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Remediation of a phonological representation deficit in Chinese children with dyslexia: A comparison between metalinguistic training and working memory training

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Abstract

A form-preparation task in the language production field was adopted to examine output phonological representations in Chinese dyslexia and their susceptibility to training. Forty-one Chinese children with dyslexia (7–11 years old) and 36 chronological age controls completed this task. The controls demonstrated a marginally significant syllable facilitation effect ($d = -0.13$), indicating their use of syllable-sized phonological representations during speech production, while the group with dyslexia showed a significantly different pattern ($d = 0.04$), opposite to the direction of a facilitation effect. The children with dyslexia were then randomly assigned to either metalinguistic training ($N = 22$) or working memory training ($N = 19$). Only the metalinguistic training subgroup demonstrated a significant syllable facilitation effect afterward (metalinguistic: $d = -0.13$; working memory: $d = -0.01$). The results suggest the presence of a phonological representation deficit at the syllable level in Chinese dyslexia and its possible remediation by metalinguistic training. Such a phonological deficit in readers of a logographic script strongly supports the impaired phonological representation view of developmental dyslexia. A video abstract of this article can be viewed at https://youtu.be/zT2Be0xMkh0 .

KEYWORDS
dyslexia, phonological deficit, training

1 | INTRODUCTION

The extent to which phonological processing deficits contribute to developmental dyslexia across scripts is a critical research question of both theoretical and practical importance (McBride, 2016). Previous studies have widely investigated the phonological skills of children with dyslexia in various orthographies, from alphabetic transparent ones (e.g. Porpodas, 1999; Wimmer et al., 1999) and opaque ones (e.g. Manis et al., 1996; Sprenger-Charolles et al., 2000) to non-alphabetic ones (e.g., Ho et al., 2002). A meta-analytic review suggested that phonological awareness, especially phonemic awareness, most effectively predicts individual differences in reading alphabetic scripts (Melby-Lervåg et al., 2012). A different pattern (Ho et al., 2007; Shu et al., 2006), however, has been revealed in learning to read Chinese.

In contrast with alphabetic orthographies, the Chinese writing system is logographic, where no phoneme-to-grapheme correspondence exists. Most Chinese characters are compound characters consisting of a semantic and a phonetic radical. For example, the character 情 (meaning "feeling") contains a semantic radical 忄 and a phonetic radical 青. The semantic radical means "relating to the heart" and hence provides a cue to the meaning of the character. On the other hand, the phonetic radical provides a cue to its pronunciation (i.e., 情 /cing4/ and 青 /cing1/ share the same syllable irrespective of tone in Cantonese Chinese). But the phonetic cue is sometimes unreliable vis-à-vis sound information (e.g., the character

路 /lou6/ and its phonetic radical 各 /gok3/). Therefore, it is possible that the role of phonological skills in learning to read Chinese might be different from that needed in acquiring alphabetic literacy.

Another important feature of Chinese is the one-to-one-to-one relation of Chinese character, morpheme, and syllable. Each Chinese character is a morpheme, which can be combined to form a compound word (e.g., the word 電腦 "computer" consists of two morphemes, 電 "electronic" and 腦 "brain"). Besides, each character also corresponds to a syllable, so Chinese is morphosyllabic.

1.1 | Phonological deficits of Chinese children with dyslexia

Unlike in alphabetic languages, researchers have found that phonological awareness is not a strong predictor of Chinese reading difficulties relative to rapid automatized naming and some other measures (Ho et al., 2007; McBride-Chang et al., 2011; Shu et al., 2006). Nevertheless, such a discrepancy does not necessarily mean that phonological processing abilities are less important to Chinese literacy acquisition, since measures of the above-mentioned predictors usually tap multiple cognitive processes. A widely used phonological awareness task called phoneme deletion, for example, requires participants to say aloud an utterance without one of its phonemes (e.g., *cat* /kæt/ without its beginning /k/ sound becomes /æt/). In this example, a child must perceive the original utterance, maintain a phonological representation of this utterance in working memory, manipulate the representation by deleting its onset phoneme, and then formulate an output representation for articulation. The more consistent predictor of Chinese word recognition, rapid automatized naming, also involves a series of cognitive processes, including the retrieval of phonological representations as a key component. The complex nature of these tasks makes it hard to tell which level(s) of representation or processing is impaired among children with dyslexia (Ramus, 2001).

An increasing number of studies have adopted psycholinguistic experiments to examine the loci of phonological deficits in children with dyslexia. A variety of speech perception deficits (concerning speech input) have been reported across languages, including Chinese, among those with dyslexia, such as categorical perception deficits (Cheung et al., 2009; Liu et al., 2009; Serniclaes et al., 2001; Snowling et al., 2019) and rhythmic perception deficits (Goswami et al., 2011; Tong et al., 2018). However, many fewer studies have examined speech production processes (concerning speech output) in children with dyslexia. Among the multiple stages of information processing during spoken word production, phonological encoding refers to the process of integrating the retrieved phonological information into a phonological word (Dell, 1986; Levelt, 1999), which further activates phonetic representations and guides the construction of articulatory gestures. Although several experimental paradigms, adopting a chronometric approach, have been widely used to probe the phonological encoding process during spoken word production, they have rarely been adopted in research on developmental dyslexia (e.g., Truman & Hennessey, 2006). To our knowledge, few or no previous studies have investigated how Chinese children with dyslexia process output phonology during spoken word production.

Research Highlights

- The current study adopted an experimental paradigm in the language production field to examine output phonological representations in Chinese dyslexia and their susceptibility to training.
- Results suggest that the output phonological representations are less segmented into syllables among second- or third-graders with Chinese dyslexia, relative to chronological age controls.
- The impaired phonological representation view of developmental dyslexia is supported, and phonological deficits in developmental dyslexia are not limited to readers of alphabetic scripts.
- Training results suggest that the phonological representation deficit in Chinese dyslexia can be remediated by metalinguistic training but may not by working memory training.

Given the above-mentioned discrepancy in how well phonological awareness predicts reading acquisition in alphabetic languages versus Chinese, it is crucial to adopt a task that taps fewer cognitive processes than common phonological awareness measures do, in order to investigate more closely the role of phonological processing abilities in reading acquisition. Hence, the current study adopted a language production task (i.e., the form-preparation task) to compare the output phonology of Chinese dyslexic and typically developing children. If Chinese children with dyslexia showed impaired output phonological representations in this task, it would suggest the importance of phonological processing abilities even in learning to read a logographic script.

In the form-preparation paradigm (Meyer, 1990), participants need to generate spoken words in response to a certain type of stimulus category (e.g., pictures, associative words). There are two types of naming contexts: (a) a homogeneous context where all the response words in a block share a constant phonological component (e.g., a word-initial syllable shared by *con*firm, *con*duct, *con*tain), and (b) a heterogeneous context where all the response words in a block are phonologically unrelated. Before each testing block, the participants are presented and familiarized with all the testing items for the following block, making it possible for them to be aware of the phonological relatedness among the response words. Then the stimuli will be presented individually, and the naming latencies in response to the stimuli are measured. It has consistently been found that adult speakers are able to make use of the phonological relatedness and respond faster in the homogeneous context than in the heterogeneous context, although the required grain size of the shared phonological components may differ across languages (e.g. Alario et al., 2007; Kureta et al., 2006; Meyer, 1991; O'Séaghdha et al., 2010; Wong et al., 2012). This facilitation effect indicates that the shared phonological components are represented as selectable planning units which can be prepared in advance (Levelt et al., 1999; O'Séaghdha et al., 2010). That means that, in the homogeneous context, the phonological encoding process can begin with the shared phonological component even before the stimulus onset, shortening the naming latency.

