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Linguistic constraints on the cross-linguistic variations in L2 word recognition

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Abstract

This study investigated how experience with a first language (L1) writing system affects the development of the second language (L2) word recognition subskills and how L2 linguistic knowledge constrains such L1 impacts. In this study, word recognition is conceptualized as a complex construct that entails multiple subskills necessary for identifying a word based on the linguistic information (phonology and morphology) encoded in its visual form. To capture the complexity of the construct, we measured three word-form analysis skills, including orthographic, grapho-phonological, and grapho-morphological processing subskills. We then compared their relative contributions to word-meaning retrieval and reading comprehension among fifty-two college-level Chinese students who learned English in the U.S. The results demonstrated that while orthographic processing subskills were a significant predictor of word-meaning retrieval, grapho-morphological processing subskills were the only factor contributing to text comprehension. In addition, our data revealed that L2 linguistic knowledge played differential roles in mediating the contribution of the L2 word-form analysis skills to word-meaning retrieval and reading comprehension. These findings suggest that L2 word recognition development is constrained not only by previously acquired reading skills and but also by emerging knowledge of the target language. We discussed how the notion of script relativity encapsulates such complex cross-linguistic interactions among morpho-syllabic Chinese (L1), morpho-phonemic English (L2) writing systems, and L2 linguistic knowledge in L2 word recognition development.

Keywords Word recognition · L2 reading · L2 linguistic knowledge · L1 writing system

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Introduction

Writing systems encode their respective spoken languages (Frost, 2012; Perfetti, 2003; Perfetti & Harris, 2013). The meaning of a word is accessed through its phonological and morphological information presented in its graphic form. Because phonological and morphological information is encoded differently in diverse writing systems (Perfetti & Stafura, 2014; Wang et al., 2005; Zhao et al., 2014), the relative reliance on grapho-phonological and grapho-morphological mappings varies across languages. In this study, we examined the script relativity hypothesis by exploring how the properties of the first language (L1) writing system affected the relative reliance on the word-form analysis skills during the second language (L2) word-meaning retrieval and reading comprehension. We also examined how L2 linguistic knowledge constrained such L1 impacts. The primary goal of this article is to provide the detailed descriptions of the cross-linguistic interactions between L1 reading skills and L2 linguistic knowledge in L2 reading development. Based on Koda (2016), we conceptualize word recognition as a complex construct that consists of two qualitatively distinct processes, i.e., word-form analysis and word-meaning retrieval. Word-form analysis entails multiple subskills necessary for identifying a word based on its orthographic, phonological, and morphological information for the purpose of retrieving its meaning. We use “skills” and “subskills” to distinguish two levels of operations. The term “skills” refers to the higher-level operations (i.e., word-form analysis and word-meaning retrieval) and the term “subskills” denotes the components of word-form analysis (i.e., orthographic, grapho-phonological, and grapho-morphological processing).

In what follows, we clarify the assumptions underlying this study. First, as noted above, we view word recognition as a multifaceted construct that consists of multiple sets of skills and subskills (Frost, 2012; Koda, 2005, 2016). Second, from a cross-linguistic perspective, we suppose that the relative reliance on distinct subskills reflects the specific way in which phonological and morphological information is graphically encoded in a printed word (Frost, 2012; Koda, 2016; Pae et al., 2019). Based on current theories of reading skills transfer, we also presume that L1 word-form analysis skills have traceable impacts on the formation of their corresponding skills and subskills in a second language (Koda, 2007; McBride et al., 2021; Yamashita, 2018). Finally, the notion of reading universals states that word recognition is the process of converting sequences of graphic symbols into the linguistic information they encode (Frost, 2012; Perfetti & Stafura, 2014; Share, 2008). We thus assume that L2 linguistic knowledge plays a critical role in L2 word recognition development.

Word-form analysis

Orthographic processing subskills

Orthographic processing is the process of acquiring, storing, and using the spelling and visual conventions in a writing system to recognize a printed word or word parts (Stanovich & West, 1989; Treiman & Cassar, 1997). Haynes and Carr (1990) describe orthographic knowledge as an understanding of permissible spelling patterns in a particular writing system.

L2 reading research has shown that orthographic processing subskills make a unique contribution to word recognition in adult L2 learners (Kato, 2009; Nassaji & Geva, 1999). For example, Kato (2009) reported that L2 orthographic processing subskills were an important predictor of L2 reading comprehension among advanced Japanese speakers who learned English as a second language (ESL). Similarly, Nassaji and Geva (1999) measured the contribution of orthographic processing efficiency to three English reading measures among 60 Farsi-speaking advanced ESL learners. The orthographic processing efficiency was measured by a wordlikeness judgment task. The three reading measures were reading comprehension, silent reading rate, and single word reading. They found that English orthographic processing efficiency explained 4%, 4%, and 10% of the variances associated with reading comprehension, silent reading rate, and single word recognition measures, respectively. It is noteworthy that the contribution of orthographic processing efficiency to the single word reading measure disappeared when L2 linguistic knowledge was controlled, indicating that the possible complex relationships between the two variable need further examinations.

Grapho-phonological processing subskills

Grapho-phonological processing refers to "a systematic and rapid translation of spelling patterns into phonologically appropriate codes" (Nassaji & Geva, 1999). Previous studies have shown the facilitative impact of grapho-phonological processing on word recognition and reading comprehension in both L1 and L2 (Harrison & Krol, 2007; Kibby et al., 2014; Wawire & Kim, 2018). The Universal Phonological Principle (Perfetti et al., 1992) explained the centrality of phonological processing in reading acquisition across writing systems. The theory posits that reading is embedded between spoken language and its writing system. Inevitably, learning to read entails learning to map between spoken language elements (phonology and morphology) and the graphic symbols that encode them (Perfetti, 2003; Perfetti et al., 1992).

The importance of grapho-phonological processing subskills also lies in their relationship with working memory. The phonological loop, as one of the four components of working memory, is responsible for storing the phonological form of visual input (the other three are visuospatial sketchpad, central executive, and episodic buffer) (Baddeley & Jarrold, 2007). Using articulatory suppression reading, studies found that interfering normal functioning of the phonological loop prevented the reader from accumulating incoming information in working memory for recognizing known words, learning new words, and integrating local text meanings (Deng & Wang, 2006; Nairne & Kelley, 1999; Wang et al., 2021).

