THE NATURE OF VARIATION IN TONE SANDHI PATTERNS OF

SHANGHAI AND WUXI WU

By

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Abstract

The primary goal of this dissertation is to understand the variation patterns in suprasegmental processes and what factors influence the patterns. To answer the questions, we investigated the variation patterns of tone sandhi in the Shanghai and Wuxi Wu dialects of Chinese.

Shanghai disyllables and trisyllables have been documented to have two different sandhi patterns: tonal extension and tonal reduction. Some items can only undergo tonal extension, some items can only undergo tonal reduction, and some can variably undergo either type of sandhi. Previous works have indicated that the syntactic structure, semantic transparency, and lexical frequency of the items all play a role in the sandhi application. Additionally, the morpheme length of trisyllabic items (1+2, 2+1) is also expected to affect their sandhi application.

A variant forms' goodness rating experiment, together with a lexical frequency rating experiment and a semantic transparency rating experiment, showed that syntactic structure has a primary effect on sandhi application in general. It overrides the effect of semantic transparency, especially in modifier-noun items. The nature of the lexical frequency effect in Shanghai is related to the syntactic structure of the lexical item. Morpheme length effect is not found.

Wuxi disyllables and trisyllables also have been observed to have two different sandhi patterns: tonal substitution and no sandhi. Some items can only apply tonal substitution, and some can apply either form variably. Syntactic structure and semantic transparency have been

reported to affect Wuxi sandhi application, and morpheme length is also expected to have an effect in trisyllabic sandhi application.

The three rating experiments conducted in Wuxi found that due to the lexical listedness of the opaque substitution pattern, frequency influences both modifier-noun and verb-noun positively, although modifier-noun prefers tonal substitution form more. Semantic transparency effect is only apparent for verb-noun disyllables. Moreover, morpheme length also distinguishes sandhi application between 1+2 and 2+1 modifier-noun items.

In all, by using quantitative rating experiments, the present study shows that tone sandhi variation is regulated by both grammatical factors, such as syntactic structure, morpheme length, phonological opacity, and nongrammatical factors, such as lexical frequency.

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Chapter I: INTRODUCTION TO TONE SANDHI VARIATION

1.1 Background and purpose

Modern phonological theory is paying increasingly close attention to variation in phonological patterns. According to Coetzee & Pater (2011), phonological variation is "a situation in which a single morpheme can be realized in more than one phonetic form in a single environment". American English *t*/*d*-deletion (Labov, 1989; Guy, 1994; Coetzee, 2004), forms of reduplication in Ilokano (Hayes & Abad, 1989; Boersma & Hayes, 2001; Coetzee, 2006), and Japanese geminate devoicing (Coetzee & Kawahara, 2012) are all well-known examples of phonological variation. Most of the findings so far, however, have come from segmental processes. We complement this line of research by providing a comprehensive study on the variation pattern of tone sandhi in the Shanghai and Wuxi Wu dialect of Chinese. Shanghai tone sandhi has been reported to have two different patterns depending on lexical, syntactic, and semantic properties of the polysyllabic sequence: some items can only undergo one type of tone sandhi, some can only undergo the other type, and some can have both forms (Xu et al., 1981, 1982). However, it is not entirely clear what the nature of the lexical, syntactic, and semantic properties is that influences tone sandhi application and causes sandhi variation. Wuxi, a closely-related dialect with a different tone sandhi system, is also claimed to have tone sandhi variation (Xu, 2007). But its literature is even scarcer than Shanghai's. There are, therefore, a number of open questions regarding tone sandhi in these dialects. First, how do the variant forms of tone sandhi pattern in Shanghai and Wuxi? Second, what factors influence the application of tone sandhi and its variation pattern? Do they interact in the same way in the two dialects? And if not, how do the two dialects differ, and why?

This dissertation aims to investigate the factors that influence variation in disyllabic and trisyllabic tone sandhi in both Shanghai and Wuxi. The purpose is to test how grammatical and non-grammatical factors interact in tone sandhi variation, including lexical frequency, semantic transparency, syntactic structure, and morpheme length for each dialect. By comparing the two dialects, we can address the issue of how the nature of the different sandhi patterns influences the application of variant forms of tone sandhi.

1.2 Overview of the dissertation

Before the discussion of methodology, Chapter 2 introduces the tone sandhi patterns of Shanghai and Wuxi disyllables and trisyllables. Although both dialects have left-dominant sandhi,[1] Shanghai employs tonal spreading, while Wuxi employs tonal substitution. It turns out that the nature of the sandhi pattern interacts with the lexical, semantic, syntactic, and morphemic properties of the polysyllabic sequence in interesting ways in deciding the variant forms of tone sandhi in the two dialects. Chapter 3 discusses the known factors affecting tone sandhi application in the literature.

Three experiments are conducted in each dialect. Experiment 1 tests the goodness ratings of two variant sandhi forms. The results indicate the speakers' preference between the variant forms. Due to the lack of corpus data in the two dialects, the lexical frequency of the

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[1] There are two major varieties of tone sandhi patterns in Chinese dialects, right- and left-dominant sandhi. A detailed introduction will be provided in §1.5.

stimuli used in Experiment 1 was estimated by a subjective frequency rating task in Experiment 2. Experiment 3 is a semantic transparency rating experiment that examines the semantic transparency of the stimuli. These experiments allow us to investigate the interaction between the sandhi patterns and the lexical, semantic, syntactic, and morphemic properties of Shanghai and Wuxi disyllables and trisyllables. Details of the three experiments are elaborated in Chapter 4, as well as the results and discussion of the Shanghai data. The results and discussion of the Wuxi data are presented in Chapter 5.

In Chapter 6, a comparison between the results of the two dialects is provided. How different sandhi patterns and linguistic properties interact differently in the variation patterns and the phonological implication of the comparison are also discussed in this chapter. Finally, the chapter summarizes the key findings of the three experiments in Shanghai and Wuxi and proposes the directions for future research.

1.3 Significance of the dissertation

This study makes a contribution to the phonological variation in Chinese tone sandhi by providing empirical data in Shanghai and Wuxi. By clarifying the variant forms of sandhi application, we are able to get a better understanding of the dialectal sandhi variation. The inclusion of Wuxi variation is not only because the variation data in Wuxi have not be clearly documented in the literature, but also due to the different sandhi patterns of the two dialects. If the variation in Wuxi patterns differently from that in Shanghai, we will be able to see whether the difference stems from the differences in the nature of their sandhi structures, and if so, how.

In addition, this study also contributes to the study of phonological variation by looking into how lexical frequency and other linguistic properties influence suprasegmental variable processes. We begin by reviewing variation in phonology and tone sandhi in the next two sections.

