Reading and Writing
https://doi.org/10.1007/s11145-025-10739-4

What is Chinese orthographic learning via self-teaching? A systematic review and meta-analysis

Xintong Xu[1] · **Sihui Echo Ke**[1]

Received: 14 May 2025 / Accepted: 16 November 2025

Abstract

Guided by the self-teaching hypothesis, this study examined Chinese orthographic learning through a systematic review and meta-analysis, covering 13 empirical studies with 26 independent samples ($N=1403$) from 1995 to 2024. Orthographic learning outcomes, resulting from the influence of word-internal and word-external factors (e.g., context, orthographic complexity, Zhuyin, phonetic radicals, and semantic radicals), were examined via the effect sizes of Hedges' *g*. This research also explored the potential moderating effects of participants' age, the method of phonological recoding (reading aloud vs reading silently vs reading with eye tracking), and the presentation of target characters (single-character words vs two-character words vs two-character words including two target characters vs three-character phrases vs mixed). Results revealed several key findings: (1) Chinese orthographic learning via self-teaching could be defined as a development process where learners acquire and internalize the orthographic representations of Chinese characters through independent reading, leveraging phonological recoding and sublexical semantic cues. (2) Both phonetic radicals and semantic radicals demonstrated significant effects on orthographic learning, with phonetic radicals showing a larger effect size. (3) Moderator analyses on the semantic radical effect revealed no significant moderating effects of participants' age ($z=-0.22$, $p=0.412$). However, significant moderating effects were observed for the method of phonological recoding ($z=2.37$, $p=0.018$) and the presentation of target characters ($z=2.31$, $p=0.021$). These findings contribute to the evaluation of paradigms for conducting Chinese self-teaching research and provide directions for future investigations.

Keywords Self-teaching · Orthographic learning · Chinese · Systematic review

✉ Sihui Echo Ke
sihui.ke@polyu.edu.hk; echoecho.ke@gmail.com

Xintong Xu
xintong.xu@connect.polyu.hk

[1] Department of Language Science and Technology, The Hong Kong Polytechnic University, Hung Hom Bay Campus, 8 Hung Lok Road, Hung Hom, Kowloon, Hong Kong

Published online: 04 December 2025

Introduction

Orthographic learning refers to the acquisition and development of knowledge about written word forms, encompassing both word-specific orthographic representations and general writing system patterns (Siegel et al., 1995). With practice and experience, learners accumulate a substantial repertoire of written word forms and develop their own mental lexicon, gradually becoming fluent readers (Share, 2008). Therefore, orthographic learning is fundamentally important for reading and literacy acquisition. For example, if English learners master generalizable phoneme-grapheme correspondence rules, morphology, and etymological systems, they can easily decode and spell almost all words (Bowers & Bowers, 2017). As a morpho-syllabic language, Chinese demonstrates less consistent grapheme-phoneme correspondence rules, with fewer than 40% of Chinese characters containing phonetic components directly linked to pronunciation (Leong et al., 2011). However, Chinese characters exhibit a stronger connection between form and meaning, particularly as transparent semantic radicals are more closely tied to orthographic codes (Tong et al., 2017). For instance, characters containing the radical "木" (wood) are typically associated with trees or wood-related meanings, such as in "树" (tree), "枫" (maple), and "柳" (willow). Given the fundamental differences between alphabetic and non-alphabetic languages, it is crucial to assess the applicability of the prominent orthographic learning theory—self-teaching hypothesis—to the early reading development of Chinese learners.

Different from existing reviews of orthographic learning via self-teaching that are mainly based on studies of alphabetic languages (e.g., Li & Wang, 2023; Nation & Castles, 2017; Share, 2008), this research links self-teaching with the intrinsic characteristics of Chinese as a morphosyllabic language. Specifically, it examines unique internal and external word factors in Chinese self-teaching, including Zhuyin/Pinyin, phonetic radicals, and semantic radicals, through a combined approach of systematic review and meta-analysis. The findings of this research will not only provide insights into the mechanisms of Chinese orthographic learning but also inform the development of targeted instructional strategies for educators, addressing the increasing global demand for effective approaches to Chinese language acquisition.

Theoretical background: the self-teaching hypothesis

The Self-Teaching Hypothesis, first introduced by Jorm and Share (1983), is widely regarded as one of the most influential theories in reading development, particularly in relation to orthographic learning. According to this hypothesis, self-teaching is a process through which learners independently acquire new words and orthographic patterns during reading, without requiring explicit instruction (Share, 1995). Subsequently, Share (1999) established a foundational paradigm for self-teaching research. Typically, participants are required to independently read short texts containing target pseudowords that are exposed multiple times. Following the independent reading task, participants complete orthographic choice tasks, spelling tests, and other assessments (e.g., naming tasks) to enable researchers to evaluate the effects of orthographic learning via self-teaching. In addition to employing behavioral tasks to assess

the outcomes of orthographic learning, the application of eye-tracking technology to investigate the learning process has gained increasing popularity across various languages in recent years (e.g., Ginestet et al., 2021; Han et al., 2024; Li, 2020b). As proposed by Nation and Castles (2017), eye movement data can provide not only a continuous index of processing time and a partial, incremental estimate of learning but also demonstrate strong ecological validity. For example, as new words become more familiar, learners typically exhibit shorter fixation durations on these words (e.g., He, 2021; Li, 2020b; Li et al., 2019; Xiang, 2023).

The self-teaching hypothesis is characterized by four key features: item-based learning, where each word undergoes a progression from unfamiliarity to familiarity for the reader, with different words potentially existing at various stages of development simultaneously; lexicalization, where phonological recoding is viewed as a developmental process, and as word recognition becomes modularized, contextual support is no longer necessary; early onset, which suggests that even rudimentary decoding skills can suffice to establish initial or partial orthographic representations; and phonological-primary, orthographic-secondary, which posits that while phonological recoding provides the opportunity for self-teaching, it does not guarantee that orthographic learning will occur (Share, 2008).

Over the past three decades, the self-teaching hypothesis has been validated across a wide range of languages, including English, Spanish, Hebrew, French, Dutch, and Chinese, thereby establishing itself as a universal theory (Li & Wang, 2023). Moreover, self-teaching exhibits different characteristics among various types of language learners. For example, due to adults' more extensive prior orthographic knowledge, they are more adept at utilizing lexicalized decoding than children (Lien, 2017). Biliterate children exhibit a partial advantage in initial decoding and orthographic learning relative to their monolingual counterparts (Schwartz et al., 2014). While substantial experimental research has been conducted within the self-teaching framework, research examining its application to Chinese reading, particularly among different types of learners (e.g., adults vs children, dyslexic vs typically developing, monolingual vs multilingual), remains conspicuously limited (e.g., Liu, 2018).

Three self-teaching mechanisms: phonological recoding, context, and spelling

Phonological recoding, spelling, and context are three self-teaching mechanisms that enable learners to develop the orthographic knowledge necessary for skilled reading (Share, 2008). Tucker et al. (2016) further investigated the mechanisms underlying orthographic learning within the self-teaching paradigm and concluded that orthographic learning is primarily driven by a decoding-based self-teaching mechanism. This mechanism begins with word-specific learning and subsequently enables the transfer of orthographic knowledge to both morphologically related words and orthographically similar words.

Phonological recoding

Phonological recoding (or decoding), defined as the ability to translate unfamiliar printed words into their corresponding spoken forms, is a fundamental mechanism

in the acquisition of orthographic representations (Share, 1995, 2008). By directing attention to orthographic details and facilitating print-to-sound mappings, this process supports the development of precise and fully unitized orthographic representations, which are essential for achieving rapid and automatized word recognition (Shahar-Yames & Share, 2008). To examine the role of phonological recoding, Share (1999) conducted four experiments in Hebrew to eliminate the influence of pure visual exposure and other non-phonological factors. The results confirmed that word-specific orthographic representations are primarily acquired through self-teaching opportunities that occur during the phonological recoding of novel words. A computational model based on the dual-route cascaded model (ST-DRC) further demonstrates that self-teaching effectively enables the learning of monosyllabic words using basic grapheme-phoneme rules suitable for beginning readers (Pritchard et al., 2018). Subsequently, an increasing number of studies conducted in alphabetic languages have validated the critical role of phonological recoding in orthographic learning (e.g., Chrabaszcz et al., 2023). It is noteworthy that phonological recoding is not limited to reading aloud. Some studies indicate that self-teaching occurs through phonological recoding even during silent reading (e.g., Bowey & Muller, 2005; Bowey & Miller, 2007; Ketabi et al., 2012). However, reading aloud currently appears to result in better recognition and recall of pseudowords (e.g., Chrabaszcz et al., 2023; Lien, 2017).

Unlike alphabetic writing systems, where each letter contributes to a word's pronunciation, the pronunciation of Chinese characters is primarily determined by the phonetic radical—a component of Chinese semantic-phonetic compound characters that provides word-internal phonological cues (Ho & Bryant, 1997). For example, the phonetic radical "青 (qīng)" indicates pronunciation in "清 (qīng)". In addition to these word-internal cues, Chinese also employs word-external phonological coding systems, such as Pinyin (i.e., a phonological coding system that uses Roman letters and tone markings to represent phonemes in spoken Chinese) and Zhuyin (i.e., a phonetic script used primarily in Taiwan, composed of elements derived from ancient Chinese characters). For example, the Zhuyin symbols for "青" and "清" are "ㄑ ㄧ ㄥ". Accordingly, it is crucial to conduct a meta-analysis to examine the extent to which these three potential types of Chinese (Mandarin) phonological recoding—phonetic radicals, Pinyin, and Zhuyin—contribute to orthographic learning.