L2 reading research has also demonstrated that grapho-phonological processing is closely related to word recognition and text comprehension (Geva & Yaghoub-Zadeh, 2006; Gottardo et al., 2001; Jeon & Yamashita, 2014; Lervåg & Aukrust, 2010). In their synthesis based on 18 studies, Jeon and Yamashita (2014) reported a strong and positive correlation between phonological decoding and reading comprehension ($r = 0.56$, $p = 0.00$) among 2,363 foreign language and second language learners of various target languages from eight L1 backgrounds. In another meta-analysis, Lervåg and Aukrust (2010) also found significant relationships between phonological decoding and reading comprehension in six ESL studies comprising 882 children. Their analysis revealed that the overall mean correlation coefficient between decoding and reading comprehension was medium ($r = [0.45, 0.59]$) and significant ($p < 0.05$).

Grapho-morphological processing

Morphemes are the smallest units that encode both semantic and grammatical information in a language (Taylor & Taylor, 2014). As such, they are essential in connecting the visual form of a word with its meaning. L2 reading studies have shown that grapho-morphological processing efficiency has significant impacts on L2 decoding (Ke & Koda, 2021) and word-meaning inference (Ke & Xiao, 2015; Zhang et al., 2016). For instance, Ke and Koda (2021) found that English morphological awareness contributed to Chinese bimorphemic three-character pseudoword reading indirectly via the mediation of Chinese morphological awareness and Chinese monomorphemic two-character real word reading among fifty English-speaking college students who learned Chinese as a foreign language.

In addition, grapho-morphological processing ability is found to distinguish good from poor L2 readers (Hipfner-Boucher et al., 2016) and to facilitate L2 reading comprehension independently from L2 vocabulary knowledge (Chen et al., 2021; Jeon, 2011; Zhang & Koda, 2012). Specifically, Zhang and Koda (2012) found that English derivational awareness indirectly affected reading comprehension via the mediation of vocabulary knowledge and lexical inferencing ability in English among Chinese-speaking English learners at a university in China. Similarly, using a longitudinal design and a path analysis, Chen et al. (2021) reported both direct and indirect paths from early Chinese grapho-morphological knowledge to later reading comprehension among beginning-level Chinese foreign language learners. These findings collectively suggest that grapho-morphological processing efficiency affects L2 word recognition and reading comprehension. However, the results are mixed in terms of whether this impact is direct or mediated by L2 linguistic knowledge.

Script relativity: comparison between English and Chinese writing systems

One of the major questions on the linguistic relativity hypothesis is whether the script we read in our daily lives has a lasting impact on our cognition (Pae, 2020). The script relativity hypothesis has gained support from studies that have demonstrated the impact of scripts on non-linguistic cognitive skills such as arithmetic skills (Lui et al., 2021) and linguistic skills, including the relationship between vocabulary and word reading, spatial layouts, and lexical tones (Georgiou et al., 2022; Inoue et al., 2021; Winskel, 2022). Given that these studies primarily focus on the L1 reading acquisition, we tested the impacts of the L1 writing system on the relative reliance on L2 word-form analysis subskills.

Chinese and English writing systems vary in several ways. These differences offer an ideal window for investigating the script relativity hypothesis (Lui et al., 2021). While Chinese characters encode syllables and morphemes (Taylor & Taylor, 2014), the English writing system primarily encodes phonemes and morphemes. Because of its tendency to preserve morphological information in the grapheme, the English grapheme-phoneme relationship is far less transparent than most other alphabetic systems (Chomsky, 2009; Taylor & Taylor, 2014). These differences are directly related to the heavier reliance on grapho-phonological processing subskills during word recognition in English than in Chinese (Chen et al., 1995; Coltheart et al., 1994; Kim et al., 2020; Leck et al., 1995; Seidenberg, 2011; Tan et al., 2000; Van Orden, 1987; Williams & Bever, 2010; Zhou & Marslen-Wilson, 2009). For instance, using a semantic category judgment task, Van Orden (1987) asked participants to judge whether a target word was an exemplar of the preceding category. The stimuli were either homophone foils ("rows" sounds like "rose") or spelling controls (e.g., "robs" looks like "rose"). The author found that the English-speaking college students had a higher rate of false positive errors for the homophone foils than for the spelling controls. The higher false error rate was regarded as the interference of the phonologically similar information in word-meaning retrieval. In contrast, the phonological interference effect was not observed to the same extent in Chinese using a similar task (Chen et al., 1995; Leck et al., 1995). Results showing heavier reliance on phonological information by English readers than by Chinese readers were reported in studies using neuroimaging (Kim et al., 2020; Tan et al., 2000), lexical decision (Williams & Bever, 2010; Zhou & Marslen-Wilson, 2009), and priming tasks (Chen & Shu, 2001).

Conversely, both Chinese and English writing systems encode morphological information. Reflecting the morphophonemic representation in the English writing system, English-speaking children initially depend on phonological information in word recognition and gradually shift their reliance to morphological information as they go through schooling (Deacon & Kirby, 2004; Ke & Xiao, 2015; Ku & Anderson, 2003; Nagy et al., 2006; Share, 2008). As a result, English grapho-morphological processing subskills develop slowly over time throughout schooling (Deacon & Kirby, 2004; Ku & Anderson, 2003; Nagy et al., 2006). In contrast, grapho-morphological subskills play important roles in the early stages of reading development in Chinese (Choi et al., 2018; Liu & McBride-Chang, 2010; Shu et al., 2006). For instance, Choi et al. (2018) reported that Chinese morphological awareness explained larger variances in Chinese reading (12–22%) while English morphological awareness explained considerably significant, yet smaller variances (2–8%) in English reading for Chinese-English bilingual children in Grades 2, 5, and 8 in Hong Kong. These studies indicate that grapho-morphological processing subskills play a role, though to a different extent, in both Chinese and English reading comprehension.

