MA in Psychology

PSYC5210 Independent Study in Cognitive Science

Thesis

An Evaluation of the Effects of Metalinguistic and Working Memory Training on Dyslexic Children's Reading Fluency in Chinese and English

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Abstract

Dyslexic children face particular difficulty in processing linguistic information, as hindered by their deficiency in phonological awareness and working memory. Trainings targeting these two aspects may facilitate their learning to read. In the present study, it was tested whether training dyslexic children's metalinguistic skills or working memory capacity in 8 weeks would improve reading fluency in Chinese and English, and which training produced a stronger reading gain. 76 second and third graders with dyslexia in Hong Kong were recruited and randomly assigned into metalinguistic awareness (MA) group (N = 30), working memory (WM) group (29), or waitlist control group (17). In MA training, children were trained to analyze word structure – segmenting Chinese characters into phonetic and semantic components and English words into onsets and rimes. In WM training, children were taught to memorize long strings of Cantonese and English syllables in correct order. Children before and after the training were tested on reading fluency, phonological skills, and verbal working memory capacity. Data showed that all three groups had similar improvement on reading fluency, phonological skills and working memory. No one particular group had a relatively stronger effect. Despite the absence of domain-specific training effects, a larger word consistency effect on reading fluency was found in Chinese than in English. The findings suggest that MA and WM training may be beneficial to reading fluency, but higher training intensity, frequency and parents' motivational involvement are needed to create a more pronounced reading improvement for dyslexic children.

Keywords: reading fluency, metalinguistic, working memory, phonological awareness, dyslexia

Introduction

Studies on children with dyslexia's limited performance in reading fluency cast needs to examine effective ways to help dyslexic children with learning to read.

Reading fluency as "the ability to read connected text rapidly, smoothly, effortlessly, and automatically with little attention to the mechanics of reading, such as decoding" (Meyer and Felton, 1999, p. 284), reflects a person's ability to decode words in a text. Researchers have discovered several critical factors which influence dyslexic children's Chinese and English reading fluency.

Metalinguistic Awareness

Metalinguistic awareness (MA) is the ability to reflect upon and manipulate the structural features of a language. MA enables a person to be aware of the rules governing the orthography of a language. It treats language as an object of thought instead of merely a system for comprehending and producing sentences (Tunmer & Herriman, 1984). It is the awareness of the internal structure, such as suffixes, of complex words.

There are a variety of subcategories of metalinguistic awareness, each defined in terms of a particular unit of linguistic structure (Nagy, 2007). Gombert (1992) divided metalinguistic awareness into six categories: metaphonological, metasyntactic, metalexical, metasemantic, metapragmatic, and metatextual.

Vocabulary acquisition and reading comprehension are dependent on metalinguistic abilities. In particularly, phonological awareness (PA) refers to the ability to hear, detect and manipulate the sound structures (such as phonemes, onsets, rimes and syllables) of oral language. PA is different from phonemic awareness, which is easily confused with PA.

Phonemic awareness, as a subset of PA, is related to phonemes detection and manipulation, such as separating a spoken word ‘dog’ into three distinct phonemes.

In the present study, the focus is phonological awareness. Studies have found that children with better detection and manipulation of syllables, rhymes, or phonemes are quicker to learn to read. Perfetti and Zhang’s (1991) study also showed the importance of phonological processing in reading Chinese. In alphabetical writing system like English, the concept that letters represent phonemes is crucial. Unlike English, though Chinese has no grapheme-phoneme correspondence, recent studies have found the presence of Orthographic Phonological Conversion (OPC) rule, meaning orthography-phonology correspondence. MA in Chinese can be understood as the ability to analyze semantic and phonetic component of Chinese characters, in which the phonetic component provides cue to the pronunciation (Ho and Bryant, 1997).

Working Memory

Working memory (WM) is the cognitive system in human brain that provides temporary storage and manipulation of information during complex cognitive activities (Holmes, Gathercole, & Dunning, 2009). It is an essential component in learning and executive functioning as we need to process information within immediate awareness. Nagy (2007) recognized that to learn a word, getting the phonological form established in memory is essential. It is needed for retaining verbal information during reading. Phonological short-term memory is also found to predict vocabulary learning ability (Nagy, 2007). Working memory, however, has a capacity constraint, which can be expressed by the number of items or interrelationships among elements that can be held in the working memory in a reasoning task (Jaeggi , Buschkuehl, Jonides, & Perrig, 2008).

Melby-Lervåg & Hulme (2013) stated that with enlarged WM capacity, reading fluency and comprehension can be improved. To illustrate, when there is verbal linguistic input, WM allows a person to maintain, retrieve, manipulate and transform the linguistic input. As a result, the person can process the phonological information like phoneme blending and word segmentation to read efficiently (Pham & Hasson, 2014). Not only on reading, working memory capacity also predicts performance in a wide range of cognitive tasks (Klingberg, 2010).

Difference between Chinese and English Language

Chinese is a nonalphabetic language. Its visual, orthographic and phonological characteristics are different compared to alphabetic languages like English.

The basic graphic unit in Chinese is a character, which is made up of strokes combined together, such as 天, 地, 人. It is the basic unit of meaning (i.e. grapheme) and is monosyllabic, consisting of only one syllable. In Chinese, as pointed out by Kang (1993), more than 80% of the characters are ideophonetic compounds, meaning that each character comprises a semantic and phonetic component. Chinese readers would deduce the pronunciation of the character by looking at the phonetic radical that encodes the sound of the character (e.g. derive the pronunciation of 杺/sam1/ "a kind of tree" from its phonetic radical 心/sam1/) or by analogizing to another character with the same phonetic radical (e.g. associate the pronunciation of 杺 /sam1/ "a kind of tree" with 芯 /sam1/ "wick"). When the character does not follow the above-mentioned script-sound consistency, Chinese readers would have to make guesses or by rote-memorizing the pronunciation of these inconsistent characters. For example, as in the characters 跑 /paau2/, 砲 /paau3/, 匏 /paau4/ and 雹 /bok6/, they all have the same phonetic radical 包 /baau1/, but they are all pronounced differently in Cantonese as their tone are not the same. These characters are defined as having low consistency.

With this morphosyllabic (i.e. characters mapping onto morphemes and syllables) feature of Chinese, readers are required to memorize and analyze the character structure in order to give accurate pronunciation. Adding on the fact that most local primary schools do not use phonetic coding system for learning Chinese (McBride-Chang, Bialystok, Chong & Li, 2004), children's working memory load is more highly demanded.

For English, with its alphabetic nature of the script, each grapheme corresponds to a phoneme. This letter-to-sound conversion rule enables children to be aware of the subsyllabic units of words, and thus help them decode both familiar and unfamiliar words.