Context

Contextual information plays a supplementary role in the self-teaching process by compensating for partial or incomplete decoding due to limited skills or specific word properties (Li & Wang, 2023; Share, 1995). However, Share (2008) noted that while context can facilitate identify hard-to-decode words, it may lead learners to over-rely on contextual cues, neglecting orthographic details. A considerable body of research in English has examined the impact of contextual information on orthographic learning, focusing on variables such as the presence or absence of context in reading materials, the use of scrambled text, and whether helpful context is provided (e.g., Cunningham, 2006; Ricketts et al., 2008; Wang et al., 2011). For example, Wang et al. (2011) found that context had no significant influence on regular items but facilitated learning of irregular items, reinforcing the secondary role of context

in English orthographic learning. Although Chinese characters contain semantic cues within their structure, further investigation is needed to determine if contextual information similarly affects orthographic learning in Chinese.

Spelling

Spelling is believed to contribute more effectively to orthographic learning than decoding, as it requires more attention to orthographic details, which demands greater time and cognitive effort (Shahar-Yames & Share, 2008). This view is supported by empirical evidence. For example, Conrad et al. (2019) found that English-speaking children in the spelling group outperformed those in the reading group in both naming tasks and spelling production tasks. Similarly, Ouellette (2010) reported comparable findings, further highlighting the facilitative role of spelling in English orthographic learning.

However, the basic graphic unit in Chinese differs significantly from that in alphabetic languages. Taking English as an example, the basic graphic unit is the grapheme, which represents the smallest unit of written language corresponding to sound (Ehri, 2013). In contrast, the basic graphic unit in Chinese comprises square-shaped characters made up of strokes that are neither phonetic nor inherently meaningful (Shu et al., 2003). Additionally, there is no direct correspondence between the written form and pronunciation of Chinese characters. The language also includes homophones and polyphonic characters, such as "行" (pronounced as xíng or háng), where "xíng" can also be represented by other characters like "形" or "型," further increasing the complexity of learning Chinese orthography. In essence, spelling English words enhances learners' sensitivity to grapheme-phoneme correspondences, thereby facilitating orthographic learning. By comparison, the method commonly employed to measure Chinese spelling through dictation prioritizes the processing of visual information. Therefore, investigating whether a spelling mechanism exists in Chinese, and whether it manifests through character writing or Pinyin writing, is essential for evaluating the applicability of the self-teaching hypothesis to Chinese orthographic learning.

In summary, the unique characteristics of Chinese orthography, including its reliance on visual processing, the complexity of characters, and the interplay of word-internal and word-external factors, necessitate further exploration into how self-teaching operates in non-alphabetic languages.

Potential underlying mechanisms of Chinese self-teaching

As outlined earlier, Chinese characters serve as the fundamental units of the Chinese writing system. These characters are composed of strokes or stroke patterns and can be categorized into simple characters and compound characters. Notably, over 80% of Chinese characters fall into the category of compound characters, which are typically composed of a phonetic radical and a semantic radical (Shu et al., 2003). The regular phonetic radical provides phonological cues about the character's pronunciation, while the transparent semantic radical offers clues about the character's semantic category (Ho et al., 2003). According to Shu et al. (2003), semantically

transparent characters account for approximately 50–70% of the characters learned by primary school students from grades one to six. When factoring in the frequency of character usage, semantically transparent characters comprise about 30–50% of the total.

As the semantic radical is a unique orthographic component directly associated with meaning, its role in Chinese orthographic learning has sparked significant academic interest and debate (e.g., Li, 2020b; Li et al., 2021; Han et al., 2024). For example, building on the self-teaching hypothesis, Li et al. (2021) proposed a potential mechanism of semantic decoding in Chinese. Similar to phonological recoding, this mechanism is believed to support orthographic learning by linking meaning to orthography. However, their behavioral experiments with native-speaking children revealed that, despite a positive trend in the data, semantic decoding did not appear to function as a self-teaching mechanism or even as a compensatory mechanism to phonological recoding in facilitating orthographic learning. In contrast, Han et al. (2024) conducted a study with adult Uyghur L2 Chinese learners and found that although these learners were unable to complete phonological decoding, they could rapidly activate the lexical-semantic pathway while swiftly suppressing the phonological decoding process. Conversely, when phonological decoding was successful, they were able to rapidly activate the lexical-phonological-semantic pathway.

Given the various controversies in previous studies, there is a need for exploring potential new mechanisms of self-teaching in the context of the Chinese language. This will represent an important step toward achieving a globally inclusive, non-ethnocentric approach to reading across diverse linguistic features (Share, 2025).

The present study

Over the past decade, there has been a notable increase in empirical studies investigating Chinese orthographic learning within the framework of the self-teaching paradigm (e.g., Li et al., 2016; Liu, 2018; Xiang, 2023). However, no meta-analysis has been conducted to systematically and comprehensively examine the Chinese self-teaching hypothesis. Specifically, there remains a lack of clarity regarding the conceptualization of the Chinese self-teaching hypothesis, the operationalization of its research paradigm, and the extent to which various factors influence Chinese orthographic learning. In addition, with the continuous refinement of experimental designs and the advancement of psycholinguistic methodologies, new questions have emerged. For instance, does the mode of presenting pseudowords influence test outcomes? Should eye-tracking technology be incorporated to further elucidate?

This research involves a comprehensive meta-analytic review to integrate the conceptual and methodological features of the self-teaching hypothesis with the linguistic characteristics of Chinese. Its goal is to deepen the understanding of Chinese orthographic learning via self-teaching by addressing the following three research questions:

1. How has Chinese orthographic learning via self-teaching been defined and operationalized in the selected studies?

2. To what extent is orthographic learning affected by word-internal and word-external factors (e.g., context, orthographic complexity, Zhuyin/Pinyin, phonetic radicals, and semantic radicals)?
3. Are there any additional moderating effects of age, the method of phonological recoding (reading aloud vs reading silently vs reading with eye tracking), and the presentation of target characters (single-character words vs two-character words vs two-character words including two target characters vs three-character phrases vs mixed) on Chinese orthographic learning?

Methods

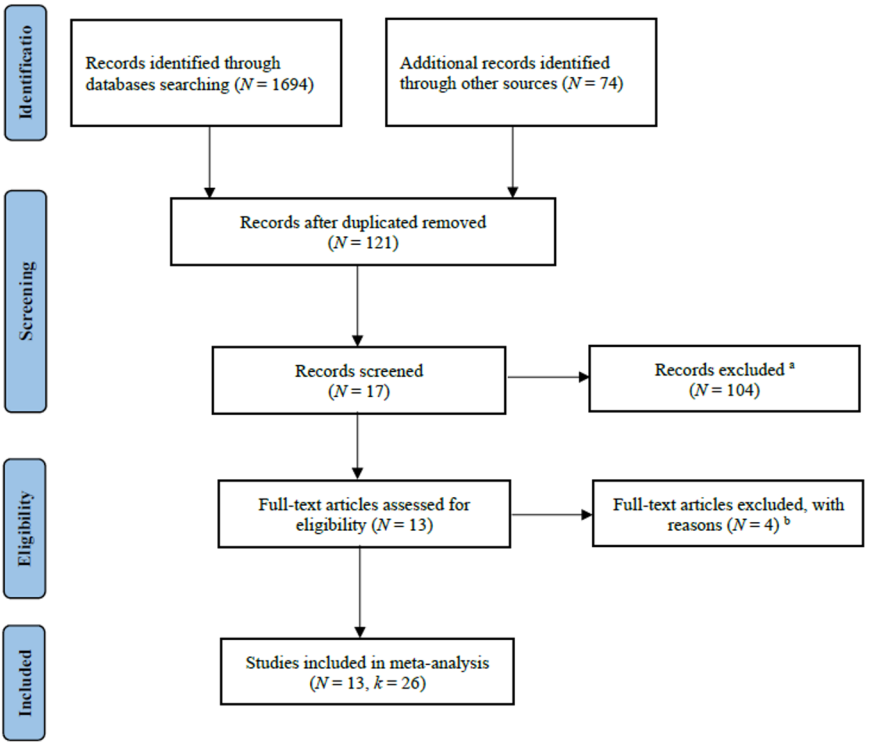
Inclusion criteria

This review included primary research that:

- Was written in English or Chinese between 1995 and 2024.
- Cited or extended the self-teaching hypothesis proposed by Share (1995).
- Included both the independent learning phase and the post-test phase.
- Involved participants who were either Chinese native speakers or L2 Chinese learners, without any learning or reading disabilities.
- Reported measurements of Chinese orthographic learning outcomes (e.g., orthographic choice, character writing test).
- Provided sample size and data necessary for calculating Hedges'g, including effect sizes, means, and standard deviations.

Literature search

The literature search was conducted in three phases. First, we used the terms "self-teaching" AND "orthographic learning" to search in Google Scholar and Web of Science. Second, the terms "自学假说 (zìxué jiǎshuō, self-teaching)" AND "词汇隐性习得 (cíhuì yǐnxìng xídé, incidental vocabulary acquisition)" were searched in the China National Knowledge Infrastructure (CNKI). Third, references from recent systematic review studies were examined (e.g., Li & Wang, 2023). As of December 1, 2024, a total of 1694 studies were identified. Finally, after screening with the inclusion criteria, 13 studies with 26 independent experiments were selected for subsequent analysis (see Fig. 1). Among these, six studies were peer-reviewed articles, five were doctoral dissertations, one was a master's thesis, and one was a preprint paper. All selected studies investigating the effects of different variables on orthographic learning employed random assignment methods. Only one study (i.e., Liu, 2018) reported self-teaching reliability information. We also examined potential publication bias by analyzing the funnel plots (see Figs. 1, 2, 3 and 4 in Online Appendix 2), yet did not find any noticeable bias.