Cross-linguistic consequences of script relativity

In L2 reading research, the involvement of L1 word-form analysis skills in L2 reading development has been well established (Ma & Ai, 2018; Nassaji & Geva, 1999; Wang et al., 2003). Take grapho-morphological processing subskills as an example. A growing body of research reported that morphological awareness in L1 Chinese significantly contributed to L2 word recognition, word meaning inference, and reading comprehension in English (Chen, 2019; Ke & Koda, 2021; Ke & Xiao, 2015; Ke et al., 2021; Luo et al., 2014; Wang et al., 2009; Zhang & Koda, 2013, 2021). In a meta-analysis including 34 correlational studies in ten languages, Ke et al. (2021) found significant cross-linguistic influences of L1 morphological awareness on L2 morphological awareness, word recognition, and reading comprehension. Similarly, Zhang and Koda (2021) found that English morphological awareness had a significant indirect effect on Chinese lexical inference ability via Chinese vocabulary knowledge and English lexical inference ability among 195 collegiate English-speaking Chinese heritage language learners. Taken as a whole, these findings suggest that the L1 word-form analysis subskills have notable influences on L2 word recognition and comprehension. They also point to the need for incorporating grapho-morphological processing as an additional facet of word-form analysis skills.

To sum up, the differential properties of the Chinese and English writing systems lead to the different degrees of reliance on the three word-form analysis subskills in word-meaning retrieval and text comprehension. While the grapho-morphological processing subskills are prominent in both Chinese and English writing systems, Chinese readers rely more heavily on orthographic over phonological processing subskills than do English readers.

Predictions

Based on the distinct features of the Chinese and English writing systems, we made the following predictions regarding the formation of the English word-form analysis skills among Chinese ESL learners. First, if the L1 writing system has traceable impacts on L2 word-form analysis subskills, Chinese ESL learners would rely more heavily upon orthographic processing subskills over grapho-phonological processing subskills in

L2 word-meaning retrieval and text comprehension. If the L1 impacts do not exist, we would detect the stronger reliance on grapho-phonological processing subskills.

Given the prominence of morphological information in both Chinese and English writing systems, grapho-morphological processing subskills are predicted to affect L2 word-meaning retrieval and reading comprehension regardless of the L1 impacts. The prominence of morphological information in both writing systems also allows us to explore the interactions between L1 word-form analysis skills and L2 linguistic knowledge in the formation of L2 word-form analysis skills. If L1 word-form analysis skills have stronger impacts than L2 linguistic knowledge on the formation of L2 word-form analysis skills, Chinese ESL learners' reliance on morphological information would be less affected by L2 linguistic knowledge. If, on the other hand, L2 linguistic knowledge overpowers the impacts of L1 word-form analysis subskills, the utilization of L2 orthographic and grapho-morphological processing would be substantially constrained by L2 linguistic knowledge.

Present study

To test the predictions above, the current study compared the relative contributions of three word-form analysis component subskills to word-meaning retrieval and text comprehension. Additionally, the study examined how L2 linguistic knowledge affected the relative reliance on those subskills. We posed the following questions:

RQ 1: What are the relative contributions of the three word-form analysis subskills (orthographic, grapho-phonological, and grapho-morphological processing) to word-meaning retrieval and reading comprehension in L2?

RQ2: How does L2 linguistic knowledge constrain the contributions of the three word-form analysis subskills (orthographic, grapho-phonological, and grapho-morphological processing) to word-meaning retrieval and reading comprehension in L2?

Participants

Fifty-three Chinese college students of English as L2 learners (19 males and 34 females) in the U.S. took part in the experiment. They had completed at least a high school education in China and did not speak any language other than Chinese and English fluently at the time of the experiment. One participant was removed from the data analysis as the participant's performance on the English reading comprehension test and the English grammar test were both below 3 SDs. Table 1 summarizes the demographic information of the participants.

Table 1 Chinese ESL participants' demographic information (N = 52)

Demographic information	M (SD)
Age in years	25.56 (4.99)
Sex	19 M, 34F
Age of learning English (year)	14.05 (3.60)
Length of residence in English environment (month)	17.55(3.84)
Self-rated English proficiency levels (0: very low—8: perfect)	5.02 (1.21)
Self-rated English reading ability (0: very low—8: perfect)	5.43 (1.24)

Tasks

Orthographic processing subskills

The wordlikeness judgment task was designed to measure the participants' orthographic processing subskills. In this task, a string of letters was shown on the center of the monitor until a response was given for up to 3 s, followed by a 500-ms inter-trial cross fixation and a 500-ms inter-trial-interval. The participants were told that none of these letter strings was a real English word. They were then instructed to judge whether each letter string could be an English word as quickly and accurately as possible by pressing the key "A" if they thought that the letter string could be an English word and the key "L" if not. The participants did three practice trials before the experiment. Their accuracy (the number of appropriate responses) and reaction times were measured and recorded.

The stimuli were adapted from Massaro et al. (1979) and were also used by Koda (1999) and Martin (2015). All stimuli had six letters. They varied in terms of the letter combination legality and positional frequency. Four sets of stimuli were created: legal letter strings with high positional frequency, legal strings with low positional frequency, illegal strings with high positional frequency, and illegal strings with low positional frequency. Each set had 20 items, and a total of 80 items were randomized across participants. The Cronbach α of this task was 0.97. The full list of the stimuli used in this task can be found in Table S1 in Supplementary Materials.

Grapho-phonological processing subskills

The pseudoword naming task was used to measure the participants' grapho-phonological processing subskills. The participants were presented with a letter string for up to 3 s, followed by a 500-ms cross fixation at the center of the monitor. There was another 500-ms inter-stimulus interval. The participants were instructed to read aloud the letter string as quickly and accurately as possible.

The stimuli were taken from the Phonetic Decoding Efficiency subtest in the *Test of Word Reading Efficiency* (Torgesen et al., 1999). There were 33 regular and irregular pronounceable English nonwords and pseudowords, including simple and short monosyllabic items that were increasingly longer and more complex. There were three practice trials before the experiment. The participants' oral responses and their reaction times were recorded. The Cronbach α of this test was 0.72.

