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L2 Chinese character recognition: Exploring the developmental patterns and benefits of radical awareness training via lexical decision priming tasks

Thesis presented by

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for the degree of

Doctor of Philosophy

University College Cork

Asian Studies

Head of School/Department: Prof. Kiri Paramore

Supervisor(s): Dr. Carlotta Sparvoli, Dr. Till Weingartner

March 2022

SIGNED DECLARATION

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Signature: Yun Zeng

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I would also like to thank Kiri for his invaluable direction. A special thanks goes out to Till, for his responsive and continued support.

Last but not least, I would like to thank my family for their love and support.

ABSTRACT

Due to the features of the Chinese writing system, character reading is a challenging task for L2 learners with an alphabetic background. In the field of Chinese character acquisition, numerous studies (Feldman and Siok 1999; Zhou and Marslen-Wilson 2000; William and Bever 2010; Wu *et al*. 2012; Zhou *et al*. 2013; Yeh *et al*. 2017; Tong *et al.* 2021) focus on the process of L1 character recognition and, to a far less extent, on L2 learners' character decoding (Williams 2013). However, the development of L2 character processing patterns has not yet been singled out. This research is intended to contribute to this endeavour by outlining developmental stages of the intermediate and advanced level. The goal is to identify the patterns of L2 learners' character processing at these two proficiency levels and compare them to the processing pattern activated by L1 readers. The study also aims to explore the modelling effect of a radical awareness training. The prediction is that (a) by increasing the knowledge of the semantic and phonetic information carried by character subcomponents, L2 learners can develop a more native-like word recognition pattern, and (b) that such improvement is also conditioned by L2 learners' proficiency level. The method employed is a lexical decision task based on the (semantic or phonological) activation of primes on target characters at the lexical and sublexical levels.

The present study analyses the process of visual character recognition by an experimental group of 29 L2 learners (13 in the critical group and 16 in the pilot group), compared to the performance of 37 native speakers (the control group), via priming experiments based on a set of 336 pairs of prime and target characters. The cycle test includes four stages of an average span of 10 days, including one week of formal Chinese study (about 18 hours) in between two priming tests. The second test is a repetition of the first test. More specifically, the cycle test consists of a radical knowledge test (only for L2 groups), the first priming experiment (for both L1 and L2 groups), a radical awareness training and the second priming experiment (only for the L2 critical group). The statistical significance of the data has been primarily calculated using the t-Test.

Concerning the control group of native speakers, the data are consistent with previous literature and show that (i) they read single characters at about the same speed as compound characters; (ii) the default processing is associated with the semantic information retrieval; (iii) semantic radicals are prioritised over phonetic radicals.

Compared to the native speakers, intermediate learners displayed a different processing pattern and advanced learners displayed a similar processing pattern showing a developmental

trend: (iv) intermediate learners read single characters faster than compound characters while advanced learners read them at a similar speed to native speakers; (v) intermediate learners used more phonological strategy than semantic strategy while advance learners prioritised the semantic strategy like native speakers; (vi) intermediate learners read phonetic radicals faster than semantic radicals while advanced learners read semantic radicals faster and closer to native speakers; hence, (vii) the degree of similarity to the native speakers' pattern increases with the level of proficiency. Lastly, (viii) the Radical Awareness Training contributes to a more native-like processing at the sublexical level for both intermediate and advanced learners. In sum, it proves a shift from phonological- and phonetic-radical- oriented processing to semantic- and semantic-radical- oriented processing. This shift took place during the third year of formal Chinese study (between 240-360 hours). The data has shown that L2 character recognition is a developing and modifiable process.

As for pedagogical implications, the research has also proven that class instruction and individual study, even for a relatively short period, can speed up the development of character processing towards a more efficient, native-like pattern. In addition, the overall results have suggested the importance of formal instruction on sublexical decomposition. They also indicate the importance of presenting the phonetic information carried by the subcomponents rather than limiting the scope to their semantic value, as typically done in classroom activities on radicals.

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Abbreviations

CA:	Correct Answer
CF:	Character frequency
CL:	Character level/sublexical level
CLB:	Common Lexical Base
CLevel:	Character level
CS:	Character stroke
CSL/L2:	Chinese as a foreign or second language
DR:	Dual-route
DRC:	Dual-route cascaded
ERP:	Event-related potential
IA:	Interactive activation
LDT:	Lexical decision task
MS:	Millisecond
PDP:	Parallel Distributed Processing
PH-NONRL:	(Character level) phonologically non-related
PH-RL (CL-PH-RL):	(Character level) phonologically related
PR-PH-NONRL:	Phonetic radical phonologically non-related
PR-PH-RL:	Phonetic radical phonologically related
PR-SE-NONRL:	Phonetic radical semantically non-related
PR-SE-RL:	Phonetic radical semantically related
PR:	Phonetic radical(s)
RA:	Radical awareness
RF:	Radical frequency
RK:	Radical knowledge
RL:	Related
RLevel:	Radical level
RS:	Radical stroke
RT:	Reaction times
SE-NONRL:	(Character level) Semantically non-related
SE-RL (CL-SE-RL):	(Character level) Semantically related
SLA:	Second Language Acquisition
SOA:	Stimulus onset asynchrony
SR-PH-NONRL:	Semantic radical phonologically non-related
SR-PH-RL:	Semantic radical phonologically related
SR-SE-NONRL:	Semantic radical semantically non-related
SR-SE-RL:	Semantic radical semantically related
SR:	Semantic radical(s)
WR:	Word recognition

CHAPTER 1: INTRODUCTION AND BACKGROUND

Due to the features of the Chinese writing system, character reading by L2 learners is remarkably challenging, and even more so when the learners' L1 relies on an alphabetic writing system. To shed light on how characters should best be taught and point out suitable strategies for achieving maximised learning outcomes, a functional theory on character decoding is in order.

Notwithstanding the numerous attempts to outline a comprehensive model, previous studies on L2 character recognition were mainly concerned with identifying the specific role played by the different component types of a character (namely, *semantic* vs *phonetic radicals*). As a result, these attempts only focus on comparing salient and non-salient components, describing the different types of *activation* (namely semantic vs phonetic) triggered at the lexical and sublexical levels by different pairs of primes and targets. For example, at the character level, the prime 目 *mù* 'eye' semantically activates the recognition of the target 看 *kàn* 'to see' ('eye' vs 'to see'), while the prime 弓 *gōng* 'bow' phonologically activates the target 公 *gōng* 'public, duke'. As shown in section 5.3.3, by combining each pair with two types of activation (semantic vs phonological), and at two levels (lexical vs sublexical), six different types of activation are found.

Few studies to date have investigated all these different types of activations in a combined experimental design, and none, to my knowledge, directly compares the responses of L1 and L2 groups or of L2 groups with different proficiencies. Also, little is known regarding if or how a training on semantic and phonetic radicals can 'model' the strategies employed by L2 learners towards a more native-like pattern. In sum, the correlation between *radical knowledge* and the different types of activation at the lexical and sublexical levels has been so far largely ignored in previous research on L2 character processing.

Finally, most of the relevant research in Chinese reading has been carried out in the areas of theoretical linguistics, applied linguistics and psycholinguistics independently, without trying to bridge these interrelated fields. The present thesis adopts a multidisciplinary approach to study L2 learning mechanisms of college students and to devise a more efficient teaching method of Chinese characters at intermediate and advanced levels. In light of such a multidisciplinary approach, this research includes a typological analysis of the Chinese writing system (focusing on its internal logic and minimal constituents), a survey of the theories and issues from a psycholinguistic perspective, an empirical study based on prime tests, and finally ends with the pedagogical implication.

Particular attention is dedicated to the issues related to word recognition (WR) of Chinese characters and the different processes activated by L1 readers and L2 learners of intermediate and advanced levels of Chinese. A cycle test has been conducted to investigate the semantic and phonological processing of visual character recognition, which includes: (a) a radical knowledge test only for L2 participants; (b) the first priming experiment for both L1 and L2 participants, (c) a radical awareness training for only L2 participants and (d) the second priming experiment only for L2 participants.

1.1 The scope and the goal of the research

1.1.1 Scope

The scope of this study is Chinese character recognition by native speakers and European learners in third-level education.

1.1.2 Goal

This study aims to investigate how Chinese characters are processed by native speakers and L2 learners. Specifically, the goal of the first priming experiment is to investigate how semantic and phonetic radicals, and how semantic and phonological information of radicals are activated in L1 and L2 character recognition; the goal of the second priming experiment is to explore the effect of a balanced radical awareness training on L2 character recognition.

1.1.3 Significance of the study

The current study contributes to the understanding of Chinese character processing in the following ways. By explaining the success of Chinese native readers, this study identifies the reading strategies that are most effective for the Chinese writing systems. The identification of character recognition patterns of native speakers and L2 learners at different developmental stages will contribute to a better understanding of the development of L2 learners in visual character recognition. This study will also contribute to understanding how explicit radical instructions and exercises help L2 learners apply more effective strategies in character reading. Additionally, this study will build up the relationship between the existing radical knowledge and developmental patterns for L2. Finally, this study will provide empirical evidence to support theoretical word recognition models that specifically account for Chinese writing.

1.1.4 Research questions

The study aimed to address the following research questions and sub-questions concerning the character recognition process:

Q. 1 Compared to native speakers, how do L2 learners access the functional properties of radicals?

- Q.1.1 For native speakers. which type of functional (semantic or phonological) properties is more critical?
- Q.1.2 For learners with two years of learning experience, which type of functional (semantic or phonological) properties is more critical?
- Q.1.3 For learners with three years of learning experience, which type of functional (semantic or phonological) properties is more critical?

Q. 2 Compared to native speakers, how do L2 learners access the two types of radicals?

- Q. 2.1 For native speakers. which type of radical (semantic or phonetic) is more prioritised?
- Q. 2.2 For learners with two years of learning experience, which type of radical (semantic or phonetic) is more prioritised?
- Q. 2.3 For learners with three years of learning experience, which type of radical (semantic or phonetic) is more prioritised?

Q. 3 How does a radical awareness training influence L2 character recognition?

1.1.5 Structure

After the outline of the scope and goal of the study, the following section in this chapter present the background of this study, namely, the most common typological classification of the different writing systems, the findings on the Chinese writing system, referring them to the general issue of Word Recognition (WR).

The following chapters address the following topics:

Chapter 2 provides the psycholinguist account on word recognition and introduces the basic methods and findings in the area of psycholinguistics, also briefly presenting the WR models developed for alphabetic writing systems.

Chapter 3 focuses on the phenomena related to the Chinese writing system and WR, with particular attention to the Phonological Mediation Hypothesis, also discussing the literature on the speech representation at the syllable level.

Chapter 4 addresses the issues on Chinese sublexical processing and presents a literature review on the priming effect as the base of the present empirical research.

Chapter 5 presents the empirical study: the research method, the groups, the test cycle and the data collection.

Chapter 6 provides the data analysis and presents findings from the radical knowledge test.

Chapter 7 includes the discussion on the main findings from the priming tasks and their pedagogical implications.

1.2 A typological classification of writing systems

Compared to spoken language as a fundamental phenomenon, written languages have been used for a short period of human history and are relatively recent. However, because of the convenience in studying written words and the value of literacy as a crucial feature of modern civilisation, a great deal of research has been focussed on visual word recognition (from now on WR). The written language is beneficial, and studying it should have critical implications for teaching Chinese as a second language.

Chinese is typically referred to as the most phonologically 'deep' orthography, and the writing system with the most arbitrary spelling correspondence. Since there is no '1-to-1' correspondence between sign and sound, it is easy to assume that reading Chinese characters involves only the meaning-based writing system. In WR, it resorts to the direct route from graphic input to meaning. However, in the literature, it is accepted that more than 80% of characters consist of phonetic compounds, each of which is composed of semantic and phonological units that do not regularly contribute to the phonetic realisation of the word (Chen *et al.* 1996； Sung and Wu 2011: 684).

1.2.1 Writing systems: phonographic and morphographic

In English, writing refers to a different domain: a style or form of composition; the art of forming visible letters or characters – handwriting. The definition of writing provided by Rogers is: 'the (systematic) use of graphic marks to represent specific linguistic utterances' (2005: 2). It is not the case that every language has a written form, and for those do have a 'well-established' writing system, not all who can speak the language can write it (Rogers 2005; Yule 2010: 212). Language can be acquired in a natural process. As a result, all people acquire at least one language as children. However, writing can only be taught and learnt consciously and sustainably (Yule 2010: 212).

Though writing is the visible realisation of a language, it does not necessarily reflect or represent all its linguistic details (related to sound and meaning). Most of the time, writing represents a combination of sound and meaning; for example, English, Chinese, etc. However, different typological classifications use different criteria when grouping writing systems. Some are only based on meaning units contained in the writings; some only consider sound units; and some take both meaning and sound into consideration at the same time (it is worth noting that a writing system that solely considers sound and not meaning does not exist).

For example, according to Rogers' typology of writing systems, one writing system representing pure meaning is classified as morphographic (with only one example – Bliss, which is a man-made writing system for people with learning difficulties); the rest are all phonologically based and classified as phonographic. However, some scholars such as DeFrancis (1989) claimed that all writing systems are phonologically based and a purely and naturally developed morphographic writing system seems impossible. Phonographic writings can be further classified based on the size of their phonological units from small to large (phoneme, mora, syllable).

Segmental or alphabetic writing systems, being the most commonly used writing system, is a type of phonemic writing system. In some phonemic writings, all the smallest phonological units of the language, phonemes, are represented, e.g., Finnish, in which case a phonemic writing system reflects all the consonants and vowels. However, in some other phonemic writings, only a part of the phonological details are represented. For example, Arabic, a Semitic language, has typical Abajad or consonantal features so that all the consonants are represented but not the vowels (Rogers 2005: 289).

Mora is a phonological unit with the intermediate size between a phoneme and a syllable. In a moraic writing system, graphemes are related to moras instead of phonemes as in alphabetic writing systems. Japanese kana and Cherokee are typical moraic writing systems in which an onset-nucleus combination (mora) would be a polyphone. It means that a grapheme would represent more than one phoneme, and this phenomenon is usual. A coda is also a mora.

In syllabic writing systems, graphemes are related to phonology at the syllable level. A complete syllable consists of an onset, nucleus and coda. According to Rogers (2005: 14-16), the only clear syllabic writing system is a Chinese dialect, Yi. However, both Rogers (2005) and Sproat (2000) agree that Chinese is also syllabic.

Another way to classify writing systems is to see if the system is primarily meaning-based or sound-based. The only meaning-based writing system currently in use is Chinese, while the rest are sound-based (Gelb 1963; Sampson 1985; DeFrancis 1989).

Also, a further detailed classical taxonomy was outlined by DeFrancis (1989), which takes morphemic information into account. According to the specific phonological units and whether there is morphemic information embedded, writings can be grouped as: (1) 'pure' syllabic (as Linear B, kana and Cherokee); (2) morpho-syllabic systems (Sumerian, Chinese and Mayan); (3) 'pure' consonantal (Phoenician, Hebrew and Arabic); (4) morpho-consonantal systems (Egyptian); (5) 'pure' phonemic (Greek, Latin and Finnish); and morpho-phonemic (English, French and Korean).

According to all the criteria mentioned above, Chinese is classified into different categories in different classifications: word syllabic (Gelb 1963), morphosyllabic (DeFrancis 1989), logographic (Sampson 1985; Comrie 2013) and syllabic (Sproat 2000; Rogers 2005). This thesis follows Sproat and Rogers' classification in which Chinese is categorised as syllabic, to allow for better comparison with other writing systems in terms of their phonological features. A collective overview of different classifications can be seen in Table 1 below.

One graphic sign can have a different number of units under different writing system classifications. For example, 'cut' has three phonemes written in three graphemes in alphabetic writing, two moras in moraic writing, and one syllable in one grapheme in syllabic writing (Rogers 2005: 14).

1.2.2 Relationship between written symbol and utterance

Another aspect of the relationship between writing and language is how perfectly the written symbols match the utterance. As a general rule, different writing systems vary mainly based on orthographic units (Frost 2005). In other words, different taxonomies have been defined to classify languages based on their decoding patterns. With Rogers' approach, writings are divided into morphographic writings and phonographic writings. Morphographic writings have graphemes (here called 'morphograms') which are primarily related to the morphemes. Unlike morphographic writing systems, the primary relationship in phonographic writing systems is the relationship between graphemes and phonological units. All the rest of the writings (phonologic writings) are categorised as phonemic, moraic and syllabic, according to the size of their phonological units: phoneme, mora, syllable, from small to large. Linguistic units such as sub-syllabic and syllabic units are transcribed in these orthographic units: phonemes in English letters; moras in Japanese kana; and syllables in Chinese characters.

Automatic conversion is possible in a phonemic writing system because each phoneme has a distinct written symbol. Hence, a regular one-to-one relationship between grapheme and phoneme would be expected. In particular, most writing systems are alphabetic, in which the mapping of a letter onto sound is typically consistent.

However, a pure and perfect phonemic writing system does not exist due to diachronic variation or other factors. Spanish is an example. It is one of the closest examples of a regular and consistent one-to-one relationship. While most of the time, this relationship in Spanish is predictable, exceptions do occur. Rogers takes grapheme <h> and phoneme /b/ as examples. In the case of <h>, there is no corresponding sound in the language. As for sound /b/, it can be represented by both graphemes <b> and

Table 1: Main typological classification of writing systems

(Graphic units of writing from letter to morpheme)

<table>
<tr><th colspan="2">Gelb (1963)</th><th colspan="2">DeFrancis (1989)</th><th colspan="2">Comrie (2013)</th><th colspan="2">Sampson (1985)</th><th colspan="2">Rogers (2005)</th><th colspan="2">Sproat (2000)</th></tr>
<tr><td rowspan="2">Alpha-
betic</td><td rowspan="2">Greek</td><td>‘Pure’
phonemic</td><td>Greek
Latin
Finnish</td><td rowspan="2">Alphabetic</td><td rowspan="3">ND</td><td>Alphabetic</td><td>Greek</td><td>Alphabetic</td><td>Greek, Latin
Finnish, Scots
Gaelic,
Byelorussian,
Mongolian, Runic
Ogham (old Irish)</td><td>Alphabetic</td><td>Greek</td></tr>
<tr><td>Morpho-
phonemic</td><td>English
French
Korean</td><td>Featural</td><td>Hangul</td><td>Alphabetic</td><td>English, Spanish,
French, Hangul,
Russian</td><td>Alphabetic</td><td>English
Korean
Devanagari</td></tr>
<tr><td rowspan="4">Syllabic</td><td>Aegean
syllabaries
Western
Semitic</td><td>‘Pure’
consonantal</td><td>Phoenician
Hebrew
Arabic</td><td>Consonantal</td><td>Consonantal</td><td>Western
Semitic</td><td>Abjad</td><td>W. Semitic
Perso-Aramaic
Egyptian, Uighur
Arabic, Hebrew</td><td>Consonantal</td><td>Perso-
Aramaic
W. Semitic</td></tr>
<tr><td>ND</td><td>Morpho-
consonantal</td><td>Egyptian</td><td>Alpha-
syllabic</td><td>Thai</td><td colspan="5">ND</td><td>Pahawh,
Hmong</td></tr>
<tr><td rowspan="2">Kana</td><td>‘Pure’
syllabic</td><td>Linear B
Kana,
Cherokee
Yi</td><td>Syllabic</td><td>Japanese
Hiragana

Cherokee</td><td>Syllabic</td><td>Linear B</td><td>Moraic</td><td>Linear B, Kana,
Cherokee, Cree-
lnuktitu, Mayan,
Sumerian
cuneiform</td><td>Core
Syllabic</td><td>Sumerian
Mayan
Japanese</td></tr>
<tr><td colspan="2">ND</td><td>Mixed
logographic
syllabic</td><td>Japanese</td><td colspan="6">ND</td></tr>
<tr><td>Word
syllabic</td><td>Sumerian
Chinese</td><td>Morpho-
syllabic</td><td>Sumerian
Chinese
Mayan</td><td rowspan="2">Logographic</td><td rowspan="2">ND</td><td>Logographic</td><td>Chinese</td><td>Syllabic</td><td>Yi, Chinese
Vietnamese
Hmong Kanji</td><td>Syllabic</td><td>Yi, Chinese</td></tr>
<tr><td>Picto-
graphics</td><td>Mayan</td><td>Morpho-
consonantal</td><td>Egyptian</td><td>Semasiographic
(Yukaghir)</td><td></td><td>Abugida</td><td>Ethiopic, Brāhmī
Nāgarī, Burmese,
Devanāgarī,
Tibetan</td><td>Poly-
consonantal</td><td>Egyptian</td></tr>
</table>

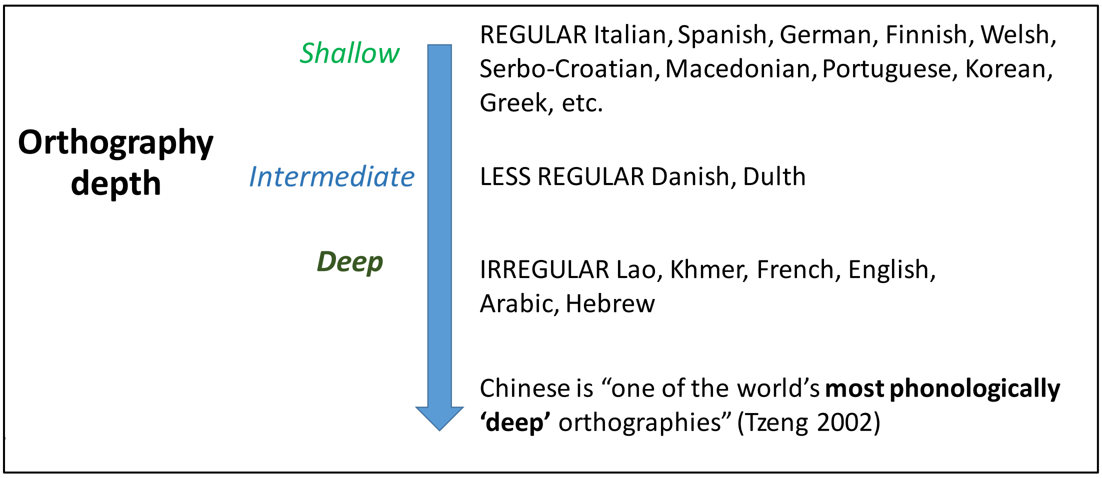
<v>. Under such circumstances, morphemic information would be needed to determine the exact word.

A greater amount of morphemic information is necessary for the English writing system, where this relationship, on the other hand, is much less predictable. For example, the phoneme /i/ can be written as orthographic symbols <ee, ea, ie, ei, y, i> as in ‘meet, mean, siege, conceive, city, spaghetti’ (ibidem: 5), or words sound the same but have different spellings, e.g., ‘air’- ‘heir’. Similarly, individual graphemes can have different sounds, such as <a> in ‘bag’ and ‘bar’; or writing sequences, such as <ea>, are pronounced differently in ‘leap, gear, bear’.

Such inconsistencies create areas of opacity where the grapheme to phoneme pattern is not regular. Since Klima's (1972: 57-80) research, the description of these phenomena has led to a typological classification of writing systems based on grapheme-to-phoneme consistency, where writings with one-to-one relations are the optimal orthography. Using a perspective based on how predictable the pronunciation is from the visual word, phonemic writing systems can be viewed as a cross-linguistic continuum, with shallow orthographies in one extreme and deep orthographies in the other. Shallow orthographies contain a more consistent correspondence between sign and sound (tending toward a ‘one to one’ match), and little morphological information is required, such as Serbo-Croatian, Italian, Spanish, German, Finnish and so on. On the other hand, for deep orthographies such as English, the correspondence between sign and sound is often irregular. With this ambiguity, a greater deal of lexical and morphemic consideration needs to be taken into account to decide the desired written form or sound. The rest of phonemic writings, such as Danish, Greek, Scots Gaelic, Mongolian, etc., sit in between them with a sign-sound relationship not entirely predictable.

Orthography depth was initially used for phonemic writings. However, a broader use of this framework puts Chinese writing as one of the world’s most phonologically ‘deep’ orthographies (Tzeng 2002: 3) (see Figure 1 below and a detailed introduction about Chinese orthography in section 1.4). Based on the seminal work by Rogers (2005) and other (i.e., Zhou and Marslen-Wilson 2000) literature, three major decoding routes will be described and presented (grapheme-to-phoneme, morpheme-to-phoneme and grapheme-to-morpheme). Accordingly, just as the alphabetic visual shape can be read as ‘ideograms’, in a similar (but peculiar way),

Figure 1: Orthographic depth



Chinese characters can also be processed through a phonological mediation. It is suggested that Chinese presents inherent features which allow, to some extent, a speech-based reading, similar to English and other languages in the family of alphabetic languages (Perfetti and Tan 1998: 101). It means that in Chinese writing, decoding a 'character regularity effect' is more likely to involve the use of the phonological mediation path (Swinney and Love 2002: 25). Such a claim is consistent with the hypothesis as supported by Tzeng (2002), Perfetti and Zhang (1991; 1995: 24), claiming that phonology can also be activated by phonetic, graphic and semantic stimuli. This theory is competing with a different framework stating that in Chinese, the process of retrieval takes place mainly at the graphic level. The direct access theory stipulates that the process from grapheme-to-morpheme instantiates faster than phonological recognition. The validity of this hypothesis (related to the delayed-phonology hypothesis) has been tested in various experiments. The testing has relied on two main techniques: masking and priming; such studies lead to the claim that the 'graphic to meaning' path has been formed from the very beginning of the character process and remained the same for L2 Chinese learners (Gao and Meng 2000: 67-76).

1.3 Chinese writing system

1.3.1 Periodisation of the Chinese writing system

Chinese writing was invented at least 3500 years ago (Shang Dynasty) in North Central China. The earliest clear evidence from history are interpretable inscriptions found on bones (ox scapula and turtle plastrons) (Boltz 1996: 191). They are called oracle-bone writing (甲骨文) because they were records of royal prophecies. Those characters carved into bones are the direct antecedents of the characters in use today (ibidem). Though they are no longer recognisable by those who only know modern forms because of the appearance changes, the fundamental structure of the characters is more or less the same.

Chinese writing has experienced unbalanced and independent regional development in addition to changes arising from the use of diverse writing materials (bamboo, silk, etc.) on which the characters were written. There were a good number of ways to write the same character in different contexts and places. The writing was first standardised and unified by Qin Shi Huang more than 2000 years ago and has remained unified ever since. However, the unified written form of Chinese did not stay the same without any changes. Chinese writing went through three phases in history:

1. Old Chinese, from roughly 1100 BC to 100 BC (Qin Dynasty)
2. Middle Chinese, 100 BC to 600 AD (Sui Dynasty)
3. Mandarin, 600 AD to present

For the period of two thousand years from 100 BC (Qin dynasty) to the early 1900s, the written form was known as a literary language (文言 *wényán*), or Classical Chinese, that is an equivalent to Classical English in the English language. Classical Chinese is extraordinarily concise and compact compared to Modern Chinese and requires many years of intensive study as it was not usually spoken. While Classical Chinese was used in writing, local dialects were used in speech. It creates a type of diglossia, and it is for all literate Chinese. A more vernacular and easier to understand written Chinese (白话 *báihuà* 'plain speech') had been used prevailingly in popular novels or stories. The plain speech was used initially in translating Buddhist scriptures dating back to 300 BC. It founded the basis for the new written form: Modern Standard Chinese (国语 *guóyŭ* 'national language') (Rogers 2005: 21-22). The national language, whose spoken form is very close to Mandarin as spoken in Beijing, has been used from the beginning of the 1900s. The language and script reforms in the PRC in the middle of the 20th century promoted a new version of Modern Standard Chinese (普通话 *pŭtōnghuà* 'common speech') written in simplified characters; this limited the number of characters for common use and also adopted a Romanised phonetic script to help with learning of the language (Taylor and Taylor 2014: 112).

There are seven major dialect groups spoken in China nowadays. Mandarin is one of them and is spoken in the northern and western areas. These dialects are very different from each other to the extent that sometimes, communication is not possible between speakers of two different dialects. It is easy to conclude that they are closely related languages rather than several dialects of the primary language. Today, speakers of different dialects may speak their dialect on formal or informal occasions. Still, the writing is always in the standard form of Chinese, except in a few situations where there is an intention to emphasise a particular dialect wording. This situation creates a different type of diglossia phenomenon for non-Mandarin Chinese speakers, in which one dialect (any dialect except Mandarin) is used for speech and another dialect (Mandarin) is used for written texts (Rogers 2005: 20-22).

Most commonly, writing systems are developed by borrowing or applying other languages. There are rare examples of writing inventions that have been created from scratch. Chinese is likely to be one of the only three; the other two are Sumerian and Mayan. The roots of almost all the writing systems in use today can be traced back to either Chinese or Semitic. Rogers argues that Chinese is the only writing system that does not involve any borrowing but develops and evolves independently among all the writing systems in use today. Though there is likely no prior model of borrowing in the invention of Chinese (ibidem: 4-5), due to globalisation there is a growing number of foreign loaned words used in Chinese vocabulary today.

Nevertheless, Chinese writing also influences the writing systems in several neighbouring countries to varying degrees. For example, in Vietnamese writing, the creation of characters has been inspired by general ideas such as Chinese character forming principles, which resulted in phonetic-semantic compounds. Only the order of components is reversed as semantic-phonetic compounds are more common in Chinese (ibidem: 76).

1.3.2 Structure of the Chinese writing system

Traditionally, Chinese characters have been written starting at the top right corner of the page, proceeding from top to bottom, with each column placed from right to left after the previous row. But this arrangement has been replaced by a modern horizontal linear organisation that is the same as English: left to right, one row after another (ibidem: 6). Each character fits in an imaginary square of equal size. The structure of Chinese characters has not changed much since oracle-bone writing (ibidem: 31). The reason why the characters are created with their distinct features is associated with the condition and purpose of their creation and the traditional Chinese way of thinking and philosophy (Hu 2016: 39). Three main factors contribute to the shape of a Chinese character:

1) The practical reason is that the original tools used to inscribe, such as stones or knives, and the hard writing surfaces (turtle, shell, bamboo or bronze) (Feldman and Siok 1999) made it easier to write in a squared frame rather than in other shapes.

2) Ancient Chinese believed that the sky was round and the ground was square. Space, time, and humanity are unified entities. Four (metal, wood, water, fire) of the five elements stand for the world's four corners (with the fifth element earth symbolising the centre). Objects within the unified entity are related to the square shape: cities, houses, fields, and characters (Zhang 1991: 32).

3) Chinese philosophy also had its influence on the invention of characters. The square fits with Chinese aesthetic values and stands for much-appreciated virtues such as integrity and uprightness. The internal structure of Chinese characters is mainly formed vertically or horizontally symmetrical, reflecting the ultimate Chinese philosophy of Yin and Yang. Even the imaginary middle line that Chinese people use to anchor character components during writing can symbolise the doctrine of the mean (Hu 2016: 40-43).

1.3.3 Phonology and romanisation of MSC

Chinese is considered to be a syllabic writing, where each Chinese character presents a syllable that consists of an initial (or onset), final (or rime) and tone. The initial is the initial consonant, whereas the final can be divided into the medial, vowel and final consonant. All syllables must have vowel(s) and the tone, while the other components are optional. The pronunciation of Chinese words is transcribed in the Roman alphabet to facilitate learners to learn Chinese pronunciation. There have been various attempts (e.g., Yale, Wade-Giles, *Guoyu luomazi*) for Chinese phonology romanisation, but none of them have achieved widespread use except pinyin. Pinyin, invented in the 1950s, is the phonological transcript officially used in the PRC today (Rogers 2005: 24-26).

1.3.4 Types of Chinese characters

Shuowen Jiezi, written by *Xu Shen* in around 100 AD, is the first book that systematically analyses the structure of characters and the rules of how they are created. Approximately 9,500 characters are categorised into three levels (Boltz 1996: 169).

First, according to their physical structure, characters are divided into two distinctions: 文 *Wen* (unit characters contain a single graphic element) and 字 *Zi* (compound characters consisting of more than one component) (ibidem: 191). Second, Xu classified characters based on 540 semantic components. Containing one of these semantic components means the character is classified under the lexicon of this component. Sometimes, one character contains more than one semantic component; only the primary semantic component would be singled out and used as the semantic classifier. Third, Xu categorised characters into six groups (六书 'six scripts'); four are related to character creation: pictogram, ideogram, semantic-semantic compound and semantic-phonetic compounds, and two are related to the extended use of existing characters.

Pictograms (象形 *xiàngxíng*) are a consistent or similar way to represent particular images in the form of picture-writing symbols, such as 人 (*rén* 'person') which conveys the image of a person, or 日 (*rì* 'sun') which is used to symbolise the image of the sun. They are unit characters and are likely to be the earliest type of characters created.

Ideograms (指事 *zhǐshì*) are also unit characters. They might be developed on or extended from pictograms which were used to represent visible and concrete forms into representing invisible or abstract ideas, such as 'above' and 'below', respectively 上 (*shàng*), 下 (*xià*).

Semantic-phonetic compounds (phonetic compounds for short, 形声 *xíngshēng*) were created by combining existing characters to form a new meaning in two stages. First, the use of a character with a specific meaning was extended for a similar/same-sound character to represent a different meaning; then, the semantic determinative was added to create a new character particular to this new meaning to avoid ambiguity (ibidem: 33-36). The classic example for the creation process of this type of character is 妈 (*mā* 'mother'), combining the phonetic part 马 (*mǎ* 'horse') and the semantic component 女 (*nǚ* 'female').

Semantic-semantic compounds or compound ideogram (会意 *huìyì*) are characters also created by using existing characters. However, in this case, the use being extended is not sound but meaning. For example, 休 (*xīu* 'to rest') combines 人

(*rén* 'person') and 木 (*mù* 'wood, tree'). The meaning of 'to rest' is conveyed by a person leaning on the tree. Also, 家 (*jiā* 'home') consists of <宀> 'roof' and <豕> 'pig'. Since each house has its pigsty, the pigsty is used to represent home. However, the legitimacy of most characters under this category is questioned by some modern scholars, e.g., Boltz (1996: 197) and Rogers (2005). These authors believe that they are phonetic compounds whose phonetic value has been lost in the long and complicated process of phonetic changes.

Redirected characters (转注 *zhuǎzhù*) are different characters related etymologically. *Shuowen Jiezi* provides an example of a character pair 考 (*kǎo* 'aged') and 老 (*lǎo* 'old'). It seems that these two different characters have similar forms, similar sounds and the same meaning.

Borrowed or rebus characters (假借 *jiǎjiè*), similar to redirected characters, are existing characters extending their use to represent their homophones or near-homophones. For example, 令 (*lìng* 'to command') is borrowed as 良 (*liáng* 'fine') in written form (Boltz 1996: 197).

By the beginning of the 18th century (Qing dynasty), several tens of thousands of characters had been created. A group of scholars were designated by the Kangxi Emperor to write a comprehensive dictionary: *Kangxi Zidian* 康熙字典 'The Kangxi Character Dictionary'. It has become the standard authority to regulate and ensure the correct use of characters (ibidem: 198-199). It contains 47,000 characters, five times the number in *Shuowen Jiezi*. It also reduced the number of semantic classifiers from 540 to 214. These 214 semantic classifiers, now called radicals, remain the basic and standard framework for lexicographical works. The most recent comprehensive character dictionary is *Hanzi Dazidian* 汉字大字典 'Great Dictionary of Chinese Characters'. The first edition was completed in 1990, including more than 60,000 characters listed under 200 radicals (Mair 1996: 200). However, the number of characters in daily use is a much smaller number than 60,000. More specifically: '1,000 characters cover around 90 percent of occurrences in typical texts; 2,400 cover 99 percent, and 3,800 cover 99.9 percent; 5,200 cover 99.99 percent and 6,600 cover 99.999 percent' (ibidem). The average estimated number of characters that a literate Chinese reader would recognise is between 2,000 to 2,500.

1.4 Chinese character: sign, sound, and meaning

As outlined in Section 1, the three major lexical constituents of word recognition are orthography, phonology, and meaning. The present section examines the relationship between these three lexical constituents in their smallest corresponding contrastive units in the Chinese language: grapheme, syllable and morpheme. The relationships between the sign, sound and meaning are relatively straightforward. Each Chinese character is a grapheme, which presents one syllable and has one meaning. However, in rare cases, a single syllable can represent more than one morpheme at a time or one morpheme is written by two or more graphemes. Moreover, grapheme, syllable and meaning can have multiple shapes in different contexts. I will elaborate explicitly on the relationships between these three lexical constituents.

1.4.1 Grapheme vs Syllable

The character is the smallest sound unit in the Chinese writing system, contrasting with other characters (Rogers: 5). The spoken chain is divided into syllables. Each syllable corresponds to one grapheme (character). The only exception where one syllable is written with two graphemes involves 'nominal forms ending in the suffix <-r>', which originally meant 'son' or 'child'. This diminutive suffix has been used in the Beijing dialect; hence, it is adopted in Modern Standard Chinese. For example, as shown in Figure 2, the syllable /huār/ 'flower' has two graphemes in writing: 花 'flower', 儿 'SUFFIX-r'. These single syllables represented by more than one grapheme are called polygraphs. Typical polygraphs in English are single phonemes represented by two letters, e.g., the sequence 'sh' represents the single phoneme /ʃ/ (Rogers 2005: 16). Rogers believes that there is another exception, in which case the single grapheme 廿 is used to represent two syllables /èrshí/. According to the Xinhua Dictionary (2015), 廿 is one syllable /niàn/ in Standard Modern Chinese. 廿 pronounced as two syllables /èrshí/ might be a phenomenon that only exists in some dialects but not in standard Chinese.

When reading a character, most commonly, one grapheme is pronounced by one syllable shape, e.g., 白 - /bái/ (Rogers 2005: 29). In a few cases, one grapheme can be pronounced by two or more syllable shapes. Those characters with multiple corresponding syllable shapes are called polyphones. For example, 行 is a polyphone associated with the syllable shapes /xíng/ and /háng/ (ibidem: 27). One similar example of a polyphone in English is that 'project' can be pronounced either /ˈprɒdʒɛkt/ or /prəˈdʒɛkt/.

Very often, one syllable has one corresponding grapheme shape in the written form, e.g., /bái/ - 白. It is also prevalent that one syllable represents several grapheme shapes, which results in homophones. Homophones are characters with graphemic distinctions but that share the same sound, e.g., /yī/ can be represented in writing by homophones: one 一, clothes 衣. Homophones are so common in modern Chinese that they have become a 'prominent feature' (ibidem: 26-28). According to Taylor and Taylor (2014: 80), each tone syllable (syllable with tone) corresponds to 11 characters on average. Without necessary morphemic information, confusion in the use of characters would occur. Homophones also exist in English, e.g., /pɛː/ can be written as pair or pear.

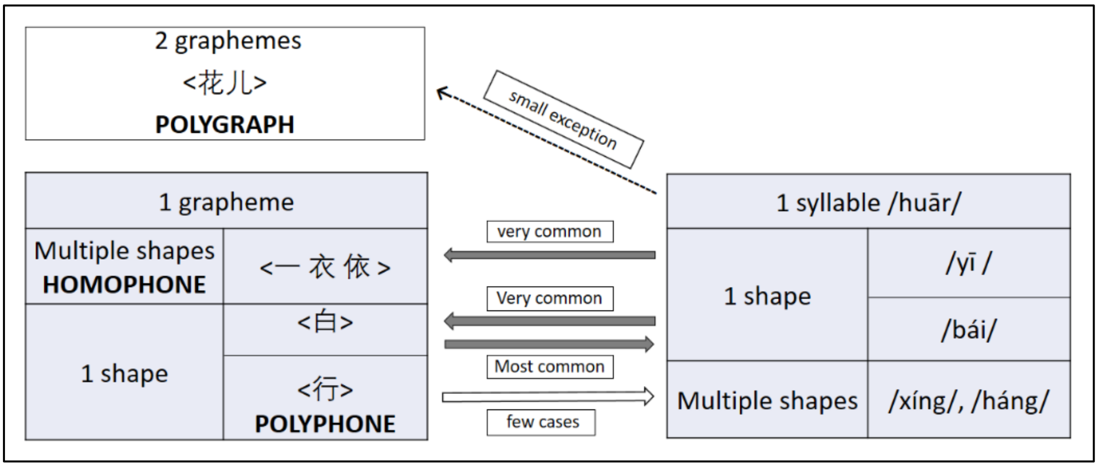


Figure 2: Frome grapheme to phoneme

1.4.2 Morpheme vs Syllable

It is normal to see that a morpheme and syllable have one to one correspondence. However, the relationship between the two is more complex than that. There are both multiple-syllable morphemes and multiple-morpheme syllables. One-syllabic morphemes consist of most cases in Chinese characters, e.g., 'white' - /bái/ 白. Multiple-syllable morphemes are a less common pattern. This type of multiple-syllable morpheme is often seen in animals and plants, e.g., 'butterfly' - /húdié/ 蝴蝶 or the foreign loaned word 'chocolate' - /qiǎokèlì/ 巧克力 (Rogers 2005: 26-27). Furthermore, though the general rule is that each syllable stands for one morpheme (e.g., /bái/ 白 'white'), there is a small exception where one syllable stands for two morphemes. It relates to the diminutive suffix <-r> mentioned earlier, e.g., /huār/ 花儿 and contains two morphemes: 花 'flower' + 儿 suffix '-r'.

It is common to see that one morpheme is represented by different syllable shapes (e.g., both syllables /kàn/ and /shì/ can mean 'to see' 看), and one syllable stands for different meanings in different contexts (e.g., syllable /yī/ can mean 'one' 一 or 'clothes' 衣 depending on the context). The former characters are synonyms which are different characters sharing the same meaning, and the latter characters are homophones which are different meanings sharing the same sound. Examples in English for such cases: 'begin' and 'start' sharing the same meaning are synonyms, and 'aunt' and 'ant' sharing the same pronunciation are homophones (see Figure 3).

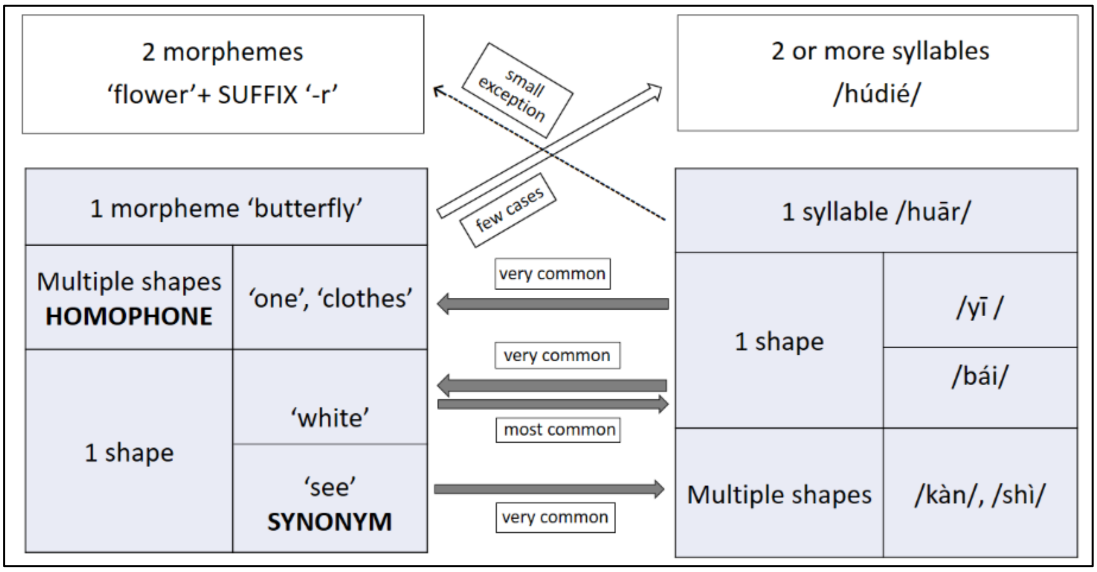


Figure 3: From morpheme to phoneme

1.4.3 Grapheme vs Morpheme

The primary relationship of grapheme is to morpheme. Most commonly, one grapheme represents one morpheme, e.g., 我 'I'. A small proportion of single morphemes are made up of more than one character. Each character has one corresponding syllable. Therefore, they are the multiple-syllable morphemes mentioned earlier (e.g., animal 'butterfly' 蝴蝶 /húdié/ or the borrowed word 'chocolate' - 巧克力 /qiǎokèlì/). English is a graphemic writing system; any words with more than one letter can be seen as a multiple-grapheme morpheme, e.g., English, <e, n, g, l, I, s, h>.

Very often, one grapheme has one meaning, e.g., 我 ‘I’. There are also abundant examples of one grapheme representing many morphemes in different situations (ibidem: 28). It falls into another category of homonym, which are characters with the same written form but having more than one meaning, e.g., 行 represents ‘to work’, ‘to conduct’, ’row’, ’profession’, etc. Similar cases in English would be that <I> means ‘myself’ and <book> means ‘printed pages’ or ‘to reserve’.

According to the general rule, each morpheme is represented by one grapheme, ‘I’ - 我. There is also a typical pattern that one morpheme can be represented by different graphemes, e.g., ‘to see’ can be written as 视 or 看 (see Figure 4).

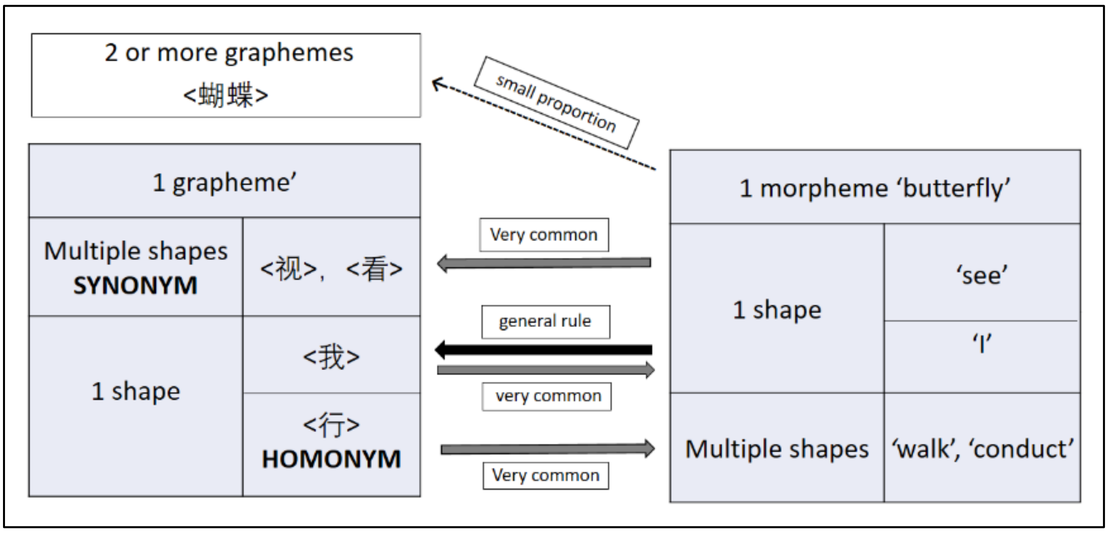


Figure 4: From grapheme to morpheme

1.4.4 Conclusions

In conclusion to this survey on the main typological features of the Chinese writing system, one central aspect can be highlighted: in the decoding processing, due to the vast number of homophone syllables corresponding to different graphemes in different contexts, for successful orthographic decoding, the morphemic information is needed. Therefore, a phonological mediation theory is consistent with the structural features of the Chinese writing system and its relation to the represented utterance. More studies need to be conducted to test the extent of this type of WR, possibly comparing semantic and phonological priming. At this stage, it can be said that, just as alphabetic languages are decoded using a grapheme-to-meaning path (which resembles ideographic processing), in a similar but peculiar way, Chinese is more effectively decoded via a phonological mediation (typically conceived to be a more ‘natural’ method for alphabetic languages). It could be said that whatever writing system is being used (alphabetic or logographic), the reader needs to resort to a twofold route. The choice may depend on the level of proficiency and on other variables that need to be identified and investigated.

In all cases, the grapheme-to-meaning direct access to the lexicon and the phonological mediation process are not mutually exclusive paths. They can be used in combination to trigger a more effective character acquisition in Chinese L2.

CHAPTER 2: THE PSYCHOLINGUIST ACCOUNT ON WORD RECOGNITION

When recognising a character, a learner searches for the correct mental representation in the mental lexicon, which matches the print form of a certain character among other possible candidates (Segui and Grainger 1990). Once the pairing process is partially or fully completed, the learner can recall the character's associated sound and meaning (Ke and Zhang 2018: 115).

