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CHINESE CHARACTER RECOGNITION
IN NATIVE AND SECOND LANGUAGE READERS

BY

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DISSERTATION

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ABSTRACT

Unlike phonographic writing systems such as that of English, Chinese has a logographic writing system, in which each grapheme encodes both sound and meaning (Sun, 2006). Thus, Chinese provides a unique perspective for the development and examination of reading theories, which are primarily based on the results of alphabetic scripts. Explaining the success of Chinese native readers is also a critical step to understand L2 character recognition and help nonnative speakers become effective Chinese readers. Although there is a growing body of research on both L1 and L2 character recognition, the literature on L1 processing has focused on context-independent character identification, and the majority of the previous studies on L2 character recognition used offline tasks. Therefore, more experimental data are needed to understand how context effects affect character recognition and the nature of L2 character processing in real time.

This study examined how characters were processed by native speakers ($N = 104$) and L2 learners ($N = 105$) under context-independent and context-embedded conditions. By using two primed-character decision tasks, Experiments 1 and 2 explored the orthographic, phonological, and semantic activation of radicals in compound character recognition. Experiment 3 tested context effects on character recognition by comparing radical activation in highly constraining and non-constraining sentence contexts using a self-paced/masked priming paradigm (Luke & Christianson, 2012, 2013). Finally, the influence of L1 orthography on L2 character recognition was examined by comparing the processing patterns of Chinese learners from four typologically different L1 writing systems including abjad, abugida, alphabet, and syllabary/logography.

The results suggest that both native speakers and L2 learners activated the orthographic, phonological, and semantic properties of radicals during character recognition under the context-independent condition. Moreover, native speakers activated radical-level and character-level

representations in parallel when reading compound characters in non-constraining sentence contexts and made specific predictions about the identity of the upcoming character in highly constraining contexts. L2 learners did not activate radical-level information when reading sentences. Nevertheless, they were sensitive to contextual cues and adopted different reading strategies as their Chinese proficiency increased. Although native speakers processed phonetic radicals and semantic radicals in qualitatively and quantitatively similar ways, L2 learners displayed different processing patterns for different types of radicals. Semantic radicals were activated earlier than phonetic radicals; L2 learners who had acquired a limited number of characters were more sensitive to phonetic radicals, whereas those who had acquired a larger number of characters were more sensitive to semantic radicals. Lastly, the results indicate that L1 orthographies may influence L2 character recognition. L2 learners from alphabetic L1 backgrounds had faster responses than those from abugida L1 backgrounds, and learners from shallow L1 orthographies had higher accuracy rates than those from deeper L1 orthographies.

These findings are consistent with previous research on context-independent character recognition and can be accommodated in the Interactive Activation Model (e.g., Taft, 2006), which posits that simple characters and complex characters are represented at different levels. The observed context effect demonstrates the methodological importance of examining character recognition in experimental settings that approximate natural reading. As for pedagogical implications, the results suggest that L2 learners may benefit from explicit instruction of phonetic radicals and teaching approaches that are sensitive to their L1 backgrounds. The study also implies that instructors should draw L2 learners' attention to character decomposition and radical properties when teaching sentence-level comprehension, so that L2 learners will be able to develop effective character processing strategies that are applicable to natural reading.

To My Parents

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Chapter 1: Introduction

1.1 Background of the study

Unlike phonographic writing systems such as that of English, Chinese has a logographic writing system, in which each grapheme (i.e., character) encodes both sound and meaning at the level of the syllable (Sun, 2006). Although the majority of characters contain some phonological information in their radicals, which are sub-character components, Chinese is not “spelled.” Furthermore, due to diachronic changes, the existing phonographic representation is inconsistent; phonological information is only loosely encoded at the sub-character level (i.e., radical level) in some characters, where the phonological variation of the cue can span a greater distance than the phoneme. Yet native speakers of Chinese manage to read the script just as efficiently as native readers of any other languages and have little difficulty processing the characters that have fossilized centuries of phonological and semantic change. Therefore, the Chinese script provides a unique perspective for the development and examination of reading theories. Current theories of word recognition and orthographic processing, which are primarily based on the results of alphabetic scripts, must accommodate the difference across writing systems and account for the success of the Chinese reader (Honorof & Feldman, 2006).

Additionally, explaining the success of Chinese native readers is also a critical step to understand character recognition in a second language¹ (L2) and help nonnative speakers become effective Chinese readers. It has been widely acknowledged in the field of L2 acquisition and pedagogy that foreign languages that are linguistically unrelated to the learner’s first language (L1) are more challenging to learn. Therefore, learning the Chinese writing system has been

¹ In this study, “second language (L2)” is used an umbrella term which refers to any language that is acquired after the learner’s native/first language.

found to be the most challenging and time-consuming task in learning Chinese for L2 learners from non-logographic L1 backgrounds (e.g., Everson, 1998). Given the growing numbers of L2 learners studying Chinese worldwide, understanding how L2 learners can acquire and process Chinese characters more efficiently has become increasingly important.

In the last two decades, there has been a growing body of research on both L1 and L2 character recognition. With regard to L1 character processing, the literature has focused on context-independent character identification. The effects of contextual cues on visual character recognition, however, have been largely ignored. As for L2 character processing, the majority of the previous studies employed offline tasks and were centered on character learning strategies; therefore, additional experimental data are needed to understand the nature of L2 character processing in real time.

1.2 Aims of the study

The primary goal of this study is to understand how Chinese characters are processed by native speakers and L2 learners from orthographically different L1 backgrounds under both context-independent and context-embedded conditions. Specifically, the aim of Experiment 1 is to investigate how the orthographic properties of radicals are activated in L1 and L2 Chinese character recognition; the aim of Experiment 2 is to further examine how the phonological and semantic properties of radicals are activated in L1 and L2 character recognition; the aim of Experiment 3 is to explore context effects on L1 and L2 character recognition by comparing radical activation in highly constraining and non-constraining sentence contexts. Finally, the study also aims to examine the influence of L1 orthography on L2 character recognition by comparing the processing patterns of L2 learners from four typologically different L1 writing systems.

The study involved 104 Chinese native speakers and 105 L2 learners from alphabetic, abjad, abugida, and logographic L1 backgrounds, who participated in two primed-character decision tasks and a self-paced/masked priming (SPaM) task (Luke & Christianson, 2012, 2013). Participants' character processing patterns were explored through statistical analyses of their response times (RTs) (i.e., linear mixed effects models) and accuracy rates (i.e., logistic mixed effects regression models) under different experimental conditions.

1.3 Significance of the study

The current study contributes to the understanding of Chinese character processing and acquisition in a number of ways.

By exploring the character processing strategies of L2 learners and potential L1 orthography transfer effects, this study will offer pedagogical suggestions for enhancing L2 learners' literacy development in Chinese. The comparison between native and L2 character recognition will contribute to the field of Second Language Acquisition (SLA) and help identify the reading strategies that are effective for the Chinese writing system and determine what kind of explicit instruction and exercises will help L2 learners acquire Chinese characters more effectively.

Additionally, this study differs from previous research on L1 character recognition to the extent that it provides empirical evidence covering both context-independent radical activation and context effects on radical activation during visual character recognition. In natural reading, characters typically occur in sentence contexts rather than in isolation. For ecological validity reasons, it is important to validate the previous findings on context-independent character recognition under context-embedded experimental conditions that approximate natural reading.

Finally, the results of the study will also provide empirical evidence as to whether theoretical word recognition models, which are mainly based on the results of experiments on alphabetic language processing, can account for reading Chinese.

1.4 The Chinese writing system

Chinese characters are composed of a series of *strokes*, which can combine in specified ways to form recurrent partials called *components* (部件 *bùjiàn*) (Taft, Liu, & Zhu, 1999). Some components are characters in their own right, whereas others are bound orthographic elements that do not occur independently. Based on the number of components in a given character, Chinese characters can be divided into two broad categories: *simple characters* (文 *wén*), which make up about 5% of all modern Chinese characters, and *complex characters* (字 *zì*), which constitute about 95% of the total characters (Li, 1993; Yin & Rohsenow, 1994). As shown in Table 1, a simple character consists of only one component that cannot be divided into further meaningful units. In addition, no phonological information is represented beneath the whole-character level, nor is there systematic correspondence between orthography and semantics or phonology (Zhou & Marslen-Wilson, 1999c). In contrast, a complex character contains two to eight components (Liu, Wang, & Perfetti, 2007).

Table 1

Example of Simple Characters and Complex Characters

Character category	Example
Simple characters	七 (<i>qī</i> , “seven”); 乜 (<i>miē</i> , “to squint”); 也 (<i>yě</i> , “also”)
Complex characters	狗 (<i>gǒu</i> , “dog”); 熟 (<i>shú</i> , “ripe”); 嚼 (<i>jiáo</i> , “to chew”)

Additionally, more than 80% of complex characters are composed of a phonetic component and a semantic component. These characters are often referred to as *phonetic compounds*, *compound characters*, or *phonograms* (形声字 *xíngshēngzì*) (Zhou & Marslen-Wilson, 1999c). Table 2

shows that semantic components (e.g., 氵 “water”) indicate the semantic category of compound characters (e.g., 清 “(water) clear”) and are often referred to as *semantic radicals* (部首 *bùshǒu*, 义符 *yìfú*, or 形旁 *xíngpáng*), whereas phonetic components (e.g., 青 *qīng*; see Table 2) provide cues to the pronunciation of the compound character (e.g., 清 *qīng*) and are thus referred to as *phonetic radicals* (声符 *shēngfú*, 音符 *yīnfú*, or 声旁 *shēngpáng*).

Table 2

Example of Compound Characters

Compound character	Semantic radical	Phonetic radical
清 <i>qīng</i> “(water) clear”	氵 “water”	青 <i>qīng</i> “blue”
晴 <i>qíng</i> “sunny”	日 “sun”	青 <i>qīng</i> “blue”
请 <i>qǐng</i> “to ask/request”	讠 “speech”	青 <i>qīng</i> “blue”

However, due to the evolution of the Chinese language and its writing system, both semantic and phonetic functions are inconsistent, resulting in many exceptions and irregular characters. As seen in Table 3, in terms of phonological relations between the phonetic radical and the whole character, compound characters generally fall into five categories: regular, semi-regular, rhyming, alliteration, and irregular. (Zhou & Marslen-Wilson, 1999c).

Table 3

Phonological Relations between Phonetic Radicals and Compound Characters

Type	Compound character	Phonetic radical
Regular	清 <i>qīng</i> “(water) clear”	青 <i>qīng</i> “blue”
Semi-regular	晴 <i>qíng</i> “sunny”	青 <i>qīng</i> “blue”
Rhyming	精 <i>jīng</i> “shrewd”	青 <i>qīng</i> “blue”
Alliteration	倩 <i>qiàn</i> “glorious”	青 <i>qīng</i> “blue”
Irregular	猜 <i>cāi</i> “guess”	青 <i>qīng</i> “blue”

Unlike letter clusters in alphabetic languages, phonetic radicals provide cues to the pronunciation of the entire character rather than only a part of it. Furthermore, phonetic radicals

can be either bound components that never occur alone (e.g., in 瑞, in which 耑 does not occur alone) or independent characters (e.g., in 珠, in which 朱 can occur alone as a simple character) which have their own meanings that are unrelated to the meanings of compound characters. For instance, the phonetic radical 青 *qīng* (see Table 3) provides hints for the pronunciation of the compound character 晴 *qíng*, but its meaning – “blue” – has nothing to do with the meaning of the compound character 晴 “sunny.”

Similar to the variation of phonetic radical regularity, semantic radicals also vary in terms of semantic transparency, which is the degree of relatedness between the meaning of a compound character and the semantic category denoted by its semantic radical (Feldman & Siok, 1999a). As demonstrated in Table 4, the semantic radical 木 “wood” is semantically transparent in the compound character 枝 “tree branch,” but is semantically opaque in 杈 “power.”

Table 4

Semantic Relations between Semantic Radicals and Compound Characters

Type	Compound character	Semantic radical
Transparent	枝 <i>zhī</i> “tree branch”	木 “wood”
Opaque	杈 <i>quán</i> “power”	木 “wood”

Analogous to the case of phonetic radicals, semantic radicals can be bound components that do not appear alone (e.g., in 情, in which 忄 does not occur alone) or independent characters on their own (e.g., in 杈, in which 木 can occur alone as a simple character), but their pronunciation is unrelated to the pronunciation of the compound characters. For example, the semantic radical 木 “wood” (see Table 4) indicates that the meaning of the compound character 枝 “tree branch” is related to “wood,” but its pronunciation *mù* has nothing to do with the pronunciation of the compound character 枝 *zhī*.

The relationship between a radical and its host character can alternatively be described with the concept of *consistency*; that is, whether a compound character’s pronunciation agrees with those of other compound characters that contain the same phonetic radical. As shown in Table 5, compound characters that contain the phonetic radical 皇 *huáng* are consistently pronounced *huáng*, whereas compound characters that have the phonetic radical 台 *tái* vary greatly in phonological consistency. Although the concept of consistency has been traditionally used to address the relationship between phonetic radicals and their host characters, semantic radicals also vary in terms of semantic transparency (e.g., Lee, 2009). As illustrated in Table 5, radical-character relatedness within the semantic radical family of 扌 “hand” varies from transparent (as in 打 “to hit”) to opaque (as in 捌 “eight”), whereas the semantic radical 冫 “ice” shows less variability.

Table 5

Consistency Relationship between Radicals and Compound Characters

Consistency		Phonetic radical	Semantic radical
Consistent	Radical	皇 <i>huáng</i>	扌 “hand”
	Character	煌 <i>huáng</i> 惶 <i>huáng</i> 蝗 <i>huáng</i>	打 “to hit” 捌 “eight” 撞 “to crash”
Inconsistent	Radical	台 <i>tái</i>	冫 “ice”
	Character	抬 <i>tái</i> 怡 <i>yí</i> 治 <i>zhì</i>	冷 “cold” 冰 “ice” 冻 “to freeze”

Finally, radicals can occur in different positions within a character, and compound characters can have a variety of graphic structures. As Table 6 shows, common structures include left-right, top-bottom, half-enclosure, and enclosure (Shen & Ke, 2007). For the purposes of this study, only compound characters with left-right structure were used because they have been shown to be easier to decompose in perceptual analyses than characters with other graphic structures (Yu, Feng, Cao, & Li, 1990).

Table 6

Common Graphic Structures of Compound Characters

Graphic structure	Example
Left-right structure	烟
Top-bottom structure	菜
Half-enclosure structure	遨
Enclosure structure	国

Chapter 2: Previous Studies on L1 Chinese Character Recognition

2.1 Previous studies on L1 Chinese character recognition

Previous studies have explored L1 character recognition by examining the roles played by different orthographic units including strokes (e.g., Peng & Wang, 1997; Wang, Tian, Han, Liversedge, & Paterson, 2014; Yan et al., 2012), components (e.g., Taft, Zhu, & Peng, 1999), phonetic radicals (e.g., Chi, et al., 2014), semantic radicals (e.g., Hung, Hung, Tzeng, & Wu, 2014), and whole characters (e.g., Zhang, Xiao, & Weng, 2012).

These studies have demonstrated that although all orthographic units may be activated during the course of visual character identification, radicals have been found to be the functional orthographic processing unit (e.g., Chen, Allport, & Marshall, 1996; Wang & Dong, 2013) and provide a major information resource for character processing (e.g., Peng, Li, & Yang, 1997). Radical properties such as radical function, quantity, position, and frequency have been found to modulate visual character recognition (e.g., Ding, Peng, & Taft, 2014; Feng, 2007; Peng & Wang, 1997; Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999; Wu, Mo, Tsang, & Chen, 2012). Because both semantic radicals and phonetic radicals constitute an important level of representation in Chinese native speakers' orthographic processing system, the processing of radical-level information is critically involved in compound character recognition, and character recognition is often achieved via radical activation (e.g., Chen & Zhang, 2008, 2012; Feldman & Siok, 1999a, b; Hue, 1992; Li & Chen, 1999; Zhou & Marslen-Wilson, 1999c; Zhou, Peng, Zheng, Su, & Wang, 2013). Furthermore, research on L1 acquisition has confirmed the critical role played by radical awareness (i.e., the implicit and explicit knowledge of the positional and functional properties of radicals) in Chinese children's literacy development (e.g., Packard et al., 2006; Shu & Anderson, 1999).

The following sections will focus on the activation of radical properties during character recognition. Compared with research on the graphic, phonological, and semantic processing at the level of the complete character, research on the sub-character level (i.e., radical level) processing is still in its infancy.

2.1.1 Orthographic activation of radicals in L1 character recognition

Converging evidence has demonstrated that the orthographic properties of radicals are automatically activated during the identification of compound characters. Shen, Li, and Zhu (1997) compared the priming effects on compound character targets that were produced by prime characters that were orthographically identical to the target's embedded radicals (e.g., 土), by characters that had one fewer stroke (e.g., 十) or one more stroke (e.g., 王) than the embedded radicals, and by unrelated controls (e.g., 日). They found that participants (N = 60) responded faster when targets were preceded by all three types of related primes at the stimulus onset asynchronies (SOAs) of 23 ms and 46 ms. Although no difference across related prime conditions was observed at 23 ms, identical-radical primes produced stronger facilitatory effects than visually similar primes did at 46 ms. These results indicate that the orthographic features of radicals are activated during the early visual processing stages of compound characters.

In a primed-character decision task, She and Zhang (1997) asked 16 native speakers to determine whether a target was a real character or not after they were presented with four types of primes for 224 ms: (1) transparent semantic radical, (2) opaque semantic radical, (3) regular phonetic radical, and (4) irregular phonetic radical, and two types of targets: high-frequency compound characters and low-frequency compound characters. The results showed that there were no priming effects for high-frequency compound character targets, whereas all four types of primes produced significant facilitatory effects for low-frequency targets. Although no main

effect of radical type and regularity/transparency were observed, She and Zhang found a significant interaction between target frequency and regularity/transparency. Specifically, for high-frequency compound character targets, regular/transparent radical primes produced larger facilitation than did irregular/opaque radical primes, whereas for low-frequency compound targets, the opposite pattern was observed. These findings suggest orthographic activation of both phonetic and semantic radicals during compound character recognition. Although no priming effects were detected for high-frequency compound character targets, the interaction effect indicated that radicals were still activated, but the activation was likely obscured by the frequency effect.

Ding et al. (2004) also investigated the orthographic activation of radicals but found results that were different from She et al.'s (1997). In a primed-character decision task, 42 native speakers were asked to decide whether a target (e.g., 𠂇) was a real character or not after being presented with three types of primes for 43 ms: (1) radical prime, which was identical to the radical of the target (e.g., 𠂇), (2) similar prime, which was orthographically similar to the radical of the target (e.g., 𠂇), and (3) unrelated control (e.g., 𠂇). The experiment revealed that radical primes produced facilitatory effects on participants' RTs, whereas similar primes produced inhibitory effects. Because the stimuli were irregular and opaque compound characters, there was no phonological or semantic overlap between the primes and targets under the radical priming condition. Therefore, Ding et al. suggest that the facilitation arises from the activation of the orthographic form of the radical.

The studies presented above reported different results with regard to the direction of priming (facilitation vs. inhibition) produced by primes that were orthographically similar to the radical of the target character. Although more research is needed to determine the direction of

priming, these studies have clearly demonstrated that the orthographic properties of radicals are automatically activated during the visual recognition of compound characters.

2.1.2 Phonological activation of radicals in L1 character recognition

The phonological activation of phonetic radicals has been extensively studied from the perspective of phonological regularity and consistency effects. Converging empirical evidence has demonstrated that at least for low-frequency compound characters, regular and consistent phonetic radicals facilitate the recognition and naming of compound characters (e.g., Fang, Horng, & Tzeng, 1986; Gao & Peng, 2005; Hue, 1992; Lee, Tsai, Su, Tzeng, & Hung, 2005; Mu, Han, & Chen, 2005; Pollatsek, Tan, & Rayner, 2000; Seidenberg, 1985; She & Zhang, 1997; Williams & Bever, 2010; Zhang, Perfetti, & Yang, 1999; Zhang & Wang, 2001).

Recent neurocognitive research has further investigated the neural mechanisms underlying regularity and consistency effects. In a functional magnetic resonance imaging (fMRI) study, Tan, Feng, Fox, and Gao (2000) found that, when compared with reading aloud of regular characters, irregular characters elicited larger MR signal intensity changes over regions including left infero-middle frontal cortex, left motor cortex, right infero-frontal gyri, bilateral anterior superior temporal areas, and anterior cingulate cortex. Additionally, the right superior parietal lobule, cuneus in the bilateral cortex, and thalamus were involved in the processing of irregular characters, but not regular characters. Peng et al.'s fMRI (2004) results also showed that bilateral fusiform gyri, the posterior superior temporal gyrus, and inferior parietal regions were more active when low-frequency irregular characters were presented relative to regular characters. Consistent with these results, Guo's (2009) fMRI study showed greater activity for irregular than regular characters in the left fusiform gyrus. In a magnetoencephalography (MEG) study, Hung et al. (2014) also demonstrated that irregular compound characters differed from

regular characters in the M250 and M350 components. With regard to consistency effects, Lee et al.'s (2004) fMRI results showed greater activity in bilateral inferior frontal cortices, the left temporo-parietal region, and the left temporo-occipital junction when participants named low-frequency, inconsistent characters as compared with consistent ones. Lee et al.'s (2007) event-related potential (ERP) study further revealed that, when compared with high-consistency characters, low-consistency characters elicited greater N170 amplitude in the frontal region, and that high-consistency characters elicited greater N400 amplitude than did low-consistency characters. Similarly, Hsu, Tsai, Lee and Tzeng's (2009) also found consistency effects of phonetic radical in compound character recognition at N170 and P200. These studies have provided neurophysiological evidence for regularity and consistency effects on Chinese character recognition.

Although regularity and consistency effects provide indirect evidence for radical-level activation in compound character recognition, it remains unclear what kind of phonological properties are activated. Zhou and colleagues were the first group to directly investigate the phonological activation at the radical level in visual character recognition. In a primed naming task (Zhou & Marslen-Wilson, 1999b), target characters (e.g., 倩 *qiàn*) were preceded by three types of primes: (1) compound characters whose phonetic radicals were homophonic to the targets (e.g., 次 *cì*, whose phonetic radical was 欠 *qiàn*), (2) the phonetic radicals as stand-alone characters (e.g., 欠 *qiàn*), and (3) unrelated controls. Their results demonstrated that low-frequency compound characters facilitated the naming of the targets. Because the compound characters themselves were unrelated to the targets, the priming effect was caused by the fact that the phonetic radicals embedded in the compound characters were homophonic to the targets. Based on these findings, Zhou and Marslen-Wilson conclude that at least low-frequency

compound characters are decomposed, and that the phonological representations of their phonetic radicals, although different from those of the whole characters, are activated during reading. For high-frequency compound characters, it is possible that they are not decomposed or the access to the phonological properties of their phonetic radical is transient and immediately suppressed by the phonology of whole characters.

Zhang, Zhou, Shu, and Xing (2003) further examined the competition between phonological activations of compound characters and their radicals in a naming experiment. In their study, 44 native speakers were asked to name regular and irregular compound characters (e.g., 吩 *fēn*, which is regular vs. 扮 *bàn*, which is irregular), as well as the phonetic radicals that were embedded in the compound characters (e.g., 分 *fēn*). For high-frequency compound characters, participants' naming responses to phonetic radicals were longer when the host compound characters were irregular than when they were regular, indicating that the phonological processing at the character level interfered with the processing at the radical level; for low-frequency compound characters, the phonological processing of whole characters and that of their phonetic radicals interfered with each other. These results demonstrate that the phonological activation of whole characters is stronger than that of their phonetic radicals, and that the phonological properties of phonetic radicals are accessed at least when they are embedded in low-frequency compound characters.

In a recent study, Zhou, Fong, Minett, Peng, and Wang (2014) investigated the time course of the phonological activation of phonetic radicals in a primed semantic judgment task with ERPs (N=19). By comparing the priming effects produced by radical-level related primes (e.g., 琴 *qín*, which was homophonic to the phonetic radical 秦 *qín* of the compound character target 榛 *zhēn*) and character-level related primes (e.g., 珍 *zhēn*, which was homophonic to the

target 榛 *zhēn*) at the SOA of 500 ms, they found a radical-level interference effect on the N170, P200, and N400 responses and a character-level effect only on the N400 responses. These findings are consistent with the previous studies and indicate that the pronunciation of the phonetic radical is activated prior to that of its host character.

Phonological processing of semantic radicals, however, has been largely ignored by the previous research; only two studies to date have examined whether the pronunciation of the semantic radical is automatically activated during compound character recognition.

In the first study, Zhou, Lu, & Shu (2000) used a primed naming task and compared 41 participants' responses to target characters (e.g., 深 *shēn*) across four priming conditions at the SOA of 57 ms: (1) character-level related prime (e.g., 身 *shēn*), which was homophonic to the target (e.g., 深 *shēn*), (2) character-level unrelated control (e.g., 京 *jīng*), (3) radical-level related prime whose semantic radical was homophonic to the target (e.g., 躲 *duǒ*, whose semantic radical was 身 *shēn*, which was in turn homophonic to the target), and (4) radical-level unrelated control (e.g., 验 *yàn*). Character-level related primes and low-frequency radical-level related primes both facilitated the naming of targets, indicating that at least for low-frequency compound characters, the pronunciation of the semantic radical is automatically accessed.

Zhou, Peng, Zheng, Su, & Wang (2013) also investigated the phonological activation of semantic radicals in a primed naming experiment with a similar design (N= 30). Consistent with Zhou et al.'s (2000) results, they also found that both character-level and radical-level related primes facilitated the naming of targets, although the radical-level effect was much weaker compared with the strong facilitatory effect at the character level.

To summarize, previous experimental data on the phonological activation of radicals suggest that both the phonological representations of radicals and those of whole characters are

automatically activated in reading Chinese. Although phonological processing at the character level does not fundamentally differ from that at the radical level, radical-level phonological activation may occur earlier than that at the character level.

2.1.3 Semantic activation of radicals in L1 character recognition

As presented above, the majority of the research on the phonological activation of radicals has focused on phonetic radicals. Similarly, previous studies on the semantic activation of radicals have been concerned with semantic radicals, and most of them approached the issue from the perspective of semantic transparency effects. The converging results demonstrate that native speakers of Chinese make more errors and take longer to make decisions on compound characters that contain opaque semantic radicals relative to compound characters that contain transparent semantic radicals (e.g., Cheng & Lan, 2011; Feldman & Siok, 1999a, 1999b; Flores d'Arcais, 1992; Lee, 2009; Leck, Weekes, & Chen, 1995; Liu, Shu, & Xuan, 2002; Williams & Bever, 2010; Xu & Deng, 2011; Yan, Zhou, Shu, & Kliegl, 2012; Yang, Peng, Perfetti, & Tan, 2000; Zhang & Peng, 1993; Zhang, Peng, Zhang, 1991; Zhang, Zhang, & Peng, 1990; Zhou & Marslen-Wilson, 1999b).

Although the effect of semantic transparency provides indirect evidence for semantic activation at the radical level during compound character recognition, it does not inform us what kind of semantic information of the radical is accessed by the reader. Zhou et al. (2013) were the first group to directly examine whether the meaning of the semantic radical was activated during compound character recognition. In a primed naming experiment, 36 native speakers of Chinese were asked to name a target character (e.g., 箭 “arrow”) after being presented with four types of primes for 100 ms: (1) character-level related prime (e.g., 弓 “bow”), which was semantically related to the target (箭 “arrow”) at the character level, (2) character-level control prime (e.g., 禾

“grain”), which was unrelated to the target; (3) radical-level related prime (e.g., 弥 “full”), whose semantic radical (弓 “bow”) was semantically unrelated to the target (箭 “arrow”), and (4) radical-level control prime (e.g., 称 “to match”), which was unrelated to the target. The results showed that for low-frequency primes, both character-level and radical-level related primes had a significant facilitatory effect on participants’ naming responses compared with control primes, indicating that the semantic information of semantic radicals that are embedded in low-frequency compound characters are automatically activated.

As for phonetic radicals, Zhou and Marslen-Wilson (1999b, c; 2002) did a series of studies to investigate whether the meaning of the phonetic radical was activated during compound character identification. By using primed naming tasks, Zhou and Marslen-Wilson (1999b, c) explored the semantic activation of phonetic radicals that were embedded in regular, rhyming, and irregular compound characters. Three types of primes were used: (1) simple characters (e.g., 风 “wind”) that were semantically related to the target (e.g., 雨 “rain”), (2) compound characters that contained (1) as their phonetic radicals (e.g., 枫 “maple” whose phonetic radical was 风 “wind”) and were thus related to the target only at the radical level, and (3) unrelated controls. To track the time course of the activation, three SOA conditions were used in the experiment: 57 ms, 100 ms, and 200 ms. Statistical analyses on participants’ naming latencies showed facilitatory effects produced by both types of related primes, indicating that phonetic radicals are decomposed during compound character identification and used to access their own semantic representations. Additionally, the radical-level priming effect was much smaller than that at the character level, and it disappeared within 200 ms after the prime was presented. This suggests that there is competition in the semantic processing system between the

representations corresponding to the whole compound characters and those corresponding to the phonetic radicals.

To replicate these results, Zhou and Marslen-Wilson (1999b, c) conducted another primed naming experiment with the same SOA conditions, in which targets were irregular compound characters (e.g., 猜 “to guess”), and primes included the phonetic radicals of the targets (e.g., 青 “blue”), characters that were related to the phonetic radicals of the targets but not the targets (e.g., 紫 “purple”), and unrelated controls. Although there were no priming effects at 57 ms, significant inhibitory effects were found at both 100 ms and 200 ms. Based on these results, the authors argue that the observed inhibition is likely to be caused by the automatic radical decomposition in reading compound characters. The presence of phonetic radicals activates the meaning of the radicals and thus increases the competition between the semantic representations of compound characters and those of their phonetic radicals.

Zhou and Marslen-Wilson (2002) further examined the semantic processing of phonetic radicals in a semantic judgment task, in which 60 participants were consecutively presented with a pair of characters for 100 ms and asked to decide if they were semantically related. The character pair consisted of a compound character (e.g., 洒 “to spray”) and a character (e.g., 东 “east”) that was either semantically related to the phonetic radical (e.g., 西 “west”) of the compound character but unrelated to the meaning of the compound character or a unrelated control (紫 “purple”). Additionally, both regular and irregular compound characters were used in the study to examine whether the potential radical-level semantic activation existed across different types of compound characters and how phonological activation interacted with semantic activation at the radical level. Comparisons of participants’ RTs across different conditions demonstrated significant inhibitory effects for both regular and irregular compound

characters when the phonetic radical of the compound character was semantically related to the other character. In line with Zhou and Marslen-Wilson's previous findings (1999b, c), this study also indicates that during compound character recognition, native speakers of Chinese automatically access the semantic representations of the embedded phonetic radicals in parallel to the access to the meanings of the whole compound characters.

Lee, Tsai, Huang, Hung, & Tzeng (2006) explored the time course of the semantic activation of phonetic radicals in a primed-character recognition task with ERPs, in which 76 native speakers were instructed to determine whether a probe was the first or the second character presented in a trial while their EEGs were recorded. There were three SOA conditions: 50 ms, 100 ms, and 300 ms, and four priming conditions: (1) the target (e.g., 妻 “wife”) was semantically related to the prime (e.g., 夫 “husband”) at the character level, (2) the target (e.g., 雨 “rain”) was semantically related to the phonetic radical embedded in a regular compound character (e.g., 枫 *fēng* “maple,” whose phonetic radical was 风 *fēng* “wind”), (3) the target (e.g., 買 “to buy”) was semantically related to the phonetic radical embedded in an irregular compound character (e.g., 讀 *dú* “to read,” whose phonetic radical was 賣 *mài* “to sell”), and (4) an unrelated control. By using the N400 component as an index of semantic processing, they found an interaction between semantic activation at the radical level and the phonological regularity of the compound character. Specifically, for priming conditions (2) and (3) described above, there were significant N400 effects at the SOAs of 50 ms and 100 ms, but the effects for condition (3) were smaller compared with those for condition (2). These results suggest that within the first 50 to 100 ms of perceiving a compound character, Chinese native speakers activate the meaning of the embedded phonetic radical, and such semantic information is more strongly activated when the host character is a regular compound character than when it is an

irregular character. Additionally, the semantic processing at the radical level is later suppressed, and no semantic information from the phonetic radical is preserved after 300 ms.

Finally, Luo, Proctor, and Weng (2015) investigated the semantic activation of both phonetic radicals and semantic radicals using a Stroop paradigm. In a color judgment task ($N = 18$), compound characters whose meanings were unrelated to colors but contained 白 “white” or 黑 “black” as a radical (e.g., 拍 “to pat,” which contained 白 “white” as its phonetic radical; and 默 “silent,” which contained 黑 “black” as its semantic radical) elicited a Stroop effect, i.e., interference in RTs. Luo et al. further examined the interaction between the effect of character frequency and the Stroop effect ($N = 44$) and found that Stroop effect appeared only for low-frequency compound characters but not for high-frequency characters. These results are consistent with Zhou et al.’s (2013) study and demonstrate that radicals are semantically activated during compound character recognition.

Consistent with the findings on the phonological activation of radicals, research on the semantic processing of radicals has provided clear evidence that semantic activation occurs at both the character level and at the radical level in parallel during reading Chinese. The semantic properties of radicals are automatically accessed during the visual recognition of its host compound character.

2.1.4 Context effects on L1 character recognition

The majority of the previous studies on radical activation employed online lexical or phonological tasks including naming, character decision, semantic judgment, and semantic categorization. Although all of these tasks can provide a sensitive measure for examining character recognition, they do not allow the study of relatively natural language processing. In natural reading, characters seldom appear alone; they are usually embedded in sentences, and the

way they are processed by the reader is often affected by sentence contexts. To date there have been only a few studies that investigated the effect of radical activation on character recognition in word context or sentence contexts, and little research has been done to directly examine how contextual cues modulate character processing.

In two semantic categorization tasks, Zhang and colleagues (Zhang & Peng, 1993; Zhang, Peng, & Zhang, 1991) investigated the role semantic radicals played in character recognition in a two-character word context. In the first study (Zhang et al., 1991), 26 native speakers were presented with two category names (i.e., females and birds) and asked to decide whether a given two-character word was a member of the categories. Six types of words were constructed: (1) both characters had transparent semantic radicals (e.g., 姐姐 “sister,” whose semantic radical was 女 “female”), (2) only the first character had a transparent semantic radical (e.g., 嫂子 “sister-in-law”), (3) only the second character had a transparent semantic radical (e.g., 大姨 “aunt”), (4) neither of the characters had transparent semantic radical (e.g., 祖母 “grandmother”), (5) one of the characters had an opaque semantic radical (e.g., 娃娃 “child,” whose semantic radical 女 “female” was unrelated to the meaning of the whole character), and (6) unrelated words (e.g., 哥哥 “older brother”). The results showed that words that contained characters whose semantic radicals were transparent (i.e., condition (1), (2), and (3)) significantly facilitated participants’ RTs relative to words that contain characters with opaque semantic radicals. This indicates that semantic radicals are activated during character identification in word context.

In the second study, Zhang and Peng (1993) further examined the activation of semantic radicals in word recognition by using a 2 (semantic radical transparency: transparent, opaque) × 2 (familiarity: high, low) design (N= 28). The results are consistent with their previous findings

(Zhang et al., 1991) and demonstrate that transparent semantic radicals facilitate character recognition at the word level. Additionally, familiarity with radicals also plays an important role in the activation of semantic radicals.

As for sentence contexts, Liu, Inhoff, Ye, and Wu (2002) were among the first to examine phonetic radical processing in an eye-movement-contingent display-change paradigm. In the study, 27 native speakers were presented with five types of previews during sentence reading: (1) identical preview (e.g., 味 *wèi* “flavor”), (2) stroke overlap preview (e.g., 珠 *zhū* “bead”), (3) semantic radical preview (e.g., 吃 *chī* “to eat,” which shared the same semantic radical with the target), (4) phonetic radical preview (e.g., 妹 *mèi* “younger sister,” which shared the same phonetic radical with the target), and (5) dissimilar preview (e.g., 笋 *sǔn* “bamboo shoot”). They found robust parafoveal phonetic radical preview benefits on both first pass and total reading time measures, and semantic-radical preview benefit only on the late measures. Because the phonetic radical preview characters were not homophonic to the target characters, Liu et al. suggested that it was the orthographic information from the phonetic radical that yielded preview benefits. In conclusion, the study demonstrates that character processing in sentence contexts also involves the activation of radical properties.

Tsai, Lee, Tzeng, Hung, and Yen (2004) also examined both character-level and radical-level phonological processing in an eye-tracking study. In the first experiment ($N = 20$), they investigated the preview benefits of characters in a boundary paradigm by manipulating the phonological and orthographic similarities between previews and targets. For example, for a target character (e.g., 罐 *guàn* “jar”), the previews included a homophone that shared the same phonetic radical with the target (e.g., 灌 *guàn* “to irrigate”), an orthographically dissimilar homophone (e.g., 贯 *guàn* “to pass through”), a non-homophone that shared the same phonetic

radical (e.g., 權 *quán* “power”), and an orthographically dissimilar non-homophone (e.g., 翁 *wēng* “old man”). The data revealed both phonological and phonetic-radical preview benefits. To further investigate whether the phonetic-radical preview benefit was due to the orthographic similarity between the target and the preview or rather due to radical-level processing, Tsai et al. conducted a second experiment ($N = 36$), where the consistency value of the target was manipulated. In the experiment, low-consistency compound character targets (e.g., 拘 *jū* “to detain”) and high-consistency compound character targets (e.g., 浴 *yù* “bath”) were presented with three types of previews: (1) a homophonic compound character that shared the same phonetic radical with the target (e.g., 駒 *jū* “foal” or 裕 *yù* “rich”), (2) a non-homophonic compound character that shared the phonetic radical (e.g., 鈎 *gōu* “hook” or 俗 *sú* “vulgar”), and (3) an unrelated preview (e.g., 莽 *mǎng* “reckless” or 流 *liú* “to flow”). Analyses on the first fixation duration data showed both types of homophonic preview benefits (i.e., previews (1) and (2)) for high-consistency targets but not for low-consistency targets, whereas analyses on the gaze duration data indicated that only the preview benefit of homophonic preview was robust regardless of target consistency. Taken together, Tsai et al. suggest that phonological computation occurs early at both the character level and radical level during Chinese sentence reading.

2.2 Theoretical models of L1 Chinese character recognition

Most theoretical models of word recognition were initially built based on reading alphabetic languages. Because the Chinese script differs significantly from alphabetic scripts in terms of visual complexity and grapheme-to-phoneme correspondence (GPC) (Ehrich, Zhang, Mu, & Ehrich, 2013), researchers have been testing whether these models account for Chinese character recognition. Although the majority of the models that have been adapted to explain

reading Chinese posit that character recognition involves radical-level activation to some extent, they differ as to how and when radical-level information is extracted and how radical-level activation and character-level activation interact with each other. Additionally, they also differ in several other aspects such as learnability and the role of the context effect.

