Studies in Second Language Learning and Teaching
Department of English Studies, Faculty of Pedagogy and Fine Arts, Adam Mickiewicz University, Kalisz
SSLLT 15 (3). 2025. 653-682. Published online: 12.05.2025
https://doi.org/10.14746/ssllt.36000
http://pressto.amu.edu.pl/index.php/ssllt

The effect of executive functions on word reading among students with Chinese as a second language (CSL)

Mingjia Cai
Education University of Hong Kong, China
https://orcid.org/0000-0002-6172-2803
s1115226@s.eduhk.hk

Xian Liao ✉
Education University of Hong Kong, China
https://orcid.org/0000-0002-4470-8436
iamliaoxian@gmail.com

Abstract

Executive functions (EF) have long been recognized as critical factors in accounting for individual differences in literacy development. However, their role in second language (L2) learning, particularly in non-alphabetic languages such as Chinese, has not been fully explored. This study endeavored to examine the role of EF in word reading among 200 Chinese as a second language (CSL) learners in Hong Kong. Participants completed a series of tasks measuring EF components, including inhibition, visual working memory, verbal working memory, and cognitive shifting, as well as tasks assessing their word reading abilities, which encompassed both single-character reading and two-character word reading. The contributions of EF to the total word reading score, single-character reading, and two-character word reading were analyzed. The results demonstrated that visual working memory and inhibition emerged as unique and significant predictors. Moreover, EF explained a greater proportion of variance in two-character word reading compared to single-character reading, suggesting that the cognitive demands of reading two-character words in Chinese differ from those of single-character reading. Additionally,

we examined the moderating effect of age on the relationship between EF and word reading. No significant moderating effect was found, indicating a constant contribution of EF to word reading across different age groups among CSL learners. These findings offer valuable theoretical insights into the role of EF in L2 literacy development and suggest practical pedagogical strategies for enhancing word reading skills among CSL learners.

Keywords: word reading; executive functions; Chinese as a second language; single-character reading; two-character word reading

1. Introduction

Executive functions (EF) refer to a set of cognitive processes that are crucial for controlling behavior, managing complex tasks, and achieving goals. These functions are essential for effective learning and problem-solving across various domains, including language acquisition (e.g., Gooch et al., 2016; Kaushanskaya et al., 2017). The contribution of EF to word reading has been well documented in both native and second language learners of alphabetic languages (e.g., Burgoyne et al., 2019; Chalmers & Freeman, 2018; Raudszus et al., 2019). In the context of Chinese word reading, which entails recognizing and comprehending logographic characters, EF are anticipated to play a crucial role in decoding, retaining, and retrieving linguistic information. This perspective is supported by research on native Chinese learners (e.g., Chung & McBride-Chang, 2011; Fong & Ho, 2022), while a significant gap persists in understanding how EF impact word reading among learners of Chinese as a second language (CSL).

Exploring this topic further is crucial due to its theoretical and practical implications. The cognitive mechanisms underlying the relationship between EF and word reading may differ between native and second language learners due to their distinct language learning experiences (Sparks, 2019). Additionally, differences in grapheme-phoneme-meaning correspondences across languages, particularly between alphabetic and non-alphabetic languages like Chinese, may affect the association between EF and word reading (Georgiou et al., 2020). This study, which examines the role of EF in word reading among CSL learners, aims to deepen our understanding of how cognitive skills affect literacy development in second language learners. To the best of our knowledge, it is one of the pioneering studies investigating the impact of EF on Chinese word reading in CSL learners, making a significant contribution to the theoretical understanding of this field. More importantly, understanding these associations in CSL learners is particularly important as the number of individuals learning Chinese as a second

language has steadily increased over the past decade (Gong et al., 2020). The complex nature of Chinese characters and their formidable orthography pose significant challenges for CSL learners, often hindering their progress in mastering the language (Leong et al., 2011; Liao et al., 2022). In response to these challenges, there is a growing demand for tailored instructional methods that can effectively support CSL learners. Our study will shed light on the cognitive mechanisms involved in mastering Chinese as a second language, ultimately contributing to the development of instructional strategies that best facilitate CSL learners' word reading abilities.

2. Literature review

2.1. The complexity of Chinese word reading

Word reading in Chinese is unique and complex due to the distinctive features of the written Chinese system. Characters are the fundamental units of the Chinese writing system, composed of strokes arranged in specific patterns within a square block. A Chinese character can range from being simple, with just a few strokes, to highly complex, involving many strokes. For example, the character "一" (yat1), meaning "one," consists of a single horizontal stroke, while "鬱" (wat1), meaning "dense" or "melancholy," is composed of more than twenty strokes. While strokes are the smallest units of Chinese characters, radicals serve as the basic building blocks, typically providing clues about the character's meaning or pronunciation. For instance, in the character 汐 (zik6, tide), 氵 (water) is the semantic radical indicating the meaning of the character, while 夕 (zik6) is the phonetic radical indicating the pronunciation. According to Shu et al. (2003), over 90% of Chinese characters are compound characters, consisting of a phonological and a semantic radical. However, unlike alphabetic scripts with regular form-sound correspondences, fewer than 30% of commonly used compound characters in Chinese are completely consistent with the sound or meaning clues provided by the radicals (He et al., 2005). Therefore, knowledge of semantic and phonetic radicals can be misleading in some situations. Furthermore, due to the limited number of radicals (around 600; Shu, 2003), characters often share radicals, leading to visual resemblances between characters (e.g., 冶 [je5, smelt] and 治 [zi6, cure]). The visual complexity, including the interweaving strokes within a square block and the resemblance between characters, requires learners to engage in visual and spatial recognition, making the memorization and recall of characters a cognitively demanding task. Additionally, the complexity of the correspondence

between radicals and character sound/meaning further poses a significant challenge for learners, particularly those whose first language uses an alphabetic system.

Unlike alphabetic languages, whose basic units of the writing system correspond to words, each Chinese character represents a morpheme, the smallest unit of the combination of sound and meaning. While some morphemes in Chinese serve as words independently, appearing as single-character words (such as 山 [saan1, mountain]), the majority of Chinese words (over 70%) consist of two morphemes, appearing as two-character words (Pan et al., 2021). Compounding is the primary method of word formation in Chinese (Tong et al., 2017), and morphemes can be recursively used to compound words. For instance, 天 [tin1] (sky) can form compound words such as 天價 ([tin1] sky + [gaa3] price, high price) and 天堂 ([tin1] sky + [tong4] space, heaven). However, two-character word reading in Chinese should not be viewed as merely processing two single characters in sequence. In a recent study by Tsang and Zou (2022) using event-related potentials (ERPs), both character-level and word-level variables (e.g., character-level variable: stroke numbers; word-level variable: pseudoword status) were found to jointly influence ERP signals during two-character word recognition within the same time window. This finding indicates that two-character words are not completely accessed character by character. Similarly, a study by Lo et al. (2019) revealed that the ERP sensitivities of single-character and two-character word reading differed, suggesting distinct neuro-cognitive processes for these two types of word reading. Moreover, recent studies have shown that two-character word reading can be more demanding than single-character reading (e.g., Pan et al., 2021; Wang & McBride-Chang, 2016; Yang et al., 2024). For example, in the study of Pan et al. (2021), conducted among 337 Hong Kong Chinese children in grades 1-3, morphological awareness was found to uniquely account for the variance in two-character word reading among, even after controlling for single-character reading. Given the vast number of Chinese words, primary learners often encounter unfamiliar words during reading. However, the question of whether cognitive skills like EF are differentially required for single-character reading versus two-character word reading has been far less explored. To gain a deeper understanding of these two reading processes, this study examines and compares the contributions of EF in both processes.