Chinese form-preparation studies have investigated the role of syllables irrespective of tone in spoken word production (e.g. Chen et al., 2002; Li & Wang, 2017; O'Seaghdha et al., 2010; Wong et al., 2012). As a tone language, Chinese lexical items can share the same consonant-vowel sequence but differ only in pitch pattern (e.g., 情 /cing4/ and 清 /cing1/ carry different tone; the number after a syllable indicates tone). We can say that 情 /cing4/ and 清 /cing1/ share the same syllable irrespective of tone. Research (e.g., Wong et al., 2012) has shown that Chinese adults are able to benefit from a homogeneous context where all the response words start with the same syllable irrespective of tone (e.g., 富貴 /fu3 gwai3/, 扶手 /fu4 sau2/, 腐敗 /fu6 baai6/), suggesting that syllables irrespective of tone are represented as selectable phonological units among mature Chinese speakers.

In the current study, we adopted a similar design, with pictures as prompts so that the nature of this task was presented as one of picture naming, making it easier for children to complete. We predicted that we would observe a similar facilitation effect in typically developing children as that found in adults. That is, we predicted that Chinese children without dyslexia would demonstrate a facilitation effect across shared syllables. More importantly, we hypothesized that Chinese children with dyslexia would not show such an effect, since they might demonstrate poor phonological representations, as demonstrated previously in their Western counterparts (Swan & Goswami, 1997b; Szenkovits & Ramus, 2005; Truman & Hennessey, 2006).

1.2 | Interventions for dyslexia

One major goal of dyslexia research is to develop effective interventions based on the identified deficits of people with dyslexia. A large number of studies have shown that phonologically based interventions can improve word reading skills of children with dyslexia in various alphabetic scripts (e.g., Elbro & Petersen, 2004; Schneider et al., 2000; Spironelli et al., 2010). Many of these have involved letter-sound training, a method which could not be applied directly to Chinese children with dyslexia.

So far, most training studies on Chinese word reading have focused on different metalinguistic skills. Due to the distinct characteristics of compound characters, Chinese readers tend to make use of the pronunciation cue carried by the phonetic radical (Ho & Bryant, 1997). One type of metalinguistic training, thus, focused on such phonological strategies and was found to be effective in improving reading performance of Chinese children with dyslexia (Ho & Ma, 1999). On the other hand, the complete overlap between Chinese characters and lexical morphemes makes morphological awareness especially important for Chinese reading (Pan et al., 2016). Morphological awareness deficits have been identified as core deficits of Chinese children with dyslexia (McBride-Chang et al., 2011; Shu et al., 2006), and morphological awareness training, another type of metalinguistic training, has been shown to improve reading performance in typically developing younger children (Chow et al., 2008; Wang & McBride, 2017; Zhou et al., 2012). Nevertheless, previous studies have not focused on such training in Chinese children with dyslexia.

Besides metalinguistic skills, working memory seems important in learning to read Chinese. Due to the lack of phoneme-to-grapheme correspondence, Chinese children typically learn to read Chinese via drill-and-practice (Wu et al., 1999). Rote memorization is needed, especially for those in Hong Kong without aid of alphabetic phonetic scripts like Pinyin and Zhuyin. Researchers have found that working memory capacity predicts Chinese children's word reading performance (Chung, & McBride-Chang, 2011; Ho et al., 2004). Hence, working memory training might facilitate reading development in Chinese children as well (Siu et al., 2018).

Importantly, different mechanisms are involved in metalinguistic training and working memory training. If output phonological representations are impaired in Chinese children with dyslexia, these two training methods might not be equally effective in remediating this deficit. In the current study, we divided our participants with dyslexia into two subgroups and provided metalinguistic training and working memory training to each subgroup respectively. By using the form-preparation task in both pretest and posttest, we aimed to compare the effects of these two training methods specifically on output phonological representations of children with dyslexia.

Since previous studies have shown the effectiveness of training in phonological strategies and morphological awareness, the current metalinguistic training program incorporated both of them and focused on radical awareness and morphological awareness. The teaching of phonological strategies was part of the radical awareness training, in which the roles of semantic radicals and phonetic radicals were emphasized. The children would learn that each Chinese character is a building block of word meaning (i.e., a morpheme) and that its pronunciation (i.e., a syllable) sometimes can be inferred from its phonetic radical. Although syllable awareness was not explicitly trained in this program, our training in morphological awareness focused on word segmentation into morphemes. Given the one-to-one-to-one relation of Chinese character, morpheme, and syllable, such a segmentation skill might increase the children's sensitivity to syllables as pronunciation units at the same time (see McBride-Chang et al., 2003, for significant correlations between syllable awareness and morphological awareness in Chinese young children). Hence, if our participants with dyslexia were less efficient in using syllables irrespective of tone as phonological planning units during the form-preparation task, it is reasonable to predict that such a deficit could be remediated by the current metalinguistic training. In contrast, the working memory training program focused on expanding the capacity of visual and verbal working memories and was hypothesized to be less effective in remediating a phonological deficit (if any).

2 | METHOD

2.1 | Participants

Forty-two typically reading children and 71 children with dyslexia in the second or third grade (7 to 11 years old, shortly after the children with dyslexia received formal diagnosis) participated in the current study. They were participants of a larger research project, which was approved by The Joint Chinese University of Hong Kong—New Territories East Cluster Clinical Research Ethics Committee (The Joint CUHK-NTEC CREC). They were native speakers of Cantonese Chinese and were recruited from Hong Kong primary schools and education authorities. Written consent was obtained from the children and their guardians. All the children with dyslexia met the following criteria: (a) formally diagnosed with dyslexia by either educational or clinical psychologists based on The Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students—Third Edition [HKT-P(III)] (Ho et al., 2016), which required adequate IQ (higher than 85), poor literacy (−1 *SD* or below), and at least one area of cognitive-linguistic deficit (−1 *SD* or below; Chung, 2017); and (b) no history of neurological or psychiatric disorders (such as ADHD or ASD), brain injury, birth complications, or significant sensory impairment. Typically developing children had no difficulty in reading or writing based on parents' report.

Data of some children were excluded from analysis due to dropouts (12 children with dyslexia, 10.6%), failure to perform the picture naming task (e.g., not obeying the instruction, adding other words in the response; 5 children with dyslexia, 4.4%), or technical errors (e.g., data loss, microphone failure, unexpected noise; 6 typically developing children and 13 children with dyslexia, 16.8%). Consequently, data from 36 typically developing children and 41 children with dyslexia remained. Table 1 shows the demographic information of the remaining participants in the two groups, and these two groups did not differ significantly in male-to-female ratio, age, grade, maternal education level, paternal education level, or monthly family income ($ps \geq 0.371$).