Grapho-morphological processing subskills

The morphological segmentation task was used to measure the participants' grapho-morphological processing subskills (Koda & Miller, 2018; Zhang & Koda, 2021). The participants were presented with an English word. They were then instructed to judge whether the word could be segmented into smaller meaningful units. If yes, they were asked to add a slash between morphemic units within the word. For instance, for the word "blackboard," the participants would add a slash after the morpheme "black" (e.g., black/board). The participants were given up to 7 s for each item.

There were 24 items in this task, including eight mono-morphemic words, eight compound words, and eight derivational words. The letter number and the word frequency were controlled across the word types. To avoid the impact of vocabulary knowledge, only high-frequency words were used in the task. The word frequency was derived from the Corpus of Contemporary American English (Davies, 2008; see Table S2 for detailed information). To confirm that these high-frequency words were indeed familiar to the participants, twenty-nine participants who voluntarily took part in the post-hoc survey scanned the vocabulary list to identify any unfamiliar words. As expected, none of the participants reported any unknown words. The Cronbach α of this task was 0.77 after the word "historical" was removed (see the Scoring section for details). The full list of the words can be found in Table S2 in Supplementary Materials.

Word-meaning retrieval

The category decision task was used to measure the participants' word-meaning retrieval. In this task, the participants were first given a category name for 1,500 ms (e.g., "animal") and then a target stimulus on the screen for up to 3 s (e.g., "panda"). They were asked to judge whether the presented stimulus belonged to the category as quickly and accurately as possible by pressing the "A" (yes) or "L" (no) key on the keyboard. Thirty-seven correct trails and 37 distractors were included in this task. These 74 stimuli came from nine of the 27 most common categories reported in Hebart et al. (2019) by sampling a set of 1,854 diverse object concepts systematically from concrete picturable and nameable nouns in the American English language. To minimize the possible impact of vocabulary knowledge, we used only high-frequency words. As in the grapho-morphological processing task, we asked the participants to scan the word list and report any unknown words to confirm that these words were familiar to them. Again, the 29 participants who had agreed to participate did not report any unknown words in this task. The full list of the stimuli can be found in Table S3 in Supplementary Materials. The Cronbach α of the current task was 0.99.

English linguistic knowledge tests

Following the tradition of L2 reading studies, linguistic knowledge was determined by knowledge of vocabulary and grammar (Bernhardt & Kamil, 1995; Jeon & Yamashita, 2014; Lee & Schallert, 1997).

Vocabulary test: The participants took part in an online English vocabulary test named LexTALE (available online at www.lextale.com). The test consisted of 40 words and 20 nonwords selected from 240 items of an unpublished vocabulary size test called "10 K" (Meara, 1996). The participants were instructed to decide whether the string of letters presented on the monitor was an existing English word or not. The past empirical studies have suggested that LexTALE is a good indicator of vocabulary knowledge, and it is also correlated substantially with general language proficiency (Izura et al., 2014; Lemhöfer & Broersma, 2012; Nakata et al., 2020).[1]

Grammar test: The grammar test consisted of 20 multiple-choice questions, which were adapted from the retired versions of the Test for English majors-Band 4 (TEM-4) and the Test for English majors-Band 8 (TEM-8) published by Shanghai Jiao Tong University Press. The participants were asked to choose which of four choices could make the sentence grammatically correct. The participants were given 10 min to finish this test. Their scores in the vocabulary test and grammar test were standardized as z scores and summed to represent their linguistic knowledge. The Cronbach α of the grammar test was 0.91.

Reading comprehension test

The participants' reading comprehension was measured by a practice version of the ACCUPLACER reading comprehension test by the College Board with 15 multiple-choice questions that tapped into the participants' gist understanding, textual inferencing, and global inferencing. The participants were given up to 10 min to finish the test. The Cronbach α of the test was 0.67.

Working memory test

The working memory test was adapted from a standardized working memory span task (Conway et al., 2005). In this test, a string of numbers varying from 3 to 9 digits appeared on the screen for one second. The participants were asked to type the number as it appeared on the screen as accurately and quickly as possible into an input box. The maximum response time was 7 s for each trial. There were 14 trials in total. The Cronbach α of the current test was 0.88.

[1] The Cronbach α of the vocabulary test is not available as it is conducted on the third-party online platform (www.lextale.com). The test produces a holistic score for each participant rather than individual score for each question.

Procedure

All tasks were approved by the ethical committee on human research of the authors' institution. The participants had an individual online meeting with an experimenter. To mimic the setting of a lab experiment to the largest extent, each participant was required to stay alone in a quiet place with earphones on. Before the experiment, they signed an online consent form and completed the Language Experience and Proficiency Questionnaire (Marian et al., 2007), which was administered to collect the participants' basic demographic information, language learning experience, and self-assessed language proficiency.

All the measures were administered via the online platform *Gorilla Experiment Builder* (https://app.gorilla.sc). This platform is an online behavioral experiment builder that has the capacity to run time-sensitive experiments (Anwyl-Irvine et al., 2020). The sequence of the tasks was counterbalanced, and that of the stimuli was randomized. The participants were shown both Chinese and English instructions before each task. They did three trials for practice. The data of the practice trials were not included in the analysis. After the experiment, twenty-nine participants who had agreed to take part in the post-hoc survey were asked to report any unfamiliar English words in the category decision task and the morphological segmentation task because the two tasks used real English words. As mentioned above, none indicated that they had encountered any unfamiliar words. The whole experiment took about 50 min.

Scoring

In the pseudoword naming task, the participants' oral responses were scored as correct based on the phonetic denotations in the standard scoring guidelines provided in the Examiner's Manual of the TOWRE (Torgesen et al., 1999) and the oral responses produced by 30 English native speakers. The participants were not penalized for foreign accents and dialectal variations, as the task was operationalized as a measure of decoding rather than a speaking or pronunciation test. A total of 329 oral responses (18.81%) were removed from the analysis because of noise or recording errors.[2] Therefore, the participants' scores in the pseudoword naming task were calculated as the proportion (%) of the correct responses out of the remaining items. The scores of seven participants were treated as missing values in the data analysis, as more than 66.67% of the responses were missing. At least 27 oral responses (81.82%) were recorded properly for the rest 45 participants.

