and $<$ grade average 1.5 *SD* on reading comprehension test), including 10 grade 3 students, 9 grade 4students, and 1 grade 5 students; 30 Children in the typical development group ($>$ grade average 1.5 *SD* both on CRMA and reading comprehension test and Chinese academic achievement score above grade average), including 7 grade 3 students, 15 grade 4 students, and 8 grade 5 students. Children with low non-verbal IQ (below 35th on RAVEN), neurological deficits, or ADHD were excluded. As Table 1 shows, all groups were comparable in terms of age,

Table 1 Demographic and Screening Data Across Groups

	WRD (n = 35)			S-RCD (n = 20)			TD (n = 36)			Group comparison
	N	M	SD	N	M	SD	N	M	SD	
Age (month)		113.5	8.79		115.8	10.51		114.97	9.91	TD = SRCD = WRD
Girl	11			9			13			
Raven		42.45	4.48		43.11	6.14		45	3.23	TD = SRCD = WRD
CRMA		940.55	249.16		1383.83	285.89		1756.31	293.55	TD > SRCD > WRD
RCT		7.86	1.78		4.05	0.76		9.72	2.24	TD > WRD > SRCD

WRD = Word reading deficit children; S-RCD = Specific reading comprehension deficit children; TD = Typically developing children; Raven = Raven progressive matrices test; CRMA = Character recognition measure and assessment scale for primary school children; RCT = Reading comprehension test

F (2, 84) = 0.66, *p* = 0.52, gender, X^2 (2) = 1.02, *p* = 0.6 and Non-verbal IQ, *F* (2, 84) = 0.66, *p* = 0.52. In CRMA, WRD was significantly worse than TD and S-RCD, S-RCD was significantly worse than TD and WRD in reading comprehension test.

Screening measures

Word recognition test

Chinese Character Recognition Measure and Assessment Scale were used for Primary School Children (Peng et al., 2013; Shu et al., 2006). In this test, children had 50 min to identify about 194 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 from grade 3 to grade 5 were 0.98, 0.97, 0.98.

Reading comprehension test

In this test, consisting of two stories of about 500 characters, participants were asked to read the stories and answer the questions below the stories, and the questions included 6 multiple choices in each story. Each question was worth 1 point. The Cronbach's alpha of each story was 0.69.

Non-verbal IQ

We used the Chinese version of Raven's Progressive Matrices (Zhang & Wang, 1985) for all three grades children. In this test, the children were required to circle the shape that best completed a pattern. There were 60 items of increasing difficulty. The total number of correct responses was the final score. The Cronbach's alpha of this test was 0.88.

Executive function measures

Working memory tests

We chose the N-back task to assess working memory (Im-Bolter et al., 2006; Peng et al., 2013). This task consisted of 1-back task and 2-back task. Participants watched different shapes on the computer screen. In the 1-back task, the first shape was stimulus shape which was displayed for 500 ms and the second shape was reaction shape, which was displayed for 1500 ms. After that, a white screen was displayed for 500 ms. The actual reaction time for participants was 2000 ms. Participants were instructed to respond whether the second shape was the same as the last one. If shapes were the same, participants pressed "G" or press "H" on the keyboard. In the 2-back task, stimulus shapes were the first shape and the second shape. The third one was a reaction shape. Participants needed to compare the third shape with the first one. All participants were asked to take part in this test. The accuracy score was the number of the correct responses made by participants. The reaction time was the time after the last shape disappears and before the participant presses a button. The Cronbach's alpha of this test was 0.75.

Inhibitory control tests

We chose color and shape Go/No Go tasks to measure inhibitory control (Aron, 2011; Simpson & Riggs, 2006). This test included color Go/No Go task and shape Go/No Go task. The shapes that we used in inhibitory control tests were circle, triangle, and square, and the colors that we used were red, blue, and yellow. In the color Go/No Go task, a group of graphics with different colors and shapes, the participants were asked to press a button "H", when they saw a particular color and ignored the shape of the graphics. In the shape Go/No Go task, a group of graphics with different colors and shapes, the participants were asked to press a button "H", when they saw a particular shape and ignored the color of the graphics. Every stimulus lasts 1500 ms and all the participants took part in this test. The error includes missing error and reaction error. The error rate was missing error plus reaction error divided by the number of all stimulus. The reaction time was the time after the last stimulus disappears and before the participant presses a button. The Cronbach's alpha of this test was 0.74.