> "The lexical representations are the word entries in the mental dictionary. Words are acquired and added to the mental dictionary as they are learned through spoken or written language. Their meanings are fleshed out, and their places in the lexicon are fortified by hearing, using, and reading the words multiple times in a variety of contexts. Their strength and stability in the lexicon define their lexical quality." (Hart and Perfetti 2008: 109)

Reading via the lexical route involves looking up a word in a mental lexicon containing knowledge about the spellings and pronunciations of letter strings that are real words (and so are present in the lexicon); reading via the non-lexical route does not refer to this lexicon, but instead involves making use of rules relating segments of orthography to components of phonology. (Coltheart 2005: 9)

> "…as opposed to nonwords, which are not pronounceable and have no meaning. (Gunther 1983: 355)
> nonsense words, which can only be pronounced by the rules, since they are not words." (Baron and Strawson 1976: 387, cit. in Coltheart 2005: 11)

2.1 Lexical access and orthography decoding

Understanding the meaning of words is essential because it is crucial to text comprehension and because it is one of the first tasks confronting L1 readers and L2 beginner readers (Seidenberg and McClelland 1989: 523). Visual word recognition, a fundamental link of reading, is intensively investigated by researchers who seek to answer how lexical processing occurs. Different models have been developed to describe the process, such as interactive activation, rule-based coding, connectionist modelling, and optimal perceivers from a Bayesian perspective (Yap and Balota 2015: 39). However, this thesis focuses primarily on behavioural studies, and other word recognition models from fields such as cognitive neuroscience are not taken into account.

For this account on WR, I will rely heavily on the seminal study by Harley (2014), under the title 'The psychology of language: From data to theory'. The author introduces the topic of WR by highlighting a specific problem connected to the sequence taking place during the process of lexical access. As underlined by Harley, when it comes to the recognition of a word, psycholinguistic researchers are not only interested in how we decide if a printed word is familiar or not, but also in how we access all the information related to the word, such as meaning and syntactic class (Harley 2014: 167).

The critical issue is whether recognition and access occur at two different stages or instead in a continuum. There has been a consistent emphasis on the gap between word recognition and word meaning access. This gap is first named by Balota as 'the magic moment' (1990: 9), which refers to a discrete moment in time when the subject has recognised the word but has yet to access meaning (Harley 2014: 167). By using Balota's terminology, it could be said that in Morton's framework, the magic moment takes place when a logogen's threshold is reached and surpassed. According to the bin model outlined by Forster (1976: 257-287), the magic moment instead happens when the representation of the orthographic stimulus sufficiently matches with the information stored in the storage for lexicon information (that is, the bin of lexical access). Both the notions of logogen threshold activation and a match between an original stimulus and internal lexical storage are reinterpreted in Becker's verification model (1980: 493-512). The fundamental difference is that for Becker, the logogen system response provides a 'set of candidates' matching with the stimulus. Such a set (corresponding to the sensory representation of the stimulus) is then verified against the sensory memory. These models have in common that an orthographic stimulus activates the retrieval of lexical information, which is a mechanism that can be triggered by the threshold activation or by a comparative process between external stimuli and internal representation.

2.1.1 Recognition and access: the magic moment

The gap first named by Balota (1990: 9-32) as 'the magic moment'. Dave Balota is a very influential scientist whose investigation is related to visual word recognition and priming. In his research, two distinct approaches to WR can be seen. The original theory (Balota 1990) is described in the following famous passage from Balota and Yap (2006: 229): 'a reasonable yet often implicit assumption underlying models of visual word-recognition tasks is that there is a magic moment in word processing' (Balota 1990). It is a discrete instant when a reader recognises a word but does not yet know its meaning. At first glance, this seems quite reasonable and inherent in most pattern recognition models; that is, how could one interpret a stimulus unless one has first recognised what that something is? In more technical terms, the magic moment is that instant when lexical identification takes place; that is, a lexical representation is sufficiently activated for a response to be executed (Institute for Behavioural Research 1991). This event unlocks access to meaning. The magic moment is when the activation level for a word detector exceeds some threshold, and lexical identification takes place.

According to Balota and Yap (2006: 230), identifying this moment is linked with two major tasks, namely, lexical decision task (Meyer *et al.* 1974) and speeded naming. However, the two authors also recognise that the measure of latencies in the tasks, as mentioned earlier, is not a reliable method to identify the magic moment (if any). The perplexities on the topic by Balota and Yap are visible in the passage below:

> However, the notion that lexical decision and naming latencies tap pre-semantic aspects of the presumed word-recognition point is inconsistent with the empirical observation that semantic effects have been reliably observed in isolated lexical decision, and to a lesser extent, naming. Also, it is increasingly clear that neither lexical decision nor speeded naming reflects a magic moment. Both paradigms have a basic problem; they measure both word-identification processes and operations specific to each task. (Balota and Yap 2006: 230)

In other words, while 'the magic moment' idea has been widely accepted and supported by empirical evidence, Balota himself has raised questions about the methods and data collecting procedures that have been commonly used to utilise such a model. More specifically, Balota (1990: 9-32) argued that the LDT and the pronunciation could not faithfully reflect the magic moment because it might mislead one into accepting isolable stages in processing. It can be argued that: lexical processing may reflect a more continuous, cascading flow of information, where experimental variables can influence early identification, decision, and late post-decision processes (McClelland 1979), depending upon the goals of the task (i.e., the task-appropriate processes) (Balota and Yap 2006: 235).

2.1.2 Recognition and access as discrete phases

In the research described above, the measuring was carried through tasks in isolation LTD and speed naming. Now this will turn the attention to a model organised in discrete phases. The previous section outlined the caveat by Balota and Yap 'to consider word recognition within a task appropriate processing framework' (2006: 252). Such a framework should be cascading. In this regard, it is essential to point out the WR reference models that Balota (1990: 9-10) had in mind when developing his theory of the magic moment. As the author says, classics models on WR have been proposed by Morton (1969: 165), Forster (1979: 85), Becker (1980: 493-512) and Norris (1986: 93-136), etc.

2.1.2.1 The box-to-arrow models

Since the seminal article by John Morton (1969: 165-178), the process of recognition has been analysed through a set of phases, where each one implies access to different types of information: graphic, phonological, semantic and finally lexical. Each stage in the process represents a node in the cognitive process called logogen (Greek meaning 'word generation'), which describes the basic unit in the recognition process. Each logogen has a specific threshold level that must be activated to move to the next stage. Broadly speaking, it could be said that the Orthographic Lexicon Threshold is 'determined by the frequency of occurrence of the printed character in the reader's daily usage'. In contrast, the Phonological Lexicon Threshold is determined by 'the frequency of access to the character's phonological form in the reader's speech experience' (Sung 2014: 40). When each node is fully activated (in other words, when it exceeds its 'activation value'), it excites the nodes with which it is consistent and inhibits the nodes with which it is not. A clear picture of the process has been provided. However, for a better understanding of the topic, in the next section, this study will offer a more detailed outline of the influential models on word recognition based on Morton's pioneering research.

The logogen is a device that accepts information from the sensory analysis mechanisms concerning the properties of linguistic stimuli and context producing mechanisms. When the logogen has accumulated more than a certain amount of information, a response (in the present case, the response of a single word) is made available. Each logogen is defined by the information it can accept, and by the response it makes available. Relevant information can be described as the members of the sets of attributes [Si], [Vi], and [Ai], these being semantic, visual, and acoustic sets, respectively (Morton 1969: 165).

Different from Becker's framework, Foster's model introduced the notion of storage for lexicon information. According to his bin model (Forster 1976), the magic moment happens when the representation from the orthographic stimulus sufficiently matches with the information stored in the bin of lexical access. The notions of logogen and the matching between the original stimulus and internal lexical storage are reinterpreted in Becker's verification model. The fundamental difference is that for Becker, the logogen system response provides a 'set of candidates' matching with the stimulus. Such set (corresponding to the sensory representation of the stimulus) is then verified against the sensory memory. A description of Becker's verification process is provided by Besner and Swan (1982):

> "For Becker, the function of the logogen system is to provide a set of candidate words, the 'sensory' set, which are consistent with the primitive features in the stimulus. These candidates are then verified against a description of the stimulus held in a non-lexical post-iconic visual memory." (Besner and Swan 1982: 313).

One thing these models have in common is that an orthographic stimulus activates the retrieval of lexical information. It is a mechanism that can be triggered by the threshold activation or by a comparative process between external stimuli and internal representation. In all cases, as underlined by Norris (2013: 517), these early models have the limitation of being simply 'box-to-arrow' type, meaning that they capture the primary sequence of the process of an input up to the production of an output. However, they neither explain what happened in each stage nor how information is operated from one point to another (Norris 2013: 517). In the early 1980s, with the emergence of new and more sophisticated models used in computational science, the scientific community gained a better idea about what was taking place in each phase and what was going to happen next.

2.1.2.2 The dual-route approach in the reading process

The research on the decoding process, from the visual stimulus to lexical access, is also at the centre of the investigation on the reading process, which is generally broken down into two distinct areas: reading aloud and reading comprehension. If we start from the assumption that this context involves the computation of three types of codes:

orthographic, phonological and semantic' (Seidenberg and McClelland 1989: 526), some fundamental questions arise. What are the relations between these three dimensions, and what is the direction of activation of their respective different thresholds? Is it unidirectional or bidirectional? As highlighted by Coltheart (2005: 6), the idea of two parallel paths (as an antecedent of the current dual-route DR approach) has been proposed at the very foundation of general linguistics, as visible in this passage from the Cours de Linguistique générale, by Ferdinand de Saussure:

> "...We read in two ways; the new or unknown word is scanned letter after letter, but a common or familiar word is taken in at a glance, without bothering about the individual letters; its visual shape functions like an ideogram." (1922, translated 1983: 34, cit. in Coltheart 2005: 6)

By the beginning of the seventies, the DR theory had already gained wide currency that expanded into psycholinguistics. It was explored by Marshall and Newcombe (1973) (see Figure 5), Forester and Chambers (1973), Baron and McKillop (1975: 91-96) and Baron (1977: 175-216). They outlined an arrow-and-box diagram describing the whole process of lexical recognition (Coltheart 2005: 7).

An example of the arrow-and-box diagram is visible in Figure 1, and it represents the whole reading aloud process according to the dual-route approach. As illustrated in the figure, two possible paths can lead from print to speech. One is the grapheme-to-phoneme path. The other is the grapheme-to-meaning route. In the latter, the orthographic information is processed as visual shape (and not as individual letters), and lexical retrieval takes place independently from the access to the phonological representation. Since sound is not involved, the grapheme-to-meaning strategy is crucial in identifying homophones, especially those embedded in 'insufficient' contexts. For instance, in a sentence such as 'give me a pear', to process the word 'pear', we cannot rely on the phonemic representation /pɛə/, which is the same as 'pair'; therefore, we have to use the print-to-meaning route (Baron and McKillop 1975: 91). We will go back to these notions in the following sections, but before then, we need to mention the application of computational modelling in this field of investigation.

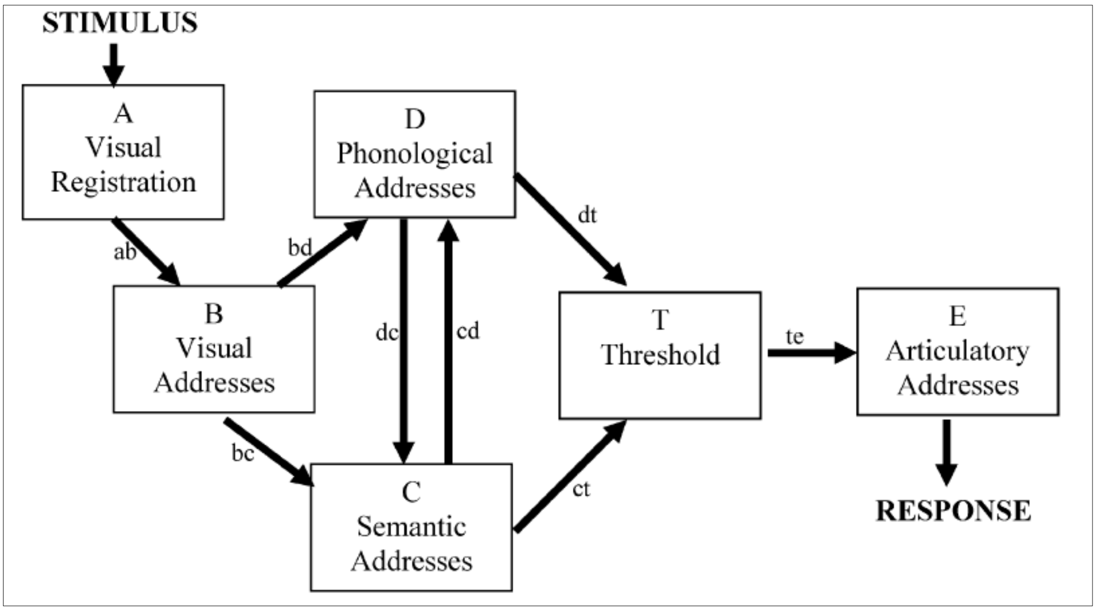


Figure 5: Reading process by Marshall and Newcombe (1973)[1]

2.1.2.3 From Arrow-and-box to computational models

These early models have the limitation of being simply 'box-to-arrow' type, meaning that they capture the primary sequence of an input process up to the production of an output. However, they neither explain what happened in each stage nor explain how information is being operated from one point to another (Norris 2013: 517-524). In the early 1980s, with the emergence of new and more sophisticated models used in computational science, the scientific community gained a better idea about what is taking place in each phase and what is going to happen in the next phase. Moreover, Balota himself had some doubts towards the methodologies which were used in successfully identifying the 'the magic moment'. In other words, a different model emerged from the literature, according to which 'lexical processing may reflect a more continuous, cascading flow of information'.

The computational ideas were initially used to examine complex nonlinear systems, such as weather-forming processes in meteorology. When applied in psycholinguistics, as stated by Noam Chomsky, they 'were also fundamental to understanding human language in another way' (Chater and Christiansen 2008: 477).

[1] from Castles *et al*. (2006: 872).

The way we process and acquire language is characterised by a computational mechanism. Therefore, it is not surprising that these models have been a central topic in the field of psycholinguistics (Ibidem).

These models are intended to explain how some psycholinguistic functions are accomplished by a set of primitive computational processes. The models perform a psycholinguistic task and produce behaviour that can be interpreted as predictions compared to human data (Lewis 2000: 287).

More specifically, computational models have become prominent for explaining the process of lexical retrieval. As underlined by Norris (2013), the earliest and most influential ones are the interactive activation (IA) models. They are inspired by human brains and view the whole WR process as an artificial network with in-built and densely interconnected nodes. To some level, they function in a way similar to our brain, where a large number of interconnected neurons work simultaneously and cooperatively. In such a framework, ‘letter features, letters, and words are represented as nodes’ (Ibidem: 518), which excite or inhibit one another across the network. As explained by Norris (2013: 518) in Figure 6, the arrowed lines represent excitatory connections from letters to words, whereas the dotted lines denote inhibitory connections.

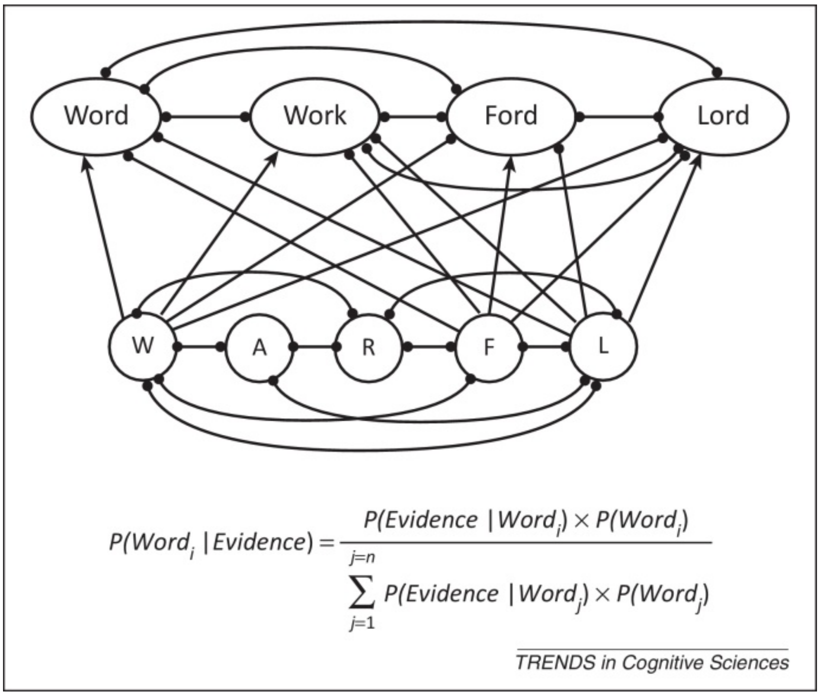


Figure 6: Norris (2013: 518) interactive activation model

Advocates of IA models further developed this framework into the Spatial Coding Model, the dual-route cascaded model, etc.

2.1.2.4 Interactive Activation and Competition (IAC)

Regarding lexical retrieval, the earliest and most influential computational models are characterised by Interactive Activation and Competition IAC. These models are inspired by human brains and view the whole WR process as an artificial network with in-built and densely interconnected nodes. Neuronal-network algorithms, such as the back-propagation learning algorithm, are applied to simulate human language processing. Therefore, to some level, IA models function similarly to our brain, where many interconnected neurons work simultaneously and cooperatively. In such a connectionist framework, 'letter features, letters, and words are represented as nodes' (Norris 2013: 518), which excite or inhibit one another across the network.

An example of an IA minimal architecture framework is visible in Figure 7, representing the process of reading the word 'make'; the connections between units on different levels are represented by arrows that 'always run in both directions, in keeping with the assumption of interactivity' (Seidenberg and McClelland 1989: 526). As highlighted by the authors, the primary assumption is that 'the process of building a representation at each of the three levels [orthography, phonology, and semantics] both influences, and is influenced by, the construction of representations at each of the other levels' (Ibidem). In this case, the process relies only on the interaction between the orthography and phonology pools (in boldface type). Such a route is possible given the features of the word 'make', where grapheme and phoneme are matched according to regular rules. However, it would not be viable for a word such as 'have', where sound and sign are mapped irregularly (according to the general rule, it would be read as 'cave').

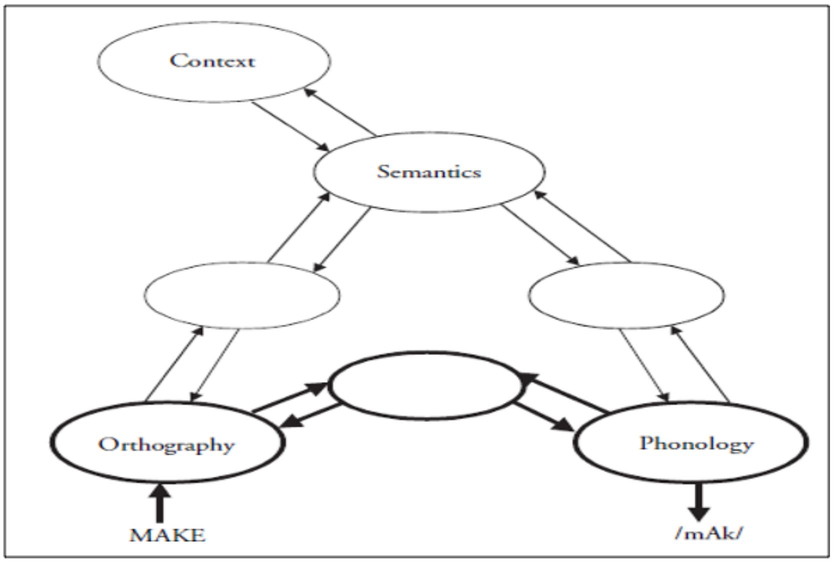


Figure 7: Lexical processing in IAC (Coltheart 2005: 17)

2.1.2.5 Dual-route cascaded model (DRC)

The interactive activation computational models have further developed through the dual-route cascaded (DRC) models, whose theoretical assumptions have been anticipated by the DR approach. In this section, we will focus on the investigation by Max Coltheart, whose account I have relied upon in several points of this paper, and whose modelling on DR started from the arrow-and-box type (1978) before moving on to the computational model on reading (Coltheart *et al.* 2001: 204). As anticipated in the previous section, the DR approach (Baron and McKillop 1975) had already postulated that when processing high-frequency words, for morphemes such as affixes (Barron 1977) and homophones (Baron and McKillop 1975), the preferred route is grapheme-to-meaning. Nonetheless, the 'grapheme-to-phoneme' method is typically used for words that are new to the reader, for which the pronunciation is retrieved directly from the phoneme sequence. In more recent research, Coltheart *et al*. devised a computational model based on two alternative procedures for computing pronunciation from print (Coltheart *et al.* 2001). The first procedure is lexical, that is, the printed input is retrieved from the mental lexicon; the second procedure is non-lexical, that is, 'involves making use of rules relating segments of orthography to segments of phonology' (Coltheart 2005: 9). The DRC model is visible in Figure 8. Different from the connectionist model by Seidenberg and McClelland (1989: 526), this processing route is usable with nonwords (i.e., 'sare'), in addition to regular words (i.e., 'make') and irregular words (i.e., 'have').

In sum, whether they refer to DR, IAC or DRC, all these theoretical models account for a correlation between the decoding strategy (lexical or non-lexical), the type of lexical material (high/low frequency, homophone, nonwords etc.) and orthography (regular or irregular mapping between letters and sounds, etc). Therefore, in this analysis, we need to turn our attention to the different writing systems.

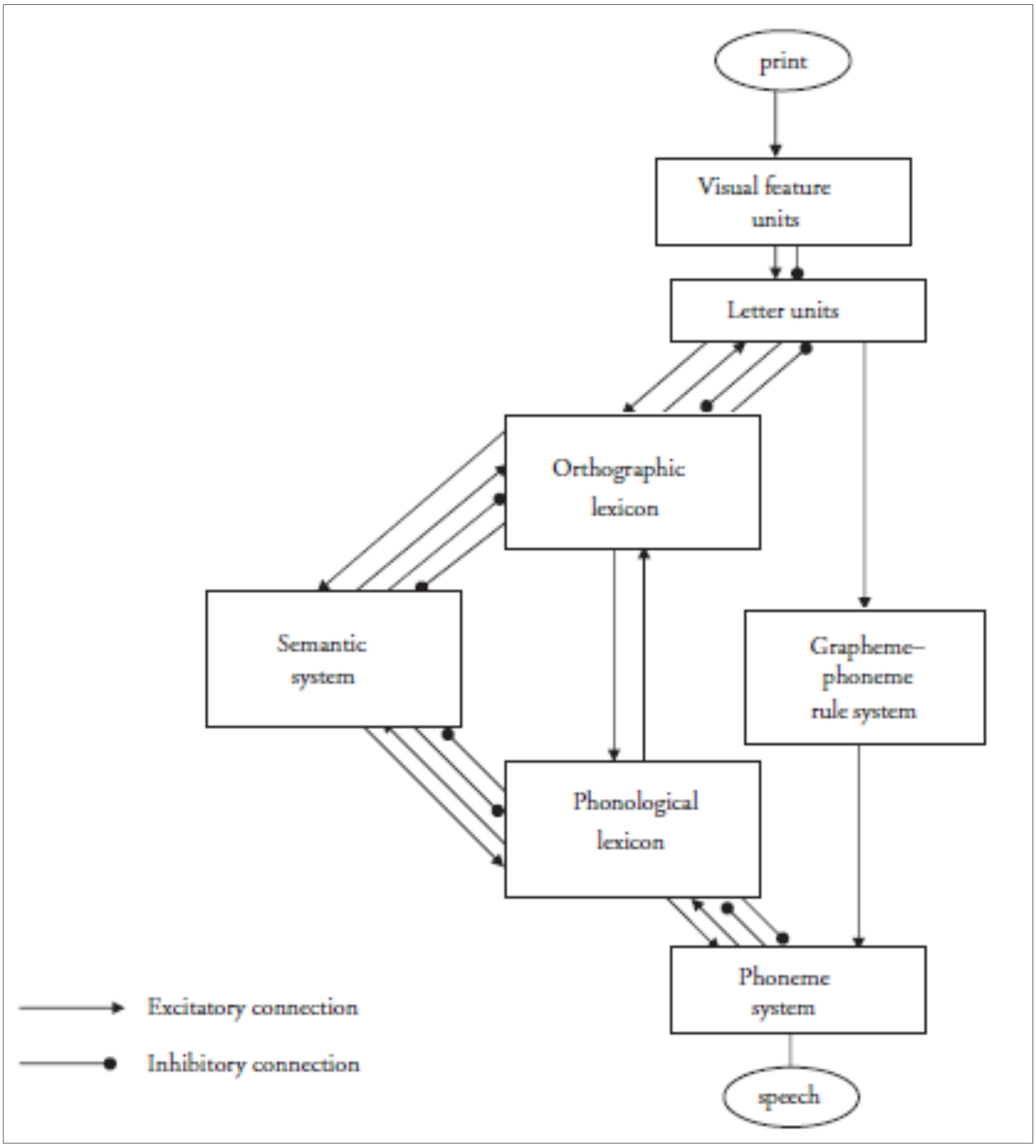


Figure 8: The DRC model by Coltheart (2005: 12)

2.2 The phonological mediation hypothesis: UDA and PMH

Writing systems influence our way of reading by placing constraints on our conceptualisation in the process of reading (Kessler and Treiman 2015: 10). Writing systems can be visually similar, i.e., Hebrew and Yiddish which use the same script, or have the same outer form, but this does not necessarily mean that they work the same. Vice versa, writing systems that look very distinct can share some critical properties in both their outer form and inner structure. Some of these similarities and differences are related to how we read.

Kessler and Treiman (2015) list properties potentially relevant to reading shared by all modern writing systems used in general literacy. 1) Universal characteristics of outer form facilitate reading — a good contrast among the basic elements of a script. For example, ‘O’ and ‘C’ share a curve but have a perceivable distinction. Minuscule differences in size, the degree of opening in the curve, or the line's thickness do not change the recognition of ‘C’ in any writing systems. Also, few mirror-image elements exist in most writing systems, such as ‘b’ and ‘d’ in English, ‘部’ and ‘陪’ in Chinese, to avoid confusion. Furthermore, elements of a script still can be identified when 50 per cent of the strokes are removed (Changizi and Shimojo 2005: 267). This redundancy means overlooking some visual characteristics of an element does not necessarily impair a successful identification. 2) Concerning the inner structure of writing, unlike musical and mathematical notation which take note of ideas, it takes note of the language. The articulation of languages can deal with words at the lexical level or phonetic level (Martinet 1960, cited in Kessler and Treiman 2015: 13). Symbols invented at the lexical level are called logograms. Each symbol represents a morpheme or word. Symbols created at the phonetic level are called phonograms; each represents a phoneme or syllable. 3) Writing does not represent all the features of a language. For example, a writing represents lexically contrastive distinctions or otherwise, it fails to do so. In the case that lexically contrastive distinctions are represented, reading would probably benefit by reducing the number of symbols, such as allophones of the same phoneme sharing the same symbols. A case in which a different phoneme is represented by the same symbol can make reading more complicated (however, readers can get help from context).

Various writing systems have developed in human history, displaying striking differences. For example, alphabetic systems are speech-based, and logographic systems are often described as ‘meaning-based’. Such diversity gives space to the essential questions: Are all readers using the same way of processing visual stimuli (written words)? How does such a process vary according to the writing system being used? Notwithstanding the considerable amount of debate and controversies, at present, there are no straightforward conclusions. Since the turn of the century, different 'universal hypotheses' have been outlined. At stake is the role of phonology in the process of visual word recognition. In the models described in the previous sections, a route from grapheme-to-phoneme had been outlined (parallel to a grapheme-to-meaning path). This postulation was not meant to indicate that lexical access is necessarily phonologically mediated. It instead predicted that such a procedure is used productively in a specific context, as with nonwords or for readers who have not developed an advanced reading skill. Though this study will present the main hypotheses which make constant reference to IAC or RDC, it is not based on instantiated models. Instead, they draw upon evidence from second language acquisition and clinical experience on different types of speech impairment, either in language-specific or in cross-linguistic contexts.

Based on the role that phonology plays in the realisation of visual word recognition, the following main hypotheses must be accounted for:

- the Universal Direct Access, abbreviated as UDA (Baluch and Besner 1991);
- the Phonological Mediation Hypothesis, abbreviated as PMH, or Strong Phonological Hypothesis (Lukatela and Turvey 1991: 951);
- the Universal Phonological Principle, abbreviated as UPP (Perfetti *et al.* 1992: 227-248).

The UDA theory claims that all writing systems use a visual route that directly leads to word reading (grapheme-to-meaning, the equivalent of the lexical procedure we discussed above). During the process, the visual features of the stimuli are matched to the orthographic information in the reader's internal dictionary (or mental lexicon); hence, the meaning is retrieved. Phonological processing happens occasionally and is therefore not a mandatory constituent of the process. Van Orden and Kloos (2005: 61-78) describe DA as follows:

> Direct access takes a visual representation of the word as input and assigns it to an abstract placeholder in the mental lexicon. Identification of a word happens in one step going from a visual representation to an entry in the mental lexicon. It is called direct access because it creates a shortcut that bypasses the grapheme-phoneme rules. To link each word's visual representation to a lexical entry requires word-by-word associations. The links develop as a reader becomes familiar with words.

The dual-route approach is a contender to this view. As underscored by Frost (2005: 272-295), the DR theory posits that the reading process involves an interplay between phonological computation (non-lexical route) and visual orthographic processing (lexical route). Moreover, though DR predicts that the preferential route might vary according to the type of orthography, it also postulates that the prerequisites for skilled reading are the acquisition of the orthographic representations (resulting from frequent exposure) and the ability to draw upon grapheme-to-meaning bypassing the grapheme-to-phoneme route (ibidem). In sum, for skilled reading, the phonological process is viewed as either a contingent necessity or an ultima ratio resorted to by unskilled readers.

In the PMH, the written input triggers automatically, and very rapidly, the activation threshold of the phonology node, independently from the writing system and the reading skills. From there, the phonological information is retrieved, and the corresponding word meaning is accessed. However, there are scenarios where the phonological computation is not accurate enough (typically due to the kind of orthography being used). In those contexts, a 'lexical reshaping' is to retrieve an accurate representation of the word. Perfetti *et al*. fine-tuned this framework regarding the specific writing systems being used (1992). Drawn from the claim that phonology is an essential constituent that is activated whenever a graphic input is encountered, the specific levels and details of phonological activation are also determined by the features of the orthography which instantiates the activation. It is, therefore, now time to turn our attention to the typological classification of the writing systems.

2.3 The role of phonology in WR

Complete and accurate phonological representation in working memory is a crucial factor in enabling vocabulary growth (Zhang, Lin*, et al.* 2014: 9). Phonological processing refers to awareness and use of the sound structure of oral language in processing written and verbal information of the language (Wagner 1988: 262; Wagner *et al.* 1997: 468).

Four phonological processing abilities are identified by Wagner (1988: 262): analysis, synthesis, coding in lexical access and coding in working memory. The former two concern phonological awareness, which refers to the awareness and access to any phonological units, including syllables, phonemes, onsets, rimes, etc., of one's language (Wagner 1988: 262; Treiman 1991: 159; Durgunoğlu and Öney 1999: 281). Phonological awareness involving analysis and synthesis is one of the critical skills in alphabetic literacy acquisition and a reliable predictor for sequential development in reading (Durgunoğlu and Öney 1999). The latter two concern coding information using phonological representations or codes of different levels in the language (Wagner 1988: 262). The purpose of coding in lexical access is to retrieve a word in a lexicon. The purpose of coding in working memory is to maintain efficient coding during the ongoing process.

Much research demonstrates that phonological processing abilities are linked to reading acquisition and development, but the underlying mechanisms have not been fully established (Wagner *et al.* 1997: 468).

English is an alphabetic writing system whose orthography is a code to represent the spoken language. To acquire word recognition skills, one has to understand two characteristic features of the English writing system.

First, there are systematic correspondences between the spoken and written forms. Writing units such as letters and letter clusters mainly map onto speech units such as phonemes and syllables. However, the correspondence is complex and inconsistent. Several reasons are proposed to explain the source of irregularities. One reason that causes this inconsistency might be that English writing represents morphological as well as phonological information. Chomsky and Halle (1968) argued that English writing follows a general principle that phonology is only encoded if rules governed by the morphological structure cannot be applied. Thus, irregular words such as ‘sign’ and ‘bomb’ can find their correct pronunciations in their morphological related words such as ‘signature’ and ‘bombard’. Although it is uncertain whether this analysis is valid, it clearly shows that English writing preserves morphological information (Seidenberg and McClelland 1989: 524). Other explanations include unbalanced changes of spoken and written forms, foreign words, language reforms and accident events (Seidenberg and McClelland 1989: 524). For example, ‘unbalanced changes’ refer to the fact that the spoken form of a language is more likely to change over time than the written form. For example, while the pronunciation of ‘bean’ in British English (same sound as ‘been’) is phonologically reduced to ‘bean’ in American English (same sound as ‘bin’), the written form remains the same.

Second, with almost indefinite combination possibilities of 26 letters in the English writing system, only a small percentage are permissible under the restriction of spelling rules, and an even smaller percentage are lexicon entries (Seidenberg and McClelland 1989: 524). Constraints may significantly influence word recognition processing by 1) facilitating readers who have the knowledge to identify possible or realised letter combinations; 2) providing cues to syllabic structures based on the fact that possible sequences of phonemes are constrained by speech organ movements and the specific language (English); 3) providing cues to morphological structures when new words are systematically organized by combining existing words which are sublexical units contributing to the meaning of the whole word. It is worth noting that morphological information encoded in English orthography is irregular and inconsistent (Seidenberg and McClelland 1989: 524-525). More specifically, one morpheme might consist of several syllables; and syllable boundaries do not reliably mark the morpheme boundaries (Zhang, Lin, *et al.* 2014: 6) as they do in Chinese.

There are two competing hypotheses which attempt to explain how word meaning is accessed for English as a first language: 1. the prelexical phonological recoding hypothesis; and 2. the direct visual accessed hypothesis. Because English speaking children learn to speak before they learn to read, it might be reasonable for one to argue that learning to read is simply the conversion of print to sound. The extant lexicon can be accessed using phonological information. Phonology recoding mediates the lexical access in skilled adult readers. Alternatively, children learn to read by forming an independent path from orthography to meaning. Phonology has no role in meaning access for proficient adult readers.

Phonological coding as one of the four above-mentioned phonological processing abilities has been commonly considered as the phonological route to word recognition (Wagner 1988: 263).

2.4 Chinese character recognition models

More than 80% of Chinese characters are phonetic compounds (Chen *et al.* 1996), in which both semantic and phonetic information is directly embedded in the characters. Half of these characters contain a pronunciation cue without considering the tones (Hsiao and Shillcock 2006: 418). The rate goes down to only approximately 26.3% for phonetic compounds with a regular pronunciation match between the phonetic compound and the whole character, depending on different criteria researchers used (Fan *et al*. 1984, cited in Williams 2013). This specific feature of Chinese characters makes it a weak claim that the non-lexical route alone is an adequate means to recognise characters. The absence of grapheme to phoneme conversion in the nature of Chinese characters has to be recaptured by a modified dual-route model.

2.4.1 Dual route for character recognition

A general agreement exists among researchers that both semantic and phonological routes are involved in Chinese reading because both phonetic and semantic information is heavily embedded in these phonetic compounds. This dual-route theory in Chinese recognition is supported by substantial studies (Williams and Bever 2010; Williams 2013). Those who support using the dual-route search model to explain how Chinese characters are visually recognised suggest that one of the routes is indirectly through the sound of characters and the other route is direct from form to meaning (Zhou and Marslen-Wilson 2000). Such a simultaneous, parallel search model is a universal model which has been proved feasible across languages, including English (Coltheart *et al.* 2001). Results found by researchers (Tan *et al.* 1996; Perfetti and Tan 1998) support this view by showing that regular phonetic radicals (which accurately indicate the sound of the character in which they are embedded) facilitate the recognition of the corresponding phonetic compounds. Thus, they proved that phonological processing also existed in Chinese character recognition. The weakness of this model, however, is that it does not explain sublexical phonological processing.

2.4.2 Triangle model

Because of the flaw of the traditional dual route model in failing to explain the non-lexical route, a Chinese-specific triangle model was proposed by Weekes and colleagues (1997) (see Figure 9).

In their experiment, an anomic patient who had intact word comprehension, word repetition and oral reading skills but with an impaired recall of words was asked to name visual inputs or oral reading characters of the same name. They found that this patient's performance on oral reading of characters was significantly better than on oral reading of pictures. It demonstrated that when naming characters, semantic representation of the character is necessarily fundamental for the normal spoken word production. In other words, when naming a character, the reader can directly retrieve the phonological information embedded within the character or its radical rather than proceed via a semantic reading pathway during which the meaning of the character has to be retrieved first.

Taft (1994) suggested a multilevel interactive-activation framework in which radicals work as a functional orthographic unit in its host character recognition, and activation of radical-level information is used in such a process.

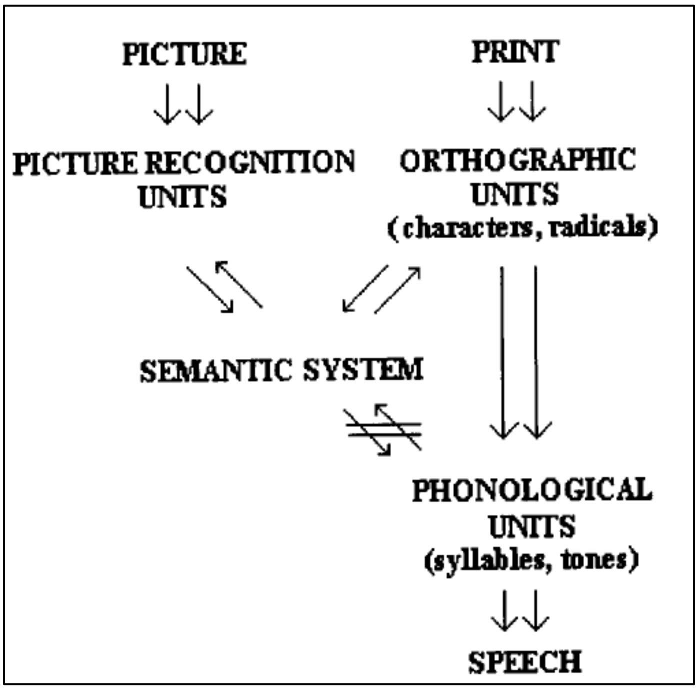


Figure 9: Model of picture naming and oral reading Weekes *et al*. (1997: 17)

2.4.3 Orthographic Awareness Model

Ke's Orthographic Awareness Model (Ke 1996, cited in Zhang and Ke 2018: 123) is a theoretical framework of the development of L2 Chinese character acquisition. In this model, Ke suggested an orderly and progressively developed acquisition process which consists of three stages (See Figure 10). Also, according to the traits of the learners at each stage, Ke believes that a systematic and explicit introduction of character construction rules are necessary to help learners develop an analytical ability in processing Chinese characters.

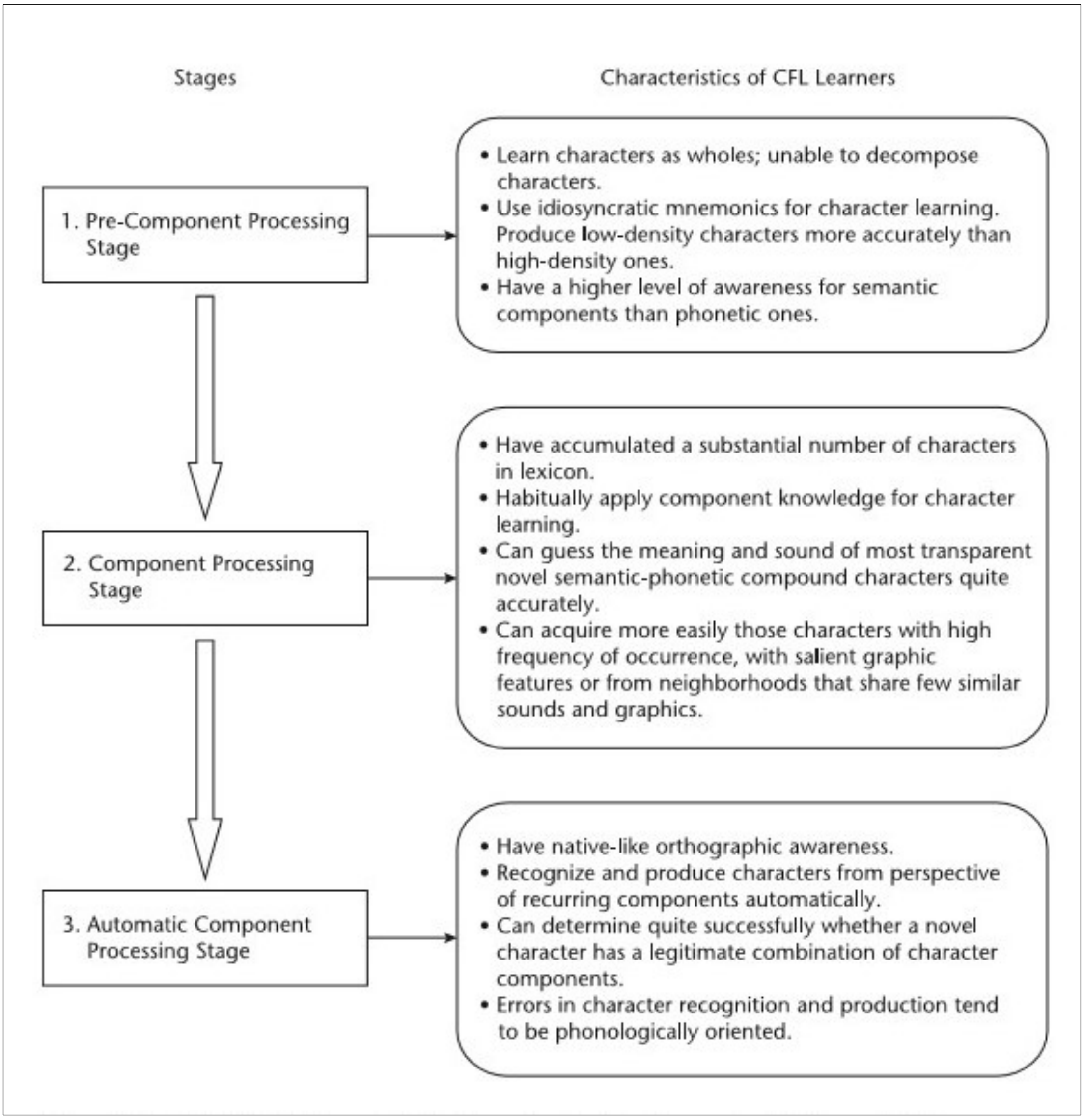


Figure 10: Orthographic Awareness Model[2]

According to the model above, three distinct stages of development are proposed.

Stage 1: The Pre-component Processing Stage. Learners lack the ability to deconstruct characters and treat individual characters as a whole. Rote learning and mnemonic memory technique are heavily depended on for learning. The most common errors learners make are shape-related. The teaching instruction given during this period should prioritise the knowledge and practice of strokes, writing order, basic structures, and high-frequency radicals and Pinyin. Particular emphasis will be given to semantic radicals, such as identifying and linking them to their host characters. By

[2] Cited in Zhang and Ke 2018: 124.

the end of this stage, learners are capable of using the frequent and familiar semantic radical patterns to infer the meaning of novel characters (Zhang and Ke 2018: 125).

Stage 2: The Component Processing Stage. With more knowledge of characters on both lexical and sublexical levels accumulated in learners' long-term memory, learners start to disassemble characters when processing them. Learners actively applying the orthographic knowledge in recognising and learning characters symbolises the end of this phase. At this point, learners are very adept in processing semantic radicals and have formed some implicit knowledge about phonetic radicals. Explicit instruction on phonetic radicals is vital to help learners establish a correct connection between print and sound. Teachers should also draw their attention to assist the learners in distinguishing characters that have similar forms.

Stage 3: The Automatic Component Processing Stage. Active application of orthographic knowledge becomes automatic, similar to the way native speakers process characters. Their high-level orthographic awareness helps them recognise characters and analyse novel characters efficiently. Only at this stage learners are capable of correctly judging if a given character is legitimate; in other words, if it follows the construction rules. The major errors made at this stage are phonologically related. Homophones might become a barrier during this time, and more effort needs to be put into helping learners overcome this confusion.

2.5 Reading strategy development: from visual strategy to phonological strategy

The visual strategy might be a first and universal strategy for Children when they start to read. Both Chinese and English native speaking children use a similar strategy when they start to learn to read: the visual strategy. Characters/words with distinctive features help reading performance, while characters/words show visual similarity interfered (Chen *et al.* 2014). Chen and colleagues conclude that visual strategy might be universal for beginner readers as they cannot process characters/words comprehensively.

Phonological strategies refer to the strategies using phonological information provided by phonetic radicals: the phonetic strategy – using the knowledge of regularity, and analogy strategy – using the knowledge of consistency (see section 3.2.2). The phonological strategy is developed after a few words are learnt. The time gap between visual and phonological strategies differs in different writing systems, which might be affected by the orthographic ‘depth’ (see section 1.2). The deeper a writing system is, the later the phonological strategy will be developed and used. Beginner children-readers of shallower languages (i.e., German and Portuguese) start to use the grapheme-phoneme correspondence rule earlier than those of relatively deeper languages (i.e., English). Chinese children have to rely on distinctive visual features of this most phonologically ‘deep’ writing system longer than English speaking children as the print-sound relations for Chinese characters are unreliable (Chen *et al.* 2014: 34). This theory is supported by Chen and colleagues (Experiment 1): with continued reading experience, the developmental trajectories of Chinese and English native speakers diverge. English children soon depend more on phonetic spelling than visual spelling after they learn a few words. Chinese children, on the other hand, still rely much on distinctive stroke features till a later time.

Previous studies investigating the development of learning strategies (Shu *et al.* 2000; Lin and Collins 2012; Chen *et al.* 2014) have found the regularity effect and the consistency effect in naming Chinese characters from Chinese L1 and L2 learners, such as However, whether the phonetic and analogy strategies develop simultaneously for Chinese speaking children is still in question. Shu and colleagues found that L1 learners developed a phonetic strategy as early as grade 2. In grade 4, they show overgeneration and start to be aware of the analogy strategy and develop it until college level (2000). This result is inconsistent with Chen and colleagues’ (2014) findings in that both the phonetic strategy and the analogy strategy are proficiently used by 2nd graders. Moreover, they found that while both 4th graders and 6th graders used the analogy strategy to learn and pronounce novel characters, 6th graders made more decisions based on analogy strategy when compared to 4th graders. The fact that older and better readers used more knowledge of consistency rather than regularity suggests that consistency is a better index to predict the sound of a character based on the sound of its embedded phonetic radical (Shu and Wu 2006: 113).

Moreover, while it is debated as to whether or not it takes two or more years’ study for Chinese speaking children to be aware of consistency, Chinese L2 adult learners show consistency effects only after two years of instruction. Thus, a more strategic approach to enforcing consistency can be designed to help L2 learners learn Chinese characters more effectively.

2.6 Phonology mediation in reading alphabetic scripts and Chinese characters

For those generally agreed on pathways from orthographic input to lexical semantic, there is a consensus that the direct mapping between orthography and semantics seems more suitable for accessing Chinese characters, and the indirect mapping via phonological mediation is more efficient for alphabetic scripts (Zhou and Marslen-Wilson 2000: 1245). Generally speaking, alphabetic scripts have a systematic mapping between orthography and phonology. Most of the time, when words are orthographically similar, their phonological features are similar too (Ma *et al.* 2015: 1). Also, the relations between orthography and semantics are mostly arbitrary. Moreover, the self-consistent and efficient visual-phonological relation is strengthened as learning progresses and dominates over the less self-consistent visual-semantic relation.

Compared with alphabetic writings, the correlations between visual-phonology and between visual-semantic are the contrary in Chinese writing. On the one hand, a much more arbitrary visual-phonological relation may not allow the same efficient computation in alphabetic languages. Characters which look similarly mostly have different pronunciations from each other. However, characters which look differently may share the same sound. Even though phonetic radicals provide some support to the phonological processing of phonetic compounds hosting them, such function is not very reliable. On the other hand, the visual-semantic relations are less arbitrary because semantic radicals, relatively speaking, consistently provide clues to the meaning of the host characters. Moreover, characters with radicals that enter into many combinations, or in other words, with high radical combinability, would receive more reciprocal activation or feedback from their character 'neighbours' (Feldmen and Siok 1999).

CHAPTER 3: CHARACTER RECOGNITION STRATEGIES

3.1 Functional orthographic units

3.1.1 Constructing units and unit phenomena

As the previous chapter highlights, Chinese writing employs a three-tier orthographic structure instead of using letters as a fundamental component in the Roman alphabetic writing systems. Strokes (also referred to as components in this thesis) form into radicals; radicals then, in turn, combine into characters (Shen 2005: 50). Radicals are classified into two categories depending on their functional role within a character: phonetic radical and semantic radical (for detailed explanation about the function of these two components see section 3.2).