1.4 Variation in phonology

Variation commonly occurs in phonology. In generative phonology, underlying lexical items may be changed by phonological derivation, which begins with the application of lexical phonological rules, followed by the application of post-lexical phonological rules (Kiparsky, 1982, 1985, 1993; Anttila, 1997). Coetzee & Pater (2011) used the more neutral terms of early and late phonology to avoid characterizing the distinction between different levels of the phonological grammar in a too theory-specific way. In general, the characteristics of early phonology are that: (a) it is sensitive to morphology due to its direct interaction with the lexicon, (b) there may be lexical exceptions,[2] (c) there are only categorical changes at this level, (d) input to this level is single words, and (e) there is no contact with phonetics. In English, for example, a tense vowel becomes lax when followed by two syllables, and the first of them is unstressed. When adding a suffix *-ity*, s*ane* [s**eɪ**n] becomes *sanity* [ˈs**æ**.nɪ.ti], profound [prəˈf**aʊ**nd] becomes profundity [prəˈf**ʌ**n.dɪ.ti].

On the other hand, for late phonology, (a) it is insensitive to morphology, (b) there are few exceptions due to the lack of contact with lexicon, (c) non-categorical changes may be

[2] The exceptions here refer to exceptions to the application of phonological rules.

introduced, (d) input to this level is whole utterances, and (e) it has direct contact with phonetics. For example, in American English, *t/d* may become a flap in intervocalic position, such as *city* [ˈsɪɾi], *tidy* [ˈtʰaɪɾi] and *mosquito* [məsˈkiɾoʊ]. It also occurs in phrases, such as in *tha[ɾ] is* and *abou[ɾ] it*. Speech rate may also influence the application of flap. The full predictability of flapping, its application across word boundaries, as well as its allophonic feature all suggest that American English Flapping is post-lexical.

According to Kiparsky (1982), only post-lexical rules may apply optionally. In other words, variation is limited to post-lexical phonology, also referred to as late phonology by Coetzee & Pater (2011). Kiparsky (1985) cited the application of English nasal place assimilation, which can occur both lexically and post-lexically. The lexical application of nasal place assimilation is obligatory, as *e*[nt]*er* cannot be realized as **e*[mt]*er* or **e*[ŋt]*er* ([mt] and [ŋt] are not legal sequences morpheme-internally), while the post-lexical application is optional, since both *gree*[n b]*ox* and *gree*[m b]*ox* are acceptable. Furthermore, Barry (1985), Nolan (1992), and Ellis & Hardcastle (2002) showed that for some speakers, the nasal in a phrase like *green box* was articulated at a range of alveolar closure locations even though it was perceived as a full labial. It indicates that gradient phonetic implementation is involved in this variable process.

Another piece of evidence for variation taking place in late phonology comes from the variable phonological process of English *t/d* deletion, in which an alveolar stop *t/d* is optionally deleted in word-final consonant clusters. For example, *west* can be realized as either [wɛst] or [wɛs]. It is found that in the production of phrases, such as *perfect memory*, the *t* deletion results from the temporal overlap gestures (Browman & Goldstein, 1990). In the production of these phrases, there is a closure for the alveolar stop *t*, but the alveolar gesture may be obscured by the surrounding consonant gestures. In casual speech (a subset of fast speech where reduction occurs), the alveolar gesture is shortened, and it is more likely to be masked by the surrounding gestures. Therefore, it is perceived as deleted. This suggests that this variable process has contact with phonetics, and there may be no phonological rule of *t/d* deletion (Bybee, 2000).

However, there is also evidence that variable processes are conditioned by morphology, a characteristic of early phonology. Guy (1991) showed that the optional application of English *t/d* deletion was conditioned by morphology. When *t/d* occurs as the coda of a mono-morpheme (*mist*), it deletes more often than when it functions as a past tense suffix (*missed*). The rate of *t/d* deletion in semi-weak past tense forms (*kept*) falls between the two. This morphologically conditioned gradient degree of *t/d* deletion is also found in other English dialects (Santa Ana, 1992; Bayley, 1997).

The forms of reduplication in Ilokano also show evidence of variation conditioned by morphology (Hayes & Abad, 1989). In Ilokano, to mark plurality, comparability, and progressive, and plural actions, stems with C + glide cluster onset may have two variant forms of reduplication: one is to reduplicate the C + glide cluster, and the other consists of the initial consonant and a corresponding long vowel. For example, the plural form of *pyék* 'chick' can be either *pye:-pyék* or *pi:-pyék*; 'crocodile' is *bwáya*, and the progressive action 'is acting like a crocodile' can be either *na-ka-bway-bwáya* or *na-ka-bu:-bwáya*. A stem that has variable forms interacts with morphology, i.e., morphology conditions Ilokano reduplication for stems beginning with C + glide.

Variable processes may be also conditioned by the lexicon. Many examples have been discussed in literature, including English vowel reduction (Bybee, 2001), English *t/d* deletion (Bybee, 2000; Coetzee, 2009a, 2009b; Phillips, 2006), French schwa deletion (Fougeron & Steriade, 1997; Racine & Grosjean, 2002), and so forth. Lexical frequency plays an important role in these phonological processes. These studies will be reviewed in more details in §3.1.

Therefore, to capture the nature of variable processes, we need an analysis in phonology proper rather than limiting it to the post-lexical level or simply treating it at the level of phonetic implementation (Coetzee & Pater, 2011).

1.5 Variation in tone sandhi

The phonetic pitch on a syllable distinguishes lexical meaning in tone languages like Chinese. The well-known example from Mandarin ma55/ma35/ma213/ma51 [3] (*mother*/*hemp*/*horse*/*scold*) illustrates that pitch change on a syllable produces meaning differences. When two tones are in contact with each other in continuous speech, the phonetic shape of the tones sometimes changes. Chen (2000) claimed that tone can be changed by neighboring tones or morphological contexts, and the affected tone may become either a new tone that only occurred in such environments or a different existing tone. This type of tone change is called tone sandhi.

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[3] Chao's (1930) system of tone numbers uses '1' to '5' to indicate pitch levels, with '1' as the lowest pitch and '5' the highest pitch.

