AUTOMATIC PROCESSING OF TONAL INFORMATION DURING VISUAL WORD RECOGNITION IN L2 CHINESE LEARNERS

by

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DISSERTATION

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DEDICATION

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I dedicate this dissertation to these people.

ABSTRACT

Automatic processing of tonal information during visual word recognition

in L2 Chinese learners

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This dissertation investigates the automatic tonal processing in a second language (L2) and a first language (L1) during visual word recognition. Four experiments were conducted to examine -- (i) whether tonal information can be automatically processed in a similar manner in L2 learners and native speakers of Chinese (Experiments 1 and 2 in Chapter 2), and (ii) whether the processing of tonal information is influenced by the involvement of the production system during L1 and L2 visual word recognition (Experiments 3 and 4 in Chapter 3). Native speakers and L2 learners of Chinese were tested using a naming Stroop task in Chapter 2. The same population of participants was tested using a button-pushing Stroop task (i.e., in silent reading) in Chapter 3. The results indicated that native speakers can automatically process tonal information regardless of whether the production system was employed or not. L2 learners, however, seemed not be able to automatically use tonal information even when the task encouraged the use of phonological information as in the naming Stroop task. This was the case despite the fact that L2 learners were confirmed to have acquired explicit phonological knowledge of the experimental stimuli in a post test in Chapter 3. The results are interpreted as evidence for the differences of

how phonological information, especially tonal information, is represented and/or processed in L1 and L2 visual word recognition systems.

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Chapter 1: Introduction

Research Questions

Modern standard Mandarin Chinese (hereinafter referred to as "Chinese") has four common lexical tones (see e.g., Malins & Joanisse, 2012; Pelzl, 2019). According to Malins and Joanisse (2012), lexical tones are defined as "variation in the fundamental frequency of a speaker's voice that is used to differentiate phonemically identical words". The four common lexical tones in Chinese are determined by two parameters: height in pitch and contour (rising, falling, or dipping) (Chao, 1948, p. 24; Pelzl, 2019). Five levels are used to describe the pitch height of Chinese tones with level 5 representing the highest pitch level and level 1 representing the lowest pitch level (Chao, 1948, p. 24). The first tone (Tone 1) is a high-level tone marked with " ¯ ". It is a steady high sound that stays at level 5 of pitch height. The second tone (Tone 2) is a rising tone marked with " ˊ ". It is a sound that rises from level 3 to level 5 in terms of the pitch height. The third tone (Tone 3) is a dipping tone marked with " ˇ ". It is a sound that starts at level 2, falls to level 1, and then rises back up to level 4 in terms of pitch height. The fourth tone (Tone 4) is a falling tone marked with " ˋ ". It is a sound that falls sharply from level 5 to level 1 in terms of pitch height. In addition to the four common tones, a fifth tone exists (Tone 5; sometimes also referred to as a zoroth tone) in Chinese -- the neutral tone. A neutral tone is thought of as a lack of tone, and it is often not described as a fully-fledged tone. This is because it is created based on its preceding tone, and it is not commonly used on isolated Chinese characters.

Tones serve as a critical part of phonological information in Chinese. In general, phonological information can be divided into segmental and suprasegmental information (e.g., Li, Lin, Wang, & Jiang, 2013). Segmental information involves phonetic information, such as vowels and consonants, while suprasegmental information entails phonological information beyond phonemic information. Tones in Chinese are considered as suprasegmental information (see e.g., Malins & Joanisse, 2012), and they serve a very important role of disambiguating various words in Chinese. That is, there are large numbers of Chinese words that share segmental information, and they can only be distinguished through tones. For example, the segmental combination "ma" can have very different meanings depending on their lexical tones: (i) "mother" 妈, mā, with tone 1; (ii) "hemp" 麻, má, with tone 2; (iii) "horse" 马, mǎ, with tone 3; and (iv) "to scold" 骂, mà, with tone 4. Here, the Roman alphabet following the Chinese characters is Pinyin, which represents segmental information in Chinese. The diacritics on Pinyin represent the tones.) This is in contrast to the suprasegmental information in English, in which lexical stress may not be as critical. For example, if an L2 speaker pronounces ***com****puter* with a stress on the first syllable, most native speakers would still understand that they are referring to computers. Without the additional information from lexical tones in Chinese, there is no way of knowing which word was uttered.

Given the importance of Chinese tones, it is critical for the L2 learners of Chinese to acquire tones in order for them to master the Chinese language. Unfortunately, the acquisition of lexical tones in Chinese presents a major challenge for L2 learners (e.g., Pelzl, 2019). Although this challenge is widely recognized, it remains unclear what the nature of the locus of the difficulties in acquiring Chinese tones is. Some potential factors for this challenge that have been commonly examined include: 1) the linguistic experience in the L1 (see e.g., Bent, Bradlow, & Wright, 2006; Burnham et al., 2015; Chang, Yao, & Huang, 2017; Gandour, 1983; Hallé, Chang, & Best, 2004; So & Best, 2014), 2) L2 proficiency (see e.g., Lee, Tao, & Bond, 2009, 2010; Zou, Chen, & Caspers, 2016), 3) tone aptitude (see e.g., Bowles, Chang, Karuzis, 2016; Li &

DeKeyser, 2017; Perrachione, Lee, Ha, & Wong, 2011; Wong & Perrachione, 2007), and 4) musical experience (see e.g., Cooper & Wang, 2012; Gottfried, 2007; Lee & Hung, 2008; Li & DeKeyser, 2017). Importantly, in these studies, tones in the L2 were still considered as part of linguistic knowledge, and they could potentially be fully acquired by L2 learners as part of their linguistic knowledge. However, Berthelsen, Horne, Shtyrov, and Roll (2020) provided ERP evidence that indicate that L2 tonal information is processed in the right hemisphere instead of the left hemisphere of the brain where linguistic knowledge is represented and processed. This finding suggests that tones in the L2 might not be represented/processed as part of linguistic knowledge. Therefore, it is important to ask whether L2 learners can represent and/or process tones in their L2 in a similar manner as native speakers. According to some researchers in second language acquisition, if a linguistic feature has been acquired implicitly, it should be processed automatically (e.g., Hulstijn, 1990; Jiang, 2004; McLeod & McLaughlin, 1986; Schmidt, 1992).

With these issues in mind, the current dissertation aims to answer the following primary research questions:

(1) Whether L2 learners of Chinese can automatically process tonal information in a similar manner as native speakers during visual word recognition, and

(2) Whether the involvement of the production system will provide different influences on the processing of tonal information in L1 and L2 visual word recognition.

Chinese provides a great testing ground for looking into how phonological information, especially tonal information, is processed during visual recognition. This is because Chinese has a very unique writing system -- a logographic writing system. In a logographic writing system, no phonological information is represented in writing. Hence, even as important as Chinese tones are, they are not visually represented in Chinese writing. The uniqueness of the Chinese writing system has provoked lots of studies to test whether phonological information is processed during visual word recognition in native speakers. Investigating the processing of phonological information allows us to have a better understanding of how phonological information is accessed in reading when phonological information is not required (e.g., Perfetti & Zhang, 1991; Tan, Hoosain, & Peng, 1995; Tan & Perfetti, 1998; Tan & Perfetti, 1999; Zhou & Marslen-Wilson, 2000). In other words, the studies on phonological processing in Chinese visual word recognition contributed to a better understanding of how phonological information is represented and/or accessed during visual word recognition in general (see e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001 for the Dual-Route Cascaded Model for visual word recognition). Since there is enough evidence supporting that tonal information is processed in L1 visual word recognition (see e.g., Li et al., 2013; Spinks, Liu, Perfetti, & Tan, 2000; Wang, Li, & Lin, 2015; Winskel & Perea, 2014; Winskel, Ratitamkul, and Charoensit, 2017), expanding this line of research into exploring whether tonal information is processed in L2 visual word recognition will allow us to have a deeper understanding on (1) how phonological information is represented and/or processed in L2, and (2) the similarities and/or differences in how phonological information is represented and/or processed in L1 and L2. In addition, with little work that has been done in L2 visual word recognition, this dissertation can serve as a starting point for future studies.

Chapter Outlines

Following Chapter 1, Chapter 2 reports findings from two experiments examining whether L2 learners can automatically process the tonal information in a similar manner as native speakers in a naming Stroop task. In this experiment, participants were asked to name the ink color of Chinese characters. The results revealed that L2 learners can automatically process segmental information but not tonal information while native speakers can process both segmental information and tonal information. The results are interpreted to suggest that tonal information might not be represented and/or processed in a similar manner in L2 learners compared to native speakers. Note that, even though phonological processing of the visual stimuli was not required in the naming Stroop task, such processing could potentially be influenced by the involvement of the production mechanism for naming the ink color. That is, native speakers might not use tonal information during visual word recognition either when no naming is required, which suggests that tonal information can be processed similarly in L1 and L2. In order to strengthen the conclusion that L2 learners of Chinese may not be able to process tonal information in a similar manner as native speakers during visual word recognition, this question was examined again, in silent reading in the next Chapter.

Chapter 3, therefore, reported two additional experiments testing speakers from the same population of participants, but using a different task, a button-pushing Stroop task (i.e., silent reading). Participants were asked to decide the ink color of Chinese characters by pressing buttons. Similar results were found as in Chapter 2 in terms of tonal processing in L1 and L2. The results showed that L2 learners can only process tonal information when it was presented along with the segmental information. However, native speakers were still able to process the tonal information independently from segmental information during silent visual word recognition. These findings are interpreted as additional evidence for the differences in tonal processing during visual word recognition in L1 and L2.

Chapter 4 provides a brief general discussion of the results obtained in Chapter 2 and Chapter 3, in which I discuss the differences in how phonological information, especially tonal information, is represented and accessed in L1 and L2.

Before proceeding to the following chapters, I would like to clarify that the current dissertation tested the processing of Chinese tones in general in L2 learners. That is, the experiments in the current dissertation were not designed to test the processing of a specific type of tone e.g., Tone 1. Even though there are some discussions on which tone(s) might be more difficult for L2 learners to acquire than others among the four lexical tones in Chinese (e.g., see Shen, 1989, in production; see Hao, 2012; Kiriloff, 1969; Lee, Tao, & Bond, 2013; Pelzl, Lau, Guo, & DeKeyser, 2019; So, 2006; So & Best, 2010, 2014; Yang, 2012, in perception), there are no extant theories that predict how different types of tones might be processed differently during visual word recognition. Hence, this dissertation assumes that different types of tones are processed in the same way in both native speakers and L2 learners. To this end, this dissertation might also serve as a starting point for future studies that look into the similarities and/or differences in processing of different types of tones during visual word recognition.

