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Compensation for poor character learning: intact visual and phonetic strategies among Chinese children with dyslexia

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Abstract

The present study investigated whether and to what extent children with dyslexia utilize visual and phonetic strategies in character learning. A paired associate learning paradigm was used in two experiments to train children's pronunciation-orthography associations of novel words, with a recall task 1 week later for retention. Experiment 1 included 32 Mandarin-speaking fifth graders with dyslexia (dyslexia group) and 28 age-matched peers (comparison group) and manipulated the availability of an arbitrary bolded stroke in Chinese character (visual cue, available vs. unavailable) of eight low-frequency real characters. The dyslexia group demonstrated poorer character learning effects than the comparison group, whereas the similar interference effect of visual cues was found across groups. Sixty-six fifth-grade children participated in Experiment 2 (dyslexia, $N = 34$). The regularity of phonetic cues of 12 pseudo-characters was manipulated into regular, semiregular, irregular, providing full, partial, or no pronunciation cues. The dyslexia group demonstrated comparable learning outcomes of regular pseudo-characters, but poorer learning on semiregular and irregular pseudo-characters than the comparison group. Importantly, they utilize semiregular phonetic cues. In both experiments, the two groups did not differ on the retention of learning. Taken together, children with dyslexia perform poorer in the learning stage, but not in visual or phonetic strategies or the retention of learning. Like their peers, they do not use arbitrary visual cues but utilize phonetic cues, and thus compensate for poor learning of regular characters and alleviate that of semiregular characters.

Keywords Character learning · Dyslexia · Paired associate learning · Phonetic radical · Visual cue ·
Yixun Li and and Yi Hui contributed equally to this work.

Literacy is one of the prerequisites for engagement in modern society, such as politics, health care, and education. With environmental linguistic input—the language that children hear from

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others around them—children naturally develop an oral vocabulary, referring to the sounds and meanings of novel words. But the development of literacy skills—the capacity to read and interpret written language— is not a passive learning experience and requires considerable effort. Written word acquisition is the foundation of these critical literacy skills, and thus a major benchmark that children must meet in order to advance their early reading capacities. If children face challenges in written word learning, the crucial foundation for their developing reading skills is at risk. Children with developmental dyslexia are a population of particular interest with regard to this concern since they demonstrate particular difficulties in word recognition, spelling, and decoding, despite their normal intelligence and sufficient education (Lyon, Shaywitz, & Shaywitz, 2003). A better understanding of how children with dyslexia acquire written words is of critical importance for enriching current reading theories and guiding the development of novel reading interventions. The present study sought to examine whether and to what extent Chinese children with dyslexia utilize visual and phonetic strategies to compensate for their poor written word learning.

Written word learning via paired associate learning among children with dyslexia

One of the primary methodologies adopted for studying written word learning among young children is the use of paired associate learning (e.g., Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Messbauer & Jong, 2006). Paired associate learning (PAL) is the process of explicitly learning the association between two stimuli, such as visual-visual stimuli (an abstract shape, e.g., , goes with another abstract shape, e.g., ), verbal-verbal stimuli (the pronunciation of a nonword, e.g., huk, goes with the pronunciation of another nonword, e.g., dof), and visual-verbal stimuli (an abstract shape, e.g., , goes with the pronunciation of a nonword, e.g., dof) (Hulme et al., 2007). Depending on the task demand of verbal-visual PAL, verbal stimuli could be real spoken words (e.g., Messbauer & Jong, 2006), and visual stimuli could be concrete pictures (e.g., Messbauer & Jong, 2006). Previous work consistently suggests that children with dyslexia have a visual-verbal PAL deficit, but demonstrate no differences on visual-visual PAL compared to normal readers (e.g., Chinese: Li, Shu, Mcbride-Chang, Liu, & Xue, 2009; Dutch: Messbauer & Jong, 2006; English: Litt & Nation, 2014).

Learning written words is a specific type of visual-verbal PAL, in which the visual stimuli are written words, thus involving learning the association between the pronunciation/meaning of a word and the written form of that word. Understanding the mechanism of word learning in dyslexia is just as critical as identifying and describing the deficits. While very few studies have directly investigated written word learning via PAL among children with dyslexia, existing work suggests that they have difficulties with learning the mapping between the written form and the pronunciation of a word, i.e., orthography-pronunciation associations (e.g., Messbauer & de Jong, 2003). Even fewer studies investigated whether and to what extent children with dyslexia apply learning strategies to compensate for their difficulties in orthography-pronunciation learning, compared to the effective strategy use among typically-developing children (e.g., visual strategies, Chen, Anderson, Li, & Shu, 2014; phonetic strategies, Chow, 2019).

In addition, most existing studies concentrate on alphabetic writing systems, yet very few on non-alphabetic writing systems such as Chinese. The current study sought to fill these gaps by focusing on Chinese children with dyslexia and their use of visual and phonetic cues in character learning using the PAL paradigm. The use of visual cues was investigated, given the visual complexity of the Chinese orthographic system and the visual attentional deficit in dyslexia (Valdois, Bosse, & Tainturier, 2004). The use of phonetic cues was also included due to the well-known phonological deficit in dyslexia (e.g., Shu, Meng, Chen, Luan, & Cao, 2005; Snowling, 1998).

The Chinese writing system and character learning strategies

The basic element of a Chinese character is called a stroke, with eight basic types of strokes in total (Law, Ki, Chung, Ko, & Lam, 1998). The number of strokes in a character ranges from 1 to 24, and the majority of the 3500 most frequently used characters have 6–13 strokes (Li & Liu, 1988). A basic stroke or a multi-stroke pattern can function as a unit to compose characters. The visual complexity of characters is not only about the number of strokes in a character, but also about the organization of these strokes. For example, 土 (*tu3*, meaning soil) and 士 (*shi4*, meaning scholar) consist of exactly the same three stokes, just organized differently, thus visually almost identical. As such, many characters are visually similar to one another and thus pose challenges to learners. Therefore, the multiple strokes in a single character can lead to a much more complex visual structure compared to the multiple letters in a single word in alphabetic writing systems, such as English. Comparatively, Chinese children may rely on sophisticated visual skills in reading more than children in alphabetic writing systems (Chen et al., 2014).

Children rely on different cues that are available to learn new written words. Based on the Stages of Reading Development theories (Ehri, 1991; Frith, 1985), beginning readers perceive and rely on the visual feature of novel words supportive for word learning. The visual features being used are normally the salient shape of letters or the sketch of a whole word, not directly relevant to the pronunciation or meaning of the word (e.g., Ehri & Wilce, 1985). Later on, when children are building grapheme-phoneme correspondence rules, they begin to utilize phonological cues (i.e., the pronunciation information embedded in word spellings, e.g., Ehri & Wilce, 1985) and spelling patterns beyond just visual cues. Despite the lack of phonological reassembly rules in the Chinese writing system, Chinese children follow similar developmental stages, including the visual stage and then the phonological stage, in learning to read (Chen et al., 2014) as their English counterparts (Ehri, 1991; Frith, 1985).