Important Factors in Language Processing

Phonological awareness and phonological working memory were found to be two important phonological skills that contribute to reading acquisition (Gathercole, Willis & Baddeley 1991). When reading alphabetic scripts like English, children need to be aware of the corresponding phonemes of the letters in order to decode words. For example, when they perceive the word *cat*, they can decode the word in phoneme level and make sense of the link between the orthography *cat* and its phonology /k^h æ t/.

This metalinguistic awareness and cognitive ability required when processing language is also present in reading Chinese. In Chinese reading, they are reflected in understanding the script-sound consistency of Chinese characters, as described in the previous section. A longitudinal study by Ho and Bryant (1997) also showed that Chinese children's pre-reading phonological awareness significantly predicted children's reading performance even after three years, regardless of their age, intelligence and socio-economic background.

Moreover, phonological working memory enables children to keep sounds of words in their short-term memory. It provides children with a necessary memory buffer when they learn the letter-sound correspondence of words or when they are recoding the words heard phonologically. Gathercole and Baddeley's (1990) study results showed that memory deficit would lead to poorer verbal vocabulary acquisition and poorer development of stable graphic-sound association, which are both necessary for reading.

Dyslexia

Developmental dyslexia is defined as a specific learning disorder with deficient literacy acquisition despite adequate intellectual ability, motivation and educational opportunities (American Psychiatric Association, 2013). It is characterized by difficulty in accurate word recognition, spelling, reading and writing. Dyslexic children in particular exhibit deficiency in phonological awareness and working memory.

Core Deficits in English and Chinese Reading

Children with dyslexia often exhibit problems in processing linguistic and phonological information. According to Phonological Deficit Hypothesis, dyslexic children face inability to establish link between orthography and phonology at phoneme, consonant-vowel and/or syllable level due to poor phonological awareness. They find it hard to attend to and segment sounds into smaller phonological units. Findings from Ho, Law and Ng (2000) suggested that dyslexic children have deficits in processing phonological information in Chinese as well as in English. They are weak in being aware of the sub-syllabic units of the English words as well as mastering the letter-to-sound conversion rule (aka grapheme-phoneme conversion rule), and hence performed poorly in decoding words. Huang and Zhang (1997) found that Taiwanese Chinese dyslexic children performed significantly worse in initial phoneme deletion, sound categorization and tone detection than average readers of the same age. In addition, as shown in van Ijzendoorn and Bus's (1994) meta-analysis, their poor performance in segmenting and reading nonwords showed that they have deficit in this phonological decoding skill.

Deficit in working memory – holding verbal information such as digits, words, and nonwords in short-term memory, is also faced by dyslexic children. Since reading involves rapid naming (Ackerman & Dykman, 1993) – recognizing and retrieving the visually presented linguistic materials rapidly, dyslexic children are normally slow readers because they are deficient in automatically processing the extraction and induction of orthographic patterns. In other words, they are less able to attend to the letter sequence instead of processing each individual letter, which make them slow in reading. They cannot decode and encode words using rapid and accurate formation of word images in Memory (Roberts & Mather, 1997).

Prior Studies on Training Interventions

Metalinguistic Awareness Training

There is emerging evidence showing that learning to read in Chinese is influenced by metalinguistic awareness training like phonological and morphological training. There are studies attempting to combine the elements of phonological and semantic knowledge of Chinese characters and to investigate their effect on Chinese reading aloud.

Zhou, Duff, & Hulme's (2017) suggested that orthography-semantics mappings was more dependent on in Chinese reading than in English. Results from Packard et al. (2006) also showed that raising children's awareness of the morphemic and orthographic structure of Chinese words could improve their Chinese learning, as shown in the study result that the children outperformed the control group in writing Chinese characters from memory.

Siu, McBride, Tse, Tong and Maurer’s (2018) study also tested 35 typically developing primary 2 children on their reading fluency before and after the training of either metalinguistic skills or working memory capacity. Their results showed that MA and WM training groups both showed more improvement in reading fluency than the control group, who received no training. This showed that metalinguistic training, which involved analyzing semantic-phonetic compound of Chinese characters, enables children to learn to read.

Apart from looking at the aspect of phonology and morphology, studies have also found the combined effect of semantic and phonetic elements on Chinese reading fluency. Zhou, Duff, & Hulme (2015) conducted a study in which Mandarin-speaking children were trained either the pronunciation alone, or the pronunciation plus meaning of subsets of the words. Results showed that the latter had a greater impact on children’s learning to read aloud words. Hence, the semantic information plays a role in helping children to read Chinese words. This effect also

For dyslexic children, this metalinguistic ability to analyze the structure of semantic-phonetic Chinese character compound could also foster their reading fluency. In Ho and Ma’s (1999) study, Chinese dyslexic children who received a 5-day intensive explicit training on character structure was found to significantly outperform the control group at post-test in reading fluency. Similarly, Packard et al. (2006) and Wu et al. (2009) also arrived at a similar conclusion that identifying and analyzing word structure improved Chinese word reading fluency. Being aware of the word structure provides informational cue to the pronunciation of the characters for children (Anderson et al., 2003).

On top of the findings regarding the relation between metalinguistic awareness and Chinese reading, some studies suggested a stronger role of semantic informational cue of words in reading Chinese than in English (Zhou et al., 2015). Yang, Shu, McCANDLISS, & Zevin

(2013) accounted this suggestion with the explanation that as English has relatively more regularities in print-to-sound mapping than Chinese, the words are largely limited by their pronunciation.

Working Memory Training

Recent studies on working memory training in Chinese have suggested that trainings that enhance working memory capacity can facilitate reading aloud in Chinese. There are studies that suggest WM can be improved through extended training.

Dahlin's (2011) training study on Swedish primary school children found that WM was related to word reading. Siu et al. (2018) also found that typically developing children with WM training had a larger verbal working memory span and had improved Chinese reading ability after the training. Moreover, Luo, Wang, Wu, Zhu, & Zhang (2013) conducted a study in which thirty children with dyslexia received working memory training including verbal memory, visuospatial memory and central executive function. The children had significantly improved in reading fluency task and rhyming task. Compared to the control group which received a low-dose version of the training (i.e. received fewer amount of time of daily training and with no difficulty level interactively adjusted), the dyslexic children have an increased pre- and post-test result in reading fluency.