2.2. EF and word reading

Word reading is a foundational skill critical for literacy development (Beck & Juel, 1995; García & Cain, 2014; Gough & Tunmer, 1986) as it enables learners to decode, understand, and engage with written text. Word reading is supported by

various linguistic and cognitive skills, including executive functions. In recent years, an increasing number of studies have focused on the association between EF and word reading (e.g., Chalmers & Freeman, 2018; Chung et al., 2018; Haft et al., 2019; Liu et al., 2018; Nouwens et al., 2017; Spencer et al., 2020; Yang & Qiao, 2021). According to the classic study by Miyake et al. (2000), EF consist of three core components, validated by empirical evidence: inhibition, attention shifting, and working memory. *Inhibition* refers to the ability to suppress automatic, dominant, or prepotent responses in situations where such reactions are inappropriate (Diamond, 2013; Kieffer et al., 2013), which is essential for controlling impulses, resisting distractions, and maintaining focus on relevant tasks. *Attention shifting*, also known as cognitive flexibility, involves the capacity to switch between different tasks, mental sets, or operations, which is particularly important for adapting to changing demands or priorities (Miyake et al., 2000). *Working memory* is the mental workspace for temporarily holding and manipulating information, enabling individuals to keep track of relevant information and update it with new inputs (Diamond, 2013). Working memory is theorized to consist of visual and verbal subsystems (Baddeley et al., 2010; Cronin et al., 2020), responsible for processing visual and verbal information respectively (Olivers & Roelfsema, 2020; Schwering & MacDonald, 2020). These components are distinct but interrelated, collaboratively facilitating complex cognitive processes.

In the process of word reading, visual and verbal working memory enable readers to retain and manipulate visual and phonological information, underpinning the connection between the written form and the sound or meaning of a character or word (Peng et al., 2018; Pham & Hasson, 2014; Vales & Smith, 2015). Inhibition plays a crucial role in suppressing irrelevant information and distractions, allowing readers to focus on translating written symbols into understandable characters or words (Christopher et al., 2012; Spiegel et al., 2021). Attention shifting allows readers to efficiently switch between individual characters or words, ensuring that the word reading process is smooth and proficient (Spiegel et al., 2021). Given the complexity of written Chinese, certain EF components can be particularly important. For example, word reading may require a high level of visual working memory to retain the complex shapes of characters. Additionally, inhibition is necessary to filter out similar-looking characters that might cause confusion and to manage the complex correspondence between radicals and characters.

Previous studies have documented the link between EF and word reading in native Chinese learners (e.g., Chung et al., 2018; Deng et al., 2019; Lan et al., 2011; Liu et al., 2018; Yang & Qiao, 2021; Zou et al., 2022). For instance, Chung et al. (2018) found that EF skills explained about 10% of the variance in word reading among 369 native Chinese kindergarteners. Furthermore, a longitudinal study by Ren et al. (2022) found that EF evaluated during preschool years were

a significant predictor of subsequent word reading performance from Grades 1 to 3. However, the importance of individual EF components seems to vary across studies. In the study of Zou et al. (2022), no significant association between attention shifting and word reading was found among native Chinese students from Grade 3 to Grade 5. Moreover, previous findings suggest that the importance of EF components may vary among learners with different proficiency levels. In the study conducted by Fong and Ho (2022), working memory was correlated with poor readers' word reading but not with that of typically developed readers. They also reported that inhibition predicted word reading in poor readers only, while attention shifting's predictive power was significant only for typically developed readers.

2.3. Effect of EF on word reading among CSL learners

Although the relationship between EF and word reading has been extensively studied in native learners, it has received considerably less attention in second language (L2) learners, especially those learning Chinese as a second language (CSL). In a recent study by Yang et al. (2023), working memory significantly explained the variance in two-character word reading among 252 CSL undergraduates. However, a more comprehensive and systematic investigation is still needed, which would provide a clearer picture of how cognitive factors underpin word reading performance among L2 learners.

Generally, L2 learners experience both a limited quantity and quality of written and oral exposure compared to native learners (Jiang, 2018). Jiang and Wu (2022) found that English L2 learners exhibit a priming effect for both semantically related pairs (e.g., words that are both orthographically similar and semantically related, such as *listen – listener*) and orthographically similar pairs (e.g., words that are only orthographically similar, such as *freeze – free*), whereas native learners show a priming effect primarily for morphologically related pairs. The authors explained that this phenomenon may stem from the limited written input L2 learners received, leading them to be more influenced by the orthographic forms of characters or words. For CSL learners, it was also found that CSL learners pay more attention to orthographic features in recognizing Chinese characters (Wang et al., 2003).

In addition, L2 learners have also been found to frequently use their first language (L1) as an interlanguage (e.g., Derakhshan & Karimi, 2015; Lakshmanan & Selinker, 2001). Consequently, L2 learners often exhibit the influence of L1 in their L2. In the context of CSL, Lin and Childs (2010) observed that they followed the horizontal orientation of writing in alphabetic languages to perceive the structure of Chinese characters. Jiang and Feng (2022) also documented that

CSL learners whose L1 is alphabetic (e.g., English) tend to employ more analytic methods for recognizing Chinese characters, focusing on strokes and subcomponents. However, this approach may not always be effective. As Loh et al. (2021) noted, CSL learners often decompose radicals into meaningless strokes and subcomponents. Considering such influence of L1 and limited exposure, it is plausible to assume that CSL learners rely more on EF to process the written form of characters.

Another critical question is whether there is a potential difference in the contribution of EF to CSL learners' word reading between younger and older students. On the one hand, the EF skills develop quickly during primary period (Diamond & Lee, 2011; Roebers et al., 2012); on the other hand, research on CSL learners has documented that word reading has been consistently important during students' literacy development (e.g., Liao et al., 2022; Wong, 2017). This evidence raises a concern whether the relationship between EF and word reading varies with age. Research has indicated that EF may be peripheral to domain-specific knowledge during reading, such as orthographic and morphological knowledge (e.g., Kim, 2015, 2019). Specifically, EF primarily assist manipulating domain-specific knowledge during reading, which in turn supports word reading (Kim, 2019). As students advance in age and accumulate more linguistic knowledge (e.g., orthographic and vocabulary knowledge), their proficiency in utilizing domain-specific skills improves. This enhanced proficiency may thereby reduce cognitive load (Perfetti, 2007), potentially decreasing the reliance on EF over time (Dong et al., 2020). However, due to variations in learning experiences, the role of EF in word reading might be complex among CSL learners. Loh et al. (2018) reported that different aspects of orthographic knowledge develop at various stages of learning among CSL learners. Specifically, visually perceived knowledge is usually acquired earlier, whereas more implicit knowledge, such as semantic and phonological information of radicals, develops later. This implies that CSL learners may continue to rely on EF to manage different newly acquired orthographic knowledge to facilitate word reading, even as they age. Nevertheless, it is necessary to examine the effect of age on relationship between EF and word reading. This can provide insights into how CSL instruction can be tailored to meet the cognitive needs of learners at different developmental stages, which is vital for developing age-appropriate interventions that support literacy development in CSL learners.

3. The present study

The study aims to examine the contributions of of EF to word reading among CSL learners. In recent years, the number of CSL students in Hong Kong has increased

significantly, reaching over 26,000 in the 2021/22 academic year (Equal Opportunities Commission, 2022). These students are typically from ethnic minority communities, often descendants of Southeast Asian immigrants, with languages such as Urdu, Hindi, or Tagalog as their first or family language. They are considered CSL learners with an alphabetic first language background (e.g., Loh et al., 2018). Due to substantial differences between Chinese and their first languages, these CSL learners often find it challenging to learn Chinese. Previous research suggests that CSL students generally fall behind their native peers by 3-4 years in terms of Chinese language proficiency (Leung et al., 2011; Liao et al., 2022; Wong, 2017; Wong & Zhou, 2022). The difficulties in word reading undermine their confidence in learning Chinese, which in turn hampers their social integration (Loh et al., 2021; Wong, 2017). Therefore, there is a pressing need for tailor-made approaches to effectively assist CSL learners in mastering Chinese (Gong et al., 2020). To address this need, the present study proposes three research questions focusing on enhancing their word reading abilities:

RQ1: Do EF significantly predict Chinese word reading among CSL learners?
RQ2: If yes, do EF contribute differently to single-character reading and two-character word reading?
RQ3: Does the impact of EF on word reading differ across various age groups among CSL learners? If so, how does the influence of each EF component change with age?

4. Methods

4.1. Participants

Participants in the study comprised 200 non-native Chinese children attending a local public primary school in Hong Kong. The cohort included 81 students from Grade 3 and 119 students from Grade 5. The mean age of the Grade 3 students was 9.20 years (*SD* = 0.84), while the Grade 5 students had a mean age of 12.08 years (*SD* = 0.65). According to self-reported data, 92% of the Grade 5 participants had resided in Hong Kong for 10 to 12 years, and 89% of the Grade 3 participants had lived in Hong Kong for more than seven years. Despite Chinese being the dominant language in Hong Kong, many of these children live in culturally segregated communities where they primarily communicate with their families in their heritage language. As a result, many CSL students continue to find learning Chinese quite challenging, even after living in Hong Kong for several years.