2.2 | Design and procedure

Each of the 41 children with dyslexia was randomly assigned to the metalinguistic training (MT) subgroup ($N = 22$) or the working memory training (WMT) subgroup ($N = 19$), stratified by school. Demographic information of these two subgroups is shown in Table 1. These two subgroups were not significantly different in male-to-female ratio, age, grade, maternal education level, or paternal education level ($ps \geq 0.301$), and marginally significant in monthly family income ($p = 0.055$). Both training programs contained 36 40-minute sessions, delivered by trained undergraduate students in a one-to-one manner. Since both Chinese and English

TABLE 1 Means and standard errors of demographic information

Characteristic		Typically developing	Dyslexic	Metalinguistic training subgroup	Working memory training subgroup
Male-to-female ratio		16:20	20:21	11:11	9:10
Age in months	*M*	101.3	102.4	102.4	102.5
	SE	1.2	1.5	2.2	2.0
	N	36	41	22	19
Grade	*M*	2.58	2.68	2.73	2.63
	SE	0.08	0.07	0.10	0.11
	N	36	41	22	19
Maternal education	*M*	2.97	2.89	2.68	3.12
	SE	0.21	0.20	0.28	0.28
	N	34	36	19	17
Paternal education	*M*	2.82	2.75	2.47	3.06
	SE	0.23	0.24	0.30	0.37
	N	33	36	19	17
Family income	*M*	3.97	3.78	3.32	4.29
	SE	0.25	0.26	0.31	0.40
	N	34	36	19	17

Note: Coding of educational levels: 1 = middle school or below, 2 = high school, 3 = preparatory, 4 = college, 5 = postgraduate; monthly family income: 1 = HKD10,000 (USD1,280) or below, 2 = HKD10,001 ~ 20,000 (USD1,281 ~ 2,560), 3 = HKD20,001 ~ 30,000 (USD2,561 ~ 3,840), 4 = HKD30,001 ~ 40,000 (USD3,841 ~ 5,120), 5 = HKD40,001 ~ 50,000 (USD5,121 ~ 6,400), 6 = HKD50,001 (USD6,401) or above.

are taught at Hong Kong primary schools, training materials in both languages were included. Each 40-minute training session consisted of 20 minutes of Chinese training followed by 20 minutes of English training (see Supporting Information for details of the English training part). Across the 36 training sessions, each three of them constituted a unit and generally lasted one week. In the last session of each unit, the training materials of that unit were briefly reviewed at the end.

The whole training program lasted approximately 3 months (MT: mean = 91.3 days, *SD* = 24.2 days; WMT: mean = 90.5 days, *SD* = 26.0 days). Before and after the training, all the children with dyslexia completed the picture naming task with the form-preparation paradigm and a Chinese word reading task as a pretest and a posttest respectively. The time interval between the pretest and the start of the training program was on average 9.5 days (*SD* = 6.2 days) for the MT subgroup and 9.1 days (*SD* = 6.3 days) for the WMT subgroup. The time interval between the end of the training program and the posttest was on average 6.5 days (*SD* = 7.3 days) and 6.8 days (*SD* = 13.2 days) for the two subgroups respectively. No significant difference existed in the timeline of testing and training between the two subgroups ($ps > 0.8$).

2.2.1 | The form-preparation task

The form-preparation task was administered with E-Prime 3.0 software. Each child was tested individually in a quiet room. Nine line drawings of common objects with disyllabic Cantonese names were used as prompts (e.g., 書包 /syu1 baau1/, meaning "schoolbag"; from Ning, 2012). They formed three homogeneous sets and three heterogeneous sets through different ways of combination. The three picture names within each homogeneous set shared the same first syllable irrespective of tone (e.g., 書包 /<u>syu</u>1 baau1/, 薯仔 /<u>syu</u>4 zai2/, 樹葉 /<u>syu</u>6 jip6/), while no such phonological relation existed within a heterogeneous set. More details can be found in the Supporting Information (Table S1).

As shown in Figure 1, at the beginning of the task, all the pictures were presented to the children one by one, together with the picture name spoken in Cantonese. They were asked to get familiar with these picture names and use them in the later picture naming task. After they named all the pictures correctly in the familiarization phase, the formal test (i.e., three homogeneous blocks and three heterogeneous blocks) was then administered after a practice block. In each block, the whole picture set was first presented together, and the children needed to name all the three pictures. If there was any error, they were reminded of the correct name. When they were ready, the pictures were then presented individually, and they needed to name the picture as soon and as accurately as possible. The children's naming responses were recorded by a microphone for later analysis. Each picture appeared four times (Cycles 1–4) in a block without immediate repetition, so there were 12 trials per block. The whole procedure of this task took approximately 10 minutes.

Some of the children (i.e., 19 typically developing children, 12 in the MT subgroup, and 6 in the WMT subgroup) completed the three homogeneous blocks first and then the three heterogeneous blocks (Version A), while the others completed the three heterogeneous blocks first (Version B). The order of context conditions for each participant remained the same in the pretest and posttest, and this variable was controlled in the statistical analyses below.

2.2.2 | The Chinese word reading task

A total of 250 Chinese characters were selected from the Hong Kong Corpus of Primary School Chinese (Leung & Lee, 2002; Lui et al., 2010), and each two of them formed a two-character word, resulting in 125 words. The corpus consists of Chinese characters that can be found in textbooks and workbooks used by Hong Kong primary schools. We selected characters with varying cumulative frequency at second grade. The list of 125 two-character words was presented to the children on a piece of paper, and they needed to read aloud the second character of each word. The task ended when the child gave incorrect or no responses for 10 items in a row. The number of correct responses was taken as the word reading score. Its Cronbach's alpha reliability coefficient is 0.98.

2.2.3 | Training methods

The same set of training materials (i.e., 72 monosyllabic words which are all compound characters and 24 disyllabic words in Chinese) was used in the two training programs, so that any difference in training outcomes could not be attributed to a difference in training materials. A training booklet was prepared for each trainer-child dyad; words in this booklet were printed together with cartoon illustrations (e.g., the word 熔 /jung4/, meaning "to melt", was illustrated with a cartoon of an erupting volcano), so as to facilitate children's comprehension. For each 3-session training unit, the number of words to be taught was 3 (1st session) +3 (2nd session) +2 (3rd session). In the third session, the children also reviewed the eight words by completing a word reading and dictation task. Monosyllabic words were taught in the first nine training units, and disyllabic words were taught in the last three training units. Different types of training activities were designed for the two training programs.

2.2.4 | The metalinguistic training

In the booklet for metalinguistic training, each monosyllabic word was decomposed into its semantic and phonetic radicals, highlighted in different colors. Also printed were two other monosyllabic words sharing the same semantic radical with the target word as well as two words sharing the phonetic radical. For example, besides teaching the pronunciation and meaning of the word 熔 /jung4/, the trainers explained the meaning of its semantic radical 火 (i.e., "relating