However, some meta-analytical studies were skeptical about whether working memory training is effective in enhancing reading performance, apart from studies that showed WM training effectiveness for both typically developing and dyslexic children. Melby-Lervåg and Hulme (2013) reviewed WM training programs and found that overall, the programs did yield reliable improvement in WM, but the effects were short-termed. When children participants were reassessed their WM level after the post-test for an average of 9 months, the effect was not sustained. In Holmes, Gathercole & Dunning's study (2009), the children who went across a training of 35 minutes per day for at least 20 days, similarly, showed an improvement of WM scores over the period of 6 months after the training program. Therefore, some researchers believed that though working memory training has positive effect on working memory capacity, and hence helpful for children with dyslexia, the positive effect is only short-term and closed to the tasks that the children were trained.

Research Gap

There are contrasting studies that suggest differed view on the effectiveness of working memory training in improving children's reading fluency. In regard this divergence, it is worth providing more evidence on whether WM training has a significant effect on dyslexic children's reading fluency.

In addition, most past studies that work on Chinese reading focus on aspects such as morphology, phonological awareness, and homophoneme awareness. Only few studies had looked into the combined effect of analyzing the phonetic-semantic structure of Chinese characters on reading fluency. Studies on the comparison between the effectiveness of different trainings were rare. Hence, more evidence could be contributed to the understanding of metalinguistic awareness and working memory training on reading fluency in Chinese and English.

Research Significance

Dyslexic children face deficits in phonological awareness and working memory capacity. In the current study, children are trained with either analyzing the structure of Chinese and English words or learning character pronunciation by rote. As the study by Meng, Lin, Wang, Jiang, & Song (2014) showed that visual perceptual processing is related to reading fluency, this current study's metalinguistic training draws children attention on the structure of the words (while analyzing the character into phonetic or semantic radical). It may shed light on which training would bring greater effectiveness for dyslexic children in reading in Chinese and English.

This study could also enrich the literature as most prior studies provided evidence that support either metalinguistic or working-memory training improves reading skills in Chinese, but not much had focused on comparing the effectiveness between the two training methods. Having provided with the findings of the effectiveness of the strategies, it is worth finding out which intervention program benefits children's reading fluency more.

In addition, in Siu's (2018) study, the two training programs had similar effect on reading fluency in typically developing children. It is worthwhile to investigate whether there would be similar effect or a stronger effect between the training programs. This could provide more information about the efficacy of training to the reading remediation programs for dyslexic children, who face more difficulty, lowered motivation and confidence in learning than typically developing children.

Research Question and Hypothesis

Past studies have shown that dyslexic children did have not enough working memory capacity to store information for them to process the phonological aspect of a word. On the other hand, past studies had also shown that analyzing structure of Chinese and English words would help dyslexic children recognize the words more easily. In this regard, it is interesting to find out whether analyzing the structure of Chinese and English words or memorizing long strings of Chinese and English syllables is more beneficial for dyslexic children' reading fluency. The current study is designed to contrast the effect these two training programs had on dyslexic children's reading fluency in Chinese and English. It also aims to find out whether metalinguistic training can improve dyslexic children's metalinguistic ability, specifically phonological skills; and whether working memory training can improve dyslexic children's working memory capacity.

In general, it is expected that both training groups would have larger improvement in Chinese and English reading fluency than the control group.

Comparing between the two trainings, it is hypothesized that metalinguistic training would be more effective than working memory training in improving Chinese and English reading fluency.

In terms of consistency of the Chinese and English words, it is hypothesized that the two trainings have different strength of effect for reading consistent and inconsistent words in Chinese and English respectively. Working memory may be more useful for reading inconsistent characters as these characters' phonetic radicals or syllables are not reliable hints in these cases for children to get phonological information of the word. Therefore, an enlarged WM capacity may be an advantage.

In terms of specificity of the trainings, it is hypothesized that both trainings would improve the skills they are meant to train respectively in each language. In other words, there is training-specific effects in both Chinese and English language. Metalinguistic training would improve dyslexic children's metalinguistic ability, specifically phonological skills; and working memory training would improve dyslexic children's working memory capacity.

Methods

Participants

76 Hong Kong Chinese second and third graders (38 boys; mean age = 8.4 years, SD = 1.07) who were diagnosed as dyslexic by the Hong Kong Education Department participated in the present study. All of the children had at least average intelligence (i.e. with IQ 90 or above) as measured by Raven's test.

Parents responded to invitation letters sent to school or by directly responding to the invitation message sent to parents with dyslexic children Whatsapp (an instant messaging application) social group, and were contacted via follow-up phone calls.

All the dyslexic children were randomly assigned into two groups: 30 children received metalinguistic skills training in Metalinguistic Awareness (MA) group (mean age = 8.53 years), and 29 received working memory training in Working Memory (WM) group (mean age = 8.45 years). The two groups did not differ significantly in age or IQ. Among these children, 28 were boys and 31 were girls. The remaining 17 children were assigned into Waitlist-Control group (mean age = 8.09 years), who received training only after the post-test.

No children dropped out after the start of the study. Parents' written informed consent on children's participation were collected at the pre-test. All testing and training sessions were conducted individually either at the children's home or in the university laboratory. Upon completion of the entire study, the children and their parents received stationery gifts and HKD300 cash coupon. The research procedures and written consent form were approved by the Ethics Committee of the Social Science Panel at The Chinese University of Hong Kong.

The group characteristics are listed in Table 1. The three groups did not significantly differ regarding gender, age, nonverbal intelligence or Chinese and English oral vocabulary (all $p > 0.27$).

Table 1. Group characteristics for training and control groups.

Characteristics	**Metalinguistic** (17M, 13F)		**Working Memory** (11M, 18F)		**Waitlist-Control** (10M, 7F)	
	Mean	*(S.D.)*	*Mean*	*(S.D.)*	*Mean*	*(S.D.)*
Age (in months)	102.40	(10.35)	101.47	(9.31)	97.07	(6.68)
Non-verbal intelligence	24.37	(6.26)	25.83	(7.07)	24.06	(6.71)
Expressive vocabulary definition:						
Chinese	39.97	(5.32)	39.97	(4.07)	39.94	(4.46)
English	30.47	(5.40)	29.79	(4.76)	31.12	(4.04)

Materials and Procedures

Two tests were administered to all children in the study at pre-test: a non-verbal intelligence test and vocabulary definition test in Chinese and in English.

A total of six tasks were administered to all the dyslexic children at both pre-test and pos-test condition: word reading fluency tests, phonological tests, and verbal working memory tests in Chinese and in English at both pre-test and post-test. All the tasks were administered individually.

The following two tests were administered at pre-test.

1) Raven's Standard Progressive Matrices (RSPM)

RSPM (Raven, Court & Raven, 1996) was a standardised test used to estimate children's non-verbal reasoning ability. There were 36 black-and-white items in Set A to C of the test. In each item, there was a target matrix with one missing part. Children had to select the best piece that completed the matrix among six to eight alternatives. The maximum score of this test was 36.