Notes. a. Studies focused on English or other languages orthographic learning via self-teaching were excluded.
b. Studies focused on Chinese orthographic learning but did not include independent self-teaching phase, cite self-teaching hypothesis, or provide orthographic learning data were excluded.

Fig. 1 Literature search and study screening

Coding of effect sizes and moderator variables in meta-analysis

To explore the impact of word internal and external factors on orthographic learning, we included studies that examined the effects of context, orthographic complexity (i.e., the number of strokes), Zhuyin/Pinyin, phonetic radicals, or semantic radicals on orthographic learning. Li (2020a) was excluded from the meta-analysis because it focused on the predictive role of children's vocabulary knowledge in orthographic learning. Given the typically small sample sizes of these studies, we calculated Hedges' g, 95% confidence intervals (CI), variance, and standard errors using the means, standard deviations, sample sizes, and other convertible statistics provided in each experiment. Additionally, due to the complexity of Chinese character visual forms, this study coded orthographic choice and character writing as distinct variables. For studies that included repeated post-tests, only data from the immediate test were recorded. In studies conducted in both interference and normal contexts (Li et al., 2020b), only data from the normal context were recorded.

Moderator variables were primarily coded based on three factors: age, the methods of phonological recoding, and the presentation of target characters. Age was represented by the average age reported for each sample. The methods of phonological recoding were categorized into silent reading (e.g., Li et al., 2021), reading aloud (e.g., Liu, 2018), and reading with eye tracking (e.g., Li, 2020b). Since only one experiment in Li et al. (2021) employed the silent reading method, we removed it from subsequent moderator analysis and meta-regression.

Given that lexical compounding is the predominant method of word formation in Chinese, and that two-character and multi-character words constitute over 90% of the vocabulary in modern Chinese (Huang et al., 2023; Tong et al., 2017), the question of how to present novel words in reading materials through various lexical forms is a distinctive issue in Chinese. Current empirical studies on Chinese orthographic learning through self-teaching address this issue with diverse considerations in the design of reading materials. However, a consensus on which presentation method is the most effective has yet to be established. The presentation of target characters in this meta-analysis was categorized into four types. The first type is single-character words, which refer to the target word appearing as a single character, such as 袜 in Xiang (2023). The second type is two-character words, which refer to the target word presented in a two-character combination, where the other character is a real word, such as 台 鲋 in Ho (2014). Given that approximately 70% of vocabulary in Chinese consists of two-character words (Huang et al., 2023), presenting target characters within two-character words closely resembles natural reading conditions in Chinese. The third type is two-character words including two target characters, which indicate that both target words are combined into a single two-character word, such as 虾 蚹 in Li et al. (2020b). The fourth type is three-character phrases, which mean that the target word is presented as part of a three-character phrase, with the other two characters being real words, for example, 电 饧 机 in Li et al. (2019).

All coding and analyses in this study were conducted using Comprehensive Meta-Analysis (CMA) software Version 3.0 (https://zh.meta-analysis.com/) and Microsoft Excel. Complete coding details are available in the Appendix.

Meta-analytic procedures

Due to the lack of studies examining Pinyin as a variable and reporting its effect size, this study focused on five key variables and organized the samples into five distinct subgroups: (1) context, (2) orthographic complexity, (3) Zhuyin, (4) phonetic radicals, and (5) semantic radicals. In Table 1, we presented the sample size and availability of post-test data for each subgroup. According to Valentine et al. (2010), even with only two studies, a meta-analysis can detect medium effect sizes if the sample size is sufficient ($n \geq 30$ per study). Therefore, we analyzed the impact of word-internal and external factors on orthographic learning within each subgroup, excluding character writing in the context and orthographic complexity subgroups.

Before proceeding with the analysis, we identified and removed outliers using the criteria outlined by Viechtbauer and Cheung (2010) (absolute standardized residuals > 3.0). Specifically, two outliers from Li et al. (2022) and the third experiment from Ho (2014) were excluded from the semantic radical subgroup, which had stan-

Table 1 Subgroup posttest data overview

Study subgroups	Sample size	Posttest	
		Orthographic choice	Character writing
Context			
Liu (2018-2) novice	25	N/A	N/A
Liu (2018-2) intermediate	31	N/A	N/A
Liu (2018-2) advanced	16	N/A	N/A
Li et al. (2020b)	67	√	√
Xiang (2023-2)	120	√	N/A
Orthographic complexity			
He (2021-1-1)	44	√	N/A
He (2021-1-2)	40	√	N/A
Zhuyin			
Ho (2014-1)	40	√	√
Li et al. (2018) Zhuyin	79	√	√
Phonetic radical			
Ho (2014-2)	22	√	√
Liu (2018-1)	45	√	N/A
Li et al. (2018) phonetic radicals	79	√	√
Li et al. (2020b)	64	√	√
Li et al. (2021)	92	√	√
Li et al. (2022)	34	√	√
Li (2020b)	67	√	√
Semantic radical			
Ho (2014-4)	20	√	√
Li et al. (2019-1)	25	√	√
Li et al. (2019-2)	16	√	√
Li et al. (2020a)	22	√	√
He (2021-3)	40	√	N/A
Li et al. (2021)	92	√	√
Li et al. (2022)	34	√	√
Li et al. (2020b)	67	√	√
Liu (2018-1)	45	√	N/A
He (2021-4-2)	69	√	N/A
He (2021-4-1)	72	√	N/A
Xiang (2023-1)	113	√	N/A
Xiang (2023-2)	120	√	N/A
Ho (2014-3)	20	√	√
Li (2020b)	64	√	√

dardized residuals of 4.54 and 3.28, respectively. Following the guidance of Ke et al. (2021) and Borenstein et al. (2009), considering the characteristics of the published literature, we employed random-effects models rather than fixed-effect models for our analyses. Additionally, to examine the variability of effect sizes between primary studies, we conducted a heterogeneity test.

Results

In this section, we first summarized the conceptualization and operationalization of Chinese orthographic learning through self-teaching. Next, we presented group findings on the impact of word-internal and word-external factors on orthographic learning, assessed through orthographic choice and character writing tests. Finally, we analyzed the moderator effects related to age, the presentation of target characters, and the methods of phonological recoding.

Definitions and operationalizations of Chinese orthographic learning in selected studies

To address RQ1, we initially reviewed the main characteristics of 13 studies comprising 26 independent samples (N=1403). The majority of the studies focused on native Chinese speakers, with only one study examining L2 Chinese learners (i.e., Liu, 2018), comprising European Americans, Hispanic Americans, and Asian Americans. Additionally, eight studies targeted children, with a mean age ranging from 8 to 10 years old (e.g., Ho, 2014; Li et al., 2016; 2022), while five focused on adults, with a mean age ranging from 19 to 26 years old (e.g., He, 2021; Liu, 2018; Xiang, 2023). Sample sizes were generally larger in studies involving native Chinese-speaking adults, with the largest sample consisting of 120 participants (Xiang, 2023). Other studies had sample sizes below 100, with the smallest being 16 participants (Li et al., 2019). Regarding research locations, six studies were conducted in Mainland China (e.g., He, 2021; Li et al., 2016, 2020a), four in Taiwan (e.g., Ho, 2014; Li et al., 2018, 2021), and three in the United States and Australia (e.g., Li, 2020b; Li et al., 2019; Liu, 2018).

Secondly, we compiled definitions of Chinese orthographic learning via self-teaching from existing perspectives. Ho (2014) defined *orthographic learning* as "the process by which children commit word forms to memory" (p. ii), while Liu (2018) described it as "the transition from mapping printed words with their oral forms to recognizing them as individual lexical units" (p. 11). Additionally, Li et al. (2022) defined *orthographic learning via self-teaching* as a process where "children can teach themselves new written words by independently reading aloud texts" (p. 20). However, to the best of our knowledge, a clear definition of Chinese orthographic learning via self-teaching has not been established. Existing research does offer valuable insights for conceptualizing this process. For example, Ho (2014) suggested that "the internal structural properties of Chinese characters, along with sublexical phonology and semantics, allow developing readers to self-teach Chinese orthographic forms" (p. ii). Drawing from previous studies, we define *Chinese orthographic learning via self-teaching* as a development process by which learners acquire and internalize the orthographic representations of Chinese characters through independent reading, leveraging phonological recoding and sublexical semantic cues.

Thirdly, we examined the methodological characteristics of research on Chinese self-teaching (see in Table 2). In the pre-test phase, six studies opted not to conduct background assessments, as participants shared similar ages, educational stages, and recent school Chinese test results, indicating comparable linguistic abilities (e.g., Li,

Table 2 Typical research methods in Chinese orthographic learning via self-teaching

Pre-test phase	Orthographic learning phase	Posttest phase
Character recognition ($k=7$)	Reading aloud ($k=8$)	Orthographic choice ($k=13$)
Radical knowledge ($k=2$)	Reading with eye tracking ($k=4$)	Character writing ($k=10$)
Spoken vocabulary ($k=1$)	Read silently ($k=1$)	Semantic related task ($k=7$)
Non-verbal intelligence ($k=1$)		Decoding recall ($k=1$)
N/A ($k=6$)		

k=the number of studies

2020b; Li et al., 2016; Xiang, 2023). More researchers adopted the character recognition task to control for learners' general character reading ability (e.g., Li et al., 2020a, 2021, 2022). Some studies also measured learner's radical knowledge, spoken vocabulary, and non-verbal intelligence (e.g., Li et al., 2018; 2021; Liu, 2018).