Chapter 2: Tonal Processing in L2 Chinese Learners in a Naming Stroop Task

Tones in Mandarin Chinese are known to be difficult for learners who are acquiring this language as a second language (L2). Even though studies have shown that L2 Chinese learners can quickly gain explicit knowledge of Chinese tones with short-term formal instruction (e.g., Wang, Spence, Jongman, & Sereno, 1999a, 1999b; Wang, Potter, & Saffran, 2020), it still remains a question as to whether tones can become implicit knowledge in L2 Chinese learners. One way of testing whether implicit knowledge of an L2 linguistic feature has been developed is to use automaticity as an indicator (e.g., Hulstijn, 1990; Jiang, 2004; McLeod & McLaughlin, 1986; Schmidt, 1992). Specifically, it is assumed that if a linguistic feature has been acquired implicitly, it should be processed automatically. This study specifically explores whether L2 Chinese learners can automatically process phonological information, especially tonal information, during visual word recognition in a similar way as native Chinese speakers.

There are several reasons as to why it is interesting and important to investigate how tonal information is processed in L2 Chinese visual word recognition. To begin, tones serve as an integral part of Chinese phonology. Tones, as suprasegmental information, are used to distinguish Chinese words that share segmental information. For example, “ma” is a segmental combination that can be used to refer to different Chinese words depending on the associated lexical tones: (i) “mother” 妈, mā, with tone 1; (ii) “hemp” , má, with tone 2; (iii) “horse” 马, mǎ, with tone 3; and (iv) “to scold” 骂, mà, with tone 4. The combination of Roman alphabet representing segmental information in Chinese and the diacritics representing tones make up the Pinyin system. The Pinyin system only serves to represent the pronunciation of Chinese words, and it is not considered as a writing system of Chinese. In fact, Chinese uses a logographic writing system. Chinese characters are used in writing, and they do not reveal any phonological information visually, tone, or segments, such as 妈 “mother”. Given this, researchers have pointed out that the Chinese writing system offers a unique testing ground for the role of phonology during visual word recognition (e.g., Perfetti & Zhang, 1991; Tan, Hoosain, & Peng, 1995; Tan & Perfetti, 1998; Tan & Perfetti, 1999). Thus, it is of interest to explore whether the covert phonological information can be automatically computed during visual word recognition of Chinese words by L2 Chinese learners.

Previous literature testing native speakers has provided a basis for comparison as to how L2 learners might compute phonological information, especially tonal information, in their L2. There has been plenty of evidence showing that phonological information in general (e.g., Perfetti & Zhang, 1991; Tan et al., 1995; Tan & Perfetti, 1998; Tan & Perfetti, 1999), and tonal information in particular (Li, Lin, Wang, & Jiang., 2013; Spinks, Liu, Perfetti, & Tan, 2000; Wang, Li, & Lin, 2015; Winskel & Perea, 2014; Winskel, Ratitamkul, and Charoensit, 2017), can be automatically computed during visual word recognition in native speakers of tonal languages. One controversy surrounding the topic is that there are mixed results as to whether tonal information can be computed independently of segmental information (Li et al., 2013; Winskel & Perea, 2014; Winskel et al., 2017). Li et al. (2013) tested Chinese characters using a naming Stroop task and found that tones can be automatically computed independent of segmental units; but Winskel and Perea (2014) and Winskel et al. (2017) reported that native speakers of Thai (a tonal language) cannot process tonal information independently using the masked priming paradigm and Stroop paradigm respectively. What is critical to this current study, however, is that these studies found that tones are automatically processed in native speakers during visual word recognition.

As far as the processing of tones in L2 Chinese visual word recognition is concerned, there has been only one study to date, presumably, that specifically investigated whether tonal information is computed during visual word recognition in L2 learners (Li, Wang, Davis, & Guan, 2019). It is important to note that there are many studies that have addressed the role of tones in L2 speakers in other areas of language processing than visual word recognition (for auditory perception, see e.g., Hao, 2012; Pelzl, Lau, Guo, & DeKeyser, 2019; and for production, see e.g., Hao, 2012; Wang et al., 2015). Li et al. (2019), in particular, conducted a homophone judgement task, in which participants were asked to decide whether the two stimuli presented on the computer screen share the same segmental and tonal information. The stimuli were either two Hanzi characters (e.g., "市 时") or a Pinyin and a Hanzi character (e.g., "shì 时"). Each target word (e.g., 市, shì, "city") was paired with one of the four phonological variations of the target character, which included: (1) a full homophone with exactly the same segmental and tonal information (S+T+, 事, shì, "problem / issue"); (2) a character sharing only segmental information (S+T-, 时, shí, "time"); (3) a character sharing only tonal information (S-T+, 掉, dìao, "drop"); or (4) a control character with different segmental and tonal information (S-T-, 本, běn, "source"). Critical analyses were based on "NO" responses since any processing of segmental and/or tonal information would lead to interference effects. They found that both native speaker and L2 learner participants showed difficulties when the two stimuli had segmental overlap. This suggests that, like native speakers, L2 learners can process the segmental information whether or not the tonal information was shared between the two characters. However, the interference effect from the S-T+ condition, which tested the independent role of tones, was only found in native speakers but not for L2 learners, which suggests that, unlike native speakers, L2 learners seemed to not process the tonal information without the segmental information. Similar results were found in their second experiment even though presenting one of the two stimuli in Pinyin significantly reduced the interference effect from the S+T- condition in the L2 learners. Based on these findings, Li et al. (2019) concluded that L2 learners do not represent and access tones in a comparable manner as native speakers.

It is important to note, however, that the homophone judgement task used in Li et al. (2019) might not have been sufficient enough to reveal whether phonological information is implicitly represented and automatically accessed in L2 Chinese for the following reasons. First, the homophone judgement task in Li et al. (2019) requires metalinguistic knowledge to complete the task. Participants might not know what homophones are. Indeed, Li et al. (2019) reported that participants needed to be trained to be able to judge whether the two Chinese words share both segmental and tonal information before they proceeded to the formal experiment. Secondly, the processing of phonological information in Li et al. (2019) could be due to conscious and strategic processing. That is, even though the L2 Chinese learners were able to process both segmental and tonal information automatically, the metalinguistic nature of the task might have somehow made them rely only on segmental information when making decisions. In fact, Taft and Chen (1992) have reported anecdotal evidence suggesting that even native Chinese speakers rely on segmental information when deciding what makes up homophones. This was the case even though tasks that tap into automatic processing indicate that native Chinese speakers are capable of computing tonal information (as in e.g., Li et al., 2013). Thus, L2 Chinese learners may have been confused when they were asked to complete the homophone judgement task in Li et al. (2019). Given these reasons, a better task is necessary to explore the question as to whether L2 learners can automatically process phonological information in a similar manner to native speakers.

In the present study, a modified Stroop task was used several reasons. First, the Stroop task is known for tapping into automatic and implicit processing of the stimuli (Stroop, 1935). In a Stroop task, participants are asked to name the ink color of the stimuli that are presented visually. Hence, the task requires neither mandatory processing of the lexical information of the stimuli nor metalinguistic knowledge. In this study, all the stimuli were presented in Chinese characters. As in any other Stroop task, it was not necessary to process these Chinese characters in order to perform the task. For example, participants are tasked with naming the ink color of the Chinese character "马" in black ink, and this can even be done by those who do not know this character as long as they know their color names in Chinese. Secondly, the Stroop task has been employed to test phonological processing in visual word recognition (see e.g., Coltheart, Woollams, Kinoshita, & Perry, 1999; Han & Verdonschot, 2019; Li et al., 2013; Spinks et al., 2000; Verdonschot & Kinoshita, 2018; Winskel et al., 2017). Thirdly, this modified Stroop task has been used to test automatic phonological processing in Chinese (e.g., Li et al., 2013; Spinks et al., 2000), and therefore it would make the findings of this study more comparable to other studies in the literature. In fact, this specific task was used in a study that found that native Chinese speakers can automatically process phonological information, including tonal information, during visual word recognition (Li et al., 2013; see also Spinks et al., 2000). Li et al. (2013), for instance, used this modified Stroop task to test whether there is facilitation depending on the Chinese characters used. In their study, six types of Chinese character stimuli were presented: (1) congruent color characters (CCC; 红, hóng, "red" in red ink); (2) incongruent color characters (ICC; 红, hóng, "red" in blue ink); (3) homophones of the color characters (S+T+; 洪, hóng, "flood" in red ink); (4) different-tone homophones of color characters (S+T-; 轰, hōng,"bake" in red ink); (5) characters that shared the same tone but differed in segments with the color characters (S-T+; 瓶, píng, “bottle” in red ink); and (6) neutral characters (S-T-; 牵, qiān, “leading through” in red ink). Significant facilitation effects were found in S+T+, S+T-, as well as S-T+ conditions, suggesting that both segmental and tonal information are activated during visual word recognition. What was interesting, however, was that there was a significant difference between S+T- and S-T+ conditions, but not between S+T+ and S+T- conditions. This latter set of findings suggests that even though tonal information is computed, it might play a secondary role, while segmental information has a primary function.

This study, therefore, reports findings from two experiments using the modified Stroop task to examine whether L2 learners of Chinese can automatically process phonological information (Experiment 2) in a similar way compared to native Chinese speakers (Experiment 1). The experimental procedure was the same as Li et al. (2013). Experiment 1 was conducted to confirm the findings in Li et al. (2013).

Experiment 1: Modified replication of Li, Lin, Wang, Jiang (2013)

The first step was to establish the reliability of Li et al.’s (2013) original results. To this end, native speakers of Chinese were tested to explore whether they can automatically process segmental and tonal information during visual word recognition in their L1.

Method

Participants.

Eighteen native Chinese speakers participated in Experiment 1 voluntarily. All of these participants reported that they have normal vision and hearing and do not have any known language or learning disabilities. Most importantly, none of these participants reported having deficiencies in identifying color. Fifteen of these participants were affiliated with the Shanghai University of Finance and Economics (SUFE) in Shanghai, China, and the other three participants were affiliated with the University of Texas at Arlington (UTA), USA. The number of participants in this study was the same as in Li et al. (2013).