Chen et al. (2014) extended the Stage of Reading Development theories to Chinese children's reading development. The visual stage is the beginning stage, in which young children perceive characters as a figure and utilize visual strategy, i.e., the distinctive visual features/shapes of characters, in character learning. Therefore, children with good visual skills are more likely to acquire reading skills well. Children with poorer geometric-figure processing skills, for instance, are less likely to become successful readers compared to their peers (Ho, Chan, Tsang, & Lee, 2002). Note that geometric-figure processing skills have been shown to predict kindergarteners' reading skills, but the predictive power no longer holds after children advance to primary school (Li, Shu, McBride-Chang, Liu, & Peng, 2012; Luo, Chen, Deacon, Zhang, & Yin, 2013). In comparison, character-configuration processing skills, the more specifically character-related visual skill, can explain unique variance in reading skills throughout kindergarten and primary school years (Luo et al., 2013). It is evident that typically developing children utilize visual features of words in word learning, such as a bolded letter in an English word, e.g., *gem* (compared to the original word *gem*), and an exaggerated stroke of a character, e.g.,  (compared to the original character厷) (e.g., Chen et al., 2014). Yet, whether or to what extent these findings apply to children with dyslexia remained open.

Followed by the visual stage, the phonological stage in Chinese described by Chen et al. (2014) highlights the critical property of phonetic radicals in character learning among typically-developing children. A phonetic radical refers to a phonetic component in a character, cuing the pronunciation of the character. For example, the character 清 (*qing1*, pure or clean) has a phonetic radical on the right: 青 (*qing1*, green). About 80–90% of Chinese characters have a phonetic radical (Li & Kang, 1993), although the reliability of pronunciation cues carried by the phonetic radical may vary.

According to Shu, Chen, Anderson, Wu, and Xuan (2003), there are a variety of phonetic radicals, including regular, semiregular, and irregular, providing full, partial, or no information about the pronunciation of the character to which it belongs. Take the phonetic radical 青 (*qing1,* green) as an example. It serves as a regular phonetic radical in the character 清 (*qing1,* pure or clean), given that they have the same pronunciation. It acts as a semiregular phonetic radical in the character 精 (*jing1*, perfect) since they have different onsets, although the same rime and tone. It functions as an irregular phonetic radical in the character 猜 (*cai1*, guess) as they have totally different pronunciations. The percentage of regular, semiregular, and irregular characters that primary school children encounter is, on average, 43%, 30%, and 12%, respectively (Shu et al., 2003). Typically developing children can effectively utilize the full and partial pronunciations from regular and semiregular phonetic radicals to aid their novel character learning (e.g., Anderson, Li, & Ku, 2003; He & Tong, 2017; Yin & McBride, 2015). Children with dyslexia are also able to utilize regular phonetic radicals (Ho, Chan, Tsang, Lee, & Chung, 2006), but whether or not they can use semiregular phonetic radicals was unclear.

The use of visual cues in character learning in Chinese children with dyslexia

Previous work did not directly investigate the use of visual cues in character learning but examined the visual skills of Chinese children with dyslexia (Ho et al., 2002; Wang et al., 2014). Ho et al. (2002) demonstrate that Cantonese-speaking children with dyslexia's visual skills are comparable to their reading-level-matched peers, but significantly poorer than their age-matched peers, pointing to the weaker visual skills in children with dyslexia probably due to a developmental delay. Beyond poor visual skills, it seems that children with dyslexia have visual perceptual learning deficits (Wang et al., 2014). In a texture discrimination task, participants were prompted to discriminate the orientation of nonverbal target bars (e.g., 135°, '\' or 45°, '/'). Both the dyslexic group and age-matched group demonstrated learning effects over training sessions, but children with dyslexia performed significantly poorer.

Building upon this body of evidence, the question of interest under investigation in this paper is whether and to what extent children with dyslexia can utilize visual cues within characters to aid in learning novel characters. It is possible that children with dyslexia have deficits in visual cue use due to the weaker visual skills and perceptual learning compared to peers such as those investigated by Chen et al. (2014) and Wang et al. (2014). However, it is also likely that after they progress to later primary school years, visual-related skills are not as critical to reading skills as it was earlier on in their schooling—a trend noted in research focusing on typically developing children (e.g., Li et al., 2012; Luo et al., 2013). The current study investigated fifth-grade Chinese children with dyslexia and their age-matched peers' visual cue use in character learning. We adapted Chen et al.'s (2014) manipulation of visual cues and used a bolded stroke in a character to provide the arbitrary salient visual clue.

The use of phonetic cues in character learning in Chinese children with dyslexia

To date, to our best knowledge, only one published study has directly examined the use of phonetic cues among Chinese children with dyslexia (Ho et al., 2006). In this paper, a PAL paradigm was utilized, in which children were exposed to the written form of four unfamiliar two-character words, four regular and four irregular characters. In the training session, children were taught both the pronunciation and the meaning of the words one by one. Then, in the PAL session, in each of the total ten trials, children were presented with each word and asked to pronounce the word. Immediate feedback and corrective pronunciations were provided for each word. One hour after the PAL session, a recall task was conducted to measure the children's retention of learning. Results showed that, for regular characters, children with dyslexia demonstrated comparable learning outcomes when compared with their reading-level-matched peers, but significantly poorer outcomes when compared with their age-matched peers, suggesting a developmental delay. However, for irregular characters, children with dyslexia showed significantly weaker learning outcomes relative to both comparison groups, pointing to a learning deficit in irregular characters. Importantly, word learning deficits were found only in the immediate learning process, but not in the retention task administered 1 h later. Children with dyslexia maintained their learning outcomes as well as did the comparison groups.

The current study aimed to extend Ho et al.' (2006) investigation by including semiregular phonetic radicals. Thirty percent of characters taught during the primary school years are semiregular characters (Shu et al., 20,013), making the use of semiregular phonetic cues foundational in character learning. No previous work examines the learning of semiregular characters in dyslexia, despite their frequency of use. It is possible that young children with dyslexia might be able to utilize semiregular phonetic cues as well, given that they have intact abilities to utilize regular phonetic cues, although show delay compared with their age-matched peers, as illustrated in work by Ho et al. (2006). However, it may also be the case that they cannot use partial phonetic cues due to their documented phonological deficits (e.g., Shu et al., 2005; Snowling, 1998). These multiple plausible explanations make an empirical investigation necessary.