According to the number of the radicals used to comprise them, characters can be categorised based on their physical structures into integral (single) characters comprised of only one radical or compound characters comprised of more than one radical. A compound character can be further categorised based on the functions of the radicals into an associative compound (contains two or more semantic radicals) and a phonetic compound (contains one phonetic radical and one semantic radical). Approximately 72%-85% of modern Chinese characters are phonetic compounds, among which 23% are regular phonetic compounds, 42% are semi-regular, and 15% are irregular phonetic compounds (Shu *et al.* 2003).

There are several ways to configure a phonetic compound visually. The relative position of the phonetic radical to the semantic radical within a character can be on the left/right, top/bottom, inside/outside or at the corner. However, the most commonly seen type of phonetic compound, which is also the focus of this thesis, is the left-right structure type, specifically that in which the phonetic radical is on the right and semantic radical is on the left.

All these three orthographic structures: stroke, radical and character, have been treated as the primary unit of visual recognition in various theoretical accounts of Chinese character processing.

3.1.2 Structural awareness

One crucial factor influencing the character recognition process concerns structural organisation, specifically, visual perception and pattern recognition skills (Taft and

Chung 1999). There are three types of structures in terms of the relative placement of radicals within a compound character: left-to-right (e.g., 胡, 湖), top-to-bottom (e.g., 想) and outside-to-inside (e.g., 国) (Zhang and Ke 2018: 110).

The experiment carried out by Taft and Chung (1999) has shown that knowledge about character structures (how to break down left-to-right compound characters into radicals) benefits the recognition results most significantly when learners were instructed at the early learning stage rather than the before and the later learning stage.

Numerous studies have shown that explicit instruction on radical knowledge based on their systematically varying features enhances the learning process (Taft and Chung 1999: 247). These systematically varying features include the categories of semantic radicals, consistency of phonetic radicals and radical structures. One of the theories underlying the phenomenon is that deeper processing might aid memory during the learning process. Unlike strokes which activate more competition at the lexical level, radicals as larger subunits are easier to memorise and more efficient to implement the interactive-activation approach in recognition (Taft and Chung 1999: 248).

3.1.3 Strokes and character structural complexity

Considering that each Chinese character is configured in an imaginative square-shaped box of the same size, the number of strokes contained in a character is referred to as character density (Zhang and Ke 2018: 105). Character complexity (density) effect refers to the influence of the stroke count on the speed and accuracy of character recognition. However, findings regarding the character density effect are mixed. Sergent and Everson (1992) found out that low-density characters (strokes less than seven) were recognised faster and more accurately than high-density characters (characters with more than seven strokes) by two learner groups: beginners (1st-year Chinese L2 college students) and intermediate learners (3rd-year Chinese L2 college students). On the contrary, no significant character density effect was found in the experiment with high proficiency Chinese L2 learners (Hayes 1987).

The incongruent relationship between character density effect and character recognition efficiency might be due to the different processing strategies adopted by Chinese L2 learners of varying proficiency levels. Beginners may tend to process characters at strokes as the smallest unit then move on to the bigger units such as radicals or even characters as a whole as their proficiency improves. This strategy shifting might explain why the character density effect can be found in lower level learners but not advanced learners.

This thesis deals with character density effectiveness which may influence the efficiency of character recognition on L2 learners of the intermediate to advanced level. Hence, strokes will be taken into account when designing the experimental material, as explained in Section 5.3.3.

3.2 Radical awareness in L1 and L2

Radicals and their structural information embedded in characters are related to the cognitive and psychological process of L1 and L2 Chinese character recognition. By the level of HSK4 (roughly equal to three years of formal Chinese learning in the third-level education setting), 70% of characters learners have learnt are phonetic compounds. According to A Dictionary of Chinese Character Information (1988), 250 semantic radicals are being used in forming phonetic compounds. Among those semantic radicals, 77 per cent of radicals are standalone characters while 23 per cent are bound radicals.

3.2.1 Semantic radical: transparency, consistency and combinability

Semantic radicals in phonetic compounds convey specific meanings related to the host characters. However, this meaning representation can be varied in *functional salience*, referring to the extent to which a semantic radical provides the information that can be used to infer the meaning for the host character (Zhang and Ke 2018: 106). This definition illustrates three functional salience properties: transparency (to what extent the meaning of a radical relates to the meaning of the host character), consistency (if a semantic radical is consistent in representing a specific meaning or stands for multiple meanings) and combinability (the number of characters which contain the same semantic radical). A high-salient radical would be one that frequently appears in many commonly used characters and has only one dominant meaning, which gives a clear clue to characters that contains it as a semantic radical (Zhang and Ke 2018: 106). A radical with high functional salience provides more information about its host characters than that with low functional salience.

Functional salience is linked to many radical properties, which heavily influence how they can be used to recognise characters. Some factors might reduce functional salience. For example, there are many types of functional relationships between a semantic radical and its host characters; or the radical is not a free-standing character; or the radical does not have a concrete meaning (Lü *et al.* 2014: 170).

Familiarity also affects how readers process the information provided by semantic radicals. The more readers know about the radicals, the more they are motivated to use them. Empirical evidence shows that for Chinese L1 readers, the familiarity with a semantic radical is strongly related to two of the functional salience properties: combinability and transparency. Functional salience is also related to the character recognition process of Chinese L2 learners. However, such facilitation is restricted to those with good radical knowledge (Lü *et al.* 2014: 181). Experiment results (Lü *et al.* 2014) have shown that Chinese L2 learners with less than two years of learning experience are generally attentive to the information of semantic radicals even though they might not have developed the skills to use the information efficiently.

When designing the experimental material (see section 5.3.3), functional salience of semantic radicals will be taken into account when choosing critical phonetic compounds according to the design requirements: 1) chosen phonetic compounds which contain semantic radicals which are standalone characters with concrete meaning; 2) semantic radicals either clearly indicate the meaning of its host character or are unrelated in meaning to its host character.

3.2.2 Phonetic radical: regularity and consistency

Phonetic radicals are related to their host characters' pronunciations in various ways. Two main indicators reveal the relationship from different aspects: regularity and consistency (Zhang and Ke 2018: 107-108). Regularity shows how precisely a phonetic radical reflects the pronunciation of its host character. If the onset and rime (and tone[3]) of a phonetic radical's syllable match those of its host character syllable, the host character is considered regular. However, if both the onset and rime of a phonetic radical's syllable are different from those of the host character's syllable, the latter is irregular. Also, there is the case of a semi-regular character when only either onset or rime from a phonetic radical and its host character matches.

[3] Tone is not taken into consideration in this research.

Consistency is defined over the orthographic neighbourhood (Braze and Gong 2018: 278) or phonetic family (Shu *et al.* 2003). It shows how consistent a character's pronunciation is with other characters which contain the same phonetic radical. It does not matter if the phonetic radicals match their hosts characters or not. Those phonetic compounds with the same phonetic radicals are neighbours. Characters in the same phonetic family contain all the neighbours and the phonetic radical itself as an independent character. For all the characters in the same phonetic family (sharing the same phonetic radical), they are consistent if they all sound the same; semi-consistent if all the neighbours sound the same, but the phonetic radical (as an independent character) sounds differently; or inconsistent if there is more than one sound among the neighbours. The level of consistency in a family of characters affects how children learn and read characters. Even semi-consistent information can be helpful in reading (Chen *et al.* 2014: 43).

Interestingly, in alphabetic writing systems, the spelling is 'a categorical distinction' (Braze and Gong 2018: 277), either regular or irregular, depending on whether the grapheme-phoneme correspondence rules are correctly followed. However, consistency is 'a continuous graded property' (Braze and Gong 2018: 277), which can take values between 0 and 1, demonstrating how entirely consistent a spelling pattern neighbourhood can be. For example, the spelling pattern <ink>'s neighbours are perfectly consistent because <ink> is pronounced the same in all the words containing it (e.g., 'link', 'pink'). However, <ave>'s neighbourhood is not so consistent because <ave> has more than one pronunciation when it appears in different words (e.g., 'have', 'pave'). How the dual route cascaded model and triangle model explain the differences between orthographic regularity and consistency is one of the main differences between the two models we elaborated earlier (see sections 2.2 and 2.5).

Lin and Collin (2012) suggested that high-frequency or familiar characters might be processed holistically and automatically while low-frequency or strange characters might be processed at the sub-lexical level. When an automatic retrieval is impossible, readers need more information to help with the recognition. Phonetic radicals are more regular in low-frequency characters than in high-frequency characters. As a result, there is a combined effect between regularity and frequency on both L1 speakers and L2 learners. For L1 adult speakers, regularity effects are very limited in recognising high-frequency characters but prominent to low-frequency and new characters (Tsai *et al.* 2005). Lin and Collins (2012) have provided evidence to support that medium level (about two years of the learning experience) L2 learners show regularity effects in naming both high and low-frequency characters.

3.3 Character level factors

Factors that might affect the character recognition processes include learner-independent factors such as frequency, orthographic neighbourhood, or learner-depend factors such as the strategies used when characters are memorised.

3.3.1 Frequency

Frequency has been proved to be an important factor in learning and reading a writing system. The majority of word recognition models took the frequency effect into account: more frequently used words can be recognised and named faster and more accurately than less frequently used words (Forster and Chambers 1973; Wang *et al.* 2003). However, the reasons used to explain the frequency effect are still controversial. It might be due to frequency-based sequential search among the candidates (Forster 1976), or different activation levels or thresholds decided by the frequency (the higher the frequency, the easier it is to be activated) (Morton 1970), or biased response (Norris 1986). These studies suggest that the frequency effect is reliable across different tasks. Also, research in both alphabetic and Chinese writing systems have shown an interesting frequency and regularity/consistency interaction effect. For Chinese character recognition, when character frequency is low, regular and consistent phonetic radicals facilitate naming speed and character recognition; however, there is no such facilitation when character frequency is high. Another finding of how frequency affects character recognition relates to the interaction between frequency and structural complexity found by Wang and colleagues (2003). In a lexical decision task, they found that simple characters could be decided faster than compound characters if they are noncharacter. This time difference appeared bigger for low-frequency characters than high-frequency characters.

3.3.2 Orthographic neighbourhood and attention direction

Words with many orthographically similar words take longer to identify than words with fewer orthographic neighbours (Altmann 1996: 7). Other than the size/number of the orthographic neighbourhood, the frequency of the neighbourhood also affects the recognition speed.

3.3.3 Learning strategies

Different learning strategies are used by L2 learners to memorise new characters and retain the characters they have already learnt. Those strategies can be roughly divided into two categories: rote learning strategies and meaningful learning strategies. Rote learning refers to the learning technique that utilises repeated memorisation. Writing a character repeatedly as a typical rote learning strategy is one of the most commonly used strategies in learning Chinese characters for L2 learners from the beginning level to the advanced level (McGinnis 1995; Yin 2003). Rote learning often leads to poor character learning results because it is associated with shallow processing, such as graphic strategies, which mainly deal with graphic features of characters and laborious and inefficient repetition (Zhang and Ke 2018: 116). However, rote learning remains an essential tool for learners, especially beginners, before they have enough knowledge to apply more analytical learning strategies.

Meaningful learning strategies are viewed as more profound; hence, more advanced strategies involve elaboratively analysing a character's internal details (Shen 2004). Meaningful learning strategies are also used by learners of different levels, including using orthographic information provided by graphic features and semantic/phonetic radicals and using mnemonic elaboration aided by imagery/personal experience (Shen 2005; Zhang and Ke 2018). In the literature, some works focus on providing supports that helping learners with the memorisation of characters (Matthews and Matthews 2007; Heisig and Richardson 2009, McNaughton and Fan 2013). By conducting deeper processing strategies, learners attach more relevant and enriched information to the characters. This elaborated information provides more cues to the learners when they retrieve the character (Zhang and Ke 2018: 118). In order to apply this kind of strategy, learners need to be aware of and have a good knowledge of the types of strokes or radicals or have the ability to elaborate. Orthographic information can also be used in the process of mnemonic elaboration when connecting abstract and unfamiliar information of a character to a concrete and familiar concept. However, learners do not necessarily utilise orthographic details correctly. For example, a learner made up a story to link the meaning of the phonetic radical 反 (*fǎn* ‘opposite’) rather than the semantical radical

片(‘sheet’) to the meaning of the host phonetic compound 版 (*bǎn* ‘edition’): the printing plate is ‘opposite’ to the final publication (Li 2009).

For all the mentioned important issues in word recognition research: print-sound correspondence effects, orthographic neighbourhood effects, number of meaning effects, they all share the possible attentional selection which chooses appropriate pathways to process and prioritise the importance of one over another available for a given word, depending on the goal engaged (Balota *et al.* 1999: 47). Without acknowledging and implementing this flexibility in lexical processing, the results from the tasks might be misleading (Balota *et al.* 1999: 49).

3.4 Character processing in L2

3.4.1 Lexical level processing

The lexical-level processing is related to processing a character’s print, sound and meaning information. Whole character processing strategies adopted by L2 readers can be revealed by their error types made during a task. For example, confusing two characters that share a strong physical resemblance (e.g., 休 and 体) indicates that the participant prioritises the graphic information. Similarly, if two characters that share the same pronunciation (e.g., 课 *kè* and 刻 *kè*) but have no physical resemblance are mistakenly recognised for one another, that means the participant pays more attention to the phonological information. The confusion also happens with two characters which are related only in meaning but not in form or sound (e.g., 兄 *xiōng* ‘older brother’ and 弟 *dì* ‘younger brother’). If participants made this type of error it means the semantic strategy is used (Zhang and Ke 2018: 112).

Beginner L2 readers mainly depend on the graphic strategy. However, with increased experience, such dependence on graphic information decreases, and they engage more in processing phonological and semantic aspects of a character (Liu *et al.* 2007). Empirical results also show that learners with a bigger vocabulary size tend to use less graphical strategies than those with a smaller vocabulary size (Jiang and Liu 2004).

This graphic strategy dependence by adult L2 readers, especially beginners, might be explained by the different word recognition processes defined by the Chinese writing system, which is different from their L1 alphabetic writing system. When

English native speakers recognise an English word, semantic processing is proceeded by activating both orthographic and phonological information simultaneously (Berent and Perfetti 1995; Coltheart *et al.* 2001). The process is different when English native speakers recognise a Chinese character. Graphic features have to be identified, and orthographic information has to be retrieved before word-level phonological and semantic processing is activated (Liu *et al.* 2007). The difference might lead to the assumption that sound has no role in helping to retrieve the meaning. However, the active role of phonology in character recognition has been found by studies on both L1 and L2 Chinese readers (Perfetti and Zhang 1995; Everson 1998).

3.4.2 Sub-lexical level processing

Sub-lexical processing of Chinese characters is different from that of alphabetic writings. In alphabetic writings, the print input only activates phonological and semantic representations at the lexical level. The semantic information of sub-lexical components would not be activated. However, the activation at the sub-lexical and lexical levels in Chinese character reading have no fundamental differences. Sound and meaning information in the mental lexicon is activated in parallel. The two-level activations accelerate or inhibit each other depending on the sub-lexical units' consistency, regularity, and opacity (Zhou *et al.* 2000).

The reason for this parallel processing of Chinese compound characters is that they are similar to compound words. In both cases, their constitutional parts have their corresponding semantic and phonological information. Unlike Chinese characters, morphemes in alphabetic writings do not usually convey semantic information. Also, visually there is usually an apparent gap between the constitutional parts within compound characters. This gap makes it easier to separate and process the sub-lexical units. There is no such gap in alphabetic writings (Zhou and Marslen-Wilson 1999a).

The Competition Model (MacWhinney 2002) illustrates that language processing is viewed as a competition between multiple linguistic cues for limited channels, and only the cue with the strongest activation in terms of time and strength wins. The activation can be modified by several factors, including association strength of the cue to the target item, the completeness of the cue matching the target item, frequency of previous cue activation, etc. By applying this model to current research, the activation of the representation of semantic and phonetic radicals that happens in character recognition compete with each other, and the activation can be raised through practices designed to increase association strength and frequency of radical activation.

3.5 Key issues in L2 character recognition

3.5.1 An intralinguistic comparison

Speakers of more than one language do not manage the languages separately (Jared 2015: 165). However, the knowledge of one language influences the way they speak, listen, read, etc., other languages. The extent to which the languages interact can be decided and complicated by factors such as typological distance, relative level, frequency of use and starting age of each language (ibidem: 165). This section focuses on how reading, more specifically, visual word recognition, is being processed by Chinese L2 adult learners whose L1 is English.

Different writing systems map their own individual spoken languages. As we discussed above, almost all the languages in the world are phonographic writing systems that are phonologically based. Phonographic writing systems can be categorised by the size of their phonological units: phoneme, mora and syllable. Chinese can be characterised as a syllabic writing system (Rogers 2005), and English is an alphabetic/segmental writing system that belongs to the phonemic writing system family. Each Chinese character as a grapheme is a monosyllabic morpheme that reflects both a unit of sound (syllable) and a unit of meaning (morpheme) (Wang, Koda*, et al.* 2003: 130).

Both Chinese and English orthographies partially and simultaneously encode information on phonological units and morpheme. Also, both writing systems have systematic rules and many irregularities. A reader's knowledge of either orthography might result from correlations among radical/letter patterns, radical sound/phonemes (syllables), morphemes, etc. Students who are learning to read Chinese or English as a second language might be facilitated by the systematic aspects of the writing systems, such as the correspondences between form and meaning or spelling and sound.

Research has proved that phonological awareness is more strongly associated with word recognition in alphabetic writing systems such as English and Korean than in morphosyllabic writings such as Chinese (McBride-Chang *et al.* 2005). However, it worth noting that both English and Chinese are significantly correlated with phonological awareness in word recognition.

3.5.2 Learner related factors in character recognition

L2 Chinese character acquisition learners are divided into three groups in the literature (Zhang and Ke 2018: 112): a. East Asian language background learners; b. Heritage background learners; c. Alphabetic language background learners. Group A learners have some advantages because characters partially constitute their writing systems, such as Japanese Kanji and Korean Hanja. Group B learners also have advantages because they had been raised in an environment of high exposure to the Chinese language. Most of them can understand or speak Chinese at different levels before they start to read, and they usually have some prior knowledge about characters. Group C are learners such as English, French, German native speakers whose writing systems are typologically remote from Chinese writing (Zhang and Ke 2018: 114). It is generally agreed upon that heritage learners (group B) have better radical awareness when compared to non-heritage learners (group A and C) (Shan and An 2010).

While Group A and Group B learners outperform Group C learners in various experimental tasks such as character naming tasks, dictation tests, etc., there are two issues concerning the L1 background in L2 character recognition that are worth noticing. Firstly, the advantage stands out mainly in the early stage of learning. With an increase in proficiency, the performance gap becomes less significant or even disappears (Koda 1996). Secondly, certain advantages demonstrated by Group A and Group B over Group C learners do not change the acquisition order of structural awareness. Left-to-right and top-to-bottom characters containing two radicals are acquired earlier than characters structured with more than two radicals. The biggest challenge is characters formed with an enclosure structure (Xu 2007).

There is also evidence which has shown that L1 language background has limited or no influence on the overall character acquisition process. Chen (2001) found out that a graphic strategy is adopted by both Japanese learners and learners with alphabetic language backgrounds. Many errors made by intermediate L2 Japanese learners are related to inadequate knowledge of radicals, which indicates that they had not fully developed a good understanding of characters at lexical and sub-lexical levels. For example, they mistook radical 忄 ('heart') for 亻 ('person') in the character 忧 ('to worry') due to the fact that they did not notice the semantic relationship between the radical 忄 ('heart') and the character 忧 ('to worry'). Also, they confused 错 *cuò* for 销 *xiāo* because they failed to identify 肖 *xiāo* as the phonological cue for the character

销. Ke (1998) analysed a character recognition task performance of both heritage and non-heritage groups. The results have shown that there is no significant difference between the two groups.

In conclusion, more than 80% of Chinese characters are phonetic compounds. Sublexical processing of those compound characters is involved in the lexical processing from the initial phase. Chinese native speakers can fully use the information from both semantic and phonetic radicals to facilitate the decoding process, while L2 learners may be on the way to construct native-like viable reading strategies. The learner's proficiency level may determine their developmental stage. Identifying L2 learners' proficiency-depending processing patterns will lead to a better understanding of the missing information or insufficient decoding strategies when they are reading characters, and will therefore lend some pedagogical implication to L2 instructions.

CHAPTER 4: SUBLEXICAL PROCESSING

This study of character recognition in Chinese L2 mainly focuses on the development of radical knowledge, and the processing of characters in sublexical units (sublexical processing). The latter is the area that is garnering the greatest interest in the literature. It helps to clarify the cognitive processes activated by L2 learners when they are reading Chinese characters. The previous studies have presented a growing number of data supporting the fact that these cognitive processes involved in visual character recognition trigger processing at the sublexical level. These cognitive activities embrace two dimensions: spelling processing and functional processing. The first is based on the orthographic component, therefore, linked to the structure and density/complexity of characters; while the second is centred on the functional information conveyed by semantic and phonetic radicals. The most important question of sublexical processing, in the linguistic field and also in the didactic field, is to clarify what path is favoured at different stages of acquisition. In other words, is it spelling or functional decoding privileged? And if the latter prevails, is the processing path mainly based on semantic radicals or phonetic radicals? Experimental research based on diversified methodologies was conducted to capture the cognitive processes at different stages. For example, there are techniques such as the lexical decision task with a blurred radical, or the more sophisticated detection which monitors eye movements, Sometimes, those techniques are combined with priming tasks in which relevant stimuli (prime characters) activate the recognition of its following stimulus.

Thanks to previous research, the picture of the recognition process has been gradually composed. Moreover, through the evaluation of the limitations of previous studies, the essential requirements for an effective stimulus design are emerging. In order to examine the major experimental protocols, highlight some limitations, and identify areas which need further investigation, this study presents an overview of the major studies, with particular attention to the experimental methods and protocols used.

4.1 Measurement of the character recognition process

Studies on the acquisition of Chinese L2 characters are currently being carried out in interdisciplinary research such as psycholinguistics, which typically implements investigations using quantitative methods (Zhang and Ke 2018: 120). In the examination of the visual recognition processing of the writing units, the priming technique is widely used. It is a technique using relevant stimuli (prime characters) to activate the recognition of the following stimulus (target character). The activation of the target allows researchers to measure the recognition time, analyse recognition errors and identify the position of activation (lexical or sublexical level, semantic radical or phonetic radical). Because primes and targets can be related in meaning, sound and form, priming techniques allow researchers to induce, and then to identify a specific type of activation (semantic, phonological or orthographically), as well as where and when it happens.

Priming is a psychological phenomenon which refers to the facilitating or inhibitive effect of the first stimulus (prime) on the response of the second (target) (Zhang and Shu 1989; Zhang and Li 2017; Zhang and Ke 2018: 106). The basic idea is that the identification time of a word can be reduced or increased by presenting a related word in advance (Altmann 1996: 7). The interfering effect is experimentally proven. It happens when the semantic, phonological or orthographic contents of the prime is activated in the time interval of presentation, just before the display of the target character (which is called stimulus onset asynchrony, or SOA). Through repeated use, priming can also enhance implicit and unintentional learning (Trofimovich and McDonough 2011: 4). However, in psycholinguistics it is solely used as an experimental tool. This technique is adopted to measure the changes in recognition speed and accuracy triggered by specific pairs of prime and target. In a lexical decision trial, the second word presented is similar to the one presented later in some way. For example, a prime and its target can have similar meaning, pronunciation or shape. Therefore, the purpose of the priming experiments used in the acquisition of Chinese L2 characters is to find out if an activation (semantic, phonological or orthographic) takes place, and if it does, where it occurs and in what temporal order. Based on the response time and errors, it is also possible to identify the types of activation which interfere with the recognition of a character (Braze and Gong 2018: 275).

In conclusion, the priming effect allows us to observe the changes in the accessibility of the semantic, phonological, orthographic constitutions of characters (Liu *et al*. 2007).

4.1.1 Lexical decision tasks on activating characters

Investigations of spelling decoding processes, and of measuring the performance of the involved subjects, typically combine priming techniques with specific tasks. For example, after being exposed to the prime, participants are usually asked to provide a response to the target (for example, click a yes/no key in a lexical decision task or provide the pronunciation of the character in a naming task).

The main experimental priming paradigms include: semantic categorisation tasks, naming tasks, masking tasks, backward masking tasks, judgment tasks, pronunciation-matching tasks, homonym recognition tasks, and lexical decision tasks (Williams and Bever 2010; Zhou *et al*. 2013; Ma *et al*. 2015).

Each type of test is designed to investigate a specific aspect of the character recognition processes. For example, in a semantic categorization, it is required to categorise a character into a meaning group; similarly, in a semantic judgment task, participants need to decide whether a pair of characters are synonymous. The data collected make it possible to capture the semantic processing processes within the character recognition activity (Chen *et al*. 2006: 180). Conversely, there are also deliveries focused on pronunciation, such as naming tasks, in which participants are instructed to pronounce target characters as quickly and as accurately as possible; or phonological judgment tasks, during which participants are asked to assess whether a couple of characters are homophones. In a masking task, the prime character is displayed for a short period of time, immediately followed by a shield (consisting of a pixel pattern) and then by the target. Participants are asked to report the characters they see, thus giving indications on orthographic processing.

In a lexical decision task, respondents have to decide whether the target is a real character or a pseudo-character. The latter are units that do not appear in the archive of Chinese characters in current use (legal characters). They are usually created by manipulating the strokes and the position of the radicals while still maintaining a combination that complies with the orthographic configuration rules of Chinese characters. The lexical decision is a recognition activity considered strategically neutral. This is because it does not logically induce recognition of either of the two radical types. Also, it does not favour either phonological or semantic processing but tends to trigger both types of activation equally (William and Bever 2010, 593, 600). Combined with priming techniques, this type of activity can be used to examine the effects of various dimensions of similarity between stimulus and target traits and to examine the role of functional components (semantic and phonetic radicals) in visual identification of characters (Feldman and Siok 1999; Tong *et al*. 2021).

Each type of task requires a different level of competence of the subjects and involves the production of different types of output. This aspect makes it very difficult to directly compare, in terms of accuracy and response time, the results of studies conducted based on different paradigms.

Furthermore, one important limitation of these studies on the decoding of Chinese characters derives directly from the type of task assigned in the experiments. Specifically, the type of task assigned can influence priming effects. For example, naming tasks lead to greater phonological processing, and semantic categorization tasks encourage greater focus on the meaning processing strategy (Shen and Forster 1999; Williams and Bever 2010).

4.1.2 Correlation conditions between prime and target

To obtain a precise picture of the different types of activation, recognition is stimulated through different types of correlations, at the lexical and sublexical levels (i.e., by operating a relationship between prime and target or between a radical of prime and target) and on the basis of semantic radical or phonetic radical.

Regarding the distinction between semantic and phonetic radicals, it is necessary to emphasise that almost all radicals have both semantic and phonological value. However, in this study, the classification is based on the position of a radical within a given semantic-phonetic character (*xíngshēngzì* 形声字)[4]. The radical placed on the left – the legal position of semantic radicals – is called semantic radical; the one on the right is called phonetic radical[5]. For example, the component 戈 *gē* 'spear' appears as a phonetic radical in 找 *zhǎo* 'to seek', and as a semantic radical in 我 *wǒ* 'I'. The reference guide for the classification of components in each semantic-phonetic compound is the Etymological Dictionary of Chinese Characters 汉字源流字典

[4] These compounds are typically designed as phonetic compounds. However, in the context of the priming experiments, the assumption is that the pictographic part, typically located on the left side of a character, carries semantic information. For this reason, in this study, the name semantic-phonetic compounds (or in short, phonetic compounds) are used for *xíngshēngzì* (cf. Sun Chaofen 2006: 104).

[5] However, we should keep in mind that in the complete inventory of semantic-phonetic compounds, 6.46% of characters have inverted radical positions (semantic component is on the right and phonetic component is on the left); while 17.50% of the characters have a structure where the semantic component is on the top and the phonetic component is on the bottom, or vice versa (Zhou 2018: 15)

Hànzì yuánliú zìdiǎn (2008). Finally, we should also remember that among the phonetic radicals, there are components that are not included in the traditional inventory of the 214 Kangxi radicals. Nevertheless, they have the function of phonetic radicals within the *xíngshēngzì*[6]. For example, in the case of 每 *měi* 'every' can be used as a phonetic radical in character such as 海 *hǎi* 'sea', 悔 *huǐ* 'to repent', and 酶 *méi* 'enzyme', etc. The type of relationship used is often coded to represent whether a prime and a target share common sublexical components. In later sections, different types of correlation will be presented. Below we propose the examples taken from Feldman and Siok (1999: 564, 567). Their study aims at the character recognition in Chinese L1, which is based on the presence of the same radical (R±) and their semantic congruence (S±). The experiment is designed to demonstrate that the recognition of characters includes the processing of semantic radicals. Based on the same radical 讠 'to talk' and the same target 论 *lùn* 'to discuss', authors identified four priming conditions:

R+ S+ the prime 评 *píng* 'to evaluate' and the target 论 *lùn* 'to discuss' share the same radical 讠 (R+) and they are semantically consistent (S+). In this case the semantic root is transparent for the prime.

R+ S- the prime 诸 *zhū* 'some' and the target share the same semantic root 讠 (R+), but they are not semantically congruent (S-). In this case the semantic root is opaque for the prime.

R- S+ the prime 述 *shù* 'to speak' and the target do not have the same semantic root 讠 (R-), but they are semantically congruent; in fact, the meaning of the prime ('to speak') is consistent with the meaning of the target ('to discuss') (S+).

R- S- the prime 竿 *gān* 'stick' and the target do not have the same semantic root 讠 (R-), and they are not semantically consistent because the meaning of the prime ('stick') is inconsistent with the meaning of the target ('to discuss') (S-).

6 For an overview of the writing units and components of the Chinese writing system, see Eletti, Casentini and Fontanarosa (2021), in this same volume.

4.1.3 Interaction between correlation and other crucial factors

The seminal investigation conducted by Feldmen and Siok (1999) has brought to light a series of methodological problems that may show a combined effect of correlation. For example, in the experiment mentioned in the previous section, R+S+ condition (the prime 评 *píng* 'to evaluate' activates the target 论 *lùn* 'to discuss'), does not isolate the effects of each kind of relation. In other words, the obtained facilitation effect could depend not only on the semantic similarity linked to the sharing of the radical, but also on the spelling similarity of the radical or on the semantic similarity of the two characters.

Furthermore, in the condition R+S- (the prime 诸 *zhū* 'some' activates the target 论 *lùn* 'to discuss'), the prime contains the shared radical but it is semantically opaque. The spelling similarity linked to the coexistence of the grapheme <讠 > can contribute to the final inhibition of the recognition of the target. To rule out this effect, the authors included visually similar primes in the R+S+ and R+S- conditions. The results indicated that the R+S+ facilitation and the R+S- inhibition did not undergo significant changes compared to the experiments with the less graphically similar ones. Since the graphic similarity has no effect, the cause of the inhibition can only be attributed to the inconsistent meaning of the prime 诸, as a combined result of activation of the meaning of the radical and opacity of the host character.

Therefore, the investigation by Feldman and Siok (1999) demonstrated that the priming effects also depend on the degree of transparency of the radicals, which is also confirmed by Chen *et al*. (2006). In addition to transparency, other factors that could influence the processing of semantic radicals are consistency, combinability and lexical frequency. Likewise, the relevant factors for phonetic processing include regularity, consistency and combinability (Zhou *et al*., 2013). Other essential factors may also be influential. For example, Jin *et al*. (2013) demonstrated that character recognition is sensitive to lexical variables such as structure in the L1 context. Starting from these assumptions, it is worth underlining here the need to carefully consider the degree of correlation between the prime character and the target character, and to devote a great deal of attention to the selection of the stimuli, possibly activating a pilot project before taking the test to wider a scale.

4.1.4 The timeline of activations

Since radicals are by definition in written form, the priming effect between the radical and the compound character that hosts it could derive from a semantic/ phonological similarity, graphic or both. To check the various dimensions of similarity, a well-thought-out project must be designed in order to dissociate the various components and to observe the desired effect. For example, if the time interval between presentation of the prime and display of the target is too close, it becomes difficult to uniquely distinguish the effect produced by the semantic characteristics of the radical from that produced by the orthographic component. This is because in narrow intervals the effects of spelling similarity prevail over the others. Therefore, another indication introduced by Feldman and Siok (1999) in order to minimise the priming effects of spelling is to extend the exposure time of the prime, which is also underlined by Cheng (2012).

In fact, it is possible to reveal the details of the similarity detected (such as the correlation dimension or the temporal trend relating to the activations), by appropriately manipulating the value of the stimulus-onset asynchrony (SOA). Participants correspond to the time interval between the prime and the target character. In this regard, valid reference benchmarks in the L1 field come from the investigations by Perfetti and Tan (1998) and from the aforementioned work by Feldmen and Siok (1999). A 243ms SOA typically triggers semantic processing. Conversely, the spelling similarity between prime and target provides facilitation only at very short SOAs such as 43ms, and it is unlikely to have significant effect at 243ms SOA.

As pointed out by Perfetti and Liu (2006: 229, 230), the phonological priming becomes facilitative precisely at the point where graphic similarity has become inhibitory (i.e., at SOA 57ms). It is a pattern which is not observed in alphabetic reading. This value seems to be confirmed by the minimum SOA (see table below) established by Zhou and Marslen-Wilson (2000: 1256) in homophonic character evaluation tasks. Participants were asked to judge as quickly and as accurately as possible whether the first and second characters they saw (for example, 独 *dú* 'solo, lonely' and 读 *dú* 'to read') in the centre of the computer screen were related phonologically. As demonstrated in such experimental conditions, the SOA index seems to be inversely proportional to response times (response latency). In other words, the response time is reduced by increasing the exposure time of the prime:

SOA	Response latency	
Pair of stimuli	*'Yes'*	*'no'*
57ms	714ms	785ms
86ms	687ms	769ms
200ms	563ms	619ms

Finally, regarding the sequence between semantic and phonological activation, Jin and colleagues (2013) found that phonological access to the phonetic part in phonetic compound characters inhibits or delays the semantic processing process but facilitates the phonological process. Tong *et al*. (2021) have shown that the SOA value can also be modulated to dissociate the priming effect at the radical level and that at the character level.

If the 'orthographic > phonological > semantic' activation sequence seems to be undisputed, several grey areas remain on the semantic activation times. Perfetti and Tan (1998: 111) proposed that, 'graphic information was activated first, within 43ms, followed by phonological information within 57ms and by semantic information within 85ms'. However, there are studies in the literature that propose conflicting results (cf. Perfetti and Liu 2006: 219).

In conclusion, these data suggest that orthographic activation occurs at the very early stages of character recognition and is later dispersed, while the processing of functional contents occurs at later stages. As a result, orthographic activation does not play a critical role in the character recognition. Finally, given that the access to different types of information seems to take place following a temporal sequence, the processing of each type of information can be isolated by identifying an appropriate exposure time for the prime.

4.1.5 Essential L2 priming procedures

Two versions of lexical decision-making activities are used in the acquisition of Chinese L2 characters: priming tasks and pseudo-character decision tasks. Regarding the use of the technique to explore the development of sublexical sensitivity, the particular reference to the awareness of radicals can be seen in the article by Eletti, Casentini and Fontanarosa (2021). As for the use of pseudo-characters combined with the priming technique, the classic procedure for the decision task (Wang, Perfetti, *et al*. 2003, Williams 2013) includes the following basic steps:

A. Pairs of correlated (semantically, phonologically or orthographically) experimental prime-targets or unrelated control prime-targets are presented;

B. the participants try to recognise the second character and the response time is recorded;

C. the data are analysed to verify if the prime (experimental or control) accelerates/inhibits the recognition time of the target.

The priming effect is confirmed only if an effect of facilitation or inhibition of the target recognition is observed. These phenomena, in fact, imply that the presence of the first character activates relevant information that is used in the processing of the second character.

Pseudo-character-based decision tasks can also be used to investigate the role of radical form and position. A faster speed and higher accuracy of recognition of real characters compared to pseudo-characters indicates that the graphic and structural component of radicals also has a significant impact in the character recognition process. However, to isolate the graphic impact more effectively, partial font blurring techniques can be used. Next, we will present the studies dedicated to the processing of the functional values of radicals, or related to the processing of their semantic and phonological value.

4.2 Studies on the influence of functional and spelling information

Compared to semantic radicals, phonetic radicals have a lower predictive power in providing information on the characters that host them. Indeed, several studies state that the cueing value of the phonetic radical is lower than that of the semantic radicals (Williams and Bever 2010; Wang *et al*. 2017). However, there is no shortage of surveys that present countertrend results (West and Travers 2007; Zhang, Yin *et al*. 2014). They have demonstrated that the role of the phonetic radical in character processing for both native readers and Chinese L2 learners cannot be ignored.

4.2.1 Effectiveness of semantic and phonological activation paths

Although experienced Chinese readers have fully developed semantic and phonetic paths, the results of the previous experiments have shown that there is a slight predisposition to rely on the semantic path over the phonological path (Williams and Bever 2010). Hence, the semantic path appears to be the default means in character recognition. This proposal is also supported by studies that have shown that the semantic path could be built before the phonological path. Shu and Anderson (1999) found that Chinese L1 children can sufficiently use the semantic information of the radicals starting from the third grade in primary school, while a reliable processing of the phonological path is found only three years later. Similar results are confirmed by Anderson *et al*. (2003). For L2 learners, Li (2005) found that after 14 to 15 months of studying in China, foreign students became good at using semantic cues to guess the meaning of characters. This processing of meaning categorisation could even be automatic. These data suggest an evolutionary progression starting from the semantic category. Given these premises, it is assumed that even Chinese L2 students might fully exploit the phonetic component, and they probably use it for its graphemic value more than its phonological value (Williams 2013: 308).

As for Chinese L2 students who have completed about three full-time years of Chinese study, Williams (2013) found that the semantic path is employed as a reliable path while the phonological path turns out to be 'shaky' and under construction. Frequent errors could force them to proceed with the alternative. Therefore, it is worthwhile to explore the dynamics of phonological activation processes and to verify to what extent they can also be induced in L2 learners.

4.2.2 The phonological activation of semantic radicals

Regarding the phonological activation of semantic radicals, a particularly influential investigation is offered in William and Bever's Experiment 2 (2010). The study involved a recognition task during which participants were asked to decide whether the matched characters presented are homonymous. There are four correlation conditions:

P+ C+ The pair of characters share the same phonological value (P+) and share the same phonetic root (C+); for example, 安 *ān* 'peace' and 氨 *ān* 'ammonia' have the same sound and share the same phonetic radical 安 *ān*.

P- C+ The pair of characters have different phonological values (P-) but share the same phonetic root (C+); for example, 位 *wèi* 'position' and 泣 *qì* 'to sob' do not have the same sound but share the same phonetic radical 立 *lì*.

P+ C- The pair of characters share the same phonological value (P+) but have different phonetic roots (C-); for example, 丰 *fēng* 'abundant' and 风 *fēng* 'wind' have the same sound but do not share the same phonetic radical.

P- C- The pair of characters have different phonological values (P-) and have different phonetic roots (C-); for example, 往 *wǎng* 'towards' and 根 *gēn* 'root' do not share the same sound or phonetic radical.

The results have showed that regular phonetic radicals in the P+C+ condition have a positive effect on the reaction time compared to the P+C- condition (in which there are no shared phonetic radicals). Irregular phonetic radicals in the P-C+ condition, however, caused delays and higher error rates in making judgments.

Basically, when phonetic radicals provide only partial indications to the characters that host them, the ability to use this radical information in recognising the whole character is limited. Despite this limitation which is related to the regularity of the phonetic component, the phonological activation of semantic radicals (already suggested by Zhou *et al*. 2000) is now a proven fact. It suggests that there is no fundamental difference between processing at the sublexical level and that at the lexical level: both meaning and sound are activated (presuming they exist) for either type of radicals.

4.2.3 Semantic activation of phonetic radicals

Since most phonetic radicals are characters by themselves which have a meaning, it is presumable that their meaning is also processed during the sublexical activation process. This semantic activation has been observed in many experiments (Zhou and Marslen-Wilson 1999b; Tsang *et al*. 2017) and has been demonstrated by Yeh *et al.* (2017) using a colour-naming Stroop task. In the experiment, participants were told to name the colour of the stimulus displayed on the screen, regardless of the meaning of the stimulus. The experiment is based on four correlation conditions between characters and the semantic value referring to colour indicated by them or a part of them. Moreover, for each of the four conditions, control characters have also been provided:

Colour-Character: Characters whose meaning is directly related to colour, for example, 青 *qīng* 'cyan'.

Valid-Radical: Characters that share the same pronunciation with their phonetic radical, but the radical has a different meaning, such as 清 *qīng* 'clear', contains the phonetic radical 青 *qīng* 'cyan'.

Invalid-Radical: Characters contain a phonetic radical referring to a colour, however, characters and their phonetic radicals are different both in pronunciation and meaning, such as 猜 *cāi* 'to guess'.

Associative-Radical: Characters that contain a radical semantically related to a colour such as 恤 *xù* 'piety', whose phonetic radical is 血 *xiě* 'blood' which is related to the colour 'red'.

The basic idea of the experiment is that the reaction time (RT) can be slowed down when the graphic colour of the font is inconsistent with the semantic value of the lexical unit considered. For example, there is a Stroop effect when the respondent has to read aloud the word 'red' displayed on the screen in green. The key finding of Yeh *et al*. (2017) was that the Stroop effect is found with characters whose meaning is not related to colour but contain a phonetic radical referring to a colour (for example, 猜 *cāi* 'to guess'). The Stroop effect is also confirmed with characters whose phonetic root is semantically associated to a colour (such as 恤 *xù* 'piety'). In addition to the confirmation that the recognition of Chinese characters involves the decomposition of characters into their constituent radicals, this investigation has also shown that the semantic value of each component is activated independently, including that of phonetic radicals.

The interference between the semantic value of the phonetic radicals and that of the semantic radicals should in theory have an important impact in the process of character recognition. However, studies dedicated to the temporal sequence of activations show that the strength of the semantic activation of phonetic radicals becomes weaker with longer SOA and disappears after 200ms (Zhou and Marslen-Wilson 1999b; Lee *et al*. 2006).

4.2.4 Studies on the impact of orthographic content

The investigations on the spelling of characters have addressed the first question of a general nature: is the impact of the graphic content also related to the type of radical (i.e., Jackson and Everson 2003)? In other words, is the activation process triggered by the grapheme related to the type of information conveyed by the radical (semantic or phonetic)? In this regard, there is general consensus on the fact that the cueing value of the orthographic component is higher in phonetic radicals than in semantic ones (Wang 2006; Williams 2013). However, it is worthwhile to present the methodologies used to reach this conclusion and also to highlight some limitations of this experimental approach.

The role of the different graphemic components (semantic or phonetic) in the decoding of orthographic information was analysed primarily through studies focusing on the 'blurred radical' character lexical decision task, a methodology introduced by Williams and Bever (2010) in a study of recognition paths by native Chinese speakers[7].

The purpose of this experimental task is to limit the recognition process to a single component (semantic or phonetic), by partially obscuring the character. To this end, pseudo-characters are also included among the experimental stimuli, as in the examples shown in Figure 11.

Pseudo character Semantic radical blurred Phonetic radical blurred (Williams 2013: 309)

Figure 11: Examples of pseudo-characters with a fuzzy radical

This methodology was then adopted by Williams (2013) to identify the impact of blurring in the encoding orthographic information and to verify which lexical decoding path or strategy, on a semantic or phonological basis, is adopted by L2 readers. Specifically, the protocol used in this study included 60 units of 30 pseudo-characters and 30 real characters. Participants were asked to perform a lexical decision task, in which they needed to press the yes or no key to decide whether each displayed unit is a real character or not. Participants were divided into two groups. Each of the groups were exposed to a different set of units. In the first experimental group, half of the characters presented had fuzzy semantic radicals and the other half had fuzzy phonetic components. In the second group, the blurred area was inverted, so that the same character that in the first group had a blurred semantic radical was now displayed with the phonetic component blurred, and the same character that in the first group had a blurred phonetic radical was now shown with a blurred semantic radical. The

[7] Specifically, Williams and Bever (2010) found a slight preference for the semantic path by native speakers.

blurring effect induced the subjects to decode the information of the non-blurred radical and allowed the researcher to selectively guide the attention on the type of radical chosen (semantic or phonetic).

From the data analysis it suggested that the phonetic component plays a crucial role in the recognition processes. A higher error rate was recorded in the identification of pseudo characters with a fuzzy phonetic radical.

In this regard, the author has pointed out an important assumption: compared to semantic radicals, phonetic ones tend to have more traits. Consequently, phonetic radicals typically provide more orthographic information. This observation is confirmed by the fact that, by crossing the reaction times with the number of strokes in the blurred area, the recognition lapse tends to increase as the phonetic component becomes more complex, regardless of which part of the character has been blurred. As noted by Williams (2013: 311), this data suggests that participants 'unpack' the orthographic information on the basis of traits, starting from the phonological component.

Finally, the impact of the number of strokes is further confirmed by comparing the performance between simplified and traditional writing. For the latter, in fact, a slowdown was observed compared to characters with a blurred phonetic radical in simplified writing. Basically, in a semantic-phonetic compound the blurring of the phonetic radical involves a greater loss of information than that of the semantic radical. The participants therefore need more time to process the phonetic radical. Hence, the author concluded that the latter is the dominant means for identifying the character. Based on the above results, Williams concluded that L2 students were aware of the phonological value of the phonetic radical, however, their knowledge of the phonetic radicals is not sufficient to implement constructive use of its phonological information to obtain reliable results. It is the orthographic information of phonetic radicals which is more valuable for them. In other words:

> "The phonetic component would be acting as a sort of 'anchor' for reading, being decoded for orthographic value before moving on to the semantic radical."
> (Williams 2013: 310-311).

It should be noted that the lexical decision task with fuzzy radical has some methodological drawbacks. First, participants may need to focus more on the fuzzy components that cause the impediment in initial lexical access (Wang *et al*. 2016: 131).

Second, semantic components are relatively smaller in size and have fewer strokes. Fuzzy semantic components may be more difficult to identify than fuzzy phonetic components at the same level. Third, from the example of Williams (2013), visible in Figure 11, we can see that the pseudo character does not have a phonological representation in lexical processing. In essence, the results could be compromised by the unbalanced information provided by these two types of components (Wang *et al*. 2016: 131).

Conclusions

During this brief review, some key points have been highlighted for the design of an empirical study on Chinese characters recognition. First of all, attention should be put on selection of the exposure times (SOA) and the list of stimuli. Appropriate correlations for activations need to be carefully explored and identified. Then, factors that can influence the recognition task have to be taken into account, such as the lexical frequency, structure, transparency, regularity, etc.

Other than the crucial impact of the factors listed, we also need to keep in mind that the lack of radical knowledge is an aspect that characterises the acquisition stage of L2 learners before the advanced level. In the literature, scenarios have been described in which a predilection of L2 learners for the orthographic value (with respect to the phonological one) is observed, which is most likely linked to the incapability of successfully following the phonological decoding path (phonological route). Furthermore, studies suggest that the ability of the semantic processing, albeit in a more advanced stage of development than the phonological one, tends to be used as a secondary measure, probably due to the habit of alphabetic writing systems which leads to the consequent poor habit of decoding semantic contents in the lexical recognition process.

These considerations suggest that the development of sublexical sensitivity and the knowledge of the semantic and phonological value of radicals represent a preliminary condition for any study that wishes to successfully investigate the recognition processes by Chinese L2 learners.

CHAPTER 5: THE STUDY

5.1 The method

5.1.1 The rationale

As mentioned in Chapter 1, the primary aim of this research is to identify a developmental route of character processing for L2 learners; the secondary goal is to test the modulation effects of radical awareness training on the developmental route. To this end, the experiment design is centred on the semantic and phonological activation of radicals when they are standalone characters and used as embedded components of whole characters. The participants were at three different levels of Chinese proficiency (intermediate, advanced and L1 native level). The data of the experiments (*Priming Test 1 and 2*) were collected before and after a radical awareness training (*Radical Awareness Training*).

The methodology is based on psycholinguistic metrics; more precisely, it relies on a combined implementation of the lexical decision task and the priming technique. The participants' reaction times (RTs) are measured against priming pairs in 12 critical conditions that are presented in section 5.3.3. The results of the two proficiency levels of L2 learners[8] were first used to identify the lexical processing patterns at each level. Then, their patterns were compared with each other and compared with L1's results irrespectively.

After designing the stimuli (see section 5.3.3), the first step was to conduct a priming test (Priming Test 1) and to collect data on the performance of native speakers; in this way, the patterns of L1 character processing would be identified.

The second step was to design and conduct a test on radical knowledge (Radical Knowledge Test) for the L2 participants.

The third step was to conduct the priming test cycle for L2 learners, which can be briefly summarised as follows (detailed Test Cycle see section 5.3):

1) Priming Test 1
2) Radical Awareness Training

[8] L2 learners are divided into Group 0 and Group 2. Group 0 is a pilot group. Group 2 contains two subgroups: Group 2 Year 2 and Group 2 Year 3. Group 2 Year 2 consists of Italian learners with two years of formal Chinese study in university. Their proficiency level is ***intermediate***; Group 2 Year 3 consists of Italian learners with three years of formal Chinese study in university. Their proficiency level is ***advanced***. Details of L2 Groups can be seen the following part of this section.