Materials and design.

The experimental items consisted of 20 Chinese monomorphemic characters, which are listed in Table 2.1. Half of the experimental characters were directly taken from Li et al. (2013), while the other half were replaced by characters with similar frequency to accommodate the L2 learners in Experiment 2. Note that all the ink colors and their characters remained the same as in Li et al. (2013). The replaced items were selected based on the following criteria. First, all the characters appear in a very common textbook for beginner learners of L2 Chinese, at least in the US (Liu, Yao, Bi, Ge, & Shi, 2008). Secondly, an experienced Chinese instructor at a university in the US confirmed that most learners should have explicit phonological knowledge of these stimuli as long as they have taken two semesters of beginner level Chinese. Thirdly, the newly selected Chinese characters were approximately matched in terms of frequency and number of strokes to the color characters. The frequency of each newly included Chinese character was checked using the Modern Chinese Character Frequency List (Da, 2004).

The design of the experiment followed Li et al. (2013). One change that was made was to not include any filler characters. This was to make sure that it was less likely for the L2 Chinese learners to encounter unknown characters in the subsequent experiment. In sum, the 20 critical items were used to create six types of stimuli: (1) congruent color characters (CCC; 红, hóng, “red” in red ink); (2) incongruent color characters (ICC; 红, hóng, “red” in blue ink); (3)

homophones of the color characters (S+T+; 洪, hóng, “flood” in red ink); (4) different-tone homophones of color characters (S+T-; 烘, hōng,”bake” in red ink); (5) characters that shared the same tone but differed in segments with the color characters (S-T+; 瓶, píng, “bottle” in red ink); and (6) neutral characters (S-T-; 牵, qiān1, “leading through” in red ink). All participants were tested on the same list.

Table 2.1. Stimuli used in Experiments 1 and 2.

Condition	Color characters	S+T+	S+T-	S-T+	S-T-
	红	洪	烘	瓶	爸
Pronunciation	hóng	hóng	hōng	píng	bà
Frequency	75	93	99	95	89
Number of strokes	6	9	10	10	8
Translation	red	flood	bake	bottle	father
	黄	皇	谎	谁	星
Pronunciation	huáng	huáng	huǎng	shéi	xīng
Frequency	78	84	97	81	77
Number of strokes	11	9	11	10	9
Translation	yellow	emperor	lies	who	star
	蓝	拦	览	尝	歌
Pronunciation	lán	lán	lǎn	cháng	gē
Frequency	91	97	96	95	89
Number of strokes	13	8	9	9	13
Translation	blue	stop	view	taste	song
	绿	律	旅	妹	雪
Pronunciation	lǜ	lǜ	lǚ	mèi	xuě
Frequency	90	76	88	91	89
Number of strokes	11	9	10	8	11
Translation	green	law	travel	younger sister	snow

Procedure

The experiment was conducted using the DMDX software (Forster & Forster, 2003). The participants were asked to fill out a language background questionnaire before proceeding to the formal experiment. Both the questionnaire and the experiment were completed in Chinese. The participants were asked to name the ink color of each Chinese character as quickly and as accurately as possible. For each trial, a fixation mark "+" appeared in the center of the screen for 500 ms followed by the target character. The target character was replaced by the following trial after a naming response was made or after 3000 ms when there was no response. There was a 1000 ms interval between trials. The trials were pseudorandomized such that participants did not see the same color or character consecutively. All the experimental stimuli were presented three times. However, the stimuli in the ICC condition were presented in different colors. In addition to the critical stimuli, eight practice trials were given at the beginning of the formal experiment. All stimuli were presented in bold Simsun 48-point font. The whole experiment was conducted using black background such that the ink colors of the experimental characters were salient, and the experimental instruction was presented using ink color of white.

Results

The response times (RTs) and error rates (ERs) were first marked manually in CheckVocal (Protopapas, 2007). No participants' ERs were higher than 20%. Thus, all participants were included in the following analyses. Outliers were modified to two standard deviations above or below each participant's mean. By-participant ANOVAs were conducted on mean RTs and mean ERs separately as dependent variables using RStudio (RStudio Team, 2015), which is based on R (R Core Team, 2013). ANOVA analyses were conducted only on the correct responses. Descriptive statistics for RTs and ERs are presented in Table 2.2.

Table 2.2. Mean reaction times (RTs) in milliseconds, error rates (ERs) in percentages, and Stroop effects (Stroop) for each condition in native speakers and L2 learners of Chinese with standard deviation of the mean in parentheses.

	Native Chinese speakers			L2 Chinese learners		
Condition	RT	ER	Stroop	RT	ER	Stroop
CCC	683 (128)	0.9 (2.7)	96***	658 (90)	4.3 (8.8)	114***
S+T+	643 (97)	0.5 (2.0)	136***	678 (112)	2.8 (5.2)	94***
S+T-	685 (109)	0.5 (2.0)	94***	694 (104)	1.9 (4.2)	78***
S-T+	717 (113)	1.4 (3.2)	62***	779 (126)	3.1 (4.7)	-7
ICC	916 (216)	12.5 (17.4)	-137***	894 (157)	15.4 (13.6)	-122***
S-T-	779 (114)	2.8 (6.4)		772 (122)	4.3 (6.7)	

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

RT analyses showed that there was a significant main effect of condition, $F(5, 85) = 36.67$, $p < .001$, $\eta_p^2 = .68$. Planned pairwise comparisons were first conducted between each experimental condition (CCC, S+T+, S+T-, S-T+, and ICC) and the neutral one (S-T-). Significant facilitation was found for four of the five conditions -- specifically, the congruent color characters (CCC) condition, $F(1, 17) = 28.12$, $p < .001$, $\eta_p^2 = .62$; the S+T+ condition, $F(1, 17) = 58.41$, $p < .001$, $\eta_p^2 = .77$; the S+T- condition, $F(1, 17) = 32.92$, $p < .001$, $\eta_p^2 = .66$; and the S-T+ condition, $F(1, 17) = 21.64$, $p < .001$, $\eta_p^2 = .56$. As expected, a significant inhibition was found for the condition of incongruent color characters (ICC), $F(1, 17) = 24.55$, $p < .001$, $\eta_p^2 = .59$, compared to the S-T- condition. Pairwise comparisons were further conducted between each of the experimental conditions to see whether facilitatory effects could be found between these experimental conditions. These comparisons revealed that the S+T+ condition was responded to significantly faster than the S+T- condition, $F(1, 17) = 22.87$, $p < .001$, $\eta_p^2 = .57$.

Similarly, the S+T+ condition was also responded to significantly faster than the S-T+ condition, $F(1, 17) = 27.45$, $p < .001$, $\eta_p^2 = .62$. The difference between S+T- and S-T+ conditions was also significant, $F(1, 17) = 8.50$, $p < .01$, $\eta_p^2 = .33$. The results thus replicate Li et al. (2013) findings in that both segmental and tonal information can be automatically processed by native Chinese speakers during visual word recognition, and that segmental information seems to have a more primary role than tonal information.

The ERs across all conditions were low except for the ICC condition with a relatively high error rate of 12.5%. ER analyses yielded a significant main effect of condition, $F(5, 85) = 7.60$, $p < .001$, $\eta_p^2 = .31$. Same set of planned comparisons as the RT analyses were conducted on ER data. The only significant difference found was between the ICC and the S-T- conditions, $F(1, 17) = 8.96$, $p < .01$, $\eta_p^2 = .35$.

Discussion

Experiment 1 clearly showed that native speakers of Chinese can automatically process both segmental and tonal (suprasegmental) information. In addition, the processing of tonal information does not require the computation of segmental information in order to show a facilitatory effect. Given that, the findings in Li et al. (2013) were confirmed that native speakers of Chinese do not have any difficulty in automatically processing tonal information and segmental information during visual word recognition of Chinese characters. This provides us with a reliable baseline for testing the processing of phonological information in L2 learners.

Using the exact same experimental design and procedure, Experiment 2 tested advanced L2 Chinese learners to explore whether phonological information, especially tonal information, can be automatically processed in a similar way.

Experiment 2: Tonal Processing in L2 Learners

This experiment aimed to examine whether advanced L2 Chinese learners can automatically process phonological information in a similar way compared to the native speakers of Chinese during visual word recognition.

Method

Participants.

A total of 34 L2 Chinese learners participated in the experiment voluntarily. All participants were asked to complete the same experiment with exactly the same procedure. They all passed the Level V of the HSK test or above with the exception of one participant who just passed the Level IV of this test. Note that this participant had a high score on their Level IV test -- i.e., 273 out of 300. Thus, I decided to include this participant in the analysis. HSK, Hanyu Shuiping Kaoshi, is a standardized Chinese language proficiency measure administered by an agency of the central Chinese government. There are six levels of HSK (levels I - VI), in which Levels I and II represent low proficiency, Levels III and IV represent intermediate proficiency, and Levels V and VI represent high proficiency. The language learning backgrounds of these L2 Chinese learner participants are presented in Table 3.3. As in Experiment 1, all participants reported to have normal vision (with no deficiency in color identification) and hearing, and had no known language or learning disabilities. They were all affiliated with SUFE.

Table 2.3. Language learning information of L2 Chinese learners with different L1 tonal status in Experiment 2.

	Atonal L1 participants		Tonal L1 participants	
	Mean (SD)	Range	Mean (SD)	Range
Age of onset (year old)	18.13 (2.06)[a]	13-21[a]	14.35 (3.00)[b]	8-18[b]
Total years of learning (year)	3.04 (1.35)	1-7	4.59 (0.87)	3-6
Length of residence (year)	2.85 (1.62)[a]	0.5-7[a]	2.77 (1.16)	1-5
Self-rated proficiency (1-10, 10 as most proficient)	7.38 (0.83)	5.75-8.75	7.07 (0.37)	6.5-7.75
Listening	7.78 (0.85)	6-9	7.82 (0.39)	7-8
Speaking	7.53 (1.05)	6-10	7.45 (0.66)	7-9
Reading	7.16 (1.25)	5-10	6.64 (0.77)	5-8
Writing	7.03 (1.43)	5-9.5	6.36 (0.98)	5-8
HSK level (I-VI)	5.06 (0.43)	4-6	5.36 (0.48)	5-6

Note. [a] One participant failed to fill out age of onset and length of residence, so the mean, standard deviation, and range is from n = 15 in atonal L1 participants.

