Develop a Web-Based Dynamic Assessment of Orthography Specificity as the Benchmark in Chinese Reading

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***Abstract*—With increasing demands on online reading programs, it is necessary to develop an online assessment tool to monitor the word reading progress. We aimed to design such an online dynamic measure in Chinese based on the language-specific feature of orthographic representation to reveal the true relationship between reading and writing relationship. A cross-sectionally design from grade 3 to 5 in Chinese primary school students was conducted. Data were collected and analyzed using a mediation model to show that the online measure of lexical specificity and word reading were mediated by orthographic awareness with a developmental trend. The results suggested that orthographic specificity uniquely contributes to explaining word reading variance, with its impact more pronounced in lower graders. Our findings implied that the online computer-assisted dynamic assessment could be used to measure the children's orthography for lower graders in the Chinese learning context. We established such a first lexical-specificity measure for online learning curves across grades. For future research, we should suggest a longitudinal follow-up should be adapted for static and dynamic performance of word reading in Chinese children.**

***Keywords*—dynamic assessment, orthographic specificity, Chinese character, word reading development**

I. Introduction

To build a better model of the reading-writing relationship, the lexical quality hypothesis posits that word knowledge consists of representations of phonology, orthography, and semantics as well as the integration of these representational features [1, 2]. To our knowledge, the online dynamic measure to assess Chinese lexical specificity is called for and should present the analogical and paralleled results with previous research [3–5]. Meanwhile, a new analytical approach is also being called for to review the essential characteristics of Chinese word reading and it is specificity in a dynamic learning environment.

To begin with, the significant implications of the current study arise from the unique characteristics of the Chinese reading framework varied from alphabetic languages. From the general theoretical framework of the reading-writing relationship of high quality lexical representation, word reading acquisition requires children to develop a cascade style of skill enhancement by solidifying the word form, sound and meaning gradually through the specific refinement of the lexical constituents [5]. Lexical specificity herein is defined as "the richness and specificity of, and distinctness between" lexical representations [3]. The previous studies in the alphabetic languages have showed a trend about a mediation relationship between the word reading and lexical specificity performance in the phonetic tasks assessed [3–5]. Young children have demonstrated that phonological specificity (e.g., bear-pear) contributes to word reading in alphabetic languages [4]. This specificity in lexical representation has been gradually acquired as the children develop the richness in the distinction of the structural representation of the lexical constituents (i.e. sound, form and meaning) [3]. However, the performance in lexical specificity is constrained by the kids' metacognitive awareness in the sub-lexical reading skills across years [6].

When alphabetic writing is being read, strengthening the phonological constitute and its orthography connection is especially important to reading success [7]. Different from the alphabetic languages, the lexical distinctiveness in the Chinese language emphasizes on its specificity in orthographic representation. In fact, eighty percent of modern Chinese characters consist of both semantic and phonetic radicals, which provide clues to characters' meaning and sound [7, 8]. In contrast to alphabetic languages, Chinese does not require phonological mediation for access to an orthography entry, and Chinese readers cannot rely on correspondences between sound and spelling for word reading. Thus, language-specific mapping between other types of representation in Chinese （e.g., the configuration, stroke order, rhymes, and tones）might be used for learning to read Chinese. For example, to distinguish the two homophone characters which contain the same radicals but in different positions[1], the learners need to pay the specificity of the configuration change and order of strokes in writing them out between these two characters. Indeed, literacy in Chinese emphasizes the role of orthographic representation uniquely in correspondence to the phonological representation in relation to meaning in learning to read Chinese [8]. As children's vocabulary grows, particularly they would begin to differentiate similar orthographic characters by paying more attention to the detailed specific representation. This shape complexity is controlled by number of strokes, configuration legality, simple and complex shapes. See Fig. 1 for details.

However, till now we know very little about other specificity than the sound representation of word learning that might predict word reading in Chinese. Few studies have explored orthographic specificity on reading, despite a long-standing assumption that it is crucial to distinguish

[1] "讫 qi4 (means to stop)" and "迄qi4 (means until a certain time point)

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written words based on only minimal orthographic differences. Thus, the current study aims to develop an online orthography assignment on word reading in Chinese children.

The originality of this study mainly includes three aspects below: (1) to establish the first Chinese lexical specific measure which could be applied for online dynamic assessment; (2) to establish the analytical approach by using the mediation analyses to reveal the essential characteristics of the Chinese word reading; (3) to capture the relationship between the word reading and the lexical specificity in dynamic assessment environment.

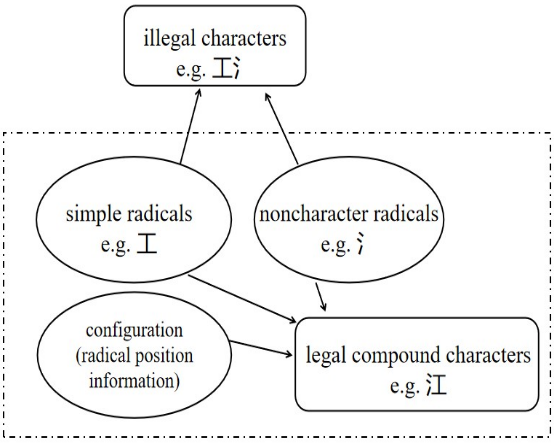


Fig. 1. An example of the structure of Chinese characters. Chinese characters are composed of basic strokes, which are the smallest building blocks of characters. These strokes are combined to form component radicals, which are the fundamental components of Chinese characters. It is important to follow certain position constraints when combining strokes to form radicals, as any deviation can result in illegal radical forms. In compound characters, the radicals are configured in a left-right or top-bottom structure. Each component of the characters has a designated and consistent position, such as left, right, top, or bottom. Random combinations of radicals can lead to the formation of illegal character forms.

Regarding the influence of orthographic specificity towards Chinese learning context, the current research aimed to explore the following two major research questions:

1) To what extent does orthographic specificity contribute to additional variance to Chinese word reading in addition to phonological awareness, after controlling for intelligent factors and working memory?
2) How does the children's sensitivity of orthographic specificity for word reading change across years/grades, and to what extent is this relationship mediated by orthographic awareness?

II. Literature Review

A. Relationship between Orthographic Specifications and Reading Skills

A series of studies have predicted the trend of the relationship between orthographic specificity and word reading. Studies on lexical specificity have focused on phonological specificity in alphabetic languages [3, 5, 9]. First, according to the lexical restructuring hypothesis [9], young children's phonological representations are initially holistic. Lexical restructuring hypothesis posits that the learning curve originated from refining the reading skill development through the enhancement of dynamic progress of orthographic specificity. Because the kids' vocabulary is quite limited and mostly contains words that sound differently, such as bear-pig. However, as their vocabulary size increases, children must also increase the specificity of their phonological representations in order to distinguish between words that have similar acoustic features, such as bear-pear. Phonological specificity, therefore, is the key construct that underlies the restructuring process. Specific phonological representations are the foundation of developing phonological awareness, which is an important predictor of word reading [10, 11].