Typologically, tone sandhi patterns in Chinese dialects fall under two main varieties: last-syllable dominant (right-dominant) and first-syllable dominant (left-dominant) (Yue-Hashimoto, 1987; Zhang, 2007). In right-dominant sandhi, the final syllable in the sandhi domain keeps the base tone, while the preceding syllables undergo sandhi. Most of Min, Southern Wu, and Mandarin dialects show this type of tone sandhi, including Taiwanese (Cheng, 1968), Wenzhou (Zheng-Zhang, 1964, 1980), and Mandarin. Both Yue-Hashimoto (1987) and Zhang (2007) argued that right-dominant sandhi tended to involve local, paradigmatic tone change, as shown in the examples in (1). The Mandarin tone sandhi in (1a) shows that a non-final dipping tone 213 (Tone 3) alternates to a rising tone 35 (Tone 2) before another dipping tone; the Taiwanese tone sandhi in (1b) shows that a tone undergoes regular changes whenever it appears in non-phrase-final positions regardless of the tone in the final position. In left-dominant sandhi, the tone on the first syllable in the sandhi domain is maintained while the following syllables undergo sandhi. It is generally found in Northern Wu dialects such as Shanghai (Zee & Maddieson, 1979) and Changzhou (Wang, 1988). The Shanghai tone sandhi in (2a) involves spreading the base tone of the first syllable to the entire sandhi domain. For example, when the tone 24 is combined with any other tone, the tones of the disyllable become 22 + 44, a result of spreading the initial base tone 24. According to Yue-Hashimoto (1987) and Zhang (2007), the rightward spreading pattern, also known as "pattern extension" (Chan & Ren 1989), is typologically the most common pattern in left-dominant tone sandhi. A different pattern that is also attested in left-dominant system is the so-called "pattern substitution" (Chan & Ren, 1989). Pattern substitution replaces the base tone of the first syllable with another tone and then spreads this tone rightward, as found in Tangxi (Kennedy, 1953) and Wuxi (Chan & Ren, 1989). In Wuxi, for example, when tone 34 is combined with any other tone, the tones of the disyllable become 55 + 31, a result of first substituting the base tone 34 with a falling tone 51 and then spreading the 51 to the disyllable, as shown in (2b).

(1) *Right-dominant sandhi:*

a. Mandarin third tone sandhi

213 → 35 / ___213

b. Taiwanese tone sandhi

51 → 55 → 33 ← 24 in non-phrase-final positions

↖ ↙

21

(2) *Left-dominant sandhi:*

a. Pattern extension in Shanghai ("X" refers to any tone in the tonal inventory)

24 + X → 22 + 44

b. Pattern substitution in Wuxi

34 + X → 55 + 31

Studies on the variation of tone sandhi have been limited. Factors attributing to variation in the literature include age, the influence of Mandarin, speech rate and bilingualism, as reviewed below.

Shi & Wang (2004) studied the variable tone sandhi patterns in Tianjin, a Northern Chinese dialect closely related to Mandarin. There are four sandhi patterns in Tianjin disyllables reported in earlier literature (Li & Liu, 1985), all of which are right-dominant, as shown in (3). For (3a), Shi & Wang (2004) showed that in tone sandhi, an LH tone (T3 in Tianjin) was realized as an H tone (T1 in Mandarin) by young speakers. For (3b), younger speakers tended to realize the sandhi H tone (T2 in Tianjin) as an MH tone (T2 in Mandarin). These variable patterns may have been caused by the dominant status of Mandarin, which has influenced the younger speakers. For (3c), younger speakers tended to apply it more regularly, with about 100% application for speakers younger than 20; on the other hand, speakers older than 70 only applied the sandhi 60% of the time. For (3d), the younger speakers had lost the sandhi pattern, and speakers older than 70 had an around 40% application rate.

(3) *Tianjin disyllabic tone sandhi:*

a. L+L → LH+L (T1+T1 → T3+T1)

b. LH+LH → H+LH (T3+T3 → T2+T3)

c. HL+L → H+L (T4+T1 → T2+T1)

d. HL+HL → L+HL (T4+T4 → T1+T4)

Liu & Gao (2003) and Gao (2004) also mentioned the disappearance of T4+T4 sandhi, and they argued that this might have also resulted from the influence of Mandarin, since there was no T4+T4 sandhi in Mandarin. Zhang & Liu (2011) further confirmed the limited application of T4+T4 sandhi from 12 Tianjin speakers (average age: 34.3).

Cheng (1970, 1973) claimed that Mandarin T3 sandhi applied variably in long phrases and sentences that had more than two adjacent third tones. An example is given in (4). For the phrase [*Lao Li*] [*mai* [*hao jiu*]] 'Old Li buys good wine', in (4a) (allegro), disyllabic feet are built first from the innermost morphological cycle, and the unfooted syllable stands on its own and maintains the base tone. In faster speech, the unfooted σ3 can be combined with an adjacent foot, and the sandhi application will be moved to subsequently larger domains. (4b) (moderato) is the case when the unfooted σ3 joins the left-adjacent foot, and (4c) (allegro) is when σ3 joins the right-adjacent foot. In the fastest speech (presto), intermediate stages of footing may be skipped and a superfoot that includes all syllables may be formed, causing all nonfinal syllables to undergo tone sandhi, as seen in (4d).

(4) [*Lao Li*] [*mai* [*hao jiu*]]

Lao Li buy good wine
'Old Li buys good wine.'
T3 T3 T3 T3 T3

a. (**T2** T3) (T3) (**T2** T3)adagio
b. (**T2** **T2** T3) (**T2** T3) moderato
c. (**T2** T3) (**T2** **T2** T3) allegro
d. (**T2** **T2** **T2** **T2** T3) presto

For long sequences with no internal structure, disyllabic feet may be built from left to right, and a leftover monosyllable joins the adjacent foot, as shown in (5a). But it is also possible for a superfoot to be formed, as in (5b), to get tone sandhi on all nonfinal syllables. The syntactic structure effect on Mandarin T3 sandhi in long sequences will be further discussed in §3.4.

(5) *jiu jiu jiu jiu jiu*
nine nine nine nine nine
'nine nine nine nine nine'
T3 T3 T3 T3 T3
a. (**T2** T3) (**T2** **T2** T3)
b. (**T2** **T2** **T2** **T2** T3)

Chang (2012) examined the variation in Taiwanese tone sandhi by comparing L1 Taiwanese-dominant speakers (average age: 61) with L1 Taiwanese speakers who switched to Mandarin-dominant in their childhood (age range: 28-40). The results showed that Taiwanese-dominant speakers had a variation in the canonical sandhi rule 24 → 33: they preferred to use 21 (66%) instead of the prescribed 33 (33%). On the other hand, the Mandarin-dominant speakers followed the 24 → 33 rule 60% of the time, and used 24 → 21 only 26% of the time. She suggested that the variant forms of the sandhi rules indicated an ongoing language change, which the Mandarin-dominant speakers did not participate in. That is to say, the Mandarin-dominant speakers' data may reflect the Taiwanese tone sandhi at an earlier stage.

In general, however, variation in synchronic tone sandhi is understudied. In this dissertation, variant patterns of tone sandhi in two Wu dialects — Shanghai and Wuxi — will be investigated in detail. The tone sandhi patterns of the two dialects will be introduced in the following chapter.

Chapter II: SHANGHAI AND WUXI TONE SANDHI

In this chapter, the Shanghai disyllabic and trisyllabic tone sandhi patterns will be introduced first. The factors that influence the application of variant sandhi forms will also be discussed. Then, Wuxi disyllabic and trisyllabic sandhi patterns will be presented, as well as the factors affecting sandhi application. A comparison of the two dialects on disyllabic sandhi productivity will also be provided.