The present study also adapted Ho et al.'s (2006) design for a more focused and clearer investigation in three critical ways: (1) the current paradigm only taught children the pronunciation of characters to be learned, to focus on the orthography-pronunciation learning, as compared to the previous methodology, in which participants were taught both the pronunciation and meaning of words in the training phase; (2) the current study used target characters which are two-radical in nature, for which only the phonetic radical has a pronunciation, compared to the previous work, for which both the phonetic radical and non-phonetic radical have a pronunciation (e.g., 赘, in which the phonetic radical 敖and the non-phonetic radical 贝 both have a pronunciation, thus presenting participants with a potential confound); (3) the current paradigm involved the use of pseudo-characters that were novel to all participants when investigating the role of phonetic radicals, compared with the previous authors' use of unfamiliar characters, which thus presented a between-item manipulation of phonetic cues, introducing a potentially confounding item bias. The current paradigm, therefore, manipulated the same pseudo-character across different experimental conditions by assigning different pronunciations across all participants, creating within-item comparisons.

The present study

The current investigation sought to examine and elucidate whether children with dyslexia can utilize visual or phonetic cues as effectively as their age-matched peers, and, if they do use one of those available cues, identifying the specific deficit in the cue they use. We conducted two experiments to examine the use of visual and phonetic cues separately. These two learning cues were intentionally isolated so as to ensure a clear experimental design.

In Experiment 1, the availability of distinctively visual features of eight low-frequency real characters (available vs. unavailable) was manipulated. All target characters were simple characters that contained no phonetic cues. In Experiment 2, the regularity of phonetic radicals of 12 pseudo-characters was classified into regular, semiregular, irregular, providing full, partial, or no pronunciation cues. Although all target pseudo-characters were two-radical compounds, neither visual nor semantic cues were involved. Departing from the extant body of research on this topic, we were the first to investigate the use of visual cues in character learning among children with dyslexia. In addition, we were among the first to include a semiregular condition in the use of phonetic cues in character learning among children with dyslexia. The paired associate learning paradigm was implemented in both experiments. Children's learning outcomes were measured during the paired associate learning as well as in a recall task 1 week later for retention.

We hypothesized that children with dyslexia would demonstrate weaker overall word learning outcomes in both experiments, given the well-documented learning deficit in dyslexia (e.g., Ho et al., 2006; Li et al., 2009; Litt & Nation, 2014; Messbauer & de Jong, 2003). However, we were not able to make specific predictions for different experimental conditions (i.e., the specific effects of the availability of visual cues and the regularity of phonetic cues) due to the lack of existing research for visual cue use, and limited existing evidence for semiregular phonetic cue use.

As for the retention of learning, Chinese children with dyslexia have difficulties in the PAL process, but not in retention (e.g., 1-h retention for character PAL, Ho et al., 2006; 1-week retention for nonword visual-verbal PAL, Li et al., 2009). We expected to replicate these findings in general, but the specific patterns we might observe under different experimental conditions remained open due to a lack of previous work.

Experiment 1: the use of visual cues in novel character learning

Participants

The participants were fifth-grade native Mandarin-speaking children from 19 classrooms in a participating primary school in Beijing, China. Information from the school's teachers was used to exclude children with hearing or articulatory problems, neurological deficits, and/or a diagnosis of attention deficit hyperactivity disorder.

The same screening procedure of dyslexia in Mainland China used in previous studies was conducted (e.g., Li et al., 2009; Shu, McBride-Chang, Wu, & Liu, 2006). Specifically, a child was identified as having dyslexia when all the following three criteria were met. First, the child was nominated and confirmed by their Chinese language teacher as facing challenges in reading but without difficulties in spoken language. Second, the child scored one grade below the mean score of Grade 5 ($M = 119.04$, $SD = 12.10$, based on Liu et al., 2017) on the character recognition task (Li et al., 2009). This is a widely used test for screening children with dyslexia in Mainland China (e.g., Shu et al., 2003; Shu et al., 2006). In the task, children were asked to read aloud a total of 150 Chinese characters in an order of increasing difficulties and stopped if making 15 successive errors; one point was awarded for each correct response. Third, they demonstrated normal intelligence on a nonverbal reasoning measure adapted from Raven, Court, and Raven (1996). Normally achieving children from the same classrooms as children with dyslexia served as age-matched peers; they were also nominated by their Chinese language teachers before tested on the character recognition and nonverbal reasoning measures.

Our final sample included 32 children with dyslexia (dyslexia group, 17 boys, mean age = 10 years and 7.72 months, $SD = 5.02$ months) and 28 age-matched peers without dyslexia (comparison group, 15 boys, mean age = 10 years and 8.96 months, $SD = 3.27$ months. The children with dyslexia scored 102.41 ($SD = 6.35$) out of 150 items on the character recognition task, significantly lower than the comparison group ($M = 122.00$, $SD = 6.48$), $t = -11.79$, $p < .001$. Two groups were comparable on the nonverbal reasoning measure, dyslexia group, $M = 42.28$, $SD = 5.13$, comparison group, $M = 43.64$, $SD = 4.98$, $t = -1.04$, $p > .05$.

Design

A 2 (group, dyslexia vs. comparison) × 2 (visual cue, available vs. unavailable) × 8 (testing trials 1–8) mixed factorial design was implemented, with the group being a between-participants factor, and the other two being within-participants factors.

Materials

Target characters Eight low-frequency real characters that have different pronunciations were selected with a frequency below 1 out of million (Beijing Language and Culture University Corpus Center, n.d.). None of these characters were included in the Chinese language curriculum in primary school, and thus could be considered novel to the participants. All target characters are simple characters without phonetic or semantic subcomponents. The number of strokes of all characters ranges from 3 to 6 ($M = 4.50$, $SD = 1.07$). All participants learned the mapping between orthography and pronunciation of all eight target characters, but the specific form of a character that a participant learned varied depending on the certain experimental condition of visual cue.

The availability of visual cue was manipulated by whether or not there was a randomly bolded stroke within a character. For instance, a target character 朩 (pronounced as *pin1*) was under the unavailable condition at its current form. By contrast, 朩(*pin1*) had one bolded stroke and thus carried salient visual cues and was in the available condition. For all the children, they learned four of the characters in the unavailable condition, and the other four in the available condition. The two conditions were counterbalanced across participants. For each of the characters, e.g., 束 (*gu3*), half of the participants learned it in the available condition, e.g., 束(*gu3*), whereas the other half learned it under the unavailable condition, e.g., 束 (*gu3*).