4.2. Measurements

A set of tasks was developed to evaluate learners' word reading abilities and EF. Additionally, age, socioeconomic status (SES), nonverbal intelligence, vocabulary knowledge, morphological awareness, and orthographic awareness were included as control variables, given their established influence on word reading. Details of these tasks are provided below.

4.2.1. Word reading

The word reading task was designed based on the work of Wang and McBride-Chang (2016). It comprised two types of tasks: 50 single characters and 100 two-character words. Students were asked to read the printed characters aloud in sequence, with their accuracy assessed by trained research assistants. The maximum score for this task was 150. Full points were awarded for correct pronunciation of single characters or two-character words, while half-points were given for minor errors, such as incorrect tone or rhyme in a single character, or mispronunciation of one character in a two-character word. All items were chosen from Chinese textbooks used in local primary and secondary schools in Hong Kong. The Cronbach's alpha for the task was .996.

4.2.2. Executive functions

Inhibition was assessed by a modified version of the Stroop Color-Word Test, adapted from Van Der Elst et al. (2008). The test consisted of three sub-tasks, each containing 51 items. The first two tasks were conducted under congruent conditions. In the first sub-task, participants were required to identify the color of a pattern (red, blue, or yellow) by pressing corresponding keys on the keyboard (e.g., "A" for red, "G" for blue, "L" for yellow). In the second sub-task, participants responded to the color indicated by the meaning of a Chinese character displayed on the screen. The third sub-task was performed under incongruent conditions, where the stimuli were Chinese characters printed in colors that did not match their meanings (e.g., the character "紅" [red] printed in blue). Participants had to respond to the color of the character while ignoring its meaning. Reaction times for each item were recorded, and the final inhibition score was calculated using the formula: Task III – [(Task I + Task II) / 2]. A lower score indicated better inhibition ability. The Cronbach's alpha for this task was .762.

Attention shifting was evaluated by means of the Wisconsin Card Sorting Test (WCST), following the procedure established by Grant and Berg (1948). In this test, participants were presented with four key cards at the top of the screen, each differing in color, shape, and number: a red circle, two green triangles, three yellow crosses, and four blue stars. Response cards appeared individually at the bottom of the screen, and participants were required to match each response card to one of the key cards based on attributes such as color, shape, or number. The sorting criteria were not provided, requiring participants to infer them from the feedback given after each choice. The sorting rules changed every 10 items, and the test comprised 60 items. The number of categories completed was used to measure attention-shifting ability. The Cronbach's alpha for this task was .700.

Verbal working memory was measured by means of the Backward Digit Span Task, adapted from Liu et al. (2019). During this task, participants listened to a sequence of recorded digits and were required to recall the sequence in reverse order. The length of the digit spans increased sequentially from two to eight, with each length containing two items. One point was awarded for each correctly recalled sequence, with a maximum possible score of 14. The task was terminated if the participant incorrectly answered two items with the same length. The final score for verbal working memory was determined by multiplying the longest span with the number of correct responses. The Cronbach's alpha for this task was .724.

Visual working memory was assessed using a task adapted from Van de Weijer-Bergsma et al. (2015). Participants were presented with a nine-box grid in the center of the screen. In each item, a pattern appeared one at a time in various positions within the grid, following a specific sequence. Participants were then required to recall and reproduce the sequence in the opposite order by clicking on the corresponding boxes in the grid. The number of grids that the pattern showed up in increased sequentially from two to eight, with each sequence length containing two items. For each correctly recalled sequence, participants were awarded one point, with a maximum possible score of 14. The task was terminated if the participant incorrectly answered two items with the same number of grids. The score of the task was calculated by multiplying the longest span by the total number of correct responses. The task demonstrated a Cronbach's alpha of .743.

4.2.3. Controlled factors

Age, SES, nonverbal intelligence, vocabulary knowledge, morphological awareness, and orthographic awareness have been found as main factors influencing literacy outcomes, particularly word reading (e.g., Corso et al., 2016; Ho et al., 2003; Kuo & Anderson, 2006; Zhou, 2021). By controlling these variables, we aimed to isolate the

specific contribution of executive functions to word reading, thereby providing a clearer understanding of their unique role in Chinese reading.

Age and SES data were collected through a questionnaire. Housing type was set as the proxy for SES, following the approach of Fuller-Thomson et al. (2000). The five housing categories – private housing estates and serviced apartments; home ownership scheme courts; village houses; public housing estates; and partitioned flats – were assigned scores from 5 to 1, respectively, representing a gradient from high to low SES.

Non-verbal intelligence was assessed using the Raven's Progressive Matrices test (Raven, 2003). Each item presented a visual geometric pattern with a missing segment, and participants had to select the correct piece from six options to complete the pattern. The total score of the task was 24, with one point per item. The test demonstrated high reliability, with a Cronbach's alpha of .970.

Vocabulary knowledge was measured by means of the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4, Dunn & Dunn, 2007). In the context of this study, the test was translated into Chinese in both directions by experienced translators. Participants were required to select one of four pictures that best matches the meaning of the spoken word. There were 72 items included, with one point per item. The Cronbach's alpha for the task was .981.

Orthographic awareness was evaluated using a task adapted from Ho et al. (2003). Participants were asked to determine whether a printed pattern was a genuine Chinese character or a pseudo-character. The task consisted of 160 items, evenly divided between real and pseudo-characters, with each correct response earning one point. The real characters were sourced from the *Frequency Statistics of Commonly Used Modern Chinese Characters* (Ho & Kwan, 2001), and the 80 pseudo-characters were based on common student errors. Both frequency effects and stroke number effects were considered during the selection process. The Cronbach's alpha for the task was .997.

Morphological awareness was evaluated using a task adapted from Kuo and Anderson (2006). Participants were asked to determine whether the first character of an orally presented word was semantically related to the meaning of the entire word. The selected words were familiar to the children in their oral language. The task contained 30 items, with one point per item. The Cronbach's alpha for this task was .921.

4.3. Procedures

The tasks were reviewed and approved by the ethical committee of the Education University of Hong Kong prior to the commencement of the study. Consent

letters detailing the study were distributed to all participating students and their parents to secure their approval.

Word decoding data were collected individually in a quiet corner of the classroom during self-study periods and after-school activity time. Well-trained research assistants provided instructions to the students and recorded the accuracy of their word decoding. With five research assistants available for this task, five students were assessed simultaneously each time. Tasks involving EF, nonverbal intelligence, vocabulary knowledge, morphological awareness, and orthographic awareness were administered over two sessions of class-wide testing, each lasting approximately 45 minutes. The executive function tasks were administered via computer, with each participant using a designated workstation, whereas the other tasks were completed using a paper-and-pencil method. Research assistants provided verbal instructions before each task commenced. To ensure adherence to the testing protocol, three trained research assistants were present in each class during the assessments. Age and SES data were collected through a questionnaire completed after class.

4.4. Analysis

The task scores were entered into SPSS 29 for comprehensive statistical analysis. Initially, descriptive statistics, including the mean, standard deviation, kurtosis, and skewness, were calculated to assess the central tendencies, variability, and distributional characteristics of the dataset. Subsequently, a Pearson correlation analysis was conducted to examine the relationships between the key variables. Hierarchical regression analyses were performed to explore the specific contributions of EF skills to word reading outcomes. Age, SES, non-verbal intelligence, vocabulary knowledge, morphological awareness, and orthographic awareness, were controlled. Finally, a moderation analysis was conducted to determine whether the relationship between EF skills and word reading was moderated by age.

5. Results

5.1. Preliminary analysis

The mean (*M*), standard deviation (*SD*), kurtosis, and skewness were initially calculated. This step provided a foundational understanding of how the data were distributed, allowing for the identification of any potential outliers or deviations from normality. The results are shown in Table 1. All variables were considered

normally distributed, as the absolute values of skewness and kurtosis were well lower than 2 (Kline, 2015). This indicates that the data were suitable for subsequent statistical analyses.