3) Priming Test 2

The fourth step is analysis of the data.

The participants are divided into three groups:

Group 1: Baseline group for identifying the benchmark native-like processing pattern involved in Priming Test 1: 37 Chinese **native speakers**, who have received at least secondary level education in mainland China;

Group 0: Experimental subjects involved in the pilot research, whose performance was analysed only for the Radical Knowledge Test: 16 Irish college students, whose proficiency levels vary from intermediate to advanced level with a four-year Chinese learning experience in a formal context;

Group 2: Critical experimental subjects involved in the Radical Knowledge Test and Priming Tests 1 and 2. There are two subgroups under Group 2[9]:

Group 2 Year 2: 8 Italian college students, **intermediate level** with a two-year Chinese learning experience in a formal context

Group 2 Year 3: 5 Italian college students, **advanced level** with a three-year Chinese learning experience in a formal context

As anticipated, Group 0 was involved in a preliminary pilot project. Even though they also participated in the priming test cycle, the data presented here only includes their Radical knowledge Test results but not Priming Tests results. This is because there are some material adjustments after the pilot project. Group 0 and Group 2 had been exposed to the same material in the Radical Knowledge Test. However, the Priming Test material has been fine-tuned after the pilot study; hence, L2 learner groups Group 0 and Group 2 were not exposed to the same material in Priming Tests. To ensure a higher degree of consistency and statistical significance, the priming results from Group 0 have been excluded from the data analysis. Also, the participation of Group 0 in priming tests will not be mentioned in the following sections to avoid confusion.

In sum, a developmental route of L2 learners' character processing is proposed in this study. Also, this study tries to answer the questions of whether and how the performance of L2 participants was 'induced' to become more native-like through a specific training on radical awareness.

[9] The data were collected in April and May 2021. Because of Covid-19 pandemic, only a few students came back their university to attend classes.

5.1.2 Predictions by proficiency level

The lexical processing of L1 speakers is viewed as the final stage of the developmental route of L2 learners. L2 learners with two years- (**Group 2 Year 2 as intermediate level**) and three years (**Group 2 Year 3 as advanced level**) learning experience are treated as two earlier stages before reaching the final stage (**native level**). The prediction for the priming effects based on different proficiency levels is that: the impact of semantic and phonological activation speeding up reaction times (RTs) might occur according to the following tendency:

Group 2 (Year 2) > Group 2 (Year 3) > Group 1

(-) ← *phonological and semantic activation* → (+)

5.1.3 The training

This part of the study aims to test if the radical training speeds up the L2's character processing patterns towards the native-like. To meet this secondary goal, L2 learners had received the Radical Awareness Training after the Priming Test 1. The Training was mainly self-training based which lasted from 45 minutes to 1 hour. It is composed of one self-learning phase (20-25 minutes) and one self-testing phase (25-35 minutes).

L2 participants were asked to wait at least one week to attend the Priming Test 2 after the Priming Test 1. During the time of waiting, they were required to finish the Radical Awareness Training no more than one day before the second experiment they chose by themselves. In this way, training effects could be preserved and reflected maximumly in the Priming Test 2 results. RTs were collected and compared between these two proficiency levels of L2 learners before and after the training to see how training influenced their lexical processing.

The prediction for the modulation effects of training is that stronger semantic and phonological activations might result from the training for both subgroups of L2 Group 2 learners (Year 2 and Year 3). However, it is difficult to predict the details of activation changes.

5.1.4 The priming test

A primed lexical decision task (mainly mentioned as 'priming test' in this study) was designed to collect information on how characters are processed by readers of different proficiency levels. All the characters used in the Priming Test 1 and 2 came from the *Common Lexical Database (汉字源流字典 Character Etymology Dictionary 2008)* which was built explicitly for this study, including all the possible characters learners had learnt or acquired.

Participants were asked to make a judgement as to whether a primed target character is a real character or not. They were asked in response to press the ‘W’ key if it is a real character or the ‘N’ key if it is not in response. In one priming test, each participant made judgements on 192 trials which consisted of 48 critical prime-target pairs and 144 filler pairs. The 48 critical priming pairs are categorised into 12 priming conditions, including 6 related conditions and 6 unrelated control conditions (each related condition matches one corresponding unrelated control condition). Each of the 6 related conditions are designed in a way that only one factor is related between primes and targets. Only this one related factor influences target reading compared to their unrelated controls in each case. In this way, this influencing factor can be isolated, and the priming effect caused by this factor can provide information such as activation type, level and location in the character processing. Based on this information, lexical processing patterns can be identified for each proficiency group; hence, a developmental route can be depicted.

The 12 conditions are listed as follows:

- 4 conditions at the lexical level
  - ✓ 1 SE-RL semantically related
  - ✓ 1 SE-NONRL semantically non-related control
  - ✓ 1 PH-RL phonologically related
  - ✓ 1 PH-NONRL phonologically non-related control
- 8 conditions at the sublexical level
  - ✓ 1 SR-SE-RL semantic radical semantically related
  - ✓ 1 SR-SE-NONRL semantic radical semantically non-related control
  - ✓ 1 SR-PH-RL semantic radical phonologically related
  - ✓ 1 SR-PH-NONRL semantic radical phonologically non-related control
  - ✓ 1 PR-SE-RL phonetic radical semantically related
  - ✓ 1 PR-SE-NONRL phonetic radical semantically non-related control
  - ✓ 1 PR-PH-RL phonetic radical phonologically related
  - ✓ 1 PR-PH-NONRL phonetic radical phonologically non-related control

5.1.5 Data processing

Response times (RTs) in the task trials in Priming Test 1 and 2 are the quantitative data collected and analysed. RTs are compared within and across proficiency levels based on 12 priming conditions. Comparisons were also performed to see the differences between the Priming Test 1 and 2 results. The results from the analysis help to understand what kind of activation (semantic or phonological) happened at which level (character or radical) and/or which location (semantic radical or phonetic radical). The processing patterns of two subgroups of L2 learners (Group 2 Year 2 and Year 3) and native speakers (Group 1) were identified and described, and a developmental route was built accordingly.

Data were analysed in t-Test (Two-Sample Assuming Unequal Variances using the Microsoft Excel version 16.50 and IBM SPSS Statistics Version 27). The detailed analysis can be seen in Chapter 6.

5.2 The participants

5.2.1 Group 1 L1 native speakers

Group 1 are 37 Chinese literate adults. At the time of participating in this study, they were either studying or working at the University College of Cork, Ireland. They were asked to fill in a language background questionnaire (shown in Appendix A). Some basic background information can be seen in Table 2. All of them are female; the average age was 26.8 years old (Range = 22-35 years old). They had all lived in mainland China for more than 20 years before studying or working in Ireland.

The following two sections present the profile of the pilot groups (Group 0) and the critical experimental group (Group 2 Year 2 and Group 2 Year 3).

Table 2: Background information of L1 participants (Group 0)

Native Speaker		Average	Range
Gender	37 female, 0 male		
Age (yrs. old)		26.8	22-35
Length of English study (yrs.)		17.6	14-22

5.2.2 Group 0 L2 Pilot experimental group (Irish learners)

Group 0 consists of 16 L2 Chinese learners enrolled at University College Cork, Ireland. A questionnaire about the participants' language background (listed in Appendix B) and the Radical Knowledge Test were conducted to evaluate their

Chinese proficiency and radical knowledge. Informal interviews were carried out to understand better what instructors had taught and what learners had learnt about radical knowledge. All the learners and both of their course instructors attended the informal interviews.

The questionnaire on the language background included sections for collecting: general information, other L2 languages and their respective time usage, the environment of Chinese learning, weekly use of Chinese and other languages and if they experienced the immersive learning in a Chinese-speaking environment. All Group 0 participants used the same textbook, New Silk Road Business Chinese. Simplified characters were taught in all the modules they had taken. Except for one participant who was doing a master's degree, the remaining 15 Group 0 were enrolled in the fourth year of Chinese (Bachelor of Arts) at the University College Cork. Their majors were: Business Commerce (4), World Language (11), and Asian Studies (1 postgraduate student). There were 8 females and 8 males. The average age of the participants was 23 years old (Range = 21-26 years old). The average age when they were first exposed to Chinese was 17.5 years old (Range = 15-22 years old), and the majority (13) of them had their first exposure[10] in a formal setting (in school), whereas 3 of them had been exposed to Chinese in an informal setting (out of school).

They had studied Chinese in the classroom for 3.65 years on average (Range = 2-4.5 years), which included about 9.8 months (Range = 0-18 months) studying in China. All the students were enrolled in or had already attended (1 postgraduate) the HSK4/5 level required modules[11]. The participants were asked to specify their certified HSK level. However, as anticipated, the certified HSK is lower than the actual level of study of learners in some cases. As visible in Figure 11, learners' levels roughly range from beginner (HSK2) to advanced level (HSK6). Nearly 90% of the participants (14) are intermediate-to-advanced level Chinese learners (see Table 3 and Figure 12).

10 The time when L2 learners who are exposed to the target language input for the very first time (Han and Rast 2014: 7)

11 Namely, CH3005 Readings in Contemporary Chinese Culture and Current Affairs, CH3017 Chinese Language (Mandarin) Level 3, and CH3011 Modern Chinese Business Language Level 3.

Table 3: L2 Group 0 learner background

L2 Learner Group 0	Average	Range
Age (year old)	23	21-26
Age of first exposure to Chinese (years old)	17.5	15-22
Years of instruction of Chinese	3.65	2-4.50
Immersion period in Chinese speaking environment (months)	9.8	0-18
Percentage of Daily use of language - English	69%	30%-95%
Percentage of Daily use of language - Chinese	15%	5%-50%

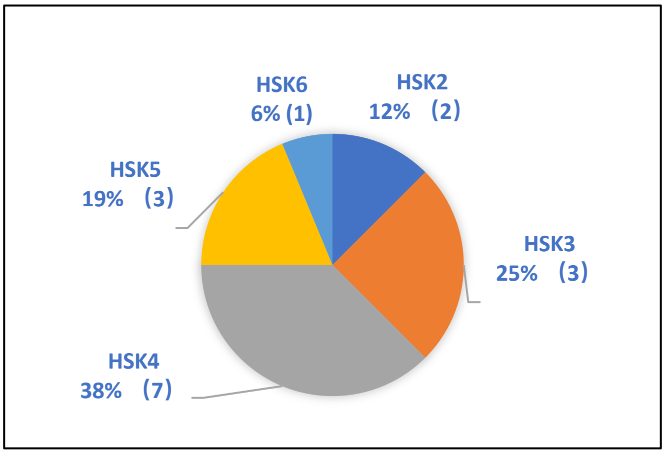


Figure 12: HSK level certificate undertaken by the participants[12]

Fifteen out of 16 of the L2 learner participants speak English as their native language. Among those English native speakers, 3 are bilingual who speak at a native-level another alphabetic language such as German, Polish and Malayalam (see Figure 13). 13 participants had learnt Irish as an L2, and 13 participants reported that they had learnt foreign languages other than Chinese, such as French (6), Spanish (4), German (3) Korean (2), Japanese (2), Italian (1), Portuguese (1) and Hindi (1). The participants also self-assessed their second language (other than Chinese) proficiency, graded from beginner to advanced

[12] The table includes the HSK certified level. Before the course started, each student level was assessed as having HSK4 as an entry level.

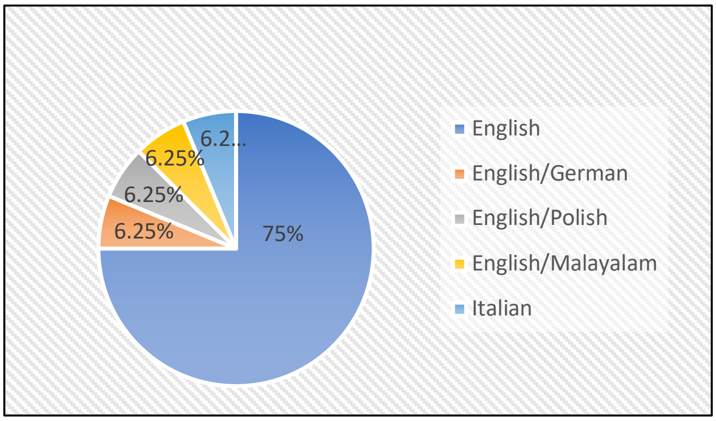


Figure 13: First language distribution

5.2.3 Group L2 Critical experimental group (Italian learners)

Group 2 are 13 L2 Italian learners enrolled at the University of Bologna, Italy. They also took the Language Background Questionnaire (Italian version, see Appendix C) before the Priming Test 1.

The questionnaire on the language background included questions for collecting: age, mother tongue, study years of Chinese, if they speak Chinese at home and if they spent more than one month in China. All 13 Group 2 participants had used the same textbook, *Il cinese per gli italiani* (*Intermedio* or/and *avanzato*). Simplified characters were taught in all the modules they had taken.

Eight of the 13 Group 2 participants (4 females and 4 males) were enrolled in the second year (mentioned as '*Year 2'* learners in this study), and the 5 remaining participants (2 females and 3 males) were enrolled in the third year (mentioned as '*Year 3'* learners in this study). They were all majoring in *lingue mercati culture dell'Asia e dell'Africa mediterranea*. The average age of the Year 2 learners was 20.38 years old (SD = 0.52 years, Range = 20-21 years old); for the Year 3 learners it was 21.80 years old (SD = 0.84 years, Range = 21-23 years old). All the participants in Group 2 are Italian native speakers, and they do not speak Chinese at home.

Group 2 Year 2 learners had studied Chinese in the classroom for two years, and Group 2 Year 3 learners had studied Chinese in the classroom for three years. One participant in Group 2 stayed in mainland China for about one month for language exchange, and the rest had no immersive experience in a Chinese-speaking environment.

5.3 The test cycle

So far, no empirical studies have been conducted on the evolutionary progression of non-native learners' lexical processing across instructional levels, and a limited amount of studies manipulated the functionality of two types of radicals in a single design (Yao 2015: 537). The purpose of this study is to investigate the possible developmental trends of Chinese L2 learners in character recognition, and to analyse the response to priming covering all possible functional activation, both at the character and radical levels. In this sense, this study tried to carry out a full factorial design, capable of providing ample material on the participants' sublexical information activation. To this end, a test cycle was conducted, comprised of the following stages:

1) *Preparatory activity:* Identification of the Common Lexical Base
2) *Test type:* Radical Knowledge Test (Group 0 and Group 2)
3) *Preparatory activity:* Preparation of the stimuli (including creating the pseudo characters)
4) *Test type:* Priming Test 1 (Group 1 and Group 2)
5) *Training session*: Radical Awareness Training (Group 2)
6) *Test type:* Priming Test 2 (Group 2)

This study aims to collect data about the different factors contributing to character recognition; more specifically, it seeks to identify:

(A) functional activations for L1 speakers and L2 learners;
(B) the activation level (character level or radical level);
(C) the activation location (semantic radical or phonetic radical);
(D) correlating the different activation to the radical knowledge and proficiency of the participants.

(A) to (D) are the underlying questions of *Priming Test 1*. By studying the priming effects obtained from two time/proficiency points (two years of learning/intermediate level; three years of learning/advanced level) in L2 learning, the development of lexical processing in reading Chinese characters can be identified. Priming Test 1 was taken by L1 (Group 1 native speakers) and L2 Group 2 (Group 2 Year 2 learners and Group 2 Year 3 learners). Before taking Priming Test 1, both L2 Groups (Group 0 and Group 2) took the Radical Knowledge Test.

The insertion of the *Training* and *Priming* 2 is instead related to the issue of the 'plasticity' of the learners' recognition strategies, which is at the core of the second set of research questions of this study. This part of the study intended to find out whether L2 recognition strategies can be shaped in the direction of strategies adopted by native or near-native speakers. In other words, Training and Priming 2 are aimed at exploring whether:

(E) lexical processing of Chinese characters is a developing and modifiable process;

(F) intensified sublexical processing improves character recognition efficiency for intermediate-to-advanced level L2 learners.

The Radical Awareness Training and the Priming Test 2 were taken by subgroups of Group 2 (Group 2 Year 2 and Group 2 Year 3).

5.3.1 Identification of the Common Lexical Base (CLB)

At the beginning of the test cycle, course materials were collected to create a character database (Common Lexical Database, also named CLB) for designing the tests. To this end, the course character lists provided by the teachers and from the course books for the previous two years of formal instruction at UCC were scrutinised. In this way, a database of 653 characters has been built, and labelled according to the following sets of information:

Column 1. Character HSK level*[13]

Column 2. Character type (形声， 指事， 会意， 假借， 象形 'phonetic compound', 'simple ideogram', 'compound ideogram', 'rebus and ideograph') *

Column 3. Character grapheme (simplified) *

Column 4. Character grapheme (traditional)

Column 5. Character meaning*

Column 6. Character segmental value*

Column 7. Character suprasegmental value

Column 8. Character structure*

Column 9. Character stroke number*

Column 10. Explanation of the character subcomponent

[13] '*' is marked for information which is critical for this study.

Column 11. Phonetic radical grapheme*

Column 12. Phonetic radical segmental value*

Column 13. Phonetic radical suprasegmental value

Column 14. Phonological regularity (regular, irregular, semiregular-rime) *

Column 15. Semantic radical grapheme*

Column 16. Semantic radical meaning*

Column 17. Semantic consistency (transparent, opaque) *

Column 18. Character frequency*

Column 19. Semantic radical as standalone character frequency in CLB*

Column 20. Phonetic radical as standalone character frequency in CLB*

According to the CLB, more than half of the characters are phonetic compounds (50.69%), among which 70.09% have the left-right structure (see Tables 4 and 5). If we consider a radical's usual functional positions, 64.35% (213 out of 331) phonetic compounds have a semantic radical on the left and a phonetic radical on the right.

Table 4: Character type and percentage in CLB

Character Type	No.	Percentage
Phonetic compounds*	331	50.69%
Phonetic compounds in traditional form but not in the simplified form	14	2.14%
Compound ideograms	160	24.50%
Pictograms	131	20.06%
Simple ideograms	16	2.45%
Rebus	1	0.15%
In total	653	100.00%

Table 5: Configuration for phonetic compounds in CLB

Configuration		No.	Percentage (CLB)	Percentage (Feldmen and Siok 1999)
SR left - PR right	左形右声*	213	64.35%	75%
SR right - PR left	左声右形	19	5.74%	5%
SR top - PR bottom	上形下声	38	11.48%	15%
SR bottom - PR top	上声下形	32	9.67%	4%
SR periphery - PR middle	外形内声	24	7.25%	1%
SR middle - PR periphery	外声内形	5	1.51%	0%
In total		331	100.00%	100%

Note. SR – semantic radical; PR – phonetic radical

Features such as regularity and transparency were not relevant in the Radical Knowledge Test context but were instead taken into full account for the creation of the stimuli list for the Priming Test 1 and 2. From this database of 653 characters stored in the Common Lexical Base (CLB), radicals extracted for the Radical Knowledge Test are categorised based on the following features:

Column 11/15. Functional role (semantic/phonological) in the hosting character from the CLB

Column 19. Semantic radical frequency of occurrence within the CLB

Column 20. Phonetic radical frequency of occurrence within the CLB

Notably, the classification into semantic vs phonetic radical is relative to the given characters included in the CLB. For instance, the radical 方 *fāng* 'square' can have both a semantic and a phonological function, depending on the specific hosting character, such as 施 *shī* 'to implement' and 访 *fǎng* 'to interview'. In this list, the functional role of a given radical depends on the hosting characters included in the CLB.

5.3.2 Testing the radical knowledge

This section presents the design of the Radical Knowledge Test administered to the sample of 29 L2 learners (16 participants in Group 0 and 13 participants in Group 2) before starting the priming and training session. Each participant was asked to write down the sound in Pinyin (tone is irrelevant) and the meaning (in English/Italian) of 37 semantic and 76 phonetic radicals. Learners were asked to finish the test in their spare time independently, without asking for help from others or checking dictionaries, and to submit the test to the researcher before they attended the Priming Test 1.

Due to the time limit in the test administration, the total radical sample for the Radical Knowledge Test could not exceed a reasonable quota; therefore, the Test consists of 113 items (37 semantic radicals and 76 phonetic radicals). All the radicals were sorted by their frequency of occurrence in the host characters within the CLB (see Table 6). The ratio between the two radical types was decided based on their individual occurrence in the CLB. It is crucial to cover a sufficient sample of characters in the CLB to collect balanced information of both radical types. With this consideration, a ratio of 1:2 (ratio between semantic radicals and phonetic radicals in all characters is 1:4) is adopted, which could be covered by selecting 37 semantic radicals (occurring in 311 characters, 47.63% of the CLB) and 76 phonetic radicals (occurring in 180 characters, 27.57% of the CLB).

As anticipated, all the radicals are from the character list (CLB) constructed based on textbooks, quizzes, and exams papers participants used in their first two years of Chinese study (for the content of the test see Appendix C[14]). It is worth noting that, as a result of the criteria outlined, all the 113 radicals included in the test are hosted in characters which *each participant had been required to memorise before enrolling into their modules*. In this way, the test should also provide us with (a) information about the specific radical knowledge resulting from the general formal instruction at this tertiary education. In other words, we can test whether learners can still internalise the feature of character sublexical components at this level of literacy, notwithstanding the lack of a focus on radical instruction in the classroom. However, the primary goal of the Radical Knowledge Test is providing (b) a base for designing the priming material and, more importantly, (c) interpreting the result of the priming test. In fact, we have to remember that the latter measures the different activations triggered by either semantically or phonologically related primes (at the lexical or the sublexical level).

[14] The only difference between the English version of Radical Knowledge Test used by Group 0 and the Italian version of it used by Group 2 is that there is no written instruction on the English version.

Table 6: An extract from the database of the CLB[15]

HSK level	Character type	Character			Semantic radical		Transparency	Phonetic radical		Regularity	Structure	Character Stroke no.	Character frequency	Semantic radical no.
3	形声	级	level	*ji*	纟	silk	opaque	及	*ji*	regular	左右	6	282	8
2	形声	红	red	*hong*	纟	silk	opaque	工	*gong*	semiregular-rime	左右	6	282.4	8
2	形声	绍	continue	*shao*	纟	silk	opaque	召	*zhao*	semiregular-rime	左右	8	644.9	8
2	形声	给	give	*gei*	纟	silk	opaque	合	*he*	irregular	左右	9	1129	8
4	形声	线	line	*xian*	纟	silk	transparent	戋	*jian*	semiregular-rime	左右	8	1424	8
2	形声	经	through	*jing*	纟	silk	opaque	𢀖	*jing*	regular	左右	8	1453	8
2	形声	纸	paper	*zhi*	纟	silk	transparent	氏	*shi*	semiregular-rime	左右	7	2071	8
3	形声	练	practice	*lian*	纟	silk	opaque	(柬)	*jian*	semiregular-rime	左右	8	2224	8
3	形声	刚	hard/just	*gang*	刂	knife	opaque	冈	*gang*	regular	左右	6	25.74	7
3	形声	刻	engrave	*ke*	刂	knife	transparent	亥	*hai*	irregular	左右	8	137.4	7
4	形声	剧	drama/acute	*ju*	刂	knife	opaque	居	*ju*	regular	左右	10	189.6	7
3	形声	刮	scratch	*gua*	刂	knife	transparent	舌	*she*	irregular	左右	8	361	7
4	形声	列	column	*lie*	刂	knife	opaque	歹	*dai*	irregular	左右	6	941.6	7
4	形声	判	judge	*pan*	刂	knife	opaque	半	*ban*	semiregular-rime	左右	7	991	7
4	形声	划	draw	*hua*	刂	knife	transparent	(畫)	*hua*	regular	左右	6	1790	7
2	形声	务	business	*wu*	力	power	opaque	(敄)	*wu*	regular	上下反	5	623.4	6
3	形声	努	make an effort	*nu*	力	power	transparent	奴	*nu*	regular	上下反	7	983.3	6
2	形声	助	help	*zhu*	力	power	transparent	且	*qie*	irregular	左右	7	988	6
3	形声	加	plus	*jia*	力	power	opaque	口	*kou*	irregular	左右	5	1077	6
0	形声	功	work	*gong*	力	power	transparent	工	*gong*	regular	左右反	5	5542	6
2	形声	动	move	*dong*	力	power	transparent	(重)	*zhong*	semiregular-rime	左右反	6	11029	6

[15] Due to the page limit, not all the relevant fields are listed here.

5.3.3 Preparation of the stimuli for priming tests

5.3.3.1 Stimuli content

There are 336 experimental character pairs in total used in the Priming Test 1 and 2, which consists of 144 filler pairs and 192 critical pairs. Critical pairs are divided into 4 versions of experimental material with 48 pairs in each experiment (see Figure 14):

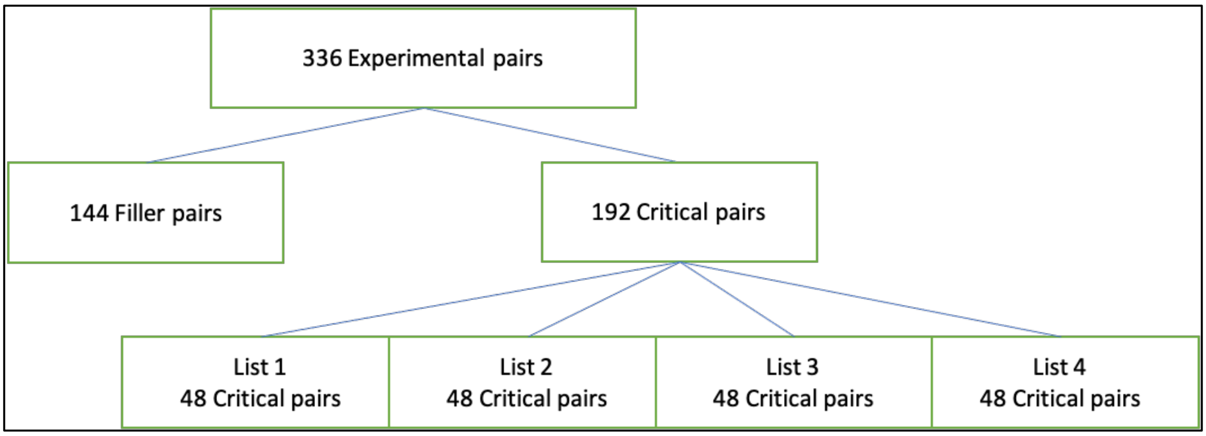
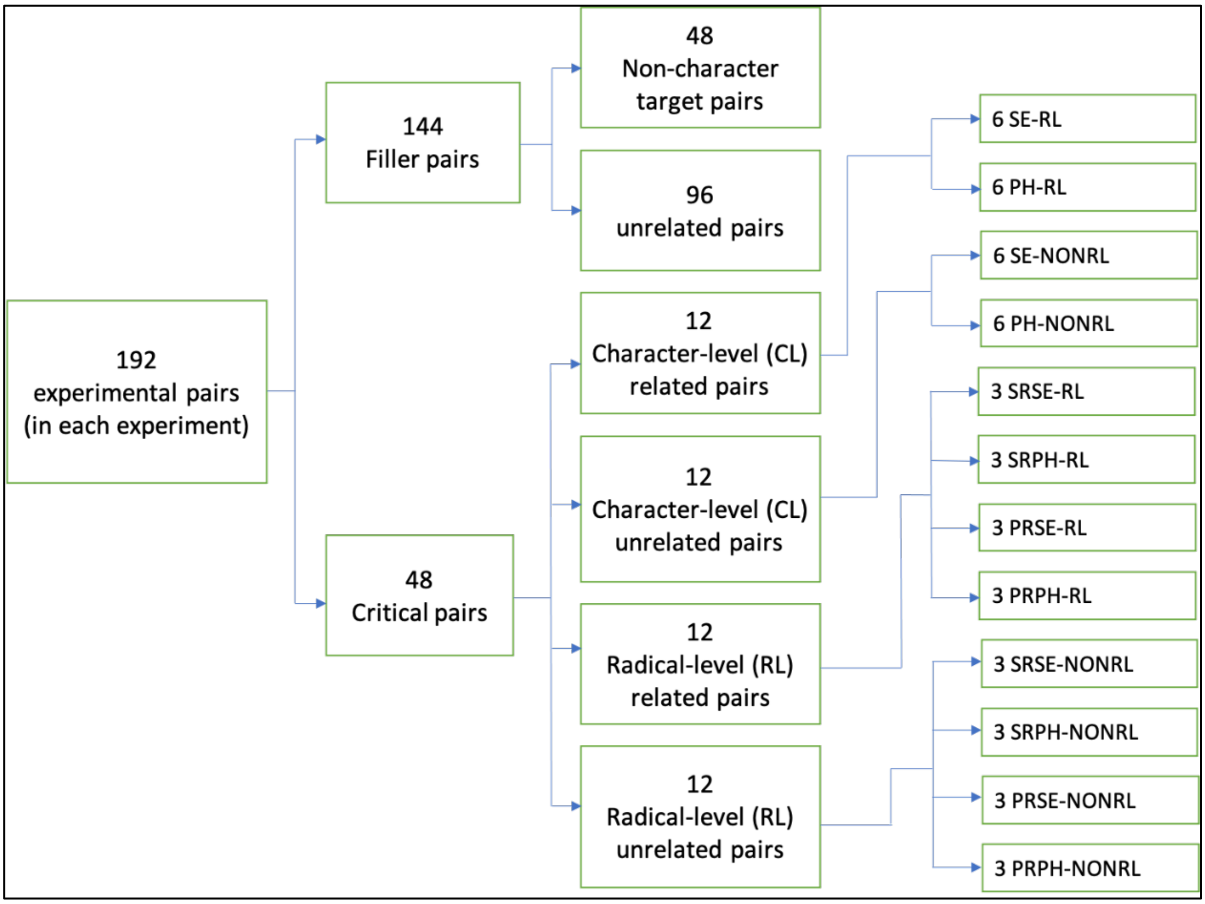


Figure 14: Stimuli used in each experiment

In a priming test, each participant was shown 192 trials and asked to make a decision based on the information a trial provided. Each trial consists of a pair of characters: one *priming character (or prime)* and one *target character (or target)*. 192-character pairs include 144 filler pairs (48 pairs with non-character targets plus 96 pairs with real character targets) and 48 critical pairs (consists of 12 priming conditions). The detailed classification of all inventory of character pairs used as stimuli can be seen in Figure 15. The sequence of the trials is pseudo-randomised. In fact, both the sequence of filler pairs and the location of each critical target character are fixed. The version of the list a participant took was also randomised. However, each list version was used in more or less the same number of times.



Note.
SR – semantic radical; PR – phonetic radical;
SE – semantically; PH – phonologically;
RL – related; NONRL – non-related.

Figure 15: Classification of all character pairs used as stimuli in the priming test

The consideration of the chosen numbers of critical and filler pairs is based on the following: a) the arrangement tried to cover as many characters in CLB as possible – 164 characters (25.11%) for critical pairs in the priming tests, while considering the criteria of the material being used. It is the maximum character number could be achieved; b) it dilutes the ratio of critical pairs to irrelevant filler pairs to 1:3, which provides enough dilution while considering the overall trial number in each experiment, in that it does not overtire participants; c) the number of fillers with non-character targets creates a real character/non-character judgement ratio of 3:1. It prevents the possible tendency of result prediction from participants, e.g., in the case that the ratio of Yes/No answers is 1:1.

5.3.3.2 Filler pairs

All the characters in filler pairs are from the CLB. The target characters in filler pairs are either real characters or non-characters. The non-characters[16] are necessary for triggering the lexical decision task, which consists of distinguishing between real characters and non-characters. The details of the two different sets of prime-target pairs for fillers are as follows (see Table 7):

a) In two-thirds of all fillers (96 out of 144 pairs), both the prime and target are real characters, but they are unrelated graphically, semantically or phonologically. As shown in the example in Table 7, 给 *gěi* 'give' as the prime, and 婆 *pó*' mother-in-law' as the target are unrelated in any way.

b) In one-third of all fillers (48 out of 144 pairs), the primes are real characters, and the target characters are non-characters. As shown in the example in Table 7, target 她 *tā* 'she' is a real character and 答 is a non-character.

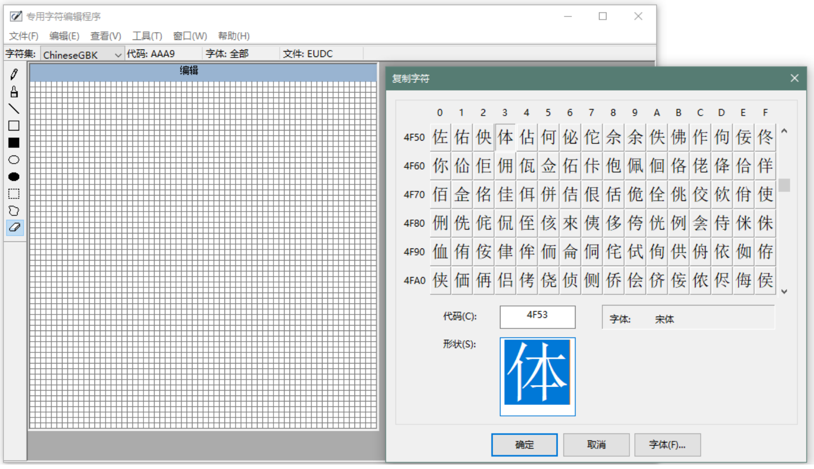
Table 7: Filler pairs and examples

Pair type	Target type	Numbers	Percentage	Example of prime-target pair
Filler pairs	Real character	48	25%	给-婆
	Non-character	96	50%	她-答
Critical pairs	Real character	48	25%	东-冬
In all		192	100%	

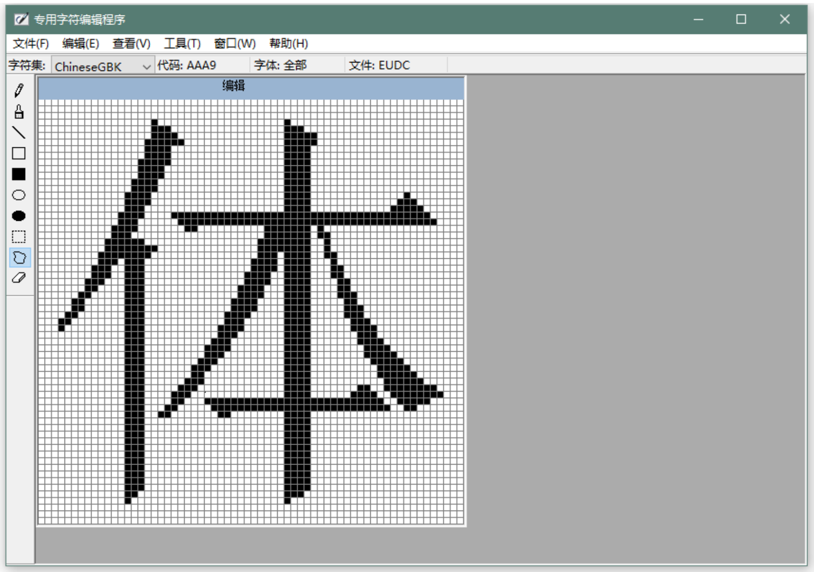
Non-characters were created by adding or deleting one stroke from existing CLB characters used in current research[17] (see below Illustrations as an example). Each non-character matches one target character in critical pairs in visual complexity/density (stroke number). As a result, each of the 48 target characters in critical pairs has its own corresponding visual complexity matching non-character. Window True Type was used to create the non-characters. These non-characters do not differ from the target characters in critical pairs in terms of size or font. The complete list of 48 non-characters can be seen in Appendix D. The following is a schematic description of the creation of non-characters in the Windows True Type.

[16] The non-characters are not used for the critical pairs. In fact, since the aim of the experimental pairs is to see whether a character priming can activate a target character, by default it implies the usage of real characters.
[17] Non-characters violate orthographic constraints of Chinese characters; hence, it is possible for subjects to recognise such non-characters solely based upon reasons of orthographic illegality.

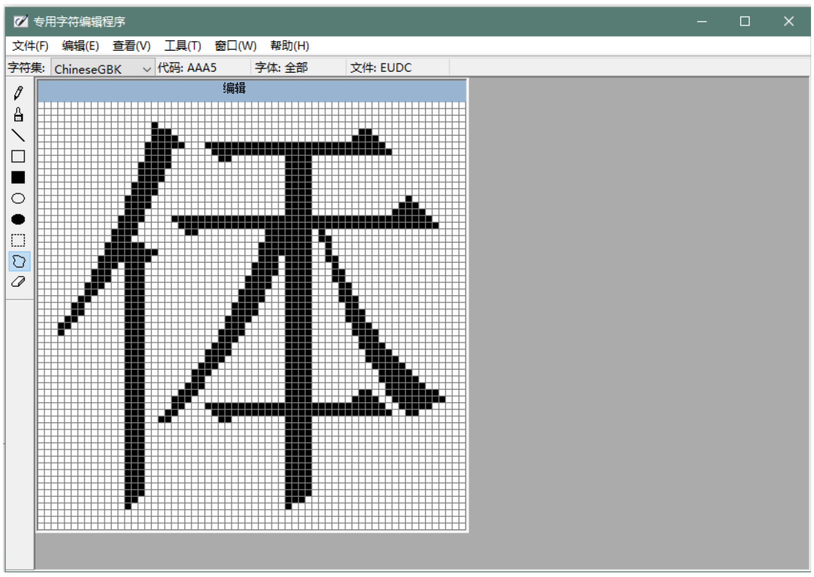
Step 1. Type the character ‘体’ in *Song* font



Step 2. Choose the character



Step 3. Add one stroke ‘一’ on top of the character to make a non-character.



5.3.3.3 Critical pairs

Critical pairs are designed to test character processing strategies for L1 native speakers and L2 Chinese learners regarding the prioritised semantic and phonological information retrieval. This information retrieval can be compared at lexical (or character) level or sub-lexical (or radical level) and between target-related primes and non-related controls.

Ideally, all the characters in critical pairs (both primes and targets) should be chosen for CLB. However, considering the strict constraints of the choosing criteria, only 86.32% (164 out of 190) characters are from the CLB. The rest are either from the HSK4/5-character list or the most frequent 3000 characters in the Character-frequency statistic database[18]. There is no character overlap between filler pairs and critical pairs.

5.3.3.3.1 Taxonomy of all prime-target relation

Critical pairs are designed to capture the following **six scenarios** and their corresponding controls in character recognition. On the character-level, a prime character activates its corresponding related target character either semantically **(CLevel-SERL)** or phonologically **(CLevel-PHRL)**. However, at the radical level, it is the radical embedded in a prime character that activates the corresponding target. If the priming radical is a semantic radical (SR), the corresponding target can be either primed semantically **(RLevel-SRSERL)** or phonologically **(RLevel-SRPHRL)**. Similarly, if the priming radical is a phonetic radical (PR), it activates its corresponding target character either semantically **(RLevel-PRSERL)** or phonologically **(RLevel-PRPHRL)**. Each of these possible activation types of critical primes are also compared with the activation made by their corresponding control prime **(NONRL)**.

In conclusion, this experiment design combines the different relations (related or non-related), activation levels (character level or radical level), activation locations (semantic radical or phonetic radical) and activation types (semantic activation or phonological activation). The comprehensive structure and taxonomy of all the critical pairs used as stimuli in this study are shown in Table 8. All 192 critical pairs can be seen in Appendix E.

[18] The database was developed by Jun Da and is available at: http://lingua.mtsu.edu/chinese-computing/statistics/char/list.php?Which=MO

Table 8: Class of all priming types in critical pairs

Priming type	Explanation	Prime	Target
CLevel-SERL	Character level, semantically related	真	假
CLevel-SE-NONRL	Character level, semantically non-related	高	假
CLevel-PHRL	Character level, phonologically related	弓	公
CLevel-PH-NONRL	Character level, phonologically non-related	巾	公
RLevel-SRSERL	Radical level, semantic radical semantically related	睡	看
RLevel-SRSE-NONRL	Radical level, semantic radical semantically non-related	锤	看
RLevel-SRPHRL	Radical level, semantic radical phonologically related	张	公
RLevel-SRPH-NONRL	Radical level, semantic radical phonologically non-related	帐	公
RLevel-PRSERL	Radical level, phonetic radical semantically related	填	假
RLevel-PRSE-NONRL	Radical level, phonetic radical semantically non-related	址	假
RLevel-PRPHRL	Radical level, phonetic radical phonologically related	特	四
RLevel-PRPH-NONRL	Radical level, phonetic radical phonologically non-related	物	四

Note. Coloured fill indicates the experimental pairs are related.[19]

5.3.3.3.2 Relation between prime and target

Each target was primed using four different primes: character-level prime (CLevel), radical-level prime (RLevel) and their respective controls (NONRL). Concerning a more fine-grained analysis of the prime-character relation, the graphemic relation is ruled out in the design. In this way, semantic and phonological priming are the only focuses. Therefore, related stimuli can only be either semantically or phonologically related character pairs. Each target is primed by its related primes at the lexical and sub-lexical levels; and by the unrelated control for each related prime. For instance, the activation of target 假 *jiă* 'fake' is analysed in four different scenarios (see Table 9):

a) Character-Level related (CLevel-RL) primes relate to the target at the character level (i.e., either are homophonic of or semantic related to the target[20]), i.e., prime

[19] 'Semantically or phonologically non-related' by no means implies that the experimental pairs are related in other ways, but simply indicates that they are 'semantically or phonologically related' primes' corresponding controls, which will be further explained in the latter part of the chapter.

[20] Synonyms, antonyms, or category coordinates refer to character pairs belonging to the same semantic category, i.e., both 米 'meter' and 寸 'inch' are length.

真 *zhēn* ‘real’ activates target 假 *jiǎ* ‘fake’ on the character level and they are semantically related but not related in any other way;

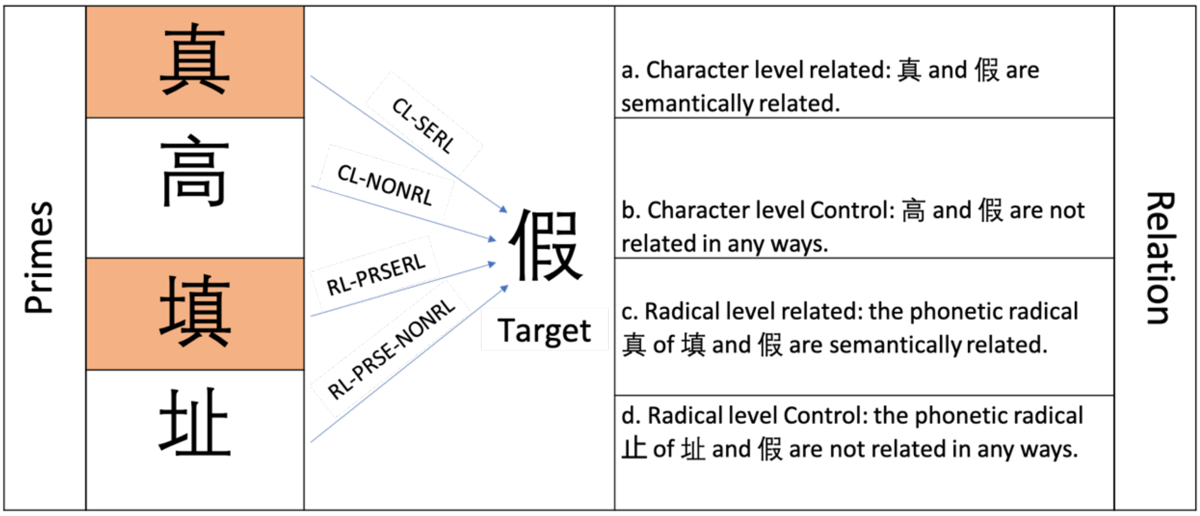
b) Character-Level unrelated (CLevel-NONRL) primes serve as a baseline of CLevel-RL condition, i.e., prime 高 *gāo* ‘tall’ is unrelated to target 假 *jiǎ* ‘fake’.

c) Radical-Level related (RLevel-RL) primes[21] are compound characters with their corresponding character-level related primes embedded as their radical. They are not related to the target semantically, phonologically or orthographically, i.e., prime 填 *tián* ‘to fill’ semantically relates its target 假 *jiǎ* ‘fake’ at the radical level because of the embedded radical 真. In addition, they are not related in other ways;

d) Radical-Level unrelated (RLevel-NONRL) primes serve as a baseline of RLevel-RL condition, i.e., prime 址 *zhǐ* ‘location’ is unrelated to target 假 *jiǎ* ‘fake’.

These four types of primes correspond to four within-subject variables: priming types (related or non-related), priming levels (character-level or radical-level), priming locations (semantic radical or phonetic radical), activation types (semantic or phonological activation).

Table 9: An example of one target character activated by its four primes



5.3.3.3.3 Relation between related primes at character and radical levels

For the same target character, its primes at the character level and radical level are related: character level primes are either the semantic radical or the phonetic radical of their corresponding radical prime. As a result, the activation type (semantically or phonologically) between the prime and the target at the character level remains at its corresponding radical level.

[21] All the radical level (RLevel) prime characters belong to the left-right categories of graphic structure of Chinese compounds, more specifically, they all have semantic radicals on the left and phonetic radicals on the right.

Compound characters selected as radical level primes have to meet specific requirements. It has to ensure that the observed priming effects are due to the semantic or phonological activation of radical properties rather than the lexical processing of whole characters. Specifically, for the primes semantic activation condition, only **opaque** phonetic compounds are used. It means that their semantic radical does not provide semantic cues for reading their meaning. For example, RLevel-SRSERL primes at the radical level are opaque because they contain a semantic radical with a meaning that is not related to the meaning of their whole characters. Their semantic radical is also used as their corresponding CLevel-SERL prime at the character level to activate the same target. Also, in the case of RLevel-PRSERL primes, all characters used in this condition are automatically opaque characters. The meaning of phonetic radicals is always different from their whole characters. Hence, there is no relation between the meaning of the phonetic radicals used as standalone characters in the CLevel-SERL condition and the meaning of their target.

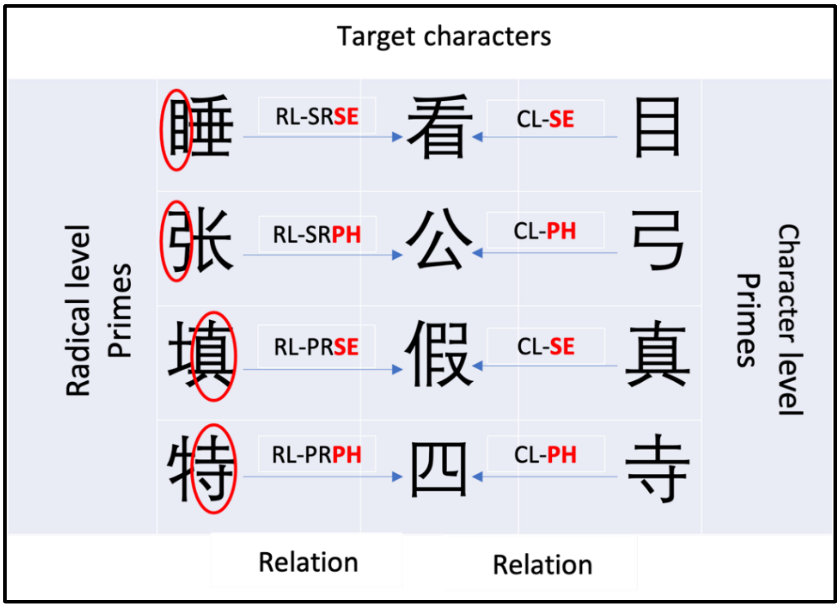
Similarly, for the phonological activation condition of radical level primes, only **irregular** phonetic compounds are used. It means that they do not share any phonological properties with their phonetic radical. For example, RLevel-PRPHRL primes at the radical level are irregular phonetic compounds because they contain a phonetic radical with different consonants and vowels properties from their own. This phonetic radical is also used as their corresponding CLevel-PHRL prime at the character level to activate the same target. In the case of RLevel-SRPHRL condition primes, we can automatically assume that they are irregular phonetic compounds because the sound of semantic radicals is always different from the sound of their host characters. As a result, its corresponding character level condition CLevel-PHRL primes – the semantic radicals are used as standalone characters, also sound differently from the same target. In this way, the activation between radical level and character level can be compared. For example (see Figure 16):

a) RLevel-SRSERL condition. CLevel-SERL prime 目 *mù* ‘eye’ semantically activates target 看 *kàn* ‘to see’ (‘eye’ vs ‘to see’); RLevel-SRSERLE prime 睡 *shuì* ‘to sleep’ also semantically activates target 看 even though their meanings (‘to sleep’ vs ‘to see’) are unrelated. This is because 睡 contains 目 as its semantic radical. In this case, RLevel-SRSERL prime 睡 is an **opaque character** – the meaning of the embedded semantic radical 目 ‘eye’ does not provide any information in terms of meaning for the host character 睡 ‘to sleep’.

b) RLevel-SRPHRL condition. CLevel-PHRL prime 弓 *gōng* ‘bow’ phonologically activates target 公 *gōng* ‘public, duke’ (*gong* vs *gong*); RLevel-SRPHRL prime 张 *zhāng* ‘a piece of’ also phonologically activates 公 even though their pronunciations (*zhang* vs *gong*) are different because 张 contains 弓 as its semantic radical. In this case, RLevel-SRPHRL prime 张 is an **irregular character** – the sound of the embedded semantic radical 弓 *gōng* does not share a consonant or vowel with the host character 张 *zhāng*.

c) RLevel-PRSERL condition. CLevel-SERL prime 真 *zhēn* ‘real’ semantically activates target 假 *jiǎ’* fake’ (‘real’ vs ‘fake’); RL-PRSERL 填 *tián* ‘to fill’ also semantically activates 假 even though their meanings are unrelated (‘to fill’ vs ‘fake’) because 填 contains 真 as its phonetic radical. In this case, RLevel-PRSERL prime 填 ‘to fill’ is an **opaque character –** the meaning of the embedded phonetic radical 真 ‘real’ does not provide any information in terms of meaning for the host character 填 ‘to fill’.

d) RLevel-PRPHRL condition. CLevel-PH prime 寺 *sì* ‘temple’ phonologically activates target 四 *sì* ‘four’ (si vs si); RLevel-PRPHRL prime 特 *tè’* special’ also phonologically activates 四 even though their pronunciations are unrelated (*te* vs *si*), because 特 contains 寺 as its phonetic radical. In this case, target-related primes are **irregular characters –** the sound of the embedded phonetic radical 寺 *sì* does not provide information in terms of the pronunciation of the host character 特 *tè*.