Secondly, according to the lexical restructuring hypothesis [12], word acquisition occurs first by oral representation by sound, and then transitioning from holistic phonological representation to more specific ones. This process becomes a more and more solid representation of sound-form-meaning representation through repeated reading and writing practices [8]. In the reading process, the enhancement between the word form and meaning is achieved through precise mapping. In the writing process, this enhancement is continuously done through a precise orthographic representation by restructuring the lexical constituents of sound, form and meaning.

Researchers have devised a word learning paradigm to measure children's phonological specificity [3, 5, 10]. This paradigm mimics the lexical restructuring process using a similar specificity task. Specifically, each item in the task contains two target words (e.g., goal, sole) and two control words (bowl, knoll). The two target words form a minimal pair, differing in one acoustic feature only, whereas the control words differ from the target words in two acoustic features. Each quadruplet is presented in three blocks. In the first block, children are asked to contrast each target word against the first control word (e.g., goal-bowl, sole-bowl). In the second block, the process is repeated with the second control word (e.g., goal-knoll, sole-knoll). In the third and final block, children are asked to distinguish between the two target words (e.g., goal-sole). As children move through the blocks, they are forced to pay attention to increasingly subtle differences, thereby enhancing the specificity of their phonological representations.

Van Goch, McQueen and Vehoeven [5] demonstrated that the phonological specificity training offered through the learning paradigm enhanced literacy skills in pre-literate Dutch children. Children in the experimental group were taught Dutch words with minimal pairs (e.g., raap 'turnip', raat 'honeycomb' and raam 'window') while in the control group, children received numeracy training. They found that the experimental group performed better on rhyme awareness, indicating that phonological specificity is one of the precursors of literacy. Krenca and colleagues [10] extended the impact of phonological specificity to word reading. In a 1-year longitudinal study involving emergent English-French bilinguals, the researchers found that English phonological specificity measured with the learning paradigm at the beginning of grade 1 predicted English word reading at the end of grade 1, and this relation was mediated through phonological awareness at the beginning of grade 1. However, the previously designed specificity tasks have their confounds with the number of total items in the learning trail, and the control items only focused on the rime features in the phonetics. These studies have taken together to suggest that phonological specificity contributes to early literacy skills, but we still know little about orthography. To fill the research void and contribute to the Chinese lexical distinctiveness, the present study extended the body of research to another aspect of lexical specificity, orthography specificity, and explored its online role in word reading among Chinese children.

More importantly, the innovation of the current web-based design considers that the web-based assessment system in this research was implemented based on the dynamic assessment theory. The theory has two major instructional characteristics. First, dynamic assessment can provide individuals with an opportunity to learn. Second, instruction and feedbacks are built into the testing process [10]. The traditional use of dynamic assessment is to categorize examinees, help them choose the specific forms of training they need to receive, and predict the learners' true ability to complete the task [10]. Moreover, it is designed to expect dynamic assessment to effectively assist teachers to teach and learners to learn in an e-Learning environment. Therefore, this research attempted to combine the two major instructional characteristics of dynamic assessment and in turn propose the idea of 'assessment as teaching and learning strategy'. In brief, the idea means that teaching and learning strategies revolve around a web-based dynamic assessment, and the Web-based dynamic assessment is seamlessly combined with the teaching activities. In the process of taking the web-based dynamic assessment, learning could take place through the guidance and instruction provided by the assessment. This web-based assessment has been conducted in previous studies in assessing the phonological specificity [3, 4], so its feasibility has been established. We were the first to have conducted an online assessment in our experimental schools for a broader range. It could capture the real-time tracking of the students' progress in the lexical specificity task training performance.

B. Orthography in Chinese

For Chinese characters learning, at first there is no need for them to have knowledge of highly specified orthographic representations; To distinguish word meanings on the basis of character configuration, such as pictograph, "山<mountain>" and "水 <water>". Their vocabulary is quite limited; Nevertheless, with their vocabulary expanding, it is necessary for children to increase the specificity of orthographic representations so as to distinguish orthographically similar characters like "秒 <second>" and "妙 <wonderful>".

Chinese characters are the functional units in the Chinese writing system. Each character corresponds to a single syllable and is usually a basic morpheme. There are overall 4000 written characters but only roughly 1000 syllables in the spoken language [13]. One inevitable consequence of such a system is the prevalence of homophones. Over 70% of the common Chinese characters share the same pronunciation with at least three other characters of different identities [14].

The orthographic forms of Chinese characters are compilations of strokes organized in squared constructions. Stroke, logographeme, and radical, are major components in Chinese orthographic representation, but none of them corresponds to sub-syllabic phonemes. As for the orthographic processing in Chinese characters, one of the most frequently asked questions concerns the grain-size of the orthographic units involved in the processing [15]. Representations of the orthographic units with different grain sizes could be all organized at the same level in the mental lexicon and are all involved in the recognition process. Logographemes have been processed in some Chinese copying tasks, and the effect of the occurrence of orthographic units (such as deleting and addition of strokes) has been observed on character recognition [16].

Another major type of Chinese characters, called phonetic compounds, contains semantic radicals that give clues to meaning and phonetic radicals that give clues to phonology. For example, the character "梅(mei2) <criticize>" can be decomposed into the semantic radical "木 < tree-related>", which indicates clues to its meaning and the phonetic radical "毎(mei3) <every>", which indicates clues to its phonology. The majority (~70%) of Chinese characters are phonograms [13]. However, the phonetic radicals in the phonograms are themselves characters, having their own pronunciations and meanings. The cues they provide to pronunciation of the phonograms are neither constant, as some may function as the phonetic parts in the certain characters and the signifiers in others; nor reliable, in that less than 30 percent of the phonetic radicals provide the correct pronunciations. In other words, a notable property of the Chinese orthography is that it has an opaque phonology-orthography mapping. Therefore, it is theoretically important to establish the online orthographic specificity task that focuses on orthographic representation in Chinese reading.

To rely only on the radical representation of the Chinese orthography for a theoretically unassailable orthographic specificity task is not possible. The roles of radicals in writing Chinese characters can possibly be twofold. First, the functions of individual radicals may affect the semantic and phonological processing in the reading and writing processes. Second, as frequently occurring orthographic units, the phonetic and semantic radicals are used as functional processing units in the mental representation. The semantic radicals in readers' mental representations are linked to the corresponding semantic features. When the syllable-to-radical mapping was consistent, direct access to the semantic radicals in the orthographic lexicon from the semantic system is possible during Chinese recognition. Similarly, mental representations of phonetic radicals are involved in character recognition and they can be accessed directly via their corresponding syllables [17–20]. Nevertheless, given the opaque relationship between phonology and orthography in Chinese, whether the processing of phonological information is associated with phonetic radicals is a muddled matter. A series of previous experiments have examined this consistency effect of semantic-phonetic radicals, we designed a 480-character database based upon the primary school students' curriculum and tested the consistency effect on word learning from grade 1 to 6. What we found is that the radical consistency factors matter for the lower graders but not for the higher graders once those older kids have achievement a more refined representation of the orthographic representation [17, 18].