2.2.1 The Interactive Activation Model

The Interactive Activation Model was initially proposed by McClelland and Rumelhart (1981; Rumelhart & McClelland, 1982). According to the model, word recognition is a result of excitatory and inhibitory interactions between detectors for visual features, letters, and words. A visual input activates detectors for visual features, which in turn activate detectors for letters, and then words. Additionally, the model suggests that active detectors at the word level may inhibit each other and send feedback to the letter level, enhancing the perceptibility of the constituent letters of the word that is in the visual display.

This model was later adapted by Taft and colleagues (e.g., Ding et al., 2004; Taft, 2006; Taft & Zhu, 1997; Taft et al., 1999) to explain character recognition among skilled adult readers of Chinese. As Figure 1 illustrates, the model posits that features, simple characters, and complex characters are represented at different levels; the feature level is lower than the simple character level, which is in turn lower than the complex character level. A simple character (e.g., 区) that can alternatively function as a radical in complex characters (e.g., 枢) is represented as both a simple character and a radical in the model, and these representations are linked with each other. Additionally, radicals that appear in different positions within complex characters each have their individual representations (e.g., 区 in 欧 vs. 区 in 枢). Finally, the model hypothesizes that there are inhibitory links between units that are activated via shared features. For example, there

are inhibitory links between the characters 欧 and 枢, and likewise, between the radical 区 that occurs on the left in complex characters and the radical 区 that occurs on the right.

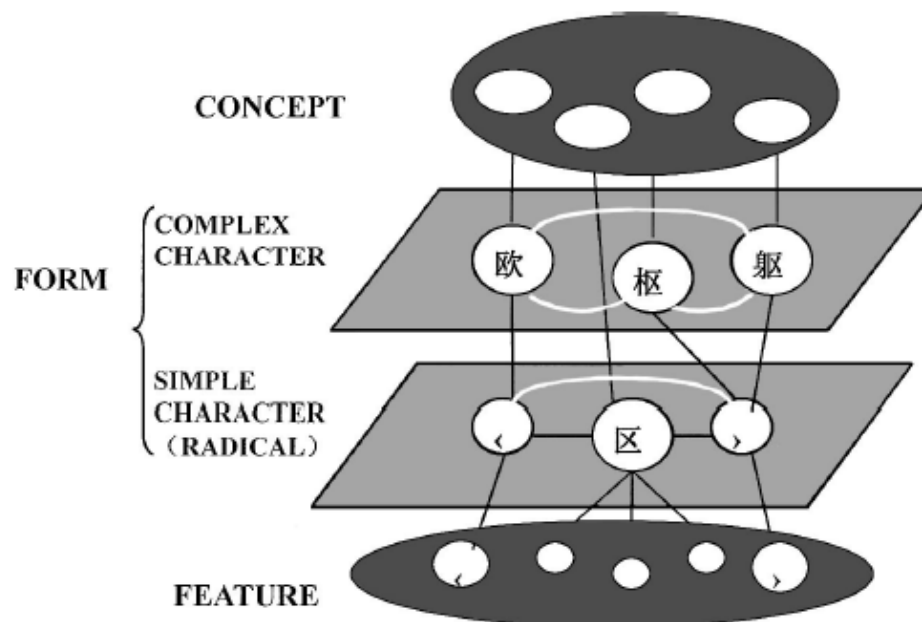


Figure 1. The Hierarchical Interactive Activation Model².

2.2.2 The Connectionist Model

The Connectionist Model was first outlined by Rumelhart and McClelland (McClelland, Rumelhart, & the PDP Research Group, 1986; Rumelhart, McClelland, & the PDP Research Group, 1986). As illustrated in Figure 2, the model follows the distributed parallel processing principle and hypothesizes that words are represented by activation patterns over sets of orthographic, phonological, semantic units, and an inter-level of hidden units. Context units are also included in the model because words typically occur in contexts, and word recognition is thus often modulated by context. These distributed representations are inter-linked with modifiable weights on the connections, and word recognition is achieved via the cooperative and

² Reprinted, with permission, from Ding et al. (2004). The nature of the mental representation of radicals in Chinese: A priming study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30 (2), 530-539.

competitive interactions among large networks of processing units. Because knowledge (e.g., linguistic knowledge of the language) is encoded as weights on connections between units, learning can gradually adjust these weights based on the statistical structure among inputs and outputs, and the hidden units may potentially facilitate the learning of complex mappings.

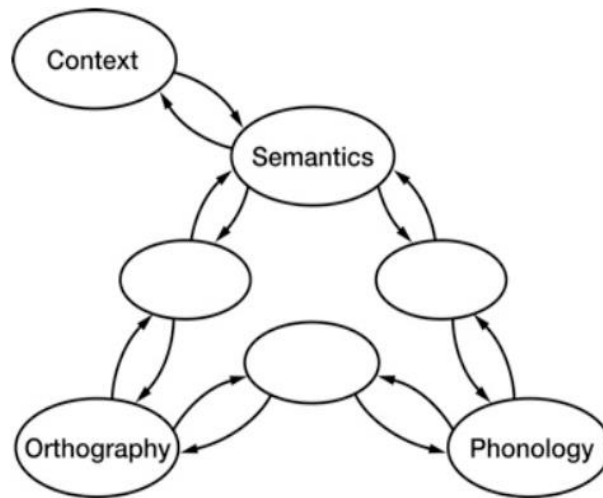


Figure 2. The Connectionist Model³.

Chen and Peng (1994) were among the first to apply the Connectionist Model to Chinese character naming. Implemented via a back-propagation algorithm, their model consisted of 420 orthographic units, which forward-fed to 200 hidden units, which in turn forward-fed to 42 phonological units. The model was able to name 1108 characters after training, and its performance showed effects of frequency, regularity, and consistency. Similarly, Hsiao and Shillcock (2005) also trained a model to map between Chinese orthography and phonology and were able to replicate the interaction between regularity and frequency effects that have been found in the empirical data of compound character naming.

By using a corpus of 4468 characters, Yang, Zevin, Shu, McCandliss, and Li (2006) trained a model to map from orthographic units to phonological units and simulated the effects of

³ Reprinted, with permission, from Seidenberg, M. & McClelland, J. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, 96 (4), 523-568.

frequency, regularity, and consistency, as well as their interactions. They then trained a second model on 103 compound characters to map orthography, phonology, and semantics, and were able to simulate the effects of semantic radical transparency and family size. Furthermore, the simulations showed a very different developmental pattern than that of English; mappings from orthography to semantics were learned faster than those from orthography to phonology, indicating that there may be qualitative differences in the development of literacy skills across writing systems. In a later study, Yang and Shu (2008) reexamined the application of the Connectionist Model to reading Chinese in two simulations. They first trained a model on 270 orthographic units, 200 hidden units, and 92 phonological units, and were able to simulate the effects of frequency, consistency, and regularity, and their interactions, which were consistent with the findings on skilled Chinese readers. In the second simulation, they trained a model using the same corpus with modified orthographic representations of phonetic radicals and only observed the effect of consistency and its interaction with frequency. Finally, these results were replicated in Yang, McCandliss, Shu, and Zevin's (2009) study, which showed that the Connectionist Model of reading aloud could be successfully adapted to explain reading Chinese characters, and its predictions were confirmed by behavioral naming experiments.

2.2.3 The Dual Route Model

The Dual Route Model (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) posits that there are three routes to word recognition: the lexical semantic route, the lexical non-semantic route, and the GPC route. As demonstrated in Figure 3, in the lexical semantic route, the visual features of a word activates the orthographic representation of word. The orthographic representation is then directly mapped onto the semantic representation of the word, which in turn activates the phonological representation of

the word. In the lexical non-semantic route, the orthographic representation of a word activate its representation in the phonological lexicon, and then the word's phonemes. The GPC route, on the other hand, converts a letter string into phonemes based on GPC rules. Additionally, the Dual Route Model hypothesizes that the lexical routes play a more dominant role in skilled reading and high-frequency word recognition, whereas the GPC route is more frequently used for low-frequency word recognition.

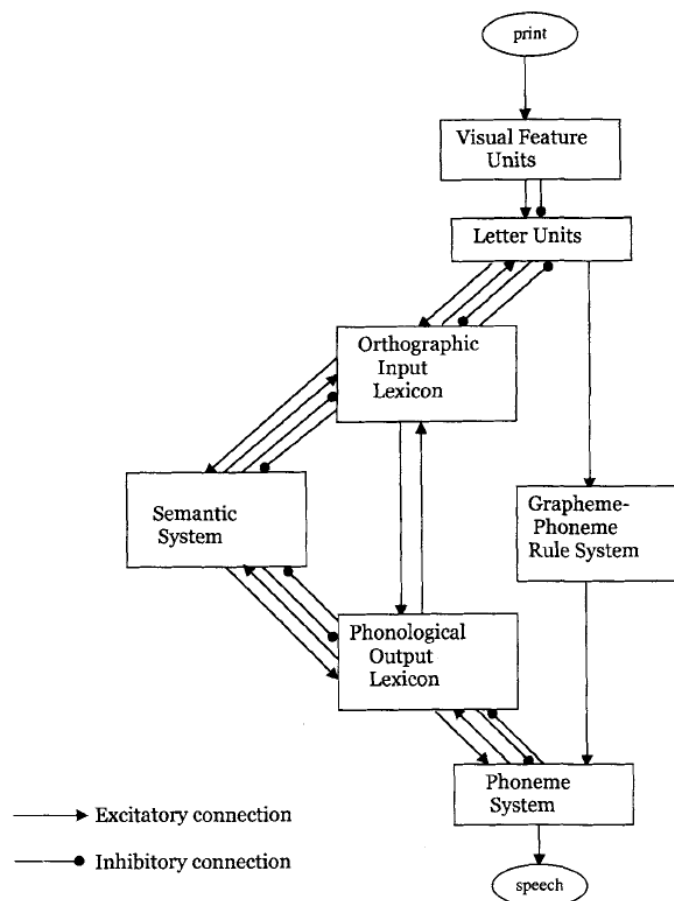


Figure 3. The Dual Route Model⁴.

Although the Dual Route Model has not yet been implemented computationally for Chinese reading, a number of empirical studies have either directly or indirectly examined

⁴ Reprinted, with permission, from Coltheart et al. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108 (1), 204-256.

whether such a model can account for Chinese character recognition. Empirical data have demonstrated that the meaning of a character can be accessed via the activation of its phonological properties (e.g., Perfetti & Zhang, 1995) or its orthographic properties (e.g., Leck et al., 1995). Research on acquired forms of dyslexia has also shown that reading Chinese can be accomplished via either the lexical route or the GPC route (e.g., Bi, Han, Weekes, & Shu, 2007; Han & Bi, 2009; Yin & Butterworth, 1992).

Based on data from an anomic patient, whose character reading performance was significantly better than her picture naming performance, Weekes, Chen, and Yin (1997) proposed a Chinese script-specific adaption of the Dual Route Model. This model consists of three levels of representation (i.e., orthographic units, phonological units, and semantic units), which are linked via a semantic pathway and a non-semantic pathway. The semantic pathway resembles the lexical semantic route in the original Dual Route Model (Coltheart et al., 1993), whereas the non-semantic pathway is a combination of the lexical non-semantic route and the GPC route, and it allows phonological activation at both the character level and the radical level. Based on this model, Weekes et al. argue that character naming can be achieved either via the mappings between a character's semantic representations and phonological output or via the mappings between its orthographic units and phonological output.

Different versions of dual route theories may vary in terms of their commitment to the modularity hypothesis (Fodor, 1983). The original Dual Route Model described by Coltheart and colleagues is to some extent committed to modularity (Seidenberg, 2012), whereas other versions may assume a parallel activation via more than one route. The horse-racing models, for example, suggest that a simultaneous activation of visual features, letters, and word-level information, and that the speed of activation is affected by the corresponding frequency of each unit (Huang &

Wang, 1992). Such an assumption of parallel activation has been supported by empirical evidence showing that radical-level processing and character-level processing may be simultaneously involved in Chinese character recognition (e.g., Yang et al., 2000; Yu, 1998).

2.2.4 Other theoretical models

Based on Biederman's (1987, 1990) recognition-by-components model, Huang and Wang (1992) proposed a modified model, which assumes that the basic principles behind character recognition and object recognition are largely similar. The Lexical Constituency Model proposed by Perfetti and colleagues (e.g., Perfetti & Liu, 2006) is another widely-cited model. This model hypothesizes that a character representation entails three interlocking constituents: orthography, phonology, and semantics, and the recognition of the character is achieved by the specification of the values of these three constituent variables. Additionally, the model suggests that graphic and phonological properties of a character are its pure form features, and that there is a functional independence between these form features and the meaning of the character. By assuming a universal role of phonology across writing systems, Perfetti and colleagues argue that, just as in alphabetic scripts, access to semantics is almost exclusively mediated via phonology in Chinese, and phonological information is activated earlier than semantic information. Although the Lexical Constituency Model has been supported by a number of empirical studies (e.g., Perfetti & Tan, 1998; Perfetti & Zhang, 1995; Tan & Perfetti, 1997) and computational simulation (e.g., Perfetti, Liu, & Tan, 2005), other studies report that access to semantics does not depend on the prior activation of phonology in Chinese (e.g., Shen & Forster, 1999; Wong, 2000; Zhang et al., 2012; Zhang, Zhang, & Kong, 2009; Zhou & Marslen-Wilson, 1999a, 2000).

Chapter 3: Previous Studies on L2 Character Recognition

Previous research on L2 character acquisition has focused on character recognition and production at the whole character level (e.g., Hayes, 1987, 1988; Ke, 1996a; Liu et al., 2007; Sergent & Everson, 1992), but recent studies have extended into radical-level processing strategies. Nevertheless, there has been less focus on the online processing at the radical level in L2 Chinese compared with the extensive research on L2 learners' radical awareness and character learning strategies.

3.1 Effect of radical awareness on L2 character recognition

Consistent with the findings on radical awareness in L1 acquisition of characters, studies on L2 acquisition also indicate that radical awareness and radical knowledge play crucial roles in the literacy development of L2 Chinese.

To capture the development of radical awareness in L2 Chinese, Ke (1996b) proposed a model that suggests that L2 learners of Chinese acquire orthographic awareness in three successive stages. In the first stage (i.e., pre-component stage), learners acquire characters as wholes with little component processing. They are unable to decompose a compound character into its constituting radicals because they have not acquired enough characters to abstract out the recurring components. In the second stage (i.e., component processing stage), learners begin to apply their knowledge of common semantic and phonetic radicals to character learning and can predict the meaning and pronunciation of a novel compound character based on its radicals. In the final stage (i.e., automatic component processing stage), learners have native-like orthographic awareness and process characters via the activation of radical information.

The hypotheses of Ke's (1996b) orthographic awareness development model have been tested by a number of empirical studies. Jackson, Everson, and Ke (2003) investigated whether

L2 learners who had studied Chinese for one year were able to apply their radical knowledge to inferring the meaning and pronunciation of novel compound characters. Their results suggest that L2 learners are able to transfer their knowledge on the semantic and phonetic radicals that they have previously learned, although they perform better on semantic radicals than on phonetic radicals. Consistent with these findings, Wang, Perfetti, and Liu's (2003) study also shows that L2 learners from alphabetic L1 background are sensitive to the structural composition of Chinese characters after a short period of Chinese study. In their study, L2 learners rejected non-characters that contained illegal radicals fastest and most accurately, followed by non-characters that contained legal radicals in illegal positions, and then those that contained legal radicals in legal positions.

L2 learners' acquisition of semantic radical knowledge and radical perception skills were also investigated in Shen and Ke's (2007) study, in which 263 L2 adult learners enrolled in first-, second-, third-, and fourth-year Chinese classes completed a radical perception test, a radical knowledge test, a radical knowledge application test, and a vocabulary test. The radical perception test, which comprised forty compound characters from four graphic structure categories, was developed to examine L2 learners' ability to decompose characters into radical units and use semantic radicals to reproduce characters when encountering novel characters. In the radical knowledge test, forty high-frequency semantic radicals were presented to assess L2 learners' passive knowledge of the sound and meaning of the radicals. The radical knowledge application test was designed to test L2 learners' ability in using semantic radical knowledge when learning novel compound characters. Lastly, participants' word knowledge was also examined in the vocabulary test, in which they were instructed to provide a sound and a meaning for forty two-character words randomly selected from their Chinese lessons. The results

demonstrate that radical knowledge, radical perception skills, and radical knowledge application skills each has its unique developmental trajectory, but there is a linear trend between L2 learners' development of radical knowledge and their ability to apply this knowledge. Although L2 learners develop radical perception skills rapidly during their first year of Chinese study, the acquisition of radical knowledge is relatively slow and the development of their ability to apply this knowledge is not synchronous with their increase in radical knowledge.

In her dissertation, Su (2010; Su & Kim, 2014) examined radical awareness levels among L2 learners across different Chinese proficiency levels and investigated the relationship between radical awareness and word recognition. In the study, 97 L2 learners, divided into elementary and advanced groups, completed a word recognition task, a character-legality decision task, a character-meaning matching task, and a character-writing task. The results indicate that advanced learners have a higher level of radical awareness than that of elementary learners. Additionally, for L2 learners across both levels, there are significant correlations between implicit radical awareness, explicit positional radical awareness, explicit functional semantic radical awareness, and word recognition performance. Finally, Su found that the explicit functional awareness of semantic radicals is the unique predictor for L2 learners' word recognition performance.

Hao and Shu (2005) investigated L2 learners' awareness of phonetic radicals by teaching 25 L2 learners three types of compound characters (i.e., fully regular, semi-regular, and characters that contained unknown phonetic radicals). They found that learners' performance was best on regular compound characters, followed by semi-regular compound characters, and worst on characters with unknown phonetic radicals, indicating that L2 learners are able to apply their knowledge of phonetic radicals to learning novel characters.

Kim (2010) investigated the reading stages L2 learners of Chinese went through in their literacy development in two experiments. In the first experiment, 70 L2 learners were asked to learn 18 novel characters that varied in terms of visual distinctiveness; in the second experiments, they learned 18 novel characters that differed in terms of phonetic consistency. The results showed that participants who had higher working memory capacities performed better in the first experiment, whereas those who knew more characters learned consistent and semi-consistent characters faster than the inconsistent characters in the second experiment. Based on these findings, Kim proposed a model of developmental stages in L2 Chinese. The model suggests that, different from L1 literacy development, adult learners bypass the visual stage and start from the phonetic stage, and then progress to the orthographic stage as their proficiency increases. Although this model differs from Ke's (1996b) model, both of them confirm the importance of radical awareness in reading Chinese as an L2.

Finally, Tong and Yip (2015) investigated whether L2 learners of Chinese were aware of the orthographic, phonological, and semantic properties of radicals, and whether their radical awareness predicted their word recognition performance. In addition to two character reading aloud tasks, a picture-character mapping task was conducted under three conditions: no cue, phonetic cue, and semantic cue, where 84 L2 learners were presented with a picture (e.g., a bridge) and asked to choose an answer from five types of pseudo-character or non-character options: (1) a pseudo-character that contained the correct semantic radical in a legal position, (2) a pseudo-character that contained the correct phonetic radical in a legal position, (3) a pseudo-character that had unrelated radicals, (4) a non-character that contained the correct semantic radical in an illegal position, and (5) a non-character that contained the correct phonetic radical in an illegal position. Their results showed that under the no-cue condition, L2 learners tended to

choose pseudo-characters that contained correct radicals in legal positions more than those that contained correct radicals in illegal positions. Additionally, there was a semantic radical bias under both no-cue and semantic-cue conditions, where learners chose pseudo-characters that contained correct semantic radicals more than those that contained correct phonetic radicals. When a phonetic cue was provided, however, the opposite pattern was observed. These findings indicate that L2 learners are able to apply their radical awareness and radical knowledge to reading novel characters and they rely more on semantic radicals than on phonetic radicals.

3.2 Effect of character learning strategy on L2 character recognition

Although it has been acknowledged that radical awareness facilitates L2 character learning, research on L2 character learning strategies indicates that radical-related strategies are largely underused.

Ke's (1998a) study indicates that although Chinese learners consider radical knowledge important, they feel the need to memorize characters as wholes and tend to practice writing characters repeatedly without taking advantage of their knowledge of the Chinese orthography. By analyzing the self-reports from 29 first-year L2 learners of Chinese, McGinnis (1999) also found that English-speaking students prefer rote repetition and creating personal stories over using semantic radicals and phonetic radicals when learning novel characters. Yin's (2003) longitudinal study on Chinese L2 learners' learning difficulties and strategies over a three-year period also reported similar findings. It was found that learners tend to use mechanical strategies such as writing characters repeatedly and reading aloud characters repeatedly, although they also attempt to memorize radicals and use radical knowledge during character learning.

Shen (2005) investigated the character learning strategies used by 95 English-speaking learners enrolled in beginning through advanced Chinese classes by using three questionnaires.

Based on the analyses on the survey results, Shen identified 30 common strategies and found that, among these strategies, orthographic knowledge-based strategies and metacognitive strategies relating to preview and review of characters are the most commonly used. Different from previous findings (e.g., McGinnis, 1999), her results indicate that L2 learners use strategies including making use of radical knowledge to encode characters.

A number of researchers further investigated the effectiveness of L2 learners' use of character learning strategies. Zhao and Jiang (2002) examined the correlations between beginning L2 learners' strategy use and their character test scores and found that memorizing characters as wholes may not be effective, whereas using knowledge of semantic radicals to learn novel characters is effective. Additionally, learning strategies have been found to affect the acquisition of compound characters to a greater extent relative to the acquisition of other types of characters. Liu and Jiang (2003) compared the effectiveness of two L2 character learning strategies: (1) radical analysis and recalling, and (2) writing characters repeatedly. Their results indicate that strategy (1) is more effective than strategy (2) for learning the orthographic forms of characters, whereas the two strategies do not differ for learning the pronunciations and meanings of characters.

Shen (2004) also explored how different learning strategies affected L2 character retention. By comparing the effectiveness of the three strategies including rote memorization, student self-generated elaboration, and instructor-guided elaboration, she found that the last two strategies resulted in better retention of characters. Based on these results, Shen suggests that deeper processing of characters yields better performance than does shallow processing.

In two recent studies, Sung (2012, 2014) explored the effects of learning strategies on L2 learners' character test performance. In the first study, Sung (2012) identified seven strategies

that were most frequently used, which included four strategies that were stroke-orthographic knowledge-based and three that were phonological-semantic-knowledge based. Among them, the stroke-orthographic knowledge-based strategies accounted for 6.8% of learners' character learning performance. In the second study, Sung (2014) identified twenty different strategies and observed that L2 learners who frequently used phonological strategies performed better on the phonological comprehension questions, whereas those who frequently used orthographic strategies performed better on the graphic comprehension, graphic production, and phonological production sections of the test.

3.3 Activation of radicals in L2 character recognition

To examine the role phonetic radicals played in L2 character recognition, Jiang (2001) conducted a paper-and-pencil test, in which 32 L2 learners (16 second-year learners and 16 third-year learners) wrote down the *pinyin* pronunciations for 80 phonologically regular compound characters and 80 irregular ones. The results showed that L2 learners performed better on regular characters than on irregular characters, and that the regularity effect was stronger for the third-year learners relative to second-year learners. These findings suggest that L2 learners are sensitive to the phonological relationship between compound characters and their phonetic radicals, and that L2 learners may use more phonetic-radical-based decoding strategies in character recognition as their Chinese proficiency increases.

Williams (2010, 2013) investigated the effects of semantic and phonetic radicals on L2 character recognition by using three different tasks. In a semantic categorization task, 30 L2 learners were presented with four characters at a time and asked to determine if each character belonged to a given semantic category. The four types of characters included: (1) a compound character with a transparent semantic radical that belonged to a given category (e.g., 狼 “wolf,”

whose semantic radical was 犭 “dog”), (2) a compound character with an opaque semantic radical and did not belong to the category (e.g., 狂 “crazy,” whose semantic radical was 犭 “animal”), (3) a character that belonged to the category (e.g., 虎 “tiger”), and (4) unrelated control (e.g., 哥 “older brother”). The results showed that L2 learners responded faster to (1) than to (3), indicating that transparent semantic radicals facilitated the activation of character meaning. Additionally, responses to (2) were also slower than those to (4), showing that opaque semantic radicals interfered with character recognition. In a homophone recognition test, the same L2 learners were shown a pair of characters and asked to determine whether the characters were homophones. Four types of characters were used: (1) two homophonic characters that had the same phonetic radical (e.g., 安 *ān* and 氨 *ān*), (2) two non-homophonic characters that had the same phonetic radical (e.g., 位 *wèi* and 泣 *qì*), (3) two homophonic characters that had different phonetic radicals (e.g., 瓷 *cí* and 词 *cí*), and (4) unrelated control characters (e.g., 往 *wǎng* and 根 *gēn*). The results showed that there was no difference between condition (1) and (3), but responses to (2) were significantly slower than those to (4), indicating that irregular phonetic radicals produced an inhibitory effect on character recognition. Lastly, in a character decision task, the same participants were presented with a compound character with either a blurred semantic radical or a blurred phonetic radical and asked to determine if it was a real character. Results showed that L2 learners were slower in identifying characters with blurred phonetic radicals relative to those with blurred semantic radicals. Taken together, Williams suggests that semantic radicals play a more important role in L2 character recognition, whereas phonetic radicals are mainly used for orthographic disambiguation rather than phonological activation.

Zhao et al. (2012) explored the neural basis of regularity effect on L2 character recognition in an fMRI study. In the experiment, 20 L2 learners from alphabetic L1 backgrounds and a control group of Chinese native speakers were presented with a compound character with either a regular or an irregular phonetic radical. Neuroimaging results showed that L2 learners exhibited stronger activation than native speakers did in the right occipitotemporal region. L2 learners also had greater activations in the ventral portions of the left inferior parietal lobule and the left inferior frontal gyrus, whereas native speakers exhibited more dorsal activations in these regions. Based on the L2 learners' brain activation, Zhao et al. conclude that they are sensitive to phonological regularity effects.

Wei and Jiang (2014) studied the effects of frequency and regularity on L2 character recognition by asking 17 advanced L2 learners to write down the *pinyin* for 30 compound characters and 10 simple characters. The results showed that for low-frequency compound characters, L2 learners are able to use phonetic radicals as phonological cues.

Lu, Koda, Zhang, and Zhang (2014) examined the effect of semantic radical transparency on character meaning inference. In a semantic category judgment test, 48 L2 learners enrolled in a third-semester Chinese class were presented with a category in English (e.g., fish), followed by a compound character (e.g., 鲤 “carp”), and asked to determine if the character was a member of the given category. Half of the characters had transparent semantic radicals, and the other half had opaque semantic radicals. Additionally, L2 learners' character inference ability was measured by a multiple-choice task and a lexical inference task, in which they were presented with 40 sentences, each containing an unfamiliar character, and asked to choose the most appropriate meaning for the character. Finally, a radical knowledge test was conducted to measure L2 learners' radical knowledge. In the test, the learners were presented with the radicals

used in the lexical inference task and asked to rate their familiarity with the radicals. Lu et al.'s results indicate that both semantic radical transparency and learner's radical knowledge influence their use of semantic radical information during character recognition.

3.4 Effect of context on L2 character recognition

To date, only three studies have examined context effects on L2 character recognition (Sun, 1992; Wang & Koda, 2013; Williams, 2010). Sun (1992) compared context-independent character recognition and context-embedded word recognition and found that graphic information is processed to a lesser degree when context is available. Similarly, Williams (2010) also compared character recognition in isolation and in sentence contexts by conducting character decision and sentence reading tasks. The character decision task, in which semantic radicals or phonetic radicals were blurred, showed that L2 learners were slower in recognizing pseudo-characters whose phonetic radicals were blurred than those whose semantic radicals were blurred. The same results were found in the task in which the characters with blurred radicals were embedded in sentences. Based on these findings, Williams argues that L2 learners may use phonetic radicals for orthographic disambiguation during character recognition.

Wang and Koda (2013) examined the effect of context on radical-level processing by having 37 first-year L2 learners from alphabetic L1 backgrounds complete three paper-and-pencil tests. The first test was a radical meaning test, in which L2 learners were asked to select the correct meaning for 15 commonly used semantic radicals. The second task was a context-independent character meaning inference task, in which L2 learners were asked to select a character that would fit a given meaning from three types of novel characters including (1) compound characters with transparent semantic radicals, (2) compound characters with semi-transparent semantic radicals, and (3) simple characters. In the last task, which was a context-

embedded character meaning inference task, L2 learners were presented with an English sentence that contained a novel character and asked to select the correct meaning for the character. Their results suggest that semantic radicals facilitate character-meaning inference in both context-independent and context-embedded conditions, and that L2 learners are sensitive to semantic radical transparency.

3.5 Effect of L1 background on L2 character recognition

Previous research has shown that L2 learners' L1 background may influence their use of Chinese character learning strategies (e.g., Arrow, 2004; Jiang & Zhao, 2001; Sung & Wu, 2011) and the way they process characters. Ke (1998b) explored whether and how a heritage background in Chinese influenced character recognition and production in L2 Chinese and found that for first-year learners, heritage language background has no effect on learners' character recognition or production. Similar results were reported in Shen's (2003) and Xiao's (2006) studies, both of which suggesting that a heritage background in Chinese has little influence on learners' reading, vocabulary, and writing performance. These studies indicate that although Chinese heritage learners may be more proficient in speaking and listening, the nature of the Chinese writing system may not allow them to transfer their existing oral and aural skills easily (Ke & Li, 2011).

In Jiang's (2003) study, 74 L2 learners who were native speakers of Japanese, Korean, Indonesian, and English were asked to write down the *pinyin* pronunciations and meanings for 30 characters that they had learned. The results revealed that there was a significant correlation between Indonesian- and English-speaking learners' performance on *pinyin* pronunciation production and character meaning production, but such a correlation was not found for Japanese- and Korean-speaking learners. These findings suggest that L2 learners from alphabetic L1

backgrounds may rely more on phonological decoding than L2 learners from Japanese L1 background.

Gao (2001) analyzed the relationship between L2 learners' orthographic errors and their L1 backgrounds and found that Japanese-speaking learners differ from L2 learners of other L1 backgrounds in that Japanese-speaking learners make fewer errors and that they tend to process compound characters as wholes. Consistent with Gao's findings, Feng, Lu, and Xu (2005) also found that L2 learners from alphabetic L1 backgrounds tend to decompose compound characters and that they are more sensitive to character components that occupy the right and the bottom positions within compound characters. L2 learners who are native speakers of Japanese or Korean, however, tend to process compound characters that have a left-right structure as wholes but decompose characters that have a top-bottom structure. Nevertheless, Lin and Collins's (2012) study on the influence of L1 background and the effects of frequency, regularity, and consistency on L2 character recognition accuracy showed different results. In their study, 22 English-speaking learners and 31 Japanese-speaking learners were asked to read 130 characters that varied in terms of regularity, consistency, visual complexity, and familiarity. The results showed that although both groups of L2 learners are able to use phonetic radical information when reading characters, the Japanese-speaking learners make greater use of radical-level information (i.e., the regularity and consistency properties of phonetic radicals) than English-speaking learners do.

Although the studies presented above reported mixed results with regard to L2 learners' processing patterns, they indicate that L1 background may influence L2 character recognition and learners' abilities to use radical-level information when reading Chinese.

Chapter 4: Overview of the Experiments

4.1 Rationale

As presented in the previous chapter, the literature on L1 character recognition has focused on context-independent character recognition, and only two studies to date (Liu et al., 2002, Tsai et al., 2004) have examined character recognition in sentence reading, and neither of these two studies investigated the influence of contextual cues (e.g., sentence predictability) on Chinese character recognition.

Research on L2 character recognition has generally focused on radical awareness and character learning strategies. Although a number of studies have also explored radical-level processing in L2 Chinese acquisition, the majority have used offline tasks such as paper-and-pencil tests and questionnaires. Additionally, previous studies on L2 character recognition were mostly concerned with the regularity and consistency effects of phonetic radicals and the transparency effect of semantic radicals. No study to date has directly explored whether and how the phonological and semantic properties of radicals are activated during L2 character processing. How context influences radical activation has also been largely ignored in the previous research on L2 character processing. Sun's (1992) study was only concerned with character-level activation, whereas Wang and Koda's (2013) used English sentences and offline tasks, which may not reflect natural reading and character processing in real time. Finally, the previous studies on the effect of L1 background on L2 character recognition mainly involved heritage learners, Japanese- or Korean-speaking learners, and learners from alphabetic L1 backgrounds, and they yield mixed results. Little is known as to how learners from other types of L1 orthographies (e.g., abugida) process characters.

To address these gaps in the literature, the current study examined L1 and L2 character recognition under both context-independent and context-embedded conditions by conducting three online experiments. Specifically, the study aimed to address the following four research questions:

- (1) How do native speakers and L2 learners access the orthographic properties of radicals during character recognition?
- (2) How do native speakers and L2 learners access the phonological and semantic properties of radicals during character recognition?
- (3) How does sentence context influence L1 and L2 character recognition?
- (4) How does the reader's L1 orthography influence his or her L2 character recognition?

The masked priming paradigm was chosen for the study, because it has been shown to be an effective tool to investigate orthographic processing. In a typical priming experiment, two stimulus items – a prime and a target – are presented sequentially in a single trial, and the relationship between them can be manipulated depending on the specific research goal (Jiang, 2012). As participants in masked priming experiments are typically unaware that priming is occurring, the behavioral patterns captured are less likely to be affected by their strategic processing or metalinguistic knowledge, and tend to reflect real-time language processing (McNamara, 2005). In addition to two primed-character decision tasks (Experiments 1 and 2), a third experiment was conducted using the combined self-paced reading and masked-priming paradigm (SPaM), which has been shown to be effective in detecting sentence context effects in early word recognition (Luke & Christianson, 2012, 2013).

4.2 Overview of the experiments

Experiment 1 was designed to answer research question (1): How do native speakers and L2 learners access the orthographic properties of radicals during character recognition. In the experiment, participants were presented with prime characters that contained the target characters as either their phonetic or semantic radicals and asked to determine if the targets were real characters. Prime frequency and target frequency were also manipulated in the experiment, and two SOA conditions were used to track the potential time course of radical-level orthographic activation. If readers automatically decomposed compound characters, significant priming effects would be expected.

Experiment 2 aimed to answer research question (2): How do native speakers and L2 learners access the phonological and semantic properties of radicals during character recognition. In order to examine whether and how the phonological and semantic properties of radicals were activated, primes were manipulated so that they were related to the target at the character level or at the radical level or unrelated. If readers automatically activated the meaning and pronunciation of the radical during compound character recognition, there should be priming effects produced by both character-level and radical-level related primes.

To address research question (3): How does sentence context influence L1 and L2 character recognition, both highly constraining and non-constraining sentences were included in Experiment 3, and primes and targets were presented within these sentence contexts. In this experiment, primes that were either (1) a radical of the target, (2) related to the target at the character level, (3) related to the target at the radical level, or (4) unrelated. If readers also activated the properties of radicals during sentence reading, there should be significant priming effects. Additionally, if readers' character processing strategies were sensitive to sentence

context information, there should also be reading time differences between highly constraining and non-constraining sentence contexts.

Finally, to answer research question (4): How does the reader's L1 orthography influence his or her L2 character recognition, L2 learners from four different types of L1 backgrounds were recruited, and their L1 orthographies include: (1) abjad, which employs writing systems where only consonants are presented (e.g., Arabic); (2) abugida⁵, which employs segmental writing systems where consonant-vowel sequences are presented as one unit, and the unit is typically based on a primary consonant letter and a secondary vowel notation (e.g., Thai); (3) alphabet, which employs writing systems where both vowels and consonants are represented by letters (e.g., English); and (4) syllabary/logography (e.g., Japanese, which employs *kanji* (Chinese characters) in addition to two syllabaries *hiragana* and *katakana*). (Daniels, 1996). Native speakers of Chinese were also recruited in the study to provide a baseline for comparison.

⁵ Abugida is also called alphasyllabary. Abugida scripts differ from pure syllabaries in that, abugida syllables beginning with the same consonant are typically written with characters based on the same sign in a regular way, and the character for a given syllable typically consists of a number of elements that designate the individual sounds of the given syllable (Bright, 2000).

Chapter 5: Experiment 1

The primary goal of this experiment was to examine whether Chinese native speakers and L2 learners activated the orthographic forms of radicals when reading compound characters. This was achieved by having participants complete a primed-character decision task, in which compound character primes (e.g., 他 *tā* “he”) contained the target characters (e.g., 也 *yě* “also”) as their radicals. Because the target character was orthographically identical to the radical of the prime, any priming effects observed would suggest that the orthographic form of the radical was activated during the visual recognition of the prime character. On the other hand, if no priming effects were observed, it would suggest that compound characters are processed as single units and that radical-level activation may not be involved.

Additionally, whether radical function and compound character/radical frequency modulated the orthographic activation of radicals was investigated by manipulations of the function of radicals (i.e., semantic or phonetic radical) as well as the frequency of compound characters and their radicals. The experiment also explored the potential time course of the orthographic activation of radicals during character recognition by using two SOA conditions (i.e., 50 ms and 200 ms). These two SOAs were chosen because at 50 ms, primes are generally not consciously perceived, i.e., primes presented for shorter periods than about 50 ms are generally below the perceptual threshold (Forster, 1998). In contrast, primes presented for 200 ms are fully visible and consciously perceived. Therefore, comparisons of priming effects at these two SOAs would address the question as to whether the orthographic activation of radicals, if any, occurred at relatively early or late stages of visual recognition. Finally, L2 learners’ L1 orthographic background information was included in the statistical analyses to examine whether and how L1 orthography influenced L2 character processing.

5.1 Participants

5.1.1 Native speakers of Chinese

Participants for Experiment 1 included 72 native speakers of Chinese, who were undergraduate or graduate students enrolled at Hangzhou Normal University and Beijing Language and Culture University, China. To document their language background information, they were asked to complete a background questionnaire (see Appendix A) and an English cloze test (see Appendix D). Their average age, English cloze test score, and length of English study are shown in Table 7.

Table 7

Experiment 1: Native Speakers' Background Information

Native speakers	Average	Range
Gender	16 males, 56 females	NA
Age (yrs)	19.63	18-34
English cloze test score	65.21/100	37.5/100-82.5/100
Length of English study (yrs)	9.69	3-20

5.1.2 L2 learners of Chinese

In addition to native speakers, 68 L2 learners of Chinese enrolled at Beijing Language and Culture University participated in Experiment 1. To measure their Chinese proficiency, they were asked to complete a background questionnaire (see Appendix B), a Chinese cloze test (see Appendix C), and an on-line Chinese character recognition test⁶. All of the L2 learner participants (except a native speaker of English) had also learned English as an L2, and 36.76% of them reported to have learned other foreign languages besides Chinese and English. Their background information is summarized in Table 8. Statistical analyses showed that L2 learners' Chinese cloze test scores significantly correlated with number of known characters ($r = 0.57$, p

⁶ The Chinese character recognition test is available at <http://www.clavisinica.com/character-test-applet.html>

< .001), length of Chinese study ($r = 0.17, p < .001$), and weekly use of Chinese ($r = 0.32, p < .001$).