Note.
The marked-red circles indicate that the location of activation is either at the semantic radical or phonetic radical;
The marked-red letters indicate if it is a semantic relation or phonological relation;
Since all these conditions are related, the 'RL' which stands for 'related' is not marked;
RL-Radical level; CL-Character level.

Figure 16: Activation at the character and radical level

5.3.3.3.4 Related primes and their unrelated controls

In this study, both target-related primes at the character level and radical level match their corresponding control primes in terms of character frequency and stroke number (see Table 10). At the character level, the mean frequency of target-related primes is 844.19 per million (SD = 1468.60, range = 12.78- 9678.75 per million), and of their target-unrelated control is 917.36 per million (SD = 1655.22, range = 25.74-11028.64 per million). At the radical level, the mean frequency of target-related primes is 506.95 per million (SD = 541.71, range = 38.35-2418.74 per million), and of their target-unrelated control is 390.70 (SD = 428.84, range = 10.73-2218.37). Target characters have a mean frequency of 1206.93 per million (SD = 1206.93, range= 12.08-5105.44 per million). There is no statistical character frequency difference (P value > 0.1) between character-level related primes and their corresponding controls (844.19 vs 917.36, P = 0.410), or between radical-level primes and their controls (506.95 vs 390.70, P = 0.123).

Table 10: Character frequency of primes and targets (per million)

	Prime				Target
	Character related	Character unrelated (control)	Radical related	Radical unrelated (control)	
Mean	844.19	917.36	506.95	390.70	987.63
Std.	1468.60	1655.22	541.71	428.84	1206.93
Range	12.78- 9678.75	25.74-11028.64	38.35- 2418.74	10.73-2218.37	12.08 - 5105.44

Other than character frequency, primes and their control also match in some other ways. At the character level, target-related primes match their corresponding control prime in character complexity (stroke number) so that they always contain the same number of strokes. However, they do not share common features in the graphic, semantic or phonological aspect. For example, target-related prime 目 *mù* 'eye' and its control 头 *tóu* '*head'* share the same character complexity, as both consist of five strokes and their respective frequencies are 936.93 and 1424.41 per million characters. However, their writing forms do not look similar; they do not share the same sound (initial, end, or combined), and their meanings are not related.

At the radical level, the related primes and their corresponding control always share the same non-critical radical. The character complexity between the two has no significant difference (8.96 vs 8.38, $p = 0.088$, > 0.05). They are not related in any other ways. The relationship between the two related primes and their unrelated controls at the radical level is slightly complicated.

In the RLevel-SRSERL condition (see Figures 17 and 18), target-related primes and their control share the same non-critical (phonetic) radical. In this case, as we can see in this example for target 男:

a. Meanings of the related primes 始 '*beginning*' and its control 治 '*to rule*' are different from the meaning of their target 男 '*male*';

b. Sounds of the related primes 始 *shǐ* and its control 治 *zhì* are different from the sound of their target 男 *nán*;

c. The related primes 始 and its control 治 control share the same non-critical (phonetic) radical 台;

d. The critical (semantic) radical of related prime 始 is 女 'female' which is semantically related to the target 男 ('female' vs 'male'); the critical (semantic) radical of its control prime 治 is 氵, which is semantically unrelated to the same target 男 ('water' vs 'male');

e. The character frequency of the related prime 始 is 585.42 per million, and of its control 治 is 812.97 per million.

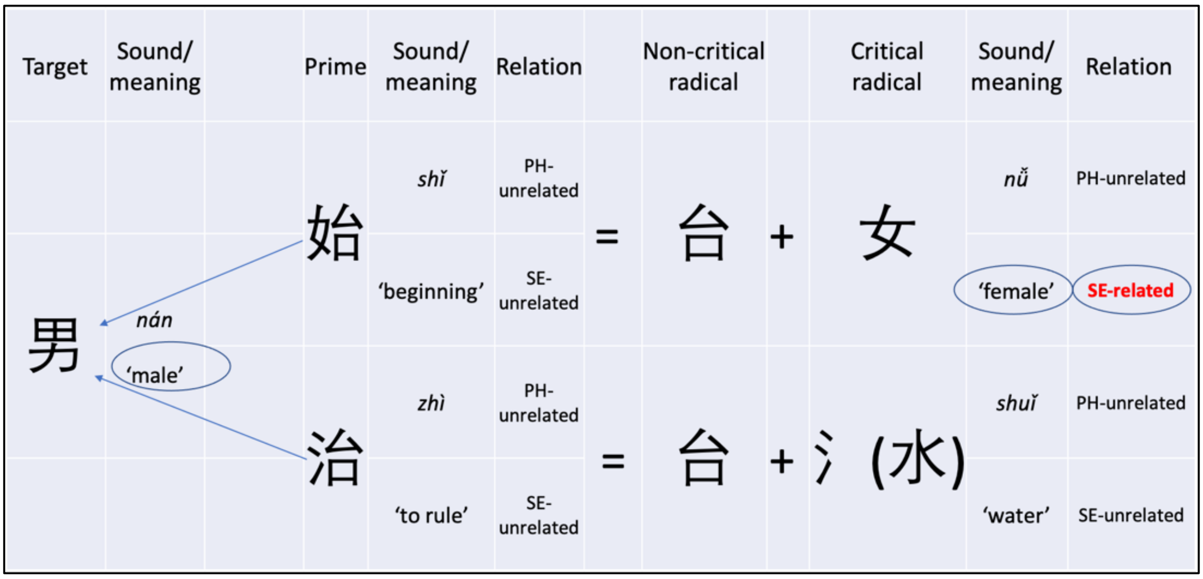


Figure 17: Semantically related and non-related primes vs target

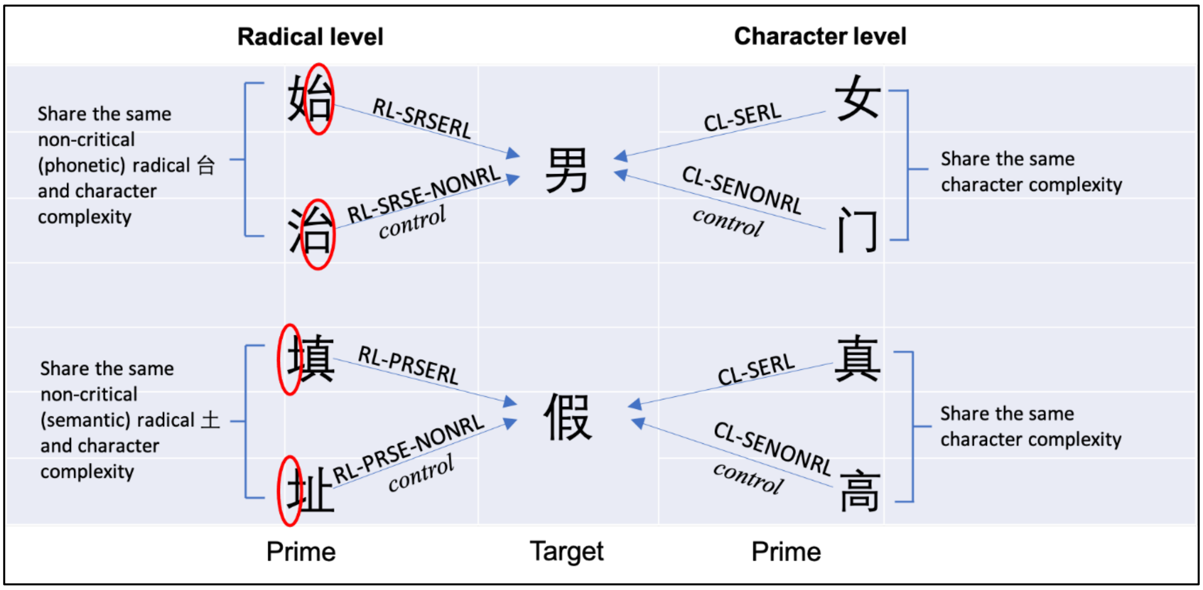


Figure 18: Target related primes and their corresponding non-related control

As a result, any observed priming effect difference between the related primes and their unrelated target can only be caused by the critical (semantic) radicals. Also, both sounds of the semantic radicals are different from their target, leaving the meaning difference of the radicals the sole reason for explaining the different time responses when priming the same target. As shown in Figure 17, only the meaning of the semantic radical of the RLevel-SRSERL prime is related to the target; the rest are unrelated. From this priming condition, we can see the semantic activation of semantic radicals.

Similarly, the other three related conditions at the radical level are also designed in a way that only one activation type at one location is isolated.

In the RLevel-SRPHRL condition, similar to the RLevel-SRSERL condition, the related primes and their unrelated prime are not related to the target in any way. Two types of primes share the non-critical (phonetic) radical. Their critical (semantic) radicals are different. The critical (semantic) radicals of the related primes activate their target phonologically, while the critical (semantic) radicals of the unrelated controls do not influence the activation of targets. It means that only the sound of embedded semantic radicals causes activation differences between the related and unrelated primes. In this priming condition, we can see the phonological activation of semantic radicals.

In the RLevel-PRSERL condition, the related primes and their unrelated prime are also not related to the target in any way. Target-related primes and their control share the same non-critical (semantic) radical. As a result, the possible activation difference between two types of primes comes from the different critical (phonetic) radicals. While the sound of both primes is different from the sound of their target, the meaning of the critical (phonetic) radical of related primes is related to the target, and it of its unrelated control is unrelated to the target. This difference in the meaning of phonetic radicals causes activation differences between the two types of primes. For example, as shown in Figure 17, 填 *tián* 'to fill' (Frequency = 38.35 per million) and its control 址 *zhǐ* 'location' (Frequency = 44.25 per million), both contain 土 *tǔ* 'earth' as non-critical (semantic) radical. Both types of primes are unrelated to their target 假 *jiǎ'* fake' in any way. Any observed priming effect difference would be caused by the different critical (phonetic) radicals (真 *zhēn* 'real' vs 止 *zhǐ* 'to stop'). Also, both sounds of the semantic radicals are different from their target 假 *jiǎ'* fake' (*zhen* vs *jia*; *zhi* vs *jia*), leaving the meaning difference of the phonetic radicals to cause activation difference. In this case, we can see the semantic activation of phonetic radicals.

In the RLevel-PRPHRL condition, similar to the RLevel-PRSERL condition, the related primes and their unrelated primes are not related to the target in any way. Two types of primes share the non-critical (semantic) radical. Their critical (phonetic) radicals are different. The critical (phonetic) radicals of the related primes activate their target phonologically, while the critical (phonetic) radicals of the unrelated controls do not influence the activation of targets.

It means that only the sound of embedded phonetic radicals causes activation differences between the related and unrelated primes. In this priming condition, we can see the phonological activation of phonetic radicals.

The critical radicals in each related condition are also the related prime to the same target at the character level. Hence, we can also see the activation of the same sign as a standalone character and embedded the radical.

5.3.3.3.5 Semantic relatedness

Relatedness is considered in three dimensions: graphical, semantic and phonological. Graphical and phonological relatedness are arbitrary. For example, if two characters share one orthographic form, i.e., a same radical, they are graphically related; otherwise, they are graphically distinct; or, if two characters share the same initial, ending or both, they are phonologically related; otherwise, they are phonologically distinct. Semantic relatedness is less arbitrary. It is more likely to be graded than dichotomous.

For this reason, semantic relatedness needs to be evaluated by Chinese native speakers for different scenarios. Firstly, because the primes selected under semantic activation conditions at the radical level (RLevel-SRSERL and RLevel-PRSERL) are opaque characters, it needs to be confirmed that the meaning of the radicals is truly unrelated to the meaning of their host character. Since the meaning of the phonetic radicals is automatically unrelated to the whole characters, only the RLevel-SRSERL condition needs to be considered. Secondly, it needs to be confirmed that that under the semantic activation situation, the meaning of the related primes is truly related to their target (CLevel-SERL), and the meaning of their control (CLevel-SENONRL) is truly unrelated to the same target.

Participants were asked to fill in questionnaires and to rate the semantic relatedness between two characters by choosing one answer from four options: completely unrelated (1 point), not so related (2 points), somewhat related (3 points) and closely related (4 points). Questionnaires A and B (see Appendix F) were designed to evaluate the following:

Questionnaire A for the RLevel-SRSERL condition. The related primes at the radical level and their embedded semantic radicals (also as their corresponding related primes at character level – CLevel-SERL condition) should be semantically unrelated. For example, the related prime at the radical level of 职 'occupation' is semantically unrelated to its semantic radical 耳 'ear'. Twenty-one L1 participants who did not take part in the priming test answered Questionnaire A. The average score for the relatedness is 2.30 (SD = 0.29, range = 1.58 – 2.58).

It is noteworthy that although 2.30 is not ideal as it is a score that lands between 'not so related' (2 points) and 'somewhat related' (3 points), there might be a response difference between L1 speakers and L2 learners. It is likely more difficult for L2 learners to notice the relatedness in some cases. For example, the relatedness between the related prime at the radical level of 购 'to buy' and its embedded semantic radical 贝 'shell' are scored as 3.38 by L1 participants. However, it might still be an opaque character for L2 learners because most of the transparent characters containing 贝 as their semantic radical are not in the CLB, i.e., 赌 'to gamble', 费 'fee', 贫 'poor', 财 'wealth', 账 'account', 贪 'greedy', 资 'capital', 贿 'bribe', 贸 'trade', 赚 'earn', and 赔 'to compensate'.

Questionnaire B for CLevel-SERL/SENONRL conditions. At the character level, the related primes should be semantically related to their target; its unrelated control prime should be semantically unrelated to the same target. For example, the related prime 东 'east' is semantically related to its target 西 'west'; while its unrelated control 电 'electricity' is semantically unrelated to the same target 西 'west'. Twenty-five L1 participants who did not take part in the priming test answered Questionnaire B. The average score for related pairs is 3.68 (SD = 0.28, range = 2.88-3.96), and for unrelated control pairs is 1.88 (SD = 0.38, range = 1.48-2.68).

5.3.4 Priming test 1

Although many studies have explored lexical processing in Chinese characters, most have evaluated processing at the character level and radical level, semantic radicals and phonetic radicals, semantic activations and phonological activation separately in different tasks. Thus, it is theoretically and methodologically important to design a single task obtaining all this available information to examine how these factors contribute to Chinese character recognition. Also, no study to date has examined how L2 learners' lexical processing strategies develop as their Chinese language proficiency improves. To address these issues, the present study applied a primed lexical decision paradigm to assess native speakers and L2's character processing, the developmental stages of the latter and the influence of radical awareness training on such processing.

5.3.4.1 Primed lexical decision task

To elicit the data from a balanced reading process, a task must be chosen to not lead subjects to be biased towards either semantic or phonological processing. To achieve this goal, this strategy-neutral reading task was used in this study to investigate visual lexical processing in proficiency levels from intermediate to native. The participants completed a lexical decision task designed to show how they use semantic and phonological information presented by the characters and their radicals when making decisions about the target characters. Priming conditions were manipulated. The character frequency and the trial sequence effect were also examined. The logic underlying this task is that if the L2 learners activate a certain type of information from either the character or its radical (semantic or phonetic radical), there would be differences in terms of response time and error rate among different stimuli. The participants were shown 192-character pairs; wherein each pair include a prime character and a target character.

5.3.4.2 Stimuli Onset Asynchrony SOA

In a consideration of the effects of the priming, the prime-target SOA is critical. In the present study, only one SOA could be used due to the limitation of materials and participants. As found in the previous research, when SOA is short, i.e., 50ms, the graphic effects were obtained; however, when SOA is longer, i.e., 180ms, the orthographic activation would be faded away while the semantic and phonological activation would be observed (Feldman and Siok 1999: 31; Liu *et al.* 2007). When SOA is 200ms, researchers (Zhou and Marslen-Wilson 1999a) have found that the representation activation strength at the lexical level was stronger than it was at the sub-lexical level; and the activation of the former inhibits the latter. When SOA is 250ms, the priming effect observed on L1 participants might be mainly attributed to the lexical level activation (Tong *et al.* 2021). After considering the character recognition proficiency difference between skilled native Chinese readers and L2 learners, a 250ms SOA was chosen to be used in the current study. It is slightly longer than the SOAs used in most similar task designs in the literature. It allows more prime processing time and possibly stronger facilitation effects from L2 learners.

During the priming test, each prime character was displayed on the screen for a duration of 250ms. After 250ms from the moment the prime character was shown, it was replaced by its target character, and the latter was displayed until the response was made. The respondent had to decide whether the target character is a real character or a non-character (see Figure 19 for Priming Test instruction). If they decide that the target character is real, they type ‘W’; for a non-character, they type ‘N’.

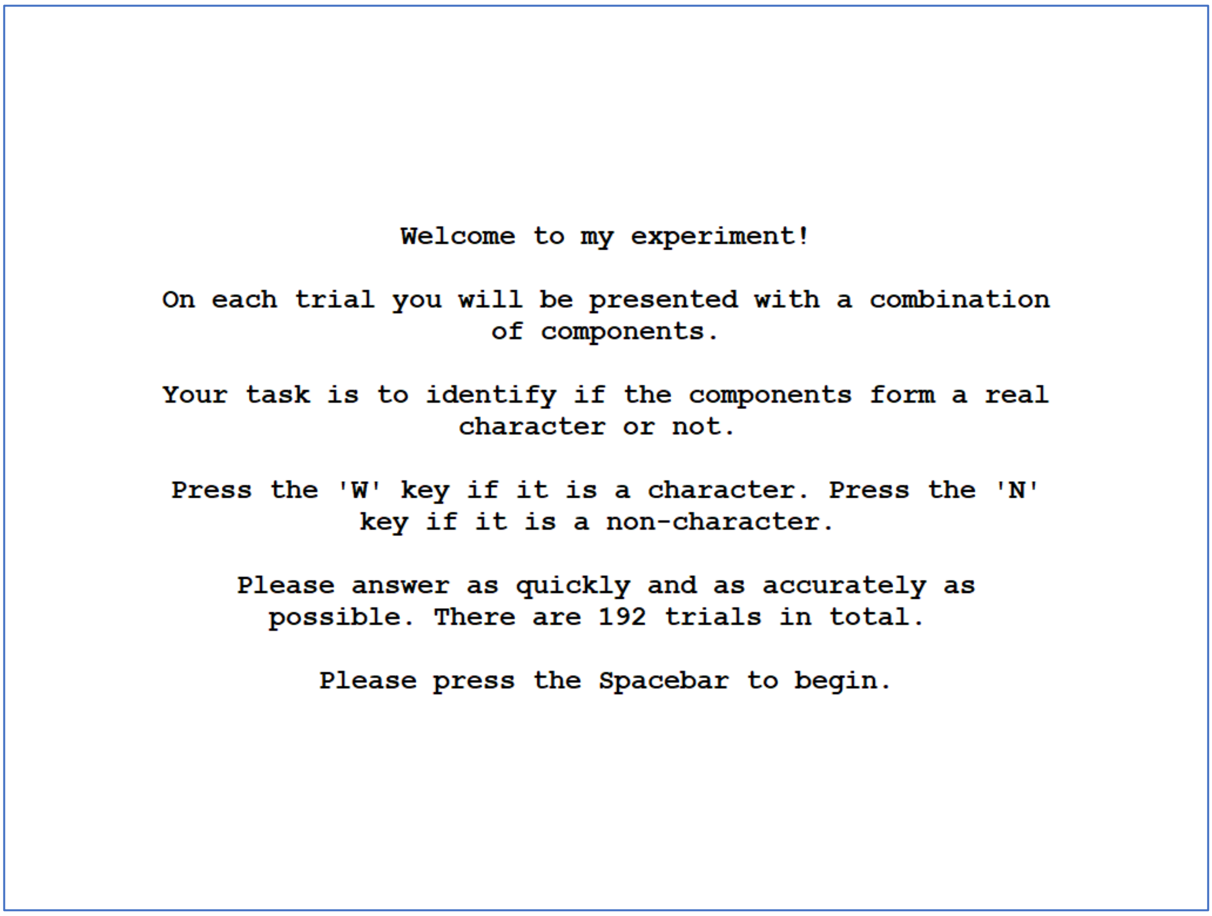


Figure 19: Lexical decision instruction screenshot

5.3.4.3 The design and procedure

A 2-priming types (related vs control) × 2-levels (character level vs radical level) × 2-locations (phonetic radical vs semantic radical) × 2-activation types (semantic vs phonological) design is used.

Participants were tested individually in a quiet and controlled illuminated room. They were required to sit in a comfortable chair and about 60 cm away from an 11-inch laptop screen (a visual angle of 1.9°). The task is to judge whether a target is a real character as quickly and accurately as possible in each trial.

The experiment was programmed and presented using E-Prime version 2.0 (Schneider *et al.* 2002). Stimuli were displayed in white against a black background and with a text size of 1.5 cm wide and 1.5 cm high (font size 66). Both related and unrelated primes were shown in *Kaiti* font and targets in *Songti* font. 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 used to ensure that there is little physical overlapping between the prime and the target, avoiding the possibility that participants react to the visual trace of the primes.

Figure 20 illustrates the procedures of the experiment. Each trial started with a fixation point ('+') first presented at the centre of the screen for 500ms, followed by a 250ms presentation of the prime, and then immediately replaced by the corresponding target character without any interval in between. The latter remained on the screen until participants decided whether it is a real character or not. 'W' keypress was required for 'yes' responses, and 'N' keypress was required for 'no' responses. The response and the time from the onset of the target to the pressing key response were recorded. In addition, participants were asked to rest both of their hands on the keyboard so they did not waste time on moving fingers or searching keys.

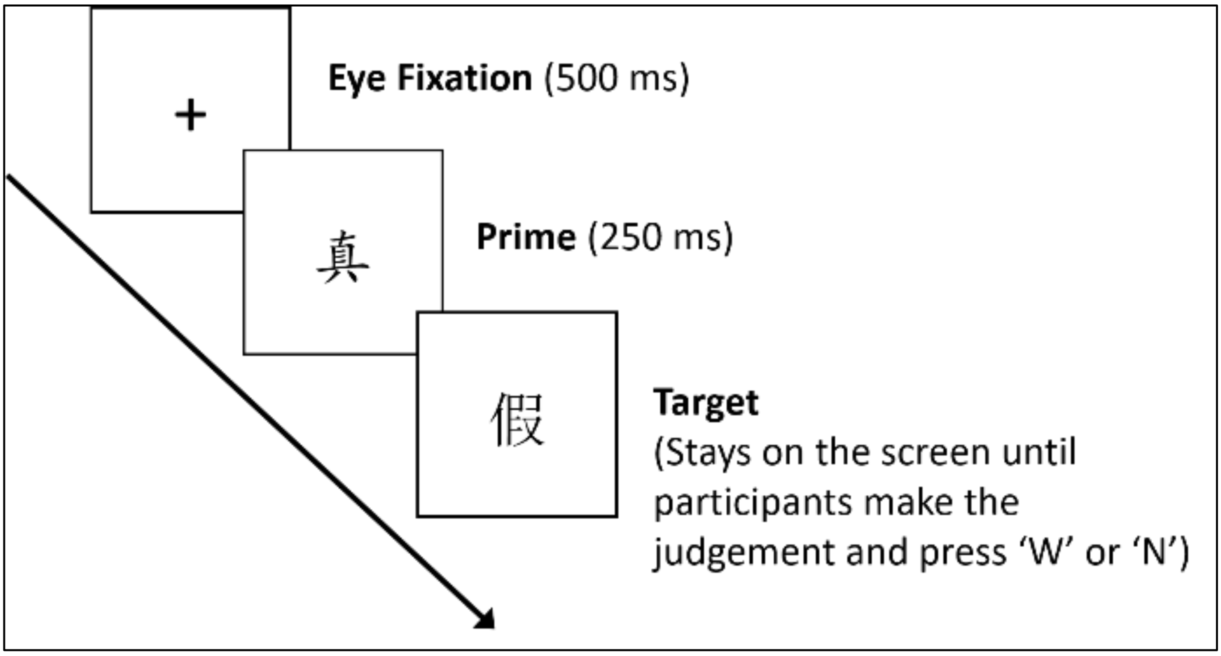


Figure 20: Experiment procedures

In the Priming Test 1, the critical pairs of stimuli (192 pairs) in the material design were divided into four experimental lists using a Latin square design; each task used one list (48 pairs). In this case, each target character only appeared once in each list to eliminate repetition effects. The repetition effect means that when a reader has just recognised a character, the speed of recognition would be faster if he sees the same character again soon. All the characters in the critical pairs are real characters, so the response should be 'W'. Each list contains the same number of trials for each priming condition. The critical pairs of two radical types and two activation types are evenly distributed in the four lists. Each of the four experimental lists contained all 12 conditions of prime-target relation: 2 conditions for character-level related pairs, 4 conditions for radical-level related pairs and their controls (see Figure 21).

A pseudo-random order was applied to both critical pairs and fillers to ensure that critical targets always appeared at the same position in each list.

Each participant only used one list. In total, each participant completed 192 trials in two test sessions. There was an optional break in the middle of the sessions. The first three trials after the break were always fillers. Prior to the experimental trial, each participant was given 10 practice trials (see Appendix D). The priming test lasted about 10 minutes for each L1 participant and 15 minutes for each L2 participant.

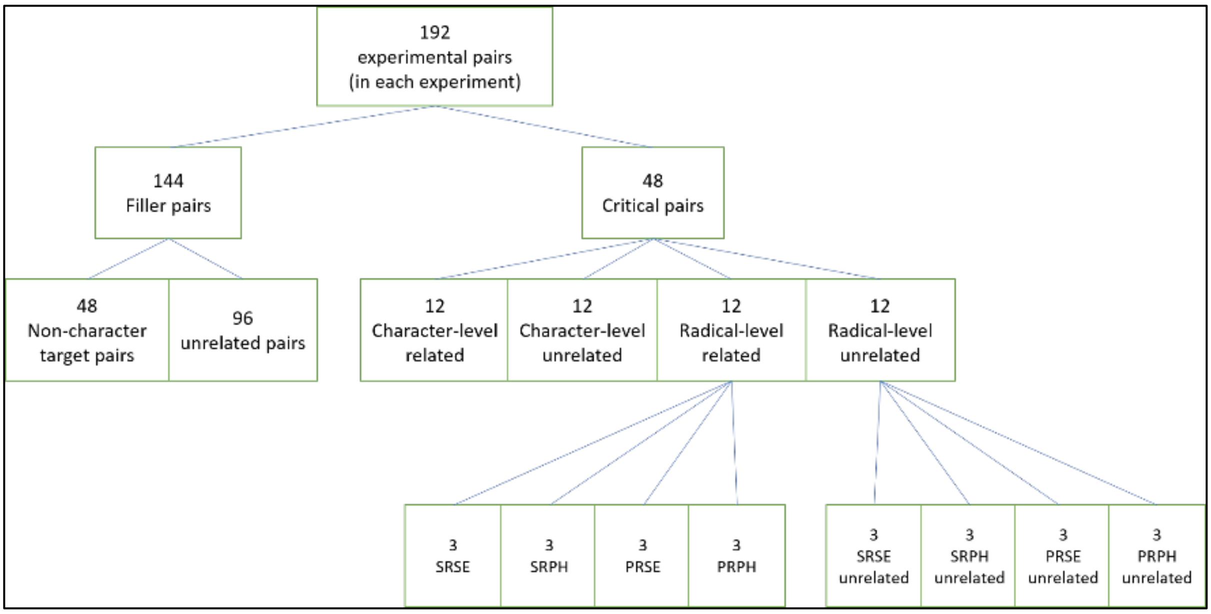


Figure 21: Classification of material used in Priming Tests

5.3.4.4 Lists of stimuli

As explained in the previous section (see section 5.3.4.3), four experimental lists cover all the 336 experimental pairs (192 critical pairs and 144 filler pairs). In each list, there are 48 critical pairs and 144 filler pairs. Each respondent was exposed to only one list. The full stimuli selected can be seen in Appendix G. A sample of it is visible below (Table 11).

Table 11: Extract from the stimuli used Priming Test 1 and 2

No.	Correct Response	List 1		List 2		List 3		List 4	
		Prime	Target	Prime	Target	Prime	Target	Prime	Target
1	w	咖	上	咖	上	咖	上	咖	上
2	n	点	杳	点	杳	点	杳	点	杳
3	w	椅	芳	椅	芳	椅	芳	椅	芳
4	w	厕	分	厕	分	厕	分	厕	分
5	w	难	虎	难	虎	难	虎	难	虎
6	w	王	网	书	网	现	网	视	网
7	n	喜	名	喜	名	喜	名	喜	名
8	w	师	期	师	期	师	期	师	期
9	w	闹	房	舒	房	野	房	舍	房
10	w	治	男	女	男	门	男	始	男
11	w	皮	毛	左	毛	波	毛	洲	毛
12	n	爱	范	爱	范	爱	范	爱	范
13	w	长	标	长	标	长	标	长	标
14	w	职	口	织	口	耳	口	岁	口
15	w	光	护	光	护	光	护	光	护
16	w	几	再	汉	再	游	再	又	再
17	n	鞋	宿	鞋	宿	鞋	宿	鞋	宿
18	w	处	里	位	里	信	里	立	里
19	w	南	馆	南	馆	南	馆	南	馆
20	w	带	辅	带	辅	带	辅	带	辅
21	w	帕	剧	帕	剧	帕	剧	帕	剧
22	w	克	觉	克	觉	克	觉	克	觉
23	w	色	贵	色	贵	色	贵	色	贵

Note. The marked yellow pairs are critical pairs; the unmarked pairs are filler pairs.

5.3.5 The Radical Awareness Training

At this stage of the test cycle after the Priming Test 1, learners received two kinds of tasks in the Radical Awareness Training: (1) radical learning practice; (2) radical awareness test. Before both tasks, a Radical Knowledge Test had already taken place to evaluate learners' current radical knowledge. In the Knowledge Test, learners were asked to write down the meaning and sound of radicals. However, in the training section, learners needed not only to learn the meaning and sound of radicals, but also the characters which contain them as both semantic and phonetic radicals. The radicals listed in the training material (see Appendix H and I) mostly follow positional and functional regularities with few exceptions because of a lack of examples. It means that when a radical is used as a semantic radical, it occupies the left side position in the host character, indicating the partial meaning of the host character; when the same radical is used as a phonetic radical, it is usually located on the right side of the host character, providing certain clues to the sound of the host character. Participants learned the radicals and their host characters in a study trial followed immediately by the awareness test with feedback. Both the learning and test tasks were administered individually by the author of this study.

Radical learning practice. After the Priming Test 1, Each L2 participant was given some learning materials about radicals and asked to learn it in their spare time. Those radicals were used in Priming Test 1. It usually took 20-25 minutes to review the list. Learners were asked to complete the self-training section the same day or no more than one day before the Priming Test 2. The learning practice could be expanded by a follow-up activity based on e-flashcards. In this case, radicals and their meaning, pictures and pronunciation would be edited on e-flashcards. Each radical is learnt in two steps. First, an e-flashcard with a radical is shown, and the sound of the radical is played automatically. Then the back of the same e-flashcard shows a picture explaining the meaning of the radical; the sound is automatically played again. Learners learn the first and second half of the radical list on two separate days. However, for this study, the author did not resort to e-flashcards. The reason is that this study aims to determine whether a typical class activity (based on exposure of both semantic and phonetic radicals) could reshape the route of character recognition.

The *Radical Awareness Test* was conducted after the learning practice. Participants were asked to take 25-35 minutes to finish the test in a quiet room. They were required to write down the sound and meaning of the radicals, and characters which contain those radical semantic and phonetic radicals. Once they finished the test, they submitted the results to the researcher.

5.3.6 Priming Test 2

There was at least one week but no more than two weeks between Priming Test 1 and 2. The time frame was decided based on the following considerations: a) Learners might respond faster when doing the same test and reading the same characters again within a short period of time. 'At least one week' in between priming tests is to reduce the familiarity of learners towards the test and the characters used in the test and, hence, reduce the repetition effect (also see section 5.3.4.3 about how to minimise the repetition effect); b) 'No more than two weeks' is because students were continuing their Chinese study during the time when the experiments were taking place. If there was too long a time in between experiments, it might be the case that the improvement of response results is from the overall character knowledge growth rather than the Radical Awareness Training; c) Participants should be allowed a reasonable time to finish self-training properly.

Priming Test 2 used the same procedures as Priming Test 1. The same L2 learners (except one learner who did not attend the Test 2 because of personal reasons) took the test. Each participant was assigned the same experimental list they used in the Priming Test 1, to maximise the training effect (one participant used a different list by mistake, which should not affect overall results).

In conclusion, the experimental design compares the priming effects of 12 priming conditions in a single experiment. In this way, building on Chen Yao (2015), it allows us to capture relations that are more fine-grained than the usual ‘semantic vs phonological activation’, which happens at only one level (character or radical level), or one location (semantic or phonetic radical). Moreover, thanks to a more articulated test cycle than those typically mentioned in the literature, this study also allows us (i) to monitor how the specific character level and radical level activations develop after a specific training on radical awareness, and (ii) to identify possible techniques for modelling the activation of Chinese character by L2 learners.

CHAPTER 6: DATA ANALYSIS

Before the critical group, namely Italian participants (Group 2 Year 2 – intermediate level and Group 2 Year 3 – advanced level) joined the experiments, a pilot group of 16 Year 4 Irish learners (Group 0 – beginner to advanced level[22]) of Chinese L2 from an Irish university took a part in this study. The pilot research consists of the same Radical Knowledge Test and a slightly different version of the Priming Test. The Priming Test used in the pilot research shares the same rationale of experiment design as the Priming Test 1 and 2 used in critical research, however, there were a small number of adjustments. The data analysis of the Radical Knowledge Test is mainly focused on the subgroups of the critical group, Group 2 Year 2 and Group 2 Year 3, with the results of the pilot group (Group 0) as supplementary material to provide extra evidence. Data analysis of the Priming Test 1 and 2 is solely based on the subgroups of the critical group, Group 2 Year 2 and Group 2 Year 3 (see Table 12).

Table 12: Differences between main and pilot research

	Group	Years of learning	Participant levels	Radical Knowledge Test results analysis	Priming Test results analysis
Critical group	Group 2	2	intermediate	✓	✓
		3	advanced	✓	✓
Pilot group	Group 0	4	beginner to advanced	✓	✗
Baseline group	Group 1		native	✗	✓

6.1 Results of the Radical Knowledge Test

The Radical Knowledge Test is intended to capture the development of radical knowledge of L2 learners at different levels of proficiency. The results of the Radical Knowledge Test combined with the results of priming tests, hopefully, can identify the relation between the existing radical knowledge and the radical strategies used by L2 learners at different proficiency levels.

6.1.1 Radical knowledge Test results

Before the priming experiment, 29 L2 learners (16 learners in Group 0 and 13 learners in Group 2) finished the Radical Knowledge Test to evaluate their existing knowledge of radicals. The results (see Table 13) are analysed within groups and cross groups. The analysis

[22] The level here simply refers to the HSK level they had passed; it does not reflect their actual proficiency. However, it does reflect less inconsistency in overall proficiency within the group as compared to the critical group.

is based on two Key Factors: location type (semantic radical also as SR and phonetic radical also as PR) and activation type (semantic activation also as SE and phonological activation also as PH). The correction rate for each radical type is the average correction rate of meaning (SE) and sound (PH) of this radical type.

Table 13: L2 learners radical knowledge results

Learning Group	Learner No.	Semantic radical correction no. and rate					Phonetic radical correction no. and rate					RK out of 226 questions	
		SE	PH	SRSE%	SRPH%	SR%	SE	PH	PRSE%	PRPH%	PR%	SR+PR	(SR+PR) %
Group 2 Year 2	1	24	24	64.86%	64.86%	64.86%	37	40	48.68%	52.63%	50.66%	125	55.31%
	2	32	34	86.49%	91.89%	89.19%	54	69	71.05%	90.79%	80.92%	189	83.63%
	3	27	23	72.97%	62.16%	67.57%	30	36	39.47%	47.37%	43.42%	116	51.33%
	4	23	15	62.16%	40.54%	51.35%	28	30	36.84%	39.47%	38.16%	96	42.48%
	5	18	19	48.65%	51.35%	50.00%	32	31	42.11%	40.79%	41.45%	100	44.25%
	6	28	24	75.68%	64.86%	70.27%	41	36	53.95%	47.37%	50.66%	129	57.08%
	7	20	21	54.05%	56.76%	55.41%	35	26	46.05%	34.21%	40.13%	102	45.13%
	8	23	22	62.16%	59.46%	60.81%	42	38	55.26%	50.00%	52.63%	125	55.31%
Group 2 Year 3	1	22	23	59.46%	62.16%	60.81%	35	43	46.05%	56.58%	51.32%	123	54.42%
	2	24	0	64.86%	0.00%	32.43%	26	0	34.21%	0.00%	17.11%	50	22.12%
	3	30	28	81.08%	75.68%	78.38%	52	60	68.42%	78.95%	73.68%	170	75.22%
	4	26	24	70.27%	64.86%	67.57%	39	44	51.32%	57.89%	54.61%	133	58.85%
	5	26	15	70.27%	40.54%	55.41%	35	39	46.05%	51.32%	48.68%	115	50.88%
Group 0 Year 4	1	22	21	59.46%	56.76%	58.11%	32	29	42.11%	38.16%	40.13%	104	46.02%
	2	26	21	70.27%	56.76%	63.51%	25	36	32.89%	47.37%	40.13%	108	47.79%
	3	25	25	67.57%	67.57%	67.57%	51	59	67.11%	77.63%	72.37%	160	70.80%
	4	12	14	32.43%	37.84%	35.14%	20	32	26.32%	42.11%	34.21%	78	34.51%
	5	21	20	56.76%	54.05%	55.41%	57	60	75.00%	78.95%	76.97%	158	69.91%
	6	9	10	24.32%	27.03%	25.68%	25	27	32.89%	35.53%	34.21%	71	31.42%
	7	14	17	37.84%	45.95%	41.89%	28	37	36.84%	48.68%	42.76%	96	42.48%
	8	15	18	40.54%	48.65%	44.59%	31	39	40.79%	51.32%	46.05%	103	45.58%
	9	28	29	75.68%	78.38%	77.03%	51	59	67.11%	77.63%	72.37%	167	73.89%
	10	17	17	45.95%	45.95%	45.95%	33	43	43.42%	56.58%	50.00%	110	48.67%
	11	17	19	45.95%	51.35%	48.65%	36	42	47.37%	55.26%	51.32%	114	50.44%
	12	20	24	54.05%	64.86%	59.46%	20	25	26.32%	32.89%	29.61%	89	39.38%
	13	25	24	67.57%	64.86%	66.22%	48	45	63.16%	59.21%	61.18%	142	62.83%
	14	15	12	40.54%	32.43%	36.49%	30	32	39.47%	42.11%	40.79%	89	39.38%
	15	27	16	72.97%	43.24%	58.11%	41	50	53.95%	65.79%	59.87%	134	59.29%
	16	13	17	35.14%	45.95%	40.54%	35	44	46.05%	57.89%	51.97%	109	48.23%

Note. SE: meaning/semantic SR: semantic radical PH: sound/phonology PR: phonetic radical

Missing data and outliers were adjusted as follows:

1) No. 2 participant in Group 2 Year 3 missed data in radical knowledge types SRPH and PRPH. The missing data is given to be the average correction rate of the rest data in the same sample group for either corresponding knowledge type;

2) The results of normality tests and One-way ANOVA tests have found that the results of the No. 2 participant in Group 2 Year 2 are significantly different from the results of the other participants in the same group and causes non-normal distribution of the data. To solve this problem, the results of this participant were adjusted to be the average correction rate of the other participants in the same sample group for each corresponding knowledge type.

The cause of 1) missing data is that the participant missed a part of the test by mistake. The cause of 2) outliers is that the participant spent a lot of spare time self-learning radical knowledge while the other participants barely spent any time at home working on this kind of knowledge (this information was obtained through informal interviews before or after the tests, as mentioned in the previous chapter).

The data were mainly analysed using IBM SPSS Statistics Version 27. P values smaller than 0.05 are considered statistically significant. P values between 0.05 to 0.1 or approximately equal to 0.1 is considered marginally significant.

6.1.2 Analysis within groups

Each group is analysed based on Key Factor 1 Location, Key Factor 2 Activation.

6.1.2.1 Key Factor 1: Location (semantic radical vs phonetic radical)

Learners in both subgroups of Group 2 (Year 2 and Year 3) have obtained a higher correction rate for semantic radicals than phonetic radicals, suggesting a better knowledge of semantic radicals. This knowledge difference is significant for Year 2 learners ($P = 0.001, < 0.05$) but not for Year 3 learners ($P = 0.150, > 0.1$). However, for Group 0 learners, only 6 out of 16 learners (37.50%) did better in semantic radicals, and the correction rate difference between the two radical types is not significant for Year 3 learners ($P = 0.802, > 0.1$) (see Table 14).

Table 14: T-Test results of radical types comparison within groups

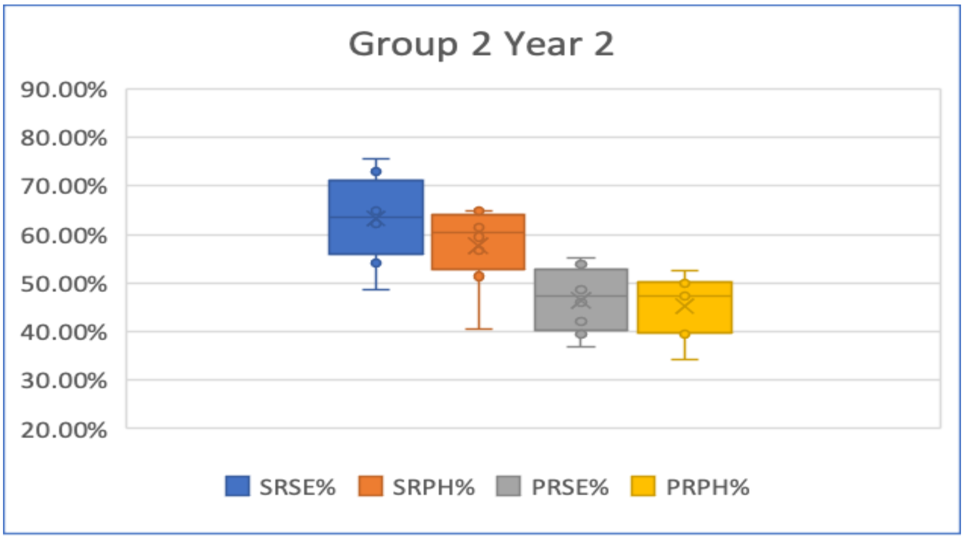
Group	Semantic radical% (SD)	Phonetic radical% (SD)	t	df	P-value
Group 2 Year 2	60.49% (7.51%)	45.86% (5.66%)	4.402	14	0.001[23]
Group 3 Year 3	65.00% (8.66%)	55.20% (10.68%)	1.594	8	0.150
Group 0	51.52% (13.89%)	50.25% (14.65%)	0.253	30	0.802

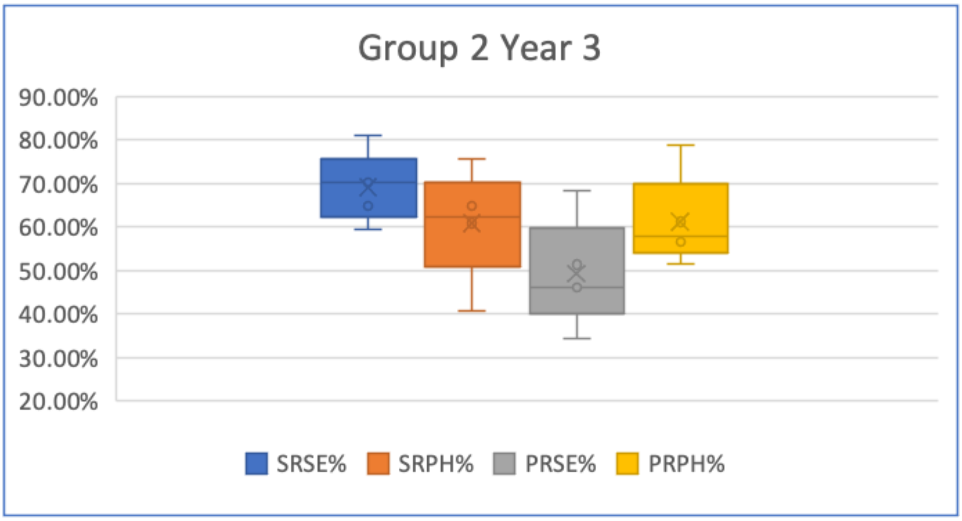
Four types of radical knowledge – meaning of semantic radical (SRSE), sound of semantic radical (SRPH), meaning of phonetic radical (PRSE) and sound of phonetic radical (PRPH) – were compared with each other in each group to see what kind of information learners knew more than the other (see Table 15 and boxplots below). The results have shown that the differences between radical knowledge types are significant for Group 2 Year 2 (df = 3, 28; F = 10.583, P = 0.000, < 0.05); marginally significant for Group 2 Year 3 (df = 3, 16; F = 2.745, P = 0.077, < 0.1), and that there is no difference for Group 0 (df = 3, 60; F = 0.790, P = 0.504, > 0.1). A post-hoc comparison using Tukey's test was selected to check individual differences between radical knowledge types for Group 2 Year 2 and Group 2 Year 3.

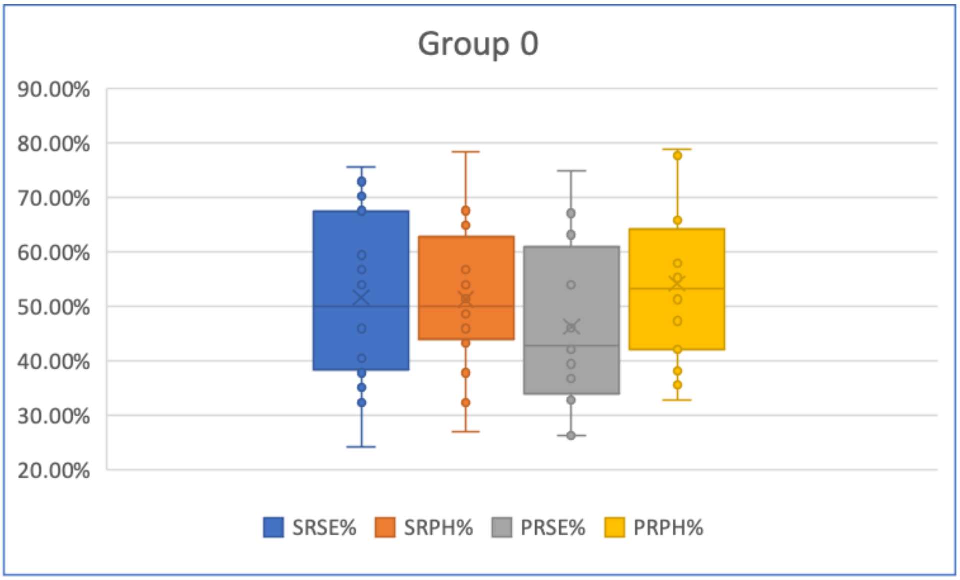
Table 15: One-way ANOVA results of comparing radical information types within groups

Group	df	F	*P-value*
Group 2 Year 2	3, 28	10.583	0.000
Group 2 Year 3	3, 16	2.745	0.077
Group 0	3, 60	0.790	0.504

[23] The highlighted cells in each table indicate that relevant data reaches statistical or marginal statistical significance.