2.1 Shanghai tone sandhi patterns

Shanghai belongs to the Taihu sub-dialect area of Northern Wu. The Shanghai Wu variety under investigation here is the main dialect spoken in the urban districts of Shanghai. According to historical practice, there are four tonal categories in Chinese dialects, Ping, Shang, Qu, Ru. Two registers based on the voicing of the initial consonant then separate each category into Yin (voiceless) and Yang (voiced), resulting in eight tones. In Shanghai Wu, diachronically, Yinshang and Yinqu merged into one tone Yinqu, and Yangping, Yangshang, and Yangqu merged into one tone, Yangqu. Therefore, there are five tones in modern Shanghai. T1 represents Yinping, T2 represents Yinqu (from historical Yinshang and Yinqu), T3 represents Yangqu (from historical Yangping, Yangshang, and Yangqu), T4 represents Yinru, and T5 represents Yangru. T1 to T3 occur on open or sonorant-closed syllables, and T4 and T5 occur on checked syllables, which are syllables closed by a glottal stop, as shown in (6). Tones on checked syllables are marked with an underline.

(6) *Shanghai tones*

Tone 1	53	Tone 2	24
Tone 3	13		
Tone 4	55	Tone 5	13

2.1.1 Disyllables

Xu, Tang, & Qian (1981) provided a detailed description of disyllabic tone sandhi patterns in Shanghai. Most of the lexicalized items undergo left-dominant tonal extension, as shown in (7). The first column in (7) represents the tone on σ1, and the first row represents the tone on σ2. For example, when T1 (53) is combined with one of the three non-checked tones, the disyllable spreads the base tone of 53 and undergoes the sandhi 53 + X → 55 +31 ("X" refers to any tone among T1 to T3). When T1 is combined with one of the two tones that only occur on checked syllables, T4 and T5, the disyllable undergoes the sandhi 53 + X → 55 + 22 ("X" refers to T4 or T5). According to Xu et al. (1981), if an item *only* undergoes left-dominant sandhi, it is a compound with a "close connection" between its components. In particular, modifier-noun compounds and a portion of the verb-noun, verb-modifier, subject-predicate, and coordinate compounds can *only* undergo left-dominant sandhi. These are called Type 1 items. For example, 描红 [ɦmiɔ22 oŋ44] (*to trace* + *red*, 'trace the characters printed in red') and 顶棚 [tin33 bã44] (*top* + *shed*, 'ceiling') are two cases that can only undergo tonal extension. The "close connection" between the two constituents, to my understanding, refers to the semantic opacity of the item, i.e., items that are closely connected are those that have a semantically opaque relationship between the constituents. But the degree to which an item is closely-connected is not clearly defined in Xu et al. (1981).

(7) *Shanghai disyllabic left-dominant sandhi (tonal extension)*

<table>
<tr><th>σ1 σ2</th><th>T1 [53]</th><th>T2 [24]</th><th>T3 [13]</th><th>T4 [55]</th><th>T5 [13]</th></tr>
<tr><td>T1 [53]</td><td colspan="3">55-31</td><td colspan="2">55-22</td></tr>
<tr><td>T2 [24]</td><td colspan="3">33-44</td><td colspan="2">33-44</td></tr>
<tr><td>T3 [13]</td><td colspan="3">22-44</td><td colspan="2">22-44</td></tr>
<tr><td>T4 [55]</td><td colspan="3">33-44</td><td colspan="2">33-44</td></tr>
<tr><td>T5 [13]</td><td colspan="3">11-13</td><td colspan="2">11-33</td></tr>
</table>

"Loosely-connected" items that are not lexicalized can *only* undergo right-dominant sandhi, whereby the first syllable loses the tonal contour and becomes a level tone, as shown in (8). Xu et al. (1981) referred to items that *only* undergo right-dominant sandhi as phrases with a "loose connection" between the components. These are called Type 2 items and include some verb-noun and subject-predicate structures. 拆桥 [tsʰɑʔ44 dʑiɔ13] (*to dismantle* + *bridge*, 'to dismantle bridges') and 心善 [ɕin44 zø13] (*heart* + *kind*, 'kind-hearted') are two examples of Type 2 items. "Loose connection," in this case, seems to indicate semantic transparency, but is again not clearly defined in Xu et al. (1981).

(8) *Shanghai disyllabic right-dominant sandhi*

53 + X → 44 + X
24 + X→ 44 + X
13 + X→ 33 + X

<u>55</u> + X→ <u>44</u> + X
<u>13</u> + X→ <u>22</u> + X

Zhang & Meng (2016) and Takahashi (2013) both showed that for right-dominant sandhi, the tones on the first syllable maintained the pitch properties of the base tones. Takahashi (2013) also showed that T1 [53] and T3 [13] did not neutralize to [44] or [33] in disyllables with different speech rates. The falling shape of T1 and the rising shape of T3 were preserved regardless of the speech rates. Therefore, it may be more appropriate to interpret right-dominant sandhi as phonetic contour reduction rather than tone sandhi.

The majority of verb-noun, verb-modifier, subject-predicate, coordinate, and adverb-adjective structures can undergo *either* left- *or* right-dominant sandhi. These are called Type 3 items. These disyllabic items can be treated as either compounds or phrases, since they can undergo both types of sandhi: they undergo left-dominant sandhi when considered as compounds and undergo right-dominant sandhi when considered as phrases. For example, in (9), When 头痛 (*head* + *ache*) means 'headache' and is used as a compound, it undergoes left-dominant sandhi; when it means 'head aches' and is used as a subject-predicate phrase, it undergoes right-dominant sandhi.

(9) *Shanghai Type 3 items tone sandhi applications*

Item	Left-dominant	Right-dominant
头痛 /dɤ13 tʰoŋ24/	[dɤ13 tʰoŋ24] *headache*	[dɤ13 tʰoŋ24] *head aches*
唱歌 /tsʰɑ̃24 ku53/	[tsʰɑ̃33 ku44] *to sing*	[tsʰɑ̃44 ku53] *to sing a particular song*

In sum, Type 1 items are compounds with the most closely-connected components; Type 2 items are phrases, with the most loosely-connected components; Type 3 items may be either compounds or phrases, and have an intermediate degree of connection between components. When a phrase is encountered, Xu et al. (1981) indicated that whether it belonged to Type 2 or 3 depended on the lexical frequency and semantic transparency (the degree of connection). For example, in (10), when the verb 拔 (/bɑʔ13/, *to pull*) is combined with three different nouns: 'river', 'grass', and 'tree', the sandhi applications are different. 拔河 (/bɑʔ13 u13/, *to pull* + *river*) is a closely connected (semantically opaque) idiomatic expression, so it only undergoes left-dominant sandhi; 拔树 (/bɑʔ13 zɨ13/, *to pull* + *tree*) is a loosely connected (semantically transparent) and rarely used phrase, so it only undergoes right-dominant sandhi. 拔草 (/bɑʔ13 tsʰɔ24/, *to pull* + *grass*) is a commonly used phrase and has an intermediate degree of connection, so it applies either left- or right-dominant sandhi.