C. The Present Study

The purpose of this study is to verify whether and to what extent orthographic awareness mediates the relationship between orthographic specificity and word reading in Chinese. Primarily, we claim that this mediation relationship follows the analogy between phonological specificity and phonological awareness shown in previous studies [3–5, 10]. In this analogy, to reexamine the theories in the richness of word representations indirectly could make a contribution to decoding skills [1–3]. According to this lexical quality hypothesis, phonological awareness, as a phonological processing skill, is the driving force for word reading skills [16]. Thus, phonological specificity exerts an indirect effect on word reading. Consistently, some previous fundamental studies have established the evidence. Krenca *et al.* [10] found that phonological specificity was connected to word reading via the mediation of phonological awareness. They showed children who performed better in the English phonological specificity task also had notably higher English phonological awareness, and that children who got higher scores on phonological awareness would have better performance on English word reading.

Moreover, the previous literature posits substantial evidence relating the independent variable of orthographic specificity to the mediator, orthographic awareness, and the dependent variable, word reading. In terms of orthographic awareness, previous studies showed that orthographic awareness played a predictive role in word reading. It can predict word reading for preschoolers [18], 7-year-old children [19] and 9-11-year-old children [20]. In addition, orthographic awareness once served as a mediator in some other relationships involved with word reading and made a unique contribution to word reading. According to Yang, Peng and Meng [20], orthographic awareness, as a basic language skill, mediated basic cognitive skills to Chinese character reading and reading comprehension. What's more, recent research has demonstrated orthographic awareness was an important predictor of reading comprehension and that it played a mediating role between writing and reading comprehension [21]. Taken together, along with the predictive power and the mediation effect of orthographic awareness for word reading, we could get such a hypothesis. Analogously, like the relationship between phonological specificity and phonological awareness, there might exist orthographic specificity which can predict word reading through the mediation of orthographic awareness. In order to investigate whether and to what extent orthographic awareness mediates the relationship between orthographic specificity and word reading in Chinese, we eliminated the interference of phonological awareness by controlling for the intelligent factors and working memory [6], only focused on the extent to which orthographic specificity contributes to additional variance in Chinese word reading.

The basic design feature of alphabetical writing systems in mapping letter strings to word sounds—any activation of orthographic representations will rapidly spread to phonological representations, making it difficult to dissociate the effects of orthography and phonology in meaning access. Categorically different from alphabetical languages, written Chinese is logographic with a weak orthography-to-phonology mapping [19], suggesting that the direct print-to-meaning pathway may be easier to demonstrate in the reading of Chinese.

The present study is one of such first attempts to explore the relationship between orthographic specificity and Chinese word reading. Despite much research in Chinese character acquisition, online assignment of orthographic specificity remains a missing piece. The specificity of Chinese characters exists in orthographic representation. We aimed to build up learners' orthographic skills on the target characters in a minimal pair that differed in one or two strokes in structural configuration. After the online learning task, participants were required to choose the target one among a quadruplet of four characters based on their knowledge acquired in the orthographic specificity task. As the contribution of orthographic learning to word reading might be affected by learners' working memory [22], we first controlled for working memory. We then treated the performance in the orthographic specificity task as an independent variable to predict word reading. We aimed to explore the following two major research questions:

1) To what extent does orthographic specificity contribute to additional variance to Chinese word reading in addition to phonological awareness, after controlling for intelligent factor and working memory?
2) How does the children's sensitivity of orthographic specificity for word reading change across years/grades, and to what extent is this relationship mediated by orthographic awareness?

III. Measures and Methods

A. Participants

A total of 270 students participated in this study. Parents of children first signed the Informed Consent Form, and then completed a background survey of developmental disorders and learning disabilities. These participants were from Grade 3 to Grade 6 in Jin-shan primary school in Ningbo, Zhejiang Province, China. Two classes from each of Grade 3 to 5 were randomly selected. There were 89 Grade 3 students from two classes (nboy = 44, ngirl = 45, Mage = 9 years,), 88 Grade 4 students from two classes (nboy = 49, ngirl = 39, Mage = 10.19 years), 93 Grade 5 students from two classes (nboy = 46, ngirl = 47, Mage = 10.41 years). The sampling procedure covered the following steps. First, the demographic questionnaires were conducted to guarantee the population selected was representative. First, the sample was representative of the school-aged children from the middle-class family in China according to their family background and socioeconomic status. Second, the mean family income ranged from 15,000 to 25,000 US dollars. Second the average parental educational level was 17.6 years of schooling, i.e., between college and postgraduate education [23]. Meanwhile, all participants were typically developing native Chinese readers and writers. Finally, there was no history of neurological disorders based on the background demographic data. The participants were all compensated with stationary at an equivalent value of 130 yuan (approximately $20 USD) to complete this study.

B. Chinese Orthographic Specificity Test

1) Theoretical rationale for the task design

Regarding the popularity of the web-based learning, it is necessary to develop such a tool for dynamic assessment online. Recently there have been some online assessments for word reading, which suggested that the tasks developed online could capture the real features of the word learning and reading performance and equally well predict the academic performance as the paper-pencil tasks [3, 4].

To establish the orthographic specificity task in Chinese, it is necessary to control the Chinese characters that share the same phonological information. Hence, the mental representation and meaning retrieval of the orthographic processes could only be attributive to the orthographic features of Chinese. Like alphabetic languages in which homophones are usually orthographically similar (e.g., “weak” and “week” in English), the current study aims to investigate the Chinese beginners’ sensitivity to distinguish the Chinese homophones that also bear some orthographic resemblance (e.g., two target characters “羚 <antelope> [target 1unfamiliar]” and “铃<bell> [target 2 unfamiliar]”, which are both pronounced as /ling[2]/ with the transposition of its semantic radicals “⺶<goat family> with “钅”<metal family>) in comparison to two other orthographic similar characters (e.g. two controlled characters, “冷 <cold> /leng[3]/”[control1, familiar] and “怜<mercy>/lian[2]/” [control 2, familiar]). In other words, we aimed to examine the two Chinese homophones that are orthographically similar but share minimal contrast from each other in their orthographic features. The grain size difference between target 1 character and control 1 character should be larger than that between target 1 and control 2, and so forth. With the grain size differences decreasing in four progressive character pairs (i.e., target1-control1, target 1-control 2, target 2-contorl 1, and target -control 2) in the four learning phases, the specificity in detecting the subtle difference in the orthographic features of Chinese in two homophones makes the character acquisition happen in the testing phase. The distinction in the structure of Chinese orthography does not imply the relationship with its spoken counterpart at the phonetic radical level considering the opaqueness and unreliability of the phonetic radicals to word representation (See Measure section for more details).