The participants' morphological segmentation responses were scored based on the segmentation answers provided by 30 native English speakers. For each word,

[2] Audio data loss is almost inevitable in the online experiment, which was adopted due to the impact of the pandemic. We used the maximum likelihood with missing values when conducting the path analysis that involved the grapho-phonological processing subskills. The technique allowed us to minimize the possible effect of the missing values in the grapho-phonological processing subskills.

Table 2 Descriptive statistics of All Measures

Measure	Mean	Std. Dev	Min	Max
Reading comprehension (scores)	10.73	1.98	6	15
Linguistic knowledge (standardized scores)	− 1.93	1.63	− 4.02	4.02
Word-meaning retrieval speed (ms)	1010.04	191.31	714.19	1485.90
Word-meaning retrieval accuracy (scores)	70.46	2.85	62	74
Orthographic processing speed (ms)	1130.16	305.59	661.89	1736.86
Orthographic processing accuracy (scores)	60.65	7.75	45	72
Grapho-morphological processing accuracy (scores)	19.79	2.52	12	23
Grapho-phonological processing accuracy (percent)	87	12	47	100
Working memory (scores)	10.94	1.70	6	13

Notes in the parentheses represent measure units of the tasks

the segmentation answer uniformly produced by more than 24 English native speakers (80%) was regarded as the correct answer. One item ("historical") was removed from the analyses because of the low agreement among the native speakers on its segmentation.

Two raters scored constructive responses from the pseudoword naming task and morphological segmentation task. They first scored the responses from five participants individually and then discussed the scoring issues. After reaching a consensus and establishing the scoring criteria, they started grading the rest of the responses that were assigned to them randomly. About 30% of the responses were double graded by the two raters. The inter-rater reliability was 92% and 100% for the pseudoword naming task and the morphological segmentation task, respectively.

Results

Descriptive statistics and binary correlations of all the measures are provided in Tables 2 and 3.

Preliminary analysis

As Table 3 shows, grapho-phonological processing accuracy and speed, which were measured by the pseudoword naming task, did not correlate with linguistic knowledge or reading comprehension. They did not correlate with word-meaning retrieval, either.

Orthographic processing accuracy, which was measured by the wordlikeness judgment task, had no correlation with linguistic knowledge or reading comprehension. It was positively correlated with word-meaning retrieval accuracy ($r=0.488$, $p=0.000$). The orthographic processing speed also had a significant positive correlation with word-meaning retrieval speed ($r=0.382$, $p=0.005$).

Grapho-morphological processing accuracy was positively correlated with linguistic knowledge ($r=0.302$, $p=0.029$) and reading comprehension ($r=0.342$,

Table 3 Binary correlations among all variables

	1	2	3	4	5	6	7	8	9
1. Reading comprehension	1								
2. Linguistic knowledge	.46***	1							
3. Word-meaning retrieval speed	−.03	−.04	1						
4. Word-meaning retrieval accuracy	.28*	.39**	.25	1					
5. Orthographic processing speed	.21	−.18	.38**	.16	1				
6. Orthographic processing accuracy	.10	.27	.15	.49***	.50***	1			
7. Grapho-morphological processing accuracy	.34*	.30*	−.04	.09	−.05	.14	1		
8. Grapho-phonological processing accuracy	.15	.13	−.03	.02	−.01	−.15	.11	1	
9. Working memory	.23	.17	−.08	.11	−.08	.16	.36**	.16	1

*$p<.05$; **$p<.01$; ***$p<.000$

$p=0.013$). However, it did not correlate with word-meaning retrieval accuracy or speed.

The participants' word-meaning retrieval accuracy had significant and positive correlations with both linguistic knowledge ($r=0.393$, $p=004$) and reading comprehension ($r=0.276$; $p=0.037$). The word-meaning retrieval speed did not correlate with linguistic knowledge or reading comprehension.

> *RQ1*: What are the relative contributions of the word-form analysis skills – in specific, orthographic, grapho-phonological, and grapho-morphological processing subskills – to word-meaning retrieval and reading comprehension in L2?

RQ1 asked if the L1 writing system would affect the relative reliance on the word-form analysis skills in word-meaning retrieval and reading comprehension in L2. To answer this question, we compared two possible models using the path analysis in Stata (Statacorp, 2019). Given that none of the speed measures were significantly correlated with the dependent variables (word-meaning retrieval and reading comprehension), the following analysis was based on the accuracy scores.

The first model presumes that the L1 writing system does not affect the readers' L2 word recognition. Should this be the case, Chinese learners of English would not rely on orthographic processing subskills more heavily than on phonological processing subskills. As such, Model 1 specifies the three word-form analysis skills equally contribute to the word-meaning retrieval and reading comprehension in L2. The hypothetical relationships in Model 1 were tested via path analysis (Fig. 1).

Figure 1 showed the results of the relative contributions of the three word-form analysis skills. Of the three subskills, only orthographic processing accuracy significantly contributed to word-meaning retrieval ($\widehat{\beta}$ = 0.50, $p<0.000$). In addition, word-meaning retrieval and grapho-morphological processing accuracy directly affected reading comprehension ($\widehat{\beta}$ = 0.28, $p=0.048$; $\widehat{\beta}$ = 0.32, $p=0.009$,

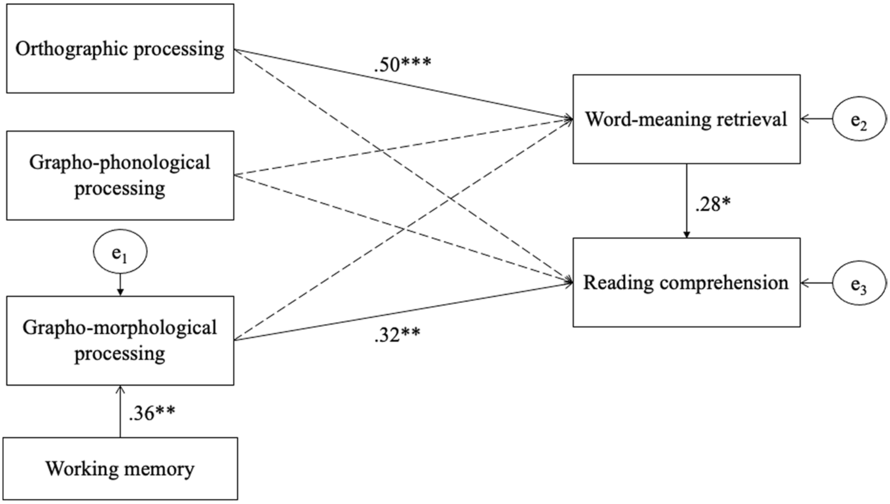

Fig. 1 Result of the Path Analysis Model with no L1 Impacts (Model 1). *Note.* dotted lines represent insignificant paths. *$p < .05$; **$p < .01$; ***$p < .000$