(10) *The application of disyllabic left- and right-dominant sandhi in Shanghai*

Examples	Left-dominant	Right-dominant	
拔河 /bɑʔ13 u13/ *tug of war*	[bɑʔ11 u13]		word, closely connected
拔草 /bɑʔ13 tsʰɔ24/ *to weed*	[bɑʔ11 tsʰɔ13]	[bɑʔ22 tsʰɔ24]	intermediate degree of connection
拔树 /bɑʔ13 zɨ13/ *to pull out a tree*		[bɑʔ22 zɨ13]	phrase, loosely connected

Some items can be either Type 1 or 3 due to their multiple meanings, as shown in (11). When 炒饭 (/tsʰɔ24 vɛ13/, *to fry* + *rice*) means 'fried rice' as a compound noun, it can only undergo left-dominant sandhi; when it means ‘to fry rice’ as a verb phrase, it can undergo either left- or right-dominant sandhi. When 东西 (/toŋ53 ɕi53/, *east* + *west*) means ‘things’, it can only undergo left-dominant sandhi; when it means ‘east and west’, it can undergo either left- or right-dominant sandhi.

(11)*Shanghai polysemant tone sandhi*

Item	Gloss	Type 1 Item	Type 3 Item
炒饭 /tsʰɔ24 vɛ13/ *to fry* + *rice*	*fried rice* (noun)	[tsʰɔ33 vɛ44]	
	to fry rice (verb)		[tsʰɔ33 vɛ44] or [tsʰɔ44 vɛ13]
东西 /toŋ53 ɕi53/ *east* + *west*	*things* (noun)	[toŋ55 ɕi31]	
	east and west (coordination)		[toŋ55 ɕi31] or [toŋ44 ɕi53]

Considering the fact that most syntactic structures apply left-dominant tonal extension, left-dominant sandhi is the more general form in Shanghai compared to right-dominant sandhi. From this discussion, we can also see that lexical frequency, syntactic structure, and semantic transparency (the degree of connection) all have effects on the variation of Shanghai disyllabic tone sandhi (Xu et al., 1981).

2.1.2 Trisyllables

For trisyllabic tone sandhi, Xu, Tang, & Qian (1982) claimed that almost all of them could undergo left-dominant sandhi, as shown in (12). Chen’s (2008) acoustic data found a significant effect of the sandhi domain-initial lexical tones on the pitch contours of the non-initial syllables throughout the whole sandhi domain in long sequences of Shanghai.

Takahashi (2013) also showed that in trisyllabic left-dominant tone sandhi, the base tone of the first syllable determined the pitch contour of the trisyllabic sequence. Therefore, the acoustic studies lend support to the claim that Shanghai trisyllabic left-dominant sandhi is indeed tonal extension.

(12)*Shanghai trisyllabic left-dominant sandhi (tonal extension)*

σ1	σ1σ2σ3
T1 [53]	55-33-31
T2 [24]	33-55-31
T3 [13]	22-55-31
T4 [55]	33-55-31
T5 [13]	11-22-13 or 11-22-33

Loosely-connected (semantically transparent) morpheme sequences, regardless of syntactic structure, may also undergo right-dominant sandhi, which is in free variation with left-dominant sandhi. There are three types of right-dominant sandhi depending on the morphosyntactic concatenation, as shown in (13). Type A applies to 1+2 structure (the two morphemes in the item have one and two syllables, respectively), in which σ1 and σ2 are loosely connected. In this case, σ1 undergoes sandhi as in right-dominant sandhi, and σ2σ3 undergoes disyllabic left-dominant sandhi. For example, in 新思想 (/ɕin53 sɿ53 ɕiã24/, *new + idea*), where 新 (/ɕin53/) means 'new' and 思想 (/sɿ53 ɕiã24/) means 'idea', σ1 reduces to a level tone [44] as in right-dominant sandhi, and σ2σ3 undergoes disyllabic left-dominant sandhi and turns into [55 31]. Type B applies to 2+1 structure when there is a loose connection between σ2 and σ3. The first two syllables undergo left-dominant sandhi with σ2 realized as 33 and σ3 maintaining its base tone. For example, in 送送侬 (/soŋ24 soŋ24 n̤oŋ13/, *to see someone off + you*), where 送送 (/soŋ24 soŋ24/) means 'to see somebody off' and 侬 (/n̤oŋ13/) means 'you', σ1σ2 undergoes left-dominant sandhi and σ2 is realized as 33, so we get [33 33] for σ1σ2; σ3 maintains the base tone. Type C applies to 1+1+1 structure in which all three syllables are loosely connected. σ1 and σ2 both undergo right-dominant sandhi, and σ3 maintains its base tone. In 请吃茶 (/tɕʰin24 tɕʰiɪʔ55 zo13/, *to invite + to drink + tea*), where 请 (/tɕʰin24/) means 'to invite', 吃 (/tɕʰiɪʔ55/) means 'to drink', and 茶 (/zo13/) means 'tea', σ1 and σ2 both undergo right-dominant sandhi and reduce to level tones [44 44]; the base tone of σ3 is preserved.

(13) *Shanghai trisyllabic sandhi variation*

Type	Syntactic structure	Item & Gloss	Right-dominant	Left-dominant
Type A 1+2	modifier-noun	新思想 /ɕin53 sɿ53 ɕiã24/ *new idea*	[ɕin44 sɿ55 ɕiã31]	[ɕin55 sɿ33 ɕiã31]
	verb-noun	拆烂污 /tsʰɑʔ55 l̤ɛ13 u24/ *to be irresponsible*	[tsʰɑʔ44 l̤ɛ22 u44]	[tsʰɑʔ33 l̤ɛ55 u31]
Type B 2+1	modifier-noun	温吞水 /uən53 tʰən53 sɿ24/ *warm water*	[uən55 tʰən33 sɿ24]	[uən55 tʰən33 sɿ31]
	verb-noun	送送侬 /soŋ24 soŋ24 n̤oŋ13/ *to see you off*	[soŋ33 soŋ33 n̤oŋ13]	[soŋ33 soŋ55 n̤oŋ31]
Type C 1+1+1	coordination	左中右 /tsu24 tsoŋ53 ɦiɤ13/ *left, middle, and right*	[tsu44 tsoŋ44 ɦiɤ13]	[tsu33 tsoŋ55 ɦiɤ31]
	verb-noun	请吃茶 /tɕʰin24 tɕʰiɪʔ55 zo13/ *to buy someone tea*	[tɕʰin44 tɕʰiɪʔ44 zo13]	[tɕʰin33 tɕʰiɪʔ55 zo31]

Xu et al. (1982) also pointed out that due to the degree of connection and lexical frequency, some trisyllables could only undergo right-dominant sandhi, and some closely-connected ones could only undergo left-dominant sandhi. For example, in (14), when the verb 看 (/kʰø24/, *to see*) is combined with three different nouns: 'doctor', 'Shanghai Opera' and 'acrobatics', the sandhi applications are different. 看医生 (/kʰø24 i53 sã53/, *to see + doctor*) is a closely connected (semantically opaque) and frequently used compound, so it only undergoes left-dominant sandhi; 看杂技 (/kʰø24 zəʔ13 dʑi13/, *to see + acrobatics*) only undergoes right-dominant sandhi; and 看申曲 (/kʰø24 sən53 tɕʰyɪʔ55/, *to see + Shanghai Opera*) applies either left- or right-dominant sandhi. According to Xu et al. (1982), the application of trisyllabic tone sandhi was determined by the degree of connection (semantic transparency) between the components and lexical frequency, which was similar to the disyllable case. However, intuitively, it is not clear that 看杂技 (/kʰø24 zəʔ13 dʑi13/, *to see + acrobatics*) and 看申曲 (/kʰø24 sən53 tɕʰyɪʔ55/, *to see + Shanghai Opera*) are different in semantic transparency or lexical frequency. Therefore, the variable sandhi forms of these trisyllables require further investigation.