Cognitive flexibility tests

It was adapted from Cartwright's multiple classification tasks to access their general color-shape flexibility and specific graphophonological-semantic flexibility (Cartwright, 2007). Each task required children to sort stimuli on two dimensions simultaneously, indicating the ability to consider flexibly multiple features of stimuli. The general color-shape flexibility task asked children to sort stimuli on color and shape, and children needed to sort on initial consonant and semantic in specific graphophonological-semantic flexibility task. Both tasks had 6 groups of pictures, including 2 groups of practice pictures and 4 groups of experimental pictures for the formal experiment. Each group had 8 pictures. In the general color-shape flexibility task, in practice stage, the researcher told participants, "I have some cards for you to sort. You can sort these two ways at the same time, by how their color and shape". After sorting the cards, the researcher described the arrangement of the sort by saying, "See, these are all red, these are all non-red, these are all circle, and these are all non-circle". Then, participants were asked to sort other cards in the same way. After that, they needed to provide a verbal justification. Researchers needed to make sure that the participants understand the rules then moved to the formal experimental stage. In formal experimental stage, researchers needed to repeat the rule and record the time for every groups of pictures. The specific graphophonological-semantic flexibility task followed the same procedure as the general color-shape flexibility task. Changed the stimulus from color and shape to initial and meaning.

For each group card, 3 points were awarded when both the sort and justification were correct. 2 points were awarded when the sort was incorrect but the participant provided a correct justification for the researcher-corrected sort. 1 point was awarded for a correct sort followed by an incorrect justification and no point for an incorrect sort and justification. Sorting times (RTs) and sorting accuracy scores were calculated for each participant. The Cronbach's alpha of these two tasks were 0.77 and 0.78.

Procedure

The measures of non-verbal IQ test, CRMA, and reading comprehension test were administered in group by trained research assistants. Participants needed to finish working memory tests, inhibitory control tests and cognitive flexibility tests individually in a quiet room, and each test took about 10–15 min.

Results

We used Multivariate analyses of variance (MANOVAs) to examine group differences on working memory test, inhibitory control test, and cognitive flexibility test. The within-subjects factor was different test (i.e., 1-back task and 2-back task for working memory; color Go/No go task and shape Go/No go task for inhibitory control; domain-general card sorting task and domain specific-card sorting task for cognitive flexibility), and the between-subjects factor was the three groups of students (i.e., WRD, S-RCD and TD).

RTs and accuracy scores in working memory tests

Means for RTs and accuracy scores of reading difficulties and controls in working memory tests were presented in Table 2. Means for RTs and accuracy scores on working memory tests were shown in Figs. 1 and 2.

Results showed a significant main effect on Participants, Wilks's $\lambda = 0.83$, F (4, 162) $= 3.94$, $p < 0.01$, $\eta^2 = 0.089$. Tests of between-participants effect showed that the effect of participants was significant on working memory RTs, F (2, 84) $= 4.11$, $p < 0.05$, $\eta^2 = 0.09$ and accuracy scores, F (2, 84) $= 8.26$, $p < 0.01$, $\eta^2 = 0.17$. Pairwise comparisons for the working memory RTs revealed that the TD group performed significantly better than the WRD ($p < 0.01$) and S-RCD groups ($p < 0.05$), but no significant differences were detected between the WRD and S-RCD groups ($p > 0.05$). For the working memory accuracy scores, the TD group performed significantly better than the WRD and S-RCD groups ($p < 0.05$), but no significant differences were detected between the WRD and S-RCD groups ($p > 0.05$).

RTs and error rate in Go/No Go tests

Means for RTs and error rate of reading difficulties and controls in Go/No go tests were given in Table 2. Means for RTs and error rate on inhibitory control tests were showed in Figs. 3 and 4.