respectively). Working memory only directly affected grapho-morphological processing accuracy ($\hat{\beta}$ = 0.36, $p = 0.002$). Generally speaking, a p-value greater than 0.05, a Root Mean Square Error of Approximation (RMSEA) less than 0.08, a Comparative Fit Index (CFI) greater than 0.95, and a standardized Root Mean Square Residual (SRMR) less than 0.05 are indices of a good model fit (Stevens, 2012; Schumaker & Lomax, 2004). The post-estimation of this model demonstrated a good model fit ($\chi^2(4) = 1.187$, $p = 0.880$; RMSEA = 0.000, pclose = 0.903; CFI = 1; SRMR = 0.030).

The results in Model 1 revealed that the participants did rely upon orthographic processing subskills more heavily than grapho-phonological processing subskills. This indicates that the L1 writing system has cross-linguistic influences on the relative contributions of the three word-form analysis subskills to L2 word-meaning retrieval and reading comprehension.

We further examined Model 2, which specifies that properties of the L1 writing system have cross-linguistic impacts on the utilization of L2 word-form analysis skills in word-meaning retrieval and reading comprehension. The model specifies first that only orthographic processing subskills contribute to word-meaning retrieval; and, second that grapho-morphological processing subskills are directly related to reading comprehension. It also stipulates that grapho-phonological processing subskills do not have a direct link with either word-meaning retrieval or reading comprehension.

Model 2 (Fig. 2) showed the relative contributions of the three word-form analysis subskills to word-meaning retrieval and reading comprehension which had been predicted based on the Chinese writing system. In the model, orthographical processing subskills were a significant predictor of word-meaning retrieval ($\hat{\beta}$ = 0.49, $p < 0.000$). In addition, word-meaning retrieval and grapho-morphological

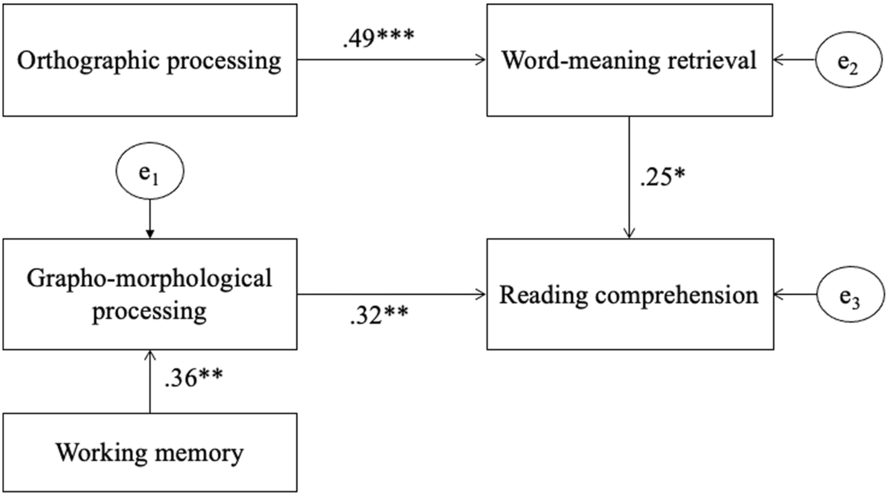

Fig. 2 Result of the Path Analysis Model with L1 Impacts (Model 2). *Note*. *$p<.05$; **$p<.01$; ***$p<.000$

processing subskills contributed significantly to reading comprehension ($\widehat{\beta}$ = 0.25, $p=0.044$, $\widehat{\beta}$ = 0.32, $p=0.008$, respectively). There was no indirect effect from orthographic processing subskills to reading comprehension via word-meaning retrieval. Also, working memory directly affected grapho-morphological processing accuracy ($\widehat{\beta}$ = 0.36, $p=0.002$). The post-estimation showed that Model 2 had a good model fit ($\chi^2(5)=1.427$, $p=0.921$; RMSEA = 0.000, pclose = 0.939; CFI = 1; SRMR = 0.038).

As noted above, both Model 1 and Model 2 have comparable good model fits. As hypothesized, the participants relied upon the orthographic processing subskills and grapho-morphological processing subskills more heavily than the grapho-phonological processing subskills. The results thus reflect the prominence of grapheme-to-morpheme mappings in the Chinese writing system. A clear implication is that L1 writing system has marked impacts on the relative reliance on the three word-form analysis subskills in word-meaning retrieval and reading comprehension among Chinese ESL learners. However, given both Chinese and English writing systems encode morphological information in the grapheme, there is a need to clarify if the reliance on the grapho-morphological processing subskills indeed stems from the impact of the L1 Chinese (morphosyllabic) writing system or from that of the L2 English (morphophonemic) writing system. Therefore, we tested if the reliance on morphological processing subskills was constrained by L2 linguistic knowledge in RQ2.

RQ 2: How does L2 linguistic knowledge constrain the contributions of the word-form analysis skills (in specific, orthographic, grapho-phonological, and grapho-morphological processing subskills) to word-meaning retrieval and reading comprehension in L2?