Chinese characters selection: Twenty quadruplets of Chinese characters were selected for the present study. All characters were taken from the vocabulary lists in the 12 volumes of the Elementary School Chinese Textbooks prepared by the Ministry of Education and used in Beijing and several other regions. Each quadruplet consisted of four words: two unfamiliar target words (e.g., ‘泊bo2’ and ‘伯bo2’), two familiar control words (e.g., ‘怕pa4’ and ‘迫po4’). The target words in each quadruplet are of the same articulation (80% of target words are of the same tone, i.e., homophone) and differ in at most two orthographic features, such as stroke number. The control words differ from the target words in at most four orthographic features and must share the same phonetic radical with the target words. The control words were given to the students two weeks before the test so as to get them familiarized with all the controls. The filler words were highly frequent compared with the targets and controls. All filler words were highly familiar characters that were unrelated in form, meaning or sound neither with the target words nor the control words. In order to avoid the test being too hard for the participants, the repetition rate of the filler words in the whole test process is 50%. Specifically, the four filler words used in each test phase were those already used in the training section of each group. The frequency sequence of the three categories are filler words, control words and target words with the filler words being the most frequent ones.

Five elementary Chinese teachers at Jin Shan primary school in Ningbo rated the testing characters on a 5-point scale from (1) highly unfamiliar to (5) highly familiar as they believed they would be known by Grade 3 children. All target words were evaluated as highly unfamiliar (rate 1 to 2) characters, whereas all controls were evaluated by teachers as highly familiar characters (rating 4 to 5) (All the statistics of characters were presented in Table 1.

Table 1. Statistics for all experimental items

	Target1	Target2	Control 1	Control 2	All fillers
Stroke	8.75	9.25	9.05	8.6	5.73
Stroke difference	≤ 2		≤ 4		≤ targets &control
Rating1	1.9	1.5	3.95	4.1	4.325
Rating2	1.75	1.4	4.1	4.05	4.4812
Rating 1-5 average	1.825	1.45	4.025	4.075	4.403
Frequency rank	2223.7	2527.1	852.9	963.15	256.506
Frequency 1(1000/million)	0.04735	0.025715	0.826925	0.434275	1.88395
Frequency 2(/1.8million)	126.9	61.35	1768.7	1154.4	256.506

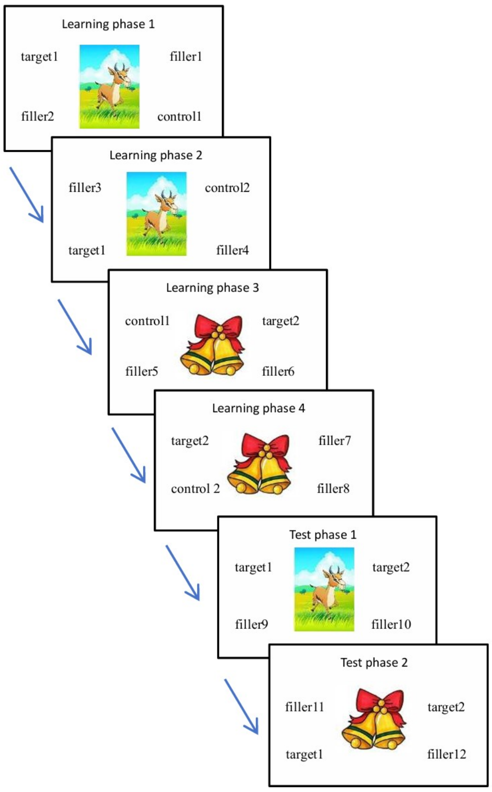
[1] *Note*: Term abbreviation: TGT=Target; CR=Control; Ave.=average

2) Operationalization of the Online Task

The online orthographic specificity task consisted of a practice phase, a training phase and a testing phase. This task was designed in E-prime Software. Each trial began with the presentation of a fixation cross (500 ms), after which four characters presented in a randomized order along with a picture corresponding to one of the target words were presented in the middle of the screen. After an auditory question (which character matches with the picture) was played while the four characters and the picture remained on the screen. The children then indicated their response to the question by pressing the target word that corresponded to the picture on the center of the computer screen at each trial. If the children chose the correct character, a picture of a smiling cartoon face appeared on the screen, indicating positive feedbacks (1000ms). If the children chose an incorrect character, a sad face was presented, indicating a wrong answer. In total, 148 trials were included. A practice phase composed of 48 trails was used to familiarize the children with the training procedure. The training phase consisted of two blocks of 80 experimental trials, and the test phase contained one block of 20 experimental trials.

3) Procedure

The learning and test trials are presented in Fig. 2. In Block 1, each target word of a quadruplet was presented once, paired with its familiar control word and two filler words [e.g., “羚ling2” (target1), “冷leng3” (familiar control1), and two fillers; then “羚ling2” (target2), “怜2” (familiar control1), and two other fillers]. In Block 2, the same procedure as Block 1 was repeated once again with another control word and the other four different filler words [e.g., “铃ling2” (target1), “冷leng3” (familiar control1), and two other fillers); then “伯bo2” (target2), “怜lian2” (familiar control2), “顶ding3” (filler word), and “秋qiu1” (filler word)] (see Fig. 1 for detail). After learning each 4 quadruplets of characters, participants moved on to the testing interfaces. For the test phase, two slides were designed for the two target words of each quadruplet. In each slide, the two target words of a quadruplet were presented together along with two filler words already used in the past training section [(e.g., “羚ling2” (target 1), “铃ling2” (target 2), and two fillers; “铃ling2” (target 2), “冷leng2” (control 1), and two fillers]. Half of the fillers were previously presented; the other half were not. Participants had to identify target 1 and target 2 on the first slide and the second slide respectively.



Note: The design and instruction in the figure as shown have been translated from Chinese to English. Since the target of the online assessment is to learn the orthography, so there were no phonetics presented in the learning interface.

Fig. 2. Learning trial interface of Chinese orthographic specificity.

Although two target words were presented together in the final test phase, both target items correspondent to either of the two target-matched pictures were displayed in the test phase. No feedback was provided in the test phase. Children had to consider orthographic overlap and the analyses were based on the proportion of characters correctly identified in the entire training session because the goal of the experiment was to assess children’s overall orthographic sensitivity to character learning. One point was awarded for each correct answer and the maximum score was 120 points. The reliability of the performance across the learning trail and the reliability of the task are presented in Table 2.