Tabel 2 Statistics for WRD, S-RCD and TD group on Executive Function Tests

Measure	WRD		S-RCD		TD		F	η^2	Post-hoc
	M	SD	M	SD	M	SD			
Working memory									
Reaction times (milliseconds)	1688.07	288.12	1666.59	290.3	1501.39	249.67	4.11^{**}	0.09	TD > WRD = SRCD
Accuracy scores	47.4	10.45	47.35	7.38	55.03	5.55	8.26^{*}	0.17	
Inhibitory control									
Reaction times (milliseconds)	1297.06	248.6	1234.66	203.89	1151.71	232.82	3.14^{*}	0.07	TD = SRCD > WRD
Error rate	0.05	0.06	0.02	0.03	0.02	0.02	3.46*	0.08	
Cognitive flexibility									
Sorting reaction times (seconds)	318.51	136.91	303.6	100.35	281.87	110.39	0.76	0.02	TD = SRCD = WRD
Sorting accuracy scores	20.09	4.37	20.15	3.69	21	3.86	0.47	0.01	

$^{*}p<0.05$. $^{**}p<0.01$

WRD = Word reading deficit children; S-RCD = Specific reading comprehension deficit children; TD = Typical children

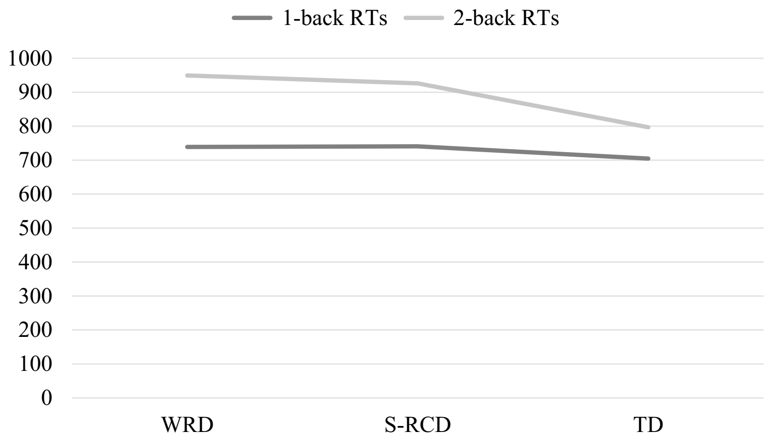

Fig. 1 Means for RTs on working memory tasks

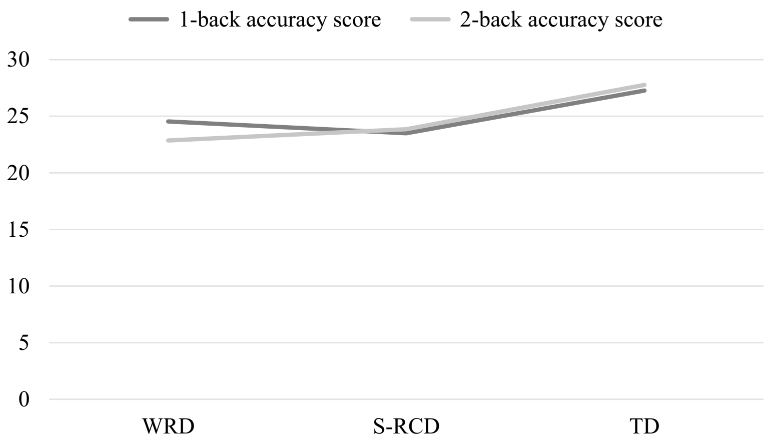

Fig. 2 Means for accuracy score on working memory tasks

Results showed a significant main effect on Participants, Wilks's $\lambda = 0.87$, F (4, 162) $= 3.01$, $p < 0.05$, $\eta^2 = 0.07$. Tests of between-participants effect showed that the effect of participants was significant on inhibitory control RTs, F (2, 84) $= 3.14$, $p < 0.05$, $\eta^2 = 0.07$ and Error rate, F (2, 84) $= 3.46$, $p < 0.05$, $\eta^2 = 0.08$. Pairwise comparisons for the inhibitory control RTs revealed that the TD group and S-RCD group performed significantly better than the WRD ($p < 0.05$), but no significant difference between S-RCD groups and TD group ($p > 0.05$). For the inhibitory control error rate, the TD group and S-RCD group performed significantly better than the WRD group ($p < 0.05$), but no significant differences were detected between the S-RCD and TD groups ($p > 0.05$).