Table 1 Descriptive statistics for word reading, non-verbal intelligence, age, socioeconomic status, linguistic knowledge, and executive functions

	M	*SD*	Skewness	Kurtosis
Word reading (total)	56.35	53.73	.49	-1.38
Single character reading	22.26	17.25	.01	-1.63
Two-character word reading	34.60	37.87	.65	-1.27
Non-verbal intelligence	16.91	8.11	-1.31	0.25
Age	10.51	1.60	-0.37	-0.79
Socioeconomic status	2.49	1.39	0.69	0.04
Vocabulary knowledge	38.92	22.79	-.09	-1.14
Orthographic awareness	129.27	54.27	-1.76	1.49
Morphological awareness	14.14	8.11	-.58	-0.63
Inhibition	.11	.07	1.14	1.20
Attention shifting	1.86	.85	.56	-0.65
Verbal working memory	22.41	18.76	1.04	0.08
Visual working memory	29.08	21.26	.46	-0.74

Pearson's correlation analysis was then performed to evaluate the strength and direction of the linear relationships among variables. This analysis offered initial insights into the potential interrelations between EF, word reading, and the controlled factors. The correlations for all variables are detailed in Table 2.

Table 2 Correlations between word reading, non-verbal intelligence, age, socioeconomic status, linguistic knowledge, and executive functions

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Word reading (total)	1												
2. Single character word reading	.96**	1											
3. Two character word reading	.99**	.92**	1										
4. Non-verbal intelligence	.42**	.46**	.39**	1									
5. Age	.41**	.36**	.41**	-.02	1								
6. Socioeconomic status	.27**	.24**	.26**	.06	.26**	1							
7. Vocabulary knowledge	.76**	.75**	.74**	.54**	.39**	.34**	1						
8. Orthographic awareness	.43**	.51**	.40**	.84**	-.06	.01	.58**	1					
9. Morphological awareness	.58**	.58**	.57**	.73**	.06	.13	.63**	.75**	1				
10. Inhibition	-.24**	-.18*	-.25**	.07	-.32**	.02	-.01	.13	.07	1			
11. Attention shifting	.17*	.15	.17*	-.18	.37**	.02	.13	-.10	-.03	-.22**	1		
12. Verbal working memory	.42**	.37**	.42**	.18*	.44**	.14	.42**	.10	.17*	-.18**	.25**		
13. Visual working memory	.34**	.29**	.35**	-.04	.22**	.10	.17*	-.07	.04	-.23**	.32**	1	

Note. ** $p < .01$, * $p < .05$.

Correlations between EF components and word reading were statistically significant, except for the correlation between attention shifting and single-character word reading. The benchmarks suggested by Akoglu (2018) were applied. Inhibition was weakly correlated with total word reading, single-character word reading, and two-character word reading, with r_s equal to -.24, -.18, and -.25, respectively ($p_s < .01$). Since the values of the inhibition score were negative, these results suggest a potential positive relationship between inhibition and word reading skills. Weak to moderate correlations were observed between verbal working memory and total word reading, single-character reading, and two-character reading, with r_s equal to .42, .37, and.42, respectively ($p_s < .01$). Visual working memory was also significantly correlated with all three types of word reading, with r_s equal to .34, .29, and .35 ($p_s < .01$). The correlations between attention shifting and word reading, particularly with two-character word reading, were relatively weak, with effect sizes both at .17 ($p_s < .05$). All EF components were weak but significantly correlated with each other, with r values ranging from -.23 to .32 ($p_s < .01$).

All controlled variables were significantly related to total word reading, single-character reading, and two-character word reading, with weak to strong effect sizes (r_s ranging from .24 to .76, $p_s < .01$). Notably, weak to moderate correlations were found between age and the three types of word reading scores. The effect sizes of the correlations between age and total word reading, and two-character word reading were both .41 ($p_s < .01$). The correlation between age and single-character word reading was .36 ($p < .01$).

5.2. Results of hierarchical regression analyses

Multiple hierarchical regression analyses were conducted to assess the impact of EF on word reading. The total word reading score, single-character reading score, and two-character word reading score were set as the dependent variables in three separate regression models. The independent variables were consistent across all three analyses and included age, nonverbal intelligence, SES, vocabulary knowledge, orthographic awareness, morphological awareness, and EF components (i.e., inhibition, attention shifting, verbal working memory, visual working memory). In Step 1, age, SES, and nonverbal intelligence were entered as control variables. In Step 2, vocabulary knowledge, orthographic awareness, and morphological awareness were added as additional control variables. Finally, in Step 3, the EF components were entered to examine their shared and unique contributions to word reading.

The results are presented in Table 3. In the first analysis, all independent variables collectively explained 69% of the variance in total word reading. The

contribution of EF was significant, representing 6% ($p < .01$) of the variance after controlling for the other variables. Inhibition and visual working memory emerged as distinct predictors of total word reading, with standardized beta weights of -.23 ($p < .01$) and .15 ($p < .05$), respectively.

In the analysis where single-character reading was the dependent variable, the effect of EF components was also significant. All variables together explained 57% of the variance in single-character reading. EF components contributed an additional 4% of the variance beyond the control variables, with inhibition and visual working memory emerging as unique predictors (β_s = -.18 and 018, respectively, $p_s < .01$).

Lastly, in the analysis of two-character word reading, all independent variables predicted 69% of the variance. The total contribution of EF components was 7%. The final standardized beta weights for inhibition and visual working memory were significant (β_s = -.25 and .13, respectively, $p < .01$), underscoring their important role in predicting two-character word reading.

Table 3 Results of hierarchical regressions analysis

		Dependent variables		
		Word reading (total)	Single character reading	Two-character word reading
Step1	*β* Non-verbal intelligence	.25**	.24***	.26***
	β Age	.41**	.40**	.41***
	β SES	.16*	.14*	.16*
	total R^2	.31**	.26***	.30**
Step 2	*β* Non-verbal	-.01	-.03	-.01
	β Age	.07	.08	.07
	β SES	.07	.001	.01
	β Vocabulary knowledge	.20**	.63***	.65***
	β Orthographic awareness	-.07	.04	-.10
	β Morphological awareness	.66***	.13*	.22**
	total R^2	.63**	.53***	.62**
	Δ R^2	.32**	.27***	.32**
Step 3	*β* Non-verbal	-.05	-.08	-.03
	β Age	-.05	.08	.06
	β SES	.04	.02	.04
	β Vocabulary knowledge	.62**	.60**	.60***
	β Orthographic knowledge	.01	.04	-.07
	β Morphological awareness	.20**	.13*	.22**
	β Inhibition	-.23**	-.18**	-.25**
	β Attention shifting	-.13	-.02	-.21
	β Verbal working memory	.05	.05	.04
	β Visual working memory	.15*	.18**	.13**
	total R^2	.69**	.57**	.69**
	Δ R^2	.06**	.04**	.07**

Note. ***$p < .001$, ** $p < .01$, * $p < .05$.

5.3. Moderation of age in the association between word reading and executive functions

To investigate potential age differences in the relationship between EF and CSL learners' word reading, a moderation analysis was performed. This analysis examined the moderating effect of age by evaluating the impact of interaction terms on the dependent variable, word reading. Interaction terms are calculated by multiplying the independent variable (i.e., EF components) with the moderator (i.e., age). In this study, four specific interaction terms were created: inhibition × age, attention shifting × age, visual working memory × age, and verbal working memory × age. A significant interaction term would indicate that the influence of a particular EF component on word reading changes depending on the learners' age.

Following the guidelines provided by Baron and Kenny (1986) and Frazier et al. (2004), the interaction terms are typically entered in the final step of the regression model to assess their unique contribution beyond the main effects of the controlled variables and the dependent variables. Therefore, based on the three-step hierarchical regression analyses presented in Section 5.2, the interaction terms were entered as the fourth step in the analysis. This approach ensures that any additional variance explained by the interaction terms is isolated, providing a clearer understanding of the moderating role of age in the relationship between EF components and word reading among CSL learners.

However, the analysis revealed that the interaction terms did not make a significant contribution to the models. For the analysis with total word reading as the dependent variable, the *p*-values associated with the standardized beta weights (β) of the interaction terms ranged from .23 to .96, all of which exceeded the significance threshold of .05. Similarly, in the analysis with single-character word reading as the dependent variable, the *p*-values for the interaction terms ranged from .22 to .92. Finally, in the analysis with two-character word reading as the dependent variable, the *p*-values ranged from .24 to .99. These results indicate that age did not significantly moderate the relationship between EF components and word reading. In other words, no significant age differences were found in how EF components such as inhibition, attention shifting, and working memory were associated with word reading performance.

6. Discussion

This study aimed to explore the role of EF in word reading among CSL learners in Hong Kong. Our findings contribute to the growing body of literature that underscores the importance of EF in literacy development, particularly in the context of L2

learners. Our study aligns with previous findings that suggest a significant contribution of EF components to word reading proficiency. Generally, these results highlight the unique cognitive demands faced by CSL learners, who must navigate the complexities of the Chinese written system with comparatively less linguistic input and reliance on EF to compensate for gaps in orthographic and semantic knowledge.