During the orthographic learning phase, all studies except Liu's (2018) Experiment Two focused on orthographic learning through reading stories. Most studies utilized expository texts containing approximately 100 characters as reading material (e.g., Ho, 2014; Li et al., 2016, 2019). The target characters were typically repeated 4 to 6 times within these texts (e.g., Li et al., 2018, 2019, 2021). Participants engaged with a minimum of 8 texts (e.g., He, 2021; Li et al., 2020a) and up to 16 texts (e.g., Li et al., 2019; Liu, 2018). Notably, an increasing number of studies have adopted eye tracking technology to explore learning processes (e.g., He, 2021; Li et al., 2019; Xiang, 2023). This approach allows researchers to examine both early word processing, measured through indicators such as skipping rate, first fixation duration, gaze duration, and re-fixation probability, and late semantic integration, assessed via regression probabilities, number of fixations, and total fixation duration across different experimental conditions (Xiang, 2023).

In the posttest phase, orthographic choice and spelling tests are commonly used to assess orthographic learning outcomes. Additionally, semantic-related tasks, including semantic production, semantic category judgment, and definition tasks, are prevalent in Chinese self-teaching research (e.g., Li, 2020b; Li et al., 2019; Liu, 2018). Compared to English, implementing spelling (character writing) tests in Chinese self-teaching research is more intricate due to the complexity of Chinese characters and their phonetic components. For example, Li et al. (2016) prompted participants to retell the story content without providing the pronunciation of the target characters, whereas Li et al. (2021) provided only the pronunciation. Ho, (2014) employed a method similar to Share (2004), first indicating the story theme, then providing the initial consonants of the target characters, and finally offering the complete pronunciation.

Finally, we summarized the mechanisms of Chinese orthographic learning as presented in various studies (see Table 3). Empirical evidence supports the crucial role of phonological recoding via self-teaching (e.g., Ho, 2014; Li et al., 2020a, 2020b). Phonetic radicals are widely regarded as the primary means of phonological recoding in Chinese characters, rather than external phonetic symbols (Ho, 2014; Li et al., 2018). Importantly, semantic radicals play a significant role in Chinese orthographic learning, with factors such as semantic category, consistency, and transparency markedly influencing the effectiveness of orthographic learning for Chinese learners (e.g.,

Table 3 Mechanisms of Chinese orthographic learning in selected studies

Study name	Viewpoints
Ho (2014)	Zhuyin is not conducive to orthographic learning, whereas those with phonetic and semantic cues significantly contribute to it. Although the impact of semantic transparency is not significant, the trend is positive.
Li et al. (2016)	Chinese orthographic learning via self-teaching is influenced by the structure of Chinese characters and the familiarity of radicals.
Liu (2018)	L2 Chinese learners were able to use the phonetic regularity and semantic transparency of radicals to learn the spellings and pronunciations of new characters in a story context.
Li et al. (2018)	After examining phonetic radicals and Zhuyin, they found that only the phonetic radicals facilitated orthographic learning.
Li et al. (2019)	Semantic decoding does not affect the reading of novel compound characters in orthographic learning, but it assists in learning semantics.
Li et al. (2020a)	Phonological recoding, semantic information, and writing practice may jointly contribute to orthographic learning.
Li et al. (2020b)	Phonological recoding plays a key role in orthographic learning. Regular phonetic radicals facilitate phonology-orthography associations, while transparent radicals support semantic-orthography mapping.
He (2021)	Both semantic transparency and category consistency of semantic radicals affect orthographic learning via self-teaching.
Li et al. (2021)	Decoding through phonetic radicals underpins Chinese orthographic learning.
Li (2020a)	Oral vocabulary learning was significantly associated with orthographic learning and the reading of pseudo-characters in natural text.
Li (2020b)	Semantic and phonological knowledge impact orthographic learning in natural text, with semantic knowledge affecting it independently of phonological knowledge.
Li et al. (2022)	Transparent semantic radicals facilitated orthographic and vocabulary learning.
Xiang (2023)	Readers use semantic radicals to construct lexical representations and determine the semantic category. When radicals are opaque, they rely on contextual information to infer meaning.

He, 2021; Li et al., 2020a; Liu, 2018). However, as we mentioned in the introduction, semantic decoding is considered not to influence the reading of novel compound characters in natural texts or orthographic learning (Li et al., 2019, 2021). This raises the question of how semantic radicals contribute to the orthographic learning of Chinese learners, which remains an area for further investigation.

Effects of word-internal and word-external factors on orthographic learning

We first reported the effect of context and orthographic complexity on orthographic learning, measured by orthographic choice. The analysis revealed that the effects were not statistically significant. In the context subgroup, Hedges's $g=0.05$, $k=2$, 95% CI [−0.18, 0.27], $z = 0.41$, $p=0.683$. The heterogeneity analysis indicated no significant variation among the samples, $Q=0.77$, $p=0.379$, $I^2 = 0.00\%$, $\tau^2 = 0.00$. (as illustrated in Table 3; Fig. 2). In the orthographic complexity subgroup, Hedges's $g=0.14$, $k=2$, 95% CI [−0.16, 0.44], $z=0.92$, $p=0.357$. The heterogeneity analysis indicated no significant variation in effect sizes across samples, $Q=0.07$, $p=0.793$, $I^2 = 0.00\%$, $\tau^2 = 0.00$ (as illustrated in Table 4; Fig. 3).

Second, the effect of Zhuyin on orthographic learning was also found to be nonsignificant. In the orthographic choice test, Hedges's $g=-0.12$, $k=2$, 95% CI

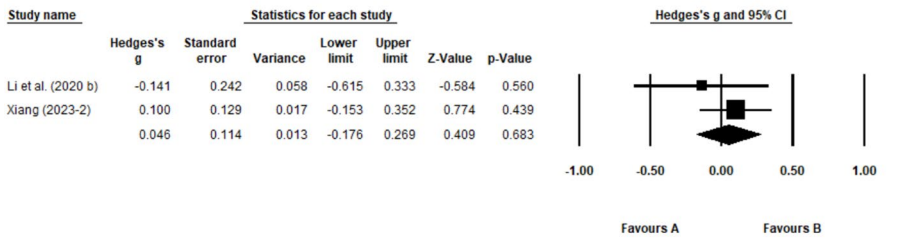


Fig. 2 Forest plot for the effect of context measuring by orthographic choice. *Note.* The results for the overall mean effect are given in the last line

Table 4 Mean effect size for groups measuring by orthographic choice

Subgroup	k[a]	Hedges' g [95% CI]	z (*p*)	Q test[b] (*p*)	I^2(%)	τ^2	Adjusted Hedges' g[c]	No. of trimmed studies
Context	2	0.05 [−0.18, 0.27]	0.41 (0.683)	0.77 (0.379)	0.00	0.00	–	0
Orthographic complexity	2	0.14 [−0.16, 0.44]	0.92 (0.357)	0.07 (0.793)	0.00	0.00	–	0
Zhuyin	2	−0.12 [−0.99, 0.76]	−0.265 (0.791)	7.86 (0.005)	87.28	0.35	–	0
Phonetic radical	7	0.89 [0.27, 1.51]	2.81 (0.005)	89.80 (<0.001)	93.32	0.63	–	0
Semantic radical	15	0.41 [0.15, 0.66]	3.14 (0.002)	77.96 (<0.001)	82.04	0.19	0.18 [0.04, 0.33]	To right of mean (k=2)

[a]Number of independently samples

[b]Heterogeneity test

[c]After trim and fill (random-effects model)

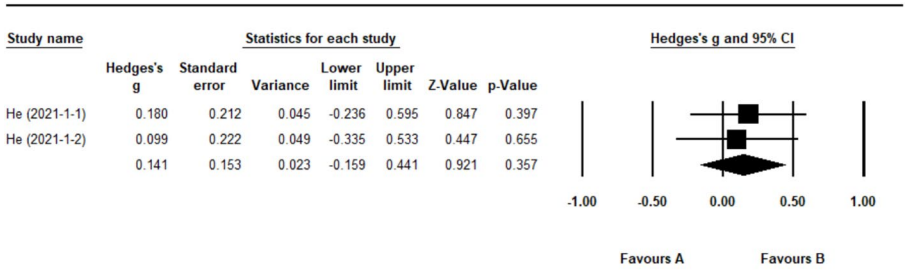


Fig. 3 Forest plot for the effect of orthographic complexity measuring by orthographic choice. *Note.* The results for the overall mean effect are given in the last line

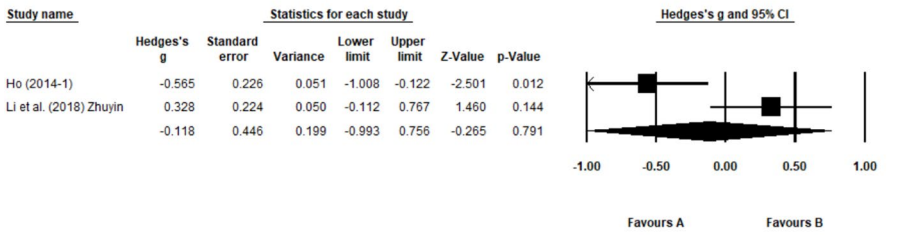


Fig. 4 Forest plot for the effect of Zhuyin measuring by orthographic choice. *Note.* The results for the overall mean effect are given in the last line

Table 5 Mean effect size for groups measuring by character writing

Subgroup	k[a]	Hedges' g [95% CI] [c]	z (*p*)	Q test[b] (*p*)	I^2(%)	τ^2
Zhuyin	2	0.28 [−0.16, 0.71]	1.25 (0.211)	3.86 (0.050)	74.08	0.08
Phonetic radical	6	0.97 [0.55, 1.39]	4.54 (<0.001)	24.72 (<0.001)	79.77	0.20
Semantic radical	9	0.55 [0.12, 0.97]	2.52 (0.012)	49.21 (<0.001)	83.74	0.32