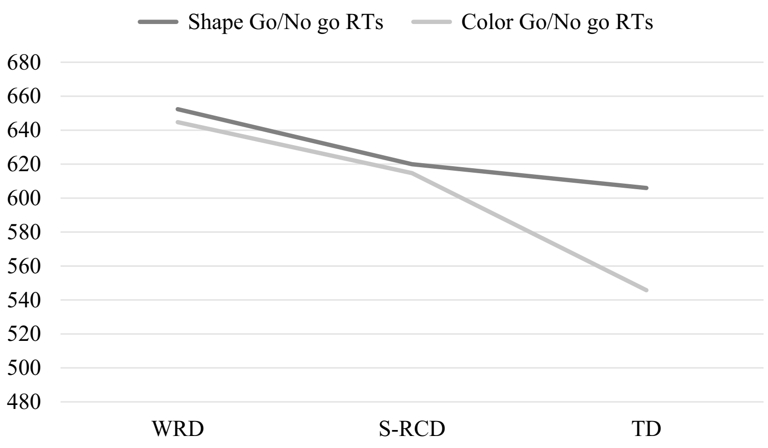

Fig. 3 Means for RTs on inhibitory control tasks

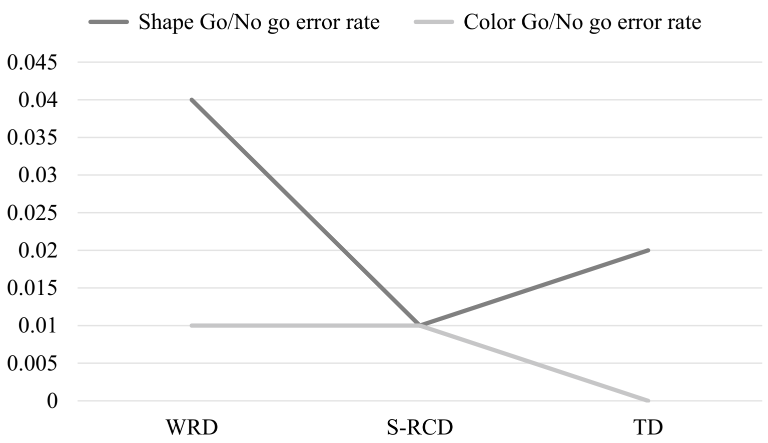

Fig. 4 Means for error rate on inhibitory control tasks

RTs and sorting accuracy scores in cognitive flexibility tests

Means for RTs and sorting accuracy scores of reading difficulties and controls in card sorting tests were given in Table 2. Means for RTs and sorting accuracy on cognitive flexibility tests were showed in Figs. 5 and 6.

Results showed no significant main effect on Participants, Wilks's $\lambda = 0.98$, F $(4, 162) = 0.44$, $p > 0.05$, $\eta^2 = 0.01$. Tests of between-participants effect showed that the effect of participants was not significant on cognitive flexibility RTs, F $(2, 84) = 0.76$, $p > 0.05$, $\eta^2 = 0.02$ and sorting accuracy scores, F $(2, 84) = 0.47$, $p > 0.05$, $\eta^2 = 0.01$.