[b] One participant failed to fill out age of onset, so the mean, standard deviation, and range is from n = 10 in atonal L1 participants.

Materials and design.

The materials and design of Experiment 2 are the same as Experiment 1 with only one exception. That is, additional questions were included in the language background questionnaire which were related to the Chinese-learning experience of those L2 Chinese learners such as the age of acquisition (AoA), length of residence (LoR) in China, and self-rated L2 Chinese proficiency.

Procedure

The procedure is the same as in Experiment 1.

Results

Data trimming procedure, as well as the by-participant ANOVAs that were conducted, were the same as Experiment 1. Seven participants were excluded because their error rates were higher than 20%. Thus, data from 27 participants were included in the analyses. Descriptive statistics are presented in Table 2.2.

The RT analysis showed that there was a significant main effect of condition, $F(5,130) = 80.14$, $p < .001$, $\eta_p^2 = .76$. Planned comparisons, similar to the native speaker analyses, were conducted. Significant facilitation was found for three of the five conditions -- specifically, in the congruent color characters (CCC) condition, $F(1, 26) = 52.34$, $p < .001$, $\eta_p^2 = .67$; the S+T+ condition, $F(1, 26) = 42.49$, $p < .001$, $\eta_p^2 = .62$; and the S+T- condition, $F(1, 26) = 34.31$, $p < .001$, $\eta_p^2 = .57$. Interestingly, however, the S-T+ condition, which only shared tonal information with the ink color, did not facilitate naming, $F < 1$. As expected, significant inhibition was found for the incongruent color characters (ICC) condition, $F(1, 26) = 59.47$, $p < .001$, $\eta_p^2 = .70$, when compared to the S-T- condition. Pairwise comparisons were further conducted between each of the experimental conditions to see how facilitatory these experimental conditions were. These comparisons revealed that the S+T+ condition was responded to significantly faster than the S-T+ condition, $F(1, 26) = 87.79$, $p < .001$, $\eta_p^2 = .77$. Similarly, the S+T- condition was responded to significantly faster than the S-T+ condition, $F(1, 26) = 51.19$, $p < .001$, $\eta_p^2 = .66$, indicating the importance of segmental information. Critically, the S+T+ condition was not responded to faster than the S+T- condition, $F(1, 26) = 2.65$, $p = .116$, indicating that tonal information is not automatically computed in L2 Chinese learners.

The ERs across all conditions were again low, except for the incongruent color characters (ICC with a higher error rate of 15.4%. ANOVAs conducted on the ERs revealed a significant main effect of condition, $F(5, 130) = 14.37$, $p < .001$, $\eta_p^2 = .36$. The same set of planned comparisons as the RT analyses were conducted on ER data. The only significant difference found was between the ICC condition and the S-T- condition, $F(1, 26) = 19.50$, $p < .001$, $\eta_p^2 = .43$.

Discussion

The results in Experiment 2 indicate that only segmental information can be automatically processed in L2 Chinese learners. As Li et al. (2019) revealed in their homophone judgment task, our study also demonstrates that tonal information does not seem to be computed even in a task that taps into the automatic processing in these L2 Chinese learners. Specifically, the S+T+ condition yielded faster response times than the S-T+ condition; the S+T- condition also was responded to faster than the S-T+ condition; and crucially, there was no response time differences between the S+T+ condition and the S+T- condition in L2 Chinese learners, all indicating that tonal information did not facilitate color naming times for these L2 learners.

The lack of L2 learner computing tonal information from this experiment may be due to the treatment of all L2 learners as a homogenous group. Specifically, some Chinese learners might have an L1 with a tone system while others might not. Previous studies demonstrated three views on how L1 tonal status might influence the identification of L2 tones -- (1) positive influence (e.g., Lee, Vakoch, & Wurm, 1996; Wayland & Guion, 2004); (2) negative influence (e.g., Wang, 2006); or (3) no effect (e.g., Hao, 2012; So, 2006). Note that Hao (2012) directly compared two groups of L2 Chinese learners with tonal and atonal L1s. It was found that

Cantonese-Mandarin and English-Mandarin bilinguals behaved similarly in auditory identification, mimicry, and reading aloud tones in L2 Chinese, which suggest that L1 tonal status does not influence L2 tonal identification. However, it is important to note that, in studies like Hao (2012), all explored the identification of L2 tones in either production and/or perception. Therefore, it is not verified whether L1 tonal status influences L2 tonal activation during visual word recognition. As such, the L2 learners were divided in the current study into two groups -- one with tonal L1s and the other with atonal L1s. Among the 27 L2 Chinese learners in the second experiment, 17 participants' L1s did not have tones (e.g., English, French, or Korean), while 11 participants' L1s did have tones (e.g., Thai, Vietnamese, or Lao). A post-hoc analysis with all conditions revealed that there was no significant difference between atonal L1 and tonal L1 participants in terms of RTs, $F(5, 125) = 1.19$, $p = .32$. The results suggest that the tonal status of L1s seems not to influence the processing of tonal information in L2 during visual word recognition. Therefore, the current finding reveals that L1 tonal status has little effect on L2 tonal processing during visual word recognition.

General Discussion

The results of this study in Chapter 2 demonstrate that L2 Chinese learners can only automatically process segmental information but not the tonal information regardless of whether their L1s have tones or not. This is in stark contrast with the native Chinese speaker results, in which both segmental and tonal information are not only automatically processed together but also independently of one another. In other words, computation of segmental information does not seem to precede computation of tonal information, nor does it seem as though segmental information is used primarily over tonal information in native speakers.

Before proceeding to the discussion on the reasons as to why tones cannot automatically be processed in L2 learners, it is important to ask whether the L2 Chinese learners in this study actually had at least some kind of explicit knowledge of how to read aloud the experimental characters. That is to say, it is possible that L2 learners did not show evidence for processing L2 tones automatically because they did not know how to pronounce the stimuli presented in this study in the first place. Unfortunately, I did not collect data on their explicit knowledge of these stimuli. However, it is extremely unlikely that this is the case as to why they failed to show automatic processing of tones. First, recall that these L2 Chinese learner participants showed evidence of computing segmental information of these stimuli. That is, there was facilitation in the S+T- condition, which suggests that they were at least somewhat familiar to the pronunciation of the stimuli. Secondly, during the selection of items, several criteria were used (such as selecting items from beginner-level textbook, checking the items with an experienced instructor, as well as selecting items that were frequency-matched to the color items) to make sure that these participants have explicitly knowledge of the tonal information of these stimuli. Given that the L2 Chinese learner participants in this study named the ink colors correctly for the most part both in terms of segments and tones, it is safe to assume that the participants have been able to name the non-color stimuli as well because the frequency of these items were comparable to the color characters. Thirdly, a post-hoc analysis confirmed that 17 out of 20 stimuli appeared repeatedly in the vocabulary lists for Levels I to V of the HSK test. For the other three stimuli, two characters (洪, hóng, "flood"; 烘, hōng, "bake") appeared in the vocabulary of Level VI of the HSK test, and only one stimulus (瓶, píng, "bottle") could not be found in the vocabulary list of any of the HSK tests. Given that all but one of the participants have successfully passed at least the level V of the HSK test, as well as the fact that they all have lived in China, it is extremely unlikely for them not to have explicit phonological knowledge of the stimuli. Therefore, it probably is safe to assume that the lack of explicit phonological knowledge of the stimuli used in this study was not the reason why these L2 Chinese learner participants failed to show evidence for automatic processing of L2 tones.

If it is assumed that the L2 Chinese learner participants have explicit phonological knowledge of the Chinese character stimuli, it is then important to consider why L2 learners cannot automatically process tonal information in the same manner as native speakers. With this, proficiency level of these L2 Chinese learners comes to mind. It is possible that their proficiency was just not high enough. Recall, however, that in order for one to pass level V of the HSK test, one must be highly-proficient in L2 Chinese. Note also that all but one of the participants have passed this level. This proficiency level of the participants matched with those in Li et al. (2019). What is interesting is that neither Li et al. (2019) participants in their explicit homophone judgment task or the participants in the implicit Stroop task were able to process tones of the Hanzi characters. This seems to suggest that, even for L2 learners who have relatively high proficiency in their L2 Chinese, it is difficult to use tonal information in a similar way as native Chinese speakers during visual word recognition.

Why is it the case that using tonal information is difficult for these highly-proficient L2 Chinese learners? First, how segmental and tonal information are represented and processed in native Chinese speakers should be considered. Taft and Chen (1992) argue that there are separate implicit representations for segmental and tonal information for native Chinese speakers (for a similar argument, see also Li et al., 2013). Taft and Chen (1992) further maintain that segmental and tonal information only gets integrated with one another when a Chinese character needs to be vocalized, otherwise these pieces of information remain separate. Indeed, Chapter 2 showed that native speakers not only were able to process both segmental and tonal information automatically, they also seem to be able to compute these pieces of information separately. That is, both S+T- and S-T+ conditions showed facilitation. Such findings may have been obtained because the modified Stroop task used in this study does not require the vocalization of the visual stimuli themselves. As such, it was possible for both segmental and tonal information to facilitate the naming of ink colors separately.

There are two possible reasons as to why highly-proficient L2 Chinese learners were not able to use tonal information. There may have been a deficit in the way tonal information is represented, and/or how this information is accessed (for similar representation/processing contrast in morphological processing, see Jiang, 2004). First, it could be the case that these L2 learners have not developed a sufficient representational system for L2 Chinese tones. Although it seems like these L2 Chinese learners have developed a rich representational system for segmental information, that does not seem to be the case for tonal information. This is in line with Li et al. (2019) who argued that tonal information is more poorly represented in non-native Chinese speakers compared to native speakers of Chinese.

Alternatively, it may be the case that these L2 Chinese learners have not developed a processing system that allows for both segmental and tonal information to be used automatically. Indeed, it seems like these L2 learners are selectively relying on segmental information, such that both S+T+ and S+T- conditions yield similar facilitation. In fact, if it is assumed that some kind of explicit representations exist in these L2 Chinese learners, the problem might not be due to the representational system but the processing system that cannot access such information in a reliable manner.