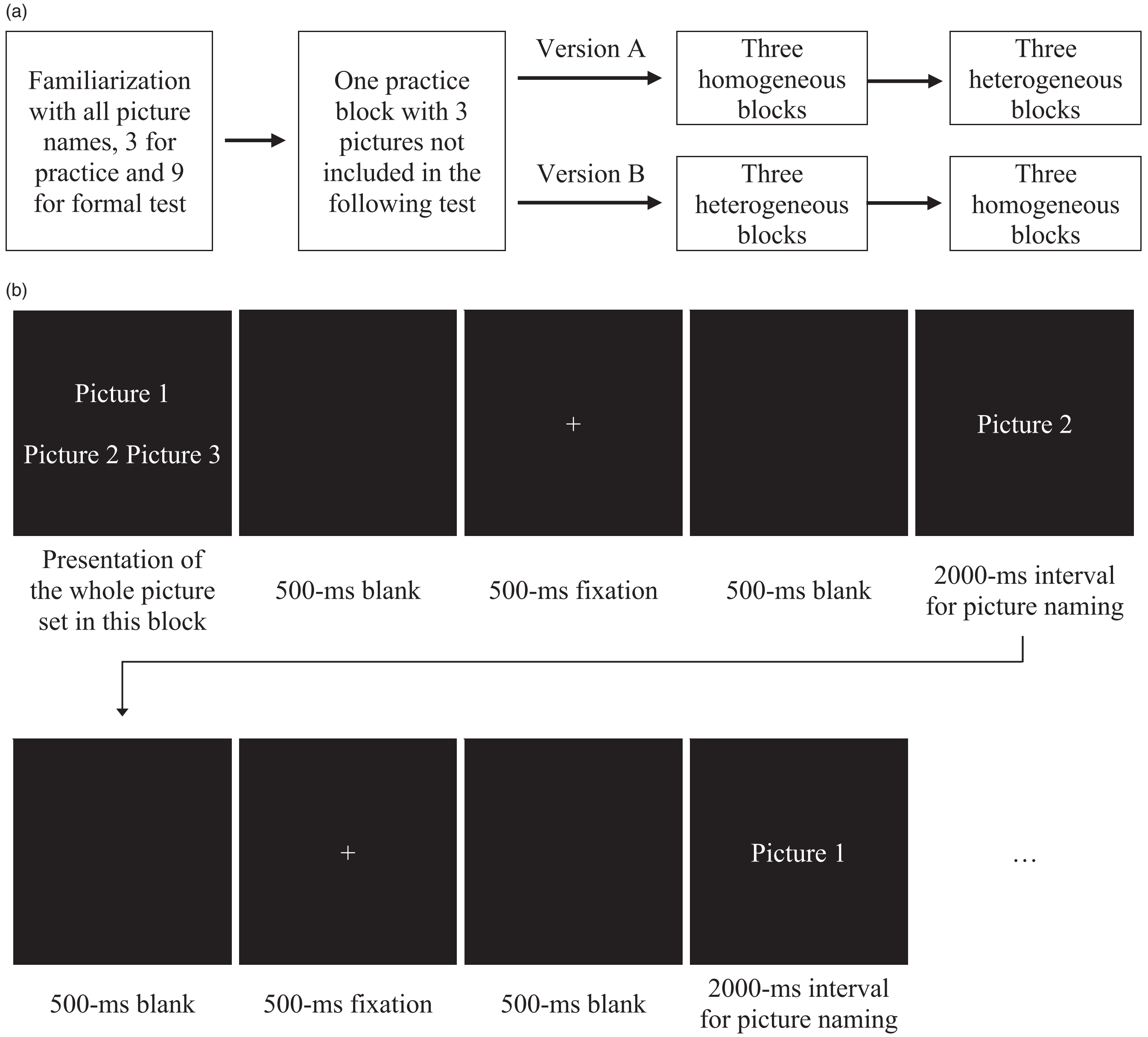

FIGURE 1 Procedure of the form-preparation task. (a) is a flow chart. All the pictures and their names were first presented in a familiarization phase. A formal test comprising three homogeneous blocks and three heterogeneous blocks (either Version A or B) was then administered after a practice block. (b) shows an example of stimuli presentation in a block (real pictures were presented during the task). In each block, the whole picture set was first presented together, and the children needed to name all the three pictures. If there was any error, they were reminded of the correct name. When they were ready, the pictures were then presented individually, and they needed to name the picture as soon and as accurately as possible. Each trial consisted of a 500-ms fixation, a 500-ms blank, a 2,000-ms presentation of the target picture, and a 500-ms blank. Naming responses within the 2,000-ms interval were recorded, and naming latencies were extracted as the time intervals between the picture onset and the response onset. A facilitation effect refers to shorter naming latencies in the homogeneous condition relative to the heterogeneous condition.

to fire") and showed other words that contained the same semantic radical (i.e., 炮 /paau3/ meaning "cannon" and 炒 /caau2/ meaning "to fry"). The trainers also introduced the function of the character's phonetic radical and showed other words sharing this radical (i.e., 榕 /jung4/ meaning "banyan tree" and 溶 /jung4/ meaning "to dissolve"). In the subsequent copying practice, the children first copied these two radicals separately and then copied the whole word.

As for the disyllabic words, the two constituent characters were highlighted in different colors, and the trainers would emphasize their role as lexical morphemes (i.e., building blocks of meaning). For example, the word 爭論 (meaning "to argue") was decomposed into 爭 (meaning "to compete for") and 論 (meaning "to discuss"). Other disyllabic words containing one of the two morphemes (e.g., 戰爭 meaning "war" and 論文 meaning "thesis") were also provided. In the copying practice, the children needed to first copy these two morphemes separately and then copy the whole word.

2.2.5 | The working memory training

In the booklet for working memory training, the words were printed in black without indication of constituent components. The children learned their pronunciation and meaning by rote. After the copying practice, they played a few games which were aimed at improving their visual and verbal working memories. Paper cards with a word printed on one side and its cartoon illustration on the other side were used as tools. The words used in the games were the same as those the children learned in the training.

In the 1st session of a training unit, the games followed procedures of forward span tests. First, the children were shown the cartoon side of a few cards in a sequence, and they needed to put these cards into the same order as presented. The number of cards in a sequence started with 2, and increased by 1 if the children performed correctly in two consecutive trials at a certain length. Hence, the sequence length was adapted to the children's performance, which applied to other games as well. Next, the trainers read aloud a sequence of words while presenting these words on the cards one by one. The children needed to recall the words in the same order as presented. If not successful, they were encouraged to try using the cards to represent the sequence. In the 2nd session, the games were derived from backward span tests: The children were shown the cartoons sequentially or heard a sequence of words while seeing them presented on the cards. This time, they needed to indicate the reverse order of these items (e.g., if the original word sequence was "熔-鬍", the correct answer was "鬍-熔"). In the 3rd session, the game was derived from n-back tests. The children were shown a sequence of words on the cards, and they needed to take the card from the trainers if this card was the same as the one presented n items ago. For example, in the 2-back game, the children needed to take the "熔" card after seeing a word sequence like "蘆-熔-鬍-熔".

2.3 | Data analyses

In the form-preparation task, incorrect responses or no naming responses within the 2000-ms interval were taken as errors. Recordings of the correct responses were checked manually with the CheckVocal software (Protopapas, 2007) to extract the naming latencies (i.e., the time interval between the picture onset and the response onset, also called reaction time or RT). After extreme values (i.e., exceeding 2.5 *SD* of individual or item mean, 3.4%) were excluded, the naming latencies were submitted to linear mixed-effects modeling (LMEM; Baayen et al., 2008; Bates et al., 2015) implemented using R Version 3.4.3 (R Development Core Team, 2019). The *lmerTest* package (Kuznetsova et al., 2017) was used to calculate *p* values with Satterthwaite approximation. The R script and output are available at https://osf.io/ukhja/.

LMEM analyses were conducted on two sub-datasets separately. The first sub-dataset comprised data of typically developing and dyslexic children in the pretest. Two main variables were entered as fixed effects, *context* with two levels (heterogeneous, homogeneous) and *group* with two levels (typically developing, dyslexic). The interaction of context and group was also entered. To control the effects of context *order* (1st, 2nd context condition) and *cycle* of picture presentation (Cycles 1–4), these two variables were entered as fixed effects. The random structure of the model included by-participant and by-item random intercepts, as well as by-participant and by-item random slopes for *context*. Deviation coding was adopted, and planned comparisons were conducted with the *multcomp* package (Hothorn et al., 2008) to test whether the naming latencies in the two context conditions were significantly different for each group of participants.