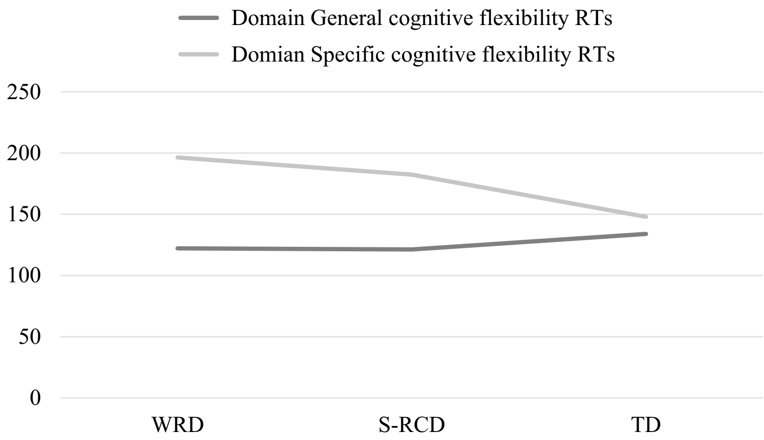

Fig. 5 Means for RTs on cognitive flexibility tasks

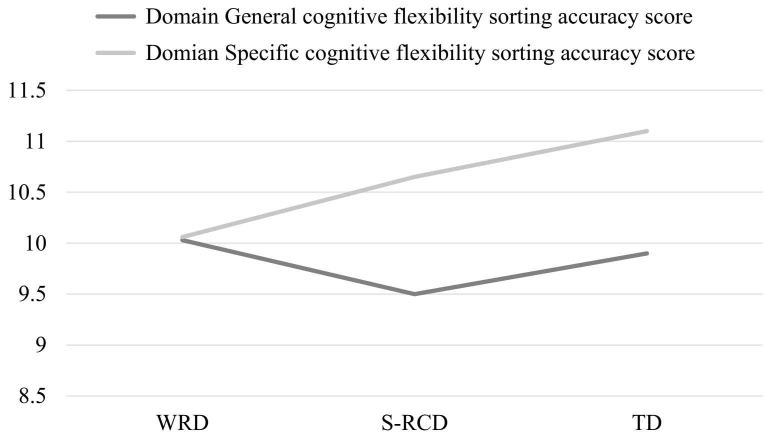

Fig. 6 Means for sorting accuracy score on cognitive flexibility tasks

Discussion

We investigated the characteristics of EF in different types of reading difficulties. Children with reading difficulties were divided into word reading deficit group and specific reading comprehension deficit group. We also selected typically developing children as a control group.

Working memory deficit and consistency across different subtypes of reading difficulties

The study focused on two types of reading difficulties, which are significantly different from the TD group in RTs and accuracy scores of working memory. We found that children with reading difficulties did have working memory deficit. This finding was consistent with previous studies that support RD children suffering working memory deficit (Potocki et al., 2017; Swanson et al., 2009). According to Locascio et al. (2010), children with WRD exhibited problems with verbal working memory and children with S-RCD showed significant deficit with controls on the spatial working memory task. Our study adopted N-back tasks to assess working memory and this tasks seemed to be useful for experimental research in working memory and well predicted inter-individual differences in reading (Jaeggi et al., 2010). It showed that Chinese children with WRD and S-RCD showed consistency with children in alphabetic language on working memory (Just & Carpenter, 1992; Locascio et al., 2010; Swanson et al., 2009).

However, we failed to find that WRD group and S-RCD group showed a significant difference in working memory tasks. This is perhaps due to the tasks used in different studies. Previous researchers indicated that children with WRD and S-RCD experienced working memory deficits when processing verbal information (Nouwens et al., 2016; Peng et al., 2013; Swanson & Berninger, 1995). Locascio et al. (2010) thought WRD showed poor performance on EF factors was a byproduct of core deficits linked to WRD, because after controlling for phonological processing, this group no longer showed EF deficits. Otherwise, S-RCD showed significant poor performance even after controlling for phonological processing. So phonological processing may be an important reason for the difference in working memory tasks among WRD and S-RCD. However, the N-back tasks involving different shapes as the stimulus used in our study did not involve domain-specific knowledge; it requires further investigation to find out if Chinese children with WRD and S-RCD show the same character in verbal working memory.

Difference in inhibitory control in WRD children and S-RCD children

Our results showed a significant difference between the WRD group and TD group in RTs and error rate of inhibitory control. However, there was no significant difference between S-RCD children and TD children, indicating that the WRD children but not S-RCD children have inhibitory control deficit. This finding was in line with previous studies that WRD children and S-RCD children showed differences in inhibitory control, compared to typically developing children (Locascio et al., 2010; Pimperton & Nation, 2010).

Although Chinese WRD children also showed delayed development of inhibitory control (Peng et al., 2013; Zhao et al., 2018), the cause of this problem may be different from that in English. The reason for the problem of WRD children's inhibitory control ability may be related to the unique features of Chinese (Peng et al., 2013; Swanson et al., 2006). There are many homophones and homograph characters in Chinese. Children cannot inhibit irrelevant information in the process of distinguishing them (such as pronunciation and meaning). Zhao et al. (2018) found that children with Chinese-language reading difficulties showed deficits in inhibitory control and that inhibitory control, independent of linguistic processing skills, could be used to predict children's Chinese-language reading difficulties. Peng et al. (2013) found the same results that children with WRD's inhibitory control had consistency across languages. However, we did not find that the S-RCD children had deficits in inhibitory control. The same finding emerged in a study involving English S-RCD children who did not show a deficit in inhibitory control (Locascio et al., 2010). Nevertheless, some research showed that Chinese children with reading difficulties had inhibitory control impairment (Peng et al., 2013; Zhao et al., 2018). The reason for this inconsistency may be due to the selection criteria. The participants in Peng et al. (2013) and Zhao et al. (2018) studies were both WRD children and their reading screening measure mainly taps character recognition skills instead of specific reading comprehension deficit children.