2) Oral Vocabulary

Two vocabulary definition tests were used to measure children's expressive vocabulary knowledge as a proxy of their general Chinese and English language proficiency.

The vocabulary subscale of Stanford-Binet Intelligence Scale (Thorndike et al., 1986) was the basis of the test design. Its test items and scoring procedures had been used in previous Chinese literacy acquisition studies (e.g. McBride-Chang et al., 2008; Zhou et al., 2014).

In the test, there were 26 frequently used Chinese two-character words and 15 frequently used English words from local primary school textbooks. They are arranged in ascending level of difficulty.

For each item, children had to listen to the experimenter read aloud a word, then they had to explain the meaning of the word. The answers were scored 0, 1, or 2 based on the accuracy and fullness of the definition given.

When children failed to define five consecutive words, the test discontinued. The maximum score of the Chinese and English tests were 52 and 30 respectively.

The following tests were administered at both pre-test and post-test in order to evaluate the training effects of MA and WM.

1) Chinese Word Reading Fluency (Chinese Consistent and Inconsistent Character Reading)

Two separate lists of Chinese single-character words were used to assess children's ability to read in Chinese, as well as to evaluate the effect of training on word reading fluency in Chinese.

The first list included 80 consistent Chinese characters (> 0.8 consistency value for all consistent characters, mean = 0.96). The consistency value of all the characters in the first list was 1 when tone was excluded, meaning that all characters shared the same phonetic component sounded the same (e.g., /wu4/, /wu4/, /wu4/, /wu4/).

The second list consisted 80 inconsistent Chinese characters (mean consistency value = 0.35). They were inconsistent as they shared a common phonetic component but were pronounced quite differently (e.g., /paau2/, /paau3/, /baau2/, /pou5/).

The Chinese characters from the two lists were not intermixed. The lists used in pre- and post-tests were also different from the lists used in the training. The same Chinese word reading fluency test was used at the pre- and post-tests.

In the test, children were given 1 min to read aloud the characters in each list as quickly and as accurately as possible, and skip over any unknown words. The maximum score for each list was 80.

2) English Word Reading Fluency (English Consistent and Inconsistent Character Reading)

Two separate lists of English monosyllabic words were used to assess children’s ability to read in English, as well as to examine the effect of training on word reading fluency in English.

The first list included 80 consistent English words, for which all other words with the same-spelling rime sound the same (e.g., boy-toy, luck-duck, feet-meet).

The second list consisted 80 inconsistent English words for which there exist other words with the same-spelling rime but a different pronunciation (e.g., toe-shoe, five-live, home-come).

The test words from the two lists were different from those used in the training. The same English word reading fluency test was used at the pre- and post-tests.

In the test, children were given 1 min to read aloud the English words in each list as quickly and as accurately as possible, and skip over any unknown words. The maximum score for each list was 80.

3) Phonological Skills Tasks in Chinese

A phonological test that included syllable and phoneme deletion was used to assess children's ability to manipulate phonological units in Chinese. The test had been used in previous Chinese children's reading studies (e.g., Shu et al., 2008; Li et al., 2012).

In its syllable-deletion section, there were two blocks of 10 three-syllable Chinese words: the first block had real words while the second block had pseudowords. Children were asked to say the word without either the initial, middle, or final syllable after the experimenter read aloud the words one by one.

In its phoneme-deletion section, there were 20 one-syllable words: 10 real words and 10 pseudowords. Children were asked to say the syllable that would be left when the initial phoneme was deleted. The same set of items was used in the pre- and post-test.

In the test, children had four practice trials with modeling and corrective feedback before the test in each section began. The tests discontinued if children made five consecutive errors in each section. The maximum score of the test was 40

4) Phonological Skills Tasks in English

A phonological test that included syllable and phoneme deletion was used to assess children's ability to manipulate syllables and phonemes in English. The test had been used in previous children's reading studies (e.g., Cheung et al., 2010; Li et al., 2012).

In its syllable-deletion section, there were two blocks of 10 three-syllable English items: the first block had real words while the second block had pseudowords. Children were asked to say the word without either the initial, middle, or final syllable after the experimenter read aloud an English word.

In its phoneme-deletion section, there were 20 one-syllable words: 10 real words and 10 pseudowords. Children were asked to say the syllable that would be left when the initial phoneme was deleted. The same set of items was used in the pre- and post-test.

In the test, children had four practice trials with modeling and corrective feedback before the test in each section began. The tests discontinued if children made five consecutive errors in each section. The maximum score of the test was 40

5) Verbal Working Memory Tasks in Chinese

A test of non-word repetition was administered to measure children's verbal working memory in Chinese. The test was based on previous children verbal working memory studies (e.g., Ho et al., 2002, 2004).

The test included 12 non-word strings that ranged from three to eight Cantonese syllables in length. Each non-word string did not carry any lexical meaning as the syllables were randomly combined. The same set of non-words was used in the pre- and post-test.

In the test, children were asked to repeat the string in the correct order after the experimenter read aloud a string of Cantonese syllables. 1 point was awarded for each correct syllable recalled and also 1 point for each correct order of consecutive pairs. Children had two practice trials before the test began. The test discontinued if children failed to repeat both items in the same span length. The maximum score of the test was 120.

6) Verbal Working Memory Tasks in English

A test of non-word repetition was administered to measure children's verbal working memory in English. The test was based on previous children verbal working memory studies (e.g., Ho et al., 2002, 2004).

The test included 12 non-word strings that ranged from three to eight English syllables in length. The same set of non-words was used in the pre- and post-test.

In the test, children were asked to recall the string in the correct order after the experimenter read aloud a string of English nonwords. 1 point was awarded for each correct non-word recalled and another 1 point for each correct order of consecutive pairs. Children had two practice trials before the test began. The test discontinued if children failed to repeat both items in the same span length. The maximum score of the test was 120.

Training Materials and Protocol

There were 8 weeks of one-on-one tutoring between pre- and post-test for dyslexic children in MA and WM training groups. Waitlist control children received the same MA or WM training after the post-test. The 8-week training included four 30-minute parent-led and one 1-hour experimenter-led tutoring sessions per week.

The experimenters were undergraduates or postgraduates, who had received a 3-hour pre-training instruction on the overview of the reading fluency training program, Chinese and English language structure, and the training activities and strategies to be executed in the tutoring sessions. Weekly individual feedback on children's learning was obtained from experimenters for reviewing and adjusting the training protocol. A log book was used by parents and experiments to keep record of the training time and children's learning performance, which was expressed in number of words correctly read and written.