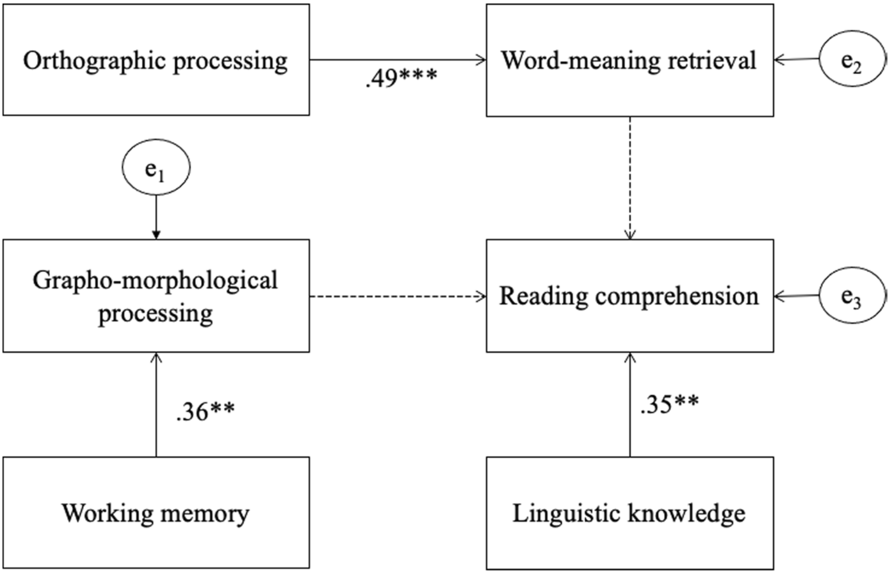

Fig. 3 Results of the Path Analysis Model with no Linguistic Constraints (Model 3). *Note.* dotted lines represent insignificant paths. *$p<.05$; **$p<.01$; ***$p<.000$

To examine the linguistic constraints on L2 word recognition, we compared two models using path analysis. Model 3 presumes that linguistic knowledge does not constrain the relationships among word-form analysis, word-meaning retrieval, and reading comprehension in L2. As such, it would only directly affect L2 reading comprehension.

Model 3 had overall a good model fit ($\chi^2(8)=11.291$, $p=0.186$; RMSEA = 0.090, pclose = 0.264; CFI = 0.922; SRMR = 0.109). As shown in Fig. 3, orthographic processing subskills significantly contributed to word-meaning retrieval ($\hat{\beta} = 0.49$, $p<0.000$). For reading comprehension, only linguistic knowledge was a significant predictor ($\hat{\beta} = 0.35$, $p=0.009$). When linguistic knowledge was entered into the model, the direct effects of the word-meaning retrieval and grapho-morphological processing subskills on reading comprehension observed in Model 2 disappeared. These results indicate that their effects might be mediated by linguistic knowledge (tested in Model 4. The following model (Model 4) tested this interpretation. The current model showed no indirect effect of orthographic processing subskills on reading comprehension via word-meaning retrieval. Also, working memory directly affected grapho-morphological processing accuracy ($\hat{\beta} = 0.36$, $p=0.002$).

In Model 4, we then tested if adding the mediating role of linguistic knowledge would increase the model fit (Fig. 4). The results demonstrated (Fig. 4) that orthographic processing subskills significantly predicted word-meaning retrieval ($\hat{\beta} = 0.49$, $p<0.000$); word-meaning retrieval ($\hat{\beta} = 0.37$, $p=0.001$) and grapho-morphological processing subskills ($\hat{\beta} = 0.27$, $p=0.024$) both significantly predicted linguistic knowledge; and linguistic knowledge in turn explained a significant portion of the variance in reading comprehension ($\hat{\beta} = 0.45$, $p<0.000$);

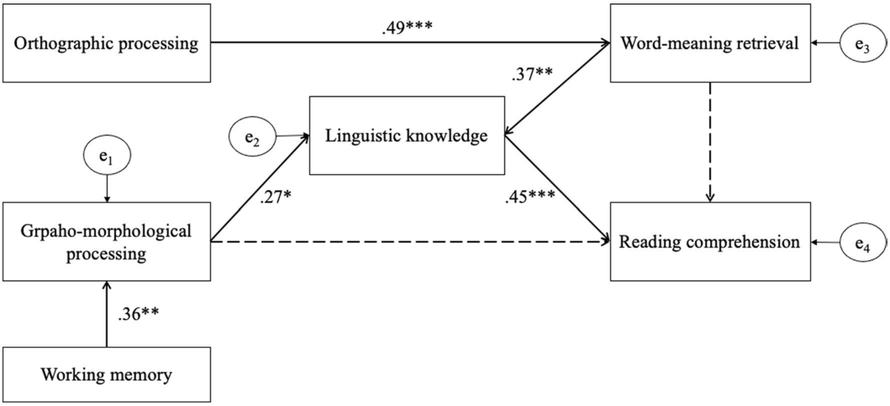

Fig. 4 Results of the Path Analysis Model with Linguistic Constraints (Model 4). *Note.* dotted lines represent insignificant paths. Given that orthographic processing subskills did not correlate with linguistic knowledge, we did not pre-specify a direct relationship between them. *$p<.05$; **$p<.01$; ***$p<.000$

working memory had a direct impact on grapho-morphological processing accuracy ($\widehat{\beta}$ = 0.36, $p=0.002$). Importantly, the subsequent analysis of the indirect paths revealed that linguistic knowledge constrained the relationships among word-form analysis, word-meaning retrieval, and reading comprehension. In specific, the indirect contribution of word-meaning retrieval to reading comprehension via linguistic knowledge was significant ($\widehat{\beta}$ = 0.17, $p=0.020$). Notably, the indirect contribution of the grapho-morphological processing subskills to reading comprehension via linguistic knowledge approached a level of significance ($\widehat{\beta}$ = 0.12, $p=0.059$). Lastly, orthographic processing subskills had an indirect impact on reading comprehension via both word-meaning retrieval and linguistic knowledge ($\widehat{\beta}$ = 0.02, $p=0.043$). In sum, Model 4 shows an improvement of the model fit via a smaller chi-square, RMSEA, and SRMR, and a larger CFI ($\chi^2(9)=9.541$, $p=0.389$; RMSEA = 0.034, pclose = 0.489; CFI = 0.987; SRMR = 0.088).