6.1. The contribution of EF to CSL word reading

When it comes to RQ1, we found that EF accounted for 6% of the variance in word reading among CSL learners, even after controlling for nonverbal intelligence, age, SES, vocabulary knowledge, orthographic knowledge, and morphological knowledge. This result aligns with findings from studies on native Chinese learners (e.g., Chung et al., 2018; Deng et al., 2019; Lan et al., 2011; Liu et al., 2018; Yang & Qiao, 2021; Zou et al., 2022), reinforcing the idea that EF play a crucial role in reading processes for CSL learners as well. Among the EF components, visual working memory and inhibition emerged as significant predictors. In the context of Chinese, where the phonological and semantic aspects of characters are deeply intertwined with their visual forms (Loh et al., 2021), the importance of visual processing can be especially pronounced. For instance, Jiang et al. (2020) demonstrated that CSL learners' reaction times slow down as the stroke complexity of characters increases, a pattern not observed in native learners. This finding suggests that CSL learners are more sensitive to the visual complexity of characters, making visual working memory a critical factor in their reading processes. Visual working memory likely supports CSL learners by enabling them to retain the visual details of characters long enough to match them with corresponding subcomponent information and radical knowledge stored in their mental lexicon. It is therefore plausible to observe the significant role of visual working memory in CSL learners' word reading. Inhibition is also crucial for word reading among CSL learners, particularly due to its role in suppressing irrelevant or misleading information during the reading process. Chinese characters often share similar radicals, which are visually similar. Given CSL learners' heavy reliance on visual information, their reading is especially susceptible to interference from these similar-looking characters. Additionally, difficulties in word reading are exacerbated by the fact that many radicals in Chinese are unreliable indicators of a character's pronunciation or meaning. Inhibition helps manage these challenges by filtering out irrelevant information, thereby supporting accurate character recognition and word reading (Chung & McBride-Chang, 2011; Ren et al., 2022), which plays a prominent role in CSL learners' word reading.

Interestingly, the contributions of verbal working memory and attention shifting to word reading were not significant in our study. This contrasts with

findings among native Chinese learners, where verbal working memory has been shown to be a significant predictor. Particularly, in a study by Yang and Qiao (2021) involving 99 Chinese kindergartners, verbal working memory, rather than visual working memory, was found to significantly contribute to word reading. This discrepancy highlights the distinct reliance on visual processing over phonological processing in CSL learners. Moreover, the reduced importance of verbal working memory among CSL learners may be attributed to their limited oral language input. With less developed oral proficiency in Chinese, CSL learners might find that verbal information plays a less critical role in supporting word reading. In this context, verbal working memory may be less crucial since less verbal information is utilized in the reading process. The non-significance of attention shifting could be attributed to CSL learners' lower proficiency in Chinese. Wang and An (2022) observed that CSL learners tend to shift their attention between characters more slowly than native learners, suggesting that they spend more time focusing on each character. This slower processing pace, likely due to their limited language proficiency, means that even if CSL learners possess strong attention-shifting abilities, the overall reading process remains slow and laborious, thereby reducing the relative importance of this skill (Fong & Ho, 2022). Nevertheless, it is noticeable that most of the variance in word reading was explained by linguistic knowledge (i.e., orthographic, morphological, and vocabulary knowledge). This is consistent with the perspectives of Fuchs et al. (2016) and Kim (2019), who argue that reading outcomes are driven by both domain-specific skills (e.g., linguistic knowledge) and domain-general skills (e.g., EF), with domain-specific skills playing a more central role in reading performance.

6.2. The roles of EF in single-character reading and two-character word reading

When comparing the contribution of EF to single-character reading versus two-character word reading (RQ2), we found that EF had a greater impact on two-character word reading, suggesting that this task involves a higher cognitive workload. Our findings are consistent with those from studies in native Chinese learners (e.g., Pan et al., 2021; Wang & McBride-Chang, 2016; Yang et al., 2024), which have suggested that reading two-character words can be more demanding than reading single characters. This increased cognitive demand might be particularly pronounced among CSL learners due to their characteristic of Chinese word reading. Previous research has shown that, compared to native Chinese learners, CSL learners often process two-character words in a more analytical manner (e.g., Gao et al., 2021; Hong & Feng, 2010). Because of limited print and oral exposure, CSL learners typically have less written and oral knowledge of two-character words stored in their mental lexicon compared to their native counterparts

(Zhang, 2017). As a result, instead of recognizing two-character words holistically, CSL learners tend to break down and analyze these words by integrating the individual characters. This analytical approach increases the visual complexity of the task, as it requires the reader to hold and integrate the visual forms of both characters in order to derive the correct meaning. Additionally, unlike single-character word reading, which primarily involves processing one character at a time, two-character word reading necessitates simultaneous processing, integration, and interpretation of both characters. This process is likely to engage multiple EF components in tandem.

Among the EF components, we observed that the contributions of inhibition and attention shifting were larger in two-character word reading compared to single-character reading. As noted by Spencer and Cutting (2021), effective word reading necessitates that learners seamlessly and continuously transition between various sources of information. In the context of Chinese, learners must switch between characters to achieve word recognition, thereby placing a greater reliance on attention shifting. Additionally, the recursive use of characters in Chinese word formation (e.g., the character 天 [tin1, sky] can form both 天堂 [tin1 tong4, heaven] and 天價 [tin1 gaa3, high price]) can cause interference during reading. Readers might be influenced by other words that contain the same characters (e.g., Wang et al., 2017; Zhou & Marslen-Wilson, 1994), which makes inhibition particularly important for suppressing irrelevant or misleading information. However, the contribution of visual working memory was weaker in two-character word reading than in single-character reading. Wang and McBride (2016) found that a character is more easily recognized when it is part of a known word than when it is presented in isolation. This is likely due to the contextual support provided by the word, which facilitates character recognition. Because characters within a word context are more easily recognized, the role of visual working memory may be reduced, as less detailed visual information needs to be extracted and retained.

6.3. The moderation effect of age on the association between EF and CSL word reading

With respect to RQ3, the current study revealed that age did not significantly moderate the relationship between EF and word reading among CSL learners, indicating a consistent and stable contribution of EF to word reading. This finding contrasts with previous meta-analyses conducted among native Chinese learners and native learners of alphabetic languages (e.g., Ober et al., 2020; Spiegel et al., 2021), which suggest that the contribution of EF decreases with age. As learners age, they tend to accumulate more linguistic knowledge, which allows them to match

sound and form information with orthographic forms more rapidly and accurately and enhances the efficiency of character/word recognition (e.g., Tong & McBride-Chang, 2010). This increased proficiency in linguistic skills might compensate for or reduce reliance on EF during word reading. The contribution of EF may therefore demonstrate a decrease with age among native learners. However, the development of these skills among CSL learners is generally slower (Leong et al., 2011; Zhang, 2017). This means that although our participants were from middle to higher grades, their linguistic skills might still be relatively basic, leading to a continued and significant reliance on EF for word reading. This finding could also help explain CSL students' underperformance of reading comprehension in Hong Kong (e.g., Liao et al., 2022; Tang & Chan, 2021; Wong, 2017). The continued dependence on EF suggests that ongoing engagement of EF in word recognition may reduce the resources available for higher-level processes, such as inferencing and monitoring, thus impeding improvement in reading comprehension.

Furthermore, learning a second language imposes unique cognitive demands due to the differences between the learner's L1 and L2 (e.g., Laufer & Eliasson, 1993; Yamashita & Jiang, 2010). In the present study, most participants were descendants of Southeast Asian immigrants, with L1s that are predominantly alphabetic languages (e.g., Urdu, Hindi, or Tagalog), whereas Chinese is a logographic language. Additionally, the methods of constructing complex words differ; for example, while compounding is the primary method in Chinese, their L1s might employ derivation, inflection, or other processes. These linguistic differences may consistently present challenges in reading Chinese, necessitating ongoing use of EF across different ages. The persistent contribution of EF to word reading has been suggested among L2 learners in various learning contexts. For instance, EF have been shown to predict both contemporary and future development of word reading among English L2 learners with Chinese as their L1 (Liu et al., 2019) and learners with Spanish as their L1 (Swanson, 2015).