The second sub-dataset comprised data of children with dyslexia in the pretest and posttest. Three main variables were entered as fixed effects, *context*, *subgroup* with two levels (MT, WMT), and *time* with two levels (Time 1, 2). The interactions of these three variables were also entered, as well as the effects of *order* and *cycle*. The random structure included by-participant and by-item random intercepts, as well as by-participant and by-item random slopes for *context* and *time* (see Supporting Information for details of model building; Table S2 template from Meteyard & Davies, 2020).

Besides LMEM analyses on RT data, generalized linear mixed-effects models (GLMMs) were used to model naming accuracy data (i.e., ACC) of the two sub-datasets with the *glmer* function (binomial distribution). The processes of model building paralleled those in the above LMEM analyses. Another two GLMMs were used to model reading accuracy data.

3 | RESULTS

3.1 | Differences between typically developing and dyslexic children in the pretest

3.1.1 | Naming latency in the form-preparation task.

Figure 2a shows the mean naming latencies of the typically developing and dyslexic children in the pretest of the form-preparation task. The LMEM formula was [RT ~ context*group + cycle + order + (1 + context | participant) + (1 + context | picture)], and its modeling results are listed in Table 2. The main effect of context was not significant, while the main effect of group and the interaction of context and group were significant. Planned comparisons further demonstrated that the RT difference between the two context conditions was marginally significant for the control children ($\beta = -32.6$, $SE = 17.2$, $p = 0.057$, $d = -0.13$) but not significant for the children with dyslexia ($\beta = 9.9$, $SE = 16.8$, $p = 0.554$, $d = 0.04$) in the pretest. Importantly, the RT difference was significantly different between the two groups ($\beta = 42.6$, $SE = 18.0$, $p = 0.018$, $d = 0.16$). The comparisons among the control children and the two subgroups with dyslexia can be found in the Supporting Information (Table S3).

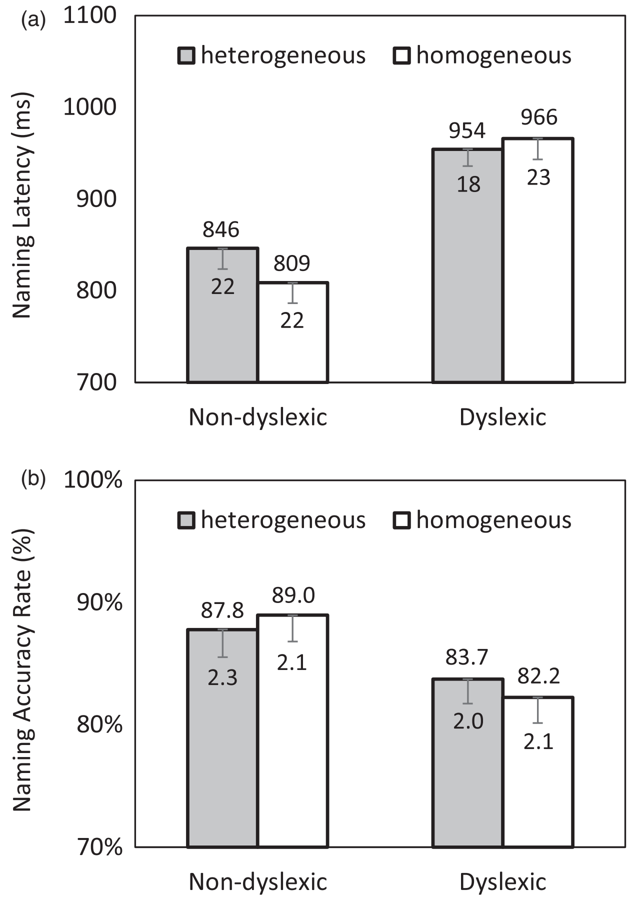

FIGURE 2 Performance of the two groups in the pretest of the form-preparation task with standard errors: (a) mean naming latencies and (b) mean accuracy rates

3.1.2 | Naming accuracy in the form-preparation task

Figure 2b shows the mean naming accuracy rates of the two groups in the pretest. The GLMM formula was [ACC ~ context*group + cy cle + order + (1 + context|participant) + (1 + context|picture)], and its modeling results are listed in Table 2. The main effect of context and the interaction of context and group were not significant, while the main effect of group was significant. Planned comparisons further demonstrated that the ACC difference between the two context conditions was not significant for both groups (control: $\beta = 0.12$, $SE = 0.15$, $p = 0.443$, $d = 0.11$; dyslexic: $\beta = -0.10$, $SE = 0.13$, $p = 0.438$, $d = -0.09$) in the pretest.

3.1.3 | The chinese word reading task

With a maximum score of 125, the typically developing children and the children with dyslexia scored 89.3 ($SE = 3.1$) and 52.7 ($SE = 4.1$), respectively, in the pretest. The GLMM formula was [ACC ~ group + (1|participant) + (1|item)], and its modeling results demonstrated that the children with dyslexia scored significantly lower than the typically developing children in the pretest ($\beta = -3.08$, $SE = 0.46$, $p < 0.00001$).

3.2 | Pretest-to-posttest change of the two subgroups with dyslexia

3.2.1 | Naming latency in the form-preparation task

Figure 3a shows the mean naming latencies of the two subgroups with dyslexia in the pretest and posttest of the form-preparation task. The LMEM formula was [RT ~ context*subgroup*time + cycle + order + (1 + context + time + participant) + (1 + context + time|picture)], and its modeling results are listed in Table 3. The main effects of context and subgroup were not significant, while the main effect of time was significant. Among their interactions, only the two-way interaction of context and time was significant; other two-way interactions and the three-way interaction of context, subgroup, and time were not significant. These results suggest that the RT difference between the two context conditions changed significantly from Time 1 to Time 2, showing a significant intervention effect. Although the three-way interaction was not significant, the RT differences in each subgroup were compared separately to examine whether both subgroups showed a significant intervention effect. Planned comparisons further demonstrated that the RT difference between the two context conditions was not significant for both subgroups in the pretest (MT: $\beta = 2.9$, $SE = 18.5$, $p = 0.875$, $d = 0.01$; WMT: $\beta = 16.1$, $SE = 19.5$, $p = 0.407$, $d = 0.06$) and became significant for the MT subgroup only in the posttest (MT: $\beta = -37.0$, $SE = 18.6$, $p = 0.047$, $d = -0.13$; WMT: $\beta = -3.4$, $SE = 19.4$, $p = 0.862$, $d = -0.01$). The pretest-to-posttest change in RT difference was significant in the MT subgroup ($\beta = -40.0$, $SE = 19.5$, $p = 0.041$, $d = -0.14$) but not in the WMT subgroup ($\beta = -19.5$, $SE = 20.6$, $p = 0.345$, $d = -0.07$).

3.2.2 | Naming accuracy in the form-preparation task.