Table 8

Experiment 1: L2 Learners' Background Information

L2 Learners	Average	Range
Gender	27 males, 41 females	NA
Age (yrs)	23.50	18-45
Chinese cloze test score	80.76/100	36/100-100/100
Number of known Chinese characters	1664	263-3032
Weekly use of Chinese (%)	56.43%	3%-95%
Length of Chinese study (yrs)	5.12	0.67-27
Age of first immersion in Chinese-speaking countries (yrs)	19.91	6-37
Length of immersion in Chinese-speaking countries (yrs)	2.75	0.04-27
Number of foreign languages studied	2.49	1-5

As shown in Table 9, the L2 learners were divided into four groups based on the orthographic typology of their L1 writing systems (Daniels, 1996).

Table 9

Experiment 1: Orthographic Typology of L2 learners' First Language Writing Systems

L1 orthography type	Languages	Number of participants
Abjad	Persian	1
Abugida	Burmese, Hindi, Lao, Nepali, Thai	24
Alphabet	English, French, Georgian, Korean, Mongolian, Portuguese, Russian, Tajik, Ukrainian, Uzbek, Vietnamese	42
Syllabary/logography	Japanese	1

In addition to orthographic typology, the depths of the L2 learners' L1 orthographies were also included in the analyses. Orthographic depth is the transparency of the relationship between the phonemes and letters of the orthography (Liberman, Liberman, Mattingly, & Shankweiler, 1980). If letters and phonemes correspond to each other completely and

consistently in an orthography, then this orthography is considered shallow. On the other hand, if the relationship between letters and phonemes are equivocal, i.e., some letters can represent more than one phoneme and some phonemes can be written in more than one way in the orthography, then the orthography is considered deep. Previous research on L1 literacy development has shown that deep orthographies demand greater phonological development and linguistic awareness on the learner's part than does a shallow orthography (e.g., Liberman et al., 1980).

The depth of orthography is conceptually different from orthography type in that it describes the nature of a given orthography from a different dimension, i.e., orthographies that belong to the same type may vary in terms of orthographic depth. For example, although both are alphabetic orthographies, English has a much deeper orthography than does Spanish. If L2 processing is influenced by the learner's L1 orthography properties (Koda, 1997), it is possible that, just as with orthographic typology, the depth of the learner's L1 orthography will also play an important role. To test this possibility, the depths of L2 learners' L1 orthographies were quantified by calculating the phoneme-to-letter ratios of the orthographies, and the ratios were included as a continuous variable in the statistical analyses. As shown in Table 10, when the phoneme-to-letter ratio of a given orthography is relatively low, as in the case of Nepali, there is a relatively complete correspondence between phonemes and letters, indicating that Nepali is orthographically shallow. When the phoneme-to-letter ratio is high, as in the case of English, a letter may correspond to a number of different phonemes, and the reader needs to rely on context-dependent GPC rules to determine which phoneme the letter represents in a given context. English is thus orthographically deeper relative to Nepali.

Table 10

Experiment 1: Orthographic Depths of L2 learners' First Language Writing Systems

L1	Phoneme-to-letter ratio	Number of participants
Thai	0.49	18
Kazakh	0.64	1
Tajik	0.86	1
Hindi	0.91	1
Nepali	0.94	1
Lao	0.97	2
Burmese	1.00	2
Georgian	1.00	1
Korean	1.03	13
Persian	1.06	1
Ukrainian	1.09	1
Uzbek	1.23	8
Russian	1.24	2
Vietnamese	1.24	1
French	1.31	1
Mongolian	1.34	10
English	1.73	2
Portuguese	1.73	1
Japanese	NA	1

5.2 Design and materials

A 3 (prime type: high-frequency related, low-frequency related, unrelated control) $\times$ 2 (target frequency: high-frequency, low-frequency)⁷ $\times$ 2 (prime-target relation: phonetic radical, semantic radical) $\times$ 2 (SOA: 50 ms, 200 ms) design was used in Experiment 1. The stimuli consisted of 48 prime-target sets (see Appendix E for the complete list).

⁷ The target frequency was manipulated so that the target characters were either high- or low-frequency. However, target frequency was treated as a continuous variable in the data analyses.

Table 11

Experiment 1: Design and Sample Stimuli

Stimulus type	Prime type			Prime-target relation	Target	
	HF related	LF related	Control		Character	Frequency
(1) PR relation, HF target						
Character	他	弛	抓	Phonetic radical	也	High
Pronunciation	<i>tā</i>	<i>chí</i>	<i>zhuā</i>		<i>yě</i>	
Translation	he	to loosen	to catch		also	
(2) SR relation, HF target						
Character	的	皈	使	Semantic radical	白	Low
Pronunciation	<i>dē</i>	<i>guī</i>	<i>shǐ</i>		<i>bái</i>	
Translation	of	to convert	to cause		white	
(3) PR relation, LF target						
Character	约	酌	城	Phonetic radical	勺	Low
Pronunciation	<i>yuē</i>	<i>zhuó</i>	<i>chéng</i>		<i>sháo</i>	
Translation	about	to pour	city		spoon	
(4) SR relation, LF target						
Character	配	酥	满	Semantic radical	酉	Low
Pronunciation	<i>pèi</i>	<i>sū</i>	<i>mǎn</i>		<i>yǒu</i>	
Translation	to match	crisp	full		evening	

Note. PR = phonetic radical; SR = semantic radical; HF = high-frequency, LF = low-frequency.

As shown in Table 11, the prime-target relation was manipulated so that targets were either the phonetic radicals (28 sets) or the semantic radicals (20 sets) of the compound character primes. Half of the targets were high frequency and the other half were low-frequency characters. Therefore, altogether there were four stimulus types: (1) phonetic-radical relation, high-frequency target, (2) semantic-radical relation, high-frequency target, (3) phonetic-radical relation, low-frequency target; and (4) semantic-radical relation, low-frequency target. Additionally, each stimulus type had three types of compound character primes: high-frequency related, low-frequency related, and unrelated control.

Only simplified characters were used in the experiment. All of them were chosen from a character-frequency statistics database⁸. The 48 high-frequency primes had a mean frequency of 1515.54 per million (range = 34.70 – 37496.70 per million), the 48 low-frequency primes had a mean frequency of 4.67 per million (range = 0.0065 – 24.70 per million), and the 24 control primes had a mean frequency of 517.44 per million (range = 2.11 – 3862.10 per million). The 24 high-frequency targets had a mean frequency of 1961.99 per million (range = 368.91 – 8895.84 per million), and the 24 low-frequency targets had a mean frequency of 27.25 per million (range = 0.79 – 235.59 per million).

Because regular and semi-regular compound characters share similar phonological properties with their phonetic radicals, any priming effects between them could be due to the processing of the whole character rather than the processing of the phonetic radical; the same also applies to transparent semantic radicals. To rule out this possibility, only compound characters that had irregular phonetic radicals were used as primes for the phonetic-radical sets, and those that had opaque semantic radicals were used as primes for the semantic-radical sets. Specifically, for the 28 phonetic-radical sets, the related primes differed from their phonetic radicals (i.e., targets) in terms of consonants and vowels. For the 20 semantic-radical sets, a semantic relatedness judgment pretest was conducted, in which 30 native speakers of Chinese who did not participate in the main experiments rated the semantic relatedness between the primes and their semantic radicals (i.e., targets) from 1 (*not related at all*) to 4 (*closely related*). The average score was 1.59, and the scores for the low-frequency primes ($M = 1.56$) did not differ from those for the high-frequency primes ($M = 1.63$).

⁸ The database was developed by the Center for Chinese Linguistics at Peking University and is available at http://ccl.pku.edu.cn:8080/ccl_corpus/CCL_CC_Sta_Xiandai.pdf

To control for repetition effects, a Latin square design was used. Three presentation lists were created; in each list, each target appeared only once but the three types of primes appeared in equal numbers. In addition, 48 sets of prime-target fillers were included in each list. For each participant, the sequence of the items on the list was pseudo-randomized. Finally, two SOAs (i.e., 50 ms and 200 ms) between primes and targets were used to track the potential time course of the orthographic activation of radicals during compound character recognition.

5.3 Procedures

The preparation of the experimental stimuli was as follows. First, all primes (in *Kaiti* font) and targets (in *Songti* font) were generated in a word-processing program and converted into individual image files. Both fonts are commonly used in the Chinese language community. Although the same character looks stylistically different in the two fonts, the structure and strokes of the character remain the same. Different fonts for the primes and targets were chosen to ensure that participants were not reacting to the visual trace of the primes, especially under the short SOA condition. Second, 48 non-characters were generated by removing strokes from or adding strokes to real, unrelated characters. These non-characters, which were used as fillers in the character decision task, did not differ from the critical characters in terms of size or font. Finally, the experiment was programmed and presented using E-Prime Professional software, version 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

Figure 4 illustrates the procedures of Experiment 1. In each trial, a fixation point (“+”) was first presented at the center of a computer screen for 250 ms, followed by a 250-ms forward mask (“##”). A prime character was then presented for either 50 ms or 200 ms, depending on the SOA condition, and then immediately replaced by the corresponding target character, which remained on the screen until participants decided whether it was a real character or not. Because

the prime character was sandwiched between the mask and the target character, participants were unlikely to consciously perceive the prime under the short SOA condition (Jiang, 2012). Half of the targets were real characters (i.e., critical items), and half were non-characters (i.e., fillers). In the experiment, 36 native speakers and 34 L2 learners were randomly assigned to the short SOA condition, and the other 36 native speakers and 34 L2 learners to the long SOA condition. None of the participants reported to have seen primes under the short SOA condition.

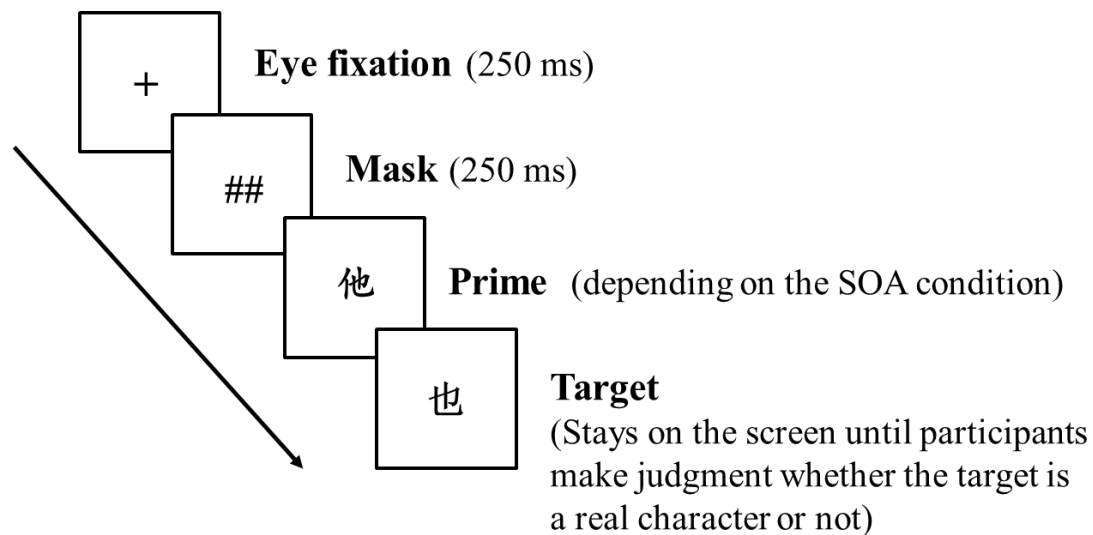


Figure 4. Experiment 1: Procedures. SOA = stimulus onset asynchrony.

Participants were tested individually in a quiet room. They were seated in a comfortable chair about 60 cm from a computer screen and were randomly assigned to one of the three experimental lists. Participants were asked to make a response to the target as quickly and as accurately as possible in each trial. They were first presented with ten practice trials, followed by the experimental trials. There was a break in the middle of the test sessions; the first three trials after the break were always fillers.

5.4 Data Analysis

The data of native speakers and those of L2 learners were analyzed separately in linear mixed effects models with random effects for subjects and items using the *lme4* package, version 1.1-7 (Bates, Maechler, Bolker, & Walker, 2014) of R, version 3.1.1 (R Core Team, 2014).

5.4.1 Native speakers of Chinese

Prior to the analyses, trials with target onset delays greater than 5 ms were dropped from the data set, which resulted in a 0.46% data loss. Additionally, RTs that were shorter than 200 ms or longer than 5000 ms were removed (0.23% of the data). These thresholds were chosen based on the distribution of RTs. The average accuracy rate of native speakers was 95.65%; only trials that were answered correctly were included in the analysis. Outliers that were two standard deviations below or above the condition means were discarded (3.67% of the total data).

RTs and target frequencies were log transformed and centered prior to the analysis. Fixed effects of the model included trial number, prime type, target frequency, prime-target relation, and SOA, and random effects were fit using a “maximal” random effects structure supported by the data (Barr, Levy, Scheepers, & Tily, 2013). This included random intercepts for subjects and items, by-subject random slopes for prime type and prime-target relation, and by-item random slope for SOA. Other fixed effects were not included as random slopes because they contributed the least amount of variance and including them caused the model to fail to converge. Only fixed effects and interactions that were statistically significant ($p < .05$) or marginally significant ($p < .1$) were retained in the model. Additionally, native speakers’ accuracy data were analyzed in a separate logistic mixed effects regression model, with fixed effects including prime type, target frequency, prime-target relation, and SOA, and random intercepts for subjects and items.

5.4.2 L2 learners of Chinese

Three items were excluded from the analysis due to low accuracy (< 60%). Trials with target onset delays greater than 5 ms were removed (0.33% of the data). Additionally, RTs that were shorter than 200 ms or longer than 10000 ms were discarded (0.46% of the data). As before, these thresholds were chosen based on the distribution of RTs. The average accuracy rate of L2 learners was 89.12%, and only trials that were answered correctly were included in the analysis. Finally, outliers that were three standard deviations⁹ below or above the condition means were excluded (2.44% of the data).

L2 learners' RT data were analyzed in a separate linear mixed effects model using the same procedures. Prior to the analysis, RTs, target frequencies, and numbers of known characters were log-transformed and all continuous variables were centered. In addition to the fixed effects that were included for the native speaker data, Chinese cloze test score, number of known characters, L1 orthography type, and L1 phoneme-to-letter ratio were also entered into the model. Random effects included random intercepts for subjects and items, and by-item random slopes for the effect of Chinese cloze test score. Finally, L2 learners' accuracy data were analyzed in a logistic mixed effects regression model in R. In the model, prime type, target frequency, prime-target relation, SOA, Chinese cloze test score, number of known characters, L1 orthography type, and L1 letter-to-phoneme ratio were included as fixed effects, and random intercepts for subjects and items were entered as random effects.

⁹ Three standard deviations instead of two (as in the case of native speakers) were used here because there was much more variation in the L2 learner data. Using two standard deviations as the trimming criterion here would therefore, cause extensive data loss.

5.5 Results

5.5.1 Native speakers of Chinese

The mean values of Chinese native speakers' RTs on the target characters for each condition are presented in Table 12.

Table 12

Experiment 1: Native Speakers' Response Times (in Milliseconds) on Target Characters

Prime-target relation	Target frequency	Prime type		
		High-frequency	Low-frequency	Control
Phonetic	High	669.74 (168.44)	677.80 (183.11)	675.78 (183.74)
radical	Low	744.80 (221.61)	764.32 (211.42)	816.61 (288.73)
Semantic	High	684.25 (181.04)	665.25 (178.71)	691.78 (195.45)
radical	Low	737.20 (218.48)	720.56 (228.21)	768.12 (233.40)

Note. Standard deviations are provided in parentheses.

Table 13 presents the output of the linear mixed effects model on Chinese native speakers' RT data. There were significant main effects of trial number ($p < .001$), target frequency ($p < .001$), prime type ($p < .001$), and significant interactions between trial number and target frequency ($p < .001$), prime type and target frequency ($p = .0026648$), and target frequency and SOA ($p = 0.0399995$).

Table 13

Experiment 1: Output of Linear Mixed Effects Model on Native Speakers' Response Times

Parameters	Estimate	SE	<i>t</i>
Intercept	0.1498000	0.0279800	5.352***
Trial number	-0.0005009	0.0000584	-8.585***
Prime type: high-frequency	-0.0326500	0.0098630	-3.310**
Prime type: low-frequency	-0.0359000	0.0101200	-3.548***
Target frequency	-0.0564700	0.0068890	-8.196***
SOA: 200 ms	-0.0180200	0.0289300	-0.623
Prime-target relation: semantic radical	-0.0215000	0.0190200	-1.125
Prime type: high-frequency × target frequency	0.0120800	0.0039240	3.077**
Prime type: low-frequency × target frequency	0.0113400	0.0039280	2.886**
Target frequency × SOA: 200 ms	0.0072280	0.0034850	2.074*
Trial number × target frequency	0.0000799	0.0000234	3.414***

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

The main effect of trial number showed that native speakers sped up as they progressed through the experiment. There was also a main effect of target frequency, where participants' RTs were faster when the target was a high-frequency character ($M = 676.98$, $SD = 181.31$) than when it was a low-frequency character ($M = 760.72$, $SD = 237.54$). As illustrated in Figure 5, there was also an interaction between trial number and target frequency, where the effect of target frequency gradually decreased over the course of the experiment.

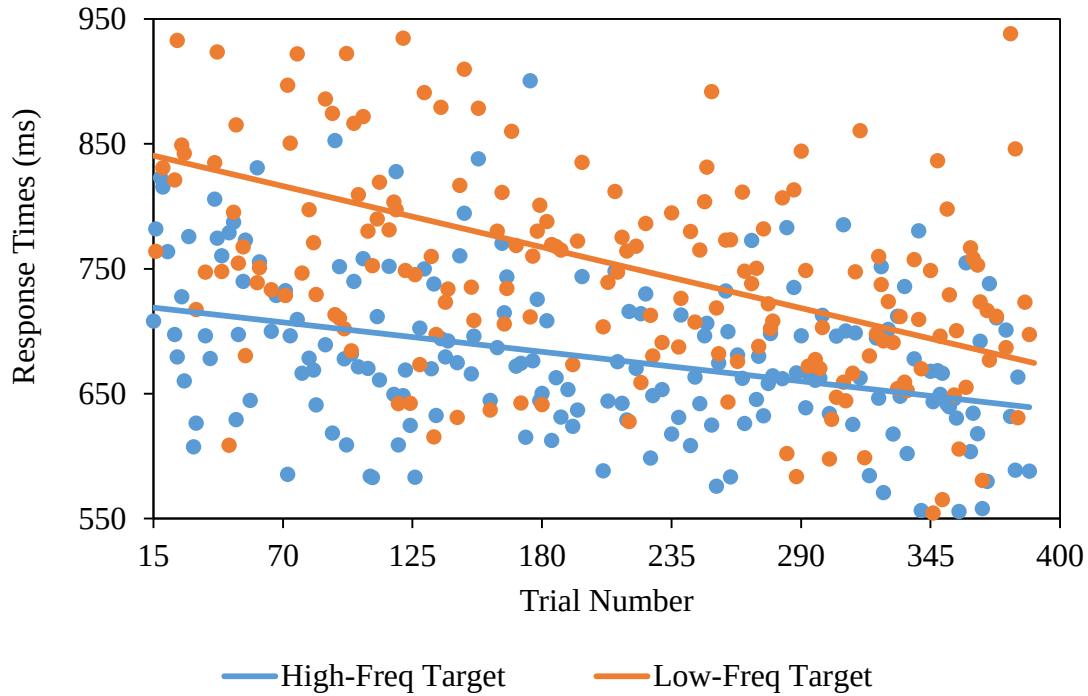


Figure 5. Experiment 1: Interaction effects (in milliseconds) of trial number and target frequency on native speakers' response times.

Figure 6 illustrates the main effect of prime type on native speakers' RTs. Responses to targets were faster when they were preceded by related primes ($M = 708.15$, $SD = 202.25$) than when they were preceded by unrelated control primes ($M = 737.27$, $SD = 236.61$). Additionally, RTs under both high-frequency related prime condition ($M = 707.86$, $SD = 200.35$) and low-frequency related prime condition ($M = 708.44$, $SD = 204.23$) were faster than those under the control condition ($M = 737.27$, $SD = 236.61$).

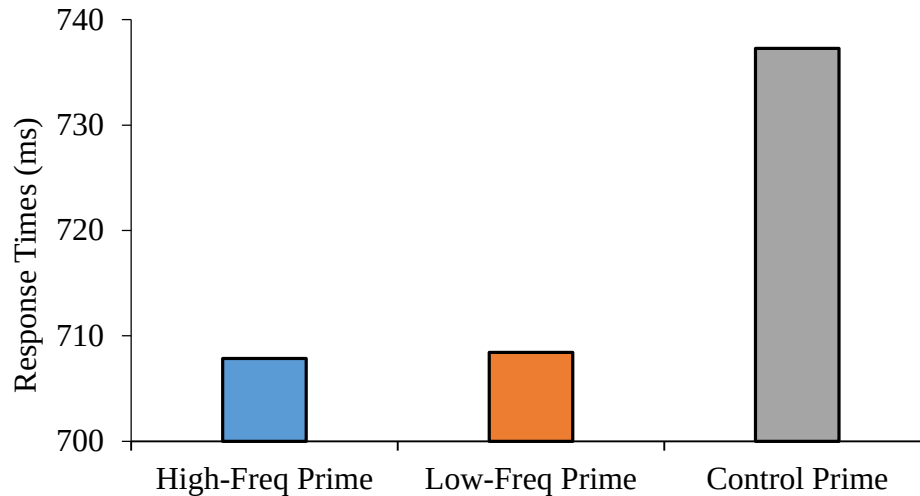


Figure 6. Experiment 1: Effects (in milliseconds) of prime type on native speakers' response times.

Furthermore, there was a significant interaction between target frequency and prime type. As shown in Figure 7, although both high- and low-frequency related primes produced facilitatory effects on low-frequency targets, such effects were not found for high-frequency targets. This was likely to be due to a floor effect, i.e., because of the participants' fast RTs on high-frequency targets, there was little room for facilitation, and the priming effects, if any, might have been obscured for high-frequency targets.

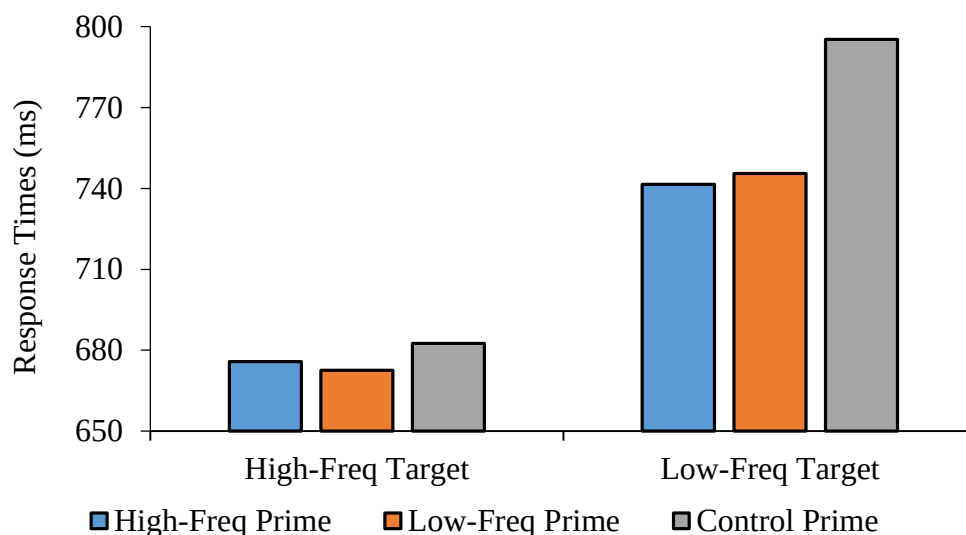


Figure 7. Experiment 1: Interaction effects (in milliseconds) of prime type and target frequency on native speakers' response times.

Lastly, the analysis also revealed a significant interaction between SOA and target frequency. As illustrated in Figure 8, although native speakers' responses to high-frequency targets at the SOA of 50 ms ($M = 677.70$, $SD = 188.37$) did not differ from those at 200 ms ($M = 676.27$, $SD = 174.18$), their responses to low-frequency targets were slower at 50 ms ($M = 770.31$, $SD = 250.35$) relative to at 200 ms ($M = 751.50$, $SD = 224.32$). Similar to the interaction between prime type and target frequency, the absence of the effect of SOA for high-frequency targets was possibly because participants' fast RTs had obscured the priming effects (i.e., a floor effect).

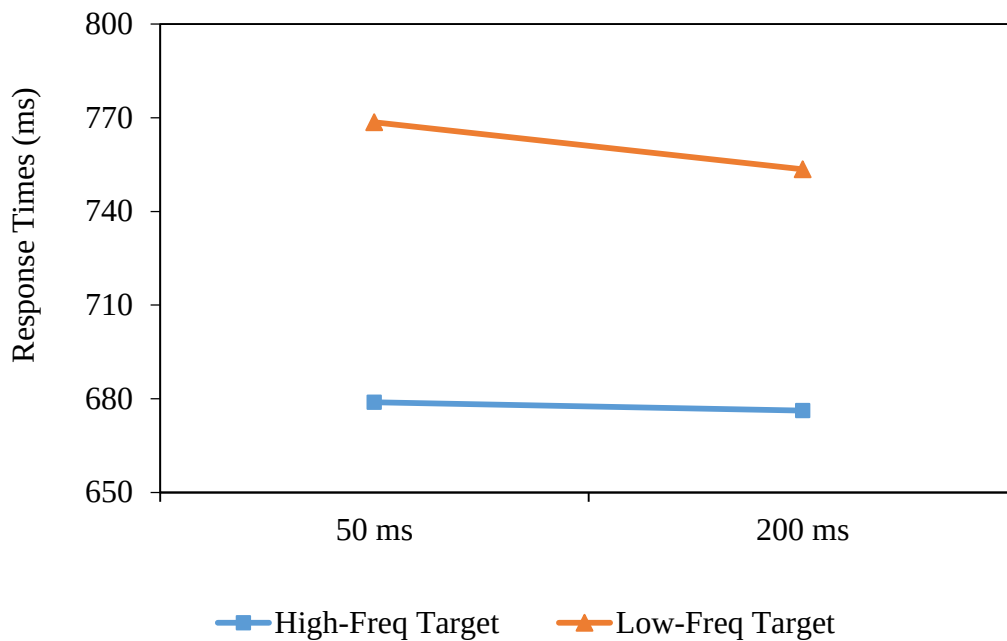


Figure 8. Experiment 1: Interaction effects (in milliseconds) of stimulus onset asynchrony (SOA) and target frequency on native speakers' response times.

The output of the logistic mixed effects model on native speakers' accuracy data is presented in Table 14. The model revealed a significant main effect of target frequency ($p < .001$) and a significant interaction between target frequency and SOA ($p = .0234000$).

Table 14

Experiment 1: Output of Logistic Mixed Effects Model on Native Speakers' Accuracy Data

Parameters	Estimate	SE	z	p
Intercept	3.85830	0.32758	11.778	< 0.001***
Prime type: high-frequency	0.03704	0.23084	0.160	0.8725000
Prime type: low-frequency	-0.12029	0.22500	-0.535	0.5929000
Target frequency	0.31500	0.06882	4.577	0.0000047***
Prime-target relation: semantic radical	0.08204	0.30508	0.269	0.7880000
SOA: 200 ms	0.01849	0.31019	0.060	0.9525000
Target frequency $\times$ SOA	-0.15609	0.06886	-2.267	0.0234000*

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, . $p < .1$

Native speakers had higher accuracy rate for high-frequency targets ($M = 0.97$, $SD = 0.16$) than for low-frequency targets ($M = 0.94$, $SD = 0.24$), and target frequency interacted with SOA. Figure 9 shows native speakers' average accuracy was higher for high-frequency targets relative to low-frequency targets at 50 ms, but such a difference was reduced at 200 ms.

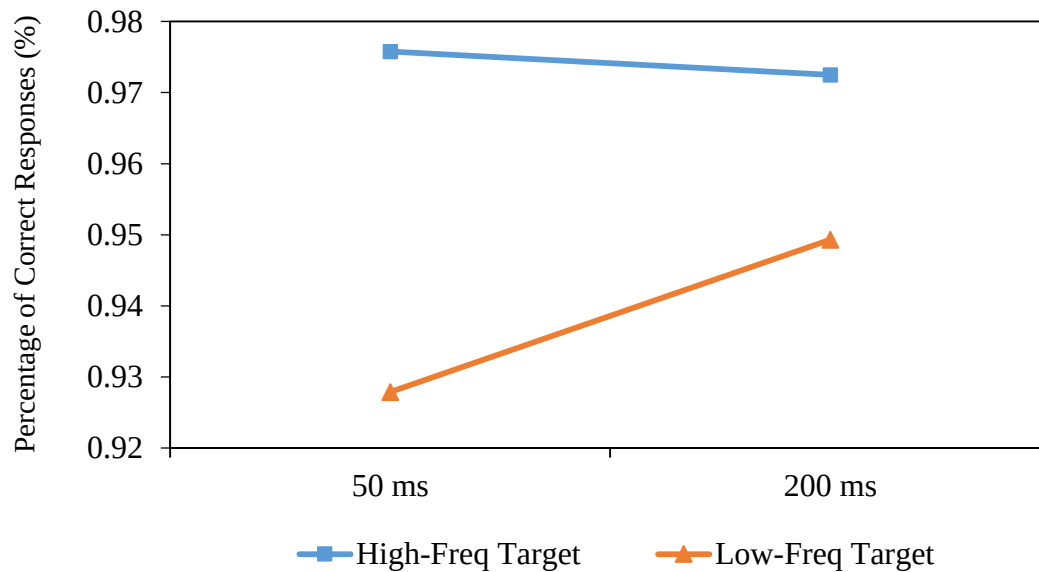


Figure 9. Experiment 1: Interaction effects (in milliseconds) of target frequency and stimulus onset asynchrony (SOA) on native speakers' accuracy.

5.5.2 L2 Learners of Chinese

The means of Chinese L2 learners' RTs for each condition are presented in Table 15.

Table 15

Experiment 1: L2 Learners' Response Times (in Milliseconds) on Target Characters

Prime-target relation	Target frequency	Prime type		
		High-frequency	Low-frequency	Control
Phonetic	High	905.24 (461.90)	934.45 (467.01)	991.33 (536.88)
radical	Low	1379.42 (899.47)	1434.17 (948.67)	1404.05 (913.45)
Semantic	High	952.68 (468.07)	904.43 (396.77)	896.70 (372.75)
radical	Low	1194.93 (611.84)	1272.12 (862.36)	1351.05 (893.70)

Note. Standard deviations are provided in parentheses.

Table 16 presents the output of the linear mixed effects model on Chinese L2 learners' RT data. There were significant main effects of trial number ($p < .001$), target frequency ($p < .001$), and L1 orthography type ($p = .0390749$), and a marginally significant main effect of prime-target relation ($p = .0548714$). The results also showed significant interactions between trial number and SOA ($p = 0.0156748$), target frequency and SOA ($p < .001$), and prime-target relation and number of known characters ($p < .001$). Finally, there was a significant three-way interaction between prime type, prime-target relation, and SOA ($p = .0268428$).

Table 16

Experiment 1: Output of Mixed Effects Model on L2 Learners' Response Times

Parameter	Estimate	SE	<i>t</i>
Intercept	0.0003676	0.2559000	0.001
Trial number	-0.0006973	0.0001233	-5.657***
Prime type: high-frequency	-0.0060270	0.0338100	-0.178
Prime type: low-frequency	0.0334400	0.0337200	0.992
Target frequency	-0.0740600	0.0078370	-9.450***
Prime-target relation: semantic radical	-0.0435800	0.0471500	-0.924
SOA: 200 ms	-0.0467100	0.0751000	-0.622
Chinese cloze test score	-0.1124000	0.3178000	-0.354
Number of known characters	0.0923100	0.0946600	0.975
L1 orthography type: abugida	0.3839000	0.2603000	1.475
L1 orthography type: alphabet	0.1181000	0.2512000	0.470
L1 phoneme-to-letter ratio	0.1477000	0.1466000	1.008
Prime type: high-frequency × SOA: 200 ms	-0.0953200	0.0475000	-2.007*
Prime type: low-frequency × SOA: 200 ms	-0.1090000	0.0474900	-2.296*
Prime-target relation: semantic radical × SOA: 200 ms	-0.0768700	0.0508400	-1.512
Prime type: high-frequency × prime-target relation: semantic radical	-0.0310300	0.0502800	-0.617
Prime type: low-frequency × prime-target relation: semantic radical	-0.0933500	0.0503400	-1.854
Trial number × SOA: 200 ms	0.0003133	0.0001296	2.418*
Target frequency × SOA: 200 ms	0.0226000	0.0063350	3.567***
Prime-target relation: semantic radical × Number of known characters	-0.1485000	0.0360600	-4.117***
Prime type: high-frequency × prime-target relation: semantic radical × SOA: 200 ms	0.1411000	0.0708800	1.991*
Prime type: low-frequency × prime-target relation: semantic radical × SOA: 200 ms	0.1830000	0.0712600	2.568*

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

First, there was a main effect of trial number, where L2 learners sped up as they progressed through the experiment. There was also a significant interaction between SOA and trial number. As illustrated in Figure 10, the effect of SOA was strong for the earlier trials, but it gradually disappeared during the course of the experiment.

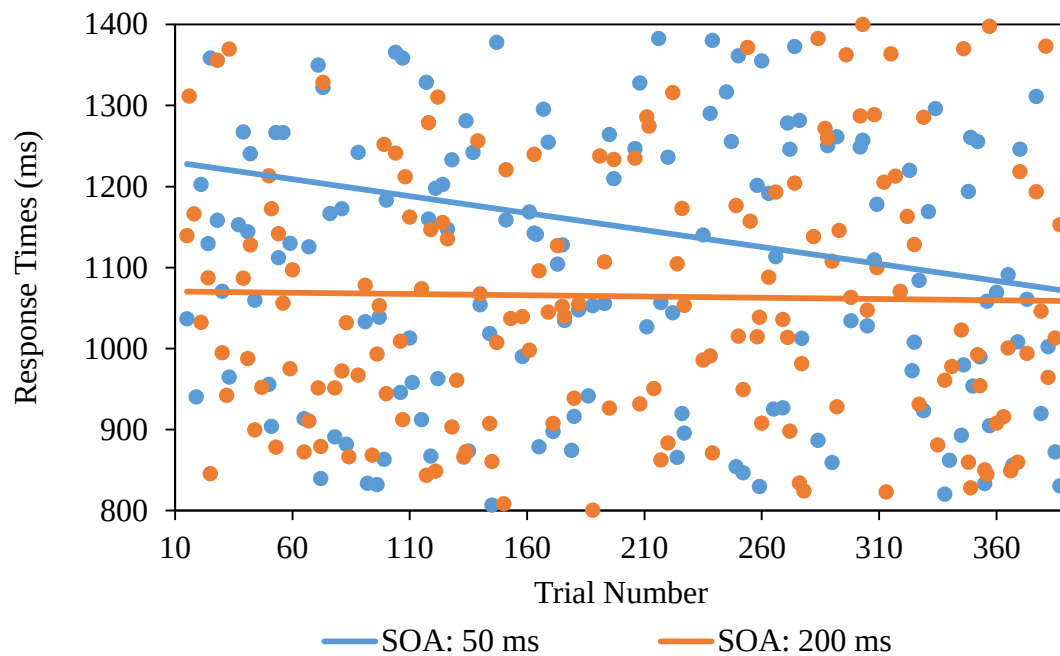


Figure 10. Experiment 1: Interaction effects (in milliseconds) of stimulus onset asynchrony (SOA) and trial number on L2 learners' response times.

The model also revealed a main effect of target frequency; participants responded faster to high-frequency target characters ($M = 933.05$, $SD = 460.55$) than to low-frequency target characters ($M = 1340.85$, $SD = 864.57$). Furthermore, the effect of target frequency interacted with the effect of SOA. As shown in Figure 11, there was little difference between L2 learners' responses to high-frequency targets at the SOAs of 50 ms ($M = 937.80$, $SD = 461.84$) and 200 ms ($M = 928.47$, $SD = 459.55$), whereas their responses to low-frequency targets were faster at 200 ms ($M = 1243.18$, $SD = 758.83$) relative to at 50 ms ($M = 1441.74$, $SD = 951.89$). There are two possible explanations for the absence of SOA effect for high-frequency targets. It was possible that, as L2 learners' responses to high-frequency targets were relatively fast, there was less room

for facilitation. Alternatively, it was also possible that L2 learners' activation of radical-level orthographic representations was less automatic for compound characters that contained low-frequency simple characters as their radicals relative to those that contained high-frequency simple characters.

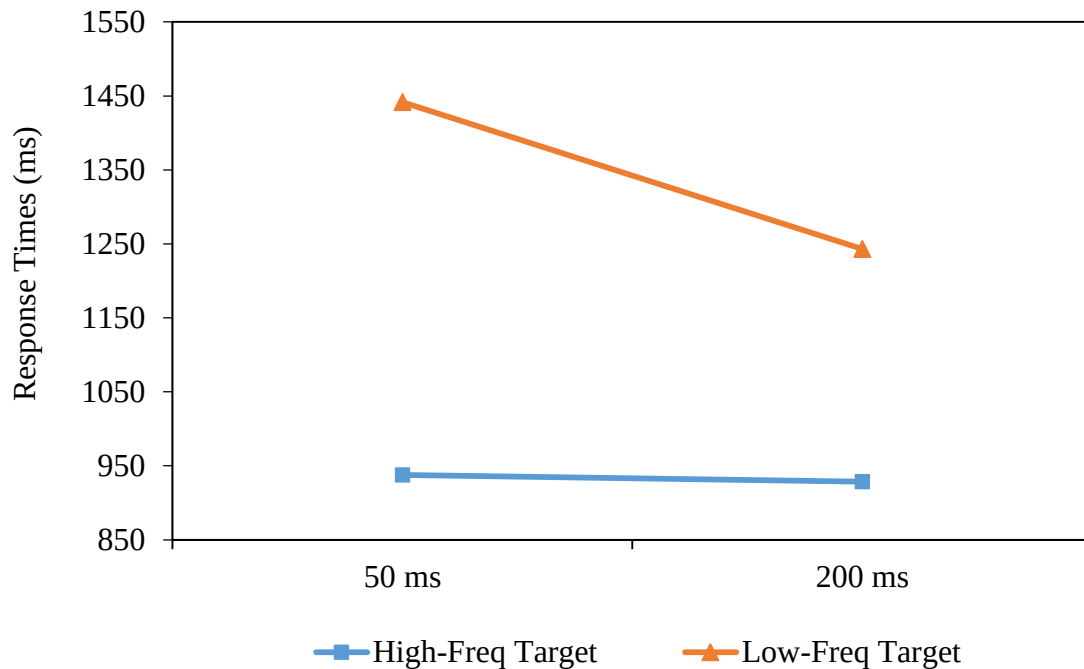


Figure 11. Experiment 1: Interaction effects (in milliseconds) of target frequency and stimulus onset asynchrony (SOA) on L2 learners' response times.