Training Stimuli

Training groups children were taught 96 Chinese and 96 English late-acquired words during the 8-week experimenter- and parent-led training. The selected words were based on a local database of primary school Chinese and English, and were unfamiliar to second graders. Among all the training words, half were consistent words and half were inconsistent words.

Training Protocol

In each parent-led tutoring session, three Chinese and three English words were taught. Training time between Chinese and English was equally split. The procedure and instructions for metalinguistic and working memory trainings were based on Siu et al.'s (2018) study.

Statistical Analyses

Training log books indicated that parents from the two training groups completed all the designated exercises with their child. The total time spent on the training was also comparable across the two groups. Therefore, it can be reasonably assumed that the training groups were equally compliant with the training.

A repeated measures ANOVAs was conducted to examine the effects of the two training methods. The ANOVAs on phonological skills and working memory consisted of one between-subject factor *group* (Metalinguistic Awareness vs. Working Memory vs. Waiting-control) and two within-subject factors *time* (T1 pre-test vs. T2 post-test) and *language* (Chinese vs. English). The ANOVA on word reading fluency contained the additional within-subject factor *consistency variable* (consistent vs. inconsistent characters). Follow-up *t*-tests comparing pre-test results to post-test results were conducted to facilitate interpretation.

Results

Table 2 summarizes the means and standard deviations of the children's performance on all measures at pre- and post-test, organized by groups.

At pre-test, the three groups were comparable in their phonological skills [Chinese: $F(2,75) = 0.288$, $p = 0.750$; English: $F(2,75) = 2.817$, $p = 0.066$], verbal working memory [Chinese: $F(2,75) = 1.404$, $p = 0.252$; English: $F(2,75) = 0.629$, $p = 0.536$] and word reading [Chinese: $F(2,75) = 0.764$, $p = 0.469$; English: $F(2,75) = 0.067$, $p = 0.9.5$] before training. The pre- and post-tests data were submitted to repeated-measures ANOVAs and the results are reported below. There is no statistically significant difference between the scores in the 3 groups in reading fluency.

Table 2. Pre-test and post-test mean performances on all measure for training and control groups.

Measures	**Metalinguistic Awareness**				**Working Memory**				**Waiting-control**			
	T1 pre-test		**T2 post-test**		**T1 pre-test**		**T2 post-test**		**T1 pre-test**		**T2 post-test**	
	Mean	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*
Chinese Word Reading Fluency:												
Consistent	24.27	(14.52)	29.80	(16.65)	23.55	(16.84)	28.79	(17.87)	18.06	(12.48)	24.94	(14.67)
Inconsistent	18.87	(11.73)	22.82	(14.73)	17.64	(13.22)	21.11	(13.52)	14.28	(9.90)	19.12	(10.51)
Chinese phonological skills	15.65	(5.45)	17.55	(6.01)	16.69	(5.59)	18.03	(4.68)	16.53	(5.64)	20.12	(5.13)
Chinese verbal working memory	4.48	(.83)	4.53	(.90)	4.62	(.90)	4.83	(1.20)	4.18	(.88)	4.59	(.87)
English Word Reading Fluency:												
Consistent	18.74	(24.64)	23.27	(28.64)	17.73	(18.27)	21.40	(22.20)	16.25	(22.28)	19.71	(21.09)
Inconsistent	16.92	(23.44)	19.68	(26.20)	15.69	(19.20)	18.55	(20.45)	14.71	(19.57)	17.88	(19.79)
English phonological skills	11.48	(5.61)	16.22	(6.06)	13.62	(6.33)	17.01	(5.68)	15.76	(6.25)	18.50	(5.32)
English verbal working memory	3.60	(.89)	3.40	(.77)	3.39	(.69)	3.97	(.73)	3.29	(1.40)	3.65	(.79)

Word Reading Fluency

Repeated measures ANOVA on reading fluency with factors as described in the previous section revealed the following.

Children's mean performance on word reading fluency in Chinese and English before and after the training are shown in **Figure 1** below. Children's performance on word reading fluency for consistent and inconsistent word stimuli is also shown. The results of the repeated measures ANOVA are summarized in **Table 3** and **3.1**.

First, regarding word reading fluency (in Chinese and in English) of all the dyslexic, it increased from the pre- to post-test (Time, $p < 0.001$). There were significant differences in word reading fluency before and after the test, meaning that children had made improvement (see Figure A).

Table 3. Results of repeated measures ANOVAs on word reading within-subject effect.

Effect	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Time	**53.782**	**1**	**72.000**	**.000**	**.428**
Time*Group	.111	2	72.000	.895	.003
Consistency	**101.589**	**1**	**72.000**	**.000**	**.585**
Consistency*Group	1.534	2	72.000	.223	.041
Language	1.238	1	72.000	.270	.017
Language*Group	.172	2	72.000	.842	.005
Time*Consistency	**5.575**	**1**	**72.000**	**.021**	**.072**
Time*Consistency*Group	.045	2	72.000	.956	.001
Time*Language	3.162	1	72.000	.080	.042
Time*Language*Group	.424	2	72.000	.656	.012
Language*Consistency	**23.875**	**1**	**72.000**	**.000**	**.249**
language * consistency * Group	.574	2	72.000	.566	.016
time * language * consistency	.799	1	72.000	.374	.011
time * language * consistency * Group	.355	2	72.000	.702	.010

Bold print indicates significant effects.

Table 3.1. Results of repeated measures ANOVAs on word reading between-subject effect.

Source	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Group	.427	2	72	.654	.012