Figure 3b shows the mean naming accuracy rates of the two subgroups in the pretest and posttest. The GLMM formula was [ACC ~ context*subgroup*time + cycle + order + (1 + context + time | participant) + (1 + context + time|picture)], and its modeling results are listed in Table 3. The main effects of context, subgroup, and time were not significant. Among their interactions, only the three-way interaction was significant. Planned comparisons further demonstrated that the ACC difference between the two context conditions remained non-significant for the MT subgroup (pretest: $\beta = 0.18$, $SE = 0.19$, $p = 0.347$, $d = 0.20$; posttest: $\beta = 0.02$, $SE = 0.18$, $p = 0.897$, $d = 0.03$; pretest-to-posttest change: $\beta = -0.16$, $SE = 0.19$, $p = 0.420$, $d = -0.17$). For the WMT subgroup, although the ACC

TABLE 2 Parameter estimates, standard errors, confidence intervals, and statistical significance in the LMEM and GLMM analyses of the typically developing and dyslexic children's picture naming performance in the pretest

	Naming latency (RT)					Naming accuracy (ACC)				
Fixed Effects	*β*	*SE*	Wald 95% CI	*t*	*p*	*β*	*SE*	Wald 95% CI	*z*	*p*
Intercept	896.8	28.0	841.9, 951.8	31.99	<0.00001***	2.22	0.16	1.91, 2.53	14.06	<0.00001***
context1	5.7	7.2	−8.4, 19.8	0.79	0.445	−0.005	0.05	−0.11, 0.10	−0.10	0.921
group1	−67.1	14.4	−95.3, −39.0	−4.67	0.00001***	0.33	0.13	0.07, 0.59	2.51	0.012*
cycle1	−27.8	5.5	−38.5, −17.1	−5.10	<0.00001***	0.21	0.07	0.07, 0.36	2.91	0.004**
cycle2	2.4	5.5	−8.5, 13.2	0.43	0.670	0.0003	0.07	−0.14, 0.14	0.004	0.996
cycle3	4.2	5.6	−6.7, 15.2	0.76	0.446	−0.10	0.07	−0.23, 0.04	−1.41	0.158
order1	−17.9	4.4	−26.5, −9.2	−4.05	0.0001***	0.16	0.05	0.07, 0.25	3.57	0.0004***
context1 × group1	10.6	4.5	1.8, 19.5	2.36	0.021*	−0.05	0.05	−0.15, 0.04	−1.15	0.249
Random Effects		Variance	*SD*	Correlation			Variance	*SD*	Correlation	
Participants	Intercept	15009.9	122.5				1.13	1.06		
	context1	743.4	27.3	−0.30			0.02	0.15	0.15	
Pictures	Intercept	5215.6	72.2				0.07	0.26		
	context1	284.9	16.9	−0.63			0.005	0.07	−1.00	

Note: Deviation coding was adopted for the following factors in both models: context (heterogeneous, homogeneous), group (typically developing, dyslexic), cycle (Cycles 1–4), order (1st, 2nd context condition). LMEM formula: RT ~ context*group + cycle + order + (1 + context | participant) + (1 + context | picture). GLMM formula: ACC ~ context*group + cycle + order + (1 + context | participant) + (1 + context | picture).
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$.

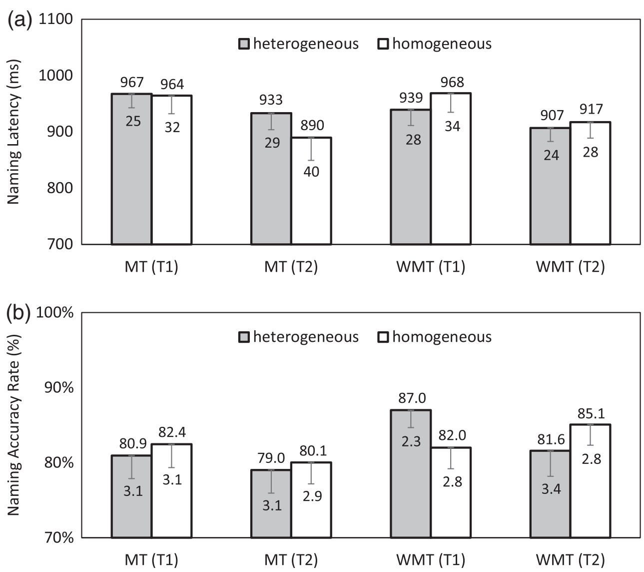

FIGURE 3 Performance of the two subgroups with dyslexia in the pretest and posttest of the form-preparation task with standard errors: (a) mean naming latencies and (b) mean accuracy rates. MT = metalinguistic training subgroup, WMT = working memory training subgroup, T1 = Time 1, T2 = Time 2

difference was not significant either (pretest: $\beta = -0.31$, $SE = 0.21$, $p = 0.133$, $d = -0.34$; posttest: $\beta = 0.21$, $SE = 0.21$, $p = 0.309$, $d = 0.23$), the pretest-to-posttest change was significant ($\beta = 0.52$, $SE = 0.22$, $p = 0.019$, $d = 0.57$) and significantly different from the pretest-to-posttest change of the MT subgroup ($\beta = 0.68$, $SE = 0.29$, $p = 0.021$, $d = 0.74$).

3.2.3 | The Chinese word reading task

The MT subgroup scored 51.2 ($SE = 5.8$) and 55.7 ($SE = 5.3$) in the pretest and posttest, while the WMT subgroup scored 54.5 ($SE = 6.1$) and 58.8 ($SE = 5.8$). The GLMM formula was [ACC ~ subgroup*time + (1 + time | participant) + (1 + time|item)], and its modeling results demonstrated that the main effect of subgroup ($\beta = -0.10$, $SE = 0.35$, $p = 0.776$) and the interaction of subgroup and time were not significant ($\beta = -0.02$, $SE = 0.05$, $p = 0.686$), while the main effect of time was significant ($\beta = -0.21$, $SE = 0.05$, $p < 0.00001$). Planned comparisons further demonstrated that the pretest-to-posttest change was significant in both subgroups (MT: $\beta = 0.46$, $SE = 0.12$, $p = 0.0002$; WMT: $\beta = 0.39$, $SE = 0.13$, $p = 0.004$).

4 | DISCUSSION

The current study adopted an experimental paradigm in the language production field (i.e., the form-preparation paradigm) to investigate the output phonological representations of Chinese dyslexic and typically developing children. The controls demonstrated a syllable facilitation effect (marginally significant), while the group

TABLE 3 Parameter estimates, standard errors, confidence intervals, and statistical significance in the LMEM and GLMM analyses of the two dyslexic subgroups' picture naming performance in the pretest and posttest