(14) *The variant sandhi application of Shanghai trisyllables*

Examples	Left-dominant	Right-dominant
看医生 /kʰø24 i53 sã53/ *to see a doctor to get treatment*	[kʰø33 i55 sã31]	
看申曲 /kʰø24 sən53 tɕʰyɪʔ55/ *to watch Shanghai Opera*	[kʰø33 sən55 tɕʰyɪʔ31]	[kʰø44 sən55 tɕʰyɪʔ31]
看杂技 /kʰø24 zəʔ13 dʑi13/ *to watch acrobatics*		[kʰø44 zəʔ11 dʑi13]

Yan (ms.) calculated the counts of trisyllables that can apply both left- and right-dominant sandhi based on Wang (2008)'s word list of 505 trisyllables. 398 of them are 2+1 modifier-noun ([M N]) items, 85 are 1+2 [M N] items, 13 are 1+2 verb-noun ([V N]) items, and 9 are 1+1+1 items (coordinate compounds and loanwords). The judgment was made by a 24-year-old male native Shanghai speaker. He was asked to judge the acceptability of applying left- and right-dominant sandhis to each lexical item. The results showed that for the 98 1+2 structure, 62% of the 13 [V N] could undergo either left- or right-dominant sandhi, and the rest of them could only undergo right-dominant sandhi. On the other hand, 13% of the 85 [M N] could undergo either left- or right-dominant sandhi, and the other 87% could only undergo left-dominant sandhi. For the 398 2+1 [M N], 33% of them could apply either left- or right-dominant sandhi, and 67% could only apply left-dominant sandhi. This indicates that (a) [M N] tends to undergo more left-dominant sandhi than [V N] does, and (b) it is more likely for the 1+2 [M N] structure to undergo left-dominant sandhi than the 2+1 [M N] structure.

Duanmu (1995) argued that Shanghai 1+2 [M N] could only apply left-dominant sandhi, while 2+1 [M N] could apply either left- or right-dominant sandhi, as shown in (15).

(15) *Shanghai tone sandhi variation*

	1+2		2+1
	tɕi ts^{h}z-pɑ̃		so-faʔ ts^{h}ɑ̃
	chicken wing		sofa factory
	'chicken wing'		'sofa factory'
	HL LH LH		HL LH LH
→	H L L	→	H L L
→	*HL L H	→	H L LH

Assuming that tone sandhi applies in a tonal domain, the sandhi patterns indicate that Shanghai 1+2 structures could only form one tonal domain, and the 2+1 structures can form either one or two tonal domains, as shown in (16).

(16) a. *Shanghai 1+2 structure*:

H L L	HL L H	
(tɕi tsʰz-pɑ̃)	*(tɕi) (tsʰz-pɑ̃)	
chicken wing		'chicken wing'

b. *Shanghai 2+1 structure*:

H L L	H L LH	
(so-faʔ tsʰɑ̃)	(so-faʔ) (tsʰɑ̃)	
sofa factory		'sofa factory'

Duanmu claimed that the asymmetry between 1+2 and 2+1 stems from the fact that Shanghai's tonal domain is left-headed. Therefore, in a 1+2 structure, if two tonal domains were formed, then there would be a stress clash, which is dispreferred. In a 2+1 structure, however, there is no stress clash even when two tonal domains are formed. Therefore, both left-dominant and right-dominant sandhi readings are possible.

In conclusion, lexical frequency, semantic transparency, syntactic structure, and morpheme length all have an effect on Shanghai trisyllabic tone sandhi application.

2.2 Wuxi tone sandhi patterns

Wuxi is also a Northern Wu dialect that belongs to the same Taihu sub-dialect area as Shanghai. The Wuxi Wu variety under investigation here is the main dialect spoken in the urban areas of Wuxi. The description of Wuxi also follows the same historical practice as Shanghai, in which the Yin and Yang registers reflect the difference in voicing of the initial consonants. T1 to T6 occur on open or sonorant-closed syllables. T7 and T8 occur on checked syllables, which are syllables closed by a glottal stop. According to the acoustic study by Xu (2007), Yinping T1, Yinshang T3 and Yinqu T5 are different in monosyllabic citation forms, while Yangping T2 and Yangqu T6 have been merged into the same contour tone in monosyllabic citation form due to historical changes, as shown in (17).

(17) *Wuxi tones*

Tone 1	53	Tone 2	113
Tone 3	223/323[4]	Tone 4	13
Tone 5	34	Tone 6	113
Tone 7	<u>5</u>	Tone 8	<u>13</u>

[4] The difference between 223 and 323 results from a gender difference according to Xu (2007). Male speakers' production is 223, and female speakers' production is 323. We will use 323 (female) in this document for consistency's sake.

2.2.1 Disyllables

Chan & Ren (1989) provided the first instrumental study of tones and tone sandhi in Wuxi Chinese, which has both pattern extension and pattern substitution. Pattern extension applies to reduplicated verbs, reduplicated nouns in baby talk, verbs with resultative or directional complement, and expressions of 'number + classifier'. Pattern substitution applies to regular compounds, phrases and reduplicated nouns. The disyllabic tone sandhi patterns are listed in (18). For example, when T1 (53) is combined with one of the six tones from T1 to T6, the disyllable undergoes the sandhi 53 + X → 33/43[5] + 34 ("X" refers to any tone among T1 to T6) in pattern substitution and 55 + 31 in pattern extension. When T1 is combined with one of the two tones that only occur on checked syllables, T7 and T8, the disyllable undergoes the sandhi 53 + X → 33/43 + 34 ("X" refers to T7 or T8) in pattern substitution and 55 + 31 in pattern extension.