Procedures

The experiment was conducted in a quiet room located in the participating school. Well-trained research assistants majored in Psychology worked with the children in a one-to-one setting. Children learned the target characters in a PAL task (e.g., Hulme et al., 2007; Li et al., 2009), in which each child spent approximately 20 min. Throughout the PAL task, children received no information about the availability of visual cues. In the beginning, all target characters were visually exposed to the children one at a time in random order. Each character was printed on a separate paper card. The experimenter verbally provided the child with the pronunciation of the character being presented and asked the child to remember the pronunciation. The child then needed to repeat the pronunciation once, in order to ensure that the child had heard and was able to pronounce the character correctly. If the child mispronounced a character, the experimenter would repeat the correct pronunciation as many times as needed, until the child could accurately repeat the pronunciation of that character.

On the subsequent testing trials, the children needed to pronounce printed target characters. There was a maximal of eight testing trials, each involving all eight target characters in random order. The random order was different on each trial across all children, with the constraint that the same character never occurred twice in immediate succession. In each testing trial, the children were presented with the written characters on paper cards one at a time and asked to pronounce the characters. If the children pronounced a character correctly, the experimenter confirmed the correct response and then verbally provided the correct pronunciation again. One point was awarded for each correct response. When the children mispronounced a character, the experimenter pronounced the character and asked the children to repeat the correct pronunciation once. Zero-point was granted for an incorrect response. Regardless of the accuracy, children always heard the correct pronunciation of each character once right after they pronounced that character. After all eight characters were tested in a testing trial, the children moved on to the next testing trial. The testing stopped if children pronounced all eight target characters correctly in two successive testing trials. In this case, the children would earn full credit for the remaining trial(s). The scoring was the number of correct responses, with a maximal of 64 (8 characters × 8 trials).

In the 1-week delayed testing trial, each child's long-term retention of the newly learned pronunciation of target characters was assessed by a recall task. The recall task was exactly the same as a testing trial in the learning phase, except that no corrective feedback was given. Children needed to pronounce each of the target characters being presented on the paper card. The maximal score was 8. A retentive percentage was calculated as the ratio of the score on the recall task to that on the eighth testing trial, according to the formula from Li et al. (2009): Retentive Percentage (%) = (Retention trial/Last testing trial) × 100%.

Results

Table 1 shows the descriptive analyses of the accuracy on the PAL task across testing trials, experimental conditions, and two groups. A mixed-design ANOVA was conducted on participants' total scores on the PAL, with group (dyslexia vs. comparison) as a between-participants factor and the availability of visual cue (available vs. unavailable) and trial (8) as within-participants factors. All the three main effects were significant, group, F (1, 58) = 5.08, $p = .028 < .05$, $\eta^2 = .081$, the availability of visual cue, F (1, 58) = 8.74, $p = .004 < .01$, $\eta^2 = .131$, and trial, F (7, 406) = 142.23, $p < .001$, $\eta^2 = .71$. Children with dyslexia performed significantly poorer than their peers in general. Participants' accuracies significantly improved over eight trials, $ps < .05$. Children's character learning was interfered by visual cues. All the two-way and three-way interactions were not significant, $ps > .11$; there was no evidence suggesting that children with dyslexia demonstrated any deficits in their use of visual cue or differed from their peers in the learning path over the course of six trials. Children's scores on the pre-test character recognition task significantly correlated to their accuracy on the PAL tasks across the available and unavailable conditions of visual cue, $ps < .05$.

Children's errors in the PAL task were classified into three categories, intra-wordlist interference, and visually similar, in addition to other errors. The description, example, and descriptive analyses of errors for the two groups are presented in Table 2. The distribution of the error types was similar across groups. Among the errors that could be categorized, most of the errors children made were intra-wordlist interference. Importantly, both groups made very few errors on visual similarity, suggesting no group differences between dyslexia and their peers.

Table 3 shows the descriptive analyses of children's accuracies on the one-week retention task as well as that of the retentive percentages across experimental conditions for both groups. A 2 (group, dyslexia vs. comparison) × 2 (the availability of visual cue, available vs. unavailable) mixed-design ANOVA was carried out on children's retentive percentages. Neither the main effect of the availability of visual cue nor that of group was significant, F (1, 58) = 2.59, $p = .09$, $\eta^2 = .048$, F (1, 58) = .083, $p = .77$, $\eta^2 = .001$, respectively. The interaction was nonsignificant either, F (1, 58) = .304, $p = .58$, $\eta^2 = .005$.

Discussion

Our critical results on the role of visual cues on character learning are threefold. First, children with dyslexia demonstrated weaker character learning outcomes than their age-matched peers, pointing to a potential character learning deficit. This was confirmed by the strong positive relationship between children's pre-test character recognition and their performance on different conditions on the PAL task shown here. This finding should be interpreted conditioned on the specific design and paradigm used here. When only visual cues are available in novel characters, without any other cues such as phonetic cues, children with dyslexia seem to show impaired character learning.

Moreover, children with dyslexia are interfered by visual cues, just like their peers. This shows that they gain no help from visual cues, and the way that they are affected by visual cues seems not to be different from their peers. Importantly, there is a trend that children with dyslexia are more sensitive to the visual cues although not significant, as indicated by a larger difference between the overall learning outcome of characters with versus without visual cues (dyslexia group, the difference is 2.53–2.78 = − .25 out of 4; comparison group, the difference is 3.11–2.97 = − .14 out of 4). Note that by the end of trial 8, the comparison group reached the ceiling, 3.96 and 3.93 out of 4 for unavailable and available conditions, respectively. However, the dyslexia group only reached 3.59 and 3.31 out of 4 for unavailable and available

Table 1 The descriptive analyses of the accuracy on phe PAL task across testing trials, experimental conditions, and two groups in Experiment 1

Visual cues	Group	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Average
Unavailable										
	Dyslexia	1.41 (1.01)	2.25 (1.22)	2.44 (1.21)	2.75 (1.08)	3.06 (1.08)	3.28 (.85)	3.47 (.88)	3.59 (.84)	2.78 (.81)
	Comparison	1.54 (1.14)	2.21 (.92)	2.75 (.97)	3.36 (.73)	3.43 (.79)	3.71 (.60)	3.89 (.32)	3.96 (.19)	3.11 (.46)
Available										
	Dyslexia	1.25 (1.05)	1.72 (1.17)	2.16 (1.27)	2.56 (1.08)	2.84 (1.19)	3.13 (1.16)	3.25 (1.11)	3.31 (1.00)	2.53 (.88)
	Comparison	1.29 (1.27)	2.04 (.96)	2.54 (.92)	3.07 (.94)	3.54 (.69)	3.61 (.79)	3.75 (.65)	3.93 (.26)	2.97 (.52)