Taking one step further, there might be a reason why these L2 Chinese learners do not access tonal information during visual word recognition. Unlike native Chinese speakers, who presumably acquired the spoken form of the word prior to the visual form, and thus all they had to do was associating phonological information to the written form of the word, L2 Chinese learners most likely learned both the visual and spoken word forms simultaneously. Somehow, during that learning process, they might have acquired the Chinese language such that they do not activate the entirety of the phonological information during visual word recognition. As mentioned, the Chinese character system is logographic, and hence, the individual characters do not represent any phonological information. Because of this, the more efficient way of processing visually-presented Chinese words for many L2 Chinese learners is to not activate all phonological information but directly access their meanings. That is, it might be more economical to only partially activate phonological information during visual word recognition.

The final question relates to how phonological information is acquired in L2 Chinese. In fact, there might be two stages of acquiring phonological knowledge in L2 Chinese. In the first stage, explicit knowledge is learned and some kind of representations are formed for both segmental and suprasegmental information (e.g., tonal information). This can account for why a brief training can contribute to the improvement of the perception and production of Chinese tones in L2 (Wang et al., 1999a, 1999b). During the second stage, the representations of segmental information are integrated into the mental lexicon as part of the implicit lexical knowledge of new L2 Chinese words. However, the implicit representations for tones might be underdeveloped relative to how richly segmental information is developed. This study revealed that tonal information is not fully developed even in highly-proficient L2 Chinese learners.

Chapter 3: Tonal Processing in L2 Chinese Learners in a Button-pushing Stroop Task

Many studies have investigated whether tonal information is processed during visual word recognition in native speakers (Li, Lin, Wang, & Jiang., 2013; Spinks, Liu, Perfetti, & Tan, 2000; Wang, Li, & Lin, 2015; Winskel & Perea, 2014; Winskel, Ratitamkul, & Charoensit, 2017). There has been only one published study so far (to the best of my knowledge) that specifically investigated whether tonal information is computed during visual word recognition in L2 learners (Li, Wang, Davis, & Guan, 2019). However, Li et al. (2019) tested native speakers and second language (L2) learners of Chinese using a task that may not have sufficiently revealed the automatic processing of tonal information in L2. Automaticity is critical because only the automatic usage of a linguistic feature indicates that it has been integrated into the mental lexicon implicitly (e.g., Hulstijn, 1990; Jiang, 2004; McLeod & McLaughlin, 1986; Schmidt, 1992). Thus, following Li et al. (2019), Chapter 2 investigated whether L2 learners of Chinese can automatically process tonal information similarly compared to native speakers. Even though the task used in Chapter 2, a naming Stroop task, allowed for the exploration of the automatic processing of tonal information in L2, the task required the activation of phonological recoding due to the naming portion of it. This might have highlighted the use of tonal information in native speakers, which led to the findings in Chapter 2 suggesting that native speakers can process tonal information during visual word recognition but L2 learners cannot. This chapter, instead, tests whether there are differences in the processing of segmental and tonal information between native speakers and L2 learners in a task in which phonological recoding is not required. Such comparisons would clarify what part of phonological processing during visual word recognition is similar between these two participant groups. This issue is important because it will allow a better understanding of the properties of the L2 visual word recognition system as compared to the L1 visual word recognition system. Hence, the study in this chapter examines how differently highly-proficient L2 learners of Chinese use tonal information relative to native speakers in silent reading.

As mentioned, the results in Chapter 2 showed that L2 learners might not be able to automatically process the tonal information in a similar manner compared to native speakers. In Chapter 2, native speakers and L2 learners of Chinese were to complete a naming Stroop task. Specifically, participants were asked to name the ink color of some Chinese characters in Chinese. The Stroop task is accepted as a task that taps into the automatic and implicit processing of the experimental stimuli (Stroop, 1935). Although it was originally designed to tap into automatic semantic processing (e.g., Ashcraft, 1989; Rayner & Pollatsek, 1989), recently, it has been used to test automatic phonological processing (see e.g., Coltheart, Woollams, Kinoshita, & Perry, 1999; Han & Verdonschot, 2019; Li et al., 2013; Spinks et al., 2000; Verdonschot & Kinoshita, 2018; Winskel et al., 2017). Using the naming Stroop task, six conditions were tested in Chapter 2: (1) congruent color characters (CCC; 红, hóng, “red” in red ink); (2) incongruent color characters (ICC; 红, hóng, “red” in blue ink); (3) homophones of the color characters (S+T+; 洪, hóng, “flood” in red ink); (4) different-tone homophones of color characters (S+T-; 烘, hōng,”bake” in red ink); (5) characters that shared the same tone but differed in segments with the color characters (S-T+; 瓶, píng, “bottle” in red ink); and (6) neutral characters (S-T-; 牵, qiān1, “leading through” in red ink). Facilitation effects were found in the CCC, S+T+, S+T-, and S-T+ conditions compared to the control condition, the S-T- condition, in native speakers, while only the CCC, S+T+, S+T- conditions showed facilitation effects in L2 learners. The facilitation effect found in the S-T+ condition in native speakers, but not in L2 learners, was taken to suggest that L2 learners do not seem to be able to automatically process the tonal information in a similar manner compared to native Chinese speakers.

It remains unclear, however, whether the difference in tonal processing between native speakers and L2 learners of Chinese in Chapter 2 is because a component of the naming Stroop task requires some kind of phonological recoding. That is, even though, in the naming Stroop task, participants do not need to process the phonological information of the visual stimuli to complete the task, the production mechanism was still necessary for the vocalization of the ink color. The vocalization of the ink color could have potentially influenced the phonological processing of the visual stimuli in native speakers, such that their reliance on phonological information might have been more highlighted than what would normally be the case during silent reading. Indeed, Shen and Forster (1999) showed that, in native speakers, whether phonological information is processed during visual word recognition in Chinese might depend on the tasks. Specifically, Shen and Foster (1999) found that, when the task requires phonological processing (as in a naming task compared to a lexical decision task), then this encourages participants to use phonological information more so even for stimuli that do not require phonological encoding. Therefore, a different task that does not require the activation of the production mechanism should make it clear whether advanced L2 learners are that much different from native speakers during visual word recognition without production.

Note that Li et al. (2019) did adopt a task that did not involve the production system to compare the tonal processing in native speakers and L2 learners of Chinese. Specifically, Li et al. (2019) asked native speakers and L2 learners of Chinese to complete a homophone judgement task. In such a task, participants needed to decide whether the two stimuli presented on the computer screen share the same segmental and tonal information by pushing buttons on a computer keyboard. They found that L2 learners seemed not to be able to process the tonal information without the segmental information, while native speakers can process tonal information independently. Based on these findings, Li et al. (2019) formed a similar conclusion as in Chapter 2 that L2 learners do not represent and access tones in a comparable manner as the native speakers. It is important to note, however, that the homophone judgement task used in Li et al. (2019) allows strategic processing and requires metalinguistic knowledge to complete. Therefore, Li et al. (2019) struggles to reveal how tonal information might be represented and processed implicitly. Similarly, Chapter 2 could not reveal whether the difference in the implicit processing of tonal information in L1 and L2 was influenced by the naming portion of the naming Stroop task (i.e., the difference between advanced L2 learners of Chinese and native speakers might have been enhanced due to the task). So the question remains as to whether the automatic use of phonological information, especially tonal information, during silent reading in advanced L2 learners is actually that different from native speakers.

Thus, the study in this chapter was designed to follow up Chapter 2 to further examine whether the difference in the automatic usage of tonal information between native speakers and L2 learners would still be observed if no phonological recoding is required (i.e., in silent reading). Native speakers and L2 learners were tested using a task that does not require any activation of the phonological information of the experimental stimuli -- a button-pushing Stroop task. Two experiments were reported -- Experiments 3 and 4. Experiment 3 tested whether native speakers can automatically process the tonal information in silent reading by asking participants to complete the button-pushing Stroop task, which served as the control group. Experiment 4 tested whether advanced adult L2 Chinese learners can automatically process the tonal information in a similar manner compared to native speakers using the same experimental design and procedure of Experiment 3.

Experiment 3: Silent Tonal Processing in Native Chinese Speakers

Method

Participants.

A total of 10 native Chinese speakers participated in Experiment 1 voluntarily. All of these participants reported that they have normal vision and hearing, and do not have any known language or learning disabilities. None of these participants reported having deficiencies in identifying color. All participants were affiliated with Shanghai University of Finance and Economics in Shanghai, China.

Materials and design.

The experimental items consisted of 20 Chinese monomorphemic characters, which are presented in Table 3.1. Four ink colors (grey, blue, purple, green) and their characters were selected. Among the four colors, two colors (blue and green) remained the same as in Li et al. (2013) and Chapter 2. The two other ink colors and their characters (grey and purple) were selected to make sure that the four color characters included in this study represent all four common Chinese tones. Specifically, grey is tone 1(灰, hūi, “grey”); blue is tone 2 (蓝, lán, “blue”); purple is tone 3 (紫, zǐ, “purple”); and green is tone 4 (绿, lǜ, “green”). The rest of the items were selected based on the following criteria. First, the frequency of each Chinese character matched with the Chinese characters of ink colors in terms of frequency and number of strokes. The frequency was checked using the Modern Chinese Character Frequency List (Da, 2004). Secondly, all characters except one character (紫, zǐ, “purple”) were confirmed to appear in the vocabulary list of the HSK test to accommodate L2 Chinese learners in Experiment 4. The HSK test, Hanyu Shuiping Kaoshi, is a standardized Chinese language proficiency measure administered by an agency of the central Chinese government. Thirdly, an experienced Chinese instructor at a university in the US confirmed that most items are commonly used in the beginner level Chinese courses and most learners should have explicit phonological knowledge of these stimuli as long as they have taken two semesters of beginner level Chinese. These 20 items were used in the two tasks of the experiment: (1) the button-pushing Stroop task and (2) the Pinyin identification task.

The design of the current button-pushing Stroop task strictly follows Chapter 2. That is, the 20 experimental items were used to create six types of stimuli: (1) congruent color characters (CCC; 灰, hūi, “grey” in grey ink); (2) incongruent color characters (ICC; 灰, hūi, “grey” in blue ink); (3) homophones of the color characters (S+T+; 挥, hūi, “wave” in grey ink); (4) different-tone homophones of color characters (S+T-; 回, húi, “return” in grey ink); (5) characters that shared the same tone but differed in segments with the color characters (S-T+; 听, tīng, “listen” in grey ink); and (6) neutral characters (S-T-; 再, zài, “again” in grey ink).