No difference in cognitive flexibility in different subtypes of reading difficulties

This study found that all subtypes of children did not show significant cognitive flexibility impairment whether it is on the sorting speed (RTs) or the sorting accuracy scores. This finding was not consistent with other studies, which indicated that reading difficulties children showed deficit in cognitive flexibility in English (Cartwright et al., 2010, 2017, 2019; Guajardo & Cartwright, 2016; Hung & Loh, 2020; Kieffer et al., 2013; Yan & Yu, 2006). Previous research found that the relation between flexibility and reading is unclear, especially in those with reading acquisition in languages other than English. Monette et al. (2011) failed to find that flexibility predicts a composite measure of the children's reading and writing skills in Grade 1 among French-speaking kindergarteners. Berninger and Nagy (2008) referred to a greater need for flexibility when mappings between the features of print are complex. Opaque orthographies have many-to-one or one-to-many mappings between orthography and phonology, which slows the development of word reading (Seymour et al., 2003) and renders the activation of phonology from print difficult (Share, 2008). As mentioned earlier, in Chinese that is an opaque language, children with WRD and S-RCD may not easily display cognitive flexibility impairments (Cole et al., 2014). Another reason may be due to phoneme-grapheme correspondences. Chinese characters showed more semantic-phonetic characteristic. Chinese learners may not need to flexibly shift between graphophonological and semantic aspects of their printed language because it does not have systematic grapheme-phoneme connections in the same way that alphabetic languages do. It is quite possible that other Chinese-print specific flexibility is involved and future research should investigate that.

Conclusion

This study showed that executive function showed difference impacts on word reading deficit children and specific reading comprehension deficit children in Chinese. The performance on working memory has consistency across languages whereas inhibitory control and cognitive flexibility deserve further investigation. The present study advances our understanding of the EF involved in different types of reading difficulties, and how they interact with one another to support the reading process in Chinese children.

Limitations and future directions

The present study had a few limitations that should be addressed. First, our results were based on data from 35 children with word reading deficit and 20 children with reading comprehension deficit. The findings should be interpreted with caution because of the small sample size. Larger samples are needed to further validate the findings, especially between WRD and S-RCD. Second, there is no standardized reading comprehension test in Chinese. The S-RCD children were selected based on researcher-designed reading comprehension measures. Future research is needed to conduct more rigorous screening on the selection of participants based on standardized tests, to examine the characteristics of the executive functions of the participants. Third, domain-specific nature of working memory and inhibitory control should also be considered. Future research should consider the relationships between domain-specificity of working memory and inhibitory control and reading. Fourth, n-back tasks may not be the typical task to assessing working memory and they are frequently used in cognitive neuroscience studies (Redick & Lindsey, 2013). Although several studies showed that n-back tasks could be used for assessing working memory, more typically-used working memory measures should be included. Finally, the current research design is not longitudinal, which limits our ability to make statements regarding the causes of reading difficulties and whether the observed relations may shift over time.

Theoretical and educational implications

The present findings point to some potentially important implications for researchers and practitioners. First, research on reading difficulties in Chinese mainly stays at the level of word-level (Peng et al., 2013; Zhao et al., 2018), ignoring the children who just have difficulty in reading comprehension. The findings of this study add to current literature on the relationship between different subtypes of reading difficulties. Second, developing reading-related research is an important breakthrough for us to understand the human mind, and reading difficulties research, as an important part of the entire reading research, has important theoretical implications to understand the development, acquisition, and mechanisms about reading.

Our findings may also have some implications for intervention work. We found that WRD children showed deficits both in working memory and inhibitory control; S-RCD children have a working memory deficit. These findings indicate that the significance of adopting distinguished educational strategies, especially putting executive skill interventions into the hands of classroom teachers. Studies suggest that executive skills interventions may be helpful for students with RCD (Cartwright et al., 2017) since students with low reading comprehension showed greater gains in reading comprehension after the intervention than students with high reading comprehension.

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