The mean of the raw scores out of 4 and the standard deviation (in parentheses)

Table 2 The mean number and percentage (in parentheses) of errors for both groups on phe PAL task in Experiment 1

Type of errors	Description	Examples	Visual cues available[a]		Visual cues unavailable[b]	
			Dyslexia	Comparison	Dyslexia	Comparison
Intra-wordlist interference	The target character was pronounced as another target character learned in the PAL task.	冃 (*lei3*) was pronounced as卌 (*yan2*)	63 (34%)	60 (32%)	72 (45%)	64 (45%)
Visually similar	The target character was pronounced as another character having a similar spelling form.	冃 (*lei3*) was pronounced as月 (*yue4*)	6 (3%)	16 (9%)	8 (5%)	6 (4%)
Others	Errors other than the above categories.	–	114 (62%)	109 (59%)	80 (50%)	72 (51%)
Total			183	185	160	142

[a] Visual cues available refer to an arbitrary bolded stroke in a character

[b] Visual cues unavailable refer to a normal form of a character

Table 3 The descriptive analyses of the accuracy on the delayed testing trial and that of retentive percentage for both groups in Experiment 1

Task	Visual cues	Dyslexia group	Comparison group
Retention trial			
	Available[a]	1.66 (1.10)	1.86 (1.08)
	Unavailable[b]	1.53 (0.92)	1.68 (1.25)
Retentive percentage (%)			
	Available	52.08 (39.66)	47.62 (27.49)
	Unavailable	41.67 (24.68)	42.26 (31.09)

The mean of the raw scores out of 4 and the standard deviation (in parentheses)

[a] Visual cues available refer to an arbitrary bolded stroke in a character

[b] Visual cues unavailable refer to a normal form of a character

conditions, respectively. It seems to indicate that regardless of the interference effect of visual cues, the comparison group learns all the characters. In comparison, the dyslexia group cannot fully acquire all the characters at least within eight learning trials, and their learning outcome is hindered by the visual cues even in the last trial. It might suggest that children with dyslexia rely on the cues in words more than their peers. Note that future research is warranted to test this possibility due to the insignificance of the group × the availability of visual cue interaction in the present study.

Also, children with dyslexia are comparable with their peers regarding the 1-week retention of learning, regardless of the availability of visual cues, in line with previous findings for 1-h word retention (Ho et al., 2006) and 1-week nonword retention (Li et al., 2009).

Experiment 2: the use of phonetic cues in pseudo-character learning

Participants

The participant recruitment and screening were exactly the same as that in Experiment 1. The parental consent was attained prior to the experiment. Sixty-six children were involved in Experiment 2, the dyslexia group ($N = 34.19$ boys, mean age = 10 years and 7.88 months, $SD = 4.95$ months; character recognition: $M = 102.53$, $SD = 6.18$; Raven's Standard Progressive Matrices: $M = 42.26$, $SD = 5.07$), and the comparison group ($N = 32$, 8 boys, mean age = 10 years and 8.72 months, $SD = 3.26$ months; character recognition: $M = 121.69$, $SD = 6.39$; Raven's Standard Progressive Matrices: $M = 44$, $SD = 4.98$). The comparison group scored significantly higher than the dyslexia group on the character recognition task ($t = -12.38$, $p < .001$), but not on Raven's Standard Progressive Matrices ($t = -1.4$, $p > .05$). All 60 participants from Experiment 1 participated in Experiment 2. Experiment 2 was conducted 1 month later than Experiment 1, and thus could be considered an independent investigation.

Design

A 2 (group, dyslexia vs. comparison) × 3 (phonetic cue, regular vs. semiregular vs. irregular) × 6 (testing trials 1–6) mixed factorial design was applied. Group was a between-participants factor, and the other two were within-participants factors.

Materials

Target pseudo-characters Twelve two-radical pseudo-characters were developed, each which was a novel combination of a real semantic and phonetic radicals on its left and right, respectively, and thus novel and plausible to the participants. Regarding the structure, nine pseudo-characters were left-right, e.g., and the other three were top-bottom, e.g., . The number of strokes of all pseudo-characters ranges from 6 to 10 ($M = 7.82$, $SD = 1.17$). Only the radicals that were familiar to the participants were included since the current interest was to examine whether and to what extent the children could utilize phonetic cues based on their existing knowledge of radicals. All phonetic radicals are stand-alone characters, and thus each has a legit pronunciation. The participants were familiar with the pronunciation of all phonetic radicals supported by our pilot study, in which the current participants reached a mean accuracy rate of .99 on pronouncing all twelve phonetic radicals. All semantic radicals are not stand-alone characters and thus do not have a legit pronunciation. The current participants were considered being familiar to the meaning of all semantic radicals given that we only chose the semantic radicals on which typically developing third graders had a mean accuracy rate of .96.

The regularity of phonetic cue was manipulated by assigning a pseudo-character with different pronunciations. For instance, a target pseudo-character  had a phonetic radical: 天*tian1*.  was under the regular condition when assigned with *tian1*, the semiregular condition when assigned with *jian1*, and the irregular condition when assigned with *hai2*. All participants learned the orthography-pronunciation mapping of all twelve pseudo-characters, four regular, semiregular, and irregular pseudo-characters. But the pronunciation assigned to a specific pseudo-character that a participant learned varied depending on the experimental condition. The three conditions were counterbalanced across participants. For each pseudo-character, one third of the participants learned it in the regular, semiregular, or irregular conditions.

Procedures

The PAL used in Experiment 2 was exactly the same as that in Experiment 1, except that children learned 12 pseudo-characters, and there were six testing trials in total. Accordingly, the maximal score in the PAL task was 72 (12 pseudo-character × 6 trials), and the maximal score on the 1-week delayed testing trial was 12.