Items in the six conditions were further assigned into six blocks based on binary color combinations out of the four colors: (1) grey and blue, (2) grey and purple, (3) grey and green, (4) blue and purple, (5) blue and green, and (6) purple and green. In each block, all items in the six conditions were repeated twice. In addition, the positions (right or left) of the two colors in each block were randomly determined. Effort was made to make sure no identical characters appeared consecutively. Hence, each item appeared six times in the button-push Stroop task.

This design was to guarantee that any type of the binary combinations of the four Chinese tones were included in the button-pushing Stroop task.

Three lists were created based on the randomized order of the six blocks in the button-pushing Stroop task. The effort was made to engage the participants as much as possible while they were completing the experiment to guarantee the validity of the findings.

For the Pinyin identification task, 20 multiple choice questions were prepared. Each question consists of one of the 20 Chinese characters as the target character and 4 options of Pinyin combinations. The four options were made by combining the four common Chinese tones with the segmental information of the target Chinese character. For example, the target character, 蓝, "blue", was assigned with "1) lān 2) lán 3) lǎn 4) làn" as the four options for choice, in which the second option "2) lán" is the correct option for the question. Even though the order of the 20 characters was randomly determined, the Pinyin identification task remained the same for all three lists.

Thus, all three lists contained the same items, but having different orders for the binary color combinations in the Stroop task. Each participant was randomly assigned to complete only one of the three lists.

Table 3.1. Stimuli used in Experiments 3 and 4.

Condition	Color char	S+T+	S+T-	S-T+	S-T-
	灰	挥	回	听	再
Pronunciation	hūi	hūi	húi	tīng	zài
Frequency	92.99	83.89	52.68	63	60
Number of strokes	6	9	6	7	6
Translation	Grey	Essential[a]	Return	Listen	Again

	蓝	拦	懒	读	狗
Pronunciation	lán	lán	lăn	dú	gǒu
Frequency	91.73	97.11	97.86	84	92.7
Number of strokes	13	8	16	10	8
Translation	Blue	Stop	Lazy	Read	Cold
	紫	子	字	写	今
Pronunciation	zǐ	zǐ	zì	xiě	jīn
Frequency	95.49	26.50	70.62	73	67
Number of strokes	12	3	6	5	4
Translation	Purple	Son	Character	Write	Today
	绿	律	旅	谢	钱
Pronunciation	lǜ	lǜ	lǚ	xiè	qián
Frequency	90.45	76.88	88.30	87	80
Number of strokes	11	9	10	12	10
Translation	Green	Law	Tourism	Thank	Money

Note. [a] This is the translation provided in the HSK vocabulary list. However, the primary meaning of this character is "wave (v.)".

Procedure

The experiment was conducted using the DMDX software (Forster & Forster, 2003). The participants were asked to fill out a language background questionnaire before proceeding to the formal experiment.

In the button-pushing Stroop task, participants were asked to identify the ink color of each Chinese character by pressing either the left or the right "Shift" button on a computer keyboard. They were instructed to identify the ink color as quickly and as accurately as possible. For each trial, a fixation mark "+" appeared in the center of the screen for 500 ms followed by the target character. The target character was replaced by the following trial after a response was made or after 3000 ms with no response. There was a 1000 ms interval between trials. As mentioned, all trials were presented six times, and they were pseudorandomized such that participants did not see the same character consecutively. Six practice trials were given at the beginning of each block. Participants were informed to take a break between blocks if needed.

Following the button-pushing Stroop task, participants were asked to complete the Pinyin identification task by pressing one of four buttons representing Arabic number 1 to 4 on a computer keyboard to indicate the correct pronunciation (Pinyin) for each of the experimental stimuli. For each trial, a target Chinese character appeared in the center of the screen along with its correct pronunciation and three distractors presented below it. For example, the color character of blue "蓝" was presented right above "1) lān 2) lán 3) lǎn 4) làn" at the center of a screen, in which participants should press the key of number two on the keyboard to indicate that "lán" is the correct answer. Each trial remained on the screen until a response was made or after 4000 ms. All 20 experimental stimuli were presented only once. Four practice trials were given at the beginning of this task. Participants were also informed to take a break if needed before they started this task.

The whole experiment was conducted using a black background such that the ink colors of the experimental characters were salient. The experimental instruction and stimuli in the Pinyin identification task were presented using a white ink color. All stimuli were presented in bold Simsun 48-point font.

Results

One participant's error rate (ERs) was higher than 20% in the Pinyin identification task. Thus, nine participants were included in the following analyses. Data was trimmed so that reaction times (RTs) longer than 1200ms were excluded from the analysis. Outliers were adjusted to 3 standard deviations (SDs) above or below each participant's mean. The criteria for RT cutoff follows Kouider and Dupoux (2004) since they used a button-pushing Stroop task as well. This trimming procedure affected approximately 11.23% of the data. All responses on the items that were responded incorrectly in the Pinyin identification task were then excluded. By-participant ANOVAs were conducted on mean RTs and mean ERs separately as dependent variables using RStudio (RStudio Team, 2015), which is based on R (R Core Team, 2013). ANOVA analyses were conducted only on the correct responses. Descriptive statistics for RTs and ERs are presented in Table 3.2.

Table 3.2. Mean reaction times (RTs) in milliseconds, error rates (ERs) in percentages, and Stroop effects (Stroop) for each condition in native and L2 Chinese learners with standard deviation of the mean in parentheses.

	Native Chinese speakers			L2 Chinese learners		
Condition	RT	ER	Stroop	RT	ER	Stroop
CCC	432 (82)	6.5 (9.6)	27*	505 (71)	15.2 (16.2)	2
S+T+	441 (90)	2.8 (3.6)	18	487 (68)	23.5 (20.2)	20*
S+T-	438 (89)	0 (0)	21	496 (66)	8.9 (11.2)	11
S-T+	433 (101)	0.9 (2.8)	26**	492 (73)	5.7 (8.6)	15
ICC	512 (135)	16.2 (12.4)	-53*	530 (76)	19.3 (13.5)	-23
S-T-	459 (99)	7.4 (13.6)		507 (74)	5.4 (7.9)	

Note. * $p < 0.05$, ** $p < 0.01$

RT analyses showed that there was a significant main effect of condition, $F(5, 40) = 11.95$, $p < .001$, $\eta_p^2 = .60$. Planned pairwise comparisons were first conducted between each experimental condition (CCC, S+T+, S+T-, S-T+, and ICC) and the neutral one (S-T-). Significant facilitation was found for two of the five conditions -- specifically, the congruent color characters (CCC) condition, $F(1, 8) = 8.04$, $p < .05$, $\eta_p^2 = .50$, and the S-T+ condition, $F(1, 8) = 16.76$, $p < .01$, $\eta_p^2 = .68$. In addition, as expected, a significant inhibition was found for the condition of incongruent color characters (ICC), $F(1, 8) = 8.48$, $p < .05$, η_p^2

= .51. There was a strong trend for significant facilitation in the S+T+ condition, $F(1, 8) = 3.47$, $p = .09$, and in the S+T- condition, $F(1, 8) = 4.87$, $p = .06$. Further pairwise comparisons did not reveal any significant differences between the other experimental conditions. The results are in accordance with the findings in Chapter 2 in that tonal information can be automatically processed by native Chinese speakers during visual word recognition even when no production mechanism is involved.

Descriptive statistics showed that the error rates across all trial conditions were low, ranging from 0 % to 7.4 %, except for the ICC condition with a relatively high error rate of 16.2%. ER analyses yielded a significant main effect of condition, $F(5, 40) = 4.15$, $p < .01$, $\eta_p^2 = .34$. The same set of planned comparisons as the RT analyses were conducted on ER data. The only significant difference found was between the S+T+ and the S+T- conditions, $F(1, 8) = 5.33$, $p < .05$, $\eta_p^2 = .40$.

Discussion

Experiment 3 clearly showed that native Chinese speakers can process the tonal information automatically, which is evidenced by the finding that there was a significant facilitation effect in the S-T+ condition. This finding is in accordance with the results in Chapter 2. However, native speakers do not seem to use the segmental and tonal information together or segmental information independently in silent reading because there are only strong trends for the facilitation Stroop effects in the S+T+ and S+T- conditions. It is important to note that such effects might be observed with more statistical power. So the current findings will be interpreted with caution.

The findings raise the following question: why might native Chinese speakers not process the segmental and tonal information together or segmental information independently in silent reading? According to Taft and Chen (1992), native Chinese speakers have separate implicit representations for segmental and tonal information, and they remain separate unless there is vocalization. Since the silent nature of the button-pushing Stroop task in the current study did not require participants to activate the phonological information, there was no need for participants to activate or integrate the segmental and tonal information of the visual stimuli, which led to no effect in the S+T+ condition. Similarly, the silent nature of the current task can account for the lack of a facilitation effect in the S+T- condition. Then the question remains as to why tonal information was used as indicated by the facilitation effect in S-T+ condition. Note that Li et al. (2013) and Chapter 2 both reported that native Chinese speakers processed the tonal information independently even when there was no need for activating the phonological information of the visual stimuli. The automatic processing of tonal information in native speakers could simply be due to the importance of tones in Chinese. The common four lexical tones in Chinese are required to distinguish the numerous Chinese characters that share the same segmental information. Therefore, tonal information might be too critical to be neglected during the lexical access of Chinese characters even in silent reading in native speakers. What is important, however, is that the only facilitation effect appearing in the S-T+ condition, but not in the S+T+ and S+T- conditions, provides convincing evidence that tonal information is represented separately from the segmental information in native speakers. What is even more important is that the results in Experiment 1 confirmed that tonal information can be automatically processed in native speakers, but this time this information can be processed during silent visual word recognition.

Thus, the findings in Experiment 3 provided us with a reliable baseline to test whether L2 Chinese learners can automatically process tonal information in a similar manner compared to native speakers during silent reading in Experiment 4.

Experiment 4: Silent Tonal Processing in L2 Chinese Learners

Method

Participants.