Group 2 Year 2
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
SRSE%
SRPH%
PRSE%
PRPH%


Group 2 Year 3
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
SRSE%
SRPH%
PRSE%
PRPH%


Group 0
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
SRSE%
SRPH%
PRSE%
PRPH%

The post hoc results (see Table 16 and 17) have shown that Group 2 Year 2 learners knew significantly more about the meaning of semantic radicals (M = 63.30%, SD = 8.93%) than the meaning and sound of phonetic radicals (M = 46.44%, SD = 6.62 %; M = 45.27 %, SD = 6.40%), with P values 0.001 and 0.000, < 0.05, irrespectively. In addition, they knew significantly more about the sound of semantic radicals (M = 57.69%, SD = 8.24%) than the meaning and sound of phonetic radicals (M = 46.44%, SD = 6.62 %; M = 45.27 %, SD = 6.40%), with P values 0.031 and 0.015, < 0.05, irrespectively. These results match the overall results mentioned above, that they knew semantic radicals better than phonetic radicals, and this knowledge difference is significant at the 0.05 level (P = 0.001). There is no significant difference between the meaning and the sound of semantic radicals, or of phonetic radicals.

Group 2 Year 3 learners also knew more about the meaning of semantic radicals (M = 69.19 %, SD = 8.02%) than of the meaning of phonetic radicals (M = 49.21%, SD = 12.43%), with P value 0.051. The difference is marginally significant at the 0.05 level. There is no meaningful difference between the meaning of semantic radicals and the sound of either radical, or between any two of the other three types of radical information.

Unlike like two subgroups in Group 2, Group 0 learners did not have any prioritised types of radical knowledge among the four types because none of the comparisons reach the meaningful level (P > 0.1).

Table 16: Mean correction rates of radical knowledge types of each group

Group	Radical knowledge type			
	SRSE	**SRPH**	**PRSE**	**PRPH**
Group 2 Year 2	63.30% (8.93%)	57.69% (8.24%)	46.44% (6.62%)	45.27% (6.40%)
Group 2 Year 3	69.19% (8.02%)	60.81% (12.75%)	49.21% (12.43%)	61.19% (10.55%)
Group 0	51.69% (16.06%)	51.35% (13.46%)	46.30% (15.02%)	54.19% (14.90%)

Table 17: Post Hoc results of comparison radical knowledge types within groups

Group	Radical knowledge type	Mean correction rate% (SD)	Radical knowledge type	Mean correction rate% (SD)	P value
Group 2 Year 2	**SRSE**	63.30% (8.93%)	**PRSE**	46.44% (6.62%)	0.001
			PRPH	45.27% (6.40%)	0.000
	SRPH	57.69% (8.24%)	**PRSE**	46.44% (6.62%)	0.031
			PRPH	45.27% (6.40%)	0.015
Group 2 Year 3	**SRSE**	69.19% (8.02%)	**PRSE**	49.21% (12.43%)	0.051

6.1.2.2 Key Factor 2: Activation (semantic and phonological activation)

The semantic and phonological knowledge of radicals are also compared within groups. The correction rate of semantic activation is the average correction rate of the meaning of two radical types; the correction rate of phonological activation is the average correction rate of the sound of two radical types. The results (see Table 18) have shown that the correction rates between semantic and phonological activation within groups. Group 2 Year 2 learners had a slightly higher semantic activation correction rate as compared to the phonological activation correction rate (54.87% vs 51.48%). Both Group 2 Year 3 and Group 0 learners had a slightly higher phonological activation correction rate (59.20% vs 61.00%; 49.00% vs 52.78%). However, the difference between meaning and sound of all three groups did not reach significancy ($P > 0.01$).

Table 18: T-Test results of activation types comparison within groups

Group	Semantic activation% (SD)	Phonological activation% (SD)	t	df	P-value
Group 2 Year 2	54.87% (6.19%)	51.48% (6.68%)	1.053	14	0.310
Group 2 Year 3	59.20% (9.75%)	61.00% (11.14%)	-0.272	8	0.793
Group 0	49.00% (13.83%)	52.78% (12.27%)	-0.817	30	0.420

6.1.3 Analysis across groups

The analysis across groups is also based on Key Factor 1 (location), and Key Factor 2 (activation).

6.1.3.1 Key Factor 1: Location (semantic radical vs phonetic radical)

Usually, the longer a learner studies in a formal setting such as university (as L2 participants in this study), the higher proficiency (e.g., speaking fluency, character knowledge) they would reach. It is reasonable to expect that the known radical knowledge also follows this trend. While the length of study impacts the overall knowledge of semantic radicals, $F(2, 26) = 3.202$, $P = 0.057$, $0.05 < P < 0.1$, which is marginally significant, it does not influence the overall knowledge of phonetic radicals, $F(2.26) = 0.911$, $P = 0.414$, > 0.1. Post hoc tests using the Bonferroni test has been performed to find out the individual differences between groups in the case of semantic radicals. The results have shown that the difference between Group 2 Year 3 ($M = 65.00\%$, $SD = 8.66\%$) and Group 0 ($M = 51.52\%$, $SD = 13.89\%$) can be seen as marginally significant at 0.1 ($P = 0.102$) (see Table 19 and 20).

Table 19: One-way ANOVA results of radical types comparison across groups

Radical type	df	F	P-value
Semantic radical	2, 26	3.202	0.057
Phonetic radical	2, 26	0.911	0.414

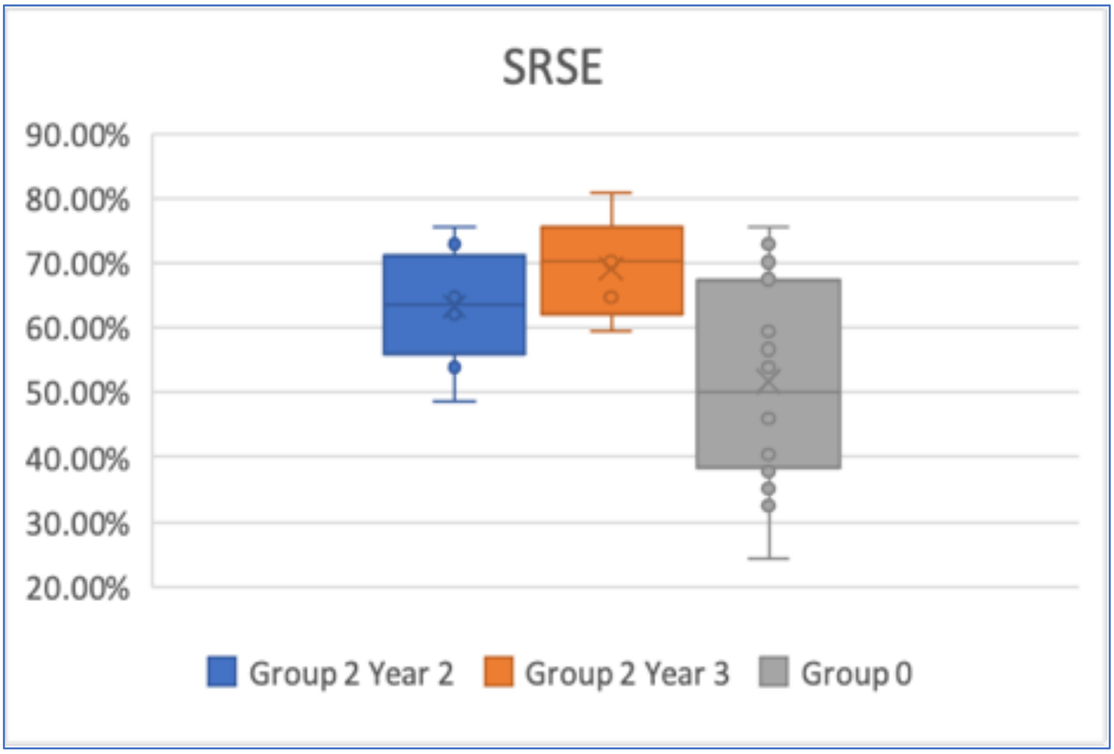
Table 20: Post hoc results of comparison across groups

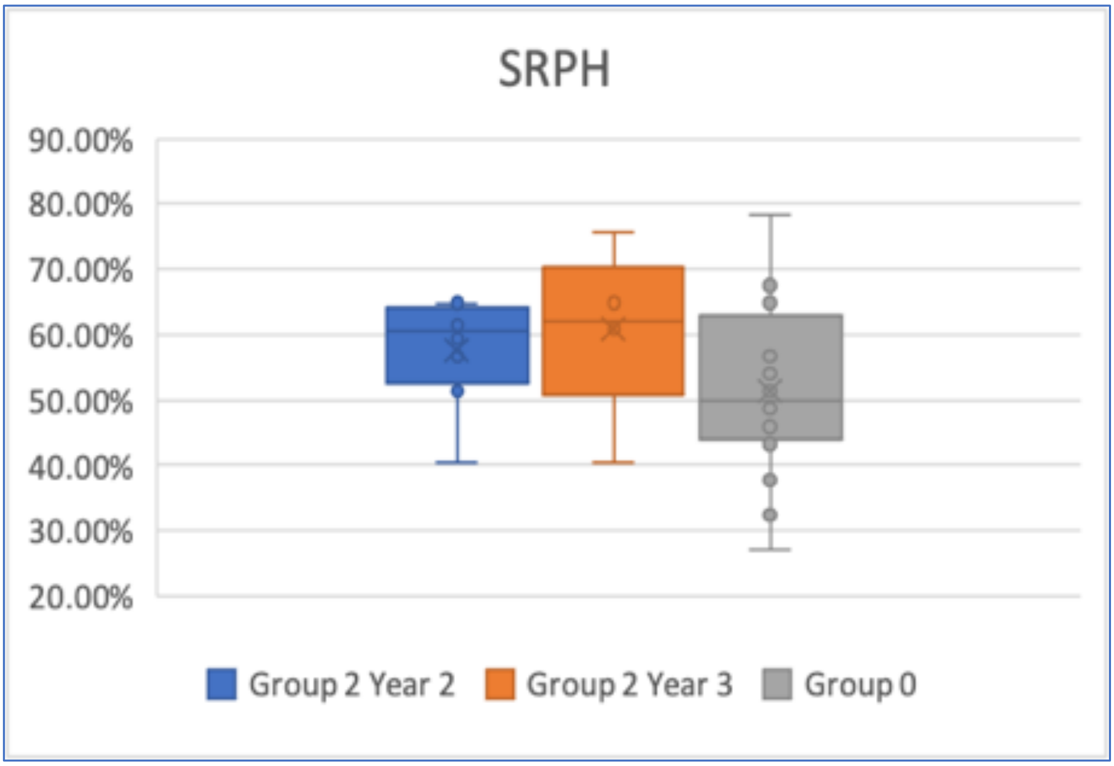
	Group 2 Year 2	Group 2 Year 3	Group 0	P-value
Semantic radical		65.00% (8.66%)	51.52% (13.89%)	0.102
SRSE		69.19% (8.02%)	51.69% (16.06%)	0.052
PRPH	45.27% (6.40%)	61.19% (10.55%)		0.103

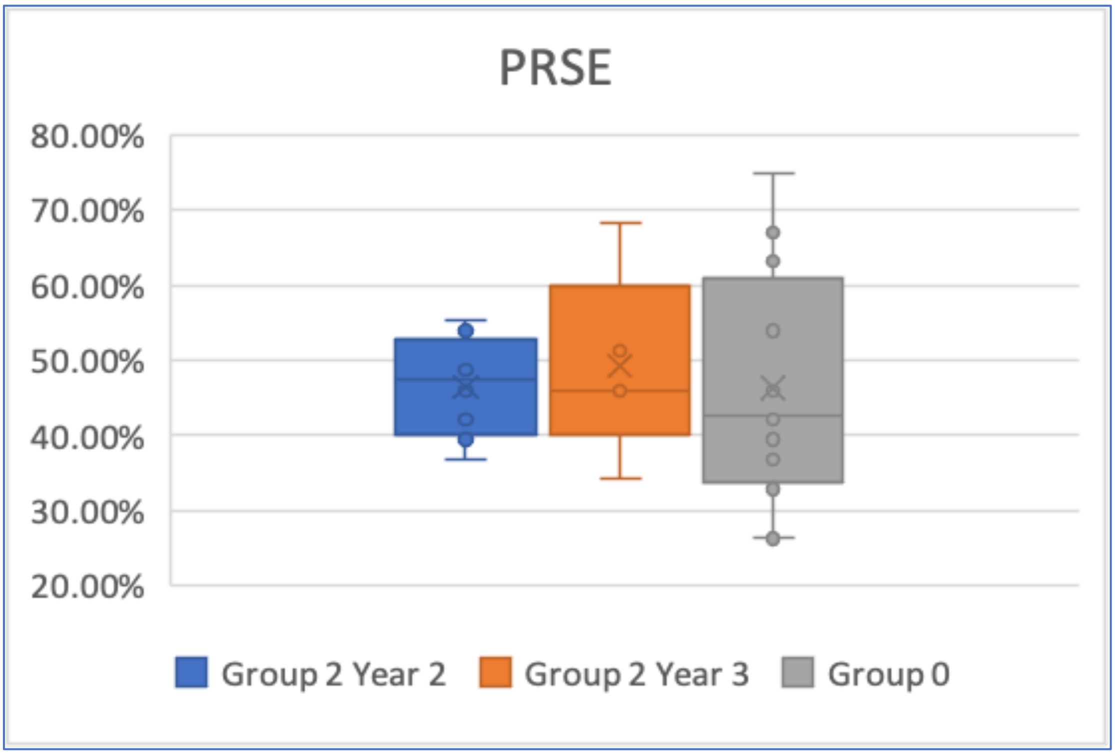
Each of the four radical knowledge types was compared using One-way ANOVA to see if there is any difference across the groups. The results have shown that there are significant differences among the groups in terms of the meaning of semantic radicals (SRSE), F (2, 26) = 4.127, P = 0.028 < 0.05; and that there are marginal differences in terms of the sound of phonetic radicals (PRPH), F (2, 26) = 2.676, P = 0.088 (see Table 21). In order to check for individual differences between groups, post-hoc comparisons using the Bonferroni test was selected. The results have shown that the difference in terms of the meaning of semantic radicals between Group 2 Year 3 (M= 69.19%, SD = 8.02%) and Group 0 (M = 51.69%, SD = 16.06%) and the difference in terms of the sound of phonetic radicals between Group 2 Year 2 (M= 45.27%, SD = 6.40%) and Group 2 Year 3 (M = 61.19%, SD = 10.55%) are both marginally significant, 0.05 < P < 0.1 (P = 0.052, and 0.103 irrespectively) (see above Table 20).

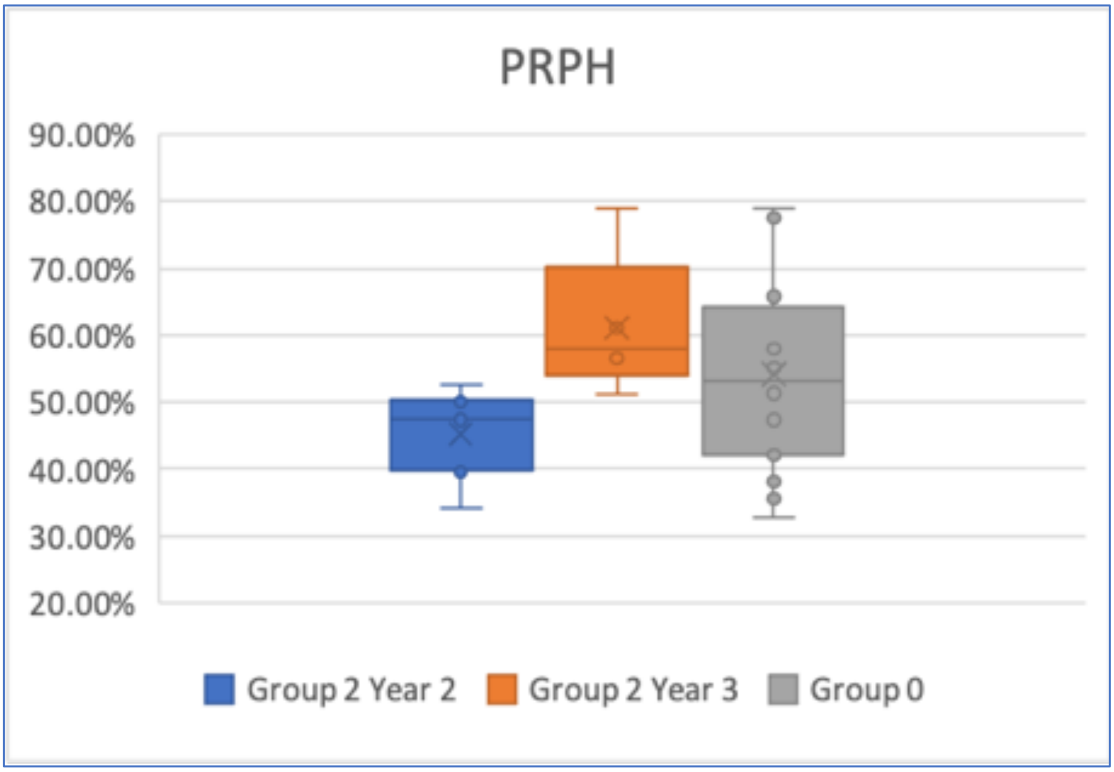
Table 21: One-way ANOVA results of comparing radical knowledge types among groups

Radical type	df	F	P-value
SRSE	2, 26	4.127	0.028
SRPH	2, 26	1.479	0.246
PRSE	2, 26	0.103	0.903
PRPH	2, 26	2.676	0.088


SRSE
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
Group 2 Year 2
Group 2 Year 3
Group 0


SRPH
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
Group 2 Year 2
Group 2 Year 3
Group 0


PRSE
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
Group 2 Year 2
Group 2 Year 3
Group 0


PRPH
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
Group 2 Year 2
Group 2 Year 3
Group 0

6.1.2.2 Key Factor 2: Activation (semantic and phonological activation)

The semantic and phonological knowledge of radicals were compared across groups using One-way ANOVA. The results have shown that the mean correction rate of neither semantic knowledge (meaning), nor the phonological knowledge (sound) of the three participant groups are significantly different from each other (P = 0.199, and 0.276 irrespectively, > 0.1) (see Table 22).

Table 22: Anova Single Factor results of comparing activation types across groups

Activation	df	F	P value
Semantic	2, 26	1.720	0.199
Phonological	2, 26	1.352	0.276

6.2 Discussion and conclusion of the Radical Knowledge Test

6.2.1 The causes of different results across groups

Three reasons might be able to explain the RK test results: radical features, instruction and learner differences.

Cause I: Radical features. Semantic radicals and phonetic radicals have some contrastive features. For example, compared to phonetic radicals, semantic radicals are much fewer in number (roughly 4:1). Semantic radicals are always meaningful, while phonetic radicals do not necessarily have a meaning. Semantic radicals are more reliable in cuing information related to their host characters, while the cuing power of phonetic radicals is relatively weak. In addition, semantic radicals are generally shared by more characters and higher in consistency. As a result, semantic radicals are relatively easier for teachers to teach and for learners to acquire.

Cause II: Instruction. The in-class instruction on radicals during the first one or two years of learning would help learners to have a kickstart of building up their knowledge of radicals. However, because semantic radicals are less in number, more meaningful and more reliable, they unavoidably become the more preferrable radical type in formal instruction, especially when the instruction time is limited. This is exactly what happened to some study groups in this study. Based on the oral background survey, which was performed informally before or after the priming tests, some learners reported some amount (less than one hour in total) of instruction on radicals in their classes. The instruction was mainly focused on semantic radicals, even more so on the meaning of semantic radicals. Consequently, learners might have developed a biased learning towards semantic radicals when they were learning on their own.

Cause III: Learner differences. First, the majority of Group 2 learners graduated from language schools (second-level education equivalence) which are specialised in second language education for students who are interested in becoming multilinguals. Nonetheless, all Group 0 learners only had second language subjects as one of the compulsory subjects rather than the main focus in school. They were learning Chinese with various learning motivations (better work prospects, culture, etc.). Second, Group 2 Italian participants had to pass through competitive enrolment selection before being accepted to their elite Italian university. Among them, those who volunteered to participate in this study were the top 10% - 15% of all students in their classes. However, enrolment election for the Irish university where Group 0 Irish participants were in was less competitive. All the Fourth-year students of the year when the experiment was taking place participated this study. Their Chinese proficiency levels were less congruous: ranging from meeting the minimum requirements to passing exams at the advanced level.

6.2.2 Importance of instruction

In general, learners know more about semantic radicals than phonetic radicals. This knowledge discrepancy is significant for Group 2 Year 2 but not significant for Group 2 Year 3 and Group 0. The insignificant results for Group 2 Year 3 and Group 0 might be caused by a variety of reasons.

For Group 2 Year 2, the most plausible explanations for their significant result are the 'easier-to-learn' and 'more reliable' features of semantic radicals combined with instruction biased towards this type of radicals.

For Group 2 Year 3, the significance of knowledge difference between two radical types disappeared. This can be explained by the relatively fewer number of semantic radicals. Because the number of semantic radicals is much smaller than that of phonetic radicals, and because the number of commonly used semantic radicals is even more limited in the first two years of L2 learning, semantic radical knowledge might not grow much during another year's Chinese learning once it has reached certain level. However, the accumulating of phonetic radical knowledge might continue during the third year. By the end of the third year of learning, learners' knowledge gap between the two of radical types had been narrowed to the point that there is not meaningful difference between them.

Unlike learners in Group 2 (Year 2 and Year 3), the learners with four-year learning experience in Group 0 had not received any formal instruction on radicals. The radical knowledge had been acquired solely by themselves during the four years of learning Chinese as a second language. The insignificant variation between the knowledge of two radical types may be directly linked to the lack of the biased instruction. Another reason that might also explain this insignificant result, similar to what happened to Group 2 Year 3, is related to one semantic radical feature: there are only so many semantic radicals to learn at this language proficiency. However, this radical feature-related cause can be ruled out by the fact that there is a marginally significant knowledge difference of semantic radicals between Group 2 Year 3 and Group 0. It means there were still some semantic radicals to be learnt at this stage. Group 0 did not know more about semantic radicals as compared to phonetic radicals only because they did not have instruction biased towards semantic radicals. In addition, learner differences might also contribute to the difference.

By comparing two radical types within each group and across groups, the effectiveness of formal instruction on radicals is confirmed, even if it is as short as one hour. After two years of Chinese learning, learners' semantic radical knowledge does not increase significantly because there are a limited number of semantic radicals to learn at this proficiency level. However, without a certain amount of time in formal instruction, semantic radical knowledge could not be acquired adequately simply from learning characters or other aspects of Chinese study. It may take at least four years in a natural learning process to acquire semantic radical knowledge to a satisfactory level, and may take even longer to reach a fully functional level which is close to native speakers. It is possible that in-class instruction plays a critical role in introducing the semantic and phonological functions of radicals to the learners. This role might be more important for semantic radicals compared to phonetic radicals.

6.2.3 Fast growth of the sound of phonetic radicals

Looking into the details of radical knowledge, it is found that Group 2 Year 2 learners knew significantly more about the meaning of semantic radicals than the meaning/sound of phonetic radicals, and knew more about the sound of semantic radicals than the meaning/sound of phonetic radicals; Group 2 Year 3 learners marginally significantly knew more about the meaning of semantic radicals than the meaning of phonetic radicals; Group 0 did not know significantly more about any one knowledge type than the rest.

The results of Group 2 Year 2 learners can again be explained by the 'easier-to-learn' and 'more reliable' features of semantic radicals and instruction biased towards this type of radicals. Also, it has shown that **when learners were learning semantic radicals, they tended to learn both the meaning and the sound of the radicals**.

The significant difference between the meaning of semantic radicals and the meaning of phonetic radicals remains for Group 2 Year 3 learners. However, the differences between the meaning of semantic radicals and the sound of phonetic radicals disappeared. Similarly, the differences between the sound of semantic radicals and the meaning/sound of phonetic radicals also disappeared. Combined with the result that Group 2 Year 3 learners knew marginally significant more sounds of phonetic radicals than Group 2 Year 2 learners has shown that the knowledge of phonetic radicals is the kind of radical knowledge that grows the fastest and most significantly among the four knowledge types during the third year of Chinese learning. It further explains why learners did not know significantly more about semantic radicals than phonetic radicals anymore. Because the meaning of phonetic radicals did not grow at the same pace as the sound of phonetic radicals, it means that **unlike semantic radicals, learners learn more about the sound than the meaning of the phonetic radicals**. The cause is directly related to a feature of phonetic radicals, that not all the phonetic radicals have a meaning. This feature might enhance the learning habit in which learners might deliberately ignore the meaning even in the cases where phonetic radicals do have a meaning. It is reasonable to assume that the meaning of phonetic radicals is the kind of radical knowledge that grows the slowest.

Radical knowledge types are relatively balanced for Group 0 as there is no prioritised knowledge type. This result might be due to the relatively low knowledge level of both semantic and phonetic radicals.

6.2.4 Conclusion

During the first two years of Chinese learning, semantic radicals are the radical type that is learnt earlier and faster. Learners accumulate significantly more knowledge of semantic radicals than phonetic radicals during that time. The reasons causing better performance on semantic radicals as compared to phonetic radicals might be the semantic radical-prioritised formal instruction and the different features between two radical types. This unbalanced knowledge is mostly likely first caused by in-class instruction which is mainly focused on semantic radicals. It may give learners the impression that semantic radicals are the more important and useful radical type. Hence, learners tend to pay more attention to semantic radicals in their further learning. In addition, the features of phonetic radicals – bigger in number and not always meaningful, also defer the accumulation of the phonetic radical knowledge.

Then, during the third year, accumulation of the knowledge of phonetic radicals catches up. Learners acquire more knowledge about phonetic radicals compared to semantic radicals mainly because of 1) a fast growth of the sound knowledge of phonetic radicals 2) the slowing down of the growth of semantic radicals after a certain threshold being reached. The knowledge boost of the sound of phonetic radicals might be because learners start to observe the consistency and regularity of phonetic radicals when they know a larger number of characters. They can obtain more sound knowledge of phonetic radicals through the sound of characters that contain them as a constitutional part with the positional information. As a result, learners become better in using the sound information of known characters to guess the sound of the unknow component, as well as using the sound of the known component to guess the sound of unknown characters. The knowledge gap between semantic radicals and phonetic radicals narrows to the level that the only significant difference happens between the meaning of semantic radicals and phonetic radicals. By the end of the third year, the meaning of semantic radicals remains the most known radical knowledge type followed by the sound of phonetic radicals. The growth trend of sound of phonetic radicals is likely to continue in the following few years of study.

From the test results of Group 0, we can say that the development of radical knowledge does not necessary corelate with the years of study. One learner who has been studying Chinese for two years can know as much radical knowledge as another learner who has studied for four years. Without certain amount of instruction and learning time specifically devoted to radical knowledge, the accumulation of radical knowledge can be slow and limited in a natural acquiring process.

The differences shown between Group 0 and Group 2 learners may point out different key influencers for the development of radical knowledge types. With better knowledge of Chinese, which is normally directly linked to the learning duration and learning effort, learners have a better awareness of using learnt characters to guess the sound of unknown radicals/characters even if they did not receive explicit instructions on phonetic radicals. Compared to phonetic radicals, the knowledge of semantic radicals seems to be more directly linked to explicit instruction and study in a formal setting.

A further investigation is needed to find out the effectiveness of a balanced instruction with equal emphasis on both radical types. However, we do not know if formal instruction which gives propositional emphasis on phonetic radicals would accelerate the knowledge accumulation speed as early as in the second year, as it does with the semantic radicals.

While considering why the semantic radical prioritised instruction is usually delivered in this way, we surmise that the reasons could be: instructors might not see the value of phonetic radicals; they consider the learning of phonetic radicals to be less effective when compared to sematic radicals; instruction time is limited; pure laziness. It is worth to see how well-designed learning materials of radicals based on learners' known characters and not yet learnt characters, which is balanced with both types of radicals considering their different features, would benefit learners in both the short and long term.

In addition, it is reasonable to assume that when learners know more about certain type of information, they tend to be better at using the strategy which is more relevant to that type of information in reading. For this reason, we can predict that learners with more than two years of study are stronger at using phonological strategies than learners with two years of study, at least at the radical level. This development of radical knowledge may fundamentally link to the lexical accessing strategies learners use, at least at the sublexical level.

6.3 Results of the Priming Test

The main purpose of Priming Test 1 and 2 is to identify the lexical processing pattern of readers at different proficiency levels. In addition, as we discussed earlier about the efficacy of formal radical instruction, we have concluded that formal instruction which usually only focuses on semantic radicals have a big influence on the knowledge development of semantic radicals, hence, potentially semantic activation of sub-lexical processing. However, we do not know if formal instruction can also have a similar effect on phonetic radicals, as well as phonological activation. In order to find out how a balanced instruction influences sub-lexical processing, a radical knowledge training was carried out between two lexical decision priming tests.

In the analysis of both L1 and L2 results, the analysis for accuracy is not carried out as the number of mistakes is low and can be ignored.

6.3.1 L1 Priming Test results

Data were analysed only on critical pairs. Prior to the analysis, RTs that were shorter than 300ms or longer than 5000ms were removed (0.29% of the total data). The average accuracy rate of native speakers was 98.99%. Only trials that were answered correctly were included in the analysis; wrong answers were removed (1.00% of the total data). After the removal of the above data, the mean RT of native speakers is 709.78ms (SD = 384.28ms). RTs that are longer than 1100ms were treated as outliers and discarded (about one standard deviations above the condition means)[24] (6.75% of the total data). These thresholds were chosen based on the distribution of RTs. The data were mainly analysed using Independent-Samples T Test using IBM SPSS Statistics Version 27.

The normality of the distribution of each priming type's RT was tested. In the rare case that samples did not conform normal distribution, the outliers were given the value of 90% percentile result rather than the mean or simply being removed. This decision is made based on the big differences between the value of outliers and the sample mean, as well as the limited amount of data.

The results of L1 learners were analysed according to level (character vs radical) and location (semantic radical vs phonetic radical), activation (semantic vs phonological), and priming effect (related vs non-related), with each comparison including priming types as follows:

- Level (character vs radical)

  Character level (CLevel): SE-RL, SE-NONRL, PH-RL, PH-NONRL

  Radical level (RLevel): SR-SE-RL, SR-PH-RL, PR-SE-RL, PR-PH-RL, SR-SE-NONRL, SR-PH-NONRL, PR-SE-NONRL, PR-PH-NONRL

- Location (semantic radical vs phonetic radical):

  Semantic radical (SR): SR-SE-RL, SR-PH-RL

  Phonetic radical (PR): PR-SE-RL, PR-PH-RL

- Activation (semantic vs phonological)

  Semantic activation (SE): SE-RL, SR-SE-RL, PR-SE-RL

  Phonological activation (PH): PH-RL, SR-PH-RL, PR-PH-RL

- Priming effect (related vs non-related)

  Related (RL): SE-RL, PH-RL, SR-SE-RL, SR-PH-RL, PR-SE-RL, PR-PH-RL

  Non-related (NONRL): SE-NONRL, PH-NONRL, SR-SE-NONRL, SR-PH-NONRL, PR-SE-NONRL, PR-PH-NONRL

[24] In the literature, for example Yao (2015), used two standard deviations above the condition means as an outlier threshold. However, considering the amount of data collected in this research and maximal statistically reliability, above one SD (1100ms) is a reasonable threshold.

The descriptive data of RTs of native speakers can be seen in Table 23 below.

Table 23: L1 RTs (in milliseconds)[25] of 12 critical priming types

Group 1 L1		
Level	**Priming type**	**Mean RT**
Character + Radical	**RL**	625.36 (136.40)
	NONRL	635.83 (149.61)
Character (CL/CLevel)	**CLevel-RL**	620.27 (134.53)
	CLevel-NONRL	641.10 (154.62)
	CL-SE-RL	611.42 (133.19)
	CL-SE-NONRL	632.90 (152.30)
	CL-PH-RL	629.56 (135.72)
	CL-PH-NONRL	649.45 (156.98)
Radical (RL/CLevel)	**RLevel-RL**	630.67 (138.35)
	RLevel-NONRL	630.55 (144.47)
	RL-SR-SE-RL	621.11 (124.73)
	RL-SR-SE-NONRL	619.43 (135.47)
	RL-SR-PH-RL	620.85 (132.79)
	RL-SR-PH-NONRL	635.92 (124.66)
	RL-PR-SE-RL	632.25 (135.71)
	RL-PR-SE-NONRL	608.73 (148.34)
	RL-PR-PH-RL	650.78 (160.64)
	RL-PR-PH-NONRL	657.73 (165.03)

Note. Standard deviations are provided in parentheses. Marked grey types are 12 critical priming types

6.3.1.1 Key Factor 1: Level and Location

According to the experiment design, the primes can also be categorised based on different levels of the primes: character/lexical level (CL or CLevel) and radical/sublexical level (RL or RLevel); within the radical level the primes can be categorised into two different locations: semantic radical (SR) and phonetic radical (PR). Results see Table 24 below:

[25] All RTs listed in the following tables are in milliseconds.

Table 24: RTs at different levels and locations

L1 (Group 1)						
Level	**Character Level Mean RT**	**Radical Level Mean RT**	**Diff**	**P value**	**df**	**t**
	630.67 (141.17)	630.61 (145.39)	0	0.497	1279	0.007
Location	**Semantic Radical Mean RT**	**Phonetic Radical Mean RT**	**Diff**	**P value**	**df**	**t**
	620.98 (128.47)	641.20 (148.07)	20	0.099	309	-1.289

Note. Standard deviations are provided in parentheses.

The two levels are character level (630.67ms, SD = 141.17ms) including priming types SE related/ non-related and PH related/non-related, and radical level (630.60ms, SD = 145.39ms) including priming types SR-SE-related/non- related, SR-PH-related/non-related, PR-SE-related/non-related and PR-PH-related/non-related. The RT difference is 0ms, P = 0.497 > 0.05, which can be considered statistically insignificant (see Table 24, Figure 23 and 24).

The two locations are semantic radicals (620.98ms, SD = 128.47ms), including SR-SE related and SR-PH related primes, and phonetic radicals (641.20ms, SD = 148.07ms), including PR-SE related and PR-PH related primes. The RT difference is +20ms, P = 0.099, which is marginally significant (see Table 24 and Figure 23). Since there is no character frequency difference between the SR related primes and PR related primes (P = 0.272, > 0.1) or between the imbedded semantic radicals and phonetic radicals when they are standalone characters (P = 0.421, > 0.1), the RT difference can only be from the priming effect of the radicals. The results from different locations have shown that native speakers recognise a target character faster when it is primed by another character which contains a semantic radical that relates to the target than when it contains a phonetic radical that relates to the target. In other words, native speakers process semantic radicals faster than phonetic radicals.

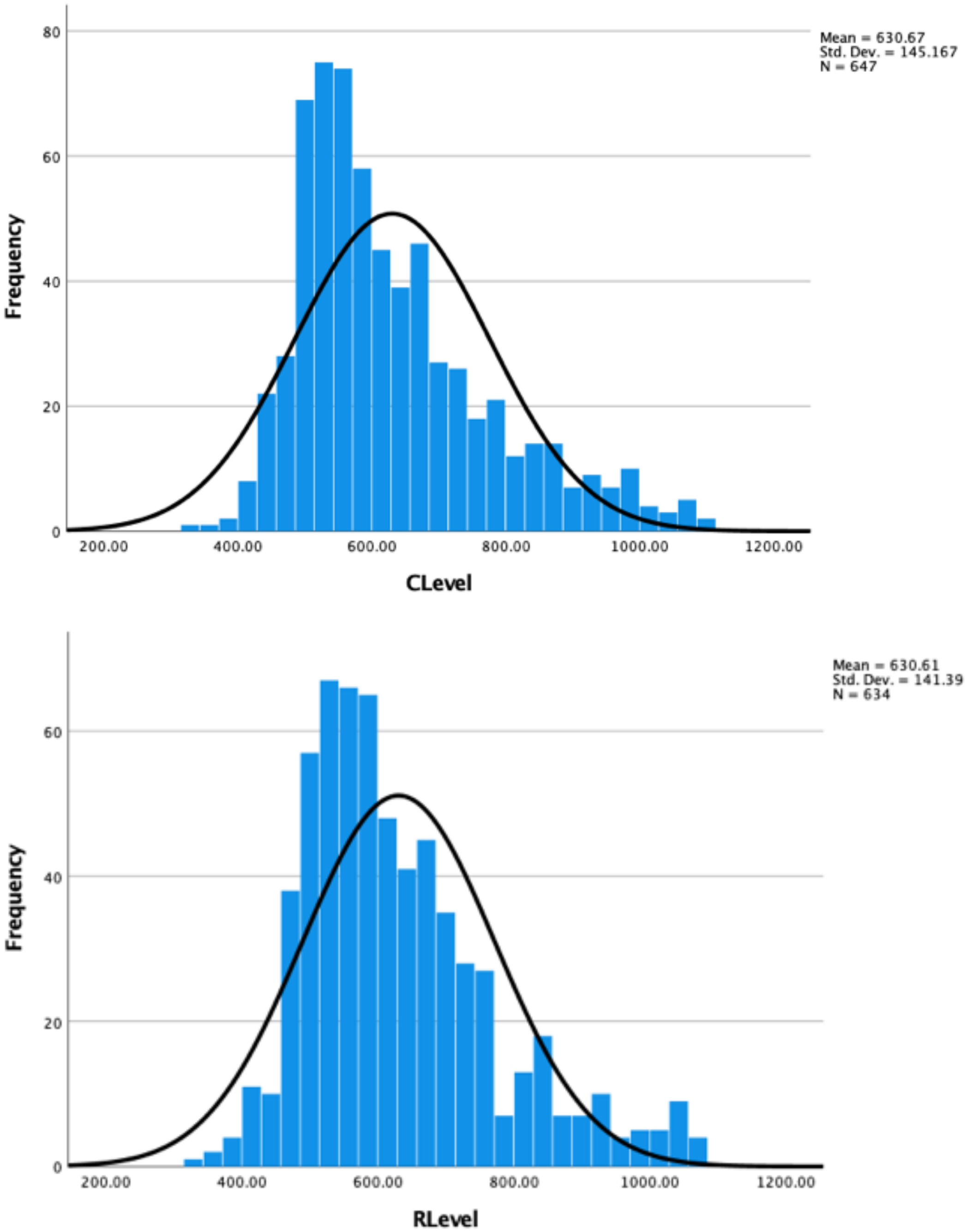


Figure 22: Distribution of RT for Character level and Radical level primes

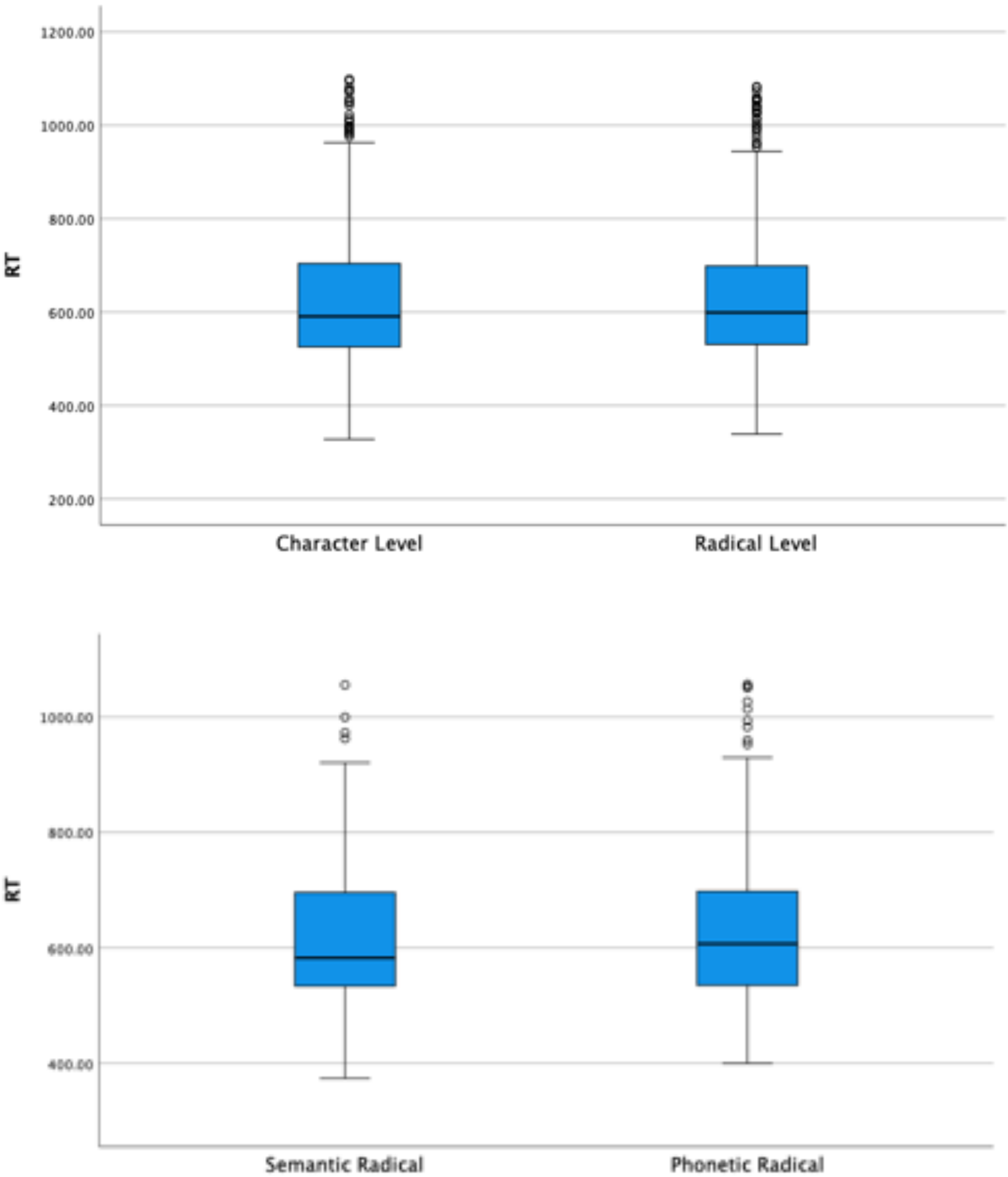


Figure 23: Boxplot of RT for semantic radical (SR) and phonetic radical (PR) prime

6.3.1.2 Key Factor 2: Activation

As it is shown in the table (see Table 25), The RT is faster when primes are semantically related to the target (618.79ms, SD = 131.63ms) than when they are phonologically related to the target (632.17ms, SD = 141.06ms), P = 0.109, ≈ 0.1, with a RT difference of 13ms of marginal significance. This difference is marginally significant at the character level (RT Diff = 18ms, P = 0.113, ≈ 0.1) but insignificant at the radical level (RT Diff = 8ms, P = 0.300, > 0.1). Since the character frequency is controlled so that there is no significant difference (P > 0.1) between each priming pair being compared, and in addition, the stroke number does not affect the reading time for native speakers (Zhang and Ke 2018: 103), the RT difference could be only caused by the processing time of primes. It means native speakers process the semantic information of a character faster than the phonological information, at least at character level.

Table 25: RTs of activation types at difference levels and locations for L1

Group 1 L1											
Position		**SE Mean RT**	**PH Mean RT**	**Diff**	**P value**	**df**	**t**	**CF Diff P value**	**CS Diff P value**	**RF Diff P value**	**RS Diff P value**
Level & Location		618.79 (131.63)	632.17 (141.06)	13	0.109	626	-1.236	0.385	0.415	-	-
Level	**CL**	611.42 (133.19)	629.56 (135.72)	18	0.113	321	-1.214	0.253	0.449	-	-
	RL	626.57 (129.93)	634.84 (146.74)	8	0.300	303	-0.526	0.253	0.449	0.289	0.382
Location	**SR**	621.11 (124.73)	620.85 (132.79)	0	0.495	160	0.013	0.400	0.408	0.143	0.282
	PR	632.25 (135.71)	650.78 (160.64)	19	0.224	139	-0.762	0.482	0.188	0.170	0.126

Note. Standard deviations are provided in parentheses. Priming effects that reached significance are highlighted.
CF: Character frequency
CS: Character stroke number
RF: Radical frequency
RS: Radical stroke number

An alternative way to look at the activation is to compare the radical difference of each activation type (see Table 26). From the results we can see that there is a tendency that semantic radicals were processed faster than phonetic radicals semantically (621.11ms, SD = 124.73ms vs 632.25ms, SD = 135.71ms, Diff = 11ms, P = 0.297, > 0.1) and phonologically (620.85ms, SD = 132.79ms vs 650.78ms, SD = 160.64ms; Diff = 30ms, P = 0.104, ≈ 0.1). The difference in phonological activation between the two radical types is marginally significant. Hence, it is statistically meaningful.

It is worth noticing that when comparing semantic activation, the compared semantic radicals have less strokes than phonetic radicals (4.25 vs 6.17, Diff = 1.92, P = 0.020). It might not have any effect on native speakers but might do so on L2 learners. In terms of phonological activation, there is a marginal difference in the character frequency between two radical types when they are seen as standalone characters. Semantic radicals have a higher mean character frequency. This might affect the processing of both L1 readers and L2 learners.

Table 26: RTs of activation type between two types of radicals for L1

Group 1 L1										
Activation type	**SR Mean RT**	**PR Mean RT**	**Diff**	**P value**	**df**	**t**	**CF Diff P value**	**CS Diff P value**	**RF Diff P value**	**RS Diff P value**
SE	621.11 (124.73)	632.25 (135.71)	11	0.297	153	-0.536	0.354	0.254	0.188	0.020 < 0.05 SR RS (4.25) PR RS (6.17)
PH	620.85 (132.79)	650.78 (160.64)	30	0.104	138	-1.265	0.167	0.061 > 0.05 SR CS (9.58) PR CS (8.25)	0.058 ≈ 0.05 SR RF (999.73) PR RF (448.94)	0.099 > 0.05

Note. Standard deviations are provided in parentheses. Priming effects reached significance are highlighted.
CF: Character frequency
CS: Character stroke number
RF: Radical frequency
RS: Radical stroke number

6.3.1.3 Key Factor 3: Priming effects

A priming effect is obtained when a prime is related to its target and the related information accelerates or inhibits the recognition of the latter. In the case of native speakers, all priming results obtained are positive: the related information accelerates the recognition.

The results (see Table 27) have shown that there is a 10ms RT difference between all related primes (RT = 625.36ms, SD = 136.40ms) and all non-related primes (RT = 635.83ms, SD = 149.61ms). The RT difference is marginally significant, as P = 0.096, 0.05 < P < 0.1.

The priming effect has mainly happened at the character level but not at the radical level. A 21ms facilitation has occurred when related primes are radicals stand as independent single characters (RT = 620.27ms, SD = 134.53ms vs RT = 641.10ms, SD = 154.62ms, P = 0.034 < 0.05). The RT difference between SE-related primes (RT = 611.42ms, SD = 133.19ms) and their non-related control (632.92ms, SD = 152.30ms) is +21ms, P value 0.087, marginally significant. Similar facilitation is also observed when the primes are phonologically related to the targets. The RT difference between PH-related primes (RT = 629.56ms, SD = 135.72ms) and their non-related prime (RT = 649.45ms, SD = 156.98ms) is +20ms, P = 0.114, ≈ 0.1, which is seen as marginally significant.

However, there was no priming effect observed between the overall radical related primes and their non-related controls (RT = 630.67ms, SD = 138.35 vs RT = 630.55ms, SD =

144.47ms, P = 0.496); or between any of the four radical level priming types and their non-related controls (P > 0.1).

Table 27: L1 priming results

Group 1 L1							
Priming type	**Mean RT**	**Priming type**	**Mean RT**	**Diff**	**P value**	**df**	**t**
RL	625.36 (136.40)	**NONRL**	635.83 (149.61)	10	0.096	1272	-1.309
Character Level-RL	620.27 (134.53)	Character Level-NONRL	641.10 (154.62)	21	0.034	645	-1.829
CL-SE-RL	611.42 (133.19)	CL-SE-NONRL	632.90 (152.30)	21	0.087	327	-1.362
CL-PH-RL	629.56 (135.72)	CL-PH-NONRL	649.45 (156.98)	20	0.114	316	-1.208
Radical Level-RL	630.67 (138.35)	Radical Level-NONRL	630.55 (144.47)	0	0.496	632	0.010
RL-SR-SE-RL	621.11 (124.73)	RL-SR-SE-NONRL	619.43 (135.47)	-2	0.468	157	0.081
RL-SR-PH-RL	620.85 (132.79)	RL-SR-PH-NONRL	635.92 (124.66)	15	0.226	164	-0.754
RL-PR-SE-RL	632.25 (135.71)	RL-PR-SE-NONRL	608.73 (148.34)	-24	0.151	155	1.035
RL-PR-PH-RL	650.78 (160.64)	RL-PR-PH-NONRL	657.73 (165.03)	7	0.397	150	-0.262

Note. Standard deviations are provided in parentheses.