	Naming latency (RT)					Naming accuracy (ACC)				
Fixed Effects	*β*	*SE*	Wald 95% CI	*t*	*p*	*β*	*SE*	Wald 95% CI	*z*	*p*
Intercept	938.1	30.0	879.3, 996.9	31.26	<0.00001***	1.80	0.14	1.53, 2.06	13.24	<0.00001***
context1	2.7	7.0	−11.0, 16.4	0.38	0.711	−0.01	0.07	−0.15, 0.12	−0.18	0.859
subgroup1	2.8	17.7	−31.8, 37.5	0.16	0.874	−0.12	0.12	−0.35, 0.11	−1.05	0.294
time1	25.6	10.3	5.5, 45.7	2.49	0.017*	0.09	0.09	−0.09, 0.27	0.98	0.326
cycle1	−32.1	6.1	−43.9, −20.2	−5.30	<0.00001***	0.19	0.06	0.07, 0.32	3.00	0.003**
cycle2	3.2	6.1	−8.7, 15.2	0.53	0.598	0.09	0.06	−0.04, 0.21	1.38	0.167
cycle3	1.3	6.2	−10.9, 13.4	0.20	0.839	−0.15	0.06	−0.27, −0.03	−2.44	0.015*
order1	−19.2	3.7	−26.4, −11.9	−5.18	<0.00001***	0.02	0.04	−0.07, 0.11	0.47	0.635
context1 × subgroup1	5.9	4.0	−2.1, 13.8	1.45	0.150	−0.04	0.05	−0.13, 0.05	−0.81	0.416
context1 × time1	−7.4	3.6	−14.4, −0.5	−2.09	0.036*	0.05	0.04	−0.03, 0.12	1.25	0.212
subgroup1 × time1	2.2	10.2	−17.8, 22.1	0.21	0.831	0.03	0.09	−0.15, 0.20	0.31	0.761
context1 × subgroup1 × time1	−2.6	3.6	−9.5, 4.4	−0.72	0.472	−0.08	0.04	−0.16, −0.01	−2.31	0.021*
Random Effects		**Variance**	***SD***	**Correlation**			**Variance**	***SD***	**Correlation**	
Participants	Intercept	12223.6	110.6				0.49	0.70		
	context1	120.2	11.0	−1.00			0.03	0.18	0.12	
	time1	3698.7	60.8	−0.13	0.13		0.25	0.50	0.12	−0.64
Pictures	Intercept	5289.4	72.7				0.04	0.21		
	context1	297.1	17.2	−0.37			0.02	0.15	−0.76	
	time1	14.5	3.8	0.95	−0.64		0.006	0.08	0.99	−0.85

Note: Deviation coding was adopted for the following factors in both models: context (heterogeneous, homogeneous), subgroup (metalinguistic training, working memory training), time (Time 1, 2), cycle (Cycles 1–4), order (1st, 2nd context condition). LMEM formula: RT ~ context*subgroup*time + cycle + order + (1 + context + time | participant) + (1 + context + time|picture). GLMM formula: ACC ~ context*subgroup*time + cycle + order + (1 + context + time|participant) + (1 + context + time | picture).

*$p < 0.05$,

**$p < 0.01$,

***$p < 0.001$.

with dyslexia did not. After training, the MT subgroup showed a significant facilitation effect, but the WMT subgroup did not.

4.1 | The nature of deficits in output phonology

In the homogeneous context of our form-preparation task, the whole picture set was presented to the children at the beginning of each block, whose names all shared the same first syllable irrespective of tone. If syllables irrespective of tone were represented as selectable planning units, the children could prepare such a unit in advance and respond faster in each of the following trials (relative to the heterogeneous context). The marginal significance of the syllable facilitation effect (i.e., −32.6 ms) in the control children suggests that second- and third-graders in Hong Kong started to use syllables irrespective of tone as selectable planning units in spoken word production. This is consistent with the finding of Li and Wang (2017) that second-grade Chinese children started to show a trend of syllable facilitation effect (i.e., −5 ms) while fourth-graders had already shown a robust effect (i.e., −24 ms) as adults did (i.e., −18 ms). Although there is ongoing controversy over the exact mechanism of the facilitation effect in the form-preparation paradigm (e.g Levelt et al., 1999; O'Séaghdha & Frazer, 2014), it has been argued that this effect taps phonological representations rather than phonetic representations or articulatory programs (Meyer, 1990; O'Séaghdha et al., 2010). We believe that this is true in our study, where the picture names in the homogeneous condition carried different types of tone in their first syllables. Since different articulatory programs were engaged to produce the same syllable with different tones, the facilitation effect was unlikely to originate from the late stages of motor programing and execution. It likely instead manifested representations of syllables irrespective of tone at the phonological level.

The RT difference between the two context conditions in the children with dyslexia (i.e., 9.9 ms) was significantly different from that in the controls (i.e., −32.6 ms), indicating that the phonological representations of syllables irrespective of tone were impaired in these children with dyslexia. This is consistent with the phonological representation hypothesis (Snowling, 2000; Swan & Goswami, 1997a, 1997b), which proposes that a core deficit of readers with dyslexia lies in their deficient phonological representations. Importantly, the current finding provides direct and unambiguous evidence for the specific way in which these phonological representations could be impaired. The children with dyslexia were unable to make use of the phonological information provided, namely, that the picture names in a homogeneous block all started with the same syllable irrespective of tone. This result suggests that their phonological representations were poorly specified at the syllable level. One possibility is that the children with dyslexia adopted holistic representations that were not segmented into syllables. Alternatively, the children with dyslexia might store syllables with different tones as totally distinct representations, which could also hinder their preparation in advance. The latter possibility, however, is less likely to be true. Previous studies have shown that Chinese children with dyslexia perceive lexical tones less categorically (Cheung et al., 2009; Liu et al., 2009) and less accurately (Tong et al., 2018). Although input and output phonological representations might involve two systems, their development should arguably influence one another. Thus, the impaired output phonological representations of the syllables with different tones should be less categorical, rather than more differentiated as suggested by the latter possibility. Therefore, the best interpretation of the current finding is that the output phonological representations of the children with dyslexia were less segmented into syllables.

In addition, one major debate about the phonological representation hypothesis is whether the deficits lie in the phonological representations themselves in the mental lexicon or in the access to these representations (e.g., Boets et al., 2013; Ramus & Szenkovits, 2008). Ramus and Szenkovits (2008) argued that individuals with dyslexia show phonological deficits only when the task is highly demanding of phonological access (e.g., explicit access in phonological awareness tasks and multiple speeded access in rapid naming tasks). In a few tasks that were less demanding, they found no phonological deficit in their participants with dyslexia, supporting the deficient phonological access view. As noted by Ramus and Szenkovits, their analysis as to whether one task was demanding in terms of phonological access was ad hoc. In the current form-preparation task, the pictures of common concepts were used as prompts, making it as simple as picture naming. Only one picture was presented in each trial, so there was no need for multiple speeded access or high working memory load. Hence, we argue that this task was not demanding.

Nevertheless, one may notice that besides the absence of the facilitation effect, the children with dyslexia were significantly slower and less accurate than the typically developing children. This is consistent with the deficient phonological access view, although alternative accounts are available (e.g., deficient lexical selection or motor execution). Suppose that the children with dyslexia had intact phonological representations and inefficient access to them, then what result pattern should be expected? It is reasonable to expect slower and less accurate naming performance in the children with dyslexia, but we argue that as long as their phonological representations were segmented into syllables, they should have been able to prepare the syllable irrespective of tone in advance for the phonological encoding process, a process that would take place sooner or later. Therefore, the absence of a syllable facilitation effect favors the impaired phonological representation view. It is not contradictory that the children with dyslexia might have inefficient access to their phonological representations in the meantime, whether because of the degraded representational quality or not. Their deficits might, in fact, lie in both the phonological representations and the process of phonological access (Boets et al., 2013; Ramus, 2014). However, the current study could not address this possibility, due to the unknown locus of the difficulty underlying their slower and less accurate performance.

4.2 | Effects of metalinguistic training versus working memory training

Overall, the intervention effect on phonological representations of the children with dyslexia, as reflected in the form-preparation task, was significant. The three-way interaction of context, subgroup, and time on the RT was non-significant. However, when the two subgroups were examined separately, only the MT subgroup showed a significant syllable facilitation effect after training and a significant pretest-to-posttest change (from 2.9 to −37.0 ms); the WMT subgroup showed a trend of getting closer to the typical facilitation effect but did not improve significantly (from 16.1 to −3.4 ms). These results seemed to indicate that the metalinguistic training program was effective in improving the poorly specified phonological representations of the children with dyslexia while the working memory training program was not effective enough. Further investigation on the effects of these two types of training is needed.