In sum, in RQs 1 and 2, we tested the L1 impacts on the L2 word-form analysis skills during L2 word-meaning retrieval and reading comprehension. We also examined how the relative reliance on the word form analysis skills is constrained by L2 linguistic knowledge. The path analyses yielded two major findings. First, as predicted, the orthographic and grapho-morphological processing subskills played more significant roles in word-meaning retrieval and reading comprehension than did the grapho-phonological processing subskills. Second, linguistic knowledge differently mediated the contribution of word-form analysis skills and word-meaning retrieval to reading comprehension. These findings imply that the L1 writing system has lasting impacts on L2 word recognition development and, also that L2 linguistic knowledge alters the L1 impacts on the utilization of L2 word-form analysis subskills for retrieving word meanings.

Discussion

In the current study, word recognition is seen as a dual-faceted construct consisting of word-form analysis and word-meaning retrieval. Of the two, word-form analysis varies across languages because the way the graphs encode phonological and morphological information varies in diverse writing systems (Frost, 2012; Seidenberg, 2011). Two questions arose: First, how do such variations affect word recognition development in an additional language? Second, how does L2 linguistic knowledge affect cross-linguistic influences of the L1 word-form analysis skills on L2 word recognition development?

Consistent with the previous findings (Chen & Shu, 2001; Wang et al., 2003; Williams & Bever, 2010), we found that the features of the L1 writing system had detectable influences on L2 word recognition. As a morphosyllabic system, the Chinese writing system does not directly encode phonological information. Previous studies (Chen & Shu, 2001; Wang et al., 2003) have shown that compared with alphabetic readers, Chinese readers are less attuned to phonological information in word recognition and text comprehension. The current study provides additional evidence suggesting that grapho-phonological mapping subskills make little contribution to either word-meaning retrieval or reading comprehension. As Model 2 shows, orthographic processing subskills were the only significant predictor of word-meaning retrieval. These results are consistent with the predictions we made based on our analysis of the features of the Chinese and English writing systems. The features of the L1 writing system influence the formation of L2 word-form analysis skills. The findings thus support the notion of script relativity that prior experience with a particular writing system has lasting impacts on the development of linguistic cognition from a cross-linguistic perspective (Pae, 2020).

It is hard to determine whether the heavier reliance on grapho-morphological than grapho-phonological mappings can be a reliable indicator of the lasting L1 impacts because both Chinese and English writing systems encode morphemes. Therefore, we then examined how L2 linguistic knowledge affected the reliance on orthographic and grapho-morphological processing subskills. We found that the mediating role of L2 linguistic knowledge in the contribution of grapho-morphological processing subskills to reading comprehension was insignificant yet reached an almost significant level ($p = 0.059$). In addition, the contribution of orthographic processing subskills to reading comprehension was mediated by L2 word-meaning retrieval and linguistic knowledge. The insignificant mediating role of linguistic knowledge in the grapho-morphological processing subskills indicates that the utilization of L2 grapho-morphological processing is not substantially constrained by L2 linguistic knowledge. This finding seemingly supports our prediction that the impacts of the L1 writing system overpower L2 linguistic knowledge. However, given the small p-value ($p = 0.059$) and the relatively small sample size, this finding is tentative and needs further research evidence.

Furthermore, our results from Model 4 revealed that L2 linguistic knowledge played differential roles in mediating the contributions of the orthographic and grapho-morphological processing subskills to word-meaning retrieval and reading comprehension. These results clearly imply that a distinct word-form analysis component subskill requires a specific facet and amount of linguistic knowledge to fulfill its function in word-meaning retrieval and reading comprehension. It seems reasonable to suggest that insufficient linguistic knowledge, thus, suppresses L2 learners' utilization of word-form analysis skills in meaning construction at word and text levels.

Surprisingly, L2 grapho-morphological processing subskills did not affect word-meaning retrieval. Rather, it made a significant contribution to reading comprehension (Model 2). There are two possible explanations. First, the lack of relationship between grapho-morphological processing subskills and word-meaning retrieval might be the result of the relatively small number of multi-morphemic words used in the word-meaning retrieval task. Second, as argued by Deacon and Kirby (2004), morphological skills might have a greater role in building text meanings than in reading single words. Indeed, this explanation is consistent with our finding in Model 2 that grapho-morphological processing subskills directly contributed to reading comprehension, but not to word-meaning retrieval. It is essential that these explanations be directly addressed in future studies to clarify the role of grapho-morphological processing subskills in word-meaning retrieval.

Conclusion

This study examined the impacts of the L1 writing system on the contribution of L2 word-form analysis skills to word-meaning retrieval and reading comprehension. The study also explored the constraints imposed by L2 linguistic knowledge on their contributions. Findings indicate that the features of the L1 writing system have a lasting impact on the way L2 learners analyze word forms in retrieving word meanings and integrating them into local text meanings. Our results also suggest that L2 linguistic knowledge mediates the relationships among word-form analysis, word-meaning retrieval, and reading comprehension in L2.

The mediating role of L2 linguistic knowledge implies that linguistic knowledge constrains the way L2 learners use word-form analysis skills in meaning construction both at the word and text levels. This, in turn, suggests that L2 learners cannot employ their word-form analysis skills—orthographic and grapho-morphological processing skills, in particular—effortlessly and efficiently until they develop sufficient knowledge of the language. Hampered by their insufficient linguistic knowledge, low-proficiency learners are less likely to make use of the information derived from the word-form analysis processes in constructing word and text meanings. It is critical that word-form analysis skills be practiced as a means of meaning making at and beyond the word level (i.e., selection of the context-appropriate word meaning and word-text integration, see Koda, 2016 and Perfetti et al., 2008).

Importantly, the relative reliance on the word-form analysis skills and their relation to L2 linguistic knowledge are consistent with the predictions we made based on the analyses of L1 and L2 writing systems. These findings lend support to the script relativity hypothesis. A clear implication is that we could identify possible sources of challenges L2 learners may face in learning to read in a typologically different language and writing system. Such analysis should be incorporated in L2 reading instruction and teacher training for language instructors.

Finally, it would be beneficial for future research to incorporate measures of L1 word recognition skills to directly test the hypothesized impacts of the L1 writing system on L2 word recognition development. Direct measures of L1 word recognition skills would provide more precise information on cross-linguistic influences of L1 script-specific features and, in so doing, help us understand processing variations stemming from script-specific features.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11145-022-10266-6.

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