Table 2. Stroke number difference between two targets and target-control pairs

	Stoke number difference				
	0	1	2	3	4
Target and target	35%	50%	15%		
Target and control		30%	45%	10%	15%

Note: Within each group, 35% of targets have no stroke number difference, 50% of targets have One stroke difference, and 15% of targets have Two stroke difference. For the stroke difference between target and control, 30% has One stroke difference, 45% has Two stroke difference, 10% has Three stroke difference, and 15% has Four stroke difference. No five or more stroke difference between any pairs of target and control.

C. Other Measures

1) Backward digit span

The backward Digit Span was used to assess working memory [24, 25]. The central executive component of working memory has been argued to play a crucial part in the performance of span tasks, especially backward span [24]. The task aims to assess the relations among age, working memory, and backward digit span. The task consists of 10 sets of randomly presented digits. The number of digits per set gradually increases from 5 to 9. For example, when listening to 5, 9, 1, 3, 7, 2, the participants were required to write these digits in a certain backward order. For example, the last but two digits, which should be “3”. The total testing time for this test was 2 minutes. One point was awarded for each correct set and the maximum score was 10. This task was a group-administered test. Instructions were given in Chinese, but the students were required to write Arabic numerals (i.e., 1-10). The Cronbach alpha of test-retest reliability of this test ranged from .79 to .83 across grade 3-5.

2) Phonological awareness

We adapted three judgment tasks to measure Chinese PA [26]. This task contained both a Mandarin tone awareness task, and a Chinese onset and rime awareness task. The examiner read three items per set, and the child was asked to judge which one out of the three items did not share the same onset, rime, or tone. For example, the child listened to the sound of the words 1 /lai4/(赖), 2 /lao3/(老), and 3 /hai4/(害) and decided that 2 /lao3/(老) had a different “beginning” (onset). In this example, the child would circle “2” on the answer sheet. The tone awareness task examined the four tones of Mandarin. The Chinese onset and rime awareness tasks each had 16 sets, and the Mandarin tone awareness task had 16 sets. The total score was 48 points. The participants were allowed three minutes to complete the task. The

Cronbach alpha test-retest reliability of this test ranged from 0.83 to 0.88 across grade 3–5.

3) Orthographic awareness

Following Guan *et al.* [27, 28], we used a lexical decision task to assess the orthographic awareness. To select materials for the lexical decision task, we randomly sampled 240 characters (40 from each grade level) from the curriculum for grade 3 to 5, ensuring that the items were representative of the compound regularities and configurations of Chinese characters. The basic configurations included left-right, top-down, and outside-inside. We defined characters as high consistency if the semantic radical appeared with the same pronunciation in more than 50% of characters [29] and low if not, and we used the curricular grade level as a proxy for AoA. Another 240 pseudo-characters were created by adding, deleting, or shifting one stroke from the radicals within a legal character. The children received a practice trial to familiarize themselves with the task and then moved on to the real testing session, in which they indicated whether each of the 480 characters was a real character or not, one at a time; RT and accuracy were recorded by the computer, but were not used for analysis. The accuracy rates on this Chinese lexical decision task were used to produce the OA score in percentage (maximum 1 point). The reliability coefficients of this set of measures ranged from 0.71 to 0.88 from grade 3 to 5.

4) Vocabulary

It was a standardized test of receptive vocabulary (Peabody Picture Vocabulary Test, PPVT) [30]. It was an individualized assessment adapted version in Chinese. A series of plates were shown in the test, consisting of four pictures. The students were required to choose the pictures that the experimenter named the vocabulary based on the four pictures. The task difficulty increased gradually based on each grade-level. What is more, it was very essential for teachers to know students' receptive vocabulary size, in order to measure whether they would be capable of comprehending the texts or listening tasks [31]. The task was the case in point. The test contained 50 multiple-choice questions in Chinese. The presentation order in Chinese was counterbalanced. The students were required to match words that they heard with the correspondent pictures. It took 6 minutes to complete the test. One point was awarded for each correct answer and the maximum score was 50.

5) Word reading

Miles and Ehri [32] highlighted that efficient word reading involved retrieving familiar written words from memory automatically by sight, and sounding out letters or guessing from context only when unfamiliar words were encountered. The aim of the task was to test participants' ability to read as many Chinese characters within 10 minutes. The participants were required to read every word twice aloud. One point was awarded for each correct answer for each utterance, and the maximum score was 100.

D. Procedure of the Study

The children were tested in the fall of Grade 3-5. They were tested over seven sessions: (1) Phonological Awareness, (2) backward digit span, (3) Orthographic Awareness, (4) Word reading, (5) Receptive Vocabulary, and (6) computerized orthographic specificity test. Both group assessments and one-on-one individualized assessments were conducted. The group assessment included a set of paper-pencil tests and a series of computerized tests. The paper-pencil test contained phonological awareness (PA), backward digit span (BDS) and receptive vocabulary (RV) assessed in the group format. The computerized tests included Chinese orthographic specificity, and lexical decision of orthographic awareness task (OA). All the measures were administered among Grade 3 to Grade 5 students. The one-on-one individualized tests contained word reading tests.

Teachers and researchers who were trained to be familiarized with the assessments administered the paper-pencil tests, and all the paper-pencil measures were assessed in their individual classrooms for 20 minutes from Grade 3 to Grade 5, Chinese orthographic specificity tests in computer rooms for 45 minutes, one-on-one test for 10 minutes in quiet meeting-room settings.

IV. RESULT AND DISCUSSION

A. Descriptive Statistics

Table 3 presents the descriptive statistics among all measures in this current study. Table 4 presents the correlational coefficients among all the measures for grade 3, 4 and 5 respectively.

Table 3. Descriptive statistics of all Measures in grade 3, 4, and 5

	Grade 3	**Grade 4**	**Grade 5**		**Group differences**	
	M(SD)	M(SD)	M(SD)	Cronbach's α	p-value	η
WM	3.98(2.1)	4.17(2.4)	4.95(2.3)	0.78	0.512	0.002
PA	26.15(9.0)	36.90(7.42)	42.2 (9.9)	0.91	0.000	0.302
OA	0.57(0.13)	0.63(0.18)	0.71(0.16)	0.80	0.001	0.041
Vocab	19(8.9)	24(7.3)	37(5.6)	0.90	0.001	0.041
OS	48(4.8)	69(7.1)	86(7.6)	0.88	0.001	0.040
WordRead	33.83(17.60)	62.25(16.08)	69.15(15.4)	0.78	0.000	0.417

Note. Term abbreviation: WM = working memory, PA = phonological awareness,
OA = orthographic awareness, Vocab = Vocabulary,
OS = Orthographic Specificity, WordRead = Word Reading.