However, it is important to note that the participants in our study were within a relatively narrow age range. Previous studies indicating a significant moderating effect of age typically covered a broader age spectrum, from kindergarteners to adult learners (e.g., Ober et al., 2020; Spiegel et al., 2021). Thus, additional studies are expected to explore whether developmental variations in the relationship between EF and word reading become more evident when examining a broader age range.

7. Conclusions, limitations and implications

This study sheds light on the significant role of EF in word reading among CSL learners. Our findings reveal that EF account for a notable proportion of the variance in

word reading performance. Specifically, visual working memory and inhibition emerged as key predictors, highlighting the unique cognitive demands posed by the Chinese writing system and the distinct learning experiences of CSL learners. The study also underscores the heightened cognitive workload associated with two-character word reading. Additionally, our findings suggest that the contribution of EF remains consistent across different age groups, indicating sustained reliance on these cognitive resources.

However, there are a few limitations to the present study. First, we did not measure or control for the first language proficiency of our participants. Future studies should consider including this factor as a control variable, given the potential influence of L1 literacy (Loh et al., 2018). Furthermore, the CSL learners in this study were all based in Hong Kong and were predominantly exposed to traditional Chinese characters. Since there are two types of Chinese scripts (i.e., simplified and traditional Chinese) which come with distinct visual complexities and radical-character correspondences (Yang & Wang, 2018), the cognitive demands of word reading may differ across these scripts (e.g., Liu & Hsiao, 2012; Liu et al., 2016). Therefore, caution should be exercised when generalizing these findings to CSL learners using simplified Chinese.

Despite these limitations, our findings provide valuable insights for improving the reading achievement of CSL learners. Considering that visual working memory has been identified as a significant predictor of word reading, instructional strategies should focus on strengthening students' visual processing skills. Teachers can incorporate reading-specific EF tasks that help students break down and analyze the visual components of Chinese characters, such as character recognition games and the use of visual aids like flashcards or character maps (Cartwright et al., 2020). Additionally, since inhibition emerged as a critical factor in word reading, teaching strategies should include exercises that enhance students' ability to filter out irrelevant information. For example, visual comparisons between characters with similar written forms (e.g., 逐 [zuk6, chase] and 啄 [doek3, peck]) could be provided through flashcards to help students memorize and distinguish characters more proficiently. Moreover, our study highlights that CSL learners often process two-character words more analytically due to their limited familiarity with compound words. Therefore, we suggest that teachers provide explicit instruction on the structure and formation of compound words in Chinese to assist CSL learners in transitioning from analytical to holistic processing. Activities such as character combination exercises, morpheme analysis, and compound word construction tasks can help students understand how individual characters combine to form words (e.g., Ke & Koda, 2019; Tong & McBride-Chang, 2010; Tong et al., 2017), making the reading of two-character words more intuitive and less cognitively demanding.

References

Akoglu, H. (2018). User's guide to correlation coefficients. *Turkish Journal of Emergency Medicine, 18*, 91-93. https://doi.org/10.1016/j.tjem.2018.08.001

Baddeley, A., Allen, R., & Vargha-Khadem, F. (2010). Is the hippocampus necessary for visual and verbal binding in working memory? *Neuropsychologia, 48,* 1089-1095. https://doi.org/10.1016/j.neuropsychologia.2009.12.009

Baron, R., & Kenny, D. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173-1182. https://doi.org/10.1037/0022-3514.51.6.1173

Beck, I. L., & Juel, C. (1995). The role of decoding in learning to read. *American Educator*, *19*(2), 8.

Burgoyne, K., Malone, S., Lervåg, A., & Hulme, C. (2019). Pattern understanding is a predictor of early reading and arithmetic skills. *Early Childhood Research Quarterly*. https://doi.org/10.1016/J.ECRESQ.2019.06.006

Cartwright, K., Bock, A., Clause, J., August, E., Saunders, H., & Schmidt, K. (2020). Near- and far-transfer effects of an executive function intervention for 2nd to 5th-grade struggling readers. *Cognitive Development*, *56*, 100932. https://doi.org/10.1016/j.cogdev.2020.100932

Chalmers, K., & Freeman, E. (2018). A comparison of single and multi-test working memory assessments in predicting academic achievement in children. *The Journal of Psychology, 152,* 613-629. https://doi.org/10.1080/00223980.2018.1491469

Chung, K., Lam, C., & Cheung, K. (2018). Visuomotor integration and executive functioning are uniquely linked to Chinese word reading and writing in kindergarten children. *Reading and Writing, 31,* 155-171. https://doi.org/10.1007/S11145-017-9779-4.

Chung, K., & McBride-Chang, C. (2011). Executive functioning skills uniquely predict Chinese word reading. *Journal of Educational Psychology, 103,* 909-921. https://doi.org/10.1037/A0024744

Christopher, M., Miyake, A., Keenan, J., Pennington, B., Defries, J., Wadsworth, S., Willcutt, E., & Olson, R. (2012). Predicting word reading and comprehension with executive function and speed measures across development: A latent variable analysis. *Journal of Experimental Psychology. General*, *141*(3), 470-488. https://doi.org/10.1037/a0027375

Corso, H. V., Cromley, J. G., Sperb, T., & Salles, J. F. (2016). Modeling the relationship among reading comprehension, intelligence, socioeconomic status, and neuropsychological functions: The mediating role of executive functions. *Psychology & Neuroscience*, *9*(1), 32-45. https://doi.org/10.1037/pne0000036

Cronin, D., Peacock, C., & Henderson, J. (2020). Visual and verbal working memory loads interfere with scene-viewing. *Attention, Perception, & Psychophysics, 82,* 2814-2820. https://doi.org/10.3758/s13414-020-02076-1

Deng, Q., Choi, W., & Tong, X. (2019). Bidirectional cross-linguistic association of phonological skills and reading comprehension: Evidence from Hong Kong Chinese-English bilingual readers. *Journal of Learning Disabilities*, *52,* 299-311. https://doi.org/10.1177/0022219419842914

Derakhshan, A., & Karimi, E. (2015). The interference of first language and second language acquisition. *Theory and Practice in Language Studies*, *5*(10), 2112. https://doi.org/10.17507/tpls.0510.19

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135-168.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333,* 959-964. https://doi.org/10.1126/science.1204529

Dong, Y., Tang, Y., Chow, B., Wang, W., & Dong, W. (2020). Contribution of vocabulary knowledge to reading comprehension among Chinese students: A meta-analysis. *Frontiers in Psychology*, *11*, 525369. https://doi.org/10.3389/fpsyg.2020.525369

Dunn, L. M., & Dunn, D. M. (2007). *Peabody Picture Vocabulary Test* (4th ed.). Pearson.

Equal Opportunities Commission. (2022). Ethnic minority students need more than funding. https://www.eoc.org.hk/zh-hk/Articles/Detail/634

Fong, C., & Ho, C. (2022). Executive functions in Chinese kindergarten children with early reading problems. *Dyslexia*, *28*(3), 325-341. https://doi.org/10.1002/dys.1714

Frazier, P., Tix, A., & Barron, K. (2004). Testing moderator and mediator effects in counseling psychology research. *Journal of Counseling Psychology, 51,* 115-134. https://doi.org/10.1037/0022-0167.51.1.115

Fuchs, L., Geary, D., Fuchs, D., Compton, D., & Hamlett, C. (2016). Pathways to third-grade calculation versus word-reading competence: Are they more alike or different?. *Child Development, 87,* 558-567. https://doi.org/10.1111/cdev.12474

Fuller-Thomson, E., Hulchanski, J., & Hwang, S. (2000). The housing/health relationship: What do we know? *Reviews on Environmental Health, 15,* 109-134. https://doi.org/10.1515/REVEH.2000.15.1-2.109

Gao, F., Wang, J., Zhao, C., & Yuan, Z. (2021). Word or morpheme? Investigating the representation units of L1 and L2 Chinese compound words in mental lexicon using a repetition priming paradigm. *International Journal of Bilingual Education and Bilingualism, 25,* 2382-2396. https://doi.org/10.1080/13670050.2021.1913984

García, J. R., & Cain, K. (2014). Decoding and reading comprehension: A meta-analysis to identify which reader and assessment characteristics influence the strength of the relationship in English. *Review of Educational Research*, *84*(1), 74-111. https://doi.org/10.3102/0034654313499616

Georgiou, G., Torppa, M., Landerl, K., Desrochers, A., Manolitsis, G., De Jong, P., & Parrila, R. (2020). Reading and spelling development across languages varying in orthographic consistency: Do their paths cross? *Child Development, 91,* e266-e279. https://doi.org/10.1111/cdev.13218

Gong, Y., Lai, C., & Gao, X. (2020). The teaching and learning of chinese as a second or foreign language: The current situation and future directions. *Frontiers of Education in China, 15,* 1-13. https://doi.org/10.1007/s11516-020-0001-0

Gooch, D., Thompson, P., Nash, H., Snowling, M., & Hulme, C. (2016). The development of executive function and language skills in the early school years. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 57,* 180-187. https://doi.org/10.1111/jcpp.12458

Gough, P., & Tunmer, W. (1986). Decoding, reading, and reading disability. *Remedial and Special Education, 7,* 6-10. https://doi.org/10.1177/074193258600700104

Grant, D. A, & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology, 38*(4), 404-411.