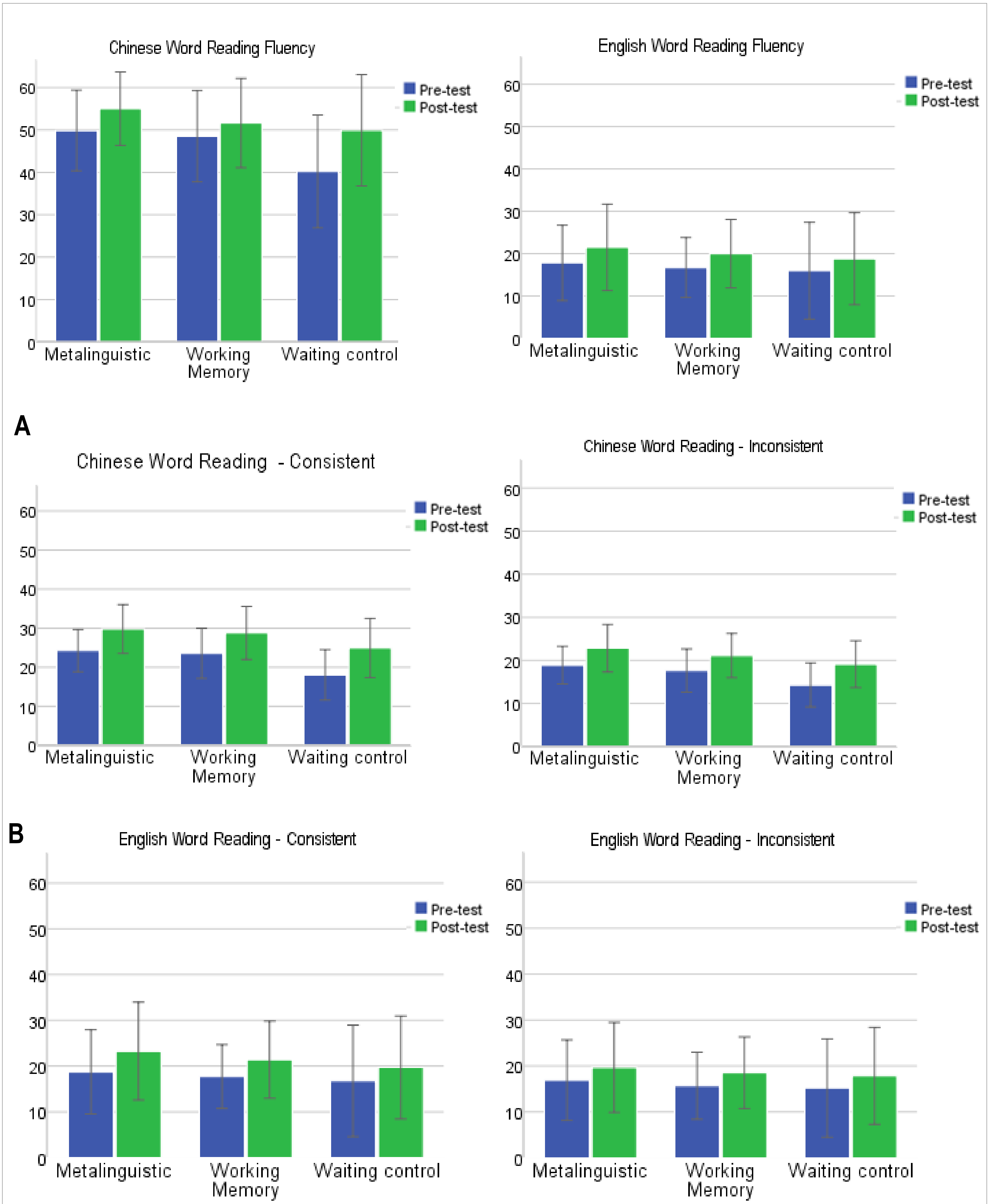

Figure 1. Pre-post training effects in consistent and inconsistent word reading in Chinese **(A)** and English **(B)** for the three groups. Error bars represent standard deviations.

However, it was surprising to find that there was a lack of a modulation of the time effect by training. Reading fluency increased generally but did not increase particularly in any one of the three groups. Children in metalinguistic and working memory groups did not show more pronounced reading fluency improvement that those in the waitlist-control group (Time x Group, $p = .895$).

In addition, when comparing between the two training groups, there was no significant reading fluency change from pre- to post-test ($p = .757$). In order words, children's word reading fluency did increase, but the group children were in did not make the children more or less improved.

Regarding consistency: the consistent and inconsistent word items present in the test, it was found that children generally performed better for consistent words than inconsistent words (Consistency, $p < 0.001$). In addition, this improvement was more pronounced for consistent words than inconsistent words (Time x Consistency, $p < 0.05$).

In addition, in terms of the effect of language, when comparing from pre- and post-test, children tended to have greater improvement in reading Chinese word stimuli (i.e. to read more fluently) than English word stimuli (Time x Language, $p = .080$). Moreover, the word consistency effect on reading fluency was larger in Chinese than in English (Language x Consistency, $p < 0.001$). This means children read Chinese consistent items better than inconsistent items and this performance difference was larger than that in. Though when looking at the two language stimuli alone, Chinese word stimuli were not significantly read more fluently than English stimuli (Language, $p = .270$).

Phonological Skills (Metalinguistic Awareness)

Repeated measures ANOVA on phonological skills with between-subject factor *group* and within-subject factors *time* and *language* revealed the following.

Children's mean performance in phonological tests at pre- and post-tests are presented **in Figure 2** below. The results of the repeated measures ANOVA are summarized in **Table 4** and **4.1**. The repeated measures ANOVA showed that children's phonological performance increased from pre- to post-test ($p < 0.001$). In addition, it was found that children performed significantly better in Chinese phonological test than in English phonological test ($p < 0.001$). There was also Time x Language effect ($p < 0.05$), with the increase in English phonological performance greater than that in Chinese from pre- to post-test.

However, there was no particular group effect for phonological skills performance. The 3 groups all had increase in phonological skills from pre- to post-tests, but no one group's improvement was significantly different from the two other groups.

Table 4. Results of repeated measures ANOVAs on phonological awareness within-subject effect.

Effect	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
time	**39.747**	**1**	**72.000**	**.000**	**.356**
time * Group	.718	2	72.000	.491	.020
language	**39.938**	**1**	**72.000**	**.000**	**.357**
language * Group	1.855	2	72.000	.164	.049
time * language	**4.570**	**1**	**72.000**	**.036**	**.060**
time * language * Group	2.555	2.	72.000	.085	.066

Bold print indicates significant effects.

Table 4.1. Results of repeated measures ANOVAs on phonological awareness between-subject effect.

Source	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Partial Eta Squared**
Group	1.392	2	72.000	.255	.037