A total of 17 L2 Chinese learners participated in the experiment voluntarily. They all passed the Level V of the HSK test or above. As mentioned, HSK, Hanyu Shuiping Kaoshi, is a standardized Chinese language proficiency measure administered by an agency of the central Chinese government. There are six levels of HSK (levels I - VI), in which Levels I and II represent low proficiency, Levels III and IV represent intermediate proficiency, and Levels V and VI represent high proficiency. The language learning backgrounds of these L2 Chinese learner participants are presented in Table 3.3. As in Experiment 3, all participants reported to have normal vision (with no deficiency in color identification) and hearing, and had no known language or learning disabilities. All L2 Chinese learners resided in China at the time when they participated in the current study.

Table 3.3. Language learning information of L2 Chinese learners in Experiment 4.

	L2 Chinese learners	
	Mean (SD)	Range
Age of onset (year old)	16.82 (4.05)[a]	6-22[a]
Total years of learning (year)	3.87 (3.06)[b]	1-10[b]
Length of residence (year)	3.04 (3.32)[c]	0.33-10[c]

Self-rated proficiency (1-10, 10 as most proficient)	6.85 (1.13)[d]	4.75-8.25[d]
Listening	7.42 (1.55)	5-10
Speaking	6.79 (1.55)	4-9
Reading	7.17 (1.21)	5-9
Writing	6.04 (1.23)	4-8
HSK level (I-VI)	5.43 (0.49)	5-6

Note. [a] One participant failed to fill out age of onset, so the mean, standard deviation, and range is from n = 13 participants.

[b] Four participants failed to fill out years of learning, so the mean, standard deviation, and range is from n = 10 participants.

[c] Two participants failed to fill out length of residence, so the mean, standard deviation, and range is from n = 12 participants.

[d] Two participants failed to fill out self-rated proficiency, so the mean, standard deviation, and range is from n = 12 participants.

Materials and design.

The materials and design of Experiment 4 are the same as Experiment 3 except that additional questions were included in the language background questionnaire. The questions were related to the Chinese-learning experience of those L2 Chinese learners such as the age of acquisition (AoA), length of residence (LoR) in China, and self-rated L2 Chinese proficiency.

Procedure

The procedure is the same as in Experiment 3.

Results

A total of three participants' ERs were higher than 20% in the Pinyin identification task. Thus, data from 14 participants were included in the following analyses. The data trimming remained the same as Experiment 1. That is, the RTs longer than 1200ms were excluded from the analysis. Outliers were modified to 3 standard deviations above or below each participant's mean. This trimming procedure affected 16.5% of the data. The responses of the items that were identified incorrectly in the Pinyin identification task were removed. By-participant ANOVAs were conducted on mean RTs and mean ERs separately as dependent variables using RStudio (RStudio Team, 2015), which is based on R (R Core Team, 2013). ANOVA analyses were conducted only on the correct responses. Descriptive statistics for RTs and ERs can be found in Table 3.2.

RT analyses showed that there was a significant main effect of condition, $F(5, 65) = 4.16$, $p < .01$, $\eta_p^2 = .24$. Planned pairwise comparisons were first conducted between each experimental condition (CCC, S+T+, S+T-, S-T+, and ICC) and the neutral one (S-T-). The only significant facilitation effect was found in the S+T+ condition, $F(1, 13) = 4.71$, $p < .05$, $\eta_p^2 = .27$. Surprisingly, no significant facilitation was found in the congruent color characters (CCC) condition, $F(1, 13) = .03$, $p = .87$. No significant inhibition was found for the incongruent color characters (ICC) condition either, $F(1, 13) = 3.90$, $p = .07$, compared to the S-T- condition.

Descriptive statistics showed that the error rates in the conditions for the L2 Chinese learners were generally higher than one for the native speakers, ranging from 5.4% to 23.5%, with the S+T+ condition having the highest error rate. ER analyses yielded a significant main effect of condition, $F(5, 65) = 4.76$, $p < .001$, $\eta_p^2 = .27$. Same set of planned comparisons as the

RT analyses were conducted on ER data. The significant difference was found in the CCC condition, $F(1, 13) = 5.91$, $p < .05$, $\eta_p^2 = .31$, the S+T+ condition, $F(1, 13) = 14.82$, $p < .001$, $\eta_p^2 = .53$, and the ICC condition, $F(1, 13) = 13.39$, $p < .001$, $\eta_p^2 = .51$ compared to the S-T- condition. Further comparison revealed that the ER for the S+T+ condition was significantly higher than the one for the S+T- condition, $F(1, 13) = 8.97$, $p < .05$, $\eta_p^2 = .41$.

Discussion

Experiment 4 showed that, unlike native speakers, highly-proficient L2 Chinese learners cannot automatically process the tonal information as shown by the lack of a facilitation effect in the S-T+ condition. Thus, the results indicate that, even though advanced L2 Chinese learners were tested, they still used phonological information differently from native speakers when no phonological recoding was required.

It is important to note that the lack of the automatic processing of the tonal information in the L2 learners in Chapter 3 cannot be due to the lack of explicit knowledge of the stimuli. This is because the Pinyin identification task was included following the button-pushing Stroop task, in which participants needed to explicitly know the correct segmental and tonal information for each stimulus in order to pick out the correct answer. Crucially, all the responses that were included in the data analyses came from the items that were identified correctly in the Pinyin identification task. Therefore, it is safe to assume that the L2 Chinese learner participants know the correct pronunciation of the stimuli that were included in the final analysis. In other words, they have formed some kind of explicit representations for both the segmental and the tonal information of stimuli that were included in the analysis. Yet, those L2 participants still seemed not to be able to automatically process the tonal information of those visual stimuli in their L2.

It is also important to consider the potential L1 transfer effect in terms of tonal status. Similar to the L2 participants in Chapter 2, the L2 Chinese learner participants in this Chapter 3 also come from different L1 backgrounds. Some participants' L1s do not have tones such as Russian, Japanese or English (n=7), while other participants' L1s do have tones such as Thai, Lao, or Vietnamese (n=7). However, all the L2 Chinese learner participants were treated as a homogeneous group in the current study. Therefore, it was possible that the L2 tonal information might be in those who have tonal L1s but not in those who have atonal L1s. It is important to note, however, that Li et al. (2019) and Chapter 2 reported the lack of tonal processing in L2 also treated L2 Chinese learners as a homogeneous group. More importantly, in Chapter 2, a post-hoc analysis was conducted, in which the 27 L2 Chinese learner participants were divided into two groups based on their L1 tonal status: tonal L1ers (n=11) and atonal L1ers (n=16). It seems that the lack of automatic tonal processing in L2 was not influenced by the L1 tonal status during visual word recognition even when the two groups of L2 participants had comparable L2 language learning backgrounds. Interestingly, a recent ERP study also reported evidence for no influence from L1 tonal status into L2 tonal processing (Berthelsen, Horne, Shtyrov, & Roll, 2020). Berthelsen et al. (2020) reported that tonal L1ers and atonal L1ers did not show difference in their performance of a L2 tonal perception task at the behavioral level (but there might be difference at the neurophysiological level). Note that their conclusion was based on an auditory experiment. So, it will be interesting to expand the findings in these behavioral experiments to further explore whether L1 tonal status indeed does not influence L2 tonal processing during visual word recognition when other research methods are used, such as EEG.

Though it might be obvious, L2 proficiency is another factor that might lead to the difficulty in the automatic processing of L2 tones. Recall that, however, all of the L2 Chinese learner participants have passed at least level V of the HSK, which suggests that they are all highly-proficient in their L2 Chinese. The proficiency level of these participants matched with those in Li et al. (2019) and Chapter 2. Despite that the L2 participants in these studies were all highly proficient in their L2 Chinese, they still had difficulty in processing tonal information either in an offline task, as in Li et al. (2019), or in an online task, as in Chapter 2 and in the current study. Together, the findings of these studies suggest that it may be extremely difficult even for highly-proficient L2 learners to process the tonal information during visual word recognition. A more interesting question, however, is whether the change of proficiency might influence the processing of tonal information in L2. Berthelsen et al. (2020) showed that L2 learners seem to be able to process tones in an online task after one day of training. This finding suggests that tonal information might be automatically processed in very low-proficient L2 learners of tonal languages. Thus, the findings in Berthelsen et al. (2020) and the current study suggest that the change of proficiency might lead to the change of how information is represented and processed in L2 learners. However, note that Berthelsen et al. (2020) tested morphosyntactic tones, which is different from lexical tones such as Chinese tones, in speech perception. Therefore, further research is necessary to test whether tonal information can be automatically processed during visual word recognition at the very initial stage of learning Chinese as an L2.

General Discussion

The results of the two experiments in this chapter showed that native Chinese speakers automatically process the tonal information even in silent reading since the facilitation Stroop effect was found in the S-T+ condition; L2 Chinese learners, however, do not seem to be able to automatically process the tonal information unless it was presented along with the segmental information because the facilitation effect was only found in the S+T+ condition. The results confirmed the findings in Chapter 2 in two ways – (1) L2 learners seem not be able to automatically process the tonal information during visual word recognition, and (2) tonal information is indeed processed differently in L1 and L2 during visual word recognition with or without the activation of the production mechanism.

Now, excluding the potential influences from L1 transfer and L2 proficiency as discussed earlier in the discussion sections of this chapter, what might be the possible accounts for why highly proficient L2 learners cannot automatically process tonal information? In Chapter 2, I proposed that L2 Chinese learners might have deficits in both the way tonal information is represented and/or accessed. This argument is further supported by the current findings. Even though neither Chapter 2 nor this chapter was able to identify the locus of the deficit of the automatic tonal processing in L2 learners, it is clear that the findings in Chapters 2 and 3 suggest that L2 learners represent and/or access tonal information differently compared to native speakers during visual word recognition. Indeed, some neurophysiological findings indicate that native speakers and L2 learners of Chinese use different brain areas to process Chinese tones (Klein, Zatorre, Milner, & Zhao, 2000). Klein et al. (2000) used positron emission tomography (PET) to determine the areas that were used for processing Chinese tones in native speakers and L2 learners of Chinese. They found that an area in the left hemisphere of the brain where other linguistic information is processed was used in native speakers (see also Wang, Jongman, & Sereno, 2001), while L2 learners used an area in the right hemisphere. Their findings suggest that tonal information might not be represented as part of the linguistic information in L2 learners compared to native speakers. Thus, there might be fundamental differences in how tonal information is represented and/or processed in native speakers and L2 learners of Chinese.