Although the current form-preparation task is not a typical syllable awareness task, it reflects an ability to specify a word at the syllable level, which the syllable awareness tasks are intended to measure. Hence, we can broadly say that the syllable awareness of the MT subgroup was significantly improved by the training. Recall that the current metalinguistic training program focused on radicals and morphology in Chinese, whereas syllable awareness was not explicitly trained. The improvement in syllable awareness, indeed, is consistent with the close association between syllable awareness and morphological awareness in Chinese (McBride-Chang et al., 2003; Pan et al., 2016). One important aspect of morphological awareness is awareness of morphological structure in a word (Liu & McBride-Chang, 2010), i.e., knowing that a compound word comprises smaller meaning units. This involves the ability to segment a word into morphemes and is one main target of our metalinguistic training program. Given the morphosyllabic nature of Chinese, it is not surprising that this program also improved the children's ability to segment a word into syllables.

On the other hand, syllable awareness has been found to be a weaker predictor of Chinese reading acquisition than morphological awareness is (McBride-Chang et al., 2011; Pan et al., 2016), and phonological awareness training seems ineffective in Chinese reading improvement (Zhou et al., 2012). One possible explanation for these seemingly contradictory findings is that morphological awareness is much more complex than syllable awareness. Apart from the ability to segment a word into morphemes, morphological awareness also includes the abilities to differentiate homophones and to construct novel words based on specific morphological structures (e.g., noun + noun; Liu & McBride-Chang, 2010). Syllable awareness may relate to the segmentation aspect but not the other aspects of morphological awareness. It has been found that the correlations between syllable awareness and different measures of morphological awareness are not always robust (McBride-Chang et al., 2003). Due to the large number of homophones and a lack of clear word boundaries in Chinese, sophisticated morphological skills are especially important for reading acquisition, and thus a stronger predictor than syllable awareness. Accordingly, the phonological awareness training may not benefit those other aspects of morphological awareness and fail to improve Chinese reading ultimately. Hence, the importance of syllable awareness to Chinese reading may largely rely on the close association between syllables and morphemes in Chinese. This could explain why morphological awareness better predicts Chinese reading acquisition than syllable awareness does.

Nevertheless, the role of syllable awareness is not trivial, especially from a developmental perspective. Syllable awareness might be one of the earliest segmentation abilities that emerge in typical language development (Shu et al., 2008), and set the foundation for morphological awareness. The development of sophisticated morphological skills depends on morpheme segmentation, which is closely related to syllable segmentation. Pan et al. (2016) found that preliterate syllable awareness contributed significantly to the variance in post-literate morphological awareness. Although syllable awareness alone is not sufficient for Chinese reading acquisition, a lack of it may result in a series of problems including reading difficulties. Hence, the transfer effect on syllable awareness should be considered as an advantage of the current metalinguistic training method.

As for the current working memory training, although it did not remediate the poorly segmented phonological representations, the pretest-to-posttest change in ACC difference between the two context conditions was significant, from a lower ACC in the homogeneous condition to a reversed trend. In the form-preparation paradigm, it is not typical to observe a significant difference in ACC. A slightly lower ACC in the homogeneous condition was once found in Meyer (1990), but its significance level fluctuated across experiments. Meyer (1990) proposed that it might reflect a higher difficulty in lexical selection when all the possible response words shared the same syllable. Our WMT subgroup showed a similar trend in the pretest, but the ACC in the homogeneous condition became non-significantly higher than that in the heterogeneous condition in the posttest. It might be that the working memory training program enabled the children to develop a response strategy in the homogeneous condition to help exclude incorrect responses (e.g., the beginning part of all the possible response words sounded similar, so a response word with a very different beginning should be incorrect). To keep such a strategy in mind while completing the picture naming task might require a relatively good working memory. Without more evidence in the literature, our explanation for the current ACC results is rather post hoc. Further studies are needed to explore the potential mechanism.

Overall, although the word reading scores improved in both subgroups with dyslexia after training, only the MT subgroup improved significantly on the syllable facilitation effect in the form-preparation task. Hence, different mechanisms might underlie the improvement of the two subgroups in their Chinese reading ability. The improvement of the MT subgroup might result from remediation of the phonological representation deficit, while that of the WMT subgroup might be compensation-based instead.

4.3 | Theoretical and practical implications

Although the phonological representation hypothesis of developmental dyslexia has received substantial support from previous phonological awareness studies and analyses of picture naming errors in people with dyslexia (e.g., Elbro et al., 1998; Katz, 1986; Swan & Goswami, 1997b), impaired phonological representations are hardly the only account for those observed deficiencies. As mentioned in the introduction, multiple cognitive processes could be the potential loci of various difficulties. With the methodological advantage of the form-preparation paradigm, the current study found that the phonological representations were less segmented into syllables among Chinese children with dyslexia in the second or third grade, relative to their chronological age controls. Besides corroborating the importance of syllable-sized representations in the early stages of Chinese reading acquisition (e.g., Pan et al., 2016), this finding adds original evidence to the impaired phonological representation view of developmental dyslexia. Moreover, it lends strong support to the notion that phonological deficits in developmental dyslexia are not limited to readers of alphabetic scripts.

This is also the first study to directly compare the effects of metalinguistic training and working memory training on a specific deficit in Chinese children with dyslexia. The current metalinguistic training program effectively remediated the poorly segmented phonological representations, while the working memory training program seemed not as effective. Nevertheless, both training programs led to comparable gains in Chinese word reading, suggesting that the remediation-based mechanism and the compensation-based one worked comparably well at the behavioral level. Note that our participants were second- and third-graders, who were beginning readers. It is possible that relatively low difficulty in the beginning-level materials allowed the deficit to be compensated for at the behavioral level. If this is true, the compensation-based mechanism might be unable to match the remediation-based one as the readers proceed to a more advanced level. Therefore, similar comparisons among older participants and longitudinal studies tracking follow-up effects of these two training methods would be highly valuable.

4.4 | Limitations

Previous studies have tried to classify Chinese developmental dyslexia into different subtypes (Ho et al., 2007; Ho & Siegel, 2012; Wang & Yang, 2014), but the findings are, so far, inconsistent. Still, one may agree that not all Chinese children with dyslexia have phonological deficits. The current finding was based on group means and did not indicate which children with dyslexia had poorly segmented phonological representations and which ones did not. It is statistically possible to estimate the facilitation effect for each individual, but we doubt whether it is appropriate to do so with the current design of the form-preparation task. As mentioned in the method part, some of the children completed the homogeneous blocks before the heterogeneous blocks, while the others did it in the reverse way. The order of context conditions is considered to be controlled when using LMEM and GLMM analyses to compare group means, but we are not sure whether the individual-level estimation of the facilitation effect was reliable considering potential individual differences in the order effect. One improved design for future studies is to adopt an ABBA sequence for the context conditions. Another nine pictures can be selected to generate new picture sets so that the children do not need to repeat the same blocks twice in the ABBA design. The available picture triplets whose names share the same first syllable irrespective of tone were limited at the time this study was designed. It is also why we used the same stimuli in the pretest and the posttest, which may need to be improved in future studies.

4.5 | Conclusions

The phonological representations of Chinese children with dyslexia are less segmented into syllables than those of typically developing children. This phonological deficit can be remediated by the current metalinguistic training program which focuses on radical awareness and morphological awareness, but may not by the working memory training program.

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CONFLICT OF INTEREST

The authors declare that no competing interests exist.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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