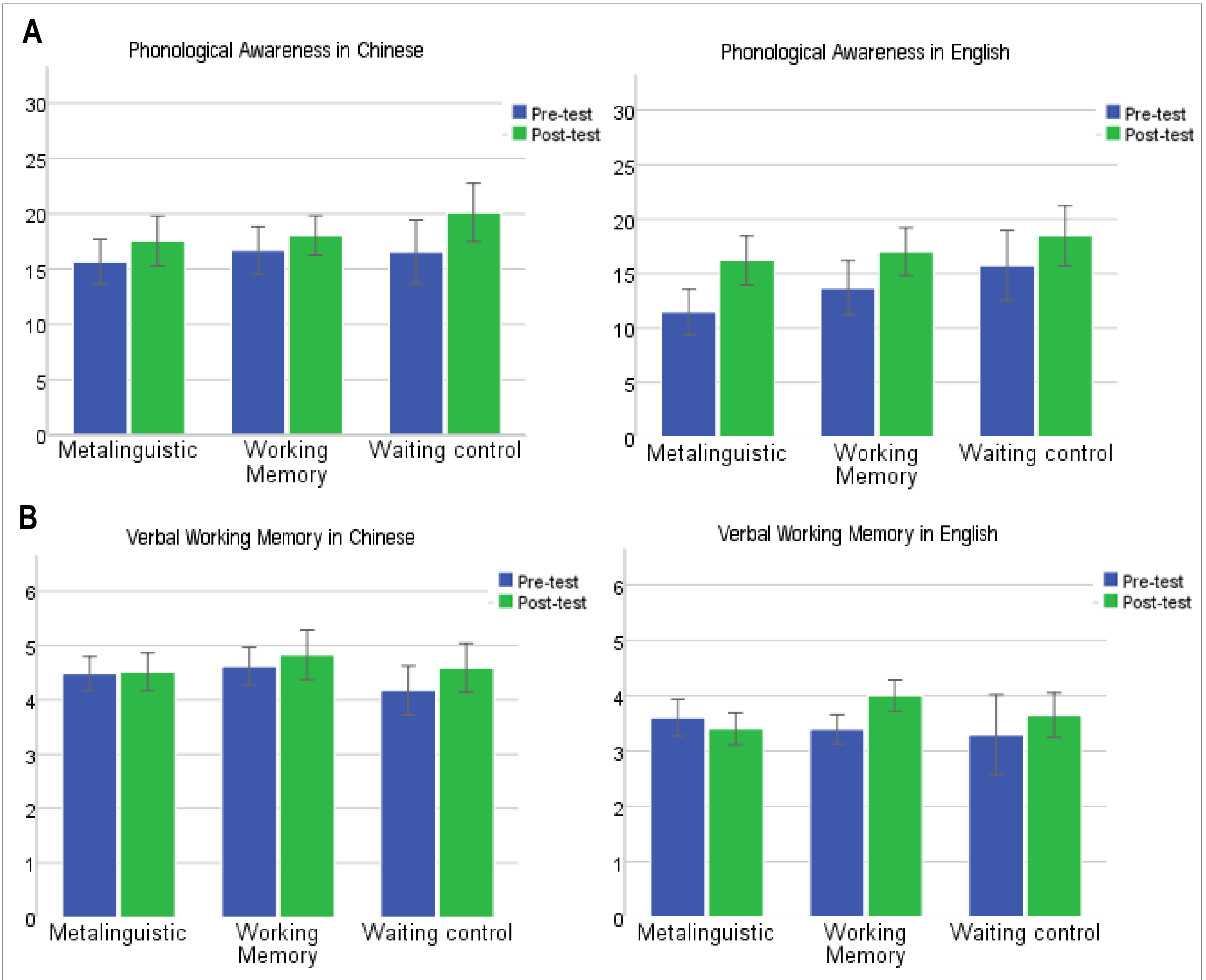

Figure 2. Pre-post training effects in Chinese and English phonological **(A)** and verbal working memory **(B)** for the three groups. Error bars represent standard deviations.

Verbal Working Memory

Repeated measures ANOVA on verbal working memory with between-subject factor *group* and within-subject factors *time* and *language* revealed the following.

Figure 2 above also showed children's mean performance in Chinese and English non-word repetition tasks at both time points. The results of the repeated measures ANOVA are summarized in **Table 5** and **5.1**. The repeated measures ANOVA showed that working memory performance increased from pre- to post-tests (Time, $p < 0.05$).

Table 5. Results of repeated measures ANOVAs on verbal working memory within-subject effect.

Effect	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
time	**4.502**	**1**	**71.000**	**.037**	**.060**
time * Group	2.774	2	71.000	.069	.072
language	**115.831**	**1**	**71.000**	**.000**	**.620**
language * Group	.194	2	71.000	.824	.005
time * language	.068	1	71.000	.795	.001
time * language * Group	2.115	2	71.000	.128	.056

Bold print indicates significant effects.

Table 5.1. Results of repeated measures ANOVAs on verbal working memory between-subject effect.

Source	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Group	1.668	2	71	.196	.045

There tend to be an interaction effect between time and group on phonological performance (Time x Group, $p = 0.069$), particularly for working memory group.

Moreover, MA group had a decrease in English working memory performance from pre-to post-tests, as can be seen in the **figure 2** above. There was also the effect of language, with children performed better in Chinese than in English working memory tests ($p < 0.001$).

Discussion

The present study aimed to evaluate the effect the two training programs had on dyslexic children's reading fluency in Chinese and English. Dyslexic children either underwent the metalinguistic training on analyzing word structure or underwent the working memory training on memorizing long strings of syllables.

The results indicated that both trainings could enhance dyslexic children's word reading fluency, but no particular training was more effective in improving reading fluency, since waitlist-control children also showed improvement. Trainings in this study found not to yield larger improvement in Chinese and English reading fluency than the control group. Possible explanations for this absence of group effect would be discussed below.

Despite this null result, a significant Time effect on reading fluency was observed. All three groups showed increase in reading fluency from pre- to post-tests. There was also larger consistency effect in Chinese than in English. In order words, the improvement in reading fluency was more pronounced for consistent characters than for inconsistent characters, and this improvement was more pronounced for reading Chinese than for English.

Moreover, there were also improvement in phonological skills and working memory in the three groups, though no training-specific effects were observed (i.e. the two trainings did not effectively enhance the respective skills they were meant to train). For working memory, in particularly, there was a slight Time x Group interaction effect, with two training groups increased while that of waitlist-control group decreased in working memory span performance.

Limited Group Effect on Reading Fluency

Since all 3 groups showed increase in reading fluency from pre- to post-test but with no Time x Group interaction effect, it is of reasonable judgement that the increase in reading fluency might not due to the training children underwent. In order words, as dyslexic children in waitlist-control group also showed improvement in reading fluency, there might not be a significant causal influence of metalinguistic and working memory trainings on learning to read.

One possible explanation for this was the insufficient randomized design for control group in the study. Dyslexic children participants were randomly assigned into MA or WM experimental groups by chance, in order to reduce extraneous variables. However, participants in the waitlist-control group were not randomly assigned. A batch of dyslexic children when recruited were directly selected into the control group, without randomly assigned into the three groups.

This posed a presence of confounding variables such as age and baseline reading fluency level without being controlled. The age of control group is not similar to that of the training groups. Although children's age difference was not statistically significant, it was observed that waitlist-control children were on average 4.85 months younger than those in training groups (see Table 1). In addition, their pre-test Chinese and English word reading fluency, Chinese phonological skills as well as Chinese and English verbal working memory were all lower than the training group children (see Table 2).

While it is possible to conclude that the trainings did not effectively enhance children's reading fluency as there was no significant difference between the experimental groups and the control group, there could also be other possible interpretations.