Results

Table 4 shows the descriptive analyses of children's accuracies on the PAL task across experimental conditions for both groups. A mixed-design ANOVA was conducted on participants' total scores on the PAL, with group (dyslexia vs. comparison) as a between-participants factor and the regularity of phonetic cues (regular vs. semiregular vs. irregular) and trial (6) as within-participants factors. All the three main effects were significant, group, $F\,(1, 64) = 6.14$, $p = .016 < .05$, $\eta^2 = .087$, trial, $F\,(5, 320) = 118.08$, $p < .001$, $\eta^2 = .65$, and the regularity of phonetic cues, $F\,(2, 128) = 79.83$, $p < .001$, $\eta^2 = .555$. Children with dyslexia performed

Table 4 The descriptive analyses of the accuracy on the PAL task across testing trials, experimental conditions, and two groups in Experiment 2

Phonetic regularity	Group	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
Regular								
	Dyslexia	3.38 (.82)	3.47 (.75)	3.74 (.51)	3.82 (.52)	3.88 (.41)	3.94 (.24)	3.71 (.37)
	Comparison	3.22 (.87)	3.56 (.72)	3.84 (.37)	3.91 (.30)	3.97 (.18)	3.97 (.18)	3.74 (.26)
Semiregular								
	Dyslexia	1.32 (1.17)	2.00 (1.34)	2.68 (1.27)	2.76 (1.21)	3.24 (1.18)	3.32 (.98)	2.55 (.95)
	Comparison	1.84 (1.34)	2.47 (1.19)	3.09 (1.06)	3.22 (.87)	3.66 (.83)	3.72 (.68)	3.00 (.77)
Irregular								
	Dyslexia	.97 (.90)	1.56 (1.44)	2.21 (1.53)	2.44 (1.46)	2.76 (1.42)	3.12 (1.20)	2.18 (1.11)
	Comparison	1.41 (1.43)	2.25 (1.46)	2.81 (1.28)	3.44 (.95)	3.59 (.95)	3.69 (.86)	2.86 (.91)

The mean of the raw scores out of 4 and the standard deviation (in parentheses)

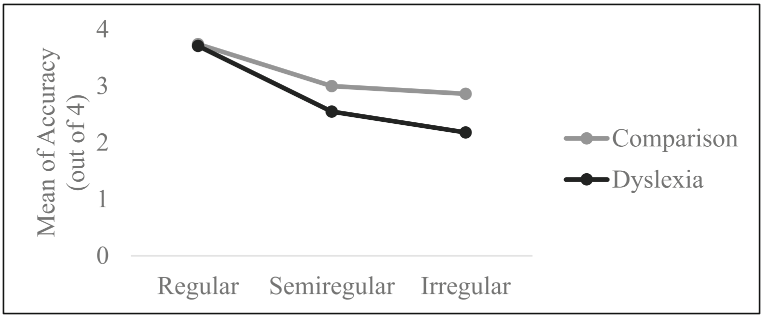

Fig. 1 The significant interaction between the regularity of phonetic cues and group

significantly poorer than their peers in general. Participants' accuracies significantly improved over the first five trials, $ps < .05$, and remained comparable between trials 5 and 6, $p = .96$. Children learned regular pseudo-characters significantly better than semiregular pseudo-characters, $p < .001$, and acquired semiregular characters significantly better than irregular characters, $p < .01$.

The regularity of phonetic cues × group interaction was significant, F (2, 128) = 5.33, $p = .006 < .01$, $\eta^2 = .077$ (See Fig. 1). There was no significant difference between two groups on learning regular characters, $p = .93$. However, the dyslexia group demonstrated poorer learning outcomes on semiregular and irregular characters than the comparison group, $ps < .05$.

Moreover, the regularity of phonetic cues × trial was significant, F (10, 640) = 15.23, $p < .001$, $\eta^2 = .19$ (See Fig. 2). For regular pseudo-characters, children's accuracies tended to be comparable across 6 trials, $ps > .14$. By contrast, for both semiregular and irregular pseudo-characters, children's accuracies progressed significantly from trials 1 to 4, $ps < .05$, and then remained comparable from trials 4 to 6, $ps > .14$. The trial × group interaction or the three-way interaction was not significant, F (5, 320) = .59, $p = .71$, $\eta^2 = .089$, F (10, 640) = .56, $p = .84$, $\eta^2 = .009$, respectively. Children's scores on the pre-test character recognition task significantly correlated to their accuracy on the PAL tasks in the semiregular and irregular conditions of phonetic cues, $ps < .01$, but not under the regular condition, $p > .10$.

Children's errors in the PAL task were classified into four categories, phonetic derivation, phonetic analogy, intra-wordlist interference, and visually similar, in addition to other errors. See Table 5 for the description, example, and descriptive analyses of errors for each category for the two groups. Across groups, children made more errors when learning semiregular characters than irregular characters. Regarding group differences, in comparison to the comparison group, the dyslexia group made fewer errors on phonetic derivation than the other

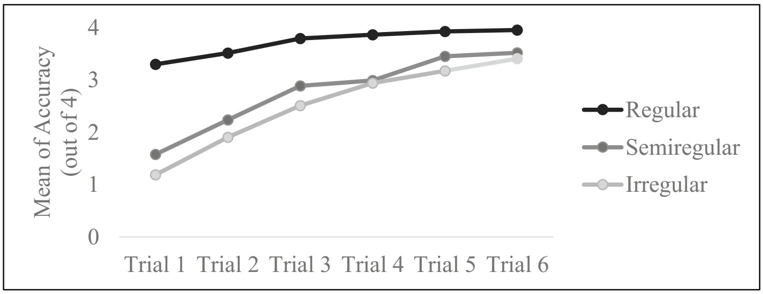

Fig. 2 The significant interaction between the regularity of phonetic cues and trial

Table 5 The mean number and percentage (in parentheses) of errors for both groups on the PAL task in Experiment 2

Type of error	Description	Examples	Regular phonetic cues		Semiregular phonetic cues		Irregular phonetic cues	
			Dyslexia	Comparison	Dyslexia	Comparison	Dyslexia	Comparison
Phonetic derivation	The pronunciation of the phonetic component was used incorrectly as the pronunciation of the whole character.	抆(*xiu1)* was pronounced as 文(*wen2*)	—	—	46 (23%)	42 (31%)	27 (12%)	25 (18%)
Phonetic analogy	The target character was pronounced as another character having an identical phonetic radical.	抆(*xiu1*) was pronounced as 坟(*fen2*)	8 (16%)	8 (27%)	3 (2%)	3 (2%)	5 (2%)	7 (5%)
Intra-wordlist interference	The target character was pronounced as another character learned in the PAL task.	抆(*xiu1)* was pronounced as 笌(*ya2*)	9 (18%)	4 (13%)	25 (13%)	18 (13%)	28 (12%)	23 (16%)
Visual similar	The target character was pronounced as another character having a similar spelling form.	抆(*xiu1*) was pronounced as 拔(*ba2*)	0	0	3 (2%)	1 (1%)	1 (0%)	0
Others	Errors other than the above categories.	—	32 (65%)	18 (60%)	119 (61%)	70 (52%)	166 (73%)	85 (61%)
Total			49	30	196	134	227	140

Table 6 The descriptive analyses of the accuracy on the delayed testing trial and that of retentive percentage for both groups in Experiment 2

Task	Phonetic cues	Dyslexia group	Comparison group
Retention trial			
	Regular	3.74 (0.62)	3.56 (0.72)
	Semiregular	2.06 (1.30)	2.72 (1.05)
	Irregular	1.71 (1.34)	1.91 (1.35)
Retentive percentage (%)			
	Regular	94.85 (14.80)	90.10 (19.45)
	Semiregular	60.05 (41.12)	67.97 (31.12)
	Irregular	49.75 (39.75)	48.70 (33.41)

The mean of the raw scores out of 4 and the standard deviation (in parentheses)

types of errors and had a lower percentage of phonetic analogy errors on regular pseudo-characters.