Table 4. Correlational table among all measures across grade 3, 4, and 5

Grade 3	WM	PA	OA	Vocab	OS	WordRead
WM						
PA	0.260**					
OA	−0.073	0.060				
Vocab	−0.055	−0.023	1.000			
OS	0.186*	0.153	0.127	0.187		
WordRead	0.338**	0.538**	0.138*	0.084	0.168*	
Grade 4	**WM**	**PA**	**OA**	**Vocab**	**OS**	**WordRead**
WM						
PA	0.383**					
OA	−0.021	0.264**				
Vocab	−0.017	0.252**	0.252**			
OS	0.213*	0.377**	0.231*	0.267**		
WordRead	0.174*	0.559**	0.238**	0.207*	0.388**	
Grade 5	**WM**	**PA**	**OA**	**Vocab**	**OS**	**WordRead**
WM						
PA	0.130					
OA	−0.031	0.197				
Vocab	0.178*	0.471**	0.197*			
OS	0.233*	0.275**	0.251*	0.147		
WordRead	0.124	0.491**	0.152*	0.288*	0.114	

Note. **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); Term abbreviation: WM = working memory, PA = phonological awareness, OA = orthographic awareness, Vocab = Vocabulary, OS = Orthographic Specificity, WordRead = Word Reading.

B. Hierarchical Multiple Regression Analyses

Three separate HMR analyses were conducted for each grade. From Table 5, we could observe the relative contribution of each independent variable to the dependent measure of word reading. For grade 3, the four variables at Step 4 provided a total of 35.9% variance explaining word reading. Each step of additional variables into the model provided varied contributions to word reading. WM at step 1 contributed to 11.4% of total variance, PA at step 2 contributed to 21.8%, Orthographic Awareness at Step 3 explained 2.1% of total variance, and the orthographic specificity provided an additional 0.18 % of variance explaining word reading.

Table 5. The last step of HR analyses results to word reading from 4 IVs

Steps			Coefficient estimate	t	p-value	R^2 change
Grade 3	1	WM	0.215	3.358	0.001	0.114
	2	PA	0.465	7.328	0.000	0.218
	3	OA	0.143	2.334	0.021	0.021
	4	OS	0.170	1.133	0.115	0.018
Grade 4	1	WM	0.146	3.689	0.492	0.030
	2	PA	0.498	6.965	0.000	0.284
	3	OA	0.038	2.574	0.036	0.008
	4	OS	0.233	2.756	0.003	0.032
Grade 5	1	WM	0.241	1.995	0.321	0.117
	2	PA	0.077	3.466	0.001	0.062
	3	OA	0.605	1.108	0.280	0.008
	4	OS	0.161	1.115	0.166	0.016

In comparison, for grade 4, the four variables at Step 4 provided a total of 35.4% variance explaining word reading. In details, WM at step 1 contributed to 3% of total variance, PA at step 2 contributed to 28.4%, Orthographic Awareness at Step 3 explained .09% of total variance, and Orthographic Specificity provided an additional 3.2 % of variance explaining word reading. We can see the Orthographic Specificity provided increasing explaining power to word reading from lower grade 3 to higher grade 4.

In comparison, for grade 5, the four variables at Step 4 provided a total of 18% variance explaining word reading. In details, WM at step 1 contributed to 11.7% of total variance, PA at step 2 contributed to 5.2%, Orthographic Awareness at Step 3 explained .08% of total variance, and the orthographic specificity provided an additional 0.16% of variance explaining word reading. We can see the orthographic specificity did not provide increasing explaining power to word reading when children reached to grade 5, the relative maturity level of word reading and writing stage.

C. Mediation Analyses

In Fig. 3, we can see the mediating role of Orthographic Awareness to the relationship between Orthographic Specificity and Word Reading in Grade 3, 4 and 5 respectively. In all three grades, orthographic awareness affects word reading. But all the effects in Grade 3 and Grade 5 are not as significant as those in Grade 4. The direct effect between orthographic specificity and word reading is significant in Grade 4 ($p < 0.01$).

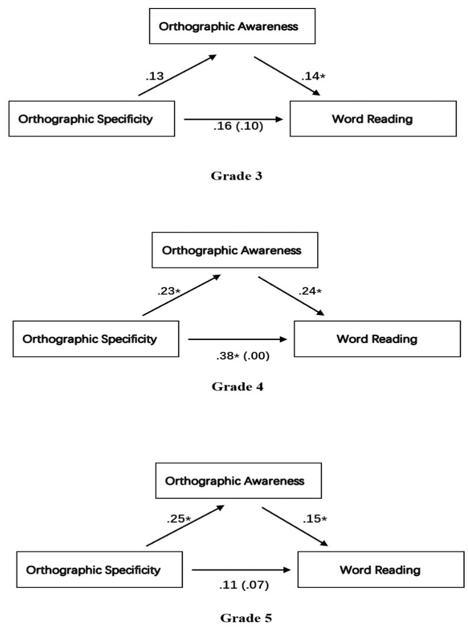


Fig. 3. Standardized regression coefficients for the relationship between orthographic specificity and word reading as mediated by Orthographic Awareness in Grade 3 and Grade 4 respectively. The standardized regression coefficient between orthographic specificity and word reading, controlling for PA, OA, is in parentheses.

D. Discussion

The present study is one of the first attempts to explore the relationship between orthographic specificity and word reading. By controlling working memory, phonological awareness, and orthographic awareness, we examined to which extent orthographic specificity could contribute to word reading, how children's sensitivity of orthographic specificity developed across years/grades, and to what extent orthographic awareness mediates the orthographic specificity to word reading.

The major findings of our research are as follows. First, orthographic specificity provides a significantly additional contribution to word reading after controlling for working memory, phonological awareness, and orthographic awareness for grade 4 only. Second, orthographic awareness plays a mediation role in enhancing the relationship between orthographic specificity and word reading, but this pattern holds water for grade 4 only. Third, there exist developmental differences between children in grade 3, 4 and 5. Children in grade 5 performed better than those in grade 3 and Grade 4. We discuss the major findings in the following.

1) Orthographic specificity contributes unique variance for word reading

In the current study, we explored how the online orthography task is related to word reading in Chinese through online measures. The network can systematically integrate the orthographic representations of Chinese and design sophisticated orthographic specificity tasks. Through online orthography tasks, learners are no longer limited by time and place, and can choose training time more freely. Online learning tasks become more intelligent and personalized after computer evaluation, and the computer will be sorted out in time to store and evaluate the current learning status of learners. From grade 3 to grade 5, these four variables of working memory (WM), phonological awareness (PA), orthographic awareness (OA) and orthographic specificity (OS) provided a total of 37.1%, 35.4% and 20.3% variance respectively. After controlling for WM, PA and OA, OS provided an additional contribution to word reading. For grade 3 children, OA explained 2.1%, and OS explained 1.8% of the total variance. For grade 4, OA contributed 0.8% and OS explained 3.2% of total variance. In comparison, for grade 5, OA contributed 0.8%, and OS provided an additional 1.6 % of variance explaining word reading. Taken together, we can see the orthographic specificity provided increasingly explaining power to word reading from lower Grade 3 to higher Grade 4, but this contribution decreased from Grade 4 to Grade 5.