The improved reading fluency of the two training groups could also be interpreted as an indication of a certain degree of the trainings' effectiveness. Since the control group was not sufficiently randomized, the improvement yielded in control group could be of different reasons from the training groups.

Time Effect on Word Reading Fluency

One significant observation was the presence of time effect on children's reading fluency. Children with dyslexia in all three groups improved in word reading fluency from pre- to post-tests, regardless of whether they had received trainings or not. There were several possible explanations for this finding.

First, the schooling children received during the period of 8 weeks in the study might have influenced the post-test result. As all the children participants received normal schooling between pre- and post-times, learning to read in Chinese and English was involved. Children might have enlarged vocabulary bank and learnt decoding strategies at school. Students might have drawn on this information acquired while doing the post-test assessment on Chinese and English word reading fluency. Thus, their reading fluency showed improvement from pre- to post-tests.

Second, concerning test design, the same Chinese and English word reading fluency test was used at the pre- and post-tests. It was for the purpose of effectively comparing children's pre-test and post-test answers so as to observe any changes in reading fluency performance. However, there might be practice effect when the test was taken more than once. When the test was re-administered, children might have been aware of the questions on the test, hence led to a score inflation. On the contrarily, children could also become bored or tired of the test and hence performed worse in the test, but on average this was not observed in the present study.

Third, motivation from parents might have influenced children's reading fluency. As some children participants were recruited through parents responding to invitation letters sent to schools, while some were from sending direct invitation message on Whatsapp (an instant messaging application) to existing social groups organized by parents with dyslexic children, the latter would contribute to the study with more-concerned parents. These parents who were more concerned about their dyslexic children would have a higher degree of devotion in the study, in terms of the practice and encouragement they demonstrated in the parent-led MA or WM training sessions, or the external academic support they sought for beyond this study. Hence, this motivation effect may cause an improvement in reading fluency.

Difference to Training Studies on Typically Developing Children

In the present study, the results disconfirmed the first hypothesis that both training groups would have larger improvement in Chinese and English reading fluency than the control group. It was striking that the effect observed in Siu et al.'s (2018) study was not found in the present study. With the same study design as that of Siu et al.'s (2018) study on typically developing children, the tests administered to dyslexic children in this study did not yield the same larger improvement trainings had brought in Siu et al.'s (2018) study. This might be due to the following reasons.

First, the training materials used in the present study was the same as those in Siu et al.'s (2018) study on typically developing children. With regard of the learning difficulties and impairment dyslexic children faced, it is possible that Siu et al.'s (2018) training intensity was insufficient for dyslexic children, in terms of the frequency of training during the whole study period, duration of each training, the time span of the whole study period and the amount of training materials. The present study training period lasted for 8 weeks, same as that of Siu et al.'s (2018) study. With no lengthened duration and extra training sessions, it is possible that the training intensity was insufficient to create a significant impact on dyslexic children.

Second, dyslexic children had comparatively lower learning motivation than typically developing children. It is a common observation that dyslexic children faced higher chance of academic failure at local mainstream schools, especially in dictation, writing and reading. The difficulties encountered both academically and emotionally when learning to read make them link language learning to failure and unpleasant experience. This creates a rejection or lost of interest and self-confidence in learning to read. Thus, it is possible that the dyslexic children participants in this study might felt less motivated or reluctant to engage in the MA or WM trainings or in the post-tests. This might account for the absence of significant effect trainings had on reading fluency in the present study.

Third, student helpers' skillfulness and familiarity to the training materials, procedure and the test might also influence the test result. With student helpers being responsible to administer the test and the MA or WM training sessions, if they were unskilled, not sufficiently trained or with low motivation to execute their duty, the training session might not be execised to its full effectiveness. Hence children's performance in subsequent tests at the post-test might be negatively affected.

Larger Consistency Effect in Chinese Than in English

A larger increase in reading fluency for consistent characters than for inconsistent characters was observed in all three groups. In particular, this improvement in reading fluency for consistent characters was more pronounced in reading Chinese than in English. there was larger consistency effect in Chinese than in English. Thus, it can be inferred that during trainings, as children were exposed to consistent and inconsistent characters, they were more sensitized to the consistency properties of words. As a result, they could utilize this information during reading to decode words.

Improvement in Phonological Awareness and Working Memory

Present study results indicated that there were increase in phonological skills and working memory from pre- and post-tests in all three groups, but the two trainings did not particularly effectively enhance the respective skills they were meant to train.

To my surprise, the data showed that an increased metalinguistic awareness was as beneficial as an increased working memory span in improving phonological skills and working memory from pre- to post-tests. In addition, interestingly, there was a slight Time x Group interaction effect on working memory. The two training groups improved while the waitlist-control group decreased in working memory span performance.

The presence of increased WM after trainings but a decreased WM for control group might imply that increased exposure to characters apart from during normal school hours is beneficial to children's working memory capacity. Unlike children in the training groups, the waitlist-control children were not exposed to additional Chinese and English characters as they did not receive any PA or WM trainings. This main difference might thus account for their decreased working memory span after the 8-week training time at the post-test.

Limitations

A limitation of the present study is the insufficient randomized design for the control group. Though there is random assignment of children in the two training groups, participants directly entering the waitlist control group created the problem that extraneous variables were not optimally reduced. This may have contributed to the absence of statistically significant group effect on reading fluency. Before pre-test, yet all three groups' characteristics were tested to be reasonably comparable, having a randomized control group may further ensure more equivalent groups.

Another potential problem is that part of the training sessions was conducted by the parents, whose procedure and instruction might not be unanimous and thus made the training less reliable. Having said that, as the training protocol involved trained experimenters meeting the child per week to follow-up and monitor the progress, it is of reasonable judgment that weekly 1-hour experiment-led tutoring session could minimize the differences in training quality.

The present study did not find a significant metalinguistic or working memory training effect on enhancing reading fluency, however, as discussed in previous sections, the effects might have been undetected due to different reasons. It is possible that with a randomized controlled design together with adjusted training materials and protocol suiting the learning needs and motivational features of dyslexic children, a more pronounced effect the trainings have in dyslexic children can be shown. Past studies that look into one specific type of training, for example just MA or WM alone, did report a significant effect the training had on dyslexic children. Therefore, with an even further aim to directly compare the efficacy of the two trainings, the present study should have had contributed to research in this area and acted as a reference for future similar research.

Future studies may try to tap on the motivational characteristics and evaluation of learning experiences the dyslexic children have, and look into how metalinguistic awareness benefits dyslexic children's reading fluency in a degree relative to working memory capacity. Future research could also separate the elements of phonology and morphology in MA training, as this combination obscures the reading fluency improvement, which could be due to phonological training or morphological training, or both.

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