There was a significant three-way interaction between prime type, prime-target relation, and SOA. As illustrated in Figure 12, semantic radical primes produced significant facilitatory effect at the SOA of 50 ms, whereas phonetic radical primes produced facilitation at 200 ms.

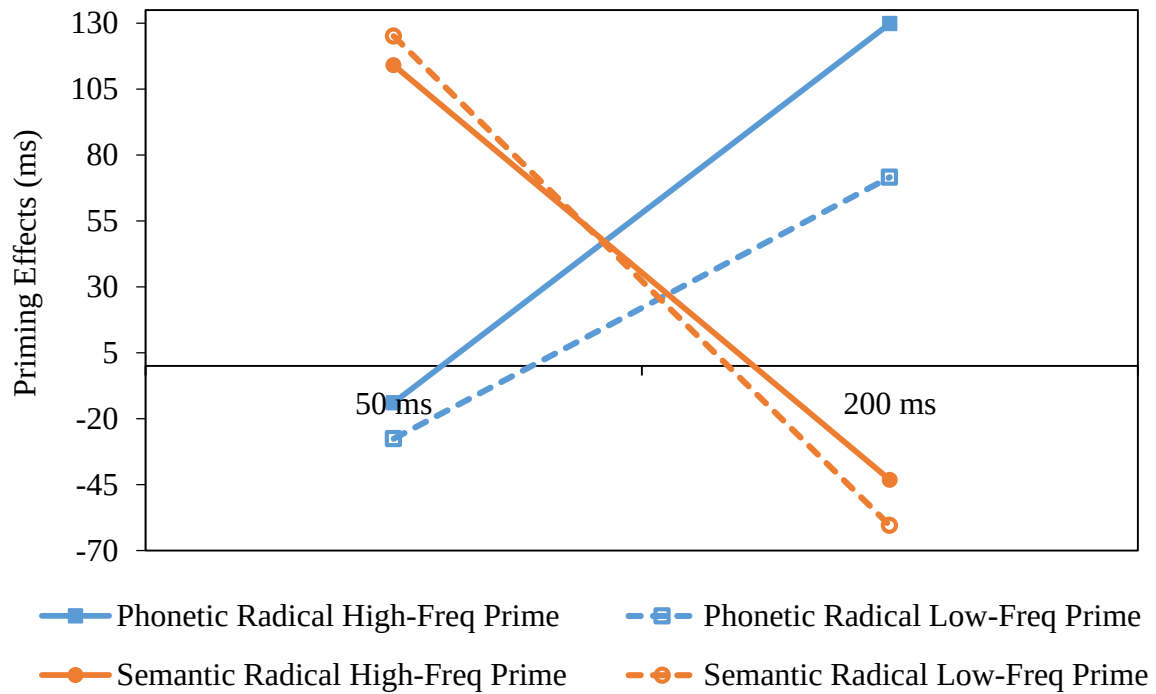


Figure 12. Experiment 1: Interaction effects (in milliseconds) between prime type, prime-target relation, and stimulus onset asynchrony (SOA) on L2 learners' response times.

There was also a marginally significant effect of prime-target relation, where L2 learners' responses to semantic radical sets ($M = 1078.94$, $SD = 642.86$) were numerically faster than those to phonetic radical sets ($M = 1125.29$, $SD = 727.14$). Furthermore, the effect of prime-target relation interacted with the number of characters L2 learners knew at the time of the experiment. As Figure 13 shows, L2 learners who had acquired a limited number of characters responded to phonetic-radical sets faster relative to semantic-radical sets, whereas those who had acquired a larger number of characters responded to semantic-radical sets faster.

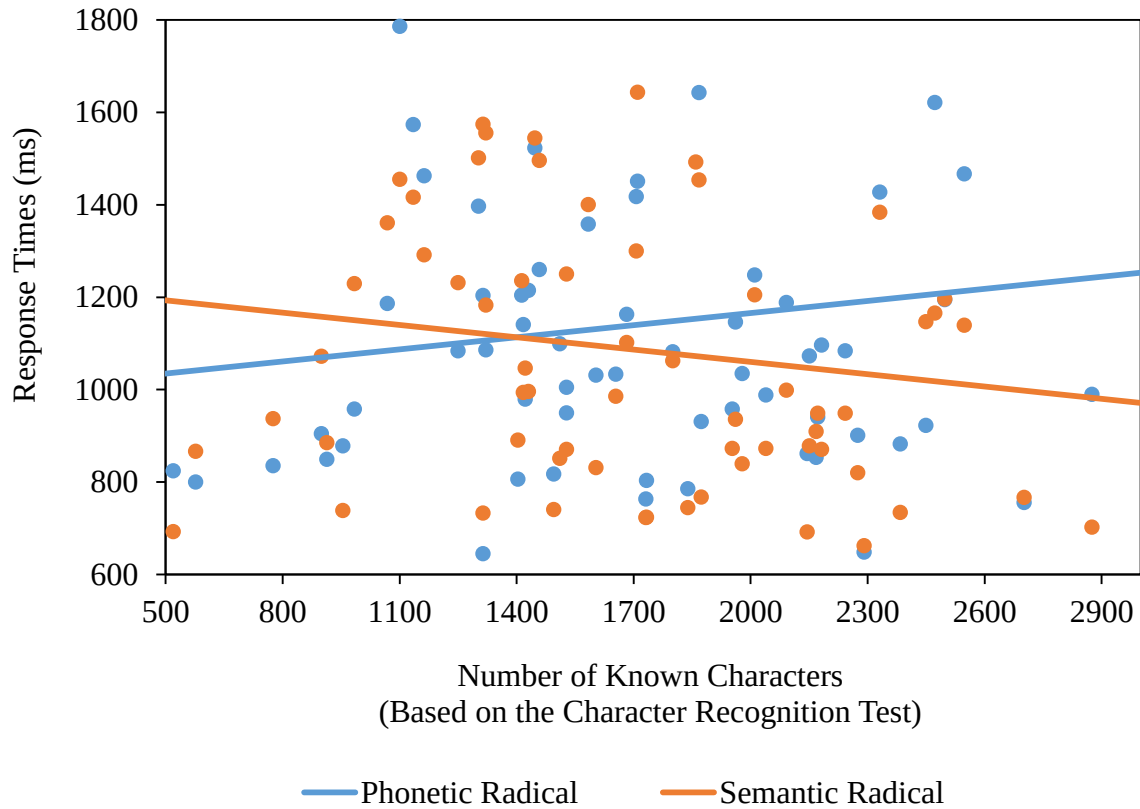


Figure 13. Experiment 1: Interaction effects (in milliseconds) of prime-target relation and number of known characters on L2 learners' response times.

Lastly, Figure 14 presents the significant main effect of L1 orthography type. On average, L2 learners coming from alphabetic L1 backgrounds had significantly faster RTs ($M = 1037.79$, $SD = 633.59$) than those from abugida L1 backgrounds ($M = 1244.94$, $SD = 774.82$). However, this difference was unlikely to be due to a proficiency effect, as there was no statistical difference between the average Chinese cloze test score of the participants from alphabetic L1 backgrounds ($M = 82.35$, $SD = 12.01$) and the average score of the participants from abugida L1 backgrounds ($M = 79.35$, $SD = 17.07$), or between the average number of characters known by the alphabetic group ($M = 1672.44$, $SD = 582.77$) and that of the abugida group ($M = 1640.78$, $SD = 629.78$).

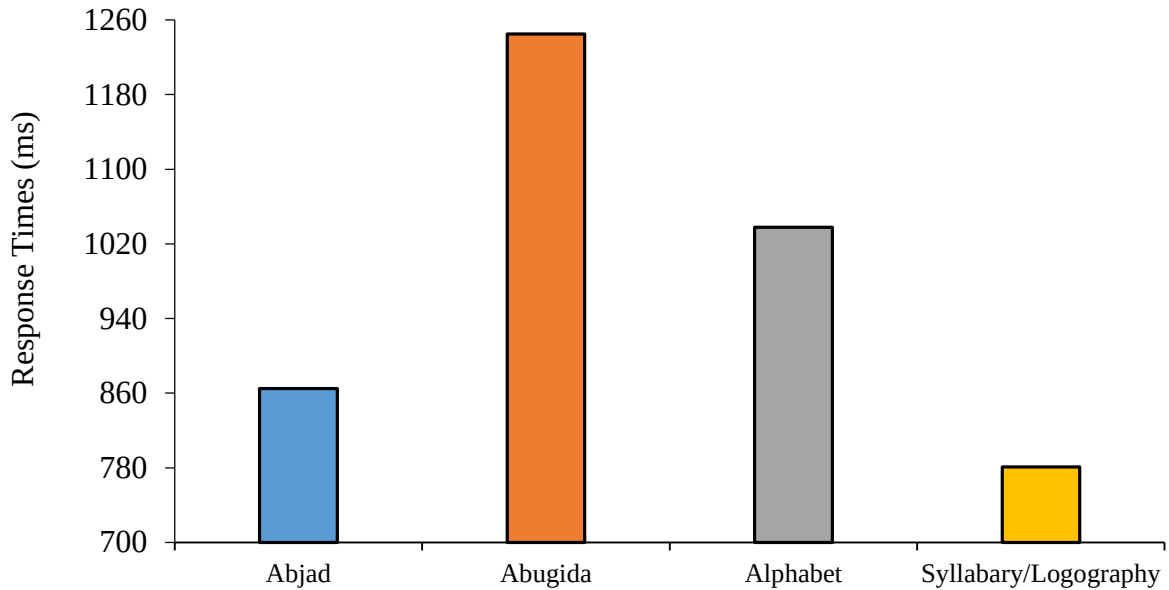


Figure 14. Experiment 1: Effects (in milliseconds) of first language orthography type on L2 learners' response times.

The output of the logistic mixed effects model on L2 learners' accuracy data is presented in Table 17. The model showed significant main effects of target frequency ($p < .001$) and number of known characters ($p = .03190$). On average, L2 learners' accuracy rate for high-frequency targets ($M = 0.97$, $SD = 0.16$) was higher than that for low-frequency targets ($M = 0.81$, $SD = 0.39$). L2 learners' accuracy also increased as they acquired more Chinese characters. The average accuracy for L2 learners who knew 250-1700 characters was 0.86 ($SD = 0.34$) and 0.93 ($SD = 0.25$) for L2 learners who knew 1700-3500 characters at the time of the experiment.

Table 17

Experiment 1: Output of Logistic Mixed Effects Model on L2 Learners' Accuracy Data.

Parameters	Estimate	SE	z	p
Intercept	3.27980	1.12109	2.926	0.00344**
Prime type: high-frequency	0.22304	0.17014	1.311	0.18988
Prime type: low-frequency	-0.03258	0.16450	-0.198	0.84298
Target frequency	0.53583	0.05632	9.515	< 0.001***
Prime-target relation	0.07150	0.24402	0.293	0.76953
SOA: 200 ms	0.30027	0.25781	1.165	0.24414
L1 orthography type: abugida	-0.16178	1.13672	-0.142	0.88682
L1 orthography type: alphabet	-0.56752	1.09833	-0.517	0.60536
L1 phoneme-to-letter ratio	-0.88432	0.56154	-1.575	0.11530
Number of known characters	0.77037	0.35903	2.146	0.03190*
Chinese cloze test score	1.32588	1.18846	1.116	0.26458

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

5.6 Discussion

The purpose of Experiment 1 was to investigate whether the orthographic forms of radicals were activated during compound character recognition. The results of the experiment can be summarized as follows: First, compound character primes facilitated both Chinese native speakers' and L2 learners' responses to the embedded radicals, indicating that at least the orthographic forms of radicals were activated during compound character recognition. Second, Chinese native speakers processed phonetic radicals and semantic radicals in qualitatively and quantitatively similar ways, whereas L2 learners' processing patterns differed as a function of radical type. For L2 learners, semantic radical sets produced priming effects earlier than phonetic radical sets. Additionally, L2 learners who had acquired a limited number of characters responded to phonetic-radical sets faster, whereas those who had acquired a larger number of

characters responded to semantic-radical sets faster. Finally, L2 learners from alphabetic L1 backgrounds had faster RTs than those from abugida L1 backgrounds. Given that there was no statistical difference in terms of their scores on the Chinese proficiency test or the character recognition test, such a difference was likely due to L1 orthographic influence.

For Chinese native speakers, compound character primes produced significant facilitatory effects regardless of compound character frequency. Because there was no phonological or semantic overlap between the primes and targets, the facilitation indicates that both high- and low-frequency compound characters are automatically decomposed and that at least the orthographic forms of their radicals are activated. This finding is consistent with the several previous studies (e.g., Ding et al., 2004; Shen et al., 1997) and partially consistent with She and Zhang's (1997) results, where priming effects were found for low-frequency but for not high-frequency compound characters.

This discrepancy between She and Zhang's results and the current study may be due to the fact that compound characters were used as targets in their study but primes in the current study. In She and Zhang's study, the radicals embedded in high-frequency characters might have been activated, but given the fast RTs for the high-frequency targets, there was little room for facilitation, and thus radical activation might have been obscured. This assumption is consistent with the results for high-frequency radical targets in the current study. Although both high- and low-frequency compound character primes produced significant facilitatory effects on low-frequency radical targets, such priming effects were not found for high-frequency targets. Similar to She and Zhang's results on high-frequency compound character targets, participants' fast RTs on the high-frequency radical targets might have obscured the priming effects in the current study (i.e., a floor effect).

Although there was no significant main effect of SOA on native speakers' performance in the experiment, the interaction between target frequency and SOA suggests that the orthographic activation of radicals during compound character recognition may be stronger at the SOA of 200 ms than 50 ms. It was possible that, at the SOA of 50 ms, the decomposition of compound character was not yet completed, and prime characters thus had not produced strong facilitation, leading to the dominant effect of target frequency. At the SOA of 200 ms, the completion of compound character decomposition gave rise to stronger priming effects and significantly facilitated the recognition of target characters, leading to the reduction of RT difference between high- and low-frequency targets. Although native speakers responded to low-frequency targets faster and more accurately at the SOA of 200 ms relative to at 50 ms, no difference was found for high-frequency targets. As mentioned above, this was possibly because the fast RTs for high-frequency targets had obscured any observable difference due to a floor effect.

For L2 learners of Chinese, the three-way interaction between prime type, prime-target relation, and SOA shows that the orthographic properties of semantic radicals were activated as early as 50 ms after the compound characters were presented, but the facilitation disappeared at 200 ms. The orthographic activation of phonetic radicals, on the other hand, was not detectable until 200 ms after the stimulus onset. Taken together, Experiment 1 suggests that L2 learners also activate the orthographic forms of radicals during compound character recognition, which is consistent with previous studies that demonstrated L2 learners' sensitivity to radical level information during character recognition (e.g., Jiang, 2001; Wang et al., 2003; Wei & Jiang, 2014; Zhao et al., 2012).

The three-way interaction also suggests that L2 learners activate the orthographic features of semantic radicals earlier in comparison with phonetic radicals. This is in line with the

marginally significant main effect of radical, which showed that L2 learners' responses to semantic radical sets were faster than to phonetic radical sets. The interaction between prime-target relation and number of known characters further indicates that semantic radicals may be acquired faster and better than phonetic radicals. Although L2 learners' acquisition of semantic radicals progressed as a function of their character knowledge, their acquisition of phonetic radicals remained incomplete even at the advanced level. This finding is consistent with a number of previous studies (Jackson et al., 2003; Ke & Li, 2011; Tong & Yip, 2015), which showed that L2 learners performed better on semantic radicals than on phonetic radicals.

The interaction between prime-target relation and number of known character also shows that, for L2 learners who had limited knowledge of Chinese characters, their responses to phonetic-radical sets were faster than those to semantic-radical sets; for those who had greater knowledge of characters, however, the opposite pattern was observed – semantic-radical sets received faster responses than phonetic-radical sets. There are several possible reasons for the processing difference between semantic radicals and phonetic radicals. First, the difference could be due to classroom instruction and Chinese language textbooks, which place a stronger emphasis on semantic radicals relative to phonetic radicals (Jackson et al., 2003; Zhang, 2009). Additionally, although L2 learners may use phonetic radicals as orthographic cues (Williams, 2010, 2013), they are likely to use semantic-radical-related learning strategies more than phonetic-radical-related strategies (Chen, 2011). Another possible reason for the difference concerns the developmental stages in reading Chinese as an L2 (Kim, 2010) and the nature of the Chinese orthography, i.e., there are about 200 semantic radicals (as listed in the *Xinhua* Dictionary) but a much larger number of phonetic radicals. For example, an analysis on 3262 compound characters covered in the Chinese language textbooks for primary schools in China

shows that these compound characters contain 1426 phonetic radicals (Shu, Wu, Zheng, & Zhou, 1998). Furthermore, semantic radicals tend to be more reliable than phonetic radicals. An analysis on 3130 Chinese characters shows that their semantic radicals' average score for semantic transparency was 4.201 on a 7-point Likert scale (Lee, 2009). Analyses on phonetic radicals, on the other hand, indicate that only about 30-36% of them provide reliable phonological cues (Yin, 1991; Zhou, 1978). Taken together, it was possible that L2 learners who had acquired a limited number of characters were in the phonetic stage and thus more sensitive to phonetic radicals. On the other hand, L2 learners who had acquired a larger number of characters entered the orthographic stage and became sensitive to the regularity and consistency properties of radicals (Kim, 2010). As these higher-level L2 learners were likely to be implicitly or explicitly aware that semantic radicals tended to be more reliable than phonetic radicals, they showed more sensitivity to semantic radicals and processed them faster than phonetic radicals.

The interaction between target frequency and SOA shows that the orthographic activation of radicals was stronger at the SOA of 200 ms than at 50 ms, indicating that L2 learners might not have completed compound character decomposition at the SOA of 50 ms. As little priming effect had occurred at this time point, the effect of target character frequency was dominant. At the SOA of 200 ms, when the decomposition of compound character primes was completed, the priming effect facilitated the recognition of target characters and thus reduced the effect of target frequency. Like native speakers, L2 learners also responded to low-frequency targets faster at the SOA of 200 ms relative to at 50 ms, but no difference was found for high-frequency targets. Again, this may be caused by a floor effect for high-frequency targets.

Finally, L2 learners coming from alphabetic L1 backgrounds had faster RTs than those from abugida L1 backgrounds. This indicates that learners' L1 orthography may influence the

way they process characters in L2 Chinese. As mentioned above, such a RT difference was unlikely to be due to discrepancies in terms of the two groups' Chinese proficiency, as no statistical difference was observed in their cloze test scores or character recognition test scores. This finding supports the assumption that L1 orthography-based processing strategies are transferred to L2 reading, and L2 word recognition is to a large extent constrained by the learner's L1 orthography properties (Koda, 1997). In the context of the present study, abugida orthographies such as Thai have qualitatively different features when compared with alphabetic scripts, and native readers of Thai have been found to process the script using a syllabic level of segmentation rather than phonemic reading (Winskel, 2009). Therefore, it was likely that, due to their reading experience in the L1 scripts, L2 learners from abugida L1 backgrounds were less skilled at compound character decomposition and radical-level processing compared with their counterparts from alphabetic L1 backgrounds. Thus, the transfer of the abugida group's L1 reading strategies led to slower responses in the experiment. This finding is consistent with Feng et al.'s (2005) results, where L2 learners from alphabetic L1 background were found to be more likely to decompose compound characters compared with learners from other L1 backgrounds.

In conclusion, the results of Experiment 1 suggest that both native speakers and L2 learners activate the orthographic forms of radicals during compound character recognition. Nevertheless, it remains unclear if such activation was purely form based or is evidence for a deeper level of radical processing (i.e., the activation of the phonological and semantic properties of radicals). Because there was graphic overlap between primes and targets in Experiment 1, it was difficult to rule out the possibility that the facilitation observed here was simply due to orthographic similarity rather than activation of radical-level information during compound character recognition. To test this possibility, Experiment 2 was conducted, in which graphically

distinct primes and targets were used to explore whether the phonological and semantic properties of radicals were activated during compound character recognition.

Chapter 6: Experiment 2

The goal of Experiment 2 was to investigate whether the phonological and semantic properties of radicals were activated during compound character recognition. To achieve this, a second primed-character decision task was conducted, in which primes were phonologically or semantically related to targets (e.g., 麦 *mài* “wheat”) either at the character level (e.g., 卖 *mài* “to sell,” which was related to the target at the character level) or at the radical level (e.g., 犊 *dú* “calf,” which contained 卖 *mài* “to sell” as its phonetic radical and was thus related to the target at the radical level). Different from Experiment 1, where primes and targets shared orthographic form overlap, the primes and targets used in the current experiment were graphically distinct but phonologically or semantically related. Therefore, if radical-level related primes produced facilitatory effects relative to unrelated control primes, it would suggest that radical-level phonological and/or semantic information had been activated during compound character recognition. On the other hand, if no priming effects were observed in Experiment 2, it would suggest that the activation at the radical level observed in Experiment 1 was purely form based.

As in Experiment 1, to investigate whether radical function played a role in compound character recognition, the prime-target relation was also manipulated in Experiment 2 so that the targets were either the phonetic radicals or semantic radicals embedded in the radical-level related primes. Moreover, the potential time course of radical-level activation was examined by using two SOA conditions (i.e., 50 ms and 200 ms). Lastly, to further explore the influence of L1 orthography on L2 character recognition, L2 learners’ L1 background information was included in the statistical analyses.

6.1 Participants

Because the stimuli of Experiment 2 were different from those used Experiment 1, the participants from Experiment 1 also took part in Experiment 2.

6.2 Design and materials

As shown in Table 18, a 2 (prime type: related, control) $\times$ 2 (prime level: character level, radical level) $\times$ 2 (prime-target relation: phonetic radical, semantic radical) $\times$ 2 (activation type: phonological activation, semantic activation) $\times$ 2 (SOA: 50 ms, 200 ms) design was used in Experiment 2. The stimuli consisted of 84 prime-target sets (see Appendix F for the complete list), and each set contained four types of primes: (1) character-level related prime, which was related to the target at the character level; (2) character-level control prime, which matched with the character-level related prime in terms of visual complexity (i.e., same stroke number) and frequency, but was otherwise unrelated to the target; (3) radical-level related prime, which was not semantically, phonologically, or orthographically related to the target at the character level; however, as a compound character, it contained the character-level related prime as its radical, and was thus related to the target at the radical level; and (4) radical-level control prime, which was also a compound character with the same radical (i.e., the non-critical radical) as the radical-level related prime, and matched with it in terms of frequency, but was otherwise unrelated to the target.

Additionally, to investigate whether phonetic radicals were activated differently than semantic radicals, the prime-target relation was manipulated so that the character-level related prime was either a phonetic radical (42 sets) or a semantic radical (42 sets) of the radical-level related prime. Finally, to explore whether the semantic properties of radicals were activated differently than their phonological properties, the activation type was manipulated. In 42 sets (21

phonetic-radical sets and 21 semantic-radical sets), the target was a homophone of the corresponding character-level related prime; in the other 42 sets (21 phonetic-radical sets and 21 semantic-radical sets), the target was semantically related to the character-level related prime.

Table 18

Experiment 2: Design and Sample Stimuli

Stimulus type	Prime type				Prime-target relation	Target	Activation type
	Character level Related	Control	Radical level Related	Control			
(1) PR relation, PA							
Character	卖	其	犊	牯	Phonetic radical	麦	Phonological activation
Pronunciation	<i>mài</i>	<i>qí</i>	<i>dú</i>	<i>gǔ</i>		<i>mài</i>	
Translation	to sell	it	calf	cow		wheat	
(2) SR relation, PA							
Character	耳	尽	耽	枕	Semantic radical	尔	
Pronunciation	<i>ěr</i>	<i>jìn</i>	<i>dān</i>	<i>zhěn</i>		<i>ěr</i>	
Translation	ear	to end	to delay	pillow		you	
(3) PR relation, SA							
Character	寸	亡	付	借	Phonetic radical	尺	Semantic activation
Pronunciation	<i>cùn</i>	<i>wáng</i>	<i>fù</i>	<i>jiè</i>		<i>chǐ</i>	
Translation	inch	to die	to pay	to lend		ruler	
(4) SR relation, SA							
Character	田	业	畸	犄	Semantic radical	农	
Pronunciation	<i>tián</i>	<i>yè</i>	<i>jī</i>	<i>jī</i>		<i>nóng</i>	
Translation	field	business	abnormal	horn		farming	

Note. PR = phonetic radical; SR = semantic radical; PA = phonological activation; SA = semantic activation

Experiment 2 used the same character-frequency statistics database as in Experiment 1. Target characters had a mean frequency of 600.24 per million (range = 9.55 – 6406.13 per million). Character-level related primes had a mean frequency of 826.88 per million (range = 1.22 – 9201.13 per million), and the corresponding character-level controls had a mean frequency of 1033.50 per million (range = 0.19 – 9544.12 per million). The radical-level related primes had a mean frequency of 73.66 per million (range = 0.14 – 1111.49 per million), and the corresponding radical-level controls had a mean frequency of 75.99 per million (range = 0.29 – 2733.02 per million). There were no statistical differences in terms of frequency between

character-level related primes and their corresponding controls, or between radical-level primes and their controls.

As in Experiment 1, compound characters that met specific requirements were selected as primes to rule out the possibility that the observed priming effects were due to phonological or semantic processing of whole characters rather than the activation of radical properties. Specifically, for sets under the phonological activation condition, compound characters (i.e., radical-level related primes) differed from their radicals (i.e., character-level related primes) in terms of consonants and vowels; for sets under the semantic activation condition, two semantic-relatedness judgment pretests¹⁰ were conducted. The first pretest was conducted to select radical-level related primes that had semantically opaque radicals. In this test, 30 native speakers of Chinese, who participated in the pretest of Experiment 1 but not in any of the main experiments, rated the semantic relatedness between the radical-level related primes and their semantic radicals (i.e., the corresponding character-level related primes) from 1 (*not related at all*) to 4 (*closely related*), and the average score was 1.68. Additionally, to make sure that character-level related primes were truly semantically related to targets under the semantic activation condition, and that control characters were truly unrelated, a second pretest was conducted, in which 15 native speakers of Chinese, who did not participate in any previous tests, rated the semantic relatedness between primes and targets on the same four-point scale. On average, character-level related primes scored 3.18, and the corresponding control primes scored 1.30.

¹⁰Thirty-one prime-target sets (see Appendix F) were adapted from Zhou & Marslen-Wilson' (1999c) and Zhou et al.' (2013) materials. These characters were not included in the semantic relatedness judgment pretests, as they were already normed by the paper authors.

6.3 Procedures

Experiment 2 used the same procedures as Experiment 1. Two SOA conditions (i.e., 50 ms and 200 ms) were used to track the potential time course of the activation effects and were treated as a between-subject factor; 36 Chinese native speakers and 34 L2 learners were randomly assigned to the short SOA condition, and the other 36 native speakers and 34 learners to the long SOA condition. No participants under the short SOA condition reported to have seen the primes.

6.4 Data analysis

6.4.1 Native speakers of Chinese

The same data analysis procedures used in Experiment 1 were also used in Experiment 2. Specifically, trials with target onset delay greater than 5 ms were dropped prior to the analyses, which resulted in a 0.41% data loss. Additionally, RTs that were shorter than 200 ms or longer than 5000 ms were discarded (0.20% of the data). The average accuracy rate was 97.72%; only trials that were answered correctly were included in the analysis. Finally, outliers that were two standard deviations below or above the means were excluded (3.64% of the total data).

As in Experiment 1, native speakers' RT data were analyzed using a linear mixed effects model in R. RTs and target frequencies were log transformed and centered prior to the analysis. Fixed effects included trial number, prime type, prime level, prime-target relation, activation type, SOA, and target frequency, and random effects included random intercepts for subjects and items, by-subject random slopes for the effects of prime-target relation and activation type, and by-item random slope for the effect of SOA. Native speakers' accuracy data were analyzed in a separate logistic mixed effects regression model. Prime type, prime level, prime-target relation,

activation type, SOA, and target frequency were entered as fixed effects; subject and item were included as random effects.

6.4.2 L2 learners of Chinese

One item was excluded from the analysis due to low accuracy (< 60%). Trials with target onset delays greater than 5 ms were not included, which resulted in a 0.30% data loss. Additionally, RTs that were shorter than 200 ms or longer than 10000 ms were removed (0.36% of the data). The average accuracy rate was 94.19%; only trials that were answered correctly were included in the analysis. As in Experiment 1, outliers that were three standard deviations below or above the means were also discarded (2.12% of the data).

The data of the L2 learners were analyzed in a separate linear mixed effects model, in which prime type, prime level, prime-target relation, activation type, SOA, target frequency, L1 orthography type, L1 phoneme-to-letter ratio, Chinese cloze test score, and number of known characters were included as fixed effects. Random effects included random intercepts for subjects and items, by-subject random slopes for the effects of prime type, prime-target relation, and prime level, and by-item random slope for the effect of SOA. Prior to the analyses, RTs, target frequencies, and numbers of known characters were log-transformed, and all continuous variables were centered. L2 learners' accuracy data were analyzed in a separate logistic mixed effects regression model, with prime type, prime level, prime-target relation, activation type, SOA, target frequency, L1 orthography type, L1 phoneme-to-letter ratio, Chinese cloze test score, and number of known characters as fixed effects, and subjects and items as random effects.

6.5 Results

6.5.1 Native speakers of Chinese

The mean values of Chinese native speakers' RTs on the target characters for each condition are shown in Table 19.

Table 19

Experiment 2: Native Speakers' Response Times (in Milliseconds) on Target Characters

Prime-target relation	Prime type			
	Character level		Radical level	
	Related	Control	Related	Control
Phonetic radical	696.59 (215.81)	700.41 (211.84)	718.78 (228.83)	731.60 (236.45)
Semantic radical	681.85 (199.85)	695.87 (214.74)	709.31 (213.79)	715.63 (218.40)

Note. Standard deviations are provided in parentheses.

Table 20 presents the output of the linear mixed effects model on Chinese native speakers' RT data. The model revealed significant main effects of trial number ($p < .001$), target frequency ($p < .001$), prime type ($p = .04986$), prime level ($p < .001$), significant interactions between prime level and SOA ($p = .04518$), between prime level and target frequency ($p = .03925$), and a three-way interaction between prime type, prime level, and SOA ($p = .03606$).

Table 20

Experiment 2: Output of Linear Mixed Effects Model on Native Speakers' Response Times

Parameters	Estimate	SE	<i>t</i>
Intercept	0.0964600	0.0289700	3.3290**
Trial number	-0.0004610	0.0000403	-11.442***
Prime type: related	-0.0097600	0.0122000	-0.8000
Prime level: radical level	0.0485300	0.0122500	3.9610***
Prime-target relation: semantic radical	-0.0152000	0.0111400	-1.3640
Activation type: semantic	0.0011650	0.0107400	0.1080
SOA: 200 ms	0.0081900	0.0360300	0.2270
Target frequency	-0.0210200	0.0042540	-4.9430***
Prime level: radical level × SOA: 200 ms	-0.0497600	0.0171900	-2.8940**
Prime level: radical level × target frequency	0.0086890	0.0042140	2.0620*
Prime type: related × prime level: radical level	-0.0170200	0.0172600	-0.9860
Prime type: related × SOA: 200 ms	-0.0126900	0.0171500	-0.7400
Prime type: related × prime level: radical level × SOA: 200 ms	0.0508900	0.0242700	2.0970*

Note. SOA= stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

The main effect of trial number showed that native speakers sped up as they progressed through Experiment 2. The main effect of target frequency suggested that native speakers' RTs also increased as a function of target frequency.

As illustrated in Figure 15, the main effect of prime type demonstrated that native speakers' responses to targets were faster when they were presented with a related prime ($M = 701.53$, $SD = 215.07$) relative to its corresponding control prime ($M = 710.93$, $SD = 220.93$). Although this was true for both character-level and radical-level primes, there was also a main effect of prime level. Targets following character-level primes received faster responses ($M = 693.62$, $SD = 210.62$) than those following radical-level primes ($M = 718.83$, $SD = 224.56$).

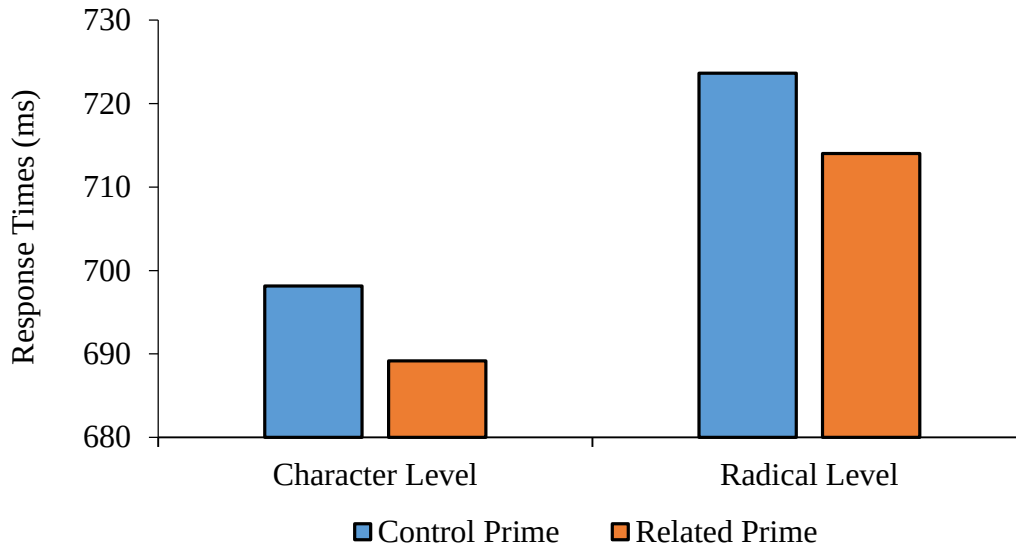


Figure 15. Experiment 2: Effects (in milliseconds) of prime type and prime level on native speakers' response times.

As showed in Figure 16, the significant interaction between prime level and SOA indicated that, for targets following character-level primes, there was little RT difference between the SOAs of 50 ms ($M = 694.63$, $SD = 221.74$) and 200 ms ($M = 692.63$, $SD = 199.24$). For those following radical-level primes, however, native speakers' RTs at the SOA of 200 ms ($M = 707.85$, $SD = 210.87$) were faster than those at 50 ms ($M = 730.00$, $SD = 237.25$).

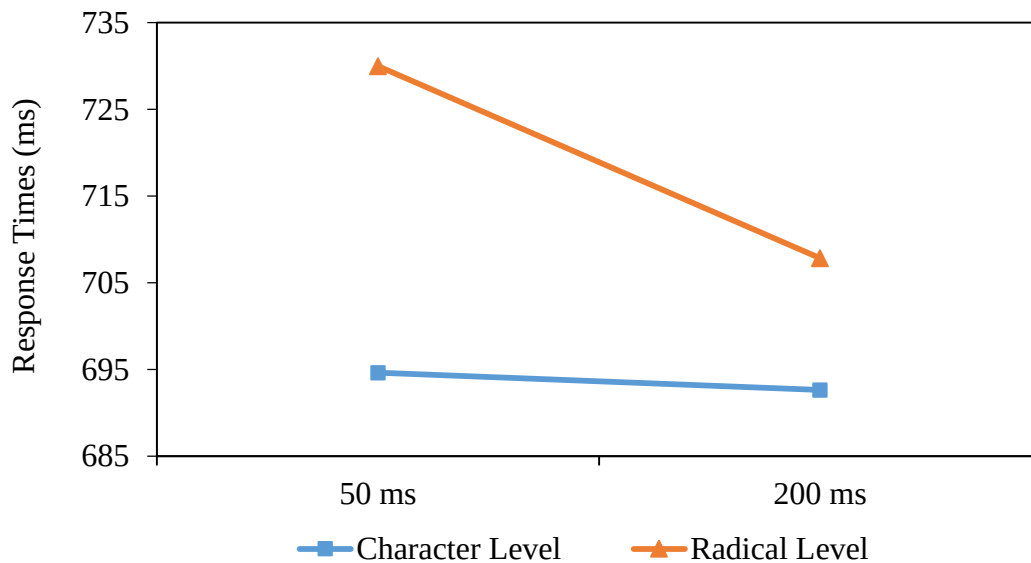


Figure 16. Experiment 2: Interaction effects (in milliseconds) of prime level and stimulus onset asynchrony (SOA) on native speakers' response times.

Furthermore, prime level also interacted with target frequency. As illustrated in Figure 17, although there was a significant effect of target frequency under the character-level priming condition, the frequency effect was not significant under the radical-level priming condition.

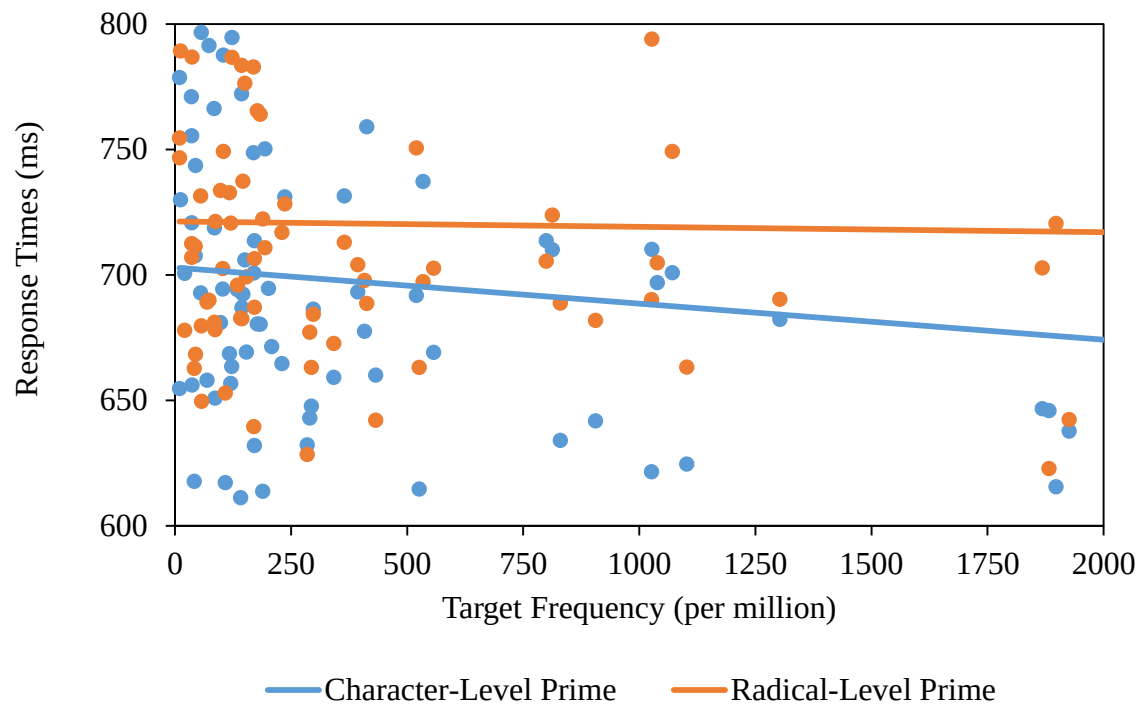


Figure 17. Experiment 2: Interaction effects (in milliseconds) of prime level and target frequency on native speakers' response times.