[a]Number of independently samples

[b]Heterogeneity test

[c]After trim and fill (random-effects model)

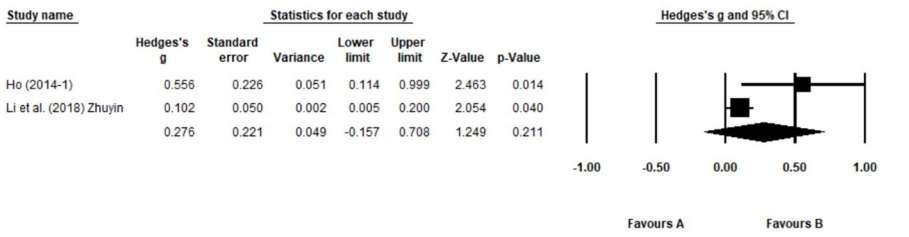


Fig. 5 Forest plot for the effect of Zhuyin measuring by character writing. *Note.* The results for the overall mean effect are given in the last line

[−0.99, 0.76], $z=-0.265$, $p=0.791$. There was significant heterogeneity in effect size, $Q=7.86$, $p=0.005$, $I^2=87.28\%$, $\tau^2=0.35$. (as illustrated in Table 4; Fig. 4). In the character writing test, Hedges's $g=0.28$, $k=2$, 95% CI [−0.16, 0.71], $z=1.25$, $p=0.211$. The heterogeneity analysis also showed significant variation, $Q=3.86$, $p=0.050$, $I^2=74.08\%$, $\tau^2=0.08$. (as illustrated in Table 5; Fig. 5).

Third, the effect of phonetic radicals on orthographic learning was found to be significant, exhibiting a large effect size. According to Cohen's guidelines, Hedges'

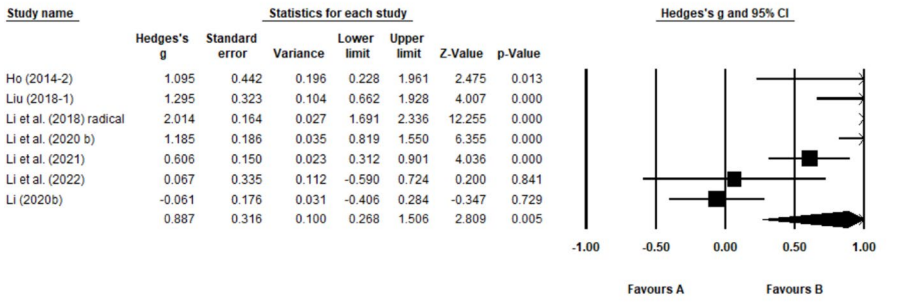


Fig. 6 Forest plot for the effect of phonetic radicals measuring by orthographic choice. *Note.* The results for the overall mean effect are given in the last line

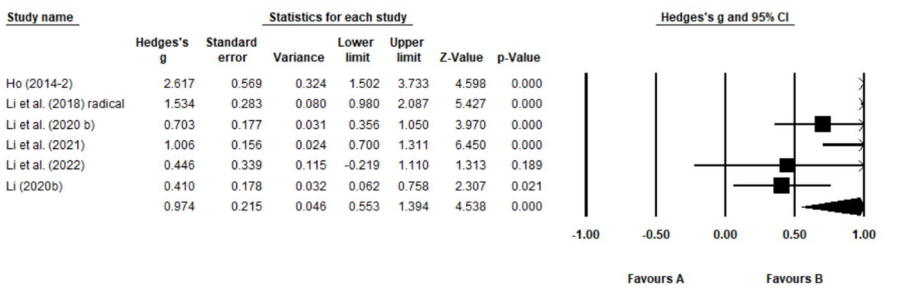


Fig. 7 Forest plot for the effect of phonetic radicals measuring by character writing. *Note.* The results for the overall mean effect are given in the last line

g values of 0.20, 0.50, and 0.80 correspond to small, medium, and large effect sizes, respectively (Lakens, 2013). In the orthographic choice test, Hedges's $g=0.89$, $k=7$, 95% CI [0.27, 1.51], $z=2.81$, $p=0.005$. The heterogeneity analysis indicated significant variation among the samples, $Q=89.80$, $p<0.001$, $I^2 = 93.32\%$, $\tau^2 = 0.63$. (as illustrated in Table 4; Fig. 6). In the character writing test, Hedges's $g=0.97$, $k=6$, 95% CI [0.55, 1.39], $z=4.54$, $p<0.001$. The heterogeneity analysis also indicated significant variation, $Q=24.72$, $p<0.001$, $I^2 = 79.77\%$, $\tau^2 = 0.20$. (as illustrated in Table 5; Fig. 7).

Lastly, the effect of semantic radicals on orthographic learning was analyzed. We found a small yet significant effect size (Lakens, 2013) in the orthographic choice test (Hedges's $g=0.18$, $k=13$, 95% CI [0.04, 0.33], $z=2.54$, $p=0.011$). There was no significant heterogeneity in effect size among the samples ($Q=20.50$, $p=0.058$, $I^2 = 41.47\%$, $\tau^2 = 0.03$) (as illustrated in Table 4; Fig. 8). The effect size was medium and significant in the character writing test (Hedges's $g=0.55$, $k=9$, 95% CI [0.12, 0.97], $z=2.52$, $p=0.012$). The heterogeneity analysis indicated significant variation ($Q=49.21$, $p<0.001$, $I^2 = 83.74\%$, $\tau^2 = 0.32$) (as illustrated in Table 5; Fig. 9).

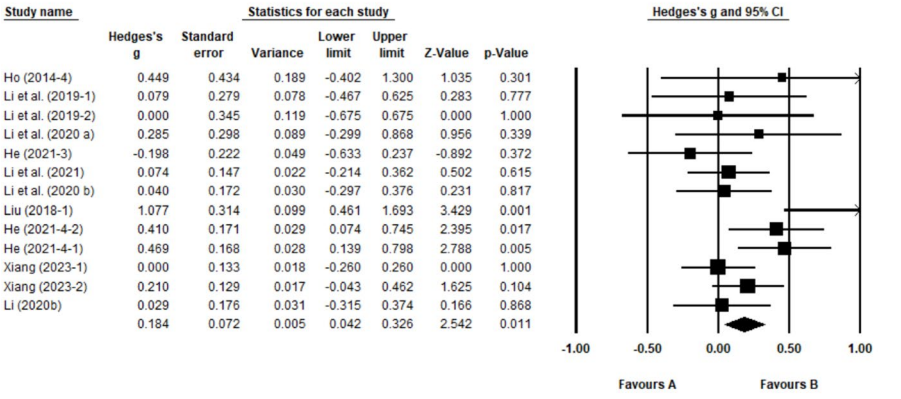


Fig. 8 Forest plot for the effect of semantic radicals measuring by orthographic choice. *Note.* The results for the overall mean effect are given in the last line

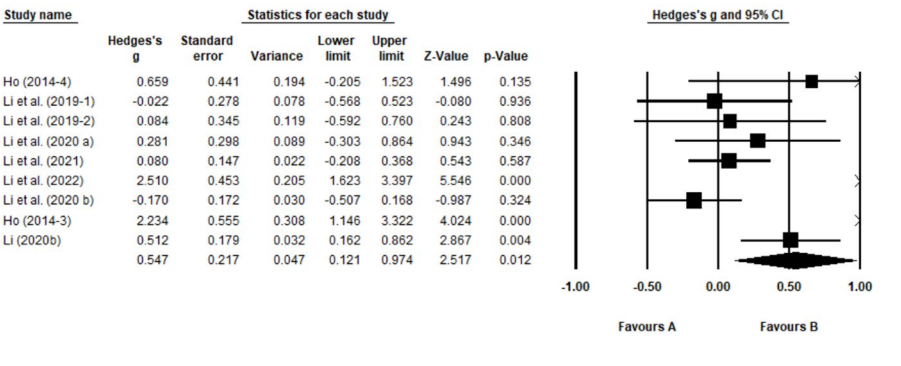


Fig. 9 Forest plot for the effect of semantic radicals measuring by character writing. *Note.* The results for the overall mean effect are given in the last line

In summary, to answer the RQ2, the findings revealed that both phonetic and semantic radicals significantly influenced orthographic learning, whether measured through orthographic choice or character writing. Specifically, phonetic radicals exhibited a larger effect size.

The moderating effects of age, the presentation of target characters, and the methods of phonological recoding

According to Borenstein et al. (2021), a minimum of 10 studies is required to detect moderators with adequate power, particularly when heterogeneity is present. Therefore, the moderator analysis was conducted only within the semantic radical subgroup measured by orthographic choice. First, we calculated the moderating effect

by subgroup analysis. Results shown in Table 6 suggested that both the presentation of target characters and the method of phonological recoding had significant effects on the relationship between semantic radicals and orthographic learning ($z=2.31$, $p=0.021$; $z=2.37$, $p=0.018$, respectively).

In subsequent meta-regression analysis, age was entered first, followed by the presentation of target characters and the method of phonological recoding. As illustrated in Model 1 in Table 7, age did not have a significant moderating effect. In Model 2, when the presentation of target characters was entered after age, the two could explain around 76% of the variance ($R^2=0.76$, Q (4)$=10.11$, $p=0.039$). In Model 3, the method of phonological recoding had an additional significant effect, accounting for about 6% of variance over and above the presentation of target characters ($R^2=0.84$, Q (5)$=12.00$, $p=0.035$). According to the results of the moderator analysis and meta-regression analysis, employing two-character words to represent a single target character (Hedges's $g=0.84$) is more effective in facilitating orthographic learning. Additionally, reading aloud (Hedges's $g=0.42$) demonstrates superior effectiveness compared to reading with eye tracking (Hedges's $g=0.15$).