Haft, S., Caballero, J., Tanaka, H., Zekelman, L., Cutting, L., Uchikoshi, Y., & Hoeft, F. (2019). Direct and indirect contributions of executive function to word decoding and reading comprehension in kindergarten. *Learning and Individual Differences, 76,* 101783. https://doi.org/10.1016/j.lindif.2019.101783

He, Y., Wang, Q., & Anderson, R. C. (2005). Chinese children's use of subcharacter information about pronunciation. *Journal of Educational Psychology, 97*(4), 572-579. https://doi.org/10.1037/0022-0663.97.4.572

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, S. W., & Kwan, C. W. (2001). *Frequency statistics of commonly used modern Chinese characters.* CUHK.

Hong, W., & Feng, C. (2010). A study of the differences between csl learners and chinese native speakers in Chinese two-character compound word recognition [in Chinese]. *Modern Foreign Languages, 33*(4), 387-394.

Jiang, N. (2018). *Second language processing: An introduction*. Routledge.

Jiang, N., & Feng, L. (2022). Analytic visual word recognition among Chinese L2 learners. *Foreign Language Annals, 55*(2), 540-558.

Jiang, N., Hou, F., & Jiang, X. (2020). Analytic versus holistic recognition of Chinese words among L2 learners. *Modern Language Journal, 104,* 567-580. https://doi.org/10.1111/modl.12662

Jiang, N., & Wu, X. (2022). Orthographic priming in second-language visual word recognition. *Language Learning, 72*(3), 625-645. https://doi.org/10.1111/lang.12488

Kaushanskaya, M., Park, J., Gangopadhyay, I., Davidson, M., & Weismer, S. (2017). The relationship between executive functions and language abilities in children: A latent variables approach. *Journal of Speech, Language, and Hearing Research: JSLHR, 60*(4), 912-923. https://doi.org/10.1044/2016_JSLHR-L-15-0310

Ke, S., & Koda, K. (2019). Is vocabulary knowledge sufficient for word-meaning inference? An investigation of the role of morphological awareness in adult L2 learners of Chinese. *Applied Linguistics, 40,* 456-477. https://doi.org/10.1093/APPLIN/AMX040

Kieffer, M. J., Vukovic, R. K., & Berry, D. (2013). Direct and indirect roles of executive functioning in reading comprehension for students in urban fourth-grade classrooms. *Reading Research Quarterly, 48*, 333-348. https://doi.org/10.1002/rrq.54

Kim, Y. (2015). Language and cognitive predictors of text comprehension: Evidence from multivariate analysis. *Child Development, 86,* 128-144. https://doi.org/10.1111/cdev.12293

Kim, Y. (2019). Hierarchical and dynamic relations of language and cognitive skills to reading comprehension: Testing the direct and indirect effects model of reading (DIER). *Journal of Educational Psychology*, *112*(4), 667-684. https://doi.org/10.1037/edu0000407

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford Publications.

Kuo, L., & Anderson, R. (2006). Morphological awareness and learning to read: A cross-language perspective. *Educational Psychologist, 41,* 161-180. https://doi.org/10.1207/s15326985ep4103_3

Lakshmanan, U., & Selinker, L. (2001). Analyzing interlanguage: How do we know what learners know? *Second Language Research*, *17*(4), 393-420. https://doi.org/10.1191/026765801681495886

Lan, X., Legare, C. H., Ponitz, C. C., Li, S. & Morrison, F. J. (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American preschoolers. *Journal of Experimental Child Psychology, 108*(3), 677-692. https://doi.org/10.1016/j. jecp.2010.11.001

Laufer, B., & Eliasson, S. (1993). What causes avoidance in L2 learning. *Studies in Second Language Acquisition, 15,* 35-48. https://doi.org/10.1017/S0272263100011657

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

Liao, X., Loh, E., & Cai, M. (2022). Lexical orthographic knowledge mediates the relationship between character reading and reading comprehension among

learners with Chinese as a second language. *Frontiers in Psychology, 13*, 779905. https://doi.org/10.3389/fpsyg.2022.779905

Lin, P. Y., & Childs, R. A. (2010). An analysis of orthographic processing: Non-Chinese and Chinese readers' visual-spatial concept. In J. Chen, C. Wang & J. C. Charlotte (Eds.), *Teaching and learning Chinese: Issues and perspectives* (pp. 257-278). Information Age Publishing.

Liu, T., Chuk, T. Y., Yeh, S. L., & Hsiao, J. H. (2016). Transfer of perceptual expertise: The case of simplified and traditional Chinese character recognition. *Cognitive Science*, *40*(8), 1941-1968. https://doi.org/10.1111/cogs.12307

Liu, C., Chung, K., & Fung, W. (2019). Bidirectional relationships between children's executive functioning, visual skills, and word reading ability during the transition from kindergarten to primary school. *Contemporary Educational Psychology*, *59*, 101779. https://doi.org/10.1016/J.CEDPSYCH.2019.101779

Liu, S., Liu, D., Pan, Z., & Xu, Z. (2018). The association between reading abilities and visual-spatial attention in Hong Kong Chinese children. *Dyslexia*, *24*(3), 263-275. https://doi.org/10.1002/dys.1584

Liu, T., & Hsiao, J. (2012). The perception of simplified and traditional Chinese readers. *Journal of Vision*, *12*(9), 533. https://doi.org/10.1167/12.9.533

Lo, J., McBride, C., Ho, C., & Maurer, U. (2019). Event-related potentials during Chinese single-character and two-character word reading in children. *Brain and Cognition*, *136*, 103589. https://doi.org/10.1016/j.bandc.2019.103589

Loh, E. K. Y., Liao, X., & Leung, S. O. (2018). Acquisition of orthographic knowledge: Developmental difference among learners with Chinese as a second language (CSL). *System, 74*, 206-216. https://doi.org/10.1016/j.system.2018.03.018

Loh, E., Liao, X., Leung, S., & Tam, L. (2021). How do Chinese as a second language (CSL) learners acquire orthographic knowledge: Component, structure and position regularity. *Language Awareness, 30,* 297-316. https://doi.org/10.1080/09658416.2021.1972115

Miyake, A., Friedman, N., Emerson, M., Witzki, A., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100. https://doi.org/10.1006/cogp.1999.0734

Nouwens, S., Groen, M. A., & Verhoeven, L. (2017). How working memory relates to children's reading comprehension: The importance of domain-specificity in storage and processing. *Reading and Writing, 30*(1),105-120. https://doi.org/10.1007/s11145-016-9665-5

Ober, T., Brooks, P., Homer, B., & Rindskopf, D. (2020). Executive functions and decoding in children and adolescents: A meta-analytic investigation. *Educational Psychology Review, 32,* 735-763. https://doi.org/10.1007/s10648-020-09526-0

Olivers, C., & Roelfsema, P. (2020). Attention for action in visual working memory. *Cortex*, *131,* 179-194. https://doi.org/10.1016/j.cortex.2020.07.011

Pan, D., Yang, X., Lui, K., Lo, J., McBride, C., & Ho, C. (2021). Character and word reading in Chinese: Why and how they should be considered uniquely vis-à-vis literacy development. *Contemporary Educational Psychology*, 65, 101961. https://doi.org/10.1016/J.CEDPSYCH.2021.101961

Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H., Dardick, W., & Tao, S. (2018). A meta-analysis on the relation between reading and working memory. *Psychological Bulletin, 144,* 48-76. https://doi.org/10.1037/bul0000124

Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading, 11,* 357-383. https://doi.org/10.1080/10888430701530730