This pattern of varied contribution of OS to word reading can be explained by two points. First, due to the Inverted U-shaped model theory [27], the law of language cognitive development, which is obvious in the early primary school stage, it is known that 10-years-old children are in their critical period for language development, during which it is the best time for the linguistic subtle sensitivity to influence children's cognitive abilities and literacy. Consistently, according to Schadler and Thissen [33] via the Stroop task to measure children's reading ability, they found that children's level of word reading peaked in the fourth-grade. Second, after Grade 5, when children are over 11 years old, they might be more dependent on cognitive skills rather than subtle differences in orthographic representation to distinguish similar characters. The previous study also revealed a similar pattern: with increasing age, there was a development in the top-down component of attentional systems [33]. Therefore, along with the top-down recognition skills, thus the influence of orthographic specificity for Grade 5 diminishes.

To reiterate, orthographic specificity could be defined as the ability to build specific lexical items based on minimal orthographic differences. In our orthographic specificity task, we had a practice phase, a learning phase, and a test phase. In the test stage, each slide contains two target characters that have similar structures yet different semantic radicals, one familiar control word and a familiar filler word [e. g., "泊bo2" (target 1), "伯bo2" (target 2), "顶ding3" (filler word), and "秋qiu1" (filler word); "泊bo2" (target 1), "伯bo2" (target 2), "构gou4" (filler word), and "放fang4" (filler word).] Target 1 and target 2 have to be identified through corresponding pictures respectively. Children got 1 point for one correct answer. In view of the features of Chinese characters, we assume orthographic specificity as the fundamental word identification skill. Children with higher orthographic specificity ability perform better on word recognition. The result has verified the hypothesis.

To sum up, orthographic specificity provided a unique variance explaining word reading only in grade 3 and grade 4. For children in grade 5, with their cognitive skills developing [33, 34], orthographic specificity might not exert an obvious effect on their performance in word reading.

2) Orthographic awareness mediates orthographic specificity to word reading

In general, a given variable can be defined as a mediator "to the extent that it accounts for the relation between the predictor and the criterion" [35]. In the present study, we found that orthographic awareness served as a mediator in the relation between orthographic specificity and word reading. In other words, orthographic specificity affects word reading through orthographic awareness. Our results showed that the mediation pattern in that relationship is partial, for it occurs when the direct effect of orthographic specificity on word reading decreases nontrivially but not to zero with the addition of potential mediator orthographic awareness. That is to say, orthographic specificity can still contribute unique variance to word reading with the addition of orthographic awareness. The online orthography task will become more accurate through computer and program algorithms, and the effectiveness of training will be increasingly improved. Different from offline orthography tasks, there are fewer training opportunities and materials, and there is no adjustment at any time according to the individual learner's own situation, online orthography tasks will match the corresponding exercises according to the learning situation of the learners in real time, consolidate the weak points and regularly review the knowledge that has already been learned. During this process, orthographic awareness is also cultivated and improved, thus the effect of orthographic specificity on word reading is further enhanced.

In the current study, it is found that orthographic awareness can predict orthographic specificity. In addition, improvement in the ability to build up orthographic representation knowledge on the basis of minor orthographic distinctions (i.e., orthographic specificity) will be conducive to fostering orthographic awareness, which in turn influences word reading. Consequently, it can be said, the greater the influence of orthographic awareness is, the greater the influence of orthographic specificity on word reading is.

It is known that most previous research investigated the role of orthographic awareness through its predictive power in word reading [36–38]. According to Ho *et al.* [36], orthographic awareness can predict word reading in preschool period. It predicts concurrent Chinese reading for 7-year-old children [37] and 9-11-year-old children [38]. Besides that, there are studies indirectly proving the importance of orthographic awareness in word reading. To examine the cognitive profile of Chinese developmental dyslexia, via a number of literacy and cognitive tasks, it is found that orthographic-related difficulties may be the crux of the problem in Chinese developmental dyslexia. The lack of orthographic awareness might engender impairments in Chinese children with developmental dyslexia [39–41].

Literature persists that orthographic awareness plays an important role in word reading [37, 38, 42]. And if we wonder why orthographic awareness mediates orthographic specificity to word reading, we need to know the correlation between orthographic specificity and orthographic awareness, and how this correlation changes when the relationship is still salient between orthographic specificity and word reading.

Orthographic specificity can be viewed as the sensitivity of orthographic representations. Whereas, orthographic awareness is the ability to visually recognize legal symbols and patterns within words in print. Orthographic awareness can also be referred one component of print knowledge. It is the understanding of the print conventions or knowledge of word spelling [43]. This implicit knowledge needs to be trained to become explicit [44] by showing rules to the learners. The stroke configuration assessed in the orthographic specificity task included the knowledge of legal components of characters (stroke, radical, and whole character), and the positional and functional constraints of radicals. With the help of the training, minor orthographic differences (i.e., orthographic specificity) between the word pairs (e.g., "羚(antelope)" and "铃(bell)") can be detected among the language beginners.

The goal of our study is to test how the orthographic representation knowledge could be built up through online orthographic specificity training. The online training procedure attempted to enhance learners' sensitivity of orthographic representations to figure out the pattern of linguistic system based upon the stroke configuration of the Chinese characters. During the process, the participants learned new word pairs (e.g., "秒<second>" and "妙<wonderful>") with subtle orthographic differences in Chinese (the two characters of a pair are Chinese homophones that are orthographically similar but have fine distinctions in the orthographic feature). After several trials of such sensitivity training, the learners' implicit orthographic representations became more specified in the learning process. Consequently, in our study, children with higher specified orthographic representations performed better in the online orthographic specificity task.

Analogously, like the relation between phonological awareness and phonological specificity, as phonological awareness develops with age, the sense of subtle sensitivity of phonological representations is also strengthened [5]. Hence, in terms of the correlation between orthographic awareness and orthographic specificity, orthographic awareness can predict orthographic specificity, while exposure to word pairs involving minimal orthographic contrasts (i.e., orthographic specificity) affects orthographic awareness, which in turn predicts word reading. Our study is the first attempt to show this pattern of mediation relationship.

In the current study, results show that the better children performed in the online orthographic specificity task, the greater orthographic awareness they have. In addition, greater orthographic awareness is more conducive to wording reading. Hence, in the online orthographic specificity task, differing from the previous research in phonological specificity and phonological awareness tasks [16], it is believed that orthographic awareness alone is not the only factor contributing to children's word reading. Both orthographic specificity and orthographic awareness work together as important individual difference factors in word reading when Chinese children begin to master reading skills.