Table 6 shows the descriptive analyses of children's accuracies on the 1-week retention task as well as that of the retentive percentages across experimental conditions for both groups. A 2 (group, dyslexia vs. comparison) × 3 (the regularity of phonetic cues, regular vs. semiregular vs. irregular) mixed-design ANOVA was carried out on children's retentive percentages. The main effect of the regularity of phonetic cues was significant, F (2, 128) = 42.40, $p < .001$, $\eta^2 = .398$. Children's retention of learned regular pseudo-characters was significantly better than that of semiregular characters, $p < .01$, and that of semiregular characters was significantly better than that of irregular characters, $p < .01$. Neither the group effect nor the interaction was significant, F (1, 64) = .016, $p = .898$, $\eta^2 = .000$, F (2, 128) = .931, $p = .397$, $\eta^2 = .014$.

Discussion

The findings from Experiment 2 indicate that children acquire regular pseudo-characters very fast; they reached high accuracy at the first testing trial (dyslexia group, 3.38 out of 4, comparison group, 3.22 out of 4), and yielded the ceiling at trial 3 (dyslexia group, 3.74 out of 4, comparison group, 3.84 out of 4). However, in learning semiregular and irregular pseudo-characters, children need more learning trials, seeming to be at least four. These apply to both groups of children. In terms of the group differences, children with dyslexia learn the regular pseudo-characters equally fast and well compared to their peers, but have difficulties in learning semiregular and irregular pseudo-characters indicated by poorer performance than their peers. This was confirmed by the strong positive relationship between children's pre-test character recognition and their performance on semiregular and irregular pseudo-characters, but not on regular pseudo-characters.

In learning regular characters, Ho et al. (2006) find that children with dyslexia aged 8 years and 8 months show a developmental delay, but not a deficit; their learning outcomes of regular characters were comparable to reading-level-matched peers, although significantly poorer than age-matched peers. Our dyslexia participants were 2-year older than theirs. As a starting point, the present evidence shows that the turning point of when children with dyslexia catch up with their age-matched peers in learning regular characters is earlier than fifth grade. The exact time point of this shift needs to be pinned down in future investigations.

Our finding regarding the poor learning of irregular characters is converging with Ho et al.'s (2006) findings. In their study, in learning irregular characters, children with dyslexia showed significantly weaker learning outcomes than both the reading-level-matched and age-matched comparison groups, pointing to a learning deficit. We further suggest that children with dyslexia also learn semiregular characters more poorly than their age-matched peers. It is possible that children with dyslexia have a learning deficit in semiregular characters as well. We did not aim to tease apart whether such poorer learning outcomes suggest a developmental delay or a learning deficit, an important question for future researchers.

Importantly, the present findings show that children with dyslexia are able to utilize semiregular phonetic cues and thus alleviate their poor learning of semiregular characters; they learn semiregular pseudo-characters significantly better than irregular pseudo-characters. Their abilities to use partial phonetic cues seem to be intact, although they seem not to be able to fully compensate for their impaired learning as their use of regular phonetic cues in fifth grade. It is possible that their use of semiregular phonetic cues might be able to eventually fully compensate for the poor learning of semiregular characters. The current design was not designed to examine whether or not their utilization of semiregular cues could improve even more over time. Future investigation can aim to address this possibility by extending to older children or even with a longitudinal design.

Note that in the last testing trial, the comparison group reached the ceiling, 3.72 and 3.69 out of 4 for semiregular and irregular conditions, respectively. However, the dyslexia group only reached 3.32 and 3.12 out of 4 for semiregular and irregular conditions, respectively. It seems to indicate that regardless of the regularity of phonetic cues, the comparison group learned all the characters. In comparison, the dyslexia group cannot fully acquire semiregular or irregular characters at least within six learning trials, although they can learn regular characters without difficulties. Noticeably, there is a trend that children with dyslexia are more sensitive to the semiregular phonetic cues than their peers, evidenced by a larger difference between the overall learning outcome of semiregular and irregular pseudo-characters (dyslexia group, the difference is 2.55–2.18 = .37 out of 4; comparison group, the difference is 3.00–2.86 = .14 out of 4).

Moreover, children with dyslexia are comparable with their age-matched peers regarding the overall 1-week retention of learning, consistent with previous findings for 1-h word retention (Ho et al., 2006) and 1-week nonword retention (Li et al., 2009). Note that children's retention of newly learned regular characters is better than that of semiregular characters, followed by irregular characters.

General discussion

The present study investigated how Chinese children with dyslexia utilize visual and phonetic cues in character learning compared to their age-matched peers. We specifically focused on orthography-pronunciation learning using a PAL paradigm. In terms of novelty, we firstly investigated the use of visual cues, as well as that of the semiregular phonetic cues. Our three critical findings are (1) children with dyslexia have poorer character learning performance than their age-matched peers, except for regular characters; (2) like their peers, they do no use visual cues in fifth grade, and they utilize phonetic cues instead; (3) their retention of newly learned characters is as good as their peers. In the following sections, we discuss these major findings in detail compared to previous work.

Poor character learning performance among children with dyslexia

The current two experiments consistently suggest that children with dyslexia learn novel characters more poorly than their age-matched peers, indicated by the weaker learning outcomes regardless of the availability of visual cues and the regularity of phonetic cues (except for the regular condition, as discussed below) in the PAL process. The finding on overall weaker learning outcomes on novel words among children with dyslexia compared to their peers is in line with previous work (e.g., Ho et al., 2006; Li et al., 2009; Messbauer & de Jong, 2003). We extended previous work by considering the effects of visual and phonetic strategies.

The current finding should be interpreted conditioned on the specific design and paradigm used here. When only visual cues are available in novel characters, without any other cues such as phonetic or semantic cues, children with dyslexia show impaired character learning. In addition, when only phonetic cues are available, without any other cues, including visual or semantic cues, children with dyslexia have difficulties in learning semiregular and irregular characters. However, these findings should not be generalized to other contexts directly. For example, when both visual cues and phonetic cues are available in characters, children with dyslexia may not necessarily have a general character learning deficit, a possibility for empirical investigations in future research.