Pham, A., & Hasson, R. (2014). Verbal and visuospatial working memory as predictors of children's reading ability. *Archives of Clinical Neuropsychology: The Official Journal of the National Academy of Neuropsychologists, 29*(5), 467-477. https://doi.org/10.1093/arclin/acu024

Raudszus, H., Segers, E., & Verhoeven, L. (2019). Situation model building ability uniquely predicts first and second language reading comprehension. *Journal of Neurolinguistics*, *50*, 106-119. https://doi.org/10.1016/j.jneuroling.2018.11.003

Raven, J. (2003). Raven Progressive Matrices. In R. S. McCallum (Ed.), *Handbook of nonverbal assessment* (pp. 223-237). Kluwer Academic/Plenum Publishers. https://doi.org/10.1007/978-1-4615-0153-4_11

Ren, L., Hu, B. Y., & Wu, H. (2022). Early executive function predicts children's Chinese word reading from preschool through Grade 3. *Contemporary Educational Psychology, 69*, 102054. https://doi.org/10.1037/a0024744

Roebers, C., Cimeli, P., Röthlisberger, M., & Neuenschwander, R. (2012). Executive functioning, metacognition, and self-perceived competence in elementary school children: An explorative study on their interrelations and their role for school achievement. *Metacognition and Learning, 7,* 151-173. https://doi.org/10.1007/s11409-012-9089-9

Schwering, S., & MacDonald, M. (2020). Verbal working memory as emergent from language comprehension and production. *Frontiers in Human Neuroscience, 14*, 68. https://doi.org/10.3389/fnhum.2020.00068

Shu, H. (2003). Chinese writing system and learning to read. *International Journal of Psychology, 38,* 274-285. https://doi.org/10.1080/00207590344000060

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

Sparks, R. (2019). Why reading is a challenge for US L2 learners: The impact of cognitive, ecological, and psychological factors in L2 comprehension. *Foreign Language Annals, 52,* 727-743. https://doi.org/10.1111/flan.12432

Spencer, M., Richmond, M., & Cutting, L. (2020). Considering the role of executive function in reading comprehension: A structural equation modeling approach. *Scientific Studies of Reading, 24,* 179-199. https://doi.org/10.1080/10888438.2019.1643868

Spencer, M., & Cutting, L. (2021). Relations among executive function, decoding, and reading comprehension: An investigation of sex differences. *Discourse Processes, 58,* 42-59. https://doi.org/10.1080/0163853x.2020.1734416

Spiegel, J., Goodrich, J., Morris, B., Osborne, C., & Lonigan, C. (2021). Relations between executive functions and academic outcomes n elementary school children: A meta-analysis. *Psychological Bulletin, 147*(4), 329-351. https://doi.org/10.1037/bul0000322

Swanson, H., Aviles, A., Owen, H., Guzman-Orth, D., Melgarejo, M., & Bachman, E. (2015). Growth in working memory and inhibition predicts literacy in English language learners: A cross-sectional and longitudinal study. *Memory, 23,* 748-773. https://doi.org/10.1080/09658211.2014.927504

Tang, M., & Chan, S. (2022). Effects of word semantic transparency, context length, and L1 background on CSL learners' incidental learning of word meanings in passage-level reading. *Journal of Psycholinguistic Research, 51,* 33-53. https://doi.org/10.1007/s10936-021-09786-z

Tong, X., & McBride-Chang, C. (2010). Developmental models of learning to read Chinese words. *Developmental Psychology, 46*(6), 1662-1676. https://doi.org/10.1037/a0020611

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

Tsang, Y. K., & Zou, Y. (2022). An ERP megastudy of Chinese word recognition. *Psychophysiology, 59*(11), e14111. https://doi.org/10.1111/psyp.14111

Vales, C., & Smith, L. (2015). Words, shape, visual search and visual working memory in 3-year-old children. *Developmental Science*, *18*(1), 65-79. https://doi.org/10.1111/desc.12179

Van de Weijer-Bergsma, E., Kroesbergen, E. H., Prast, E. J., & Van Luit, J. E. (2015). Validity and reliability of an online visual-spatial working memory task for self-reliant administration in school-aged children. *Behavior Research Methods, 47*(3), 708-719. https://doi.org/10.3758/s13428-014-0469-8

Van Der Elst, W., Van Boxtel, M., Van Breukelen, G., & Jolles, J. (2008). Detecting the significance of changes in performance on the Stroop Color-Word Test, Rey's Verbal Learning Test, and the Letter Digit Substitution Test: The regression-based change approach. *Journal of the International Neuropsychological Society, 14,* 71-80. https://doi.org/10.1017/S1355617708080028

Wang, J., & An, N. (2022). What are the characteristics of good Chinese second language readers? Evidence from eye movements. *Journal of Chinese Writing Systems, 6,* 17-37. https://doi.org/10.1177/25138502221068900

Wang, M., Perfetti, C., & Liu, Y. (2003). Alphabetic readers quickly acquire orthographic structure in learning to read Chinese. *Scientific Studies of Reading, 7,* 183-208. https://doi.org/10.1207/S1532799XSSR0702_4

Wang, W., Lu, A., He, D., Zhang, B., & Zhang, J. (2017). ERP Evidence for Chinese compound word recognition: Does morpheme work all the time? *Neuroquantology*, *15*(3), *142-152.* https://doi.org/10.14704/NQ.2017.15.3.1105

Wang, Y., & McBride, C. (2016). Character reading and word reading in Chinese: Unique correlates for Chinese kindergarteners. *Applied Psycholinguistics, 37*(2), 371-386. https://doi.org/10.1017/S014271641500003X

Van de Weijer-Bergsma, E., Kroesbergen, E. H. & Van Luit, J. E. H. (2015). Verbal and visual-spatial working memory and mathematical ability in different domains throughout primary school. *Memory and Cognition, 43,* 367-378. https://doi.org/10.3758/s13421-014-0480-4

Wong, Y. (2017). The role of radical awareness in Chinese-as-a-second-language learners' Chinese character reading development. *Language Awareness, 26,* 211-225. https://doi.org/10.1080/09658416.2017.1400039

Wong, Y., & Zhou, Y. (2022). Effects of metalinguistic awareness on Chinese as a second language spelling through the mediation of reading and copying. *Reading and Writing, 35,* 853-875. https://doi.org/10.1007/s11145-021-10167-0

Yamashita, J., & Jiang, N. (2010). L1 influence on the acquisition of L2 collocations: Japanese ESL users and EFL learners acquiring English collocations. *TESOL Quarterly, 44,* 647-668. https://doi.org/10.5054/TQ.2010.235998

Yang, X., & Qiao, L. (2021). Direct effects of visual skills and working memory on Chinese character reading in young children. *Infant and Child Development*, *30*(4), e2231. https://doi.org/10.1002/icd.2231

Yang, L., Xiong, Y., & Chen, Q. (2023). The role of linguistic and cognitive skills in reading Chinese as a second language: A path analysis modeling approach. *Frontiers in Psychology, 14*, Article 1131913. https://doi.org/10.3389/fpsyg.2023.1131913.

Yang, X., Pan, D. J., Lo, C. M., & McBride, C. (2024). Same or different: Chinese character reading and word reading of young readers with development. *Reading and Writing*, *37*(4), 817-839. https://doi.org/10.1007/s11145-022-10255-9

Yang, R., & Wang, W. S. Y. (2018). Categorical perception of Chinese characters by simplified and traditional Chinese readers. *Reading and Writing*, *31*, 1133-1154. https://doi.org/10.1007/s11145-018-9832-y

Zhang, D. (2017). Word reading in L1 and L2 learners of Chinese: Similarities and differences in the functioning of component processes. *Modern Language Journal, 101*(2), 391-411. https://doi.org/10.1111/modl.12392

Zhou, J. (2021). The contribution of morphological awareness and vocabulary knowledge to Chinese as a second language reading comprehension: A path analysis. *Journal of Psycholinguistic Research, 51,* 55-74. https://doi.org/10.1007/s10936-021-09810-2

Zhou, X., & Marslen-Wilson, W. (1994). Words, morphemes, and syllables in the Chinese mental lexicon. *Language and Cognitive Processes, 9,* 393-422. https://doi.org/10.1080/01690969408402125

Zou, Z., Zhao, W., & Li, M. (2022). The deficit profile of executive function in Chinese children with different types of reading difficulties. *Reading and Writing*. https://doi.org/10.1007/s11145-021-10194-x