(18) *Wuxi disyllabic tone sandhi*

<table>
<tr><th>σ2 / σ1</th><th>T1 /53/</th><th>T2 /113/</th><th>T3 /323/</th><th>T4 /13/</th><th>T5 /34/</th><th>T6 /113/</th><th>T7 /5/</th><th>T8 /13/</th><th>Patterns</th></tr>
<tr><td rowspan="2">T1 /53/</td><td colspan="6">33/43+34</td><td colspan="2">33/43+34</td><td>Substitution</td></tr>
<tr><td colspan="6">55+31</td><td colspan="2">55+31</td><td>Extension</td></tr>
<tr><td rowspan="2">T2 /113/</td><td colspan="6">35+31</td><td colspan="2">35+31</td><td>Substitution</td></tr>
<tr><td colspan="6">33+55</td><td colspan="2">33+5</td><td>Extension</td></tr>
<tr><td rowspan="2">T3 /323/</td><td colspan="6">44+55</td><td colspan="2">44+5</td><td>Substitution</td></tr>
<tr><td colspan="6">33/43+34</td><td colspan="2">33/43+34</td><td>Extension</td></tr>
<tr><td>T4 /13/</td><td colspan="2">33+55</td><td colspan="4">33/43+34</td><td colspan="2">33+5</td><td>Substitution</td></tr>
</table>

[5] The variation between sandhi tone 33+34 and 43+34 again results from a gender difference: the former is used by male speakers, while the latter is used by female speakers. We again use the female speakers' transcription 43+34 in this document.

<table>
<tr><td></td><td colspan="2">35+31</td><td colspan="2">35+31</td><td>Extension</td></tr>
<tr><td rowspan="2">T5 /34/</td><td colspan="2">55+31</td><td colspan="2">55+31</td><td>Substitution</td></tr>
<tr><td colspan="2">44+55</td><td colspan="2">44+5</td><td>Extension</td></tr>
<tr><td rowspan="2">T6 /113/</td><td colspan="2">33+55</td><td colspan="2">33+5</td><td>Substitution</td></tr>
<tr><td colspan="2">33/43+34</td><td colspan="2">33/43+34</td><td>Extension</td></tr>
<tr><td>T7 /5/</td><td>3+55</td><td>3+34</td><td rowspan="2">5+5</td><td rowspan="2">3+5</td><td>Substitution</td></tr>
<tr><td>T8 /13/</td><td>3+55</td><td>3+34, 3+55[6]</td><td>Substitution</td></tr>
</table>

The data in (18) also show that certain sandhi patterns are determined by the tone on σ2: for T4, T7, and T8, the tonal substitution pattern is determined by whether σ2 has T1, T2 or T3, T4, T5, T6. Based on this observation, Chan & Ren (1989) argued that Wuxi reflected a historical shift from last syllable dominance to first syllable dominance, and the historical scenario was as follows: at an earlier stage, σ2 carried stress and preserved its tone while σ1 lost its base tone and received a sandhi tone. Stress then shifted to σ1 and the sandhi tone was subsequently spread to the sandhi domain, which resulted in the substitution pattern in present day Wuxi. The occasional relevance of the tone on σ2 in pattern substitution is the reflection of the different sandhi tones on σ1 triggered by different tones on σ2 at the earlier stage.

Lexical frequency effect on Wuxi disyllabic tone sandhi application is not mentioned in the descriptive literature. Yan & Zhang (in press) conducted a productivity test on Wuxi disyllables composed of non-checked Yin tones. The materials included real words (e.g. 开窗 *to open the window*), pseudo words (e.g. 煎伞 *to fry* + *umbrella*, real morphemes but non-existent combinations), and novel words (e.g., tsia55 金 tsia55 + *gold*, an accidental-gap

[6] There is variation between 3+34 and 3+55 for T8+T3, T4, T5, T6.

syllable in the initial position and a real word in the final position). They discovered that there was a significant difference between real words and pseudo words in the productivity of tonal substitution in Wuxi. Tonal substitution is not fully productive in pseudo words, but fully productive in real words. This leaves open the question of whether frequency has an effect on Wuxi disyllabic tone sandhi.

Xu (2007) claimed that some verb-noun, subject-predicate, and coordinate structures could have variant forms of tone sandhi; while some items with a "close connection" between the components only apply tonal substitution. The examples are given in (19). As shown below, the components of 倒霉 (/tɐ323 mɛ13/, *to fall* + *mold*, 'bad luck'), 家生 (/ka53 sæ̃53/, *family* + *to be born*, 'furniture'), and 大小 (/dɐɤ113 siɔ323/, *large* + *small*, 'size') are "closely connected" as a result of high usage frequency, so they can only apply tonal substitution. The "close connection," similar to the Shanghai case, can be interpreted as semantic opacity of the item. In other words, the constituents of a closely-connected lexical item has a semantically opaque relationship. But Xu (2007) did not clearly define the "close connection," nor the relation between lexical frequency and "close connection."

(19) *Wuxi disyllabic tone sandhi variation*

Structure	Item & Gloss	tonal substitution	no sandhi
verb-noun	服毒 /voʔ13 doʔ13/ *to take poison*	[voʔ3 doʔ55]	[voʔ13 doʔ13]
	倒霉 /tɐ323 mɛ13/ *bad luck*	[tɐ44 mɛ55]	
subject-predicate	天好 /tʰiɪ53 hɐ323/ *weather is fine*	[tʰiɪ43 hɐ34]	[tʰiɪ53 hɐ323]

	家生 /ka53 sæ̃53/ *furniture*	[ka43 sæ̃34]	
coordination	风雨 /foŋ53 y13/ *wind and rain*	[foŋ43 y34]	[foŋ53 y13]
	大小 /dɐɤ113 siɔ323/ *size*	[dɐɤ33 siɔ55]	

Furthermore, the productivity test of Yan & Zhang (in press) showed that although there was no difference in tone sandhi application between real [V N] and [M N] items, a difference occurred in novel items. There was a significant interaction between the syntactic structure and sandhi application. The sandhi form applied to 30% of the novel words with an [M N] structure, but only 24% with a [V N] structure; on the other hand, the no sandhi form appeared in only 8% of the novel words with an [M N] structure, but 13% with a [V N] structure. This suggests that [M N] tends to undergo tone sandhi more often, and [V N] tends to maintain its base tones, but variation is expected in both cases.

To sum up, whether there is a frequency effect on sandhi application is currently unclear, but syntactic structure and semantic transparency (the degree of connection) both have an influence on Wuxi disyllabic tone sandhi application.

2.2.2 Trisyllables

Wang (2008) is the only study that describes the sandhi patterns of Wuxi trisyllables. It is reported that the trisyllable applies tonal spreading after applying pattern substitution on σ1σ2, as shown in (20). The sandhi patterns apply to all trisyllables regardless of their morpheme length, i.e., 1+2 and 2+1. For example, when σ1 is in T2 /113/, σ1σ2 undergoes pattern substitution 113 + X → 35 +31, and then the disyllabic sandhi pattern spreads to the whole trisyllable as 35 + 55 + 31. The trisyllabic patterns for T1, T4B, T7B, and T8B do not seem to be the spreading of the disyllabic sandhi pattern exactly, and the sandhi patterns for T4A, T6, T7A and T8A have a default low tone 31 at the right edge.