Moreover, in both experiments, the comparison groups always reached the ceiling by the last testing trial, regardless of the availability of visual cues and the regularity of phonetic cues. By contrast, the dyslexia group only reached the ceiling on the learning of regular characters but did not fully acquire other types of characters in the PAL task. The quantity of learning trials matters for children with dyslexia, as pointed out in He and Tong (2017). Specifically, Chinese children with dyslexia demonstrate impaired learning effects of a repeated sequence of target positions (left, right, up, or down), with a small number of exposures (i.e., 40 times), but not large number of exposures (i.e., 180 times). It might apply to character learning as well. It might be possible that children with dyslexia need more learning trials to reach the same learning outcomes as their peers in character learning. In the current study, we only had 8 and 6 learning trials in Experiments 1 and 2, respectively. Future researchers can aim for including more learning trials to test this hypothesis.

Children with dyslexia have intact abilities to use visual and phonetic cues in characters

We found an interference effect of visual cues in Experiment 1 and the facilitative effect of regular and semiregular phonetic cues in Experiment 2, across groups. Despite the poor performance in the learning stage, children with dyslexia do not differ from their peers regarding the use of visual and phonetic cues. Similar to their peers, in fifth grade, they use phonetic cues instead of visual cues in character learning, and thus they are able to compensate for their poor learning of regular characters and alleviate that of semiregular characters. These findings can be interpreted from a developmental perspective. Based on the Stages of Reading Development theories (Ehri, 1991; Frith, 1985) and their extensions in Chinese (Chen et al., 2014), children progress from the visual stage (i.e., using visual cues from the visual feature of words) to the phonological stage (i.e., utilizing phonological cues from the pronunciation information contained in word spellings) in learning to read. Specifically, Chen et al. (2014) suggest that at the visual stage, Chinese children's character learning is facilitated by the salient visual features embedded in a character, i.e., the exaggerated stroke of a character, e.g., 厷, compared to the original character 厷. Later on, at the phonological phase, children can pronounce unfamiliar characters based on the pronunciation cues carried by the phonetic components of characters. Note that Chen et al.'s (2014) participants were in kindergarten when being at the visual stage.

The current finding might suggest that Chinese fifth-graders, including children with dyslexia, are beyond the visual stage. They are at the phonological stage, and they effectively use phonetic cues in character learning. As such, visual cues might have distracted children's attention and thus hindered their efforts on processing characters at a larger unit, e.g., multiple-stroke patterns rather than an individual stroke. This might be the potential answer to why the visual cues in Experiment 1 hindered children's learning outcomes and why the regular and semiregular phonetic cues in Experiment 2 facilitated children's learning effects.

Critically, both experiments suggest that children with dyslexia rely on the visual and phonetic cues more than their peers. This is evident by the findings that they show a larger interference effect of visual cues in Experiment 1, and the larger facilitation of regular and semiregular cues in Experiment 2, compared to their peers. These point to the possibility that children with dyslexia are more in need, as well as being able to utilize learning strategies to compensate for their impaired visual-verbal paired associate learning abilities. Understanding the mechanism of written word learning strategies among children with dyslexia is a key milestone to support them to overcome their deficits being unpacked in the past decades. Therefore, we invite more direct investigations on written word learning strategies among children with dyslexia to further this line of work.

Children with dyslexia have intact retention of learning

In written word acquisition, the long-term retention of learning is just as critical as the learning process. To tap into children's retention of learning, we conducted the 1-week follow-up testing on their recall of the pronunciation of learned characters in both experiments. Children with dyslexia show intact retention of character learning across experiments. Regardless of the availability of visual cues and the regularity of phonetic cues, their retentive percentages were just as good as their peers. This finding is consistent with previous work suggesting that children with dyslexia have intact 1-week retention of nonword visual-verbal associations (Li et al., 2009), and we extended the previous finding to character learning.

The current finding is also in line with Ho et al.'s (2006) finding that children with dyslexia maintain newly learned regular and irregular characters for 1 h without difficulties (Ho et al., 2006). We extended the previous finding to 1 week and considered the effects of visual cues and phonetic cues. For all the children, the availability of visual cues does not affect their retention of learning, whereas, they maintain newly learned regular characters better than semiregular characters, followed by irregular characters. Collectively, these findings suggest that children with dyslexia show poorer performance on the build-up of orthography-pronunciation associations but not in their long-term retention. They appear to need more exposures or learning opportunities in reading acquisition than do their typically developing peers. But their established associations seem not to be subject to loss more than their peers.

Limitations and future directions

Some limitations of the current investigation need to be mentioned and require caution in interpreting our findings. First, the two experiments included a relatively small number of stimuli, i.e., eight unfamiliar characters in Experiment 1 and 12 pseudo-characters in Experiment 2. This was to avoid overwhelming our participants in the two-week experimental period. As a result, we only had four items under each experimental condition. Note that we had multiple testing trials, thus multiple observations, for each item (i.e., eight/six testing trials in Experiment 1/2), which provided considerable variations in the data that can capture individual differences among children, and support the statistical analysis being conducted appropriately. In our study, in either experiment, children with dyslexia did not reach ceiling on the last testing trial in any learning conditions, with an exception for regular characters. Due to the lack of previous research to form comparisons, we do not yet have clear evidence to comment on whether or not increasing a number of stimuli would work. We suggest that future investigations may try to include more stimuli, maybe with a more extended experimental period.

Noticeably, our main focus was whether and to what extent children with dyslexia use visual and phonetic cues compared to age-matched peers, as a starting point. Further examining whether the differences between children with dyslexia and their peers are due to a developmental delay or a learning deficit is a critical question for future researchers. Another future direction is to include visual and phonetic cues in one experiment to examine whether they interplay. We isolated these two factors for a clean design. But building upon our findings, future work can further investigate the more complex scenario of the cue use in character learning.

Moreover, for the future, the use of semantic cues should be considered as well given the importance of semantic components in characters. Lastly, previous research on character learning via PAL has heavily concentrated on orthography-pronunciation learning. Children's learning of orthography-meaning associations needs to be studied as well.

Conclusions The current investigation sought to understand whether children with dyslexia utilize visual or phonetic cues as effectively as their age-matched peers and identify the specific deficit in their cue use, if any. Two experiments examined the use of visual cues and phonetic cues, respectively. Findings suggest that children with dyslexia show poor performance at the character learning stage, but not in the use of visual and phonetic cues or in the retention of learning. Like their peers, they use phonetic cues instead of visual cues, and thus compensate for their poor learning of regular characters and alleviate that of semiregular characters.

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