Figure 18 illustrates the three-way interaction between prime type, prime level, and SOA. Although the priming effects produced by character-level related primes were facilitatory at both SOAs, the facilitation was stronger at 200 ms (13.79 ms) relative to at 50 ms (4.01 ms). However, a different pattern was observed for radical-level related primes. Compared with control primes, radical-level related primes produced facilitatory priming effects (27.61 ms) at the SOA of 50 ms, but inhibitory effects (-7.97 ms) were observed at 200 ms, indicating that the activation of radical-level information may be suppressed.

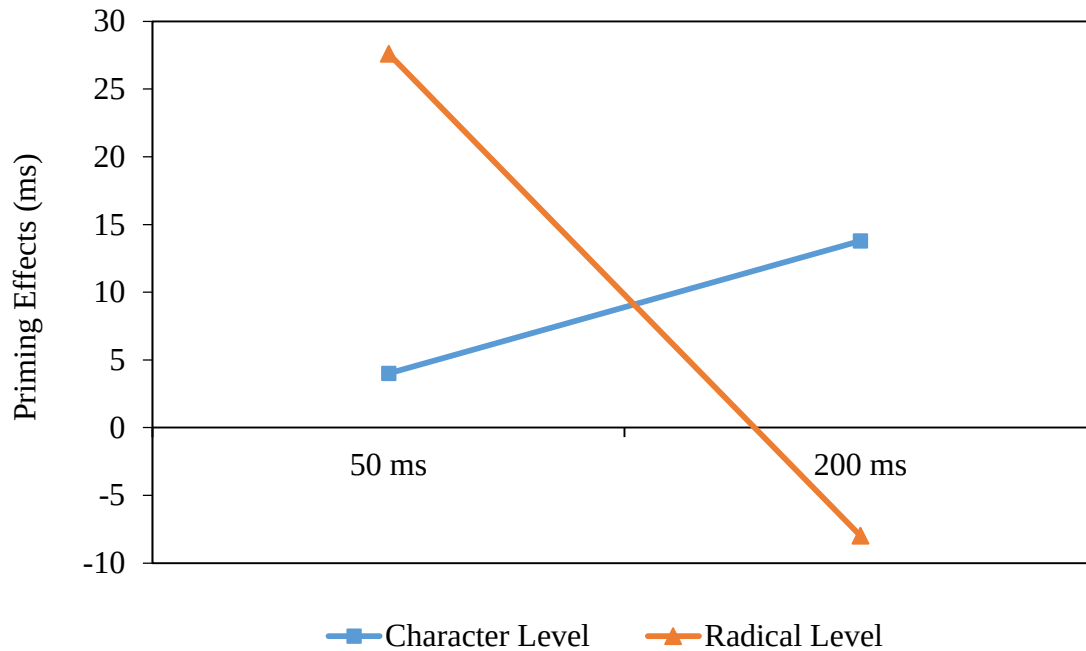


Figure 18. Experiment 2: Interaction effects (in milliseconds) of prime type, prime level, and stimulus onset asynchrony (SOA) on native speakers' response times.

The results of the logistic mixed effects model analysis of native speakers' accuracy data are summarized in Table 21. No significant predictors were found.

Table 21

Experiment 2: Output of Logistic Mixed Effects Model on Native Speakers' Accuracy Data

Parameters	Estimate	SE	z	p
Intercept	4.401709	0.288265	15.270	< 0.001***
Prime type: related	0.077550	0.175454	0.442	0.658
Prime level: radical	-0.274035	0.177247	-1.546	0.122
Prime-target relation: semantic radical	-0.018488	0.223399	-0.083	0.934
Activation type: semantic	-0.298003	0.224154	-1.329	0.184
Target frequency	0.027493	0.077301	0.356	0.722
SOA: 200 ms	0.001357	0.237694	0.006	0.995

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

6.5.2 L2 learners of Chinese

L2 learners' mean RTs for different conditions are reported in Table 22, and the output of the linear mixed effects model is presented in Table 23.

Table 22

Experiment 2: L2 Learners' Response Times (in Milliseconds) on Target Characters

Prime-target relation	Prime type			
	Character level		Radical level	
	Related	Control	Related	Control
Phonetic radical	1130.94 (649.63)	1125.38 (641.40)	1160.55 (654.83)	1185.48 (669.30)
Semantic radical	1161.30 (662.99)	1164.88 (644.33)	1172.24 (658.80)	1225.16 (719.90)

Note. Standard deviations are provided in parentheses.

As shown in Table 23, the linear mixed effects model on L2 learners' RTs reported significant main effects of trial number ($p < .001$), target frequency ($p < .001$), and prime level ($p = .008440$). There were also significant interactions between prime-target relation and number of known characters ($p = .001381$), and prime type and target frequency ($p = .041960$).

Table 23

Experiment 2: Output of Linear Mixed Effects Model on L2 Learners' Response Times

Parameters	Estimate	SE	t
Intercept	-0.0984400	0.2629000	-0.374
Trial number	-0.0006061	0.0000784	-7.735***
Prime type: related	-0.0147800	0.0104500	-1.414
Prime level: radical	0.0270500	0.0102400	2.642**
Target frequency	-0.0750900	0.0084990	-8.835***
Prime-target relation: semantic radical	0.0254000	0.0226100	1.123
Activation type: semantic	-0.0096890	0.0221400	-0.438
SOA: 200 ms	0.0345600	0.0670600	0.515
L1 orthography type: abugida	0.3382000	0.2691000	1.257
L1 orthography type: alphabet	0.1355000	0.2597000	0.522
L1 phoneme-to-letter ratio	-0.0316000	0.1509000	-0.209
Chinese cloze test score	-0.0040670	0.3228000	-0.013
Number of known characters	0.1022000	0.0981200	1.042
Prime-target relation × number of known characters	-0.0793000	0.0241100	-3.289**
Prime type: related × target frequency	0.0145600	0.0071590	2.034*

Note. SOA= stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

First, the main effect of trial number again showed that L2 learners sped up significantly as they progressed through the experiment. The main effect of target frequency indicated that high-frequency targets received faster responses relative to low-frequency targets.

The main effect of prime level demonstrated that L2 learners' responses were faster when targets were presented after character-level primes ($M = 1145.63$, $SD = 649.48$) in comparison with when they were presented after radical-level primes ($M = 1186.04$, $SD = 676.49$).

Figure 19 illustrates the significant interaction between prime type and target frequency. Low-frequency targets following related primes received faster responses than those following

control primes, but the RT difference across these two priming conditions was reduced for high-frequency targets. As discussed before, the absence of priming effects here was likely to be due to a floor effect for high-frequency targets.

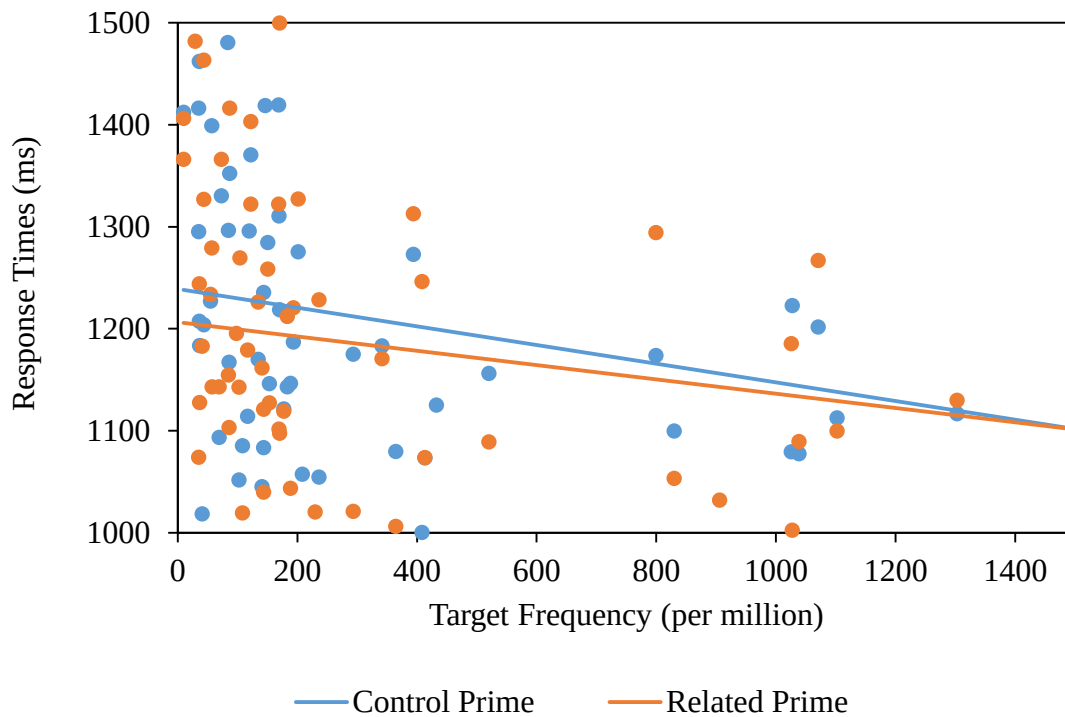


Figure 19. Experiment 2: Interaction effects (in milliseconds) of prime type and target frequency on L2 learners' response times.

The interaction between number of known characters and prime-target relation, which was observed in Experiment 1, was also returned by the model here. As shown in Figure 20, L2 learners who had acquired a limited number of characters responded to phonetic-radical sets faster relative to semantic-radical sets; in contrast, L2 learners who had acquired a larger number of characters responded to semantic radical sets faster (Figure 21).

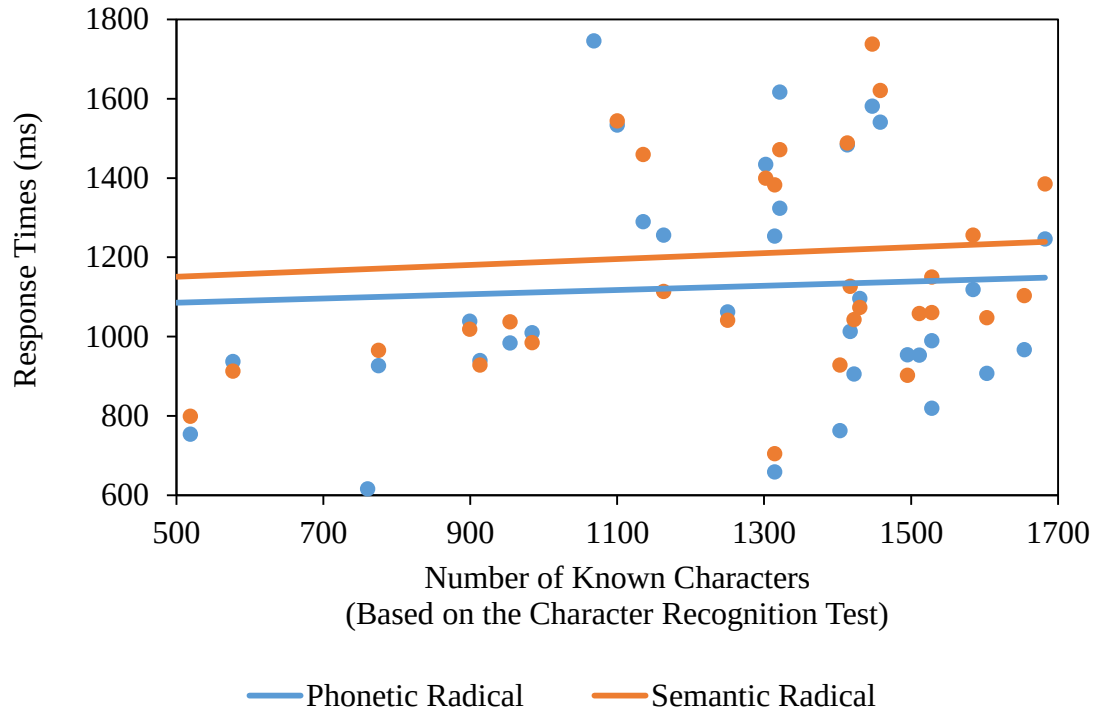


Figure 20. Experiment 2: Interaction effects (in milliseconds) of prime-target relation and number of known characters on lower-level L2 learners' response times.

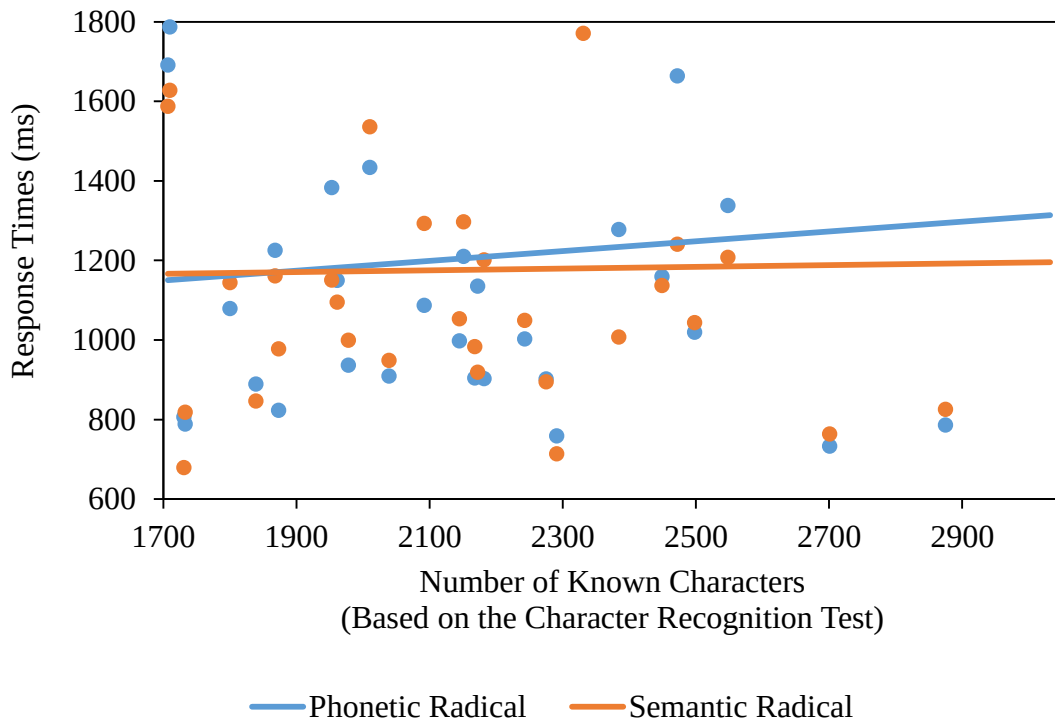


Figure 21. Experiment 2: Interaction effects (in milliseconds) of prime-target relation and number of known characters on higher-level L2 learners' response times.

Table 24 presents the results of the logistic mixed effects model on L2 learners' accuracy data. The analysis revealed a significant main effect of target frequency ($p < .001$), indicating that L2 learners' accuracy was higher for high-frequency targets than for low-frequency targets. There was a significant main effect of Chinese cloze test score ($p = .032278$), suggesting that L2 learners who scored higher on the Chinese cloze test made fewer errors in the experiment than those who scored lower on the cloze test.

Table 24

Experiment 2: Output of Logistic Mixed Effects Model on L2 Learners' Accuracy Data

Parameters	Estimate	SE	z	p
Intercept	5.03170	1.35407	3.716	0.000202***
Prime type: related	-0.09115	0.13181	-0.692	0.489218
Prime level: radical	-0.09542	0.13065	-0.730	0.465190
Prime-target relation: semantic radical	-0.34518	0.24968	-1.383	0.166816
Activation type: semantic	-0.12340	0.24951	-0.495	0.620918
SOA: 200 ms	0.15063	0.26723	0.564	0.572982
Target frequency	0.47268	0.09126	5.180	< 0.001****
L1 orthography type: abugida	-0.81490	1.35795	-0.600	0.548444
L1 orthography type: alphabet	-1.18104	1.32469	-0.892	0.372627
L1 phoneme-to-letter ratio	-0.53542	0.58073	-0.922	0.356540
Chinese cloze test score	2.57842	1.20434	2.141	0.032278*
Number of known characters	0.54368	0.36000	1.510	0.130983

Note. SOA = stimulus onset asynchrony. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

6.6 Discussion

The purpose of Experiment 2 was to investigate whether the phonological and semantic properties of radicals were activated during compound character recognition. The major findings of the experiment are summarized as follows: First, radical-level related primes facilitated native speakers' responses to targets, indicating that native speakers automatically activate the

phonological and semantic information at the radical level when processing compound characters. Second, although little priming effect was observed on L2 learners' responses to high-frequency targets, related primes produced facilitation on low-frequency targets relative to control primes, indicating that L2 learners also activate the phonological and semantic properties of radicals during compound character recognition. Third, the interaction between prime-target relation and number of known characters suggests that although L2 learners who have limited knowledge of characters may be more sensitive to phonetic radicals, learners who have a larger number of characters tend to be more sensitive to semantic radicals.

In line with previous results on radical-level activation (Lee et al., 2006; Luo et al., 2015; Zhang et al., 2003; Zhou & Marslen-Wilson, 1999b, c, 2002; Zhou et al., 2000; Zhou et al., 2013; Zhou et al., 2014), the native speaker data in the current experiment showed that both character- and radical-level related primes facilitated responses to targets, suggesting that compound characters are decomposed and that the phonological and semantic properties of the embedded radicals are automatically retrieved. This radical-level activation cannot be attributed to graphic form overlap or mediation through phonological or semantic activation of compound characters, because only phonological irregular or semantically opaque radicals were used in the experiment.

Additionally, native speakers' responses were faster when they were presented with simple character primes (i.e., character-level primes) than when they were presented with compound character primes (i.e., radical-level primes). This main effect of prime level is consistent with the hypothesis of radical-level activation and indicates that both of the radicals embedded in the compound character primes may be activated, leading to stronger interference compared with simple character primes that contain only one component.

Furthermore, the interaction between prime level and SOA indicates that there was little RT difference between the SOAs of 50 ms and 200 ms under the character-level priming condition, whereas RTs were faster at the SOA of 200 ms relative to at 50 ms under the radical-level priming condition. There are two possible explanations for the interaction effect. First, it is possible that, as in Experiment 1, there was little room for facilitation under the character-level priming condition; the fast RTs may have obscured the difference between the two SOA conditions due to a floor effect. The second possibility is that, as discussed above, the representations of the radicals embedded in the compound character primes (i.e., radical-level primes) were automatically activated at the SOA of 50 ms and caused interference with the activation of the representations of the whole characters. The interference was resolved at the SOA of 200 ms, as participants could consciously perceive the primes under this condition. Therefore, RTs were faster at 200 ms relative to 50 ms under the radical-level priming condition.

The stronger effect of target frequency at the character level compared with that at the radical level suggests competition between the representations of whole characters and the representations of their embedded radicals. For character-level primes, native speakers' RTs decreased as a function of the frequency of the target character because there were no competing representations activated simultaneously. For radical-level primes, however, there appeared to be competition between the representations of the whole character and the representations of the embedded radicals, and the activation of character- and radical-level representations were likely to interfere with each other. Therefore, the effect of target frequency was likely to have been dampened by the competition between the different representations under the radical-level priming condition.

This hypothesis was further supported by the three-way interaction between prime type, prime level, and SOA. Although both character- and radical-level related primes produced facilitation at 50 ms, a different pattern was observed at 200 ms, when character-level related primes produced stronger facilitation, but radical-level related primes produced inhibition. This priming pattern, which has been previously reported (Lee et al., 2006; Zhou & Marslen-Wilson, 1999b, c; Zhou et al., 2014), also suggests that there is a competition between character-level activation and radical-level activation during the visual recognition of characters in L1 Chinese. Although both radical-level and character-level representations are likely to be activated during the early stages of visual processing, radical-level activation may be subsequently suppressed at the later stages, leading to the inhibitory effects observed in the current experiment.

As for L2 character recognition, the significant main effect of prime level also suggests that L2 learners may have activated the representations of the prime characters along with the representations of the embedded radicals under the radical-level priming condition. The competition between the representations was likely the reason for the slower responses under the radical-level priming condition relative to the character-level priming condition, where no competition was involved.

This possibility was further supported by the significant interaction between prime type and target frequency. Although little priming effect was observed for high-frequency targets possibly due to a floor effect, low-frequency targets following related primes received faster responses than those that followed control primes. This interaction indicates that L2 learners also activate both character-level and radical-level representations during compound character recognition.

Lastly, there was also a significant interaction between prime-target relation and number of known characters. As in Experiment 1, L2 learners who had limited knowledge of characters responded to phonetic-radical sets faster relative to semantic-radical sets. Learners who had greater knowledge of characters, on the other hand, did not show such a difference; in fact, their responses to semantic radical sets were faster than those to phonetic radical sets. Given that there was no frequency difference between phonetic-radical targets ($M = 591.34$ per million) and semantic-radical targets ($M = 619.08$ per million), this difference may reflect a discrepancy between the acquisition of phonetic radicals and semantic radicals over the course of their Chinese study. Consistent with the results of Experiment 1, this discrepancy suggests that although L2 learners may begin by using phonetic radicals as orthographic cues (Williams, 2010, 2013), they gradually shift to processing strategies that emphasize semantic radicals and tend to neglect the function of phonetic radicals due to a number of potential reasons, including classroom instruction, character learning strategies, Chinese language textbooks, the nature of the Chinese orthography, and the developmental stages in reading Chinese as an L2 (as discussed in Experiment 1).

To summarize, Experiments 1 and 2 indicate that both Chinese native speakers and L2 learners decompose compound characters and activate the orthographic, phonological, and semantic representations of radicals during compound character recognition. Nevertheless, both of the experiments used character decision tasks. Although such tasks have been used as an effective tool to investigate word/character perception across languages, the visual processing involved in this type of task is quite different from natural reading; words/characters are typically presented in isolation with no contextual information, and non-words/non-characters or pseudo-words/pseudo-characters are typically required by the nature of the task. Therefore, findings

based on lexical/character decision tasks may not necessarily explain what is happening in natural reading.

To examine whether and how contextual information modulates the way Chinese native speakers and L2 learners process compound characters and activate radical properties, a third experiment was conducted, in which target characters occurred in both highly constraining and non-constraining sentence contexts.

Chapter 7: Experiment 3

The goal of Experiment 3 was to investigate whether radical properties were activated during compound character recognition in sentence contexts and how contextual information affected radical activation. This was achieved by using a novel experimental paradigm developed by Luke and Christianson (2012, 2013) – a combined self-paced reading and masked-priming paradigm (SPaM).

To replicate Experiments 1 and 2 in sentence contexts and test the activation of orthographic, phonological, and semantic properties of radicals at one setting, the order of the materials used in the previous experiments were inverted in the current experiment. Therefore, compound characters (e.g., 祝 *zhù* “to wish”) were used as targets rather than primes in Experiment 3. The primes, which were presented for 50 ms in the experiment, included four types: (1) orthographically identical to the radical of the target (e.g., 兄 *xiōng* “brother”), (2) phonologically or semantically related to the target at the character level (e.g., 凶 *xiōng* “fierce”), (3) phonologically or semantically related to the target at the radical level (e.g., 住 *zhù* “to lodge”), and (4) unrelated controls (e.g., 丑 *chǒu* “ugly”).

Although facilitatory priming effects were expected in Experiments 1 and 2, interference effects were predicted in the current experiment due to the inverted order of the materials. Because the previous experiments have shown that reading compound characters involves the automatic activation of both character-level and radical-level representations, it was predicted that the preactivation of radical properties would increase the competition between the representations of the whole character and those of its radicals. When radical properties differ from those of the compound character, as in the case of irregular phonetic radicals and opaque

semantic radicals used in the current experiment, this competition should slow down the reader's access to the compound character targets.

As in previous experiments, relations between primes and targets and activation types were also manipulated so that the primes were phonologically or semantically related to the phonetic radicals or semantic radicals embedded in the targets. By comparing the priming effects across these conditions, it would be possible to examine whether radical function and activation type played important roles in compound character processing during sentence reading. To test the influence of L1 orthography on L2 character recognition during sentence reading, L2 learners' L1 background information was also included in the statistical analyses.

In the current experiment, target characters were presented in highly constraining or non-constraining sentence contexts, and their occurrences were thus either expected or unpredictable. Based on previous research on reading alphabetic scripts (e.g., Federmeier, 2007; Luke & Christianson, 2012), it was predicted that highly constraining contexts should facilitate readers' prediction of the orthographic, phonological, and semantic properties of the upcoming compound character, whereas character recognition in non-constraining contexts should be similar to that under the context-independent condition.

Another possibility was that participants' fast RTs might obscure any priming effects in Experiment 3. Because character recognition in sentence contexts was expected to be much faster than that in a character decision task, the magnitude of priming effects was expected to be smaller than that observed in Experiments 1 and 2. Therefore, participants' fast RTs might cause a floor effect, compressing the means for each condition together and in turn obscuring any priming effects.

7.1 Participants

7.1.1 Native speakers of Chinese

Because there was overlap between the materials used in Experiments 1 and 2 and those used in Experiment 3, a new group of 69 participants from the same participant pool were recruited for Experiment 3, none of whom had participated in any of the previous experiments or pretests. There were 32 native speakers of Chinese, who were undergraduate or graduate students enrolled at Beijing Language and Culture University, China. As in previous experiment, they were instructed to complete a background questionnaire (see Appendix A) and an English cloze test (see Appendix D). Their background information is presented in Table 25.

Table 25

Experiment 3: Native Speakers' Background Information

Native speakers	Average	Range
Gender	7 males, 25 females	NA
Age (yrs)	25.36	19-27
English cloze test score	75.31/100	42.5/100-90/100
Length of English study (yrs)	11.00	10-17
National Higher Education Entrance Examination score (Chinese)	113.28/150	88/150-129/150
National Higher Education Entrance Examination score (English)	124.88/150	89/150-142/150

7.1.2 L2 learners of Chinese

Additionally, 37 L2 learners of Chinese were recruited for Experiment 3. Due to technical failure during the experiment, two participants were unable to complete the experiment, and their data were thus not included in the analysis. All of the L2 learners were undergraduate or graduate students enrolled at Beijing Language and Culture University, China. They were asked to complete a background questionnaire (see Appendix B) and a Chinese cloze test (see Appendix C). With the exception of three native speakers of English, 79.41% of the L2 learner

participants had studied English as an L2, and 21.62% of them reported to have studied other foreign languages besides Chinese and English. L2 learners' background information is summarized in Table 26. Statistical analyses showed that their Chinese cloze test scores significantly correlated with the length of Chinese study ($r = 0.61, p < .001$), length of immersion in Chinese-speaking countries ($r = 0.18, p < .001$), and weekly use of Chinese ($r = 0.21, p < .001$).

Table 26

Experiment 3: L2 Learners' Background Information

L2 Learners	Average	Range
Gender	13 males, 24 females	NA
Age (yrs)	25.36	18-44
Chinese cloze test score	81.89/100	36/100-100/100
Weekly use of Chinese (%)	62.44%	5%-100%
Length of study (yrs)	5.02	0.5-29
Age of first immersion (yrs)	22.29	14-42
Length of immersion (yrs)	1.85	0.08-5.83
Number of foreign languages studied	1.97	1-4

As in previous experiments, L2 learners were divided into four groups based on the orthographic typology of their L1 writing systems (Daniels, 1996). As shown in Table 27, the abjad group consisted of 1 participant whose L1 was Arabic; the abugida group consisted of 15 participants, whose L1s included Thai and Nepali; the alphabet group consisted of 20 participants, whose L1s included English, French, Spanish, Indonesian, Korean, Uzbek, Mongolian, and Vietnamese; and the syllabary/logography group consisted 1 participant, whose L1 was Japanese. Table 28 presents the phoneme-to-letter ratios of the L2 learners' L1 orthographies.

Table 27

Experiment 3: Orthographic Typology of L2 learners' First Language Writing Systems

L1 orthography type	Languages	Number of participants
Abjad	Arabic	1
Abugida	Nepali, Thai	15
Alphabet	English, French, Spanish, Indonesian, Korean, Uzbek, Mongolian, Vietnamese	20
Syllabary/logography	Japanese	1

Table 28

Experiment 3: Orthographic Depths of L2 learners' First Language Writing Systems

L1	Phoneme-to-letter ratio	Number of participants
Thai	0.49	13
Nepali	0.94	2
Korean	1.03	5
Indonesian	1.08	3
Spanish	1.11	1
Arabic	1.21	1
Uzbek	1.23	2
Vietnamese	1.24	1
French	1.31	1
Mongolian	1.34	2
Tswana	1.38	1
English	1.73	4
Japanese	NA	1

7.2 Design and materials

Experiment 3 used a 2 (sentence predictability: low, high) $\times$ 2 (activation type: phonological activation, semantic activation) $\times$ 2 (prime-target relation: phonetic radical, semantic radical) $\times$ 4 prime type (character-level related, radical-level related, radical, unrelated control) design. The stimuli consisted of 48 sets of sentences (96 sentences in total; see Appendix G for the complete list), 48 target characters, and 192 prime characters.

As shown in Table 29, there were two sentences in each set, both of which contained an identical compound character target. The target was unpredictable in one sentence, but highly predictable in the other sentence. Four types of primes were constructed for each target. As shown in the first example (i.e., phonological activation of phonetic radicals) in Table 29, each prime set included: (1) a radical prime (兄 *xiōng* “brother”), which was orthographically identical to the radical that was embedded in the compound character target (祝 *zhù* “to wish”), (2) a character-level related prime (住 *zhù* “to lodge”), which was a homophone of the target (祝 *zhù* “to wish”) and was thus related to the target at the character level; (3) a radical-level related prime (凶 *xiōng* “fierce”), which was a homophone of the radical (兄 *xiōng* “brother”) that was embedded in the target (祝 *zhù* “to wish”), but unrelated to the target character. It was thus only related to the target at the radical level; and 4) a control prime (e.g., 丑 *chǒu* “ugly”), which was phonologically, semantically, and orthographically unrelated to the target, but was matched with the radical-level related prime (凶 *xiōng* “fierce”) in terms of stroke number and frequency.

To examine whether phonetic radicals were processed differently than semantic radicals in sentence contexts, the prime-target relations of the stimuli were controlled so that the radical prime was either a phonetic radical (24 sets) or a semantic radical (24 sets) of the target character. To explore whether the phonological properties of radicals were activated differently than the semantic properties, two activation types were included in Experiment 3; the character-level and radical-level related primes were either homophones of (24 sets) or semantically related to (24 sets) the target and or the radical of the target.

Table 29

Experiment 3: Design and Sample Stimuli

1. Phonological activation of phonetic radicals	
Low-constraint sentence	我们全家祝你新年快乐，每一天都健康快乐。(Cloze probability: 0) Our family wishes you a Happy New Year, each day filled with good health and joy.
High-constraint sentence	在这新春佳节来临之际，我衷心地祝你幸福。(Cloze probability: 0.91) In the spirit of this holiday season, I sincerely wish you happiness.
Prime-target set	Target: 祝 zhù Radical prime: 兄 xiōng Character-level related prime: 住 zhù Radical-level related prime: 凶 xiōng Control prime: 丑 chǒu
2. Semantic activation of phonetic radicals	
Low-constraint sentence	他没见过驴也没见过马，不知道两者的区别。(Cloze probability: 0) He has never seen a donkey or a horse and does not know the difference.
High-constraint sentence	动物界也有很多混血儿，骡就是马和驴生的。(Cloze probability: 1) There are many hybrids in the animal kingdom; for example, a mule is the offspring of a horse and donkey.
Prime-target set	Target: 驴 donkey Radical prime: 户 household Character-level related prime: 骑 to ride Radical-level related prime: 家 family Control prime: 高 tall

Table 29 (cont.)

3. Phonological activation of semantic radicals	
Low-constraint sentence	
他们把窗 封 得严严实实，然后把门也关上了。(Cloze probability: 0)	
They closed the windows and then shut the door.	
High-constraint sentence	
由于能见度实在太低了，高速公路都被 封 了。(Cloze probability: 0.83)	
Because of extremely low visibility, the highway was closed .	
Prime-target set	
Target: 封 <i>fēng</i>	
Radical prime: 圭 <i>guī</i>	
Character-level related prime: 风 <i>fēng</i>	
Radical-level related prime: 归 <i>guī</i>	
Control prime: 付 <i>fù</i>	
4. Semantic activation of semantic radicals	
Low-constraint sentence	
其实可以 租 一辆越野车，然后开车去那里玩。(Cloze probability: 0)	
You can just rent an SUV and then drive there for a trip.	
High-constraint sentence	
如果旅行时需要照相机，可买或借或 租 一台。(Cloze probability: 0.92)	
If you need a camera for your trip, you can just buy, borrow, or rent one.	
Prime-target set	
Target: 租 to rent	
Radical prime: 禾 grain	
Character-level related prime: 借 to borrow	
Radical-related prime: 苗 sprout	
Control prime: 岩 rock	

As in previous experiments, to rule out the possibility that the priming effects observed were due to phonological or semantic overlap between compound characters and their radicals rather than the activation of their radicals, only characters that met specific requirements were selected. For sets under the phonological activation condition, compound characters (i.e., target) differed from their radicals (i.e., radical primes) in terms of consonants and vowels; for sets

under the semantic activation condition, two semantic-relatedness judgment pretests were conducted. As in Experiment 2, the first pretest was conducted to ensure that the compound characters that were chosen as targets had opaque semantic radicals. In the test, 30 native speakers of Chinese, who had participated in the previous norming tests but not any of the main experiments, rated the semantic relationship between the target characters and their semantic radicals on 1 (*not related at all*) to 4 (*closely related*) scale; the average score was 1.90, indicating that the target characters had opaque semantic radicals. A second norming test was then conducted to make sure that the character-level related primes were truly related to the targets, the radical-level related primes were related to the radicals of the targets, and that the control primes were truly unrelated. For this purpose, 26 native speakers of Chinese, who did not participate in the main experiments, were recruited to complete a semantic judgment test. They were asked to rate the semantic relationship between primes and targets on the same four-point scale. On average, character-level related primes scored 3.52, radical-level related primes scored 3.50, and control primes scored 1.33.

The same character-frequency statistics database used in the previous experiments was used here. Radical primes had a mean frequency of 54.24 per million (range = 1.22 – 131.42 per million), character-level related primes had a mean frequency of 89.84 per million (range = 9.42 – 131.42 per million), the radical-level related primes had a mean frequency of 103.82 per million (range = 9.42 – 131.42 per million), control primes had a mean frequency of 106.66 per million (range = 9.92 – 131.42 per million), and targets had a mean frequency of 112.94 per million (range = 3.06 – 474.19 per million).

To explore context effects on character recognition, 96 sentences were designed to make the target characters as predictable as possible in half of the sentences and as unpredictable as

possible in the other half of the sentences, with predictability quantified by cloze probability. To assess these sentences, 64 native speakers of Chinese who did not participate in the main experiments were recruited to perform a sentence-fragment completion task. They were given the first part of the sentences, up to but not including the target characters, and instructed to complete the fragments based on their first intuition. For the 48 sentences under the low-predictability condition, the participants completed the fragment with the target character 0% of the time, indicating that the targets were unpredictable in these sentences. For the 48 sentences under the high-predictability condition, the participants completed the given fragment with the target character 76.01% of the time (range = 33.33% – 100%), indicating that the sentences were highly constraining. To control for wrap-up effect, all of the target characters were embedded in the middle of the sentences. Specifically, all sentences consisted of 20 segments, and targets occurred in the fifth segment under the low-predictability condition and within fourteenth to eighteenth segments under the high-predictability condition.

A Latin square design was used to control for repetition effects. Eight presentation lists were created; in each list, the same target appeared only once but four types of primes appeared in equal numbers. Each list contained 24 phonetic-radical prime-target sets and 24 semantic-radical prime-target sets; half of the trials were under the phonological activation condition, and the other half under the semantic activation condition. Six practice sentences were presented before the main experiment, and two filler sentences were presented before the target sentences in the main experiment. Additionally, yes/no comprehension questions were created for each sentence in the experiment. In each list, half of the sentences had a “yes” answer, and the other half had a “no” answer. All target sentences were presented in a random order for each participant.

7.3 Procedures

The procedures of Experiment 3 are illustrated in Figure 22. Participants were first presented with a fixation point (“+”) on the left side of a computer screen. Once he or she pressed the space bar, the target sentence was presented on the screen, with hash marks (“##”) in the place of characters. The mask for the first character of the sentence remained on the screen for 200 ms, and was then replaced by a prime character, which was presented for 50 ms. The prime character was then replaced by a target character. Once the participant finished reading the character and pressed the space bar, the target character was replaced with underlines (“_”), and the sequence began again for the next character. Participants were instructed to read the sentences at their normal speed, and their RTs were measured from the onset of each target character. After the last character of each sentence was presented, participants saw a yes/no comprehension question in the center of the screen and were instructed to answer it based on what they had just read. After the question was answered, the fixation point reappeared on the screen and the process for the next sentence began.

To prevent participants from noticing the critical items in the experiment, each character in the sentences was presented after a prime character (Luke & Christianson, 2012). For characters that were non-critical items, the prime characters were the same as the targets.

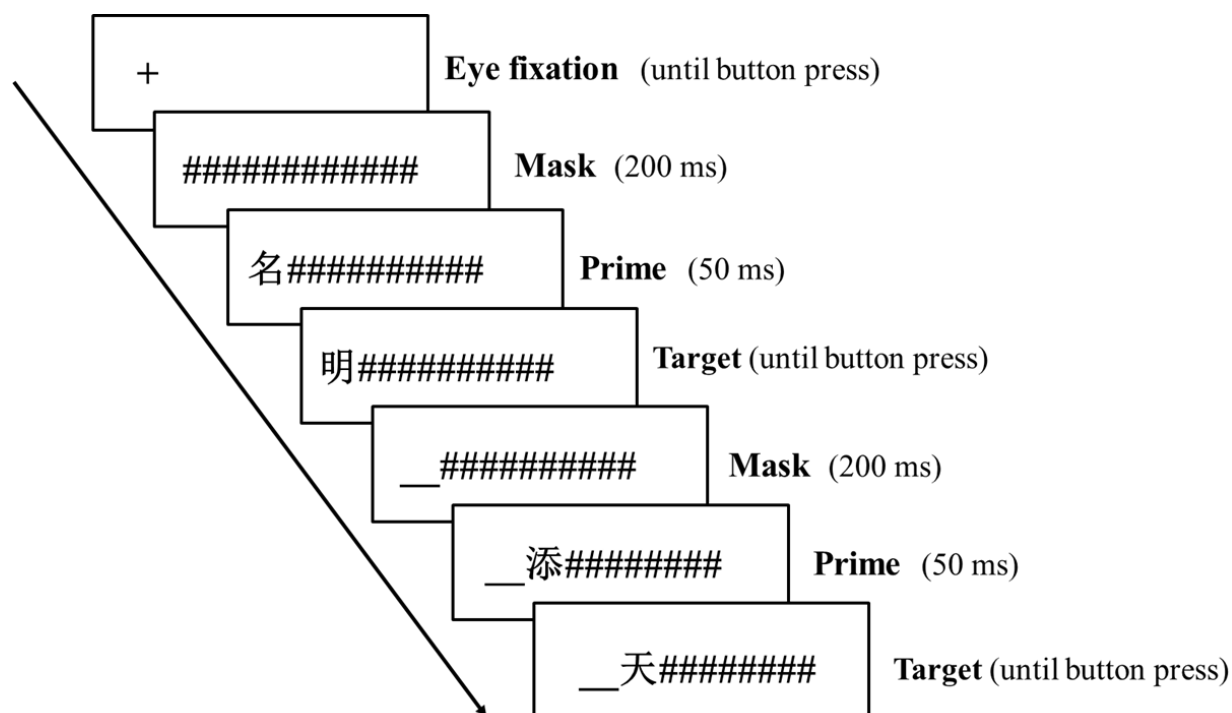


Figure 22. Experiment 3: Procedures.