In summary, in response to RQ3, we conducted moderator subgroup and meta-regression analyses, revealing that the presentation of target characters and the methods of phonological recoding significantly moderated the effects of semantic radicals on orthographic learning. The finding underscores the importance of considering methodological approaches in future research on orthographic learning.

Table 6 Moderator analysis for the effect of semantic radicals on orthographic learning

Moderator	Moderator variable	k[a]	Hedges's g	95% CI	Q test[b] (p)
The presentation of target characters	Single-character words [c]	2	0.11	[−0.10, 0.31]	
	Three-character phrases	4	0.05	[−0.14, 0.25]	
	Two-character words	2	0.84	[0.24, 1.43]	
	Two-character words including two target characters	5	0.21	[−0.03, 0.46]	
	Overall	13	0.14	[0.02, 0.26]	6.35 (0.096)
The methods of phonological recoding	Reading aloud	4	0.42	[−0.06, 0.90]	
	Reading with eye tracking	8	0.15	[−0.00, 0.31]	
	Overall	12	0.18	[0.03, 0.33]	1.11 (0.293)

[a]Number of independent samples

[b]Heterogeneity test

[c]Some are presented as single characters, while others are embedded in two-character words

Table 7 Meta-regression analysis results with age, the presentation of target characters, and the methods of phonological recoding as covariates for the effect of semantic radicals on Chinese orthographic learning

Covariate	Hedges's g	SE	z (*p*)	95% CI
Model 1 (R^2 = 0.00, *Q* (1) = 0.05, *p* = 0.823)				
Intercept	0.267	0.304	0.88 (0.190)	[−0.328, 0.862]
Age	−0.003	0.015	−0.22 (0.412)	[−0.033, 0.026]
Model 2 (R^2 = 0.76, *Q* (4) = 10.11, *p* = 0.039)				
Intercept	−0.340	0.342	−0.99 (0.160)	[−1.011, 0.330]
Age	0.022	0.016	1.38 (0.084)	[−0.009, 0.053]
Target character: three-character words (vs single character words)	−0.178	0.201	−0.88 (0.188)	[−0.572, 0.216]
Target character: two-character words (vs single character)	0.853	0.295	2.89 (0.002)	[0.275, 1.432]
Target character: two-character words including two target characters (vs single character)	0.206	0.160	1.29 (0.099)	[−0.108, 0.519]
Model 3 (R^2 = 0.84, *Q* (5) = 12.00, *p* = 0.035)				
Intercept	−0.680	0.435	−1.56 (0.059)	[−1.533, 0.173]
Age	0.071	0.044	1.61 (0.053)	[−0.015, 0.157]
Target character: three-character words (vs single character words)	−0.420	0.281	−1.50 (0.067)	[−0.969, 0.130]
Target character: two-character words (vs single character)	0.423	0.466	0.91 (0.182)	[−0.490, 1.336]
Target character: two-character words including two target characters (vs single character)	0.179	0.155	1.15 (0.124)	[−0.125, 0.482]
Phonological recoding: reading with eye tracking (vs read aloud)	−0.663	0.560	−1.19 (0.118)	[−1.760, 0.434]

Discussion

The present study systematically (a) explored the definition and operationalization of Chinese orthographic self-teaching, (b) examined the effects of word-internal and word-external factors on orthographic learning, and (c) investigated the moderating effects of age, the presentation of target words, and the method of phonological recoding. The main findings were as follows:

(1) In the selected studies, there has been an inconsistent definition of Chinese orthographic learning, and some researchers did not provide any definition. A three-phase paradigm with pre-learning, learning, and post-learning phases has been widely adopted in the selected studies. Yet, they also varied significantly in terms of the specific mechanisms (i.e., the use of phonetic radicals, the use of semantic radicals, Zhuyin, context, spelling) under examination.
(2) For the orthographic choice outcome, both phonetic radicals (Hedges's $g = 0.89$, $z = 2.81$, $p = 0.005$) and semantic radicals (Hedges's $g = 0.18$, $z = 2.54$, $p = 0.011$) demonstrated significant effects. Similar patterns were observed in character

writing tasks (phonetic radicals: Hedges's g = 0.97, $z = 4.54$, $p < 0.001$; semantic radicals: Hedges's $g = 0.55$, $z = 2.52$, $p = 0.012$).

(3) Moderator analyses focusing on the semantic radical effect revealed no significant moderating effects of participants' age ($z = -0.22$, $p = 0.412$). However, significant moderating effects were identified for the presentation of target characters ($z = 2.31$, $p = 0.021$) and the methods of phonological recoding ($z = 2.37$, $p = 0.018$). Meta-regression analysis showed that the model incorporating these two moderators could explain 84% of the variance in the outcomes.

The definition and operationalization of orthographic learning via self-teaching in Chinese

We propose that Chinese orthographic learning via self-teaching can be conceptualized as a developmental process in which learners acquire and internalize the orthographic representations of Chinese character words through independent reading, utilizing phonological recoding and sublexical semantic cues. Furthermore, the meta-analytic findings suggested that both phonetic and semantic radicals played crucial roles in Chinese self-teaching, the weight of phonetic radicals was greater, whereas no significant effect was observed for the utilization of context. This discrepancy could be due to the fact that regular phonetic radicals provided precise phonological information for pronouncing Chinese characters, whereas transparent semantic radicals offered only semantic category cues, requiring more complex cognitive processing for interpretation (Ho & Bryant, 1997; Shu & Anderson, 1997). Additionally, contextual information does not always unambiguously point to a specific character. In cases where phonological decoding fails, semantic radicals may serve as a more effective supplementary mechanism compared to contextual cues (Xiang, 2023).

However, the relative weights between phonetical radicals versus semantic radicals in Chinese orthographic learning remain a topic of debate. For instance, both Li et al. (2019) and Xiang (2023) observed that while the transparency and category consistency effects of semantic radicals were significant during the early stages of learning, these effects diminished as learners' lexical representations became more integrated after several exposures. They proposed two hypotheses: (1) the effects of semantic transparency may be influenced by phonological processes, and (2) presenting new words in a sentential context may lead learners to rely more on contextual cues, thereby paying less attention to semantic radicals. In contrast, other studies that manipulated phonological recoding have suggested that transparent radicals support semantic-orthographic mapping and exert a stronger influence on learning the phonological forms of irregular characters (e.g., Li et al., 2020b; Liu, 2018).

As noted above, there is a lack of standardized methodologies in existing research on Chinese orthographic learning through self-teaching. While the majority of studies employed the three-phase testing paradigm, methodological inconsistencies were particularly evident in the orthographic learning process, including variations in text length, differences in the presentation of target words, and significant disparities in the frequency of target word exposure. For example, Xiang (2023) required native adults to read 16 short stories, each approximately 200 words in length, with novel words exposed 9 times. In contrast, Ho (2014) examined Chinese orthographic learn-

ing among native children, requiring them to read aloud 10 short stories, each around 120 words long, with novel words presented only 4 times in the control group. Even experimental designs targeting similar types of Chinese learners exhibit discrepancies. For instance, like Xiang (2023), Li et al. (2019) also utilized eye tracking to explore the learning processes of native adults; however, participants were required to read 16 stories, each approximately 120 words long, with novel words exposed only 5 times. Taken together, these issues leave the question of whether a unique mechanism underpins Chinese orthographic learning unresolved, underscoring the need for future research to design and implement more systematic and rigorous behavioral experiments focusing on Chinese learners from diverse backgrounds.

Word internal and external factors in Chinese orthographic learning

Phonological recoding has been widely recognized as a fundamental mechanism in Chinese orthographic learning, as evidenced by the empirical studies reviewed in this paper. Notably, decoding through phonetic radicals serves as a cornerstone of Chinese orthographic acquisition (Li et al., 2021). However, it is surprising that little research to date has explored the impact of phonological recoding via Pinyin or a combination of Pinyin and phonetic radicals on orthographic learning within the self-teaching paradigm. In a study focusing on adult Chinese native speakers, Chen et al. (2019) demonstrated that Pinyin input can activate sublexical character orthography. This finding underscores the importance of investigating whether Pinyin could serve as an alternative pathway for phonological recoding among Chinese learners.

Moreover, research on the role and applicability of context and spelling mechanisms in Chinese orthographic learning remains notably limited. Specifically, the context subgroup included only three studies: two examining the presence or absence of context (Li et al., 2020b; Liu, 2018), and one investigating the strength of context (Xiang, 2023). Consequently, whether contextual information serves as a supplementary mechanism to phonological recoding in Chinese orthographic learning requires further exploration. Regrettably, no studies have directly investigated the spelling mechanism, which may be attributed to the challenges associated with the spelling pathway. Beyond the three major mechanisms, compared to self-teaching studies in other languages (as noted by Li & Wang, 2023), research on Chinese has paid relatively little attention to the complexity of its orthography. For example, to the best of our knowledge, although two independent samples have used stroke count as a variable (He, 2021), no studies have yet explored the structural features of Chinese characters or the usage of stroke patterns. While previous research has provided valuable insights, it has also raised numerous questions that warrant further investigation.