6.3.2 L2 Priming Test results

The analysis of the Priming Test data of L2 learners was processed in a similar way to L1 readers. Prior to the analysis, RTs that were shorter than 300ms or longer than 5000ms were removed (0.53% of the total data). The average accuracy rate of L2 learners is 93.14%. Only trials that were answered correctly were included in the analysis; wrong answers were removed (6.86% of the total data). After the removal of above data, the mean RT of L2 learners is 893.45ms (SD = 281.83ms). RTs that are longer than 1800ms were treated as outliers and discarded (about three standard deviations above the condition means) (8.19% of the total data). These thresholds were chosen based on the distribution of RTs and the consideration of overall data loss (15.58% of the total data). The data of L2 learners were analysed using the same statistic tools as which were used for analysing native speakers. P values smaller than 0.05 are considered statistically significant. P values between 0.05 to 0.1 or approximately equal to 0.1 is considered marginally significant.

Similar to the analysis of native speakers, data of L2 learners were also analysed according to level (character vs radical) and location (semantic radical vs phonetic radical), activation (semantic vs phonological) and priming effect/relation (related vs non-related), within Group 2 Year 2 and Group 2 Year 3 learner groups irrespectively. Furthermore, there are another three layers of comparison in order to depict the developing route of character recognition for L2 learners: Group 2 Year 2 vs Group 2 Year 3, first experiment vs second experiment (before vs after the Radical Awareness Training), and within Group 2 Year 2 and Group 2 Year 3.

The descriptive data of RTs of Group 2 Year 2 and Group 2 Year 3 can be seen in Table 28 below.

Table 28: L2 RTs of 12 critical priming types

Level	Priming type	1st Exp Mean RT		2nd Exp Mean RT	
		Year 2	Year 3	Year 2	Year 3
Character + Radical	RL	900.63 (275.29)	904.83 (262.42)	838.43 (233.37)	900.46 (302.23)
	NON	911.79 (279.19)	957.03 (273.56)	900.99 (318.49)	854.28 (292.20)
Character (CL/CLevel)	CL-RL	894.68 (296.16)	908.72 (265.31)	828.22 (239.48)	909.95 (318.93)
	CL-NONRL	883.00 (255.30)	949.00 (270.56)	903.68 (336.42)	875.81 (340.12)
	CL-SE-RL	902.57 (301.06)	860.82 (199.96)	863.80 (240.49)	901.81 (308.90)
	CL-SE-NONRL	863.61 (237.60)	923.52 (247.48)	906.72 (356.98)	877.14 (341.15)
	CL-PH-RL	884.15 (293.79)	908.49 (206.28)	787.69 (235.07)	888.93 (301.01)
	CL-PH-NONRL	905.71 (276.36)	957.22 (258.16)	900.09 (315.86)	840.44 (263.63)
Radical (RL/CLevel)	RL-RL	906.43 (255.09)	901.44 (262.33)	848.91 (228.05)	890.63 (286.55)
	RL-NONRL	937.53 (298.08)	966.09 (279.56)	898.23 (301.34)	831.46 (232.24)
	RL-SR-SE-RL	925.55 (241.40)	805.07 (171.82)	838.25 (169.38)	809.64 (245.72)
	RL-SR-SE-NONRL	937.82 (243.94)	1038.10 (316.83)	917.74 (280.26)	884.08 (256.94)
	RL-SR-PH-RL	900.36 (220.04)	911.33 (247.31)	845.84 (184.13)	923.64 (263.13)
	RL-SR-PH-NONRL	824.18 (130.76)	1004.08 (309.33)	946.67 (379.16)	833.50 (258.69)
	RL-PR-SE-RL	894.37 (273.64)	947.31 (294.89)	823.35 (198.38)	875.71 (275.19)
	RL-PR-SE-NONRL	917.62 (380.30)	866.31 (205.77)	892.16 (311.21)	753.25 (141.80)
	RL-PR-PH-RL	874.68 (236.05)	951.83 (326.75)	833.88 (234.75)	964.00 (370.23)
	RL-PR-PH-NONRL	1022.95 (312.48)	973.64 (288.89)	817.71 (200.72)	792.00 (139.29)

Note. Standard deviations are provided in parentheses. Marked grey types are 12 critical priming types.

6.3.2.1 Analysis between groups (Group 1 and Group 2)

The analysis between groups is based on Key Factor 1 Level and Location, and Key Factor 2 Activation.

6.3.2.1.1 Key Factor 1: Level and Location

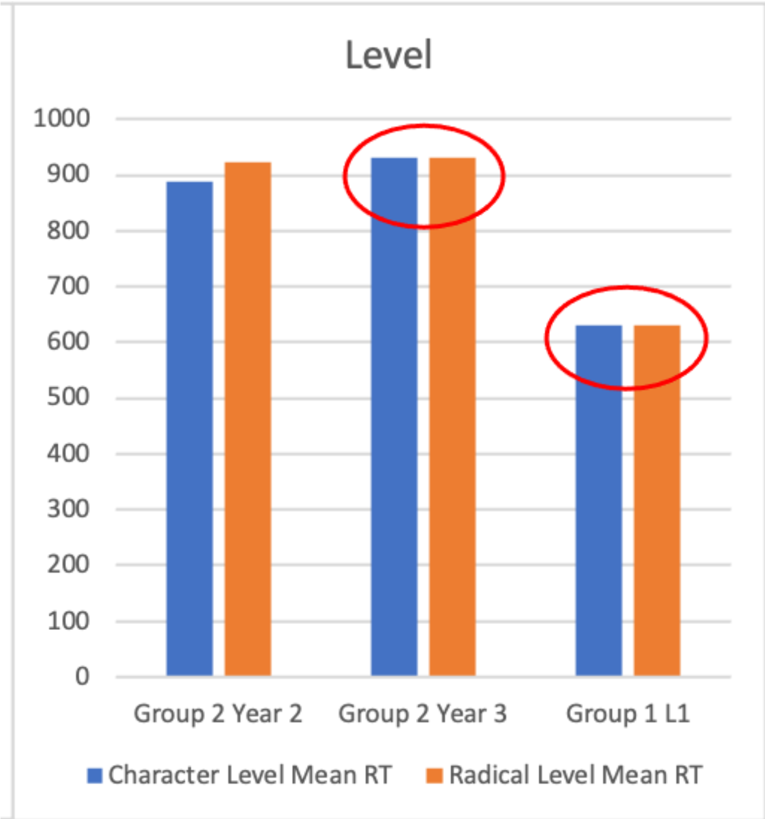
From the results of different levels (see Table 29 and Figure 24), we can see that Group 2 Year 2 learners read character level related primes faster than radical level related primes (888.88ms, SD = 275.77ms vs 922.55ms, SD = 277.80ms, Diff = 34ms, P = 0.140, ≈ 0.1), the difference being marginally significant. Group 2 Year 3 learners read character level related primes as fast as radical level related primes (930.07ms, SD = 267.52ms vs 931.52ms, SD = 271.06ms, Diff = 1ms, P = 0.485, > 0.1). Only the results from Group 2 Year 3 learners are in line with the results of Group 1 native speakers.

In terms of different locations (also see Table 29), also different from Group 1 native speakers, Group 2 Year 2 has shown a tendency of a slower processing of semantic-radical-related primes than phonetic-radical-related primes (926.73ms, SD = 259.13ms vs 884.53ms, SD = 252.26ms, Diff = -42ms, P = 0.233, > 0.1), however, the difference is not significant; similar to Group 1 native speakers, Group 2 Year 3 read semantic-radical-related primes faster (860.03ms, SD = 217.27ms vs 949.48ms, SD = 304.01ms, Diff = 89ms, P = 0.108, ≈ 0.1).

Table 29: RT at different levels and locations for Group 1 and 2 (1st Experiment)

Position	Group	Character Level Mean RT	Radical Level Mean RT	Diff	P value	df	t
Level	Group 2 Year 2	888.88 (275.77)	922.55 (277.80)	34	0.140	315	-1.082
	Group 2 Year 3	930.07 (267.52)	931.52 (271.06)	1	0.485	199	-0.038
	Group 1 L1	630.67 (141.17)	630.61 (145.39)	0	0.497	1279	0.007
		Semantic Radical Mean RT	**Phonetic Radical Mean RT**				
Location	Group 2 Year 2	926.73 (259.13)	884.53 (252.26)	-42	0.233	77	0.733
	Group 2 Year 3	860.03 (217.27)	949.48 (304.01)	89	0.108	52	-1.256
	Group 1 L1	620.98 (128.47)	641.20 (148.07)	20	0.099	309	-1.289

Note. Standard deviations are provided in parentheses.



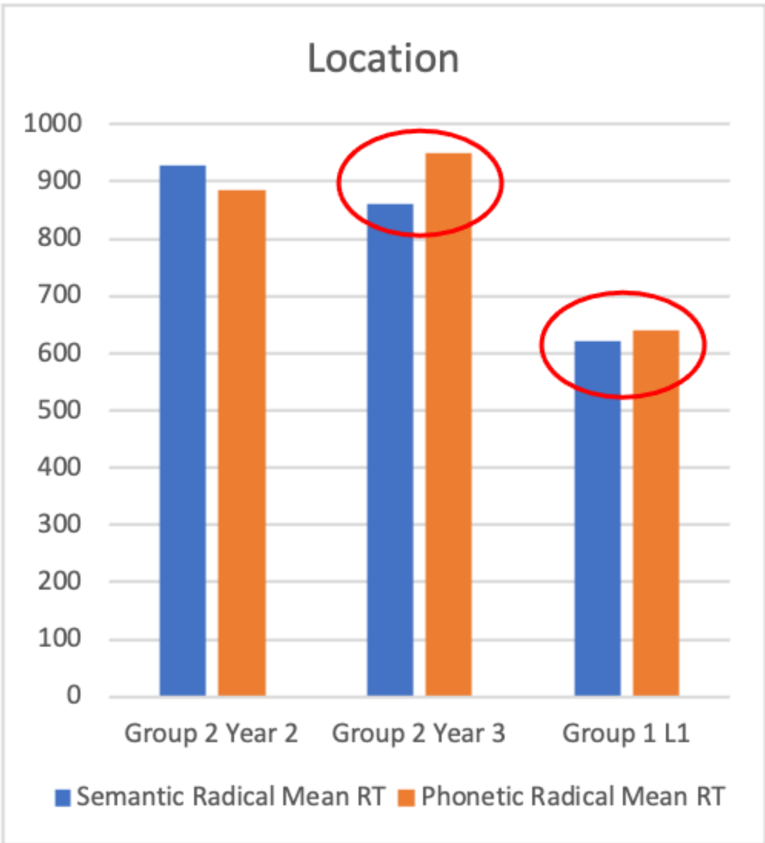


Figure 24: Comparison between levels and locations

6.3.2.1.2 Key Factor 2: Activation

As seen in Table 30, Group 2 Year 2 learners tended to read meaning-related primes slower than sound-related primes in both levels and positions. The mean RT difference between the two activation types at the character level is -18ms (902.57ms, SD = 301.06ms vs 884.15ms, SD = 293.79ms, P = 0.395); at the radical level is -10ms (911.10ms, SD = 245.24ms vs 901.39ms, SD = 259.53ms, P = 0.433); for semantic radical is -25ms (925.55ms, SD = 241.40ms vs 900.36ms, SD = 220.04ms, P = 0.365); for phonetic radical is -20ms (894.37ms, SD = 273.64ms vs 874.68ms, SD = 236.05ms, P = 0.407). None of the differences reach statistical significance.

The trend shown by Group 2 Year 3 learners is opposite to that of Group 2 Year 2. They tended to read meaning-related primes faster than sound-related primes in all four priming types. The mean RT difference between the two activation types at the character level is +48ms (860.82ms, SD = 199.96ms vs 908.49ms, SD = 206.28ms, P = 0.213); at the radical level is +56ms (873.56ms, SD = 245.24ms vs 929.33ms, SD = 280.22ms, P = 0.220); for semantic radical is +106ms (805.07ms, SD = 171.82ms vs 911.33ms, SD = 247.31ms, P = 0.097); for phonetic radical is +5ms (947.31ms, SD = 294.89ms vs 951.83ms, SD = 326.75ms, P = 0.486). None of the differences reach statistical significance except for phonetic radical-related priming condition.

It seems that learners with two years of learning experience used more sound-based strategies, while learners with three years of learning experience used more meaning-based strategies, as native readers do.

Table 30: RTs of activation types at difference levels and locations for Group 1 and 2

(1st Experiment)

Position		Group	SE Mean RT	PH Mean RT	Diff	P value	df	t
Level	Character level	Group 2 Year 2	902.57 (301.06)	884.15 (293.79)	-18	0.395	75	0.268
		Group 2 Year 3	860.82 (199.96)	908.49 (206.28)	48	0.213	45	-0.804
		Group 1 L1	611.42 (133.19)	629.56 (135.72)	18	0.113	321	-1.214
	Radical level	Group 2 Year 2	911.10 (254.04)	901.39 (259.53)	-10	0.433	77	0.168
		Group 2 Year 3	873.56 (245.24)	929.33 (280.22)	56	0.220	52	-0.778
		Group 1 L1	626.57 (129.93)	634.84 (146.74)	8	0.300	303	-0.526
Location	Semantic radical	Group 2 Year 2	925.55 (241.40)	900.36 (220.04)	-25	0.365	39	0.347
		Group 2 Year 3	805.07 (171.82)	911.33 (247.31)	106	0.097	27	-1.334
		Group 1 L1	621.11 (124.73)	620.85 (132.79)	0	0.495	160	0.013
	Phonetic radical	Group 2 Year 2	894.37 (273.64)	874.68 (236.05)	-20	0.407	36	0.237
		Group 2 Year 3	947.31 (294.89)	951.83 (326.75)	5	0.486	23	-0.036
		Group 1 L1	632.25 (135.71)	650.78 (160.64)	19	0.224	139	-0.762

Note. Standard deviations are provided in parentheses.

The activation types are also compared within radical types (see Table 31). Again, Group 2 Year 2 has shown an opposite trend compared to the native speakers while Group 2 Year 3 has shown a similar trend as the native speakers. When reading meaning, Group 2 Year 2 read semantic radical-related primes slower than phonetic radical-related primes (925.55ms, SD = 241.40ms vs 894.37ms, SD = 273.64ms, Diff = -31ms, P = 0.350); when reading sound, Group 2 Year 2 also read semantic radical-related primes slower (900.36ms, SD = 220.04ms vs 874.68ms, SD = 236.05ms, Diff = -26ms, P = 0.366).

In contrary, Group 2 Year 3 read both meaning and sound faster for semantic radicals (805.07ms, SD = 171.82ms vs 947.30ms, SD = 294.89ms, Diff = +142ms, P = 0.073; 911.33ms, SD = 247.31ms vs 951.83ms, SD = 326.75ms, Diff = +41ms, P = 0.359), with the difference in meaning reaching significance.

Table 31: RTs of activation between two types of radicals for Group 1 and 2

(1st Experiment)

Activation type	Group	SR Mean RT	PR Mean RT	Diff	P value	df	t
SE	Group 2 Year 2	925.55 (241.40)	894.37 (273.64)	-31	0.350	39	0.388
	Group 2 Year 3	805.07 (171.82)	947.30 (294.89)	142	0.073	19	-1.516
	Group 1 L1	621.11 (124.73)	632.25 (135.71)	11	0.297	153	-0.536
PH	Group 2 Year 2	900.36 (220.04)	874.68 (236.05)	-26	0.366	36	0.347
	Group 2 Year 3	911.33 (247.31)	951.83 (326.75)	41	0.359	25	-0.367
	Group 1 L1	620.85 (132.79)	650.78 (160.64)	30	0.104	138	-1.265

Note. Standard deviations are provided in parentheses.

6.3.2.1.3 Key Factor 3: Priming effects

The results (see Table 32) have shown that there is a trend of an overall positive priming effect for both Group 2 Year 2 (900.63ms, SD = 275.29ms vs 911.79ms, SD = 279,19ms, Diff = +11ms) and Group 2 Year 3 (904.83ms, SD = 262.42ms vs 957.03ms vs 273.56ms, Diff = +52ms) learners. However, the positive priming effect is not statistically meaningful for Group 2 Year 2 (P = 0.360, > 0.1), while it is marginally meaningful for Group 2 Year 3 (P = 0.085, 0.05 < P < 0.1). The results of Group 2 Year 3 is closer to the results of the Group 1 native speakers, which also obtained a marginally meaningful positive result (see 6.3.1.3).

Unlike Group 1, both Group 2 Year 2 and Year 3 learners did not obtain any priming effect at the character level but only at the radical level. When Group 2 Year 2 learners read semantic radical phonologically-related primes, they obtained a negative priming effect of -76ms (900.36ms, SD = 220.04ms vs 824.18ms, SD = 130.76ms, P = 0.101, ≈ 0.1); when they read phonetic radical phonologically-related primes, they obtained a positive priming effect of +148ms (874.68ms, SD = 236.05ms vs 1022.95ms, SD = 312.48ms, P = 0.050, < 0.1). It seems that Group 2 Year 2 learners are more sensitive to sound. Group 2 Year 3 learners have shown an opposite pattern. When they read semantic radical semantically-related primes, they obtained a positive priming effect of +233ms (805.07ms, SD = 171.82ms vs 1038.10ms, SD = 316.83ms, P = 0.028, < 0.05); when they read phonetic radical semantically-related primes, they obtained a negative priming effect of -81ms (947.31ms, SD =294.89ms vs 866.31ms, SD = 205.77ms, P = 0.213, > 0.1). However, the P value of this negative priming effect does not reach statistical significance.

Table 32: Group 2 (1st Experiment) priming results

Group 2 Year 2							
Priming type	**Mean RT**	**Priming type**	**Mean RT**	**Diff**	**P value**	**df**	**t**
RL	900.63 (275.29)	**NONRL**	911.79 (279.19)	11	0.360	315	-0.358
Character Level-RL	894.68 (296.16)	**Character Level-NONRL**	883.00 (255.30)	-12	0.397	151	0.261
CL-SE-RL	902.57 (301.06)	**CL-SE-NONRL**	863.61 (237.60)	-39	0.254	81	0.665
CL-PH-RL	884.15 (293.79)	**CL-PH-NONRL**	905.71 (276.36)	22	0.378	66	-0.312
Radical Level-RL	906.43 (255.09)	**Radical Level-NONRL**	937.53 (298.08)	31	0.238	162	-0.715
RL-SR-SE-RL	925.55 (241.40)	**RL-SR-SE-NONRL**	937.82 (243.94)	12	0.434	42	-0.168
RL-SR-PH-RL	900.36 (220.04)	**RL-SR-PH-NONRL**	824.18 (130.76)	-76	0.101	29	1.306
RL-PR-SE-RL	894.37 (273.64)	**RL-PR-SE-NONRL**	917.62 (380.30)	23	0.414	38	-0.220
RL-PR-PH-RL	874.68 (236.05)	**RL-PR-PH-NONRL**	1022.95 (312.48)	148	0.050	39	-1.692
Group 2 Year 3							
Priming type	**Mean RT**	**Priming type**	**Mean RT**	**Diff**	**P value**	df	t
RL	904.83 (262.42)	**NONRL**	957.03 (273.56)	52	0.085	199	-1.381
Character Level-RL	908.72 (265.31)	**Character Level-NONRL**	949.00 (270.56)	40	0.228	98	-0.750
CL-SE-RL	860.82 (199.96)	**CL-SE-NONRL**	923.52 (247.48)	63	0.163	49	-0.993
CL-PH-RL	908.49 (206.28)	**CL-PH-NONRL**	957.22 (258.16)	49	0.238	47	-0.718
Radical Level-RL	901.44 (262.33)	**Radical Level-NONRL**	966.09 (279.56)	65	0.117	99	-1.198
RL-SR-SE-RL	805.07 (171.82)	**RL-SR-SE-NONRL**	1038.10 (316.83)	233	0.028	13	-2.114
RL-SR-PH-RL	911.33 (247.31)	**RL-SR-PH-NONRL**	1004.08 (309.33)	93	0.193	26	-0.881
RL-PR-SE-RL	947.31 (294.89)	**RL-PR-SE-NONRL**	866.31 (205.77)	-81	0.213	24	0.812
RL-PR-PH-RL	951.83 (326.75)	**RL-PR-PH-NONRL**	973.64 (288.89)	22	0.434	21	-0.169

Note. Standard deviations are provided in parentheses.

6.3.2.2 Analysis within groups (between 1st and 2nd experiments)

The analysis within each group is based on Key Factor 1 Level and Location, Key Factor 2 Activation.

6.3.2.2.1 Key Factor 1: Level and Location

Generally speaking, both Group 2 Year 2 and Year 3 learners tended to respond faster in the second priming test at both levels and positions compared to the first priming test. The RTs for primes at the radical level tend to be shortened even more than for the primes at the character level (RT difference changed from +34ms to +8ms for Year 2; +1ms to -31ms for Year 3). This implies that the Radical Awareness Training improved the processing of compound characters more at sub-lexical level. The Radical Awareness Training may also have improved the processing of semantic radical-related primes more than phonetic radical-related primes for Group 2 Year 2 (RT difference changed form -42ms to -1ms), and improved the processing of phonetic radical-related primes more than semantic radical-related primes (RT difference changed from +89ms to +50ms) (see Table 33).

Table 33: RTs at different levels and locations of 1st and 2nd Experiments

Level							
Learner group	**Exp. no.**	**Character Level Mean RT**	**Radical Level Mean RT**	**Diff**	**P value**	**df**	**t**
Group 2 Year 2	**1st**	888.88 (275.77)	922.55 (277.80)	34	0.140	315	-1.082
	2nd	864.68 (291.85)	872.72 (266.18)	8	0.403	292	-0.246
Group 2 Year 3	**1st**	930.07 (267.52)	931.52 (271.06)	1	0.485	199	-0.038
	2nd	893.35 (262.29)	862.18 (256.47)	-31	0.222	205	0.767
Location							
Learner group	**Exp. no.**	**Semantic radical Mean RT**	**Phonetic radical Mean RT**	**Diff**	**P value**	**df**	**t**
Group 2 Year 2	**1st**	926.73 (259.13)	884.53 (252.26)	-42	0.233	77	0.733
	2nd	841.95 (174.41)	841.32 (242.76)	-1	0.495	73	0.013
Group 2 Year 3	**1st**	860.03 (217.27)	949.48 (304.01)	89	0.108	52	-1.256
	2nd	866.64 (256.47)	916.46 (318.91)	50	0.264	52	-0.635

Note. Standard deviations are provided in parentheses.

6.3.2.2.2 Key Factor 2: Activation

At the character level, Group 2 Year 2 learners tended to read phonologically-related primes faster than semantically-related primes in the first priming test. Now this difference reaches marginal significance (863.80ms, SD = 240.49ms vs 787.69ms, SD = 235.07ms, Diff = -76, P = 0.083, < 0.1). This is mainly caused by the improved RT of phonologically-related primes (884.12ms, SD = 293.79ms vs 787.69ms, SD = 235.07, Diff = 96ms, P = 0.068, < 0.1). Group 2 Year 3 learners have shown a similar trend of faster reading in sound-related primes as the RT difference changed from +48ms to -42ms (see Table 34).

At the radical level, both Group 2 Year 2 and Year 3 learners have shown bigger improvement on semantic processing. In particular, the RT difference between semantic and phonological processing for Group 2 Year 3 changed from +56ms to +100ms and the difference reaches marginal significance (P = 0.103, ≈ 0.1). In addition, Group 2 Year 2 learners significantly increased their processing speed on semantic processing (911.10ms, SD = 254.04ms vs 829.56ms, SD = 180.23ms, Diff = 82ms, P = 0.05, < 0.1). Before the Radical Awareness Training, Group 2 Year 2 learners tended to read semantic radical phonologically-related primes faster, whereas after the training they tended to read semantically-related primes faster. This is mainly because they processed significantly faster for semantically-related primes in the second experiment (925.55ms, SD = 241.40ms vs 838.25ms, SD = 169.38ms, Diff = 87ms, P = 0.094, < 0.1). Group 2 Year 3 learners continued to read semantically-related primes faster than phonologically-related primes (RT difference changed from +106ms to +114ms).

Before the Radical Awareness Training, Group 2 Year 2 learners tended to read phonetic radical phonologically-related primes faster, now they tended to read semantically-related primes faster. Group 2 Year 3 learners continued to read semantically-related primes faster (RT difference changed from +5ms to +88ms).

In short, the Radical Awareness Training seems to promote more phonological processing at the character level and more semantic processing at the radical level for both semantic and phonetic radicals.

Table 34: RTs of activation types at difference levels and locations

(1st and 2nd Experiments)

Learner group	Exp. no.	PH Mean RT		Diff	P value	df	t
Level - Character level							
Group 2 Year 2	1st	902.57 (301.06)	884.15 (293.79)	-18	0.395	75	0.268
	2nd	863.80 (240.49)	787.69 (235.07)	-76	0.083	75	1.400
Group 2 Year 3	1st	860.82 (199.96)	908.49 (206.28)	48	0.213	45	-0.804
	2nd	930.96 (340.11)	888.93 (301.01)	-42	0.313	54	0.490
Level - Radical level							
Group 2 Year 2	1st	911.10 (254.04)	901.39 (259.53)	-10	0.433	77	0.168
	2nd	829.56 (180.23)	840.37 (205.67)	11	0.405	73	-0.243
Group 2 Year 3	1st	873.56 (245.24)	929.33 (280.22)	56	0.220	52	-0.778
	2nd	842.68 (258.20)	942.27 (311.02)	100	0.103	52	-1.284
Location - Semantic radical							
Group 2 Year 2	1st	925.55 (241.40)	900.36 (220.04)	-25	0.365	39	0.347
	2nd	838.25 (169.38)	845.84 (184.13)	8	0.447	37	-0.134
Group 2 Year 3	1st	805.07 (171.82)	911.33 (247.31)	106	0.097	27	-1.334
	2nd	809.64 (245.72)	923.64 (263.13)	114	0.124	26	-1.185
Location - Phonetic radical							
Group 2 Year 2	1st	894.37 (273.64)	874.68 (236.05)	-20	0.407	36	0.237
	2nd	823.35 (198.38)	833.88 (234.75)	11	0.443	34	-0.146
Group 2 Year 3	1st	947.31 (294.89)	951.83 (326.75)	5	0.486	23	-0.036
	2nd	875.71 (275.19)	964.00 (370.23)	88	0.247	24	-0.696

Note. Standard deviations are provided in parentheses.

When processing meaning-related primes, Group 2 Year 2 learners tended to process phonetic radicals faster than semantic radicals in the first priming test. In the second priming test, the RT difference was narrowed from -31ms to -15ms. A similar trend happened to Group 2 Year 3 learners as RT difference between the two radicals narrowed from +142ms to +66ms in the second priming test. When processing sound-related primes, Group 2 Year 2 learners tended to show a bigger improvement for reading semantic radicals than phonetic radicals (RT difference changed from -26ms to -12ms); Group 2 Year 3 learners persisted in tending to read semantic radicals faster than semantic radicals (see Table 35).

Table 35: RTs of activation types at difference locations

（1st and 2nd Experiments）

Activation type	Group	Exp. no.	SR Mean RT	PR Mean RT	Diff	P value	df	t
SE	Group 2 Year 2	1st	925.55 (241.40)	894.37 (273.64)	-31	0.350	39	0.388
		2nd	838.25 (169.38)	823.35 (198.38)	-15	0.400	38	0.255
	Group 2 Year 3	1st	805.07 (171.82)	947.30 (294.89)	142	0.073	19	-1.516
		2nd	809.64 (245.72)	875.71 (275.19)	66	0.255	26	-0.67
PH	Group 2 Year 2	1st	900.36 (220.04)	874.68 (236.05)	-26	0.366	36	0.347
		2nd	845.84 (184.13)	833.88 (234.75)	-12	0.434	33	0.169
	Group 2 Year 3	1st	911.33 (247.31)	951.83 (326.75)	41	0.359	25	-0.367
		2nd	923.64 (263.13)	964.00 (370.23)	40	0.375	24	-0.324

Note. Standard deviations are provided in parentheses.

6.3.2.2.3 Key Factor 3: Priming effects

There is no priming effect obtained from the overall related primes in the first priming test for Group 2 Year 2 (Diff = 11ms, P = 0.360), but there is a +63ms positive priming effect that happened in the second priming test. This priming effect came primarily from priming at the character level, more specifically, from the sound-related primes (787.69ms, SD = 235.07ms vs 900.09ms, SD = 315.86ms, Diff = 112, P = 0.048, < 0.05). The previous marginally significant negative priming effect that happened on semantic radical phonologically related primes (Diff = -76ms, P = 0.101, ≈ 0.1) disappeared and showed an opposite trend of a positive priming effect (Diff = +101ms, P = 0.159, > 0.1). However, the previous marginally significant positive priming effect happened on phonetic radical phonologically related primes (Diff = 148ms, P = 0.050) disappeared and showed an opposite trend of a negative priming effect (Diff = -16ms, P = 0.421, > 0.1).

For Group 2 Year 3, the originally obtained overall related positive priming effect (+52ms, P = 0.085ms) disappeared in the second priming test and shows a trend of a negative priming effect (-46ms, P = 0.130, P > 0.1). The trend of negative priming effects happened both at the character and radical levels. At the character level, the original positive priming trends with semantically-related and phonetically-related primes now became negative, changing from +63ms to -25ms, and +49ms to -48ms irrespectively. At the radical level, the original significant positive priming effect happened in semantic radical semantically-related primes lost its significance (the difference changed from +233ms to +74ms) (see Table 36).

Table 36: Group 2 priming results of 1st and 2nd Experiments

	1st Experiment						2nd Experiment					
	Group 2 Year 2											
Priming type	**Mean RT Related**	**Mean RT Non-related**	**Diff**	**P value**	**df**	**t**	**Mean RT Related**	**Mean RT Non-related**	**Diff**	**P value**	**df**	**t**
RL vs NONRL	900.63 (275.29)	911.79 (279.19)	11	0.360	315	-0.358	838.43 (233.37)	900.99 (318.49)	63	0.028	292	-1.930
Character Level	894.68 (296.16)	883.00 (255.30)	-12	0.397	151	0.261	828.22 (239.48)	903.68 (336.42)	75	0.060	127	-1.568
CL-SE	902.57 (301.06)	863.61 (237.60)	-39	0.254	81	0.665	863.80 (240.49)	906.72 (356.98)	43	0.267	66	-0.627
CL-PH	884.15 (293.79)	905.71 (276.36)	22	0.378	66	-0.312	787.69 (235.07)	900.09 (315.86)	112	0.048	67	-1.686
Radical Level	906.43 (255.09)	937.53 (298.08)	31	0.238	162	-0.715	848.91 (228.05)	898.23 (301.34)	49	0.136	128	-1.105
RL-SR-SE	925.55 (241.40)	937.82 (243.94)	12	0.434	42	-0.168	838.25 (169.38)	917.74 (280.26)	79	0.148	29	-1.065
RL-SR-PH	900.36 (220.04)	824.18 (130.76)	-76	0.101	29	1.306	845.84 (184.13)	946.67 (379.16)	101	0.159	24	-1.020
RL-PR-SE	894.37 (273.64)	917.62 (380.30)	23	0.414	38	-0.22	823.35 (198.38)	892.16 (311.21)	69	0.207	37	-0.828
RL-PR-PH	874.68 (236.05)	1022.95 (312.48)	148	0.050	39	-1.692	833.88 (234.75)	817.71 (200.72)	-16	0.421	28	0.201
	Group 2 Year 3											
RL vs NONRL	904.83 (262.42)	957.03 (273.56)	52	0.085	199	-1.381	900.46 (302.23)	854.28 (292.20)	-46	0.130	211	1.132
Character Level	908.72 (265.31)	949.00 (270.56)	40	0.228	98	-0.75	909.95 (318.93)	875.81 (340.12)	-34	0.295	107	0.541
CL-SE	860.82 (199.96)	923.52 (247.48)	63	0.163	49	-0.993	901.81 (308.90)	877.14 (341.15)	-25	0.390	53	0.281
CL-PH	908.49 (206.28)	957.22 (258.16)	49	0.238	47	-0.718	888.93 (301.01)	840.44 (263.63)	-48	0.269	51	0.620
Radical Level	901.44 (262.33)	966.09 (279.56)	65	0.117	99	-1.198	890.63 (286.55)	831.46 (232.24)	-59	0.126	102	1.151
RL-SR-SE	805.07 (171.82)	1038.10 (316.83)	233	0.028	13	-2.114	809.64 (245.72)	884.08 (256.94)	74	0.229	24	-0.754
RL-SR-PH	911.33 (247.31)	1004.08 (309.33)	93	0.193	26	-0.881	923.64 (263.13)	833.50 (258.69)	-90	0.185	26	0.914
RL-PR-SE	947.31 (294.89)	866.31 (205.77)	-81	0.213	24	0.812	875.71 (275.19)	753.25 (141.80)	-122	0.089	24	1.389
RL-PR-PH	951.83 (326.75)	973.64 (288.89)	22	0.434	21	-0.169	964.00 (370.23)	792.00 (139.29)	-172	0.082	21	1.447

Note. Standard deviations are provided in parentheses.

CHAPTER 7: Discussion and conclusion of the Priming Test

7.1 L1 Discussion and conclusion of the Priming Test

7.1.1 Equal efficiency of reading single characters and phonetic compounds

The difference between mean RT at the character level and radical level is not significant in this research. In other words, native speakers can read phonetic compounds as fast as they can read single characters.

It is not in line with the previous research (Zhou *et al.* 2000), in which they found that when primes are related at Radical Level (RL), the RTs were longer than when they are related at Character Level (CL). They suggested that because RL primes have a lower mean character frequency than CL primes, it takes a longer time to process RL primes, leaving a shorter time to process the target. In this study, however, the mean character frequency of RL primes (880.77 per million, SD = 1556.91 per million) is actually higher than that of CL primes (448.83 per million, SD = 489.47 per million), P = 0.005, < 0.05. Theoretically, the mean RT at the character level should be longer than it is at the radical level. Nevertheless, the facilitation of a higher character frequency of RL primes is not reflected in the mean RT. This might be due to the priming effect obtained by character level primes, and due to the fact that no priming effect was obtained by radical level primes

For CL primes, on the one hand, the character frequency in this study is lower than that of RL primes, hence, it took a longer time to activate the information. On the other hand, the activated information in turn facilitated the recognition of the target. For RL primes, the character frequency is higher, which resulted in a faster activation. However, the activated information is irrelevant to the target, bringing no facilitation, because RL primes only relate to the target at the radical level. From results of Factor 3 Priming effects, we also know that there was no priming effect at the radical level. The result of no significant RT difference between the mean RTs of two levels may suggest that the priming effect of CL primes counterbalanced the slower activation brought about by the lower frequency.

7.1.2 Partially obtained priming effect due to SOA

Priming effect is only observed at the character level of priming but not at any radical level of priming. The reason may be the SOA, or stimulus-onset asynchrony. In order to keep consistency of experiment design between native speakers and L2 learners, the same 250ms SOA has been applied to both groups in the priming test design.

From the literature (Wu 2012: 377) we know that character recognition is a time sequency event in which the information retrieval follows a time sequency. The previously retrieved information decays quickly after a certain time. When SOA is 57ms, there is significant priming effect of the embedded radicals on their phonologically or semantically related target. When SOA is 200ms, the priming effect at the radical level is reduced. Also, there is a parallel processing happening at the radical level and at the character level. They facilitate and compete with each other.

By 250ms, the information retrieved at the radical level may be already decayed to an uninfluential strength or may be overpowered by information retrieved at the character level, causing no effect on recognising the target character. Furthermore, the information retrieved at the character level by radical related primes had no effect on the target in either shape, sound or meaning.

It also explains that the priming effect caused by character level primes is only marginally significant as the information at character level is also decaying. The results provide the evidence to suggest that though the processing at the radical level and the character level are parallel, the information activation at the character level lasts longer and stronger than that on the radical level. The activation on the character level still exists at 250ms and inhibits the activation at the radical level.

7.1.3 Prioritised semantic route

From the activation type analysis, we know that native speakers process semantic information faster than phonological information, at least at character level. This difference is marginally significant. At the radical level it has also shown such a tendency, but the difference in either semantic radicals or phonetic radicals did not reach significance. The results did not reach significance. This may be because at the radical level, the relevant sublexical information had decayed to an uninfluential degree at 250ms SOA, as we discussed earlier.

Native speakers' meaning retrieval is a faster and more dominant activation compared to their sound retrieval at the character level. It confirms that for the average literate Chinese readers, the semantic route to lexical access is a default route which is consistent with previous studies (Williams and Bever 2010; Yeh *et al.* 2017). It may also be the case that at the radical level there is full activation of both semantic and phonological activation, but the semantic one is prioritised.

In other words, educated native speakers use both full semantic and phonological paths in character decoding at the lexical level and the sub-lexical level. There is a tendency that the semantic decoding strategies are preferable to the phonological ones when it comes to reading. This indicates that the semantic path is the default path of character recognition, which is in line with the Dual Route model in which it is explained that the semantic route is the dominant route over the phonological route (i.e., William and Bever, 2010).

7.1.4 Faster reading of semantic radicals over phonetic radicals

The results from different locations have shown that native speakers recognise a target character faster when it is primed by another character which contains a semantic radical that relates to the target, compared to when it contains a phonetic radical that relates to the target. In others words, native speakers process semantic radicals faster than phonetic radicals.

The reason for this preference can be easily interpreted as that because the semantic route is prioritised as we just discussed, and semantic radicals provide meaning and phonetic radicals provide sound, it is only logical that semantic radicals are prioritised. However, the data analysis has shown more profound reasons: there are both semantic and phonological activations for either radical type; the efficiency difference in information processing between the two mainly happened on a phonological rather than semantic retrieval when SOA is as long as it is in this research. In other words, native speakers retrieve the meaning with the same efficiency for both radical types but retrieve the sound faster for semantic radicals than phonetic radicals.

The faster processing of semantic radicals might be due to the following reasons: first, the more efficient processing of semantic radicals due to their features: 1) in commonly used characters, there are about 200 semantic radicals and 800 phonetic radicals, with a reliability percentage of 65% and 18.5% respectively (Taylor and Taylor 1983; Hoosain 1991); 2) the character frequency of semantic radicals as standalone characters is higher (with a marginal difference in this research design); 3) sematic radicals have higher combinability (more likely to appear in different characters) than phonetic radicals (Wang 2006). In all, semantic radicals are smaller in size, higher in combinability and more reliable when compared to phonetic radicals. Second, the result has shown that there was no significant difference ($P = 0.495$ and $P = 0.224$, > 0.1) between semantic activation and phonological activation within semantic and phonetic radicals. Especially for semantic radicals, the mean RT of semantic related primes is almost the same as the mean RT of phonologically related primes (Diff = 0ms). It may mean that the activation of meaning and sound were equally efficient in semantic radicals. However, there is a tendency of faster semantic activation than phonological activation within phonetic radicals (19ms). The activation difference within phonetic radicals may mean that native speakers do not process phonetic radicals as efficiently as semantic radicals: semantic processing is equally efficient and phonological processing is unequally efficient at either location/radical type. This radical-type difference may be caused by the statistical features in position-sensitive representations rather than the role of function. This statistical feature difference might also be reflected in how learners learn radicals as explained in 6.2.3. Learners tend to learn both meaning and sound for semantic radicals and learn more sound than the meaning for phonetic radicals. Third, semantic radical processing is prioritised because of radical feature and/or positional advantage – semantic radicals in this research are always at the left side of the compound characters which is in line with the left-to-right reading habit.

This result may contradict to our conscious feeling about processing radicals: we get meaning from the semantic radicals and sound from the phonetic radicals. However, from the data analysis we know that both meaning and sound information are activated for both radical types. It provides extra evidence to support Taft's model that the processing of semantic radicals and phonetic radicals is similar. In addition, the results provide support for the results of Wang et. al (2017) about semantic radicals' dominant role in the recognition of phonetic compounds.

7.1.5 Conclusion

In conclusion, the native speakers' results of the Priming Test have provided additional evidence to support the previous research that character processing is a time event and that there are both semantic and phonological activations happening in parallel at both lexical and sublexical levels. The information retrieved from both levels facilitate or compete with each other. Furthermore, the results also confirm that between the hypothesised universal twin routes of lexical access, the semantic route is the default or primary means of lexical access. In terms of priming level, this acceleration is evident on the character level but no so much at the radical level due to the design of this experiment. In terms of priming location, the semantic radical is the prioritised radical type because their sound information can be processed with equal efficiency as meaning information.

Further research would be warranted to find out how native speakers processing times vary under shorter SOAs, and to find out the processing difference between single characters and phonetic compounds, and to further uncover more detailed information about the priming effect between two types of radicals and within each type of radical. The prediction is that the priming effect also happens at the radical level, and native speakers process single characters faster than compound characters when the character frequency is controlled. However, it would be a challenge to design an experiment with matched character frequency between single and compound characters.

7.2 L2 Discussion and conclusion of the Priming Test

7.2.1. The natural development of character recognition for L2 learners

The processing patterns of L2 learners at the intermediate and advanced level are depicted in the aspects of reading single and complex characters and reading strategies concerning activation types and radical types.

7.2.1.1 Mixture of positive and negative priming effects

The lexical decision priming experiment used in this research is designed to compare the RTs between stimuli pairs related and non-related to the same target. When there is a RT difference, a priming effect is obtained. The effect can be either facilitating or inhibiting. A facilitating effect means that the related retrieved information accelerates the processing of the target character; the RT in this case is shorter than the RT when retrieved information is irrelevant. An inhibiting effect means that the related retrieved information impedes the processing of the target character. The RT is longer in this case than the RT when retrieved information is loosely related. In either the case of facilitation or inhibition, the information activated by that prime works on the processing of the target, hence, the priming effect is viewed as achieved.

For example, when one sees the word *nurse* before they see *doctor*, they recognise *doctor* faster than when they see *cake* beforehand. This is the facilitation of the priming effect. Similarly, if instead of *nurse* they see the word *dope* before the word *doctor*, the priming effect might work in the opposite way, since *dope* is probably at the back of the queue for activated predicating candidates such as *hospital*, *needle*, *medicine* etc. In the mental lexicon, these candidates which are relatively less active, or have a lower activation threshold, may lead to a counteracting effect on the speed of recognising the word *dope.* The reader has to rule out the wrong candidates before verifying the correct one. As a result, *dope* causes a longer reaction time. This scenario may happen when the relation is not strong enough, or there are other words/characters with which the prime words/characters activate first.

L1 native speakers have shown priming effects at both character level conditions but none of the four radical level conditions. On the contrary, both subgroups of learners with two years' experience and learners with three years' experience have shown some priming effects at the radical level conditions but not at character level conditions.

The reason why L1 native speakers did not obtain priming effects at the radical level is explained in 7.1.2. It is due to the choice of SOA in the experiment design. However, it is very strange that L2 leaners did not obtain priming effects at the character level, since character level primes are a constituent part of radical level primes. If L2 learners could process radical level primes and retrieve information from them, they must be able to process character level primes. Taking a closer look at the priming results, we found that the priming effect at the radical level is a mixture of positive and negative impact. It might happen when some retrieval meaning/sound activates the target and when some information is activated which actually impedes the activation of the target as explained above.

In all, this mixed priming effect might be a result of limited character usage due to experiment design. In the design of the priming test in this research, the strength of relation had to be compromised in some cases, considering all stimuli had to be chosen from the Common Lexical Base which contains a limited number of characters. It does not affect the processing of L1 readers but might do so for the L2 learners.

7.2.1.2 The difference of reading single characters and phonetic compounds

Learners with two years of learning experience read character level-related primes faster than radical level-related primes. In other words, they read single characters faster than compounds. On the contrary, learners with three years of learning experience might read primes at both levels at a similar speed, which is a speed similar to native speakers.

Three factors might affect the RTs in terms of location for L2 learners: character frequency, priming effect and stroke number. As we discuss in 7.1.1., the mean character frequency of character level primes is lower than that of radical level primes in the experiment design of this study. Hence, without considering other factors, single characters should be recognised slower than compound characters. Both learner subgroups have yielded priming effects at the radical level. However, for both subgroups the priming effects are mixed with both positive and negative impacts. As a result, stroke number might be a critical factor. When a character is composed of a smaller number of strokes, it is easier to process. The shortened processing is because fewer strokes counterbalance the delay of reading characters that occur less frequently and even speeds up the overall processing time. It might mean that learners with two years of learning are more susceptible to the effects of character complexity than learners with three years of learning experience. However, we cannot rule out the possibility of a stronger positive priming effect at the radical level happening to learners with three years of learning experience. Either being less susceptible to character complexity or having stronger positive priming effect at the radical level indicates that the processing strategies of learners of three years' learning experience are more similar to native speakers' than learners of two years' learning experience.

7.2.1.3 The difference between semantic and phonological activations

At both the character and radical level, learners with two years' learning have shown the trend of a prioritised phonological route; learners with three years' learning have shown the trend of a prioritised semantic route as that of the native speakers. This might be explained by L1 interference. L2 learners in this study are all alphabetic language native speakers that use a predominant phonological processing strategy for reading. They might continue to use this strategy in learning Chinese for at least the first two years. By the year three, they start to use more semantic strategies like native speakers. This transfer might be due to the language specific features of Chinese systems.

7.2.1.4 The difference between reading semantic and phonetic radicals

In spite of semantic radical bias present in in-class radical training, learners with two years' experience seem to read phonetic radicals faster than semantic radicals. They tend to read phonetic radicals faster both in meaning and sound. There are two hypotheses to explain why they read phonetic radicals faster. First, as explained in the previous section, because of the learners' language background, the default strong phonological processing strategy is naturally transferred in the reading Chinese characters. Since semantic radicals do not always indicate sound but phonetic radicals do, they probably pay more attention to the latter as they always provide sound clues even if it is not fully reliable. Second, since the influence of orthographic/graphic features declines with learning years, we can assume that there are bigger impacts for features such as the pure size of the component or stroke numbers. Because in most cases the phonetic radical takes up more space than the semantic radical in a phonetic compound, phonetic radicals are simply more visually noticeable than semantic radicals. As a result, a faster processing of phonetic radicals for learners with two years of learning experience might strongly link to the orthographic features rather than the functional features of this type of radical. This result provides extra evidence to support the conclusion found by Williams (2013) regarding L2 learners using phonetic radical analysis as their default recognition strategy. On the contrary, learners with three years' experience read semantic radicals faster. They tend to read semantic radicals faster both in meaning and sound.

The pattern shown by the learners with three years' experience seems to share the same pattern shown by the native speakers. However, it is not the same. When reading semantic radicals, native speakers process the meaning and the sound with similar efficiency; however, learners with three years' experience process the meaning faster than the sound.

One thing worth noticing is that even though learners with two years of learning experience knew more about the sound and meaning of semantic radicals than phonetic radicals, they did not necessarily read semantic radicals faster. This result provides extra evidence to the claim (Shen 2007) that automatic processing of Chinese radicals cannot be reached dramatically or without the gradual forming process of a new cognitive structure.

7.2.1.5 Conclusion

From the above analysis about L1 native speakers and L2 learners on character recognition, we now can generalise a natural development route for L2 learners. It is clearly shown by the data that the longer they study Chinese as a second language, or the higher Chinese language efficiency they obtain, the closer their character processing patterns are to the native speakers' (see Figure 26).

Intermediate-level learners tend to read single characters faster than compound characters. This is very likely caused by character complexity. Single characters are a part of compound characters and the number ratio is roughly 1:2 in this study. This means that learners with two years' learning experience still break down characters into strokes rather than into bigger constructional units such as components (部件 '*bujian*') or the functional unit such as radicals, like native speakers do. An improvement can be seen in advanced-level learners. They seemed to be less affected by the character stroke number because they read compound characters as fast as single characters. It might mean that after another year's Chinese learning they realise it is more efficient to process characters based on larger units. This finding provides extra evidence to the previous research into how character density influences learners at different proficiency levels (Hayes 1987; Everson 1992). Another reason that might contribute to the decrease in speed difference is the stronger activation at the radical level for advanced learners. However, there is no clear evidence on how exactly the mixed effects influenced the overall recognition of compound characters.

Intermediate-level learners tend to prioritise phonological strategies over semantic strategies, while advanced-level learners prioritise semantic strategies over phonological strategies, as native speakers do. As we know, native speakers of shallower languages start to use the grapheme-phoneme correspondence rule after a few words are learnt. They continue to develop and strengthen the use of this rule in the following years of study. They heavily depend on phonological spelling in visual reading. Italian native speakers are no exception. They seem to transfer this sound-dominant strategy into the learning of Chinese which is a writing system that is mainly meaning-based. The preferred strategy shifts from the sound strategy to the meaning strategy, which is more fit to the specific features of the target language, after another year's learning.