(20) *Wuxi trisyllabic tone sandhi*

<table>
<tr><td>Base tone</td><td colspan="2">σ1σ2</td><td colspan="2">σ1σ2σ3</td><td colspan="2">Example</td></tr>
<tr><td>T1 /53/</td><td colspan="2">43-34</td><td colspan="2">43-43-34</td><td colspan="2">收音机 /ɕiɐɤ53 in53 ɕi53/ radio</td></tr>
<tr><td>T2 /113/</td><td colspan="2">35-31</td><td colspan="2">35-55-31</td><td colspan="2">人民币 /zən113 min113 bi113/ RMB</td></tr>
<tr><td>T3 /323/</td><td colspan="2">44-55</td><td colspan="2">44-55-55</td><td colspan="2">表兄弟 /piɔ323 ɕioŋ53 di13/ cousin</td></tr>
<tr><td rowspan="2">T4 /13/</td><td colspan="2">A: 33-55[7]</td><td colspan="2">A: 33-55-31</td><td colspan="2">语音学 /ŋ̥y13 in53 ɦiɔ<u>13</u>/ Phonetics</td></tr>
<tr><td colspan="2">B: 43-34[8]</td><td colspan="2">B: 43-43-34</td><td colspan="2">女主角 /ŋ̥y13 tsʮ323 kɔʔ5/ leading actress</td></tr>
<tr><td>T5 /34/</td><td colspan="2">55-31</td><td colspan="2">55-55-31</td><td colspan="2">意大利 /i34 da113 li113/ Italy</td></tr>
<tr><td>T6 /113/</td><td colspan="2">33-55</td><td colspan="2">33-55-31</td><td colspan="2">电影票 /dɪ113 in323 phiɔ34/ movie ticket</td></tr>
<tr><td rowspan="2">T7 /5/</td><td>A: 3-55</td><td rowspan="4">5-5[9]</td><td>A: 3-55-31</td><td rowspan="4">5-5-5</td><td>必需品 /piʔ5 si53 phin323/
necessity</td><td rowspan="4">博物馆
/pɔʔ5 vəʔ<u>13</u> kʊ323/
museum</td></tr>
<tr><td>B: 3-34</td><td>B: 3-32-34</td><td>八宝饭
/paʔ5 pɔ323 vɛ113/
rice pudding</td></tr>
<tr><td rowspan="2">T8 /<u>13</u>/</td><td>A: 3-55</td><td>A: 3-55-31</td><td>学生会
/ɦiɔʔ<u>13</u> sæ̃53 ɦuɛ113/
students' associate</td></tr>
<tr><td>B: 3-34</td><td>B: 3-32-34</td><td>日本人
/zəʔ<u>13</u> pən323 ŋ̥in113/
Japanese</td></tr>
</table>

Yan (ms.) noted that like Shanghai, Wuxi trisyllabic forms can also undergo partial sandhi in addition to tonal substitution. There are three types of partial sandhi depending on the

---

[7] This sandhi form applies when σ2 is T1, T2, T7, or T8.
[8] This sandhi form applies when σ2 is T3, T4, T5, or T6.
[9] This sandhi form applies when σ2 is T7 or T8.

morpheme length of the trisyllables, as shown in (21). Type A applies to 1+2 structure, in which σ1 and σ2 are loosely connected. In this case, σ1 maintains the base tone, and σ2σ3 undergoes disyllabic tonal substitution. For example, in 烤羊肉 (/kʰɔ323 ɦiæ̃113 ɳyɔʔ13/, *to roast* + *lamb*), 烤 (/kʰɔ323/) means 'to roast', and 羊肉 (/ɦiæ̃113 ɳyɔʔ13/) means 'lamb'. It either undergoes tonal substitution [44 55 55] or partial sandhi. When applying partial sandhi, the σ1 tone [323] is preserved, and σ2σ3 undergoes disyllabic tonal substitution [35 31]. Type B applies to 2+1 structure when there is a loose connection between σ2 and σ3. The first two syllables undergo disyllabic tonal substitution, and σ3 maintains its base tone. In 广播站 (/kuɒ̃323 pɐɤ53 tsɛ323/, *radio* + *station*), 广播 (/kuɒ̃323 pɐɤ53/) means 'radio', and 站 (/tsɛ323/) means 'station'. In this case, when applying partial sandhi, σ1σ2 undergoes tonal substitution [44 55], and σ3 maintains the base tone [323]. Type C applies to the rare 1+1+1 structure, in which all three syllables are loosely connected. σ1σ2 undergoes substitution, and σ3 maintains its base tone. For example, in 数理化 (/sɐɤ34 li13 xu34/, *math* + *physics* + *chemistry*), 数 (/sɐɤ34/) means 'math', 理 (/li13/) means 'physics', and 化 (/xu34/) means 'chemistry'. Under partial sandhi, σ1 and σ2 undergo tonal substitution [55 31], and σ3 maintains its base tone [34].

(21) *Wuxi trisyllabic sandhi variation*

Type	Syntactic structure	Item & Gloss	Tonal substitution	Partial sandhi
Type A	modifier-noun	蓝宝石 /lɛ113 pɔ323 zaʔ13/ *sapphire*	[lɛ35 pɔ55 zaʔ31]	[lɛ113 pɔ44 zaʔ55]

1+2	verb-noun	烤羊肉 /kʰɔ323 ɦiæ̃113 ȵyɔʔ13/ *to roast lamb*	[kʰɔ44 ɦiæ̃55 ȵyɔʔ55]	[kʰɔ323 ɦiæ̃35 ȵyɔʔ31]
Type B 2+1	modifier-noun	广播站 /kuɒ̃323 pɐɤ53 tsɛ323/ *radio station*	[kuɒ̃44 pɐɤ55 tsɛ55]	[kuɒ̃44 pɐɤ55 tsɛ323]
	adverb-verb	排排坐 /ba113 ba113 zɐɤ13/ *to sit in a row*	[ba35 ba55 zɐɤ31]	[ba35 ba31 zɐɤ13]
Type C 1+1+1	coordination	数理化 /sɐɤ34 li13 xu34/ *sciences*	[sɐɤ55 li55 xu31]	[sɐɤ55 li31 xu34]
	verb-noun	等交车 /tən323 kɔ53 tsʰɐɤ53/ *to wait for the shift*	[tən44 kɔ55 tsʰɐɤ55]	[tən323 kɔ43 tsʰɐɤ34]

Yan (ms.) also found that some trisyllables can only undergo tonal substitution, but unlike Shanghai, no item can only undergo partial sandhi. For example, in (22), when the noun 证 (/tsən34/, *certificate*) is combined with two different modifiers: 'to work', and 'to marry', the sandhi applications are different. 工作证 (/koŋ53 tsɔʔ5 tsən34/, *to