The experiment was administered using E-Prime Professional software, version 2.0 (Schneider et al., 2002). Participants were tested individually in a quiet room. They were seated in a comfortable chair about 60 cm away from the computer screen and were randomly assigned to one of the eight presentation lists.

7.4 Data analysis

As mentioned above, the overall fast RTs for individual characters in sentence contexts may cause the means for all conditions to be compressed together; thus, it was possible that no priming effects would be observed in Experiment 3. Additionally, it has been commonly observed that participants often speed up as they progress through a reading task, as demonstrated by previous studies (e.g., Luke & Christianson, 2012), the significant main effect of trial number, and the significant interactions between trial number and other independent variables on both native speakers' and L2 learners' RTs that were observed in Experiments 1 and

2. Therefore, priming effects may only be detectable in the earlier trials of the experiment, but obscured as participants' reading speeds increased through the experiment (Luke & Christianson, 2012). For this reason, two separate analyses on the RT data were conducted in the current experiment; the first analysis was performed on the entire data set, and the second one was on the first half of the experiment.

As a self-paced reading task was part of the SPaM paradigm, spillover effects were also expected in Experiment 3. In a self-paced reading experiment, participants tend to press the button as quickly as possible, thus buffering each segment for reconstruction and integration later in the sentence. The use of this buffering strategy often causes results to be observed on the segment following the region of interest in the sentence rather than on the very region (Witzel, Witzel, & Forster, 2012). For this reason, participants' RTs for both the target characters (i.e., target region) and the characters that immediately followed the targets (i.e., target+1 region) were analyzed to capture potential spillover effects.

7.4.1 Native speakers of Chinese

Prior to the analyses, RTs that were shorter than 10 ms or longer than 1000 ms¹¹ were removed (3.13% of the data in the target region and 2.47% in the target+1 region). The average accuracy for the experiment was 95.77%, indicating that participants were making a conscious effort to comprehend the sentences. As in previous experiments, trials that were answered incorrectly and outliers that were two standard deviations below or above the means were discarded (4.30% of the data for the target region and 4.07% for the target+1 region). Prior to the

¹¹ These thresholds were chosen based on the distribution of the data. Due to the nature of the self-paced reading task and the design of the current experiment (i.e., each segment only contained one Chinese character, and half of the target characters were highly predictable in the given sentence contexts), RTs shorter than 100 ms made up 27.08% of the total data in the target region and 18.62% in the target+1 region, and RTs shorter than 200 ms were 58.33% of the data in the target region and 47.27% in the target+1 region. Therefore, only extreme outliers were discarded to ensure minimal information loss and data distortion.

analyses on the first half of the experiment, the same procedures were used to trim outliers, which were 3.23% of the data for the target region and 3.10% for the target+1 region.

Two linear mixed effects models were performed separately on native speakers' RTs in the target region and the target+1 region. Fixed effects included trial number, target frequency, prime type, prime-target relation, activation type, and sentence predictability (i.e., cloze probability as a continuous variable). Random effects included random intercepts for subjects and items, and by-subject random slopes for effects including prime type, prime-target relation, activation type, and sentence predictability. As before, RTs and target frequencies were log transformed, and all continuous variables were centered before the analyses.

Native speakers' accuracy data were analyzed in a separate logistic mixed effects regression model. Fixed effects included prime type, prime-target relation, activation type, sentence predictability, and target frequency; random effects included random intercepts for subject and item, as well as by-subject random slope for the effect of prime type.

7.4.2 L2 learners of Chinese

The data of three L2 learners whose accuracy rates were below 60% were not included in the analysis. RTs that were shorter than 10 ms or longer than 3000 ms¹² were removed (2.21% of the data in the target region and 0.52% in the target+1 region). The average accuracy was 84.51%, indicating that L2 learners were paying attention to the task and reading the sentences for meaning. As in previous experiments, trials that were answered incorrectly as well as outliers that were three standard deviations below or above the means were discarded (2.20% of the data in the target region and 2.09% in the target+1 region). Prior to the analyses on the data of the

¹² As mentioned above, only the extreme outliers were discarded here, because RTs shorter than 100 ms made up 9.11% of the total data in the target region and 5.99% in the target+1 region, and RTs shorter than 200 ms were 28.71% of the data in the target region and 18.62% of the target+1 region.

first half the experiment, the same procedures were used to trim outliers, which were 2.53% of the data in the target region and 2.18% in the target+1 region.

Two separate linear mixed effects models were performed on L2 learners' RTs in the target region and target+1 region. In addition to the fixed effects for the native speaker data, Chinese cloze test score, L1 orthography type, and L1 phoneme-to-letter ratio were included in the model. Random effects included by-subject and by-item random intercepts, by-subject random slopes for the effects including prime type, prime-target relation, activation type, and sentence predictability, as well as by-item random slope for the effects of Chinese cloze test score and L1 orthography type.

Finally, L2 learners' accuracy data were analyzed in a separate logistic mixed effects regression model, which included prime type, prime-target relation, activation type, sentence predictability, target frequency, Chinese cloze test score, L1 orthography type, and L1 phoneme-to-letter ratio as fixed effects, and subject and items as random effects.

7.5 Results

7.5.1 Native speakers of Chinese

For the target region, the analysis did not show any significant priming effects; for the target+1 region, the model revealed a significant three-way interactions between trial number, prime type, and sentence predictability ($p = .03881$).

As discussed above, the absence of main effects of priming here was not surprising, given that native speakers' average RT in Experiment 3 ($M = 175.88$, $SD = 103.14$) was much faster than those in Experiment 1 ($M = 719.06$, $SD = 219.83$) and Experiment 2 ($M = 706.21$, $SD = 218.04$). The fast RTs here might have obscured the priming effects in Experiment 3; as participants' reading speed increased over the course the experiment, the priming effects shrunk

and eventually disappeared. This possible explanation was confirmed by the main effect of trial number ($p < .001$) in both the target and target+1 regions and the significant interaction between trial number and other independent variables mentioned above. Therefore, presented below are the analyses on the first half of the experiment rather than those on the entire data set.

The mean values of native speakers' RTs on the target characters and target+1 characters for each condition in the first half of the experiment are presented in Table 30 and Table 31.

Table 30

Experiment 3: Native Speakers' Response Times (in Milliseconds) in the Target Region in the First Half of the Experiment

	High predictability sentence		Low predictability sentence	
	PR	SR	PR	SR
(1) Radical prime	208.31 (112.13)	183.45 (119.76)	216.07 (104.82)	193.79 (115.93)
(2) Character-level related prime	192.07 (122.81)	213.66 (111.69)	201.89 (98.40)	190.46 (100.47)
(3) Radical-level related prime	233.24 (127.07)	200.66 (130.68)	150.02 (107.07)	212.17 (107.42)
(4) Control prime	184.58 (105.97)	207.94 (121.98)	201.37 (134.37)	193.05 (123.42)

Note. Standard deviations are provided in parentheses. PR = phonetic radical; SR = semantic radical.

Table 31

Experiment 3: Native Speakers' Response Times (in Milliseconds) in the Target+1 Region in the First Half of the Experiment

	High predictability sentence		Low predictability sentence	
	PR	SR	PR	SR
(1) Radical prime	199.41 (90.72)	228.91 (103.15)	265.80 (125.28)	247.38 (131.32)
(2) Character-level related prime	206.23 (115.85)	233.68 (122.97)	248.22 (130.82)	244.80 (123.43)
(3) Radical-level related prime	222.02 (110.10)	247.00 (122.02)	240.56 (135.33)	249.82 (113.60)
(4) Control prime	209.00 (112.67)	267.46 (113.86)	247.47 (170.72)	223.79 (142.87)

Note. Standard deviations are provided in parentheses. PR = phonetic radical; SR = semantic radical.

The results of the two linear mixed effects models on native speakers' RTs in the first half of the experiment are summarized in Table 32 (target region) and Table 33 (target+1 region).

As shown in Table 32, the model on native speakers' RTs in the target region revealed main effects of trial number ($p = .003816$) and target frequency ($p = .036216$), indicating that participants sped up significantly under all conditions over the course of the first half of the experiment, and that high-frequency targets were read faster than low-frequency targets. No significant priming effects were observed in this region.

Table 32

Experiment 3: Output of Linear Mixed Effects Model on Native Speakers' Response Times in the Target Region in the First Half of the Experiment

Parameters	Estimate	SE	<i>t</i>
Intercept	0.266124	0.142639	1.866
Trial number	-0.013211	0.004549	-2.904**
Target frequency	-0.044713	0.021299	-2.099*
Prime type: radical	0.028253	0.097369	0.290
Prime type: character-level related	0.040598	0.096211	0.422
Prime type: radical-level related	0.058028	0.094126	0.616
Prime-target relation: semantic radical	0.005183	0.068427	0.076
Activation type: semantic	0.040474	0.067330	0.601
Sentence predictability	0.060135	0.097739	0.615

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, . $p < .1$

As shown in Table 33, the analysis on native speakers' RTs for target+1 characters in the first half of the experiment revealed significant effects of trial number ($p < .001$), target frequency ($p = .016245$), an interaction between prime type and target frequency ($p = .001402$), and an interaction between prime type and sentence predictability ($p = .003944$).

The effect of trial number again confirmed that participants' reading speeds increased as the experiment progressed, and the significant effect of target frequency indicated that characters immediately following high-frequency target characters were read faster than those following low-frequency targets.

Table 33

Experiment 3: Output of Linear Mixed Effects Model on Native Speakers' Response Times in the Target+1 Region in the First Half of the Experiment

Parameters	Estimate	SE	t
Intercept	0.213850	0.142139	1.505
Trial number	-0.015257	0.003716	-4.106***
Target frequency	-0.169158	0.038111	-4.439***
Prime type: radical	0.090599	0.090210	1.004
Prime type: character-level related	0.079862	0.078471	1.018
Prime type: radical-level related	0.104050	0.080271	1.296
Prime-target relation: semantic radical	0.094648	0.059911	1.580
Activation type: semantic	0.044777	0.056965	0.786
Sentence predictability	0.323665	0.141135	2.293*
Target frequency × prime type: radical	0.189781	0.051846	3.661***
Target frequency × prime type: character-level related	0.160999	0.050844	3.167**
Target frequency × prime type: radical-level related	0.153080	0.052450	2.919**
Sentence predictability × prime type: radical	-0.626642	0.186358	-3.363***
Sentence predictability × prime type: character-level related	-0.425650	0.182663	-2.330*
Sentence predictability × prime type: radical-level related	-0.169447	0.185860	-0.912

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

The interaction between prime type and target frequency on native speakers' RTs for the target+1 characters is plotted in Figure 23. Although the effect of target frequency was significant under the radical-level related prime and control prime conditions, it was not significant under the radical prime and character-level related prime conditions. This indicates that there was likely to be competition between character-level activation and radical-level activation under radical prime and character-level prime conditions, and the competition might have dampened the effect of target frequency under these two conditions.

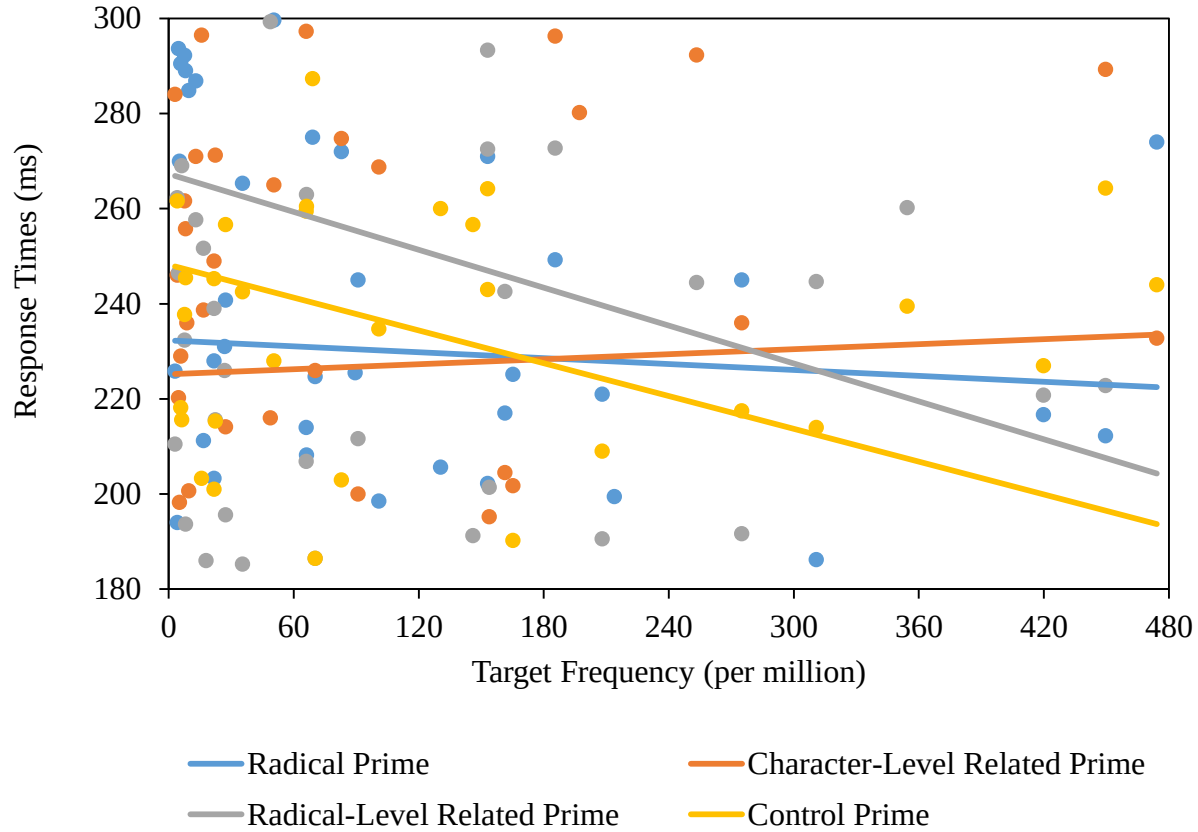


Figure 23. Experiment 3: Interaction effects (in milliseconds) of prime type and target frequency on native speakers' response times in the target+1 region.

As illustrated in Figure 24, there was also a significant interaction between prime type and sentence predictability. When the target character was unpredictable in the sentence context, radical primes, character-level related primes, and radical-level related primes all produced inhibition, indicating that both character-level and radical-level representations were activated in non-constraining sentence contexts. On the other hand, when the target was highly predictable in the sentence context, radical primes and character-level related primes produced significant facilitation, suggesting that character-level representations and the orthographic representations of radicals were activated.

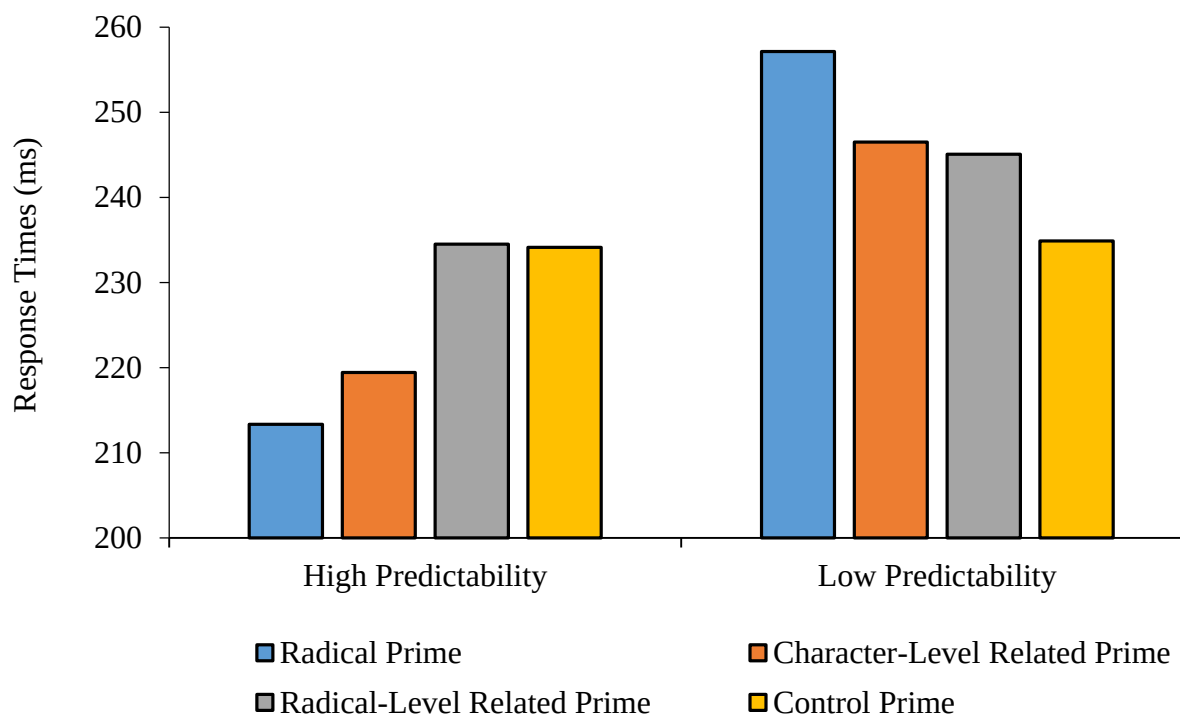


Figure 24. Experiment 3: Interaction effects (in milliseconds) of prime type and sentence predictability on native speakers' response times in the target+1 region.

The results of the logistic regression model on native speakers' accuracy data are summarized in Table 34. The analysis revealed significant main effects of target frequency ($p = .0409$) and sentence predictability ($p = .0243$). Native speakers' average accuracy rate was higher for high-frequency targets than for low-frequency targets. Accuracy also increased as a function of sentence predictability, where accuracy for sentences that had high cloze probability was higher than for those that had low cloze probability.

Table 34

Experiment 3: Output of Logistic Mixed Effects Model on Native Speakers' Accuracy Data

Parameters	Estimate	SE	z	p
Intercept	3.49368	0.57476	6.078	< 0.001***
Target frequency	0.36901	0.18044	2.045	0.0409*
Prime type: radical	0.46792	0.47404	0.987	0.3236
Prime type: character-level related	0.40671	0.57836	0.703	0.4819
Prime type: radical-level related	0.88122	0.66813	1.319	0.1872
Sentence predictability	0.90234	0.40051	2.253	0.0243*
Prime-target relation: semantic radical	0.48616	0.52203	0.931	0.3517
Activation type: semantic	0.02898	0.51708	0.056	0.9553

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

7.5.2 L2 learners of Chinese

The linear mixed effects model on L2 learners' RTs in the target region revealed significant main effects of trial number ($p < .001$), target frequency ($p = .0051520$), and Chinese cloze test score ($p < .001$). Specifically, the effect of trial number again showed that L2 learners sped up significantly as they progressed through the experiment, and that their fast RTs in the second half of the experiment might compress the means under all conditions together and obscure the priming effects. The effect of target frequency demonstrated that high-frequency characters were read faster than low-frequency characters in sentence contexts, and the main effect of Chinese cloze test score suggested that L2 learners who scored higher on the cloze test had faster reading times relative to their counterparts who scored lower on the test.

The analysis on L2 learners' RTs in the target+1 region revealed significant effects of trial number ($p < .001$) and Chinese cloze test score ($p < .001$), which are consistent with the results of the target region. Furthermore, the analysis also showed a significant main effect of

sentence predictability ($p < .001$), suggesting that L2 learners' RTs were faster when the target character was highly predictable ($M = 370.36$, $SD = 235.02$) than when it was unpredictable ($M = 443.23$, $SD = 321.49$). This indicates that L2 learners were sensitive to contextual cues, and that they actively used these cues to predict the upcoming characters during sentence reading.

Moreover, the analysis also revealed a marginally significant interaction between sentence predictability and Chinese cloze test score ($p = .0720651$), showing that L2 learners' reading strategies might change as a function of the increase in their Chinese proficiency. As illustrated in Figure 25, although L2 learners who had lower Chinese proficiency read highly predictable targets faster than unpredictable targets, such a difference was reduced as L2 learners' Chinese proficiency increased. One possible explanation for this change is that advanced L2 learners' fast RTs had obscured the difference between the two predictability conditions. An alternative possibility is that there was a shift in L2 learners' sentence reading strategies; as they became more proficient in Chinese, they relied less on contextual cues and tended to use bottom-up strategies when processing characters in sentence contexts.

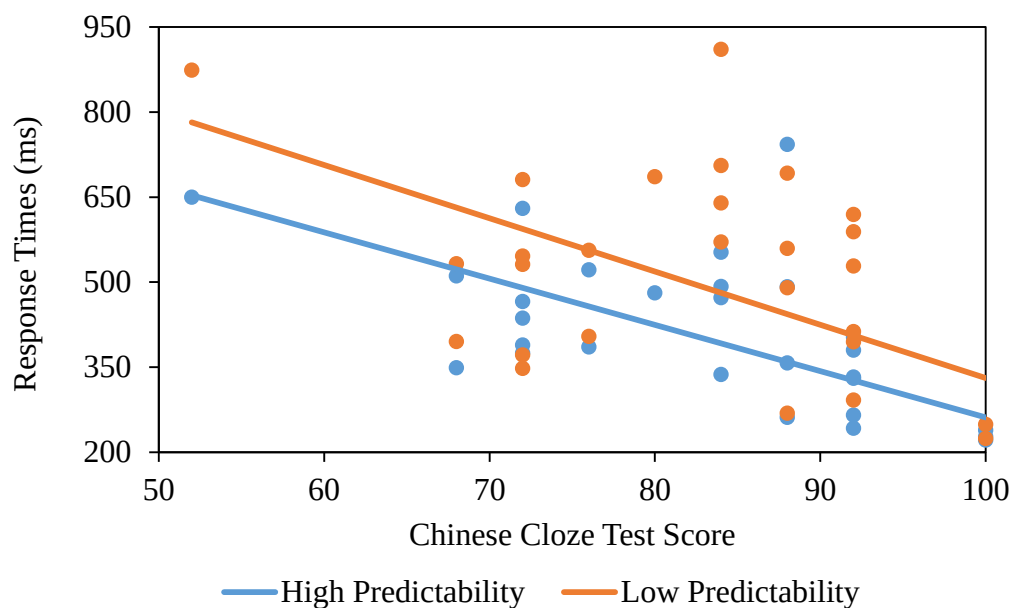


Figure 25. Experiment 3: Interaction effects (in milliseconds) of sentence predictability and Chinese cloze test score on L2 learners' response times in the target+1 region.

However, the analyses presented above did not show any significant priming effects. As discussed above, the absence of priming here was not surprising, as L2 learners' fast RTs in Experiment 3 ($M = 470.55$, $SD = 415.16$), which were much shorter than those in Experiment 1 ($M = 1104.70$, $SD = 691.24$) and Experiment 2 ($M = 1165.77$, $SD = 663.32$), might have obscured the effects. The significant effect of trial number as well as its interactions with other independent variables observed in the previous two experiment and the current experiment suggest that, just like native speakers, L2 learners also sped up as they progressed through the experiment. Therefore, effects that were not present in the second half of the experiment might be detectable in the first half of the experiment. To test this possibility, L2 learners' RT data set was divided into two parts based on the trial number, and a separate analysis was performed on the first half of the experiment, which is reported below.

Table 35 and Table 36 present the mean values of L2 learners' RTs on the target characters and target+1 characters for each condition in the first half of the experiment.

Table 35

Experiment 3: L2 Learners Response Times (in Milliseconds) in the Target Region in the First Half of the Experiment

	High predictability sentence		Low predictability sentence	
	PR	SR	PR	SR
(1) Radical prime	473.83 (381.61)	504.66 (418.96)	528.18 (487.22)	495.44 (477.10)
(2) Character-level related prime	450.38 (309.98)	492.00 (373.23)	465.63 (445.35)	441.87 (431.20)
(3) Radical-level related prime	502.33 (441.16)	546.98 (398.00)	470.67 (450.62)	338.93 (288.69)
(4) Control prime	473.86 (346.68)	456.26 (390.39)	483.41 (461.74)	555.28 (510.21)

Note. Standard deviations are provided in parentheses. PR = phonetic radical; SR = semantic radical.

Table 36

Experiment 3: L2 Learners Response Times (in Milliseconds) in the Target+1 Region in the First Half of the Experiment

	High predictability sentence		Low predictability sentence	
	PR	SR	PR	SR
(1) Radical prime	396.08 (335.86)	406.55 (242.97)	538.80 (463.49)	513.78 (420.81)
(2) Character-level related prime	360.76 (187.23)	409.67 (205.06)	493.29 (305.11)	451.70 (299.03)
(3) Radical-level related prime	403.59 (203.27)	415.18 (257.42)	439.79 (358.61)	522.90 (320.47)
(4) Control prime	368.34 (210.00)	411.62 (305.68)	545.73 (464.29)	442.88 (370.99)

Note. Standard deviations are provided in parentheses. PR = phonetic radical; SR = semantic radical.

The results of the model on L2 learners' RTs in the target region in the first half of the experiment are summarized in Table 37. The model revealed significant main effects of prime type ($p = .03782$), Chinese cloze test score ($p < .001$), and a marginally significant main effect of L1 orthography type ($p = .07574$)

Table 37

Experiment 3: Output of Linear Mixed Effects Model on L2 Learners' Response Times in the Target Region in the First Half of the Experiment

Parameters	Estimate	SE	<i>t</i>
Intercept	0.365746	0.526501	0.695
Trial number	-0.004128	0.003651	-1.131
Target frequency	-0.034433	0.019354	-1.779
Prime type: radical	-0.071199	0.070305	-1.013
Prime type: character-level related	-0.197316	0.068867	-2.865**
Prime type: radical-level related	-0.103338	0.073392	-1.408
Sentence predictability	0.148692	0.082944	1.793
Prime-target relation: semantic radical	0.036169	0.057321	0.631
Activation type: semantic	0.041484	0.058672	0.707
Chinese cloze test score	-3.405723	0.785524	-4.336***
L1 orthography type: abugida	0.358287	0.596131	0.601
L1 orthography type: alphabet	-0.515810	0.519202	-0.993
L1 phoneme-to-letter ratio	0.602393	0.465774	1.293

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

The main effect of Chinese cloze test score again showed that L2 learners who scored higher on the cloze test had faster RTs than those who scored lower. More interestingly, the model also revealed a significant main effect of prime type. As shown in Figure 26, the main effect of prime type indicated that L2 learners' RTs were faster when targets followed character-level related primes ($M = 462.14$, $SD = 388.69$) than when they followed control primes ($M = 490.64$, $SD = 446.51$). Radical primes and radical-level related primes, however, did not produced significant priming effects.

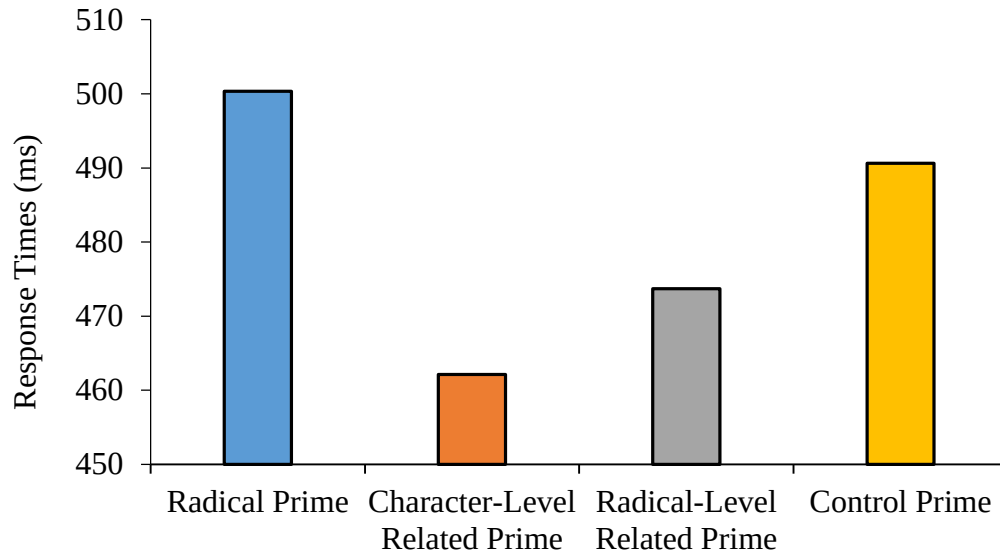


Figure 26. Experiment 3: Effects (in milliseconds) of prime type on L2 learners' response times in the target region.

The marginally significant effect of L1 orthography on L2 learners' RTs in the target region is illustrated in Figure 27. Although there was no statistical difference between the Chinese cloze test scores of the L2 learners from abugida L1 backgrounds ($M = 87.39$, $SD = 9.29$) and those from alphabetic L1 background ($M = 85.81$, $SD = 12.75$), L2 learners from abugida L1s had slower responses ($M = 580.32$, $SD = 424.42$) relative to those from alphabetic L1s ($M = 393.67$, $SD = 374.76$).

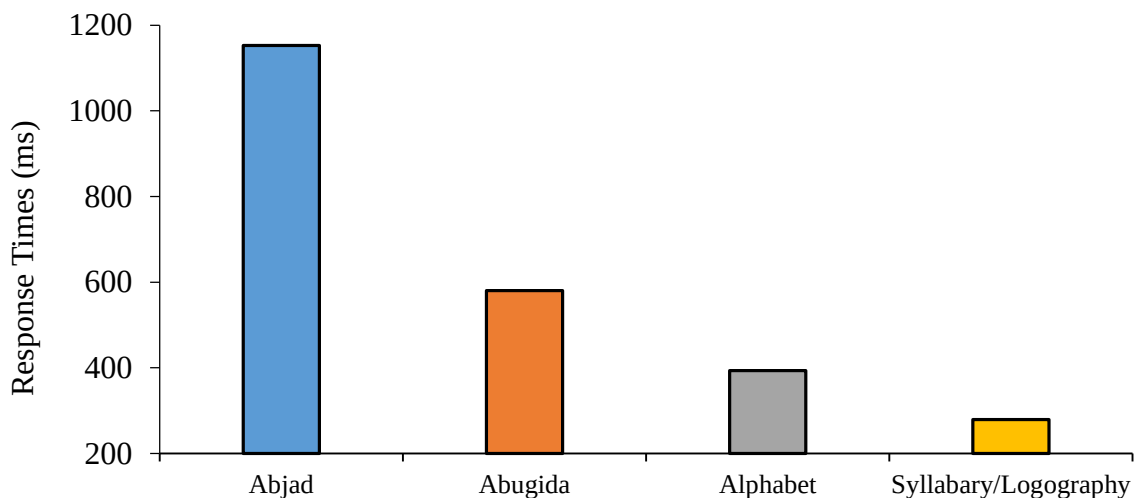


Figure 27. Experiment 3: Effects (in milliseconds) of L1 orthography on L2 learners' response times in the target region.

Table 38 presents the results of the mixed effects model on L2 learners' RTs for the target+1 characters in the first half of the experiment. The analysis revealed significant main effects of trial number ($p < .001$), sentence predictability ($p < .001$), and Chinese cloze test score ($p < .001$). All these effects are consistent with the results discussed above. Additionally, the absence of prime type effect in the target+1 region also showed that L2 learners were slower to process characters than native readers, whose data showed spillover effects.

Table 38

Experiment 3: Output of Linear Mixed Effects Model on L2 Learners' Response Times in the Target+1 Region in the First Half of the Experiment

Parameters	Estimate	SE	<i>t</i>
Intercept	0.037006	0.368377	0.100
Trial number	-0.011202	0.002948	-3.800***
Target frequency	-0.031277	0.01795	-1.742
Prime type: radical	-0.056461	0.058214	-0.970
Prime type: character-level related	-0.057057	0.056482	-1.010
Prime type: radical-level related	-0.056701	0.060265	-0.941
Sentence predictability	-0.210517	0.051493	-4.088***
Prime-target relation: semantic radical	-0.010284	0.051111	-0.201
Activation type: semantic	-0.018842	0.051361	-0.367
Chinese cloze test score	-2.550007	0.5642	-4.520***
L1 orthography type: abugida	0.557640	0.419058	1.331
L1 orthography type: alphabet	0.139450	0.365273	0.382
L1 phoneme-to-letter ratio	0.288598	0.328136	0.880

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

The results of the logistic regression model on L2 learners' accuracy data are summarized in Table 39. The analysis revealed significant main effects of sentence predictability ($p =$

.00264), Chinese cloze test score ($p < .001$), and L1 phoneme-to-letter ratio ($p = .02643$), as well as a significant interaction between prime-target relation and activation type ($p = .00698$).

Table 39

Experiment 3: Output of Logistic Mixed Effects Model on L2 Learners' Accuracy Data

Parameters	Estimate	SE	z	p
Intercept	3.12324	0.62398	5.005	< 0.001***
Target frequency	0.02500	0.08711	0.287	0.77414
Prime type: radical	0.20852	0.23225	0.898	0.36929
Prime type: character-level related	0.19583	0.23184	0.845	0.39830
Prime type: radical-level related	0.14761	0.23038	0.641	0.52170
Sentence predictability	0.64810	0.21550	3.007	0.00264**
Prime-target relation: semantic radical	-0.39023	0.35088	-1.112	0.26607
Activation type: semantic	-0.50491	0.33839	-1.492	0.13568
Chinese cloze test score	5.56485	0.87100	6.389	< 0.001***
L1 orthography type: abugida	-1.24178	0.64574	-1.923	0.05448
L1 orthography type: alphabet	-0.94781	0.56141	-1.688	0.09136
L1 phoneme-to-letter ratio	-1.05664	0.47600	-2.220	0.02643*
Prime-target relation: semantic radical × activation type: semantic	1.37024	0.50793	2.698	0.00698**

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, $p < .1$

Specifically, the model showed that the average accuracy rate was higher for sentences that had high cloze probability than for those that had low cloze probability, and that L2 learners who scored higher on the Chinese cloze test had higher accuracy rates than those who scored lower on the test.

The interaction between prime-target relation and activation type is plotted in Figure 28. For phonetic radical sets, L2 learners' average accuracy rate was higher under the phonological activation condition ($M = 0.86$, $SD = 0.34$) than under the semantic activation condition ($M =$

0.81, $SD = 0.39$); for semantic radical sets, their average accuracy rate was higher under the semantic activation condition ($M = 0.91$, $SD = 0.29$) than under the phonological activation condition ($M = 0.82$, $SD = 0.39$), indicating that L2 learners were sensitive to the functional specificity of radicals.

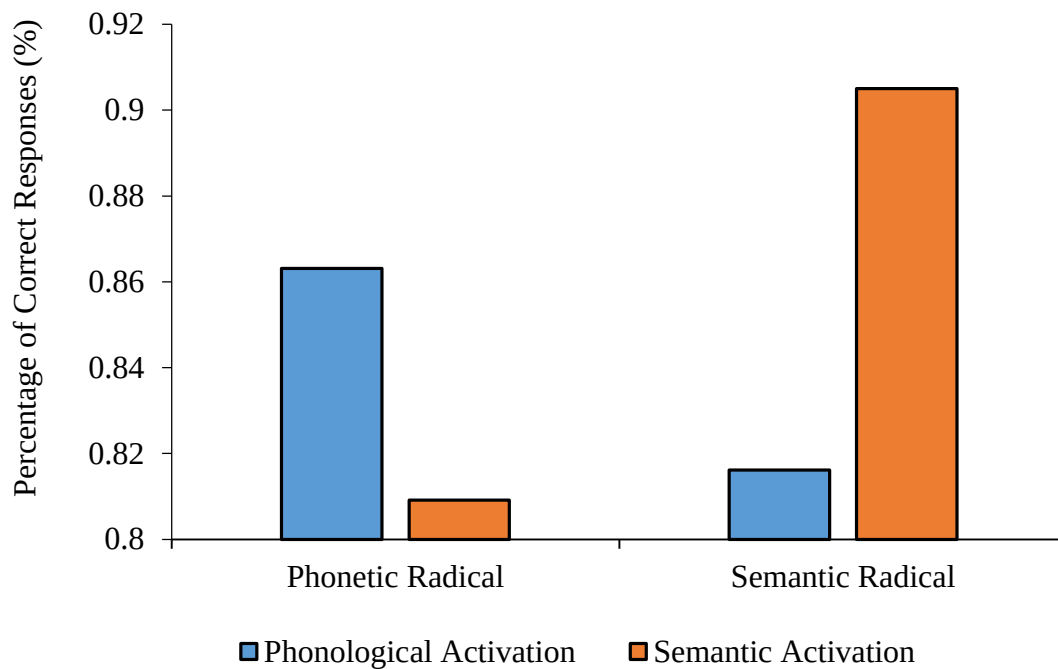


Figure 28. Experiment 3: Interaction effects (in milliseconds) of prime-target relation and activation type on L2 learners' accuracy.

Finally, Figure 29 shows that L2 learners from L1 orthographies with high phoneme-to-letter ratios had lower accuracy rates than those from L1 orthographies with low phoneme-to-letter ratios.

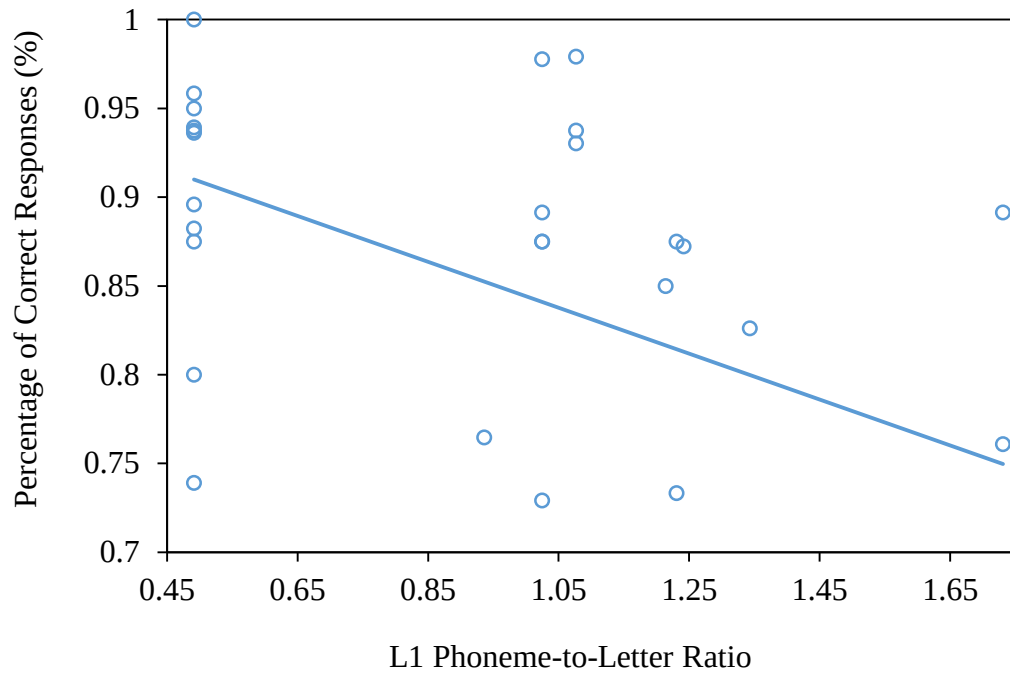


Figure 29. Experiment 3: Effects of the phoneme-to-letter ratio of first language orthography on L2 learners' accuracy.