3) Developmental trend of orthographic specificity among Chinese children

The variance orthographic specificity contributed increases from grade 3 to grade 4 and decreases from grade 4 to grade 5. In the experiment, we have tested working memory (WM), phonological awareness (PA), orthographic awareness (OA) and orthographic specificity (OS). For Grade 3, orthographic awareness explained 2.1% of total variance, and the orthographic specificity provided an additional 1.8% of variance explaining word reading. In comparison, for grade 4, orthographic awareness explained 0.8% of total variance, and the orthographic specificity provided an additional 3.2% variance explaining word reading. For grade 5, orthographic awareness explained 0.8%, and orthographic specificity 1.6% of total variance. We can see orthographic specificity provided the most explaining power to word reading in grade 4. The result is in line with previous studies. Berninger *et al.* [45] suggested that children's growth of orthographic awareness is steeper in the younger cohorts (grade one to four) than in the older cohorts (grade three to six) in English-speaking children from grade 1 to 6. More recently, a more relevant study conducted by Guan *et al.* [27] also claimed the recognition accuracy in Chinese increased sharply from grade 3 to grade 4 but plateaued afterwards.

However, why does the contribution of orthographic specificity decrease in grade 5? First, children of grade 5 are senior graders and might reach to the ceiling effects in some measure. Second, the mental abilities and literacy skills of these children, such as global processing and top-down recognition skills, might develop at a rapid pace [34]. Therefore, we can say that their level and speed of processing the character information at the global scope surpass those of local scope of processing. As a result, orthographic specificity does not show an obvious effect on word reading performance for children in grade 5, but their other abilities improved.

We could infer from our meaning analyses that orthographic specificity is learnable and its effect on word reading changes as language ability grows. According to the lexical restructuring hypothesis [12], how phonological specificity develops has been mentioned: given young children's limited vocabulary, it is unnecessary for them to differentiate words based on lexical specificity. While as their vocabulary expands, representations of words must be stored with increasing detail in order to differentiate similar words. Like phonological specificity, when children receive orthographic specificity training including learning orthographic similar word pairs, they will show improvements with respect to orthographic awareness. As orthographic awareness is improved, children will have a stronger sense of the subtle sensitivity of orthographic representations. Like what is mentioned, in our study, the participants have learned new characters in pairs, suggesting that their orthographic representation became more specified (such as "羚(antelope)" and "铃(bell)") in the process. As a result, children with highly specified orthographic representations perform better on orthographic specificity test. For children from grade 3 to grade 5, their mental abilities and literacy skills are developing at a high speed. According to the stage of learning theory, children in grade 3 and grade 4 are in lower level of word literacy development, while children in grade 5 are in higher level of word literacy development. For example, for children in grade 5, their level and speed of processing the character information at the global scope surpass those of local scope of processing. Hence, in the present study their orthographic specificity has no significant impact on word reading. While as to children in grade 4, they are in lower level of word literacy development. In addition, according to Schadler and Thissen [33], the level of word reading of children in grade 4 has reached a peak. Therefore, our study shows that the orthographic specificity makes more contribution to word reading as children are in grade 4.

The study results suggest the future research should develop a more feasible developmental reading-writing model. This could be achieved by adopting a more reliable assessment. For instance, the future measure for data collection should be more dynamic by providing instant feedbacks for recurrent learning and progress monitoring. Previous research has adopted simple tasks like word naming or lexical decision to discover the relationship among subcomponent skills in reading in the early years of literacy acquisition. For instance, it was proved that the average typically developing pupils are faster to respond to words with pronunciations that follow the rules for the spelling-sound mappings of its constituent graphemes in English [46, 47] or that are consistent with pronunciation of similar-looking words [42, 46–49]. Few studies have combined subject-level variables (such as readers' PA and OA) with item-level variables (such as frequency and other orthographic or phonological properties of words or characters) to see if and how these two levels of variables interact. Guan *et al.* [27] examined how word recognition changed between grades 1 and 6 in both L1 Chinese and L2 English. By means of the mixed linear model, Guan suggested similar and generalizable patterns of word recognition development across languages, i.e., as grade level increases, the recognition accuracy increases and RT speeds up. In particular, the recognition accuracy increased sharply from Grade 3 to Grade 4 but plateaued afterward. Therefore, future study could continuously take this mixed-linear approach to build a more reliable dynamic measure for word learning.

4) Limitations

Some limitations of the study should be acknowledged at this point. First, in this study, orthographic specificity task could not be operationalized among lower graders such as Grade 1 and 2 due to the lack of practice in using computers of this age group. Other studies have successfully assessed some Chinese word knowledge and recognition skills using computerized measures [27, 28]. Another limitation of the current study is that we failed to follow these children in longitudinal designs across years. Future studies using longitudinal follow-ups could show language development and possible static and dynamic performance of this orthographic specificity benefits in these children, which would be preferred over the one-time-measurements in the current study. It would also be interesting to compare the differences between the monolingual and bilingual performance in both the Chinese and English orthographic specificity. Moreover, some artificial language using pseudo-word tasks instead of real-word tasks might be used with these children or even younger ones to show a more fundamental mechanism of orthographic specificity in word reading.

We should also be cautious about the feasibility of the orthographic specificity task for lower grade students and the cross-sectional design conducted in the current study. For future research, a longitudinal design with a more reliable test-retest dynamic assessment should be developed to capture the dynamic developmental trends of the Chinese word reading in online learning environment.

V. Conclusion

In our study, orthographic specificity provides an additional contribution to word reading. Meanwhile, orthographic awareness plays a mediation role in enhancing the relationship between orthographic specificity and word reading, but this pattern holds water only for lower graders. There are developmental differences between children in grade 3, 4 and grade 5. We expect to develop a more feasible longitudinal assessment tool that could better capture the developmental trajectory of the reading curves prescribed by Davis (2021).

Along with previous studies, our research has demonstrated the dominant role of orthographic specificity in word reading. We have highlighted that orthographic specificity uniquely contributes to explaining variance in word reading, with its impact more pronounced in Grade 3 and 4, but not in Grade 5. It was also found that orthographic awareness partially mediates the relationship between orthographic specificity and word reading, enhancing the impact of orthographic specificity. Finally, the contribution of orthographic specificity increased from Grade 3 to Grade 4 but decreased in Grade 5. This trend reflects the developmental changes in cognitive the literacy skills.

The impact of the current study on the literature is worthwhile regarding modeling the reading components including the features of the orthographic specificity task in its dynamic assessment format and its relationship with word reading and orthographic awareness. We hope our findings could have captured a clearer reading-writing relationship for high quality. Lexical distinctiveness in word learning. Meanwhile, future online dynamic measures of word learning should also be controlled by the learners' characteristics, such as readers' awareness of sub-lexical skills like orthographic awareness and phonological awareness.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, CQG & XC; Formal analysis, LH & ZW; Resources, CQG; Supervision, CQG; Writing-original draft CQG; Writing-review & editing, CQG, WZ, LH & ZW. All authors have read and agreed to the published version of the manuscript.

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