Taking one step further, it is interesting to consider how exactly phonological information might be represented and/or accessed differently in L2 compared to in L1. The findings in the Chapter 2 and 3 might shed some light on such differences. It seems that, in native speakers, segmental and tonal information remain separate following Taft and Chen (1994). However, segmental and tonal information might remain as a holistic unit in L2 learners as suggested by the findings in the current chapter because the Stroop facilitation effect was only found in the S+T+ condition.

If the view of holistic representation of L2 phonological information is correct, the question remains as to why there were Stroop facilitation effects in both the S+T+ and S+T- conditions in Chapter 2 for L2 leaners. It could be possible that both effects came from the use of segmental information when phonological information was encouraged to be used as in the naming Stroop task in L2 learners. Indeed, there was no significant difference between the S+T+ condition and the S+T- condition in terms of effect size, $F(1, 26) = 2.65$, $p = .15$ in L2 learners in Chapter 2. Thus, tonal information could be poorly represented along with the segmental information in L2. When the task does not encourage the use of phonological information, as in the button-pushing Stroop task in this chapter, segmental information alone is sufficient to facilitate the color identification, which is evidenced by the disappearance of the facilitation effect in the S+T- condition in this chapter. Either way, the holistic representation of segmental and tonal information in L2 Chinese does not cancel the fact that tonal information is more poorly represented or accessed in L2 learners compared to native speakers of Chinese.

In short, the current study confirmed that L2 learners do not automatically process tonal information during visual word recognition, which is different from native speakers, regardless of whether the production mechanism is activated or not. The lack of automatic L2 tonal processing is highly likely to be deficient in the representational and/or the processing system. Specifically, it was speculated that L2 learners, unlike native speakers, might represent the tonal information and segmental information as a holistic unit with tonal information poorly represented.

Chapter 4: Phonological Processing Differences between L1 and L2 Visual Word Recognition

The goal of this dissertation was to explore how phonological information, especially tonal (suprasegmental) information, was processed during visual word recognition in L1 and L2 Chinese. Native speakers and highly-proficient L2 learners of Chinese were tested using two different experimental tasks – a naming Stroop task in Chapter 2 and a button-pushing Stroop task in Chapter 3. Chapter 2 showed that Stroop facilitation effects were found in S+T+, S+T-, and S-T+ conditions in native Chinese speakers, while they were only observed in S+T+ and S+T- conditions in L2 learners. The absence of Stroop facilitation effect in the S-T+ condition was replicated in Chapter 3 in L2 learners. Chapter 3 further showed that, when the production mechanism was excluded, a Stroop facilitation effect was still observed in the S-T+ (and maybe in S+T+ and S+T- conditions as well with more data) in native Chinese speakers, while the effect was only found in the S+T+ condition in L2 learners of Chinese. One critical factor in the experimental designs of Chapters 2 and 3 was whether these Stroop tasks involved the production system. This factor in the task seemed to knock out the Stroop facilitation effect in S+T- condition in L2 learners, while leaving the Stroop facilitation effect in S-T+ condition intact in native speakers. Taking the results of Chapters 2 and 3 together, they seem to suggest that: (1) native Chinese speakers can automatically process the tonal information independently during visual word recognition regardless of the involvement of the production mechanism, (2) L2 learners, in contrast, seem to not be able to automatically process tonal information whatsoever, and (3) segmental information is only automatically processed when the articulatory system is activated in L2 learners. As discussed earlier in Chapters 2 and 3, L2 learners might represent and/process tonal information in their L2 fundamentally differently from native speakers.

Indeed, the results of Chapters 2 and 3 together showed that the involvement of the production mechanism seem to provide different influences on L1 and L2 phonological processing. For native speakers, the automatic processing of segmental and tonal information together was observed in the naming Stroop task, but not in the button-pushing Stroop task. This is evidenced by the fact that the Stroop facilitation effect in the S+T+ condition was found in the naming Stroop task (Chapter 2) but not in the button-pushing Stroop task (Chapter 3) even though there was a strong trend for such an effect. While the involvement of the production mechanism seemed to influence the Stroop facilitation effect in a different condition in L2 learners, the S+T- condition, while leaving the effect intact in the S+T+ conditions. Specifically, in L2 learners, the Stroop facilitation effect in the S+T- condition was found in the naming Stroop task (Chapter 2) but not in the button-pushing Stroop task (Chapter 3). Such findings in L2 learners are not so surprising though. This is because previous studies (see e.g., Shen & Forster, 1999; Zhou & Marslen-Wilson, 2000) have shown that, even in native speakers of Chinese, phonological information was more likely to be observed when the experimental task biases the reader more toward the use of phonological information, as in a naming task. So it is possible that segmental information was more ready to be processed by L2 learners when the production mechanism was activated. What is intriguing, however, is that the production mechanism influenced the automatic processing of phonological information in L1 differently from L2 visual word recognition. More importantly, L2 learners, unlike native speakers, do not seem to automatically process tonal information even in a task that provoked the use of phonological information, as in the naming Stroop task. Hence, following Li et al. (2019), the current dissertation provides further support for the argument that L2 learners, unlike native speakers, do not seem to represent and process tonal information implicitly in their L2 Chinese using an online processing task. Of course, such a conclusion in this study is based on the lack of the Stroop facilitation effects in the S-T+ condition in Chapters 2 and 3 in L2 learners. Theoretically speaking, however, L2 learners are still able to automatically process tonal information, but they might not process such information efficiently enough to show experimental effects.

In an alternative scenario, perhaps tonal information can be automatically processed by L2 learners, but it might take these L2 learners too long to compute such information such that this information could affect their decision on the ink color to show the Stroop facilitation effects in the S-T+ conditions. As such, the tonal information of the visual stimuli was not processed fast enough to facilitate ink color naming/identification. This was the case even when phonological information was encouraged to be used as in the naming Stroop task in Chapter 2. In contrast, native speakers seem to be able to process the tonal information of the visual stimuli fast and sufficiently enough such that they always facilitate the color identification. Either way, even if we assume that L2 learners can automatically process the tonal information during visual word recognition, the failure of observing a facilitation Stroop effect in the S-T+ conditions would still suggest that the processing speed of phonological information would be relatively slower in L2 learners than in native speakers in general. In other words, it is clear that there are some differences in how phonological information, especially tonal information, is processed in L1 and L2. The question remains as to why L2 learners of Chinese might represent and/process tonal information differently from native speakers.

As discussed in the previous discussion sections in Chapters 2 and 3, L2 proficiency and the tonal status of L2 learners' L1s are obvious factors that might influence how tonal information is represented and/or processed in L2. Even though I have argued that these factors are very unlikely to influence the current findings, a more careful revisit on them might shed some light on our understanding of phonological processing during L2 visual word recognition. These discussions, in turn, would provide questions that require further research.

In terms of L2 proficiency, the L2 learners in this dissertation had relatively high proficiency in their L2 Chinese. This was evidenced by the fact that all L2 participants passed at least level V of the HSK test (except one participant who passed level IV), and this level is categorized as highly-proficient for L2 Chinese learners. The question, however, is then whether such a test was valid enough to reflect the proficiency of the participants' L2 Chinese. In other words, the reliability of the current findings to some extent depended on the validity of the HSK test. As any other language proficiency test, there is not much consensus as to what extent the HSK test actually reflects L2 Chinese proficiency. This leaves it open to the possibility that tonal information might be processed by L2 Chinese learners who have an even higher proficiency compared to the current L2 participants. What is important to the current dissertation, however, is that as high of an L2 proficiency that the current L2 participants have, they automatically processed segmental information under certain conditions but not tonal information. This suggests that L2 learners, indeed, have some difficulty in representing and/or processing tonal information in their L2. Now, it is not clear whether L2 learners who are even more proficient in their L2 Chinese might be able to automatically process tonal information in a similar manner as native speakers. That is, if we tested only those who had passed Level VI of HSK test, would they have been able to show a Stroop facilitation effect in the S-T+ condition? This is an empirical question for future studies.

Putting aside the influence from L2 proficiency, L1 influence is another factor that could potentially influence L2 tonal processing (see, e.g., Bent et al., 2006; Burnham et al., 2015; Chang et al., 2017; Hallé et al., 2004; So & Best, 2010, 2014; Wu, Chen, Van Heuven, & Schiller, 2017). In Chapter 2, the L2 learners of Chinese were divided into two groups based on whether their first language had tones or not. The results showed that L2 Chinese learners from neither groups automatically process tonal information during visual word recognition. Based on this finding, it was concluded that L1 tonal status might not influence L2 tonal processing during visual word recognition. Note that the L2 learner participants in Chapter 2 actually had diverse L1 backgrounds, and the categorization of the tonal status of their L1s (tonal vs. atonal) was rather general (i.e., the categorization was based on the world knowledge of those languages). The diverse L1 backgrounds could potentially influence L2 tonal processing differently. That is, even in L2 Chinese learners who have different tonal L1s, different pitch qualities in their L1 tones might influence L2 tonal processing differently. Interestingly, Schaefer and Darcy (2014) showed that the lexical function of pitch in different L1s influenced L2 tonal perception. Other general factors such as the orthography in L1 (alphabetic vs. non-alphabetic) (Jiang & Pae, 2020) could also potentially influence L2 tonal processing. Even though these subtle factors might influence L2 tonal processing, it is important to note that the diverse L1 backgrounds of L2 participants in Chapter 2 did not prevent them from automatically processing the segmental information. That is, both the atonal and tonal L1ers in Chapter 2 seem to automatically process the segmental information, but not tonal information. In addition, there is no extant evidence or theories indicating how these factors in L1 might or might not influence L2 tonal processing during visual word recognition. To this end, the current dissertation, hence, provided a starting point for the future studies to look into how different factors in L1, such as pitch differences in different tonal L1s, might influence L2 tonal processing during visual word recognition.

In conclusion, the current dissertation reported four experiments that directly compared the online tonal processing during L1 and L2 visual word recognition using two different tasks. The results clearly showed that highly-proficient L2 learners of Chinese have difficulty in the automatic processing of tonal information while native speakers do not. The results, thus, are interpreted as evidence for the differences in how phonological information, especially suprasegmental information such as lexical tones in Chinese, is represented and/or processed in L1 and L2 visual word recognition systems.

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