7.6 Discussion

The purpose of Experiment 3 was to investigate whether radical properties were activated during character recognition in sentence contexts and how contextual cues modulated radical-level activation.

The major findings from the native speaker data are summarized as follows. First, there was a significant effect of target frequency under radical-level related prime and control prime conditions, but the frequency effect was not significant under radical prime and character-level related prime conditions. This interaction indicates that radical-level and character-level representations were likely activated in parallel under the radical prime and character-level related prime conditions, and the competition between these representations might have dampened the frequency effect. Second, for targets that were unpredictable in the sentence, radical primes, character-level related primes, and radical-level related primes all produced

inhibition, suggesting that the preactivation of radical-level representations might have caused competition and thus interfered with the activation of character-level representations. For targets that were highly predictable in the sentence, however, radical primes and character-level related primes produced facilitation, indicating that the phonological and semantic representations of the whole compound characters, as well as the orthographic forms of their radicals were preactivated when the compound characters were expected by the reader. In other words, in highly predictable contexts, lexical activation reaches a stage – prior to encountering the prime – where phonologically and semantically related primes facilitate final access. In unpredictable contexts, though, when little to no prediction precedes the presentation of the prime, related primes start lexical activation along an ultimately incorrect route. This activation then needs to be inhibited once the target is encountered, producing the inhibitory effect of the related primes. Interference from the unrelated control is not as strong as from the related primes, however, due to the control's greater dissimilarity from the target.

As for L2 learners, there are four major findings. First, the main effect of sentence predictability on L2 learners' RTs suggests that they are sensitive to contextual cues and that they actively use contextual information to predict the upcoming characters when reading Chinese. Additionally, L2 learners may adopt different reading strategies as their Chinese proficiency increases; those at the lower level tend to use more top-down strategies and appear to rely more heavily on contextual cues, whereas L2 learners at higher proficiency levels appear to shift to bottom-up processing strategies, relying less on contextual information when reading Chinese sentences. Second, the main effect of prime type shows that only character-level related primes produced significant facilitatory effects on L2 learners' RTs. This indicates that L2 learners automatically activated the phonological and semantic representations of the whole

characters; nevertheless, they did not activate radical-level information when processing compound characters in sentence contexts. Third, the interaction between prime-target relation and activation type suggests that L2 learners were sensitive to the functional specificity of radicals in the offline task. Finally, L2 learners' L1 orthographies may influence the way they process Chinese characters. Specifically, L2 learners from abugida L1s had slower RTs than those from alphabetic L1s, and learners whose L1 orthographies had high phoneme-to-letter ratios had lower accuracy rates than those whose L1 orthographies had low phoneme-to-letter ratios.

For native speakers, the interaction between prime type and sentence predictability illustrates that native speakers utilize contextual information when reading sentences and may adopt different character processing strategies depending on the availability of contextual cues. Specifically, when the target character was unpredictable, radical primes and radical-level related primes both produced inhibitory effects relative to control primes, indicating that the preactivation of the orthographic, phonological, and semantic properties of radicals may have facilitated the decomposition of the compound character and increased the competition between radical-level representations and character-level representations. The phonological and semantic activation of the whole character had to compete with that of the radicals, resulting in native speakers' slower RTs under the radical prime and radical-level related prime conditions. This is consistent with the results of Experiments 1 and 2, as well as previous research on character recognition under context-independent conditions (e.g., Zhou & Marslen-Wilson, 1999b, c; Zhou et al., 2013). In addition to radical primes and radical-level related primes, character-level related primes also produced significant inhibitory effects in non-constraining sentence contexts. This was likely to be due to the phonological and semantic similarity between the primes and targets.

The representations of the character-level related primes, although similar to those of the targets, were incongruent with the given sentence context. In order to integrate the target into the sentence, the reader would need to suppress the activation of the competing representations of the prime, which in turn delayed their responses to the target. Taken together, these results are consistent with previous findings on character recognition in word and sentence contexts (Liu et al., 2002; Tsai et al., 2004; Zhang & Peng, 1993; Zhang et al., 1991) and demonstrate that character recognition in non-constraining sentence contexts also involves the activation of radical properties.

On the other hand, when a compound character was highly predictable in the sentence contexts, there was facilitation produced by the preactivation of the phonological and semantic representations of the whole character and the preactivation of the orthographic representations of its radicals. Because no previous studies have investigated character recognition in highly constraining sentence contexts among Chinese readers, the results of the current experiment were compared with the findings on other languages. The literature on processing alphabetic scripts suggests that there are two hypotheses regarding the effect of predictability on processing efficiency. A number of researchers argue that predictability effects kick in after lexical access and facilitate the semantic integration of the word into the sentence (e.g., Forster, 1989), whereas many ERP studies suggest that the influence of predictability occurs during lexical access, because the reader actively predicts the properties of the upcoming word (e.g., Federmeier, 2007). These ERP results indicate that readers' predictions of the identity of the upcoming word can be quite specific, including the semantic content (e.g., Federmeier & Kutas, 1999), phonology (e.g., DeLong, Urbach, & Kutas, 2005), and orthographic information (e.g., Laszlo & Federmeier, 2009) of the expected word. The results of the current experiment are consistent

with these ERP studies and with Luke and Christianson's (2012) findings on transposed-letter effects in highly constraining sentence contexts. The facilitation produced by radical primes and character-level related primes suggest that Chinese native speakers made specific predictions about the phonological and semantic representations of the whole character and the orthography of its radicals, and when the primes supported their predictions, their responses to targets were facilitated. As for the absence of the priming effects produced by radical-level related primes in highly constraining sentence contexts, there are two possible explanations. It was possible that the reader actively predicted the upcoming compound character and had preactivated the orthographic, phonological, and semantic properties of the radicals that were embedded in the compound character. However, as the phonological and semantic representations at the radical level were different from those at the character level, radical-level representations were quickly inhibited before the reader encountered the target character, and thus radical-level related primes did not produce any detectable effects. On the other hand, the orthographic representations at the radical level were not inhibited because there was orthographic overlap between the target character and its radicals, and thus radical primes produced significant facilitation. The alternative possibility was that the reader only preactivated character-level representations when processing compound characters in highly constraining sentence contexts. Because there was orthographic, phonological, and semantic overlap between character-level related primes, radical primes, and target characters, these two types of primes produced facilitatory effects. Radical-level related primes, on the other hand, did not share any similarities with the character-level representations of the target characters and thus did not produce any priming effects.

The results from L2 learners suggest that they are sensitive to contextual cues, and that they actively use these cues to predict the upcoming characters when reading Chinese sentences.

Furthermore, their reading strategies may change as a function of their Chinese proficiency; they may use more bottom-up processing strategies and rely less on contextual cues as their Chinese proficiency increases.

There was also a main effect of prime type on L2 learners' RTs, which shows that only character-level related primes produced facilitation on L2 character recognition in sentence contexts. This indicates that although L2 learners may activate radical information when reading compound characters under context-independent conditions (as in Experiments 1 and 2), they may not have access to radical-level representations when processing compound characters in sentence contexts. One possible explanation is that L2 character decomposition is less automatic and slower than L1 character decomposition. As described in Ke's (1996b) model of L2 radical awareness development, although learners who are in the component processing stage already start to apply their knowledge of radicals to character learning, only those who are in the automatic component processing stage have native-like orthographic awareness and process characters via the activation of radical-level information. It is thus possible that the L2 learners in the current experiment were in the component processing stage and had not yet reached the automatic component processing stage. They had started to decompose compound characters, as shown in Experiments 1 and 2; nevertheless, in the sentence reading task, where the processing demand was higher and working memory was taxed to a greater extent, they were unable to automatically decompose compound characters or retrieve radical-level information efficiently. Thus, they fell back on processing characters as single units. Another possible reason is that radicals are typically taught and studied in isolation or within single characters in the L2 classroom. Chinese language teachers seldom draw L2 learners' attention to radicals when teaching sentence comprehension or reading beyond single characters. Therefore, L2 learners

may be more sensitive to radicals when reading context-independent characters relative to reading characters that are embedded in sentences.

The results of Experiment 3 appear to be inconsistent with Wang and Koda's (2013) findings on L2 character recognition in sentence contexts, which found that L2 learners were sensitive to semantic radical transparency when reading sentences. However, Wang and Koda's study used an offline task, whereas the current study used an online task. The methodological difference shows that L2 learners may be able to activate radical information under offline conditions but not during online language processing, again pointing to the less automatic nature of L2 character decomposition. In line with this possibility, the interaction between prime-target relation and activation type on L2 learners' accuracy rates also illustrates that although L2 learners may not be able to activate radical information automatically during online sentence processing, they are sensitive to the functional specificity of radicals in offline measures.

Lastly, Experiment 3 shows that L2 character recognition may be constrained by the learner's L1 orthography properties (Koda, 1997). Consistent with the findings of Experiment 1, the current experiment shows that L2 learners from abugida L1 backgrounds had slower RTs relative to those from alphabetic L1 backgrounds. As discussed in Experiment 1, because native readers of abugida scripts tend to use a syllabic level of segmentation rather than phonemic reading (Winskel, 2009), L2 learners from abugida L1 backgrounds may be less skilled at compound character decomposition compared with their counterparts from alphabetic L1 backgrounds. The main effect of L1 phoneme-to-letter ratio on L2 learners' accuracy also indicates that the depth of a learner's L1 orthography may influence the way he or she processes Chinese characters. Specifically, L2 learners coming from relatively shallow L1 orthographies had higher accuracy rates than those from relatively deep L1 orthographies. A possible

explanation is that native readers of orthographically shallow languages may be better at word/character decomposition relative to those from relatively deep L1 orthographies, and these L1-based literacy skills have been transferred to L2 character recognition. It is noteworthy that the effect of L1 phoneme-to-letter ratio was not detected in Experiments 1 and 2 but emerged in the current experiment. This may indicate that Experiment 3 provided a more sensitive measurement because the SPaM task was more ecologically valid than the primed-character decision task used in the previous two experiments.

To summarize, Experiment 3 shows that native speakers automatically activate the orthographic, phonological, and semantic properties of radicals when processing compound characters in non-constraining sentence contexts. On the other hand, in highly constraining sentence contexts, they make specific predictions about the identity of the upcoming character before encountering the character. The results also indicate that L2 learners are sensitive to contextual cues, but they do not activate radical-level information when processing characters in sentence contexts. Lastly, the experiment suggests that L2 learners' L1 orthographies may influence the way they process Chinese characters.

Chapter 8: General Discussion

8.1 Summary of results

The goal of the current study was to examine how Chinese characters were processed by native speakers and L2 learners from orthographically different L1 backgrounds. Specifically, four research questions were addressed: (1) How do native speakers and L2 learners activate the orthographic properties of radicals during character recognition? (2) How do native speakers and L2 learners activate the phonological and semantic properties of radicals during character recognition? (3) How does sentence context influence L1 and L2 character recognition? and (4) How does the reader's L1 orthography influence his or her L2 character recognition? To answer these questions, two primed-character decision tasks and a primed self-paced reading task were conducted with 104 native speakers and 105 L2 learners from 4 types of L1 orthographies.

In the first primed-character decision task, it was observed that both native speakers and L2 learners activated the orthographic properties of radicals during compound character recognition. Furthermore, although native speakers processed phonetic radicals and semantic radicals in qualitatively and quantitatively similar ways, L2 learners displayed different processing patterns for different types of radicals. Semantic radicals appeared to be activated earlier than phonetic radicals; L2 learners who had acquired a limited number of characters were more sensitive to phonetic radicals, whereas those who had acquired a larger number of characters were more sensitive to semantic radicals. Finally, L2 learners coming from alphabetic L1 backgrounds had faster RTs than those from abugida L1 backgrounds, indicating that L1 orthography may influence L2 character recognition.

The second primed-character decision task further explored the phonological and semantic activation at the radical level during L1 and L2 character recognition. The results

showed that both native speakers and L2 learners automatically activated the phonological and semantic representations of radicals in parallel with those of whole characters. Consistent with the findings of Experiment 1, it was again observed that lower-level L2 learners responded faster to phonetic radicals, but higher-level learners responded faster to semantic radicals.

The last experiment showed that native speakers automatically activated the orthographic, phonological, and semantic properties of radicals when processing compound characters in non-constraining sentence contexts, but they made specific predictions of the character-level representations of the upcoming compound character when reading it in highly constraining sentence contexts. L2 learners were sensitive to contextual cues and might adopt different reading strategies as their Chinese proficiency increased. Furthermore, L2 learners did not activate radical-level information when processing compound characters in sentence contexts, although they were sensitive to radical functional specificity under the offline reading condition. Lastly, L2 learners coming from relatively shallow L1 orthographies had higher accuracy rates than those from relatively deep L1 orthographies, and learners from abugida L1s had slower RTs than those from alphabetic L1s, indicating that L1 orthographies may influence the way L2 learners process Chinese characters.

Altogether, the current study shows that native speakers automatically activate representations at both the whole character level and the radical level, but their processing strategies may change as a function of sentence predictability. L2 learners also activate radical-level information during character recognition, but the activation of phonetic radicals may be slower than that of semantic radicals. Their acquisition of semantic radicals also appears to be faster and better than that of phonetic radicals. Furthermore, when reading characters in sentence contexts, L2 learners are able to utilize contextual cues to predict the upcoming character, but

they do not activate radical-level information. Lastly, L1 orthography may influence L2 character recognition; L2 learners from alphabetic L1 backgrounds and shallower L1 orthographies may be more efficient at decomposing compound characters than those from abugida L1 backgrounds and deeper L1 orthographies.

8.2 Implications for L1 character recognition

The present study indicates that radicals provide major information for compound character processing; the orthographic, phonological, and semantic information is automatically activated in parallel at both the whole character level and the radical level during L1 character recognition. These results are consistent with the previous studies (e.g., Lee et al., 2004; She et al., 1997; Zhou & Marslen-Wilson, 1999b, c, 2002; Zhou et al., 2000; Zhou et al., 2013) and provide implications for theoretical reading models.

The current results can be accommodated in the Interactive Activation Model (e.g., Ding et al., 2004; Taft, 2006), which posits that features, simple characters, and complex character are represented at different levels. Additionally, the model hypothesizes that radicals that are also freestanding simple characters have separate representations for each form, and these representations are linked with each other. Both simple characters and complex characters are directly linked to their phonological and semantic properties. Therefore, the activation of a compound character is predicted to involve the activation of the phonological and semantic representations of its radicals. This prediction was confirmed by the facilitatory effects produced by compound character primes on radical targets, which were observed in Experiments 1 and 2. Furthermore, the Interactive Activation Model suggests that radicals that appear in different positions within a complex character each have their independent representations, and that there are inhibitory links between these representations. Based on these assumptions, the model would

predict that the activation of a simple character might inhibit the activation of a compound character containing the simple character as its radical. This prediction was confirmed in Experiment 3, where radical primes and radical-level related primes produced inhibitory effects on compound character targets. Nevertheless, the Interactive Activation Model does not address how contextual information affects character recognition.

The Connectionist Model (e.g., Chen & Peng, 1994; McClelland et al., 1986; Rumelhart et al., 1986) suggests that characters are represented by orthographic, phonological, and semantic units. Although computational simulations have shown that the Connectionist Model may be trained to replicate regularity and frequency effects that are found in behavioral experiments on reading Chinese, the model does not make clear predictions as to how radical-level properties are activated during compound character recognition. Nevertheless, the Connectionist Model posits that there are context units connected to the orthographic, phonological, and semantic units, and that word recognition is often modulated by context. These assumptions are consistent with the results of the present study, where native speakers were found to process characters differently in non-constraining and highly constraining sentence contexts.

Based on the assumptions of the Dual Route Model (e.g., Coltheart et al., 1993; Weekes et al., 1997), there are three routes to character recognition, i.e., the lexical semantic route, the lexical non-semantic route, and the GPC route, and different versions of the model may vary in terms of their commitment to modularity. In the context of the present study, the dual route theories would predict that the lexical route (i.e., character-level activation) would be the dominant route for processing high-frequency, irregular compound characters, and some variations of the theories (e.g., the horse-racing model) would predict parallel activation of character- and radical-level information. The current study shows that even high-frequency,

irregular compound characters were decomposed, and that the representations of the whole character and those of its radicals were activated in parallel. These results do not support the dual-route theories that are strongly committed to modularity, but are compatible with the versions that predict parallel activation of different routes.

With regard to context effects on L1 character recognition, the results of the present study are consistent with the previous findings that compound character processing in sentence contexts also involves the activation of radical properties (e.g., Liu et al., 2002; Tsai et al., 2004). The present study also explored how sentence predictability interacted with character processing, which had not been studied before. The results indicate that native Chinese readers make specific predictions as to the phonological, semantic, and orthographic identities of the upcoming character in highly constraining contexts, and that sentence predictability may suppress the activation of radical-level representations. These findings are consistent with behavioral and ERP studies on reading alphabetic languages (e.g., DeLong et al., 2005; Federmeier & Kutas, 1999; Laszlo & Federmeier, 2009; Luke & Christianson, 2012) and suggest that predictability effects occur during lexical access and have early influence on visual character recognition.

8.3 Implications for L2 character recognition

The present study shows that L2 learners activate radical-level representations during compound character recognition under context-independent conditions, indicating that L2 learners who have intermediate or above proficiency in Chinese are sensitive to radicals. This is consistent with a number of previous studies (e.g., Jackson et al., 2003; Wang et al., 2003; Shen & Ke, 2007). Nevertheless, when compared with L1 character recognition, L2 compound character decomposition and radical-level activation appear to be less automatic. When processing demands are higher, as in the case of processing characters in a self-paced reading

task, L2 learners are unable to engage in radical-level processing at all and fall back on processing characters as single units. These results are in line with Shen and Ke's (2007) finding that L2 learners' ability to apply radical knowledge online is not synchronous with their increase in metalinguistic radical knowledge.

This study also demonstrates the discrepancy between the acquisition of semantic radicals and that of phonetic radicals among L2 learners of Chinese. The results suggest that semantic radicals are activated earlier relative to phonetic radicals. Furthermore, although L2 learners who have acquired a limited number of characters tend to be more sensitive to phonetic radicals and may use them as orthographic cues, as suggested by Williams (2010, 2013), L2 learners who have acquired a larger number of characters are more sensitive to semantic radicals. This difference may reflect several issues in the Chinese L2 classroom and L2 learners' character learning strategies. Previous research has reported that Chinese language textbooks and instructors tend to place a stronger emphasis on semantic radicals than phonetic radicals (Jackson et al., 2003; Zhang, 2009), and that L2 learners often rely more on semantic-radical-related learning strategies relative to phonetic-radical-related strategies (Chen, 2011). These factors may have contributed to the insufficient acquisition of phonetic radicals among L2 learners.

Finally, the current study suggests that L1 orthography may influence L2 character acquisition. L2 learners from alphabetic L1 backgrounds were found to have faster RTs than those from abugida L1 backgrounds, and L2 learners from shallower L1 orthographies had higher accuracy than those from deeper L1 orthographies. These findings support Koda's (1997) argument that L1 orthography-based processing strategies are transferred to L2 reading, and L2 word recognition is often constrained by the reader's L1 orthography properties. Furthermore, the RT difference between the abugida group and the alphabet group observed in the current

study is also in line with Feng et al.'s (2005) results, which showed that L2 learners from alphabetic L1 backgrounds were more likely to decompose compound characters when compared with L2 learners from other L1 backgrounds.

8.4 Pedagogical implications

Given the drastic difference between the Chinese script and other scripts, L2 learners are often unable to transfer their L1 literacy skills to reading and writing Chinese. Therefore, Chinese instructors should not only teach literacy, but also help L2 learners develop language specific learning strategies that will enable them to acquire and process Chinese characters more effectively. To this end, three Chinese script-specific pedagogical suggestions on L2 literacy development are offered here based on the findings of the present study.

First, the current study demonstrates that although there is no processing difference between phonetic radicals and semantic radical in L1 character recognition, phonetic radicals are not utilized as much as semantic radicals by L2 learners. This difference is likely to be one of main factors contributing to the inefficiency of L2 character processing. Teacher training may be one of the solutions to this issue, as L2 learners may benefit greatly from the explicit instruction of phonetic radicals and character learning strategies which will help them use radical-level phonological information more effectively and in turn reduce their burden for rote memorization of whole characters. Furthermore, as Chinese language textbooks typically emphasize semantic radicals over phonetic radicals (Jackson et al., 2003; Zhang, 2009), providing a systematic introduction of phonetic radicals and related exercises throughout all levels of instruction may also benefit L2 learners' acquisition of Chinese characters. Ideally, simple characters should be introduced before complex characters that contain them as components, and regular/consistent compound characters should be introduced before irregular/inconsistent compound characters, so

that L2 learners can develop radical awareness quickly. This type of Chinese orthography-based systematic introduction of characters may be especially effective for heritage learners who have already acquired oral proficiency of the Chinese language and for reading/writing courses where students have already taken spoken Chinese courses. For communication-oriented curriculum, where high-frequency characters, which tend to be irregular and inconsistent, are introduced before low-frequency characters, which tend to be more regular and consistent, the current study suggests that L2 learners may benefit from instructor-guided analysis, comparison, and summary of radical families.

Second, this study shows that although L2 learners are able to activate radical-level information during context-independent character recognition, they do not utilize radical information when processing characters in sentence contexts. Native speakers, on the other hand, automatically utilize radical information when processing characters under both context-independent and context-embedded conditions. This difference may be another reason for the relatively inefficient, slow L2 character recognition. In natural reading, characters seldom occur in isolation, and they are almost always embedded in sentence contexts. It is thus possible that L2 learners make little use of radical-level information in natural reading. For this reason, drawing L2 learners' attention to character decomposition and radical properties when teaching sentence-level comprehension and reading beyond single characters may help them develop effective character processing strategies that are applicable to natural reading.

Lastly, the processing difference between L2 learners from different L1 orthographies suggest that using teaching approaches and learning strategies that are sensitive to learners' L1 backgrounds may help them acquire Chinese characters more effectively. Specifically, L2 learners whose L1 orthographies are typically processed in a non-decompositional fashion may

need additional support with regard to radical-level activation than those who are familiar with decompositional word/character processing.

8.5 Limitations and recommendation for future research

This study aimed to systematically investigate L1 and L2 character recognition, but there remain several issues that were not addressed by the present study and await future research.

First, the effects of character graphic structure and radical position were not examined in the study. As mentioned before, compound characters can have a variety of graphic structures and their radicals can occur in a variety of positions within a compound character. Previous studies have reported mixed results as to how the positional properties of radicals affect L1 character recognition (e.g., Feldman & Siok, 1997; Taft & Zhu, 1997), and little research has been done on the effect of radical position on L2 character recognition. Therefore, further research is needed to examine whether the same radical-level activation pattern also applies to processing compound characters that contain radicals in atypical positions, and how the activation of radical positional information, if any, influences L1 and L2 character processing.

Second, radical frequency was measured by the frequency count of the simple-character version of the radical rather than measures of the radical's combinability or neighborhood size in the current study. Further research is needed to compare how different radical frequency measures explain compound character recognition.

Third, only “free” radicals, which could occur alone as simple characters, were used in the current study. It remains unclear how “bound” radicals (e.g., 扌 “hand”), which may not have independent phonological or semantic representations, are processed during character recognition. Although a few researchers have examined “bound” radicals (e.g., Cheng & Lin,

2013), no study to date has investigated how the phonological and semantic representations of “bound” radicals are activated during character recognition.

Fourth, the present literature of character recognition has focused on phonetic compound characters. Little research has been done on L1 or L2 recognition of other types of characters. A recent study by Luo, Proctor, Weng, and Li (2014) investigated the activation of radical meaning during L1 recognition of indicative characters, which are constructed by integrating the meanings of two or more radicals. More research along this line is needed to explore whether Chinese readers are sensitive to different character types in online processing and whether they adopt different strategies to process different types of characters.

Furthermore, target position was not strictly controlled in Experiment 3. Target characters always occurred in the fifth segment in the low-constraint sentences, however ranged from the fourteenth to eighteenth segments in the high-constraint sentences. Future studies may use *n*-gram information to strictly control for the position of target characters within experimental sentences and thus rule out potential confounds with regard to target position.

As for L2 acquisition, the present study did not involve elementary L2 learners. It is important to investigate whether and how character recognition among Chinese L2 beginners differs from that among intermediate and advanced learners. It is equally important to investigate L2 character recognition among learners who have reached near-native or superior proficiency levels. Ke (1996b) suggests that only L2 learners who are in the automatic component processing stage (i.e., the final stage) have native-like orthographic awareness and process characters via the activation of radical-level information. Future research is needed to examine whether near-native L2 readers are able to decompose characters in a native-like way during online sentence reading.

Additionally, most of the L2 learner participants for the current study were from abugida and alphabetic L1 backgrounds. Further research on L2 learners from other types of L1 orthographies (e.g., abjad) is required to better understand the influence of L1 orthography on L2 character recognition. Other individual differences, such as character learning strategy and language aptitude, were not documented in the present study and thus not included in the analyses. Therefore, future research with detailed background information documentation may be required to determine how individual differences among L2 learners influence the way they process Chinese characters. Moreover, L2 was used as an umbrella term in the current study. Many of the L2 learner participants had studied other languages; Chinese was therefore their L3 or even L4. Future research is required to explore how additional experience in learning other types of orthographies influences the way a reader processes Chinese characters.

Finally, the findings of the current study may also serve as a potentially enlightening new proving ground for examining the relative efficacy on the two currently-debated teaching approaches: Focus-on-Forms (FonFs), where instruction is typically realized in the format of “present-practice-produce” (Ur, 1996), and Focus-on-Form (FonF), where the primary focus is on meaning rather on linguistic form (DeKeyser, 2007; Long, 1996; Shintani, 2013). Future intervention studies are required to investigate the effect of FonFs instruction of phonetic radicals and compare the effects of the FonFs and FonF approaches to teaching Chinese characters.

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Appendix A: Language Background Questionnaire (Native Speakers)

被试背景信息

(对于您所提供的个人信息我们将尊重您的隐私并严格保密)

1. 姓名: _____ 2. 年龄: _____ 3. 性别: _____
4. 出生地点: _____ 省 _____ 市
5. 职业: _____
6. 母语: _____ 方言: _____
7. 您小时候在家说什么语言? _____
8. 您的最高学历: _____
9. 您上学期间的授课语言:
小学: _____
中学: _____
大学: _____
研究生: _____
10. 您在工作时所使用的语言: _____
11. 您会哪些外语? _____
12. 请使用以下量表自评您的外语能力:

外语 1: _____	外语 2: _____	外语 3: _____	外语 4: _____	外语 5: _____
☐ 初级	☐ 初级	☐ 初级	☐ 初级	☐ 初级
☐ 中级	☐ 中级	☐ 中级	☐ 中级	☐ 中级
☐ 高级	☐ 高级	☐ 高级	☐ 高级	☐ 高级

13. 您现在正在学习英语吗? _____ 您学习英语学了多久? _____
14. 您是从几岁开始学习英语的? _____
15. 您是否有过在外国长期居住的经历 (3 个月及以上)? _____

若有, 请具体说明:

时间: _____	地点: _____	目的: _____
时间: _____	地点: _____	目的: _____
时间: _____	地点: _____	目的: _____
时间: _____	地点: _____	目的: _____

Appendix B: Language Background Questionnaire (L2 Learners)

Language Background Questionnaire

A. General Information

1. Sex: ☐ F ☐ M
2. Age: _____
3. Do you have vision or hearing problems? _____
4. University year: _____
5. Major: _____

B. Known Languages and Uses

1. Native language: _____ Dialect: _____
2. Mother's native language: _____ Dialect: _____
3. Father's native language: _____ Dialect: _____
4. Language(s) spoken at home during childhood: _____
5. Language(s) spoken at home during the first five years of your life: _____
6. Country of residence during the first five years of your life: _____
7. Language(s) of instruction during elementary school (content courses): _____
8. Country of residence from 6 to 11 years old: _____
9. Language(s) of instruction during middle and high school (content courses): _____
10. Country of residence from 12 to 17 years old: _____
11. Other foreign language(s) that you know and proficiency levels

Language	Reading	Writing	Speaking	Listening
Chinese	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native
	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native
	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native	☐ Beginner ☐ Intermediate ☐ Advanced ☐ Near-native

12. Weekly use of Chinese and other language(s)

a. % weekly use of Chinese: _____

b. % weekly use of English: _____

c. % weekly use of _____ (language): _____

d. % weekly use of _____ (language): _____ (a-d = 100%)

13. Have you taken the HSK test?

When? _____

Highest certificate level: _____

14. In what language are you the most comfortable at this time? _____

C. Learning of Chinese (learners only)

1. Age of first exposure to Chinese: _____

2. Context of first exposure to Chinese: ☐ At school ☐ Outside school ☐ Both

3. Chinese instruction

a. Number of years of Chinese instruction that you have received: _____

b. Were the majority of your Chinese teachers native speakers of Chinese? ☐ Yes ☐ No

4. Immersion(s) in a Chinese-speaking environment ☐ N/A

a. First immersion

i. Age: _____

ii. Place: _____

iii. Context: _____

iv. Duration: _____ year(s) _____ month(s) _____ week(s)

b. Second immersion

i. Age: _____

ii. Place: _____

iii. Context: _____

iv. Duration: _____ year(s) _____ month(s) _____ week(s)

c. Third immersion

i. Age: _____

ii. Place: _____

iii. Context: _____

iv. Duration: _____ year(s) _____ month(s) _____ week(s)

Appendix C: Chinese Cloze Test

Read the passage and choose the best answers to fill in the blanks.

重返大学校园

我是十年以前从这所大学 (1)_____ 的。昨天是我们学校的百年校庆，所以我回 (2)_____ 看望老师。 (3)_____ 跟老师们聊天以外，我也见到了很多 (4)_____ 。他们毕业以后有的就在这里继续 (5)_____ ，有的去了国外工作。我们见面以后都非常 (6)_____ ，大家脸上都挂着微笑。我们的同学小张现在已经是一位有名的工程师，工作 (7)_____ 忙。不过他坚持 (8)_____ 身体，每天都去跑步。小李看起来倒是不太有精神，因为她得一面工作，一面 (9)_____ 孩子。我也见到了小吴，他以前特别 (10)_____ 打篮球，常常不来上课，也不写 (11)_____ ，所以最后的毕业考试也差点儿没 (12)_____ 。加上这几年来经济不 (13)_____ ，他一直都没找到一份好 (14)_____ 。

我们见面以后第一件事就是去 (15)_____ 王老师。我们都 (16)_____ 过他的日本历史课。十年过去了，王老师的头发都 (17)_____ 了，可是他还是那么 (18)_____ 。

我们的学校变化也非常大，很多地方我们都不 (19)_____ 了，我们都已经找不到以前上课的 (20)_____ 了。我们以前住过的宿舍变成了一幢 (21)_____ 的高楼，我们常去打篮球的运动场也 (22)_____ 了一座很大的体育馆，在里边可以 (23)_____ ，也可以 (24)_____ 。 (25)_____ ，有的地方却一点儿也没变，比如说我们当年最喜欢的中国饭馆。

Please choose the best answer.

- | | | | |
|-----------|-------|-------|-------|
| _____ 1. | A. 工作 | B. 毕业 | C. 学习 |
| _____ 2. | A. 家 | B. 班 | C. 校 |
| _____ 3. | A. 除了 | B. 不但 | C. 非但 |
| _____ 4. | A. 家长 | B. 同学 | C. 孩子 |
| _____ 5. | A. 旅行 | B. 出差 | C. 工作 |
| _____ 6. | A. 高兴 | B. 满足 | C. 伤心 |
| _____ 7. | A. 不太 | B. 没有 | C. 非常 |
| _____ 8. | A. 运动 | B. 锻炼 | C. 保护 |
| _____ 9. | A. 照顾 | B. 体贴 | C. 培育 |
| _____ 10. | A. 希望 | B. 喜欢 | C. 期望 |
| _____ 11. | A. 功课 | B. 课本 | C. 考试 |
| _____ 12. | A. 参加 | B. 过去 | C. 通过 |
| _____ 13. | A. 景气 | B. 萧条 | C. 繁华 |
| _____ 14. | A. 事业 | B. 家庭 | C. 工作 |
| _____ 15. | A. 参观 | B. 拜访 | C. 访问 |
| _____ 16. | A. 上 | B. 看 | C. 讲 |
| _____ 17. | A. 灰 | B. 白 | C. 黑 |
| _____ 18. | A. 康复 | B. 衰老 | C. 精神 |
| _____ 19. | A. 记得 | B. 认识 | C. 识别 |
| _____ 20. | A. 教室 | B. 房间 | C. 房屋 |
| _____ 21. | A. 红火 | B. 长长 | C. 漂亮 |
| _____ 22. | A. 变 | B. 变成 | C. 变化 |
| _____ 23. | A. 学习 | B. 游泳 | C. 看书 |
| _____ 24. | A. 打球 | B. 篮球 | C. 球赛 |
| _____ 25. | A. 总之 | B. 虽然 | C. 不过 |

Appendix D: English Cloze Test

Please fill in the blanks in the following passage. Each blank must have one and only one word.

Joe came home from work on Friday. It was payday, but he wasn't ____1____ excited about it. He knew that ____2____ he sat down and paid his ____3____ and set aside money for groceries, ____4____ for the car and a small ____5____ in his savings account, there wasn't ____6____ much left over for a good ____7____.

He thought about going out for ____8____ at his favorite restaurant, but he ____9____ wasn't in the mood. He wandered ____10____ his apartment and ate a sandwich. ____11____ a while, he couldn't stop himself ____12____ worrying about the money situation. Finally, ____13____ got into his car and started ____14____.

He didn't have a destination in ____15____, but he knew that he wanted ____16____ be far away from the city ____17____ he lived.

He drove into a quiet country ____18____. The country sights made him feel ____19____. His mind wandered as he drove ____20____ small farms and he began to ____21____ living on his own piece of ____22____ and becoming self-sufficient. It had always ____23____ a dream of his, but he ____24____ never done anything to make it ____25____ reality. Even as he was thinking, ____26____ logical side was scoffing at his ____27____ imaginings. He debated the advantages and ____28____ of living in the country and ____29____ his own food. He imagined his ____30____ equipped with a solar energy panel ____31____ the roof to heat the house ____32____ winter and power a water heater. ____33____ envisioned fields of vegetables for canning ____34____ preserving to last through the winter. ____35____ the crops had a good yield, ____36____ he could sell the surplus and ____37____ some farming equipment with the extra ____38____.

Suddenly, Joe stopped thinking and laughed ____39____ loud, "I'm really going to go ____40____ with this?"

Adapted from American Kernel Lessons: Advanced Students' Book. O'Neill, Cornelius and Washburn (1981).

Please choose the best answer.