The sound strategy might also influence how intermediate learners process radicals. Because phonetic radicals are the radical type that provides sound cues, it is natural for intermediate learners prioritise the processing of them over semantic radicals in spite of more training on the latter. Also, phonetic radicals are normally bigger in size. They are easier to be noticed and processed. The strategy shift happens to advanced learners start to process more efficiently on semantic radicals. Advanced learners process semantic radical faster. However, at this stage, their sound processing is much weaker than their meaning processing. The faster processing of semantic radicals is a result of faster semantic processing of semantic radicals for advanced learners; on the contrary, from a faster phonological processing of semantic radicals for native speakers.

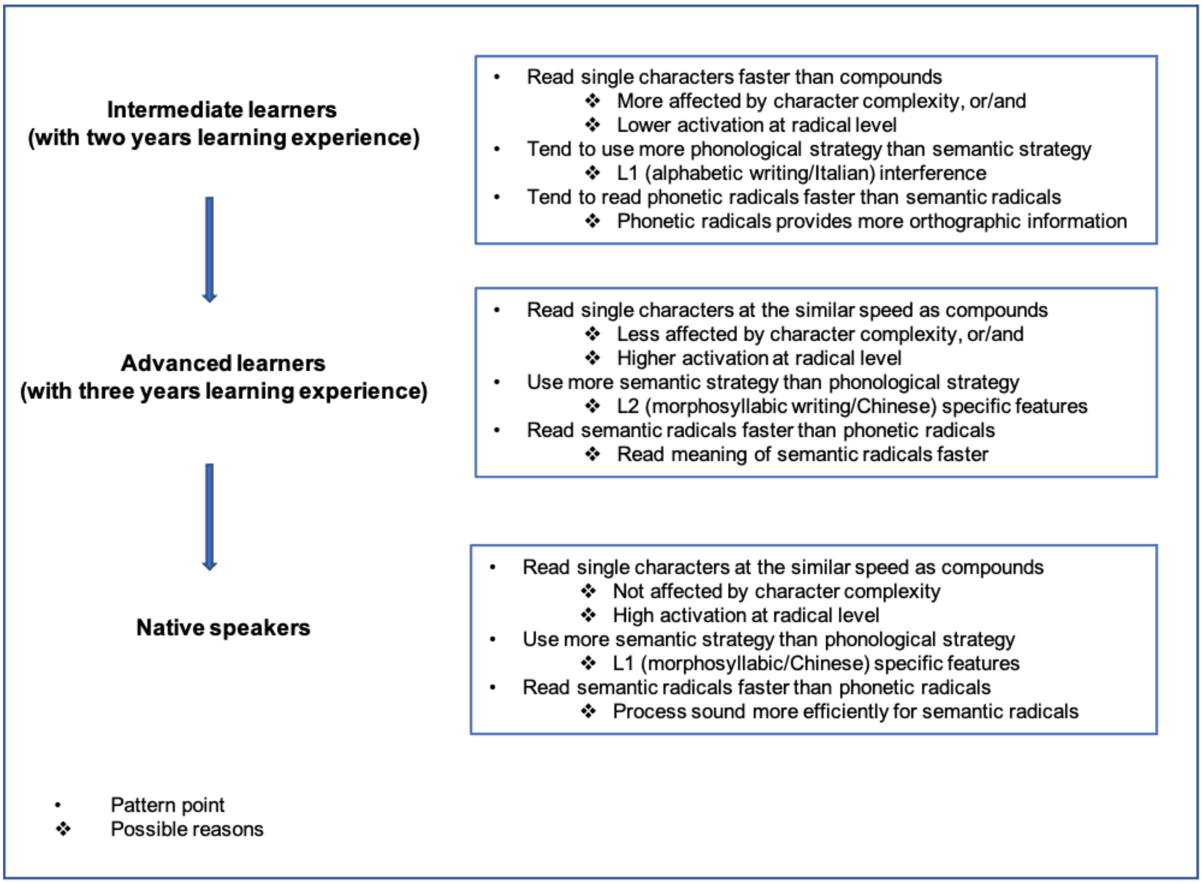


Figure 25: Natural development of Chinese character visual lexical recognition for L2

7.2.2 The efficacy of the Radical Awareness Training

The effectiveness of a knowledge balanced radical awareness training has been approved, however, learners of different proficiency levels benefit from it in different ways.

7.2.2.1 More activation at the radical level

Both intermediate and advanced learners have shown a trend towards native speakers after training in terms of processing differences between single and compound characters. They both exhibited a more efficient processing for compound characters in the second priming test than in the first one.

Intermediate learners tended to process single character faster in the first priming test, and the trend remained in the second priming test. However, the RT difference between the two character types narrowed down from +34ms to +8ms. This indicates that they benefited from the Radical Awareness Training. Advanced learners tended to process single and compound characters with similar proficiency in the first priming test. In the second priming test there is a -31ms RT difference, with compound characters being processed faster (see Figure 27).

It seems that the Radical Awareness Training caused the opposite effect on advanced learners because the result of the first priming test is closer to that of native speakers. However, as we explained earlier, there was no priming effect observed in native speakers because of the choice of SOA. We could expect positive priming effects from native speakers in shorter SOAs. In this sense, strong priming effects at radical level primes/compound characters are the expected results from the training, regardless of the RT difference between single and compound characters.

7.2.2.2 Mixed activation changes

The Radical Awareness Training caused negative effects for both intermediate and advanced groups at the character level. In other words, the patterns shown in the second priming test are further away from, instead of being closer to the patterns of native speakers. For example, the RT difference between semantic and phonological activation for intermediate learners was only -18ms, with semantic activation being less efficient. Now this difference is enlarged to -76ms. Advanced learners had a more proficient semantic activation similar to native speakers in the first priming test. Now they showed a trend of higher proficiency of phonological activation.

However, generally speaking, the training caused desired effects for both groups at the radical level. Intermediate learners had a more efficient phonological activation in the first priming text, and now they seem to have a more efficient semantic activation. Advance learners' pattern of a more efficient semantic activation not only continues in the second priming test, but the difference is enlarged.

Looking into the details at the radical level, intermediate and advanced learners experienced different changes respectively. For intermediate learners, they show a trend of more efficient semantic activation for both semantic and phonetic radicals in the second priming test. For advanced learners, they show a trend of more efficient semantic activation only for phonetic radicals. There are no changes for the semantic activation on semantic radicals (see Figure 26).

Again, it may seem that the Radical Awareness Training caused advanced learners to have a processing pattern at the radical level further from that of native speakers. Now there is a bigger processing difference between the activation types when it should have been smaller. However, we should not forget that this is very likely because the semantic strategy is also prioritised at the radical level for native speakers. It is just not observed in this study because of the SOA used.

In addition, it might mean that the Radical Awareness Training, though designed to provide balanced training on both activation types, tends to boost semantic activation over phonological activation for learners at these proficiency levels. It might also mean that advanced learners already have a highly proficient semantic activation for semantic radicals, and that there is not much room to improve with the Training.

7.2.2.3 Mixed radical changes

The Radical Awareness Training seems to lead to expected results for both intermediate and advanced learners in terms of radical processing. Intermediate learners read semantic radicals slower than phonetic radicals in the first priming test. Now this RT difference is narrowed from -42ms to -1ms. The change may be caused by more efficient semantic and phonological processing for semantic radicals. Advanced learners read semantic radicals faster and similar to native speakers in the first priming test, however, this RT difference dropped from +89ms to +50ms in the second. This change may be caused by more efficient semantic processing for phonetic radicals. This processing pattern is actually closer to the results of native speakers (see Figure 26).

It might mean that the Training, though it is designed to provide a balanced training on both radical types, tends to boost more processing on semantic radicals for intermediate learners and more processing on phonetic radicals for advanced learners.

7.2.2.4 Conclusion

The Radical Awareness Training is designed to improve the processing of both activation types and both radical types in an undifferentiated way. However, from the data we found that it improves semantic activation more than phonological activation for both proficiency groups. It improves more semantic radical processing for intermediate learners and more phonetic radical processing for advanced learners.

The goal of the training is to see if it can accelerate the development of character recognition patterns towards the patterns of native speakers. It seems that the training achieved the desired results for both intermediate and advanced learners. However, we do not know if this improvement in processing is a long-lasting result or just a temporary phenomenon.

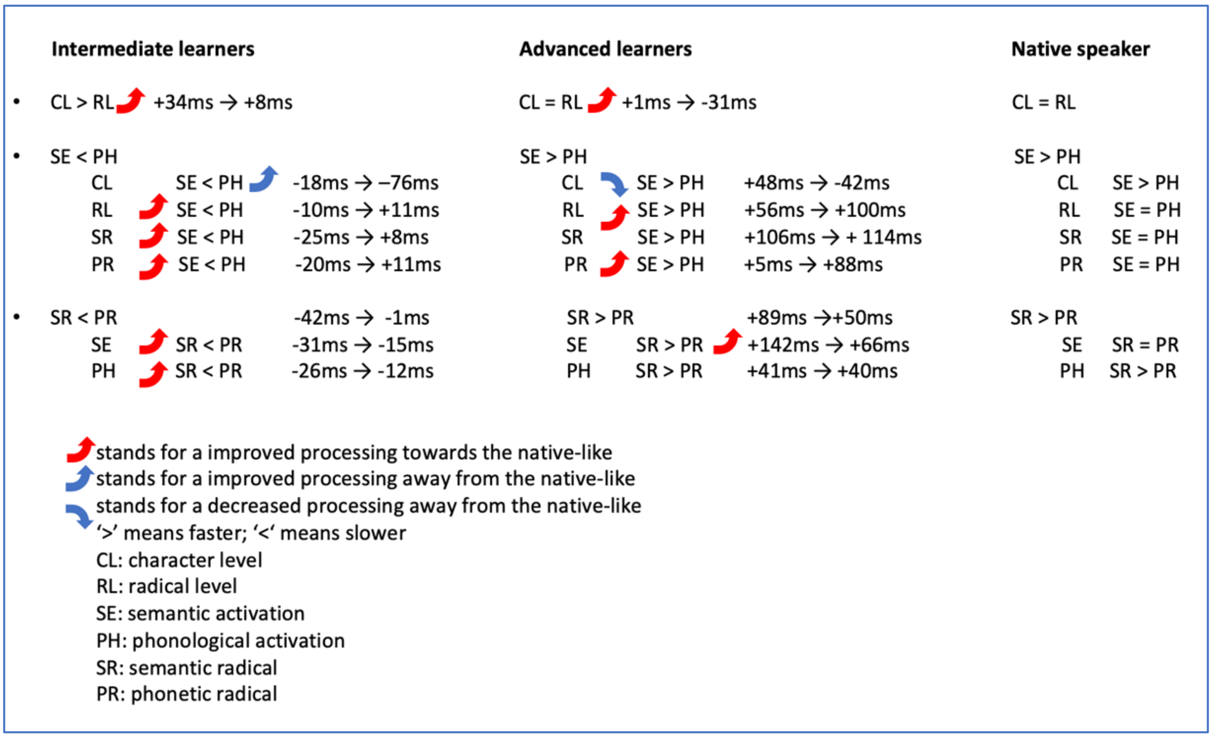


Figure 26: The effect of the Radical Awareness Training

CONCLUSION

By using a primed lexical decision paradigm, the current study examined the processing of radicals embedded in phonetic compounds and these radicals themselves as free-standing characters. These processing patterns are developed along with the knowledge of characters and radicals which is generically inherent to the years of learning. The present study shows that the patterns of intermediate learners with two years of learning experience seems to be less similar to that of native speakers when compared to advanced learners with three years of learning experience. The results demonstrate an evolutionary progression of Chinese visual character processing from the intermediate level to advanced level and on to the native level. This study has also shown the modulatory effect of radical training. A well-designed radical training which balances activation types and radical types can speed up the development towards native-like patterns for intermediate and advanced learners.

In conclusion, the result of this study has provided evidence for the theoretical hypothesis that radicals are activated in visual character recognition. It also expands prior findings by showing developmental differences in the use of linguistic (i.e., semantic and phonological) information at lexical and sublexical levels at different developmental stages of visual single Chinse character reading for L2 learners.

With reference to the research questions proposed in the first chapter concerning the function properties of radicals, this study has provided answers and empirical evidence to support the answers:

Q.1: Compared to native speakers, how do L2 learners access the functional properties of radicals?

A: For native speakers, semantic properties are more critical. Learners with three years of learning experience have shown a similar pattern to that of native speakers, while learners with two years of learning experience, for whom phonological properties seem to be more critical, have shown the opposite pattern. More specifically:

Q.1.1: For native speakers. which type of functional (semantic or phonological) properties is more critical?

A: Native speakers read meaning-related primes faster than sound-related primes with a 13ms difference (618.79ms vs 632.17ms) and this difference is marginally significant. It means semantic activation is more critical for them. More specifically, the more critical semantic activation happened at the character level.

Q.1.2: For learners with two years of learning experience, which type of functional (semantic or phonological) property is more critical?

A: Learners with two years of learning experience have shown a slower tendency when it comes to reading meaning-related primes as compared to sound-related primes at both the character (-18ms) and radical level (-10ms). Both differences do not reach significance.

Q. 1.3: For learners with three years of learning experience, which type of functional (semantic or phonological) property is more critical?

A: Learners with three years of learning experience have shown a faster tendency in reading meaning-related primes compared to sound-related primes at both character (48ms) and radical level (56ms). Both differences do not reach significance. They also have shown that when reading semantic-radical-related primes, they read meaning-related primes faster than sound-related primes with a 106ms difference, which is marginally significant. It means semantic activation is more critical, at least for reading semantic radicals. This result is in line with a slight predisposition of the semantic path over the phonological path (Shen and Forster 1999; Li 2005; Williams and Bever 2010; William 2013).

With reference to the second research question concerning the radical type, this study has also provided answers and empirical evidence:

Q.2: Compared to native speakers, how do L2 learners access the two types of radicals?

A: For native speakers, semantic radicals are more prioritised over phonetic radicals. Again, learners with three years of learning experience have shown the same pattern as native speakers, while learners with two years of learning experience, for whom phonetic radicals seem to be more prioritised, have shown the opposite pattern. More specifically:

Q.2.1: For native speakers. which type of radical (semantic or phonetic) is more prioritised?

A: Native speakers read semantic-radical-related primes faster than phonetic-radical-related primes with a 20ms difference (620.98ms vs 641.20ms), and this difference is marginally significant. It means the semantic radical is the more prioritised radical type for them. Furthermore, the difference came mainly from the more proficient processing of sound between the two radical types with a difference of 30ms (620.85ms for semantic radicals vs 650.78ms for phonetic radicals), and this difference is marginally significant. It further explains why and how semantic radicals are prioritised.

Q.2.2 For learners with two years of learning experience, which type of radical (semantic or phonetic) is more prioritised?

A: Learners with two years of learning experience read semantic-radical-related primes slower than phonetic-radical-related primes with a -42ms difference (926.73ms vs 884.53ms), and this difference is marginally significant. It means the phonetic radical is the more prioritised radical type for them. This result provides extra support for the important role of phonetic radicals (West and Travers 2007; Zhang *et al.* 2014).

Q.2.3 For learners with three years of learning experience, which type of radical (semantic or phonetic) is more prioritised?

A: Learners with three years of learning experience read semantic-radical-related primes faster than phonetic-radical-related primes with a 89ms difference (860.03ms vs 949.48ms), and this difference is marginally significant. It means the semantic radical is the more prioritised radical type for them. Furthermore, the difference came primarily from the more proficient processing of meaning between the two radical types (805.07ms vs 947.39ms) with a marginally significant difference of 142ms. It indicates that the reasons as to why semantic radicals are processed faster than phonetic radicals differ between advanced L2 learners and native speakers: one is because of the faster processing of the meaning of semantic radicals, the other is because of the faster processing of the sound of semantic radicals. This result is in line with previous research on the more prioritised semantic radicals (Williams and Bever 2010; Wang *et al.* 2017).

Finally, we need to engage on the third research question, namely:

Q.3 How does a radical awareness training influence L2 character recognition?

As shown by the data in section 6.3.2, a radical awareness training which is designed as the one used in this study can entice a processing pattern closer to natives speakers when compared to the original pattern for both groups of learners with two years' and three years' learning experience. More specifically, in terms of functional processing, both learner groups have shown the tendency of an improved semantic activation; in terms of radical processing, there is a bigger improvement in processing semantic radicals than phonetic radicals for learners with two years' experience and bigger improvement for processing phonetic radicals than semantic radicals for learners with three years' experience.

This study is the first to use a combined psycholinguistic and L2 acquisition approach to link radical awareness instruction to character recognition development. The results shed light on the shift from phonetic-oriented processing to semantic-oriented processing, and this shift takes place during the third year of formal learning at the university level (between 240-360 hours).

The data has also shown that L2 character recognition is a developing process which can be modified. Formal instruction and active study, even in a relatively short period, can speed up the development of character processing towards a more efficient, native-like pattern. Thus, it opens a new direction for future research endeavours that have the potential of enriching understanding of radical awareness in teaching and learning to read characters.

Limitations

There are some limitations in this study. First of all, a larger sample size with learners at different levels of Chinese language knowledge would be helpful to provide stronger evidence to support the conclusions. Secondly, a future study with a radical awareness training which is organised in direct instruction and guided exercise in class as well as self-learning activities might elicit stronger priming effects with regard to radicals. This information could help us understand better about which type of radical and which type of activation is prioritised. Thirdly, the phonetic compounds in sublexical conditions used in this study are all characters with radicals in their legal position, meaning semantic radicals are always on the left and phonetic radicals are always on the right. A study design which contains radicals in their illegal positions might rule out the possibility that the reading strategy for radicals of compound characters is not function-based but position-based. Last but not least, compatibility of radicals is not considered in experiment design which might have some influence in the data analysis.

Pedagogical implications

The more efficient processing of meaning over sound, as well as more efficient processing of semantic radicals over phonetic radicals shown by native speakers may indicate the most efficient reading strategies for reading Chinese characters. The reason for the use of such strategies at the sublexical level may be explained by the feature-differences between the two radical types: the number of semantic radicals is only one quarter of that of phonetic radicals and semantic radicals provide significantly more reliably indicative information about the host characters. However, this does not mean that semantic radicals are more important than phonetic radicals. Both radicals need to be recognised in order to recognise the whole character. If characters are indeed principally accessed via the visual-meaning route at both the lexical and sublexical levels, learners would eventually adopt semantic strategies as the default path and achieve higher efficiency in recognising semantic radicals when compared to the recognising of phonetic radicals regardless. As we see, the pattern differences shown between intermediate and advanced groups from the experiment results in this study already indicate such a tendency existed in natural progression.

When talking about helping learners gain more radical knowledge in order to better recognise characters, traditional teaching tends to suggest putting primary attention on semantic radicals. However, after learners were trained with a relatively balanced number of semantic radicals and phonetic radicals (a ratio of 1:2, keeping in mind the overall ratio between two types of radicals is 1:4), both proficiency groups have shown positive training effects. The training contains balanced meaning and sound information (learners needed to study both sound and meaning of each radical, providing such information exists).

After identifying ‘what to teach’ and ‘whom to teach’, it is worth discussing ‘how to teach’. First, the foundational premise for a more efficient character processing is the ability to break an unfamiliar phonetic compound into familiar functional unites – the phonetic radical and semantic radical. Learners’ sensitivity to character structures should be promoted and then they should be taught radicals and their functions explicitly. Commonly used radicals should be pointed out by the instructors every time a new character that contains that radical appears. Then learners should be asked to recombine the learnt units into familiar whole characters. This practice enables students to figure out the meaning and the sound of newly encountered characters and likely enhances learning efficiency of characters, leading to positive effects such as a faster and easier memorisation of these characters.

Presumably, it is easier to use known radicals to learn and remember unknown characters. For instance, if the readers know the meaning of 木, they might learn other words such as 材, 椅, 林, more easily than others who do not possess the knowledge of the radical 木. This is particularly true when the meaning and sound of a phonetic character can be directly inferred from its components. Second, learners should be taught phonological access strategies explicitly. For example, some formal instruction can be provided to teach learners how to identify phonetic radicals. Also, we can teach learners to group and to compare characters with the same phonetic radicals but different sounds, as well as characters with the same sound but different phonetic radicals. Instruction can also be arranged in a way that the new characters are learnt in a certain order which more closely corresponds to the existing groupings students have already made. Third, other than memorising the sound silently, students should also be encouraged to speak the sound out loud as it helps increase the efficiency of working memory, which in turn facilitates the memorising, recognising and consolidating of the sound of characters or radicals.

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APPENDIXES

Appendix A: L1 Language Background Questionnaire (Group 1)

Language Background Questionnaire (Native Speakers)

1. 年龄：______
2. 性别：______
3. 母语：______
4. 方言：______
5. 您小时候在家说什么语言？______
6. 您上学期间的授课语言：
   小学：______
   中学：______
   大学：______
   研究生：______
7. 您会哪些外语？____________________________________

8. 请自评您的外语能力：

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 □

9. 您是从几岁开始学习英语的？_________
10. 您学习英语多久了？________________

11. 您是否有在国外长期居住的经历（三个月及以上）？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: L2 Language Background Questionnaire (Group 0)

Language Background Questionnaire (L2)

A. General Information

1. Age/Gender: _________

2. Major: ______________

B. Known Languages and Uses

1. Native language(s): ______________

2. Language(s) spoken at home from birth to 5 years old: ________________

3. Country of residence from birth to 5 years old: ______________________

4. Language(s) of instruction in your primary school: ___________________

5. Country of residence from 6 to 11 years old: ________________________

6. Language(s) of instruction in your second level school(s): _____________

7. Country of residence from 12 to 17 years old: _______________________

8. Second language(s) that you know and self-estimated 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 □
	Beginner □ Intermediate □ Advanced □ Near-native □	Beginner □ Intermediate □ Advanced □ Near-native □	Beginner □ Intermediate □ Advanced □ Near-native □	Beginner □ Intermediate □ Advanced □ Near-native □

9. Weekly use of Chinese and other languages

a). % weekly use of Chinese ________________

b). % weekly use of (   )_________________

c). % weekly use of (   ) ________________

d). % weekly use of (   ) ________________

10. When did you take HSK test and what's your highest certificate level:

____

C. Learning of Chinese

1. Age of first exposure to Chinese: _______________

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

3. Number of years of Chinese instruction that you have received: _______________

4. Immersion(s) in a Chinese-speaking environment

a). First immersion

i. Age: ________________ Duration

ii. Place: ______________

iii. Context: ______________________________________

iv. Duration: ___________

b). Second immersion

i. Age: ________________

ii. Place: ______________

iii. Context: ______________________________________

iv. Duration: ___________

c). Third immersion

i. Age: ________________

ii. Place: ______________

iii. Context: ______________________________________

iv. Duration: ___________

Appendix C: L2 Language Background Questionnaire and Radical Knowledge Test (Group 2)

(*Language Background Questionnaire and Radical Knowledge Test for L2 Group-IE are separated forms, the Radical Knowledge Test is exactly the same as L2 Group-IT's but without Italian instructions.)

RESPONDANT ID________________ Pagina 1 di 2

Questionario sulla *Radical Knowledge* (L2)

Obiettivo

Questo test è parte di una ricerca sui processi cognitivi messi in atto per la decodifica dei caratteri da parte di apprendenti di cinese come seconda lingua. In particolare, questo questionario consente di misurare preliminarmente la *radical knowledge* raggiunta dopo due/tre anni di studio del cinese. Ti ringraziamo per la tua collaborazione, ricordando che i dati raccolti saranno anonimizzati e che verranno utilizzati solo ai fini di questa ricerca.

Informazioni di contesto

1. Età: ______________
2. Lingua madre: ______________
3. Anno di corso: UNIBO Cinese 2 □ UNIBO Cinese 3 c
4. Studio cinese da: 2 anni □ 3 anni □ + di tre anni □
5. Parlo cinese in famiglia: sì □ no □
5. Ho trascorso almeno un mese in Cina: sì □ no □

Istruzioni

Nella lista di seguito troverai 19 radicali semantici e 77 componenti fonetici. Probabilmente non li conosci tutti e forse di alcuni conosci solo il significato e non la pronuncia, o viceversa. Per misurare la *radical knowledge* raggiunta dopo due/tre anni di studio del cinese, ti chiediamo di:

1. Se lo sai, inserisci il significato e la pronuncia in *pinyin* (senza toni). O anche solo il significato o solo la pronuncia se non sei in grado di inserire entrambi. Per esempio:

木	**legno**	***mu***
录	**registrare**	/
穴	/	***xue***

2. Compilare il questionario rapidamente inserendo la prima risposta che ti viene in mente.
3. Se non conosci il significato o la pronuncia di un dato radicale, lascia pure il campo vuoto. Sei invitato a inserire.
4. IMPORTANTE: non usare il dizionario.
5. Hai a disposizione 20 minuti.

Semantic radical knowledge

ID	SR	Significato	Pinyin	ID	SR	Significato	Pinyin
1	扌			20	木		
2	贝			21	目		
3	艹			22	牛		
4	车			23	女		
5	彳			24	日		
6	亻			25	氵		

7	耳			26	舍		
8	犭			27	矢		
9	工			28	礻		
10	弓			29	忄		
11	禾			30	土		
12	户			31	王		
13	钅			32	讠		
14	可			33	豕		
15	口			34	辶		
16	里			35	足		
17	力			36	𠂇		
18	冫			37	阝		
19	马						

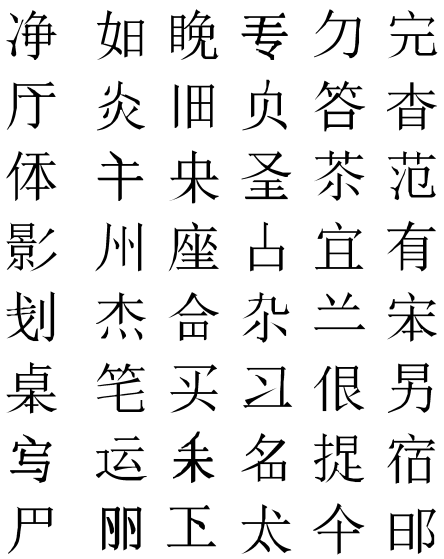
Phonetic radical [component] knowledge Pagina 1 di 2

ID	SR	Significato	Pinyin	ID	SR	Significato	Pinyin
1	旦			40	皮		
2	𠃓			41	州		
3	勾			42	舌		
4	化			43	斿		
5	采			44	气		
6	圣			45	豆		
7	列			46	兄		
8	立			47	见		
9	主			48	白		
10	故			49	支		
11	共			50	丁		
12	言			51	也		
13	叚			52	成		
14	只			53	真		
15	青			54	止		
16	句			55	司		
17	长			56	果		
18	且			57	青		
19	方			58	人		
20	戋			59	兑		
21	卑			60	斥		
22	云			61	卖		
23	欠			62	射		
24	佥			63	周		
25	巨			64	夆		
26	艮			65	取		
27	娄			66	不		
28	垂			67	包		
29	勿			68	东		
30	寺			69	完		
31	古			70	击		

32	生			71	丂		
33	台			72	予		
34	寸			73	乚		
35	月			74	酉		
36	又			75	殳		
37	每			76	隹		
38	先			77	戈		
39	去						

Appendix D: Non-characters used in the priming tests and practice trials

48 non-characters used as target characters in the priming tests



10 practice trials

No.	Correct Response	Prime	Target
1	n	禾	诞
2	w	顿	层
3	w	等	抱
4	w	第	餐
5	n	厨	快
6	w	翻	常
7	w	饭	场
8	w	符	超
9	w	该	衬
10	n	蛋	把

Appendix E: Critical Pairs for Priming Experiments

Semantic radical - Prime and Target Pairs

	Prime								Target		Activation
	Character level				Radical level						
No.	Related		Control		Related		Control				
1	贝	shell	午	noon	购	to buy	沟	ditch	钱	money	Semantic
2	车	car	风	wind	轻	light	径	path	路	to move	Semantic
3	耳	ear	岁	age	职	occupation	织	to weave	口	mouth	Semantic
4	工	to work	与	and	巧	dexterous	朽	rotten	学	to study	Semantic
5	弓	bow	巾	towel	张	*Zhang*	帐	account	拉	to pull	Semantic
6	马	horse	才	talent	验	test	检	to check	跑	to run	Semantic
7	目	eye	头	head	睡	to sleep	锤	hammer	看	to see	Semantic
8	女	female	门	door	始	beginning	治	to rule	男	male	Semantic
9	人	person	了	PARTICLE	但	but	担	burden	姐	friend	Semantic
10	舍	house	闹	to make trouble	舒	comfortable	野	wild	房	house	Semantic
11	土	earth	飞	to fly	城	city	诚	sincere	地	ground	Semantic
12	足	foot	医	medical	跟	with	根	root	手	hand	Semantic
13	贝	*bèi*	午	*wŭ*	购	*gòu*	沟	*gōu*	北	*bĕi*	Phonological
14	耳	*ĕr*	岁	*suì*	职	*zhí*	织	*zhī*	尔	*ĕr*	Phonological
15	工	*gōng*	与	*yŭ*	巧	*qiăo*	朽	*xiŭ*	共	*gòng*	Phonological
16	弓	*gōng*	巾	*jīn*	张	*zhāng*	帐	*zhàng*	公	*gōng*	Phonological
17	木	*mù*	云	*yún*	杨	*yáng*	扬	*yáng*	母	*mŭ*	Phonological
18	目	*mù*	头	*tóu*	睡	*shuì*	锤	*chuí*	木	*mù*	Phonological
19	矢	*shĭ*	穴	*xué*	短	*duăn*	逗	*dòu*	时	*shí*	Phonological
20	土	*tŭ*	飞	*fēi*	城	*chéng*	诚	*chéng*	图	*tú*	Phonological
21	王	*wáng*	书	*shū*	现	*xiàn*	视	*shì*	网	*wăng*	Phonological
22	舍	*shĕ*	闹	*nào*	舒	*shū*	野	*yĕ*	社	*shè*	Phonological
23	火	*huŏ*	今	*jīn*	烦	*fan*	顺	*shùn*	活	*huó*	Phonological
24	足	*zú*	医	*yī*	跟	*gēn*	根	*gēn*	租	*zū*	Phonological

Phonetic radical - Prime and Target Pairs

	Prime								Target		Activation
	Character level				Radical level						
No.	Related		Control		Related		Control				
1	东	east	电	electricity	陈	*Chen*	院	hospital	西	west	Semantic
2	果	fruit	表	surface	课	lesson	译	to translate	花	flower	Semantic
3	列	column	早	morning	例	example	供	for	行	row	Semantic
4	牛	cow	户	household	件	piece	住	to live	羊	sheep	Semantic
5	皮	skin	左	left	波	wave	洲	continent	毛	hair	Semantic
6	舌	tongue	舟	boat	话	words	认	to recognise	牙	tooth	Semantic
7	射	shot	拿	to take	谢	to thank	诉	to complain	弓	bow	Semantic
8	台	platform	号	number	始	beginning	姓	surname	平	flat	Semantic
9	兄	elder brother	玉	jade	祝	wish	礼	present	弟	younger brother	Semantic
10	又	again	几	several	汉	*Han*	游	tour	再	again	Semantic
11	真	real	高	high	填	to fill	址	site	假	fake	Semantic
12	周	week	青	green	调	tune	请	please	月	month	Semantic
1	白	*bái*	司	*sī*	怕	*pà*	悄	qiāo	拜	bài	Phonological
2	东	*dōng*	电	*diàn*	陈	*chén*	院	*yuàn*	冬	dōng	Phonological
3	戈	*gē*	斤	*jīn*	找	*zhǎo*	技	*jì*	哥	*gē*	Phonological
4	果	*guǒ*	表	*biǎo*	课	*kè*	词	*cí*	国	*guó*	Phonological
5	句	*jù*	田	*tián*	狗	*gǒu*	猜	*cāi*	聚	*jù*	Phonological
6	立	*lì*	处	*chù*	位	*wèi*	信	*xìn*	里	*lǐ*	Phonological
7	每	*měi*	步	*bù*	海	*hǎi*	活	*huó*	美	*měi*	Phonological
8	皮	*pí*	左	*zuǒ*	波	*bō*	酒	*jiǔ*	啤	*pí*	Phonological
9	去	*qù*	用	*yòng*	法	*fǎ*	没	*méi*	曲	*qǔ*	Phonological
10	生	*shēng*	对	*duì*	姓	*xìng*	姑	*gū*	声	*shēng*	Phonological
11	寺	*sì*	竹	*zhú*	特	*tè*	物	*wù*	四	*sì*	Phonological
12	台	*tái*	号	*hào*	始	*shǐ*	妈	*mā*	太	*tài*	Phonological

Appendix F: Semantic relatedness questionnaires

Questionnaire A

L1汉字字义相关性调查一

您好！欢迎参加我的汉字字义相关性调查！

不考虑字音和字形，请您根据第一感觉判断各题目中两个汉字字义的相关程度，选择相应的选项。字义相关程度从低到高分别是“完全不相关”、“比较不相关”、“比较相关”、“非常相关”。

本次调查有12道题目，您可以按照自己喜欢的顺序进行作答。您的意见对我非常重要，请您认真完成本次调查。感谢您的配合！

*** 1. 贝--购**

完全不相关 ○ ○ ○ ○ 非常相关

*** 2. 耳--职**

完全不相关 ○ ○ ○ ○ 非常相关

Questionnaire B

L1汉字字义相关性调查二

您好！欢迎参加我的汉字字义相关性调查！

不考虑字音和字形，请您根据第一感觉判断各题目中两个汉字字义的相关程度，选择相应的选项。字义相关程度从低到高分别是“完全不相关”、“比较不相关”、“比较相关”、“非常相关”。

本次调查有24道题目，您可以按照自己喜欢的顺序进行作答。您的意见对我非常重要，请您认真完成本次调查。感谢您的配合！

---

* **1. 东--电--西**

	完全不相关	比较不相关	比较相关	非常相关
东--电	○	○	○	○
东--西	○	○	○	○

Appendix G: Experimental Pairs for Priming Experiments

No.	Correct Response	List 1		List 2		List 3		List 4	
		Prime	Target	Prime	Target	Prime	Target	Prime	Target
1	w	咖	上	咖	上	咖	上	咖	上
2	n	点	杳	点	杳	点	杳	点	杳
3	w	椅	芳	椅	芳	椅	芳	椅	芳
4	w	厕	分	厕	分	厕	分	厕	分
5	w	难	虎	难	虎	难	虎	难	虎
6	w	王	网	书	网	现	网	视	网
7	n	喜	名	喜	名	喜	名	喜	名
8	w	师	期	师	期	师	期	师	期
9	w	闹	房	舒	房	野	房	舍	房
10	w	治	男	女	男	门	男	始	男
11	w	皮	毛	左	毛	波	毛	洲	毛
12	n	爱	范	爱	范	爱	范	爱	范
13	w	长	标	长	标	长	标	长	标
14	w	职	口	织	口	耳	口	岁	口
15	w	光	护	光	护	光	护	光	护
16	w	几	再	汉	再	游	再	又	再
17	n	鞋	宿	鞋	宿	鞋	宿	鞋	宿
18	w	处	里	位	里	信	里	立	里
19	w	南	馆	南	馆	南	馆	南	馆
20	w	带	辅	带	辅	带	辅	带	辅
21	w	怕	剧	怕	剧	怕	剧	怕	剧
22	w	克	觉	克	觉	克	觉	克	觉
23	w	色	贵	色	贵	色	贵	色	贵
24	w	城	地	诚	地	土	地	飞	地
25	w	铅	刻	铅	刻	铅	刻	铅	刻
26	n	您	厅	您	厅	您	厅	您	厅
27	w	反	卧	反	卧	反	卧	反	卧
28	w	助	不	助	不	助	不	助	不
29	w	帐	公	弓	公	巾	公	张	公
30	w	气	泳	气	泳	气	泳	气	泳
31	w	吗	子	吗	子	吗	子	吗	子
32	w	意	是	意	是	意	是	意	是
33	n	们	桌	们	桌	们	桌	们	桌
34	w	玩	歌	玩	歌	玩	歌	玩	歌
35	w	服	斥	服	斥	服	斥	服	斥
36	w	志	块	志	块	志	块	志	块
37	w	贝	北	午	北	购	北	沟	北
38	n	参	贞	参	贞	参	贞	参	贞
39	w	努	什	努	什	努	什	努	什
40	w	相	家	相	家	相	家	相	家
41	w	间	字	间	字	间	字	间	字
42	w	词	国	果	国	表	国	课	国
43	n	容	丽	容	丽	容	丽	容	丽
44	w	至	饺	至	饺	至	饺	至	饺
45	w	朽	学	工	学	与	学	巧	学
46	w	文	桥	文	桥	文	桥	文	桥
47	n	教	座	教	座	教	座	教	座
48	n	烧	很	烧	很	烧	很	烧	很
49	n	稀	个	稀	个	稀	个	稀	个
50	w	报	客	报	客	报	客	报	客
51	w	木	母	云	母	杨	母	扬	母
52	n	欧	有	欧	有	欧	有	欧	有
53	w	正	为	正	为	正	为	正	为
54	w	歉	厂	歉	厂	歉	厂	歉	厂
55	w	英	同	英	同	英	同	英	同
56	w	短	时	逗	时	矢	时	穴	时
57	n	备	完	备	完	备	完	备	完
58	n	围	运	围	运	围	运	围	运
59	n	然	邸	然	邸	然	邸	然	邸
60	w	绍	兑	绍	兑	绍	兑	绍	兑
61	w	化	好	化	好	化	好	化	好
62	n	尼	专	尼	专	尼	专	尼	专
63	w	对	声	姓	声	姑	声	生	声
64	w	系	室	系	室	系	室	系	室
65	n	断	勿	断	勿	断	勿	断	勿
66	w	重	能	重	能	重	能	重	能
67	n	她	答	她	答	她	答	她	答
68	n	种	茶	种	茶	种	茶	种	茶
69	w	酒	啤	皮	啤	左	啤	波	啤
70	w	业	要	业	要	业	要	业	要

71	w	功	适	功	适	功	适	功	适
72	w	烦	活	顺	活	火	活	今	活
73	w	请	月	周	月	青	月	调	月
74	w	术	感	术	感	术	感	术	感
75	w	错	使	错	使	错	使	错	使
76	w	饰	介	饰	介	饰	介	饰	介
77	w	姓	平	台	平	号	平	始	平
78	n	音	买	音	买	音	买	音	买
79	w	多	发	多	发	多	发	多	发
80	w	贝	钱	午	钱	购	钱	沟	钱
81	w	头	木	睡	木	锤	木	目	木
82	w	加	寿	加	寿	加	寿	加	寿
83	w	瓶	姐	瓶	姐	瓶	姐	瓶	姐
84	w	人	姐	了	姐	但	姐	担	姐
85	w	百	中	百	中	百	中	百	中
86	n	炼	宜	炼	宜	炼	宜	炼	宜
87	w	身	么	身	么	身	么	身	么
88	w	外	节	外	节	外	节	外	节
89	n	数	іШ	数	іШ	数	іШ	数	іШ
90	w	诚	图	土	图	飞	图	城	图
91	w	睡	看	锤	看	目	看	头	看
92	w	利	今	利	今	利	今	利	今
93	w	员	心	员	心	员	心	员	心
94	w	士	帮	士	帮	士	帮	士	帮
95	w	非	欢	非	欢	非	欢	非	欢
96	w	前	疼	前	疼	前	疼	前	疼
97	w	夫	忙	夫	忙	夫	忙	夫	忙
98	w	所	级	所	级	所	级	所	级
99	n	聊	占	聊	占	聊	占	聊	占
100	w	岁	尔	职	尔	织	尔	耳	尔
101	n	京	晚	京	晚	京	晚	京	晚
102	n	连	兰	连	兰	连	兰	连	兰
103	w	电	冬	陈	冬	院	冬	东	冬
104	w	唱	务	唱	务	唱	务	唱	务
105	w	东	西	电	西	陈	西	院	西
106	w	妈	太	台	太	号	太	始	太
107	w	己	糕	己	糕	己	糕	己	糕
108	n	夜	犬	夜	犬	夜	犬	夜	犬
109	w	安	蓝	安	蓝	安	蓝	安	蓝
110	n	景	未	景	未	景	未	景	未
111	n	鸡	划	鸡	划	鸡	划	鸡	划
112	w	进	刀	进	刀	进	刀	进	刀
113	n	卡	影	卡	影	卡	影	卡	影
114	w	两	会	两	会	两	会	两	会
115	w	日	选	日	选	日	选	日	选
116	w	儿	主	儿	主	儿	主	儿	主
117	w	它	机	它	机	它	机	它	机
118	w	碗	便	碗	便	碗	便	碗	便
119	w	脚	记	脚	记	脚	记	脚	记
120	w	挂	都	挂	都	挂	都	挂	都
121	w	因	起	因	起	因	起	因	起
122	n	和	体	和	体	和	体	和	体
123	w	去	曲	用	曲	法	曲	没	曲
124	w	表	花	课	花	译	花	果	花
125	w	或	方	或	方	或	方	或	方
126	w	当	朋	当	朋	当	朋	当	朋
127	n	半	工	半	工	半	工	半	工
128	n	差	净	差	净	差	净	差	净
129	w	找	哥	技	哥	戈	哥	斤	哥
130	w	开	病	开	病	开	病	开	病
131	w	金	跳	金	跳	金	跳	金	跳
132	w	包	货	包	货	包	货	包	货
133	n	双	男	双	男	双	男	双	男
134	n	乐	圣	乐	圣	乐	圣	乐	圣
135	w	谢	弓	诉	弓	射	弓	拿	弓
136	w	例	行	供	行	列	行	早	行
137	w	钟	累	钟	累	钟	累	钟	累
138	n	空	炎	空	炎	空	炎	空	炎
139	w	喂	其	喂	其	喂	其	喂	其
140	n	坐	杂	坐	杂	坐	杂	坐	杂
141	w	全	条	全	条	全	条	全	条
142	w	闹	社	舒	社	野	社	舍	社

143	w	哪	到	哪	到	哪	到	哪	到
144	w	水	本	水	本	水	本	水	本
145	w	风	路	轻	路	径	路	车	路
146	w	才	跑	验	跑	检	跑	马	跑
147	n	父	宋	父	宋	父	宋	父	宋
148	w	哦	面	哦	面	哦	面	哦	面
149	w	苹	就	苹	就	苹	就	苹	就
150	w	由	也	由	也	由	也	由	也
151	w	见	事	见	事	见	事	见	事
152	w	根	手	足	手	医	手	跟	手
153	w	填	假	址	假	真	假	高	假
154	w	手	极	手	极	手	极	手	极
155	n	念	州	念	州	念	州	念	州
156	w	呢	店	呢	店	呢	店	呢	店
157	w	给	婆	给	婆	给	婆	给	婆
158	n	巴	央	巴	央	巴	央	巴	央
159	n	样	捉	样	捉	样	捉	样	捉
160	w	林	穿	林	穿	林	穿	林	穿
161	n	易	杰	易	杰	易	杰	易	杰
162	w	住	羊	牛	羊	户	羊	件	羊
163	w	锻	鸭	锻	鸭	锻	鸭	锻	鸭
164	w	嗓	售	嗓	售	嗓	售	嗓	售
165	w	海	美	活	美	每	美	步	美
166	w	弓	拉	巾	拉	张	拉	帐	拉
167	w	只	庭	只	庭	只	庭	只	庭
168	w	园	这	园	这	园	这	园	这
169	n	局	如	局	如	局	如	局	如
170	w	句	聚	田	聚	狗	聚	猜	聚
171	n	片	笔	片	笔	片	笔	片	笔
172	w	听	年	听	年	听	年	听	年
173	w	兄	弟	玉	弟	祝	弟	礼	弟
174	n	育	习	育	习	育	习	育	习
175	w	令	玛	令	玛	令	玛	令	玛
176	n	卫	写	卫	写	卫	写	卫	写
177	n	首	丰	首	丰	首	丰	首	丰
178	w	巧	共	朽	共	工	共	与	共
179	w	特	四	物	四	寺	四	竹	四
180	n	送	尸	送	尸	送	尸	送	尸
181	w	舟	牙	话	牙	认	牙	舌	牙
182	w	思	贺	思	贺	思	贺	思	贺
183	n	市	合	市	合	市	合	市	合
184	w	亲	窗	亲	窗	亲	窗	亲	窗
185	w	边	语	边	语	边	语	边	语
186	w	练	画	练	画	练	画	练	画
187	w	德	静	德	静	德	静	德	静
188	w	根	租	足	租	医	租	跟	租
189	w	白	拜	司	拜	怕	拜	悄	拜
190	w	啡	冷	啡	冷	啡	冷	啡	冷
191	w	者	历	者	历	者	历	者	历
192	w	啊	道	啊	道	啊	道	啊	道

The marked yellow pairs are critical pairs, the unmarked pairs are filler pairs. *

Appendix H: Radical Awareness Training Material (blank)

No.	Radical	Meaning in English/Pinyin	rRadical on left	Meaning in English/Pinyin	Radical on right	Meaning in English/Pinyin
EXAMPLE	木	**Wood/*mu***	材	**wood, material/*cai***	沐	**wash/*mu***
1	白					
2	东					
3	戈					
4	果					
5	句					
6	立					
7	每					
8	木					
9	皮					
10	去					
11	生					
12	寺					
13	合					
14	寸					
15	豆					
16	击					
17	巨					
18	列					
19	卖					
20	牛					
21	欠					
22	舌					
23	射					
24	先					
25	兄					
26	言					
27	又					
28	真					
29	周					
30	贝					
31	耳					
32	工					
33	弓					
34	目					
35	矢					
36	土					
37	王					
38	足					
39	车					
40	马					
41	女					
42	人					
43	舍					

Appendix I: Radical Awareness Training Material (with answers)

No.	Radical	Meaning in English	Pinyin	Radical on left	Meaning in English/Pinyin	Pinyin	Radical on right	Meaning in English/Pinyin	Pinyin
EXAMPLE	木	**Wood**	**mù**	*材*	**wood material**	**cái**	**沐**	**wash**	mù
1	白	white	bái	的	of	de	柏	cypress	bǎi
2	东	east	dōng	N/A	N/A	N/A	栋	*(classifier for buildings)*	dòng
3	戈	go	gē	划	draw	huà	战	war	zhàn
4	果	fruit	guǒ	颗	*(classifier for small round objects)*	kē	棵	*(classifier for trees)*	kē
5	句	sentence	jù	够	enough	gòu	驹	pony	jū
6	立	standing	lì	端	end	duān	泣	cry	qì
7	每	each	měi	敏	smart	mǐn	海	sea	hǎi
8	木	wood	mù	椅	chair	yǐ	休	rest	xiū
9	皮	skin	pí	N/A	N/A	N/A	皱	wrinkle	zhòu
10	去	go with	qù	却	but	què	祛	remove	qū
11	生	health	shēng	甥	nephew	shēng	胜	win	shèng
12	寺	temple	sì	N/A	N/A	N/A	诗	poetry	shī
13	台	station	tái	N/A	N/A	N/A	抬	lift	tái
14	寸	inch	cùn	N/A	N/A	N/A	村	village	cūn
15	豆	beans	dòu	豉	a kind of food made of beans	chǐ	短	short	duǎn
16	击	hit	jī	N/A	N/A	N/A	陆	land	lù
17	巨	huge	jù	N/A	N/A	N/A	柜	cabinet	guì
18	列	column	liè	N/A	N/A	N/A	例	example	lì
19	卖	sell	mài	N/A	N/A	N/A	读	read	dú
20	牛	cattle	niú	犄	horn	jī	N/A	N/A	N/A
21	欠	owe	qiàn	N/A	N/A	N/A	歉	apologise	qiàn
22	舌	tongue	shé	刮	scratch	guā	话	words	huà
23	射	shoot	shè	N/A	N/A	N/A	谢	thank	xiè
24	先	first	xiān	N/A	N/A	N/A	洗	wash	xǐ
25	兄	brother	xiōng	N/A	N/A	N/A	祝	wish	zhù
26	言	word	yán	计	count	jì	唁	condolence	yàn
27	又	also	yòu	欢	happy	huān	叹	sigh	tàn
28	真	TRUE	zhēn	颠	humpy	diān	填	fill	tián
29	周	week	zhōu	雕	carving	diāo	调	tune	diào
30	贝	shell	bèi	赌	bet	dǔ	坝	dam	bà
31	耳	ear	ěr	聊	chat	liáo	饵	bait	ěr
32	工	work	gōng	攻	attack	gōng	江	river	jiāng
33	弓	bow	gōng	张	*(classifier for paper)*	zhāng	躬	bow	gōng
34	目	head	mù	眼	eye	yǎn	泪	tears	lèi
35	矢	arrow	shǐ	短	short	duǎn	N/A	N/A	N/A
36	土	earth	tǔ	坡	slope	pō	吐	throw up	tǔ
37	王	king	wáng	珍	treasure	zhēn	旺	vigorous	wàng
38	足	foot	zú	踢	tick	tī	捉	catch	zhuō
39	车	car	chē	辆	vehicle	liàng	阵	array	zhèn
40	马	horse	mǎ	驮	carry on the back	tuó	妈	mom	mā
41	女	female	nǚ	好	good	hǎo	汝	you	rǔ
42	人	people	rén	位	position	wèi	认	recognize	rèn
43	舍	house	shě	舒	comfortable	shū	啥	what	shá