Moderator effects on Chinese orthographic learning

According to the moderator analysis, the presentation of two-character words containing a target character has a significant positive moderating effect on the relationship between semantic radicals and orthographic learning. Previous studies, such as those by Ho (2014) and Liu (2018), adopted this presentation format by combining a target pseudo-character with a high-frequency real character to form a grammatically

valid two-character word. This approach is highly consistent with the characteristics of Chinese vocabulary, as two-character words are the most common word length in modern Chinese. For example, in the Chinese Lexical Database introduced by Sun et al. (2018), approximately 70% of the words are two-character words. Some studies use two-character words comprising two target characters (e.g., He, 2021; Li et al., 2020a, 2020b). However, new words formed by unfamiliar characters do not exist in the reader's mental lexicon, requiring learners to repeatedly focus on internal features for character-by-character decoding. This increases learning difficulty but offers the advantage of better retention due to the higher cognitive resources consumed during learning (He, 2021).

Additionally, our findings indicated that silent reading under the eye-tracking condition exhibited a smaller effect than reading aloud on the association between semantic radicals and orthographic learning. While a recent systematic review by Li and Wang (2023) on self-teaching across different writing systems found no significant differences in learning outcomes between self-teaching through silent reading and reading aloud, the original self-teaching hypothesis and subsequent empirical research have demonstrated that reading aloud leads to better recognition and recall of pseudowords compared to silent reading (e.g., Chrabaszcz et al., 2023; Lien, 2017; Rosenthal & Ehri, 2011). Chrabaszcz et al. (2023) elucidated the superior orthographic learning performance observed when reading pseudowords aloud by suggesting that oral reading allows individuals to extract more detailed phonological and orthographic information. This process facilitates the creation of interconnected representations that integrate orthography, phonology, and semantics, potentially enhancing the retention of new words in memory. Consequently, this study posits that reading aloud may help learners focus more on word-specific orthographic information, thereby facilitating orthographic learning more effectively.

However, this meta-analysis did not find a significant moderating effect of age. In other words, based on the existing empirical research, the contribution of semantic radicals to Chinese orthography is not influenced by age. As mentioned above, age differences primarily manifest in the richness of reading experience. Reading experience is crucial, as exposure to print provides the dynamic database from which learners can extract statistics and build their own nuanced lexical knowledge (Nation & Castles, 2017). According to the participant information provided by the selected studies (see Online Appendix 1), only the participants in Liu (2018) were intermediate to advanced L2 Chinese learners, with an average age of 19.84, while the others were L1 Chinese speakers. Among them, the youngest participants were second-grade Taiwanese children with an average age of 8.17 (Ho, 2014). The result seemed to suggest that the use of semantic radicals in Chinese orthographic learning is consistently facilitative for different age groups. We also acknowledge that perhaps due to the moderate sample pool, age effect was not detected. Moderator analysis of age as a critical factor should be replicated in future meta-analysis with a larger sample pool.

Pedagogical implications

Based on the findings of the meta-analysis, this paper presents the following pedagogical implications. Firstly, both phonetic radicals and semantic radicals significantly contribute to Chinese orthographic learning, underscoring the importance of acquiring radical knowledge. Educators are encouraged to employ multimedia strategies to assist learners in accumulating essential radical knowledge, which includes clear structural information about Chinese characters, vivid and detailed meanings and pronunciations of components, as well as established rules for combining radicals (Chen et al., 2013). Learners should make efforts to leverage their existing knowledge of radicals to infer the meanings and pronunciations of new Chinese characters during their daily reading activities. Research has shown that when learners achieve a certain level of vocabulary, their prior experiences in learning Chinese can facilitate the acquisition of new characters (Zhang et al., 2016). Furthermore, to enhance students' focus and enable them to extract more detailed phonetic and graphic information during reading, Chinese language teachers should assign reading aloud tasks both in the classroom and as homework. These tasks can be complemented with progressively challenging activities, such as word recognition and character writing, to reinforce the retention of new vocabulary in students' long-term memory.

Conclusions, limitations and future directions

In this meta-analysis of Chinese orthographic learning through self-teaching, we have confirmed the central roles of phonological recoding via phonetic radicals and the use of semantic cues via semantic radicals. However, there are several limitations that need to be addressed in future research. First, the small sample size limited our ability to conduct more detailed subgroup analyses. For example, with a sufficient number of independent samples, the semantic radical subgroup could be further divided into categories such as transparency, consistency, and presence or absence. Such distinctions would provide deeper insights into the contributions of both intra-word and extra-word factors to orthographic learning. Second, this study did not account for individual differences among participants. Current research primarily focuses on native Chinese-speaking adults and children, with only one study (i.e., Liu, 2018) examining adult L2 Chinese learners. Individual differences in these Chinese learners, particularly in their perception of Chinese characters and their use of Pinyin, may influence the specific mechanisms underlying their orthographic learning.

Our findings underscore the need for systematic investigations to advance the understanding of Chinese orthographic acquisition. Three fundamental questions warrant particular attention: (a) whether Pinyin functions as a secondary form of phonological recoding, (b) the mechanistic contributions of semantic radicals, and (c) the development and empirical validation of the spelling mechanism in Chinese. Beyond these theoretical questions, critical methodological considerations arise regarding optimal learning conditions, including the most effective presentation formats for reading materials, lexical-level effects on character retention, the impact of exposure frequency on new word acquisition, and testing reliability. Lastly, we invite future

research to extend self-teaching hypothesis in Chinese and to further explore the unique characteristics of Chinese orthographic acquisition.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11145-025-10739-4.

Acknowledgements The first author has won the top student researcher award (co-recipient) at ARWA 2025 and the corresponding author has won the mid-career award at ARWA 2025. We greatly appreciate the support from the ARWA community.

Author contributions All authors reviewed and approved the final manuscript. [Author1]: Conceptualization, data analysis and writeup, manuscript writeup. [Author2]: Conceptualization, data analysis review, manuscript writeup.

Funding Open access funding provided by The Hong Kong Polytechnic University

Declarations

Conflict of interest The author declares no competing interests.

Ethical approval Ethical approval was not required as the study did not involve human participants.

Informed consent Informed consent was not required as the study did not involve human participants.

References

Note The selected studies are marked by *.

Borenstein, M., Cooper, H., Hedges, L., & Valentine, J. (2009). Effect sizes for continuous data. In *The Handbook of Research Synthesis and meta-analysis*, *2*, pp. 221–235.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2021). *Introduction to meta-analysis* (2nd ed.). Wiley.

Bowers, J. S., & Bowers, P. N. (2017). Beyond phonics: The case for teaching children the logic of the english spelling system. *Educational Psychologist*, *52*(2), 124–141. https://doi.org/10.1080/00461520.2017.1288571

Bowey, J. A., & Miller, R. (2007). Correlates of orthographic learning in third-grade children's silent reading. *Journal of Research in Reading*, *30*(2), 115–128. https://doi.org/10.1111/j.1467-9817.2007.00335.x

Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: A critical test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *92*(3), 203–219. https://doi.org/10.1016/j.jecp.2005.06.005

Chen, H. C., Hsu, C. C., Chang, L. Y., Lin, Y. C., Chang, K. E., & Sung, Y. T. (2013). Using a radical-derived character e-learning platform to increase learner knowledge of Chinese characters. *Language Learning & Technology*, *17*, 89–106. https://doi.org/10.64152/10125/24511

Chen, L., Perfetti, C. A., Fang, X., Chang, L. Y., & Fraundorf, S. (2019). Reading Pinyin activates sub-lexcial character orthography for skilled Chinese readers. Language. *Cognition and Neuroscience*, *34*(6), 736–746. https://doi.org/10.1080/23273798.2019.1578891

Chrabaszcz, A., Gebremedhen, N. I., Alvarez, T. A., Durisko, C., & Fiez, J. A. (2023). Orthographic learning in adults through overt and Covert reading. *Acta Psychologica*, *241*, 104061. https://doi.org/10.1016/j.actpsy.2023.104061

Conrad, N. J., Kennedy, K., Saoud, W., Scallion, L., & Hanusiak, L. (2019). Establishing word representations through reading and spelling: Comparing degree of orthographic learning. *Journal of Research in Reading*, *42*(1), 162–177. https://doi.org/10.1111/1467-9817.12256

Cunningham, A. E. (2006). Accounting for children's orthographic learning while reading text: Do children self-teach. *Journal of Experimental Child Psychology*, *95*(1), 56–77. https://doi.org/10.1016/j.jecp.2006.03.008

Ehri, L. C. (2013). Grapheme–phoneme knowledge is essential for learning to read words in English. In *Word recognition in beginning literacy*, pp. 3–40.

Ginestet, E., Shadbolt, J., Tucker, R., Bosse, M. L., & Deacon, S. H. (2021). Orthographic learning and transfer of complex words: Insights from eye tracking during reading and learning tasks. *Journal of Research in Reading*, *44*(1), 51–69. https://doi.org/10.1111/1467-9817.12341

Han, Y., Wang, Y., Liang, F., Li, X., Ma, J., & Bai, X. (2024). Phonological decoding does not affect incidental Chinese novel word learning in Uyghur readers: Evidence from eye movements. *Reading and Writing,* https://doi.org/10.1007/s11145-024-10535-6

*He, F. (2021). *The Role of Orthographic Information of New Chinese Words in Reading-Accompanied Vocabulary Learning: Evidence from Eye-Tracking* (Doctoral dissertation), Tianjin Normal University, Tianjin, China.

Ho, C. S. H., & Bryant, P. (1997). Phonological skills are important in learning to read Chinese. *Developmental Psychology*, *33*(6), 946. https://doi.org/10.1037/0012-1649.33.6.946

Ho, C. S. H., Ng, T. T., & Ng, W. K. (2003). A radical approach to reading development in chinese: The role of semantic radicals and phonetic radicals. *Journal of Literacy Research*, *35*(3), 849–878. https://doi.org/10.1207/s15548430jlr3503_3

*Ho, W. M. (2014). *Orthographic learning via self-teaching: Evidence from Mandarin Chinese* (Doctoral dissertation), University of Erfurt, Erfurt, Germany.