- | | | | |
|-----------|------------------|----------------|----------------|
| _____ 1. | D. just | E. even | F. more |
| _____ 2. | D. while | E. meanwhile | F. when |
| _____ 3. | D. bills | E. payment | F. expense |
| _____ 4. | D. oil | E. gas | F. cost |
| _____ 5. | D. money | E. payment | F. deposit |
| _____ 6. | D. too | E. just | F. so |
| _____ 7. | D. living | E. life | F. time |
| _____ 8. | D. food | E. dinner | F. diet |
| _____ 9. | D. hardly | E. only | F. just |
| _____ 10. | D. around | E. in | F. at |
| _____ 11. | D. for | E. in | F. after |
| _____ 12. | D. to | E. of | F. from |
| _____ 13. | D. they | E. he | F. she |
| _____ 14. | D. driving | E. drive | F. trip |
| _____ 15. | D. heart | E. mind | F. thought |
| _____ 16. | D. to | E. as to | F. and |
| _____ 17. | D. which | E. where | F. that |
| _____ 18. | D. place | E. path | F. road |
| _____ 19. | D. better | E. worse | F. best |
| _____ 20. | D. away | E. past | F. cross |
| _____ 21. | D. think | E. image | F. imagine |
| _____ 22. | D. field | E. ground | F. land |
| _____ 23. | D. being | E. to be | F. been |
| _____ 24. | D. had | E. has | F. have |
| _____ 25. | D. a | E. the | F. being |
| _____ 26. | A. another | B. his | C. other |
| _____ 27. | A. empirical | B. implausible | C. impractical |
| _____ 28. | A. disadvantages | B. merits | C. defects |
| _____ 29. | A. to raise | B. growing | C. rising |
| _____ 30. | A. farm | B. farmhouse | C. field |
| _____ 31. | A. at | B. to | C. on |
| _____ 32. | A. at | B. throughout | C. in |
| _____ 33. | A. then | B. he | C. in addition |
| _____ 34. | A. also | B. and | C. as well |
| _____ 35. | A. because | B. if | C. since |
| _____ 36. | A. possible | B. maybe | C. likely |
| _____ 37. | A. buy | B. bought | C. to buy |
| _____ 38. | A. money | B. deposit | C. currency |
| _____ 39. | A. out | B. in | C. up |
| _____ 40. | A. over | B. through | C. under |

Appendix E: Materials for Experiment 1

Table 40

Experiment 1: Phonetic-Radical Prime and Target Sets

Item no.	Prime type			Target	
	High-frequency	Low-frequency	Control	Character	Frequency
1	路 <i>lù</i>	辘 <i>lù</i>	咪 <i>mī</i>	各 <i>gè</i>	High
2	环 <i>huán</i>	抔 <i>póu</i>	胜 <i>shèng</i>	不 <i>bù</i>	High
3	他 <i>tā</i>	弛 <i>chí</i>	抓 <i>zhuā</i>	也 <i>yě</i>	High
4	研 <i>yán</i>	岍 <i>qiān</i>	吃 <i>chī</i>	开 <i>kāi</i>	High
5	绪 <i>xù</i>	楮 <i>chǔ</i>	孩 <i>há</i>	者 <i>zhě</i>	High
6	胡 <i>hú</i>	钥 <i>yào</i>	讷 <i>nè</i>	月 <i>yuè</i>	High
7	损 <i>sǔn</i>	坝 <i>xūn</i>	鳄 <i>è</i>	员 <i>yuán</i>	High
8	挥 <i>huī</i>	琿 <i>huī</i>	珑 <i>lóng</i>	军 <i>jūn</i>	High
9	饿 <i>è</i>	钹 <i>é</i>	细 <i>xì</i>	我 <i>wǒ</i>	High
10	江 <i>jiāng</i>	甬 <i>jiāng</i>	汉 <i>hàn</i>	工 <i>gōng</i>	High
11	课 <i>kè</i>	髀 <i>kē</i>	油 <i>yóu</i>	果 <i>guǒ</i>	High
12	法 <i>fǎ</i>	珐 <i>fà</i>	傣 <i>dǎi</i>	去 <i>qù</i>	High
13	给 <i>gěi</i>	袷 <i>jiá</i>	裨 <i>bì</i>	合 <i>hé</i>	High
14	取 <i>qǔ</i>	驭 <i>yù</i>	偎 <i>wēi</i>	又 <i>yòu</i>	High
15	眼 <i>yǎn</i>	赧 <i>yín</i>	话 <i>huà</i>	艮 <i>gěn</i>	Low
16	措 <i>cuò</i>	醋 <i>cù</i>	璜 <i>huáng</i>	昔 <i>xī</i>	Low
17	时 <i>shí</i>	酎 <i>zhòu</i>	蹂 <i>duò</i>	寸 <i>cùn</i>	Low
18	津 <i>jīn</i>	肄 <i>yì</i>	体 <i>tǐ</i>	聿 <i>yù</i>	Low
19	约 <i>yuē</i>	酌 <i>zhuó</i>	城 <i>chéng</i>	勺 <i>sháo</i>	Low
20	作 <i>zuò</i>	阼 <i>zuò</i>	认 <i>rèn</i>	乍 <i>zhà</i>	Low
21	输 <i>shū</i>	膺 <i>shù</i>	塘 <i>táng</i>	俞 <i>yú</i>	Low
22	跃 <i>yuè</i>	袄 <i>ǎo</i>	统 <i>tǒng</i>	夭 <i>yāo</i>	Low
23	执 <i>zhí</i>	孰 <i>shú</i>	决 <i>jué</i>	丸 <i>wán</i>	Low
24	摄 <i>shè</i>	漈 <i>shè</i>	滓 <i>zǐ</i>	聂 <i>niè</i>	Low
25	牌 <i>pái</i>	脾 <i>pí</i>	臆 <i>yì</i>	卑 <i>bēi</i>	Low
26	语 <i>yǔ</i>	龉 <i>yǔ</i>	拮 <i>jié</i>	吾 <i>wú</i>	Low
27	诉 <i>sù</i>	柝 <i>tuò</i>	嗒 <i>dā</i>	斥 <i>chì</i>	Low
28	偶 <i>ǒu</i>	耦 <i>ǒu</i>	很 <i>hěn</i>	禺 <i>yú</i>	Low

Table 41

Experiment 1: Semantic-Radical Prime and Target Sets

Item No.	Prime type			Target	
	High-frequency	Low-frequency	Control	Character	Frequency
1	默 silent	黷 to defile	际 boundary	黑 black	High
2	的 of	皈 to convert	使 to cause	白 white	High
3	验 to check	驳 to refute	经 through	马 horse	High
4	较 to compare	辍 to cease	馍 bun	车 vehicle	High
5	叶 leaf	吋 inch	缮 to repair	口 mouth	High
6	如 if	嫉 envy	捶 to hit	女 female	High
7	确 exact	碌 busy	情 emotion	石 stone	High
8	敏 agile	毓 to nourish	说 to speak	每 every	High
9	程 procedure	稽 to examine	鳗 eel	禾 grain	High
10	施 to execute	於 at	狩 to hunt	方 square	High
11	配 to match	酥 crisp	满 full	酉 evening	Low
12	弥 to overflow	弘 to promote	睡 to sleep	弓 bow	Low
13	龄 age	齧 dirty	政 politics	齿 tooth	Low
14	乱 messy	刮 to scrape	踞 to crouch	舌 tongue	Low
15	赫 bright	赦 to pardon	樟 camphor	赤 red	Low
16	样 shape	枉 in vain	铐 handcuff	木 wood	Low
17	知 to know	矫 to rectify	结 knot	矢 arrow	Low
18	封 to seal	卦 symbol	境 boundary	圭 jade	Low
19	幅 width	幢 building	钠 sodium	巾 towel	Low
20	外 outside	舛 mishap	柑 tangerine	夕 sunset	Low

Appendix F: Materials for Experiment 2

Table 42

Experiment 2: Phonetic-Radical Prime and Target Sets

Item No.	Prime type				Target	
	Character level		Radical level		character	Activation
	Related	Control	Related	Control		
1	卖 <i>mài</i>	其 <i>qí</i>	犊 <i>dú</i>	牯 <i>gǔ</i>	麦 <i>mài</i>	Phonological
2	止 <i>zhǐ</i>	元 <i>yuán</i>	扯 <i>chě</i>	挽 <i>wǎn</i>	指 <i>zhǐ</i>	Phonological
3	寿 <i>shòu</i>	两 <i>liǎng</i>	祷 <i>dǎo</i>	祠 <i>cí</i>	瘦 <i>shòu</i>	Phonological
4	肃 <i>sù</i>	哀 <i>āi</i>	啸 <i>xiào</i>	唉 <i>ài</i>	速 <i>sù</i>	Phonological
5	册 <i>cè</i>	永 <i>yǒng</i>	跚 <i>shān</i>	蹑 <i>niè</i>	策 <i>cè</i>	Phonological
6	末 <i>mò</i>	甲 <i>jiǎ</i>	袜 <i>wà</i>	袍 <i>páo</i>	莫 <i>mò</i>	Phonological
7	川 <i>chuān</i>	上 <i>shàng</i>	驯 <i>xùn</i>	骆 <i>luò</i>	穿 <i>chuān</i>	Phonological
8	辛 <i>xīn</i>	君 <i>jūn</i>	梓 <i>zǐ</i>	桦 <i>huà</i>	新 <i>xīn</i>	Phonological
9	聚 <i>jù</i>	熙 <i>xī</i>	骤 <i>zhòu</i>	驴 <i>lǘ</i>	剧 <i>jù</i>	Phonological
10	骨 <i>gǔ</i>	重 <i>zhòng</i>	猾 <i>huá</i>	獬 <i>jué</i>	鼓 <i>gǔ</i>	Phonological
11	坚 <i>jiān</i>	串 <i>chuàn</i>	铿 <i>kēng</i>	铍 <i>huá</i>	间 <i>jiān</i>	Phonological
12	百 <i>bǎi</i>	亦 <i>yì</i>	陌 <i>mò</i>	隙 <i>xì</i>	摆 <i>bǎi</i>	Phonological
13	带 <i>dài</i>	亲 <i>qīn</i>	滞 <i>zhì</i>	溜 <i>liū</i>	戴 <i>dài</i>	Phonological
14	真 <i>zhēn</i>	袁 <i>yuán</i>	滇 <i>diān</i>	沁 <i>qìn</i>	针 <i>zhēn</i>	Phonological
15	己 <i>jǐ</i>	干 <i>gàn</i>	妃 <i>fēi</i>	妖 <i>yāo</i>	挤 <i>jǐ</i>	Phonological
16	西 <i>xī</i>	并 <i>bìng</i>	晒 <i>shài</i>	旷 <i>kuàng</i>	吸 <i>xī</i>	Phonological
17	定 <i>dìng</i>	隶 <i>lì</i>	绽 <i>zhàn</i>	绚 <i>xuàn</i>	订 <i>dìng</i>	Phonological
18	出 <i>chū</i>	央 <i>yāng</i>	咄 <i>duō</i>	咆 <i>páo</i>	初 <i>chū</i>	Phonological
19	有 <i>yǒu</i>	伞 <i>sǎn</i>	贿 <i>huì</i>	赐 <i>cì</i>	友 <i>yǒu</i>	Phonological
20	参 <i>cān</i>	直 <i>zhí</i>	渗 <i>shèn</i>	淘 <i>táo</i>	餐 <i>cān</i>	Phonological
21	世 <i>shì</i>	右 <i>yòu</i>	泄 <i>xiè</i>	汀 <i>tīng</i>	事 <i>shì</i>	Phonological
22*	兄 <i>xiōng</i>	冉 <i>rǎn</i>	况 <i>kuàng</i>	冷 <i>lěng</i>	弟 brother	Semantic
23*	寸 <i>cùn</i>	亡 <i>wáng</i>	付 <i>fù</i>	借 <i>jiè</i>	尺 ruler	Semantic
24*	呆 <i>dāi</i>	弃 <i>qì</i>	保 <i>bǎo</i>	任 <i>rèn</i>	傻 silly	Semantic
25*	欠 <i>qiàn</i>	氏 <i>shì</i>	坎 <i>kǎn</i>	坑 <i>kēng</i>	缺 lack	Semantic
26*	急 <i>jí</i>	首 <i>shǒu</i>	隐 <i>yǐn</i>	隆 <i>lóng</i>	慢 slow	Semantic
27*	刀 <i>dāo</i>	七 <i>qī</i>	初 <i>chū</i>	袖 <i>xiù</i>	叉 folk	Semantic
28*	犬 <i>quǎn</i>	无 <i>wú</i>	伏 <i>fú</i>	伐 <i>fá</i>	狗 dog	Semantic

Table 42 (cont.)

29*	寺 <i>sì</i>	羽 <i>yǔ</i>	待 <i>dài</i>	得 <i>děi</i>	庙 temple	Semantic
30*	云 <i>yún</i>	爪 <i>zhǎo</i>	坛 <i>tán</i>	堪 <i>kān</i>	雾 fog	Semantic
31*	走 <i>zǒu</i>	豆 <i>dòu</i>	徒 <i>tú</i>	徐 <i>xú</i>	跑 to run	Semantic
32*	争 <i>zhēng</i>	米 <i>mǐ</i>	净 <i>jìng</i>	冰 <i>bīng</i>	斗 to fight	Semantic
33*	先 <i>xiān</i>	竹 <i>zhú</i>	洗 <i>xǐ</i>	泛 <i>fàn</i>	后 later	Semantic
34*	生 <i>shēng</i>	皿 <i>mǐn</i>	姓 <i>xìng</i>	姑 <i>gū</i>	死 to die	Semantic
35*	人 <i>rén</i>	几 <i>jǐ</i>	队 <i>duì</i>	除 <i>chú</i>	兽 animal	Semantic
36*	青 <i>qīng</i>	态 <i>tài</i>	猜 <i>cāi</i>	狼 <i>láng</i>	紫 purple	Semantic
37*	那 <i>nà</i>	而 <i>ér</i>	挪 <i>nuó</i>	抖 <i>dǒu</i>	这 this	Semantic
38*	开 <i>kāi</i>	手 <i>shǒu</i>	研 <i>yán</i>	矿 <i>kuàng</i>	关 to close	Semantic
39*	击 <i>jī</i>	龙 <i>lóng</i>	陆 <i>lù</i>	阶 <i>jiē</i>	打 to hit	Semantic
40*	黄 <i>huáng</i>	麻 <i>má</i>	横 <i>héng</i>	械 <i>xiè</i>	绿 green	Semantic
41*	分 <i>fēn</i>	亢 <i>kàng</i>	盼 <i>pàn</i>	眶 <i>kuàng</i>	离 to depart	Semantic
42*	对 <i>duì</i>	玄 <i>xuán</i>	树 <i>shù</i>	楼 <i>lóu</i>	错 wrong	Semantic

Note. Items with * were adapted from Zhou and Marslen-Wilson (1999c).

Table 43

Experiment 2: Semantic-Radical Prime and Target Sets

Item No.	Prime				Target	
	Character level		Radcial level		Character	Activation
	Related	Control	Related	Control		
1	立 to stand	玉 jade	靖 peaceful	婧 chaste	力 lì	Phonological
2	革 to reform	举 to raise	鞠 to bow	掬 to hold	格 gé	Phonological
3	木 wood	中 middle	楷 model	偕 together	幕 mù	Phonological
4	文 script	互 mutual	斓 colored	澜 wave	闻 wén	Phonological
5	石 stone	半 half	砰 bang	抨 to attack	实 shí	Phonological
6	音 sound	柬 note	韶 beautiful	沼 mud	阴 yīn	Phonological
7	弓 bow	大 big	弭 to quell	俚 next	宫 gōng	Phonological
8	黍 millet	登 to climb	黏 sticky	砧 anvil	鼠 shǔ	Phonological
9	耳 ear	尽 to end	耽 to delay	枕 pillow	尔 ěr	Phonological
10	禾 grain	必 must	稹 careful	缜 thorough	和 hé	Phonological
11	贝 shell	升 to rise	赅 complete	垓 tera	被 bèi	Phonological
12	田 field	业 trade	畸 abnormal	犄 horn	甜 tián	Phonological
13	矛 spear	头 head	矜 pity	衿 belt	毛 máo	Phonological
14	角 corner	夜 night	觚 goblet	弧 curve	搅 jiǎo	Phonological
15*	舟 boat	光 light	舵 helm	鸵 ostrich	粥 zhōu	Phonological
16*	羽 feather	旱 draught	翎 plume	瓴 jar	宇 yǔ	Phonological
17*	骨 bone	唐 surname	髅 bone	镂 to carve	谷 gǔ	Phonological
18*	鹿 deer	翁 old man	麒 unicorn	骐 horse	露 lù	Phonological
19*	目 eye	华 essence	睫 eyelash	婕 a name	牧 mù	Phonological
20*	片 slice	牙 tooth	牍 archive	犊 calf	骗 piàn	Phonological
21*	山 mountain	小 small	峥 steep	狰 hideous	删 shān	Phonological
22	工 work	下 down	巩 to fortify	矾 alum	商 business	Semantic
23	立 to stand	母 female	靖 peaceful	婧 chaste	起 to rise	Semantic
24	革 to reform	举 to raise	鞠 to bow	掬 to hold	改 to change	Semantic
25	文 script	互 mutual	斓 colored	澜 wave	字 character	Semantic
26	音 sound	柬 note	韶 beautiful	沼 mud	响 loud	Semantic
27	至 until	兴 excited	臻 to attain	榛 hazelnut	达 to arrive	Semantic
28	矢 arrow	主 owner	矧 short	铨 to file	箭 arrow	Semantic
29	耳 ear	尽 to end	耽 to delay	枕 pillow	听 to listen	Semantic
30	禾 grain	必 must	稹 careful	缜 thorough	苗 sprout	Semantic

Table 43 (cont.)

31	贝 shell	升 to rise	赅 complete	垓 tera	珠 pearl	Semantic
32	虫 insect	在 at	虹 rainbow	讪 conflict	草 grass	Semantic
33	田 field	业 trade	畸 abnormal	犄 horn	农 farming	Semantic
34	矛 spear	头 head	矜 pity	衿 belt	盾 shield	Semantic
35	木 wood	中 middle	楷 model	偕 together	花 flower	Semantic
36	弓 bow	大 big	弭 to quell	偁 next	射 to shoot	Semantic
37	黍 millet	登 to climb	黏 sticky	砧 anvil	粮 grain	Semantic
38	血 blood	尧 surname	衅 quarrel	绊 to trip	心 heart	Semantic
39	予 to give	太 too	豫 happy	橡 rubber	授 to grant	Semantic
40*	页 page	击 to hit	颅 skull	鸪 gull	纸 paper	Semantic
41*	土 soil	广 vast	墉 wall	慵 weary	泥 mud	Semantic
42*	王 king	风 wind	瑾 gem	槿 hibiscus	冠 crown	Semantic

Note. Items with * were adapted from Zhou et al. (2013).

Appendix G: Materials for Experiment 3

A. Phonological Activation of Phonetic Radicals

1. 我们全家**祝**你新年快乐，每一天都健康快乐。(Cloze probability: 0)
Our family **wishes** you a Happy New Year, each day filled with good health and joy.
在这新春佳节来临之际，我衷心地**祝**你幸福。(Cloze probability: 0.91)
In the spirit of this holiday season, I sincerely **wish** you happiness.
Target: 祝 *zhù*
Radical prime: 兄 *xiōng*
Character-level related prime: 住 *zhù*
Radical-level related prime: 凶 *xiōng*
Control prime: 丑 *chǒu*
2. 请你们先**脱**外套再进去，这是安检部的规定。(Cloze probability: 0)
Please **take off** your jacket before entering; this is a requirement of the security department.
神圣的殿堂内不许穿鞋，进门前请把鞋**脱**了。(Cloze probability: 1)
Shoes are not allowed in the sacred temple; please **take off** your shoes before entering.
Target: 脱 *tuō*
Radical prime: 兑 *duì*
Character-level related prime: 拖 *tuō*
Radical-level related prime: 队 *duì*
Control prime: 什 *shén*
3. 他不小心**撞**了一辆汽车，所以被警察带走了。(Cloze probability: 0)
He accidentally **hit** a car and was thus taken by the police.
他在十字路口闯了红灯，结果被一辆车**撞**了。(Cloze probability: 1)
He jaywalked at the intersection and was **hit** by a car.
Target: 撞 *zhuàng*
Radical prime: 童 *tóng*
Character-level related prime: 状 *zhuàng*
Radical-level related prime: 同 *tóng*
Control prime: 问 *wèn*
4. 即使没有**醋**也没关系的，可以用柠檬汁代替。(Cloze probability: 0)
If you do not have **vinegar**, you can use lemon juice instead.
想让鱼的味道酸酸甜甜，加糖和一勺**醋**就行。(Cloze probability: 0.82)

If you want to cook sweet and sour fish, you will need to add sugar and **vinegar**.

Target: 醋 *cù*

Radical prime: 昔 *xī*

Character-level related prime: 促 *cù*

Radical-level related prime: 西 *xī*

Control prime: 并 *bìng*

5. 如果觉得**滑**就别继续走，这种天爬山很危险。(Cloze probability: 0)

Just stop hiking if it is **slippery**; it is dangerous to climb the mountain in such weather.

因为积雪已经结成冰块，路变得很**滑**很危险。(Cloze probability: 0.75)

As the snow had turned into ice, the road became very **slippery** and dangerous.

Target: 滑 *huá*

Radical prime: 骨 *gǔ*

Character-level related prime: 华 *huá*

Radical-level related prime: 鼓 *gǔ*

Control prime: 瑞 *ruì*

6. 如果是你**掉**了钱包手机，你也一定会着急的。(Cloze probability: 0)

If you had **lost** your wallet and phone, you would be worried too.

化疗之后他显得很虚弱，头发也已都**掉**光了。(Cloze probability: 0.77)

After the chemotherapy, he looked very weak and had **lost** most of his hair.

Target: 掉 *diào*

Radical prime: 卓 *zhuó*

Character-level related prime: 吊 *diào*

Radical-level related prime: 浊 *zhuó*

Control prime: 缸 *gāng*

7. 如果孩子**咳嗽**就得吃药，否则会越来越严重。(Cloze probability: 0)

If the child starts **coughing** he will need to take medicine; otherwise, it will only get worse.

他最近得了严重的肺炎，上课时一直在**咳嗽**。(Cloze probability: 0.94)

He was seriously ill with pneumonia and was **coughing** the whole time during class.

Target: 咳 *ké*

Radical prime: 亥 *hài*

Character-level related prime: 壳 *ké*

Radical-level related prime: 害 *hài*

Control prime: 留 *liú*

8. 他喜欢吃**辣**的或者甜的，不喜欢吃酸的食物。(Cloze probability: 0)
 He likes **spicy** food and sweets, but does not like sour food.
 他从小是在四川长大的，所以很喜欢吃**辣**的。(Cloze probability: 0.91)
 He grew up in Sichuan province and thus really likes to eat **spicy** food.
 Target: 辣 *là*
 Radical prime: 束 *shù*
 Character-level related prime: 腊 *là*
 Radical-level related prime: 术 *shù*
 Control prime: 尔 *ěr*
9. 即使我们**输**了这场比赛，我也不会太难过的。(Cloze probability: 0)
 Even if we **lose** this game, I will not be too sad.
 其实重要的是坚持到底，是赢是**输**并不重要。(Cloze probability: 0.83)
 Actually never giving up is what matters; it is not that important whether we win or **lose**.
 Target: 输 *shū*
 Radical prime: 俞 *yú*
 Character-level related prime: 书 *shū*
 Radical-level related prime: 鱼 *yú*
 Control prime: 卷 *juàn*
10. 她不但买**鞋**买了好几双，裤子也买了五六条。(Cloze probability: 0)
 She not only bought several **shoes**, but also bought a couple pants.
 下个月就要参加婚礼了，得买一双新**鞋**才行。(Cloze probability: 0.82)
 I will attend a wedding next month, so I need to buy a pair of new **shoes**.
 Target: 鞋 *xié*
 Radical prime: 圭 *guī*
 Character-level related prime: 斜 *xié*
 Radical-level related prime: 归 *guī*
 Control prime: 付 *fù*
11. 虽然我们**借**了一些餐具，但是还是不太够用。(Cloze probability: 0)
 Even though we **borrowed** some utensils, there were still not enough.
 因为他们买不到这本书，只好向图书馆**借**了。(Cloze probability: 0.91)
 Because they were unable to buy this book, they had to **borrow** it from the library.
 Target: 借 *jiè*
 Radical prime: 昔 *xī*
 Character-level related prime: 届 *jiè*

Radical-level related prime: 西 *xī*

Control prime: 并 *bìng*

12. 如果想再续一个月也行，但是要及时通知我。(Cloze probability: 0)

It is okay if you want to **renew** it for one more month, but you have to let me know.

目前租期是到今年三月，如果想再续也可以。(Cloze probability: 0.75)

The current lease will expire in March this year, but you will be able to **renew** it.

Target: 续 *xù*

Radical prime: 卖 *mài*

Character-level related prime: 序 *xù*

Radical-level related prime: 麦 *mài*

Control prime: 启 *qǐ*

B. Semantic Activation of Phonetic Radicals

13. 他没见过驴也没见过马，不知道两者的区别。(Cloze probability: 0)

He has never seen a **donkey** or a horse and does not know the difference.

动物界也有很多混血儿，骡就是马和驴生的。(Cloze probability: 1)

There are many hybrids in the animal kingdom; for example, a mule is the offspring of a horse and **donkey**.

Target: 驴 donkey

Radical prime: 户 household

Character-level related prime: 骑 to ride

Radical-level related prime: 家 family

Control prime: 高 tall

14. 他们家的狗又跑了出来，在外面到处乱逛呢。(Cloze probability: 0)

Their **dog** has escaped again; it's running around right now.

他求妈妈给他买只宠物，无论是猫是狗都行。(Cloze probability: 0.92)

He begs his mom to buy a pet for him, regardless if it is a cat or a **dog**.

Target: 狗 dog

Radical prime: 句 sentence

Character-level related prime: 猫 cat

Radical-level related prime: 词 word

Control prime: 状 shape

15. 然后他就吹了那些蜡烛，还许了一个愿望呢。(Cloze probability: 0)

Then he **blew** the candles and made a wish.

他刚挂好衣服就起了风，衣服都被风吹走了。(Cloze probability: 0.73)

Right after he hung the clothes up, the wind started and **blew** the clothes away.

Target: 吹 to blow

Radical prime: 欠 to owe

Character-level related prime: 刮 to blow

Radical-level related prime: 债 debt

Control prime: 晓 dawn

16. 他觉得很**醇**口感也很好，所以就买了好几瓶。(Cloze probability: 0)

He thought it was very **smooth** and refined, so he bought several bottles.

这家酒铺是百年老字号，酿的酒又香又**醇**的。(Cloze probability: 0.92)

This distillery has a long history; their liquor has a fragrant nose and is very **smooth**.

Target: 醇 smooth (used to describe alcohol)

Radical prime: 享 to enjoy

Character-level related prime: 酒 alcohol

Radical-level related prime: 用 to use

Control prime: 主 owner

17. 这个人被**砍**得血肉模糊，送到医院也救不活。(Cloze probability: 0)

The man was **chopped** and bleeding badly; he may not make it even we send him to the hospital.

他们走到这棵大树跟前，用斧子把树给**砍**了。(Cloze probability: 1)

They walked to the tree and **chopped** it down with an axe.

Target: 砍 to chop

Radical prime: 欠 to owe

Character-level related prime: 劈 to chop

Radical-level related prime: 债 debt

Control prime: 晓 dawn

18. 听说小李**瞎**了眼睛以后，我们大家难过极了。(Cloze probability: 0)

After hearing that Xiao Li's eyes had become **blind**, we were all very sad.

他的耳朵早就已经聋了，事故后眼睛也**瞎**了。(Cloze probability: 0.83)

His ears had been deaf for a long time, and after the accident, his eyes became **blind**.

Target: 瞎 blind

Radical prime: 害 to harm

Character-level related prime: 盲 blind

Radical-level related prime: 伤 to hurt

Control prime: 刘 surname

19. 如果你想**射**那几只小鸟，就得抓紧时间开始。(Cloze probability: 0)

If you want to **shoot** those birds, you need to start as soon as possible.

看到大雁后他拉开弓箭，向那只鸟**射**了出去。(Cloze probability: 0.91)

After seeing the goose, he drew his bow and **shot** an arrow towards the bird.

Target: 射 to shoot

Radical prime: 寸 a unit of length

Character-level related prime: 弹 bullet

Radical-level related prime: 尺 a unit of length

Control prime: 韦 leather

20. 我们并不**怪**他们太粗心，只是感到非常惋惜。(Cloze probability: 0)

We do not **blame** them for being careless, but just feel that it was such a pity.

这次他真的是尽了全力，所以我完全不**怪**他。(Cloze probability: 0.71)

This time he had tried his best, so I do not **blame** him at all.

Target: 怪 to blame/strange

Radical prime: 圣 sacred

Character-level related prime: 奇 strange

Radical-level related prime: 神 deity

Control prime: 持 to hold

21. 如果觉得**软硬**刚好的话，我们就买这张床吧！(Cloze probability: 0)

If you do not think it is too **soft** or too hard, we will just go ahead and buy this bed.

看到女孩这样哭着求他，他的心顿时就**软**了。(Cloze probability: 0.73)

Seeing the girl begging him with tears, his immediately **softened** and changed his mind.

Target: 软 soft

Radical prime: 欠 to owe

Character-level related prime: 柔 soft

Radical-level related prime: 债 debt

Control prime: 晓 dawn

22. 想要用草**搓**绳子很容易，我可以教你怎么做。(Cloze probability: 0)

It is quite easy to **twist** this grass into ropes, and I can teach you how to do it.

他在手心呼了一口热气，来回**搓**了好几十下。(Cloze probability: 0.8)

He blew into his hands and **twisted** his hands several times to warm up.

Target: 搓 to twist
Radical prime: 差 bad
Character-level related prime: 捏 to knead
Radical-level related prime: 坏 bad
Control prime: 吨 ton

23. 他的这个**错**是很严重的，我应该很难原谅他。(Cloze probability: 0)
His **mistake** was actually very serious, and it might be difficult for me to forgive him.
事实上没有人是完美的，总都有犯**错**的时候。(Cloze probability: 0.75)
In reality, no one is perfect, and everyone makes **mistakes**.

Target: 错 mistake
Radical prime: 昔 the past
Character-level related prime: 误 mistake
Radical-level related prime: 旧 old
Control prime: 叶 leaf

24. 在决定了**辞**去工作以后，我再也不怕老板了。(Cloze probability: 0)
After deciding to **leave** the job, I was no longer afraid of my boss.
他实在受不了这个老板，决定辞了这个工作。(Cloze probability: 0.88)
He really could not stand the boss anymore and decided to **leave** the job.

Target: 辞 to quit
Radical prime: 辛 spicy
Character-level related prime: 别 to leave
Radical-level related prime: 辣 spicy
Control prime: 谭 surname

C. Phonological Activation of Semantic Radicals

25. 他们把窗**封**得严严实实，然后把门也关上了。(Cloze probability: 0)
They **closed** the windows and then shut the door.
由于能见度实在太低了，高速公路都被**封**了。(Cloze probability: 0.83)
Because of extremely low visibility, the highway was **closed**.

Target: 封 *fēng*
Radical prime: 圭 *guī*
Character-level related prime: 风 *fēng*
Radical-level related prime: 归 *guī*
Control prime: 付 *fù*

26. 如果缺少**酶**就会有问题，并且引起过敏反应。(Cloze probability: 0)

A lack of **enzymes** will cause health problems and allergies.

有些人喝了牛奶会不适，是缺消化**酶**的缘故。(Cloze probability: 0.56)

Some people cannot digest milk, which is usually caused by a lack of digestive **enzymes**.

Target: 酶 *méi*

Radical prime: 酉 *yǒu*

Character-level related prime: 没 *méi*

Radical-level related prime: 有 *yǒu*

Control prime: 在 *zài*

27. 虽然收的**税**比以前多了，工资却没有涨多少。(Cloze probability: 0)

Even though **taxes** have increased, salaries remained more or less the same.

当地政府修改政策之后，征收的**税**不再退还。(Cloze probability: 0.62)

After the local government revised the policies, they no longer refunded **taxes**.

Target: 税 *shuì*

Radical prime: 禾 *hé*

Character-level related prime: 睡 *shuì*

Radical-level related prime: 河 *hé*

Control prime: 构 *gòu*

28. 他买了一**磅**苹果和草莓，打算做个水果拼盘。(Cloze probability: 0)

He bought a **pound** of apples and strawberries and planned to make a fruit salad.

英国的长度单位是英寸，重量则是**磅**和盎司。(Cloze probability: 0.42)

The British units of length include inch, and the units of weight include **pound** and ounce.

Target: 磅 *bàng*

Radical prime: 石 *shí*

Character-level related prime: 棒 *bàng*

Radical-level related prime: 时 *shí*

Control prime: 但 *dàn*

29. 他觉得太**酷**了想要模仿，但是被老师制止了。(Cloze probability: 0)

He thought that it was really **cool** and wanted to do the same, but was stopped by the teacher.

他们戴着墨镜穿着风衣，看起来很**酷**的样子。(Cloze probability: 0.42)

They were wearing sunglasses and stylish coats and looked really **cool**.

Target: 酷 *kù*

Radical prime: 酉 *yǒu*

Character-level related prime: 裤 kù

Radical-level related prime: 有 yǒu

Control prime: 在 zài

30. 如果汤太稠也可以加水，最后再加一点儿盐。(Cloze probability: 0)

If the soups turns too **thick**, you can add a bit more water and some salt.

在勾芡的时候放入淀粉，汤汁就会变稠许多。(Cloze probability: 0.33)

If you add some starch to the soup, it will become much **thicker**.

Target: 稠 chóu

Radical prime: 禾 hé

Character-level related prime: 愁 chóu

Radical-level related prime: 河 hé

Control prime: 构 gòu

31. 女孩子太黏人了不太好，还是应该独立一点。(Cloze probability: 0)

It is not good for girls to become too **sticky (dependent)**; they should still be independent.

尽管很热我却不能洗澡，浑身都又湿又黏的。(Cloze probability: 0.38)

Even though it was very hot, I was unable to take a shower and felt really **sticky** and sweaty.

Target: 黏 nián

Radical prime: 黍 shǔ

Character-level related prime: 年 nián

Radical-level related prime: 鼠 shǔ

Control prime: 慈 cí

32. 他们不发帖只喜欢潜水，所以被称为潜水党。(Cloze probability: 0)

They do not write any **posts** but only like to lurk, and are thus called lurkers.

听说网站不但警告他了，还删掉他发的帖了。(Cloze probability: 0.42)

I heard that the website not only warned him but also deleted his **posts**.

Target: 帖 tiē

Radical prime: 巾 jīn

Character-level related prime: 铁 tiě

Radical-level related prime: 今 jīn

Control prime: 书 shū

33. 这种饼很酥而且不太甜，我们都特别喜欢吃。(Cloze probability: 0)

This kind of cookie will **melt** in your mouth and is not too sweet; we all really like it.

听到她说了我爱你以后，张明连骨头都酥了。(Cloze probability: 0.75)

After hearing her saying “I love you,” Zhang Ming felt that his bones had **melted** away.

Target: 酥 *sū*

Radical prime: 酉 *yǒu*

Character-level related prime: 苏 *sū*

Radical-level related prime: 有 *yǒu*

Control prime: 在 *zài*

34. 如果你想刮掉这种油漆，就得用特制的刀片。(Cloze probability: 0)

If you want to **scrape** off the paint, you will need to use a special knife.

不仅雪已经越下越大了，风也越刮越猛了呢。(Cloze probability: 0.62)

Not only did the snow get stronger, the wind also started to **blow** stronger.

Target: 刮 *guā*

Radical prime: 舌 *shé*

Character-level related prime: 瓜 *guā*

Radical-level related prime: 蛇 *shé*

Control prime: 堵 *dǔ*

35. 这种红酒配牛排很好吃，但是价格非常昂贵。(Cloze probability: 0)

This kind of wine is a good **match** with steaks, but it's very expensive.

颜色的组合其实很重要，比如红就应该配绿。(Cloze probability: 0.53)

Color combinations are quite important; for example, red should be **matched** with green.

Target: 配 *pèi*

Radical prime: 酉 *yǒu*

Character-level related prime: 佩 *pèi*

Radical-level related prime: 有 *yǒu*

Control prime: 在 *zài*

36. 这件衣服破了好几个洞，已经完全不能穿了。(Cloze probability: 0)

This piece of clothing is **broken** with holes; you cannot wear it anymore.

他说中国经济正在下滑，房产泡沫就要破了。(Cloze probability: 0.75)

He said that Chinese economy was sliding, and that the realty bubble was about to **break**.

Target: 破 *pò*

Radical prime: 石 *shí*

Character-level related prime: 迫 *pò*

Radical-level related prime: 时 *shí*

Control prime: 但 *dàn*

D. Semantic Activation of Semantic Radicals

37. 其实可以**租**一辆越野车，然后开车去那里玩。(Cloze probability: 0)

You can just **rent** an SUV, and then drive there for a trip.

如果旅行时需要照相机，可买或借或**租**一台。(Cloze probability: 0.92)

If you need a camera for your trip, you can just buy, borrow, or **rent** one.

Target: 租 to rent

Radical prime: 禾 grain

Character-level related prime: 借 to borrow

Radical-related prime: 苗 sprout

Control prime: 岩 rock

38. 其实他不**矮**而且也不胖，身材还是很不错的。(Cloze probability: 0)

He is actually not **short** or over-weight, and is in good shape.

这份工作对身高没要求，无论是高是**矮**都行。(Cloze probability: 1)

This job has no requirement regarding body height; whether tall or **short** does not matter.

Target: 矮 short

Radical prime: 矢 arrow

Character-level related prime: 短 short

Radical-related prime: 箭 arrow

Control prime: 慰 to comfort

39. 请把行李**称**一下再进去，否则您就不能登机。(Cloze probability: 0)

Please **weigh** your luggage before entering; otherwise, you will not be allowed to board.

如果你想知道它的重量，就用秤来**称**一下吧！(Cloze probability: 0.92)

If you want to know how heavy it is, you should just take a scale and **weigh** it.

Target: 称 to weigh

Radical prime: 禾 grain

Character-level related prime: 量 to measure

Radical-related prime: 苗 sprout

Control prime: 岩 rock

40. 房子非常**乱**而且非常脏，大概好久没打扫了。(Cloze probability: 0)

The house was very **messy** and dirty; it seemed that it had not been cleaned for a long time.

他们用完以后没有整理，到处都又脏又乱的。(Cloze probability: 0.89)

They did not cleaning up after using the room; it's dirty and **messy** everywhere.

Target: 乱 messy

Radical prime: 舌 tongue

Character-level related prime: 混 chaotic

Radical-related prime: 口 mouth

Control prime: 己 self

41. 我们买了**糖**和很多水果，希望孩子们会喜欢。(Cloze probability: 0)

We bought **candies** and fruits, hoping that the kids would like them.

听说孩子很喜欢吃甜食，他就带了几颗**糖**去。(Cloze probability: 0.83)

He heard that the kids really liked sweets, so he brought some **candies** with him.

Target: 糖 candy

Radical prime: 米 rice

Character-level related prime: 甜 sweet

Radical-related prime: 饭 rice

Control prime: 补 to supplement

42. 如果买个**秤**来记录体重，也许减肥就能成功。(Cloze probability: 0)

If I buy a **scale** and record my weight, maybe I will successfully lose some weight.

可是他总是分得很清楚，心中像有杆**秤**似的。(Cloze probability: 0.69)

However, he has always been very fair, as if there was a **scale** inside him.

Target: 秤 scale

Radical prime: 禾 grain

Character-level related prime: 测 to measure

Radical-related prime: 苗 sprout

Control prime: 岩 rock

43. 融化了的**蜡**滴在桌子上，他怎么擦也擦不掉。(Cloze probability: 0)

The melted **wax** dripped on the table; he couldn't clean it no matter how hard he tried.

保养这种地板非常简单，抹上一层**蜡**就行了。(Cloze probability: 0.54)

It's very easy to care for this type of hardwood floor; all you need to do is **waxing** it.

Target: 蜡 wax

Radical prime: 虫 insect

Character-level related prime: 烛 candle

Radical-related prime: 爬 to crawl

Control prime: 迪 to guide

44. 他觉得太**糟**了太失败了，所以才想要自杀的。(Cloze probability: 0)

He felt **terrible** and thought that he was a loser, so he decided to commit suicide.

我一下子丢了这么多钱，心情实在是太糟了！(Cloze probability: 0.44)

Because I lost so much money, I was feeling **terrible**.

Target: 糟 terrible

Radical prime: 米 rice

Character-level related prime: 烂 rotten

Radical-related prime: 饭 rice

Control prime: 补 to supplement

45. 桌子上也积了厚厚的灰，看来很久没人住了。(Cloze probability: 0)

There was a thick layer of dust **accumulated** on the desk; it seemed that the room had been empty for a long time.

这里的排水系统很落后，一下雨路上就积水。(Cloze probability: 0.67)

The drainage system is very backwards here; whenever it rains, water will **accumulate** on the roads.

Target: 积 to accumulate

Radical prime: 禾 grain

Character-level related prime: 集 to gather

Radical-related prime: 苗 sprout

Control prime: 岩 rock

46. 他买了一幅画送给老师，还写了一张感谢卡。(Cloze probability: 0)

He bought a **piece** painting for the teacher and wrote a thank-you card.

如果喜欢这些书画作品，你可以买一幅带走。(Cloze probability: 0.45)

If you like these art works, you can buy a **piece** to take home.

Target: 幅 piece (classifier for paintings)

Radical prime: 巾 towel

Character-level related prime: 画 painting

Radical-related prime: 布 cloth

Control prime: 史 history

47. 尽管他曾稳坐销售冠军，现在他已被开除了。(Cloze probability: 0)

Even though he was the **solidly** the sales champion, he has already been fired.

喝了酒以后他觉得头晕，连走路也走不稳了。(Cloze probability: 0.92)

After drinking, he felt dizzy and couldn't even walk **steadily**.

Target: 稳 solid/steady

Radical prime: 禾 grain

Character-level related prime: 定 stable

Radical-related prime: 苗 sprout

Control prime: 岩 rock

48. 虽然有点短但是很精彩，总之很推荐这本书。(Cloze probability: 0)

Even though it was **short**, it was fascinating; I highly recommend this book.

大家可以把评论发给我，无论是长是短都行。(Cloze probability: 1)

You can send me your comments, whether it is long or **short** does not matter.

Target: 短 short

Radical prime: 矢 arrow

Character-related prime: 矮 short

Radical-related prime: 箭 arrow

Control prime: 慰 to comfort