Huang, B., Yang, X., Dong, S., & Gu, F. (2023). Visual event-related potentials reveal the early whole-word lexical processing of Chinese two-character words. *Neuropsychologia*, *185*, 108571. https://doi.org/10.1016/j.neuropsychologia.2023.108571

Jorm, A. F., & Share, D. L. (1983). An invited article: Phonological recoding and reading acquisition. *Applied Psycholinguistics*, *4*(2), 103–147. https://doi.org/10.1017/S0142716400004380

Ke, S. E., Miller, R. T., Zhang, D., & Koda, K. (2021). Crosslinguistic sharing of morphological awareness in biliteracy development: A systematic review and meta-analysis of correlation coefficients. *Language Learning*, *71*(1), 8–54. https://doi.org/10.1111/lang.12429

Ketabi, S., Alijanian, E., & Ahmadvand, M. (2012). Vocabulary learning during reading: A comparison of a word-based strategy versus a text-based strategy. *Elixir Social Studies*, 53 (2012), 12082–12085.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Leong, C. K., Tse, S. K., Loh, K. Y., & Ki, W. W. (2011). Orthographic knowledge important in comprehending elementary Chinese text by users of alphasyllabaries. *Reading Psychology*, *32*(3), 237–271. https://doi.org/10.1080/02702711.2010.495605

Lien, B. (2017). *Applying the self-teaching hypothesis to adults: the effects of reading condition and syllable length on orthographic learning* (Doctoral dissertation). University of Pittsburgh, Pittsburgh, USA.

*Li, L. (2020a). Children's vocabulary knowledge predicts orthographic learning in Chinese: An exploratory study. In *The role of phonology and semantics in orthographic learning in Chinese: The lexical and sublexical components* (Doctoral dissertation). Macquarie University, Sydney, Australia.

*Li, L. (2020b). Phonological and semantic effects on orthographic learning in Chinese. Scientific Studies of Reading. In *The role of phonology and semantics in orthographic learning in Chinese: The lexical and sublexical components* (Doctoral dissertation). Macquarie University, Sydney, Australia.

*Li, L., Marinus, E., Castles, A., Hsieh, M. L., & Wang, H. C. (2021). Semantic and phonological decoding in children's orthographic learning in Chinese. *Scientific Studies of Reading*, *25*(4), 319–334. https://doi.org/10.1080/10888438.2020.1781863

*Li, L., Marinus, E., Castles, A., Yu, L., & Wang, H. C. (2019). Eye-tracking the effect of semantic decoding on orthographic learning in Chinese. *PsyArchiv Preprints*.

*Li, L., Wang, H. C., Castles, A., Hsieh, M. L., & Marinus, E. (2018). Phonetic radicals, not phonological coding systems, support orthographic learning via self-teaching in Chinese. *Cognition*, *176*, 184–194. https://doi.org/10.1016/j.cognition.2018.02.025

*Li, Y., Li, H., & Wang, M. (2020a). The roles of phonological recoding, semantic radicals and writing practice in orthographic learning in Chinese. *Scientific Studies of Reading*, *24*(3), 252–263. https://doi.org/10.1080/10888438.2019.1663199

*Li, Y., Li, H., & Wang, M. (2020b). Orthographic learning via self-teaching in chinese: The roles of phonological recoding, context, and phonetic and semantic radicals. *Journal of Experimental Child Psychology*, *199*, 104913. https://doi.org/10.1016/j.jecp.2020.104913

Li, Y., & Wang, M. (2023). A systematic review of orthographic learning via self-teaching. *Educational Psychologist*, *58*(1), 35–56. https://doi.org/10.1080/00461520.2022.2137673

*Li, Y., Xiao, L., & Li, H. (2022). Self-teaching in chinese: The roles of phonetic and semantic radicals in orthographic and vocabulary learning. *Journal of Research in Reading*, *45*(1), 20–42. https://doi.org/10.1111/1467-9817.12379

*Li, Y., Xiao, L., Zhang, J., Li, H., & Liu, X. (2016). 汉字结构特点和出现次数在儿童字形学习中的作用[Orthographic learning in Chinese children: Effects of character type and exposure]. *Journal of Psychological Science]*, *39*(5), 1105.

*Liu, Y. (2018). *Acquisition of Word Spellings and Meanings during Reading in Nonnative Chinese Speakers* (Doctoral dissertation), Western Kentucky University, Bowling Green, America.

Nation, K., & Castles, A. (2017). Putting the learning into orthographic learning. *Theories of reading development* (pp. 147–168). John Benjamins Publishing Company.

Ouellette, G. (2010). Orthographic learning in learning to spell: The roles of semantics and type of practice. *Journal of Experimental Child Psychology*, *107*(1), 50–58. https://doi.org/10.1016/j.jecp.2010.04.009

Pritchard, S. C., Coltheart, M., Marinus, E., & Castles, A. (2018). A computational model of the self-teaching hypothesis based on the dual-route cascaded model of reading. *Cognitive Science*, *42*(3), 722–770. https://doi.org/10.1111/cogs.12571

Ricketts, J., Bishop, D. V., & Nation, K. (2008). Investigating orthographic and semantic aspects of word learning in poor comprehenders. *Journal of Research in Reading*, *31*(1), 117–135. https://doi.org/10.1111/j.1467-9817.2007.00365.x

Rosenthal, J., & Ehri, L. C. (2011). Pronouncing new words aloud during the silent reading of text enhances fifth graders' memory for vocabulary words and their spellings. *Reading and Writing*, *24*, 921–950. https://doi.org/10.1007/s11145-010-9239-x

Schwartz, M., Kahn-Horwitz, J., & Share, D. L. (2014). Orthographic learning and self-teaching in a bilingual and biliterate context. *Journal of Experimental Child Psychology*, *117*, 45–58. https://doi.org/10.1016/j.jecp.2013.08.008

Shahar-Yames, D., & Share, D. L. (2008). Spelling as a self-teaching mechanism in orthographic learning. *Journal of Research in Reading*, *31*(1), 22–39. https://doi.org/10.1111/j.1467-9817.2007.00359.x

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. Cognition, 55(2), 151–218. https://doi.org/10.1016/0010-0277(94)00645-2

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *72*(2), 95–129. https://doi.org/10.1006/jecp.1998.2481

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of Experimental Child Psychology*, *87*(4), 267–298. https://doi.org/10.1016/j.jecp.2004.01.001

Share, D. L. (2008). Orthographic learning, phonological recoding, and self-teaching. *In Advances in Child Development and Behavior*, *36*, 31–82. https://doi.org/10.1016/S0065-2407(08)00002-5

Share, D. L. (2025). Blueprint for a universal theory of learning to read: The combinatorial model. *Reading Research Quarterly*, *60*(2), e603. https://doi.org/10.1002/rrq.603

Shu, H., & Anderson, R. C. (1997). Role of radical awareness in the character and word acquisition of Chinese children. *Reading Research Quarterly*, *32*(1), 78–89. https://doi.org/10.1598/RRQ.32.1.5

Shu, H., Chen, X., Anderson, R. C., Wu, N., & Xuan, Y. (2003). Properties of school chinese: Implications for learning to read. *Child Development*, *74*(1), 27–47. https://doi.org/10.1111/1467-8624.00519

Siegel, L. S., Share, D., & Geva, E. (1995). Evidence for superior orthographic skills in dyslexic. *Psychological Science*, *6*(4), 250–254. https://doi.org/10.1111/j.1467-9280.1995.tb00601.x

Sun, C. C., Hendrix, P., Ma, J., & Baayen, R. H. (2018). Chinese lexical database (cld) a large-scale lexical database for simplified Mandarin Chinese. *Behavior Research Methods*, *50*, 2606–2629. https://doi.org/10.3758/s13428-018-1038-3

Tong, X., Tong, X., & McBride, C. (2017). Unpacking the relation between morphological awareness and Chinese word reading: Levels of morphological awareness and vocabulary. *Contemporary Educational Psychology*, *48*, 167–178. https://doi.org/10.1016/j.cedpsych.2016.07.003

Tucker, R., Castles, A., Laroche, A., & Deacon, S. H. (2016). The nature of orthographic learning in self-teaching: Testing the extent of transfer. *Journal of Experimental Child Psychology*, *145*, 79–94. https://doi.org/10.1016/j.jecp.2015.12.007

Valentine, J. C., Pigott, T. D., & Rothstein, H. R. (2010). How many studies do you need? A primer on statistical power for meta-analysis. *Journal of Educational and Behavioral Statistics*, *35*(2), 215–247. https://doi.org/10.3102/1076998609346961

Viechtbauer, W., & Cheung, M. W. L. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*, *1*(2), 112–125. https://doi.org/10.1002/jrsm.11

Wang, H. C., Castles, A., Nickels, L., & Nation, K. (2011). Context effects on orthographic learning of regular and irregular words. *Journal of Experimental Child Psychology*, *109*(1), 39–57. https://doi.org/10.1016/j.jecp.2010.11.005

*Xiang, Y. (2023). *A Study on the Role of Semantic Radicals in Vocabulary Learning Accompanied by Reading* (Master dissertation), Tianjin Normal University, Tianjin, China.

Zhang, J., Li, H., Dong, Q., Xu, J., & Sholar, E. (2016). Implicit use of radicals in learning characters for nonnative learners of Chinese. *Applied Psycholinguistics*, *37*(3), 507–527. https://doi.org/10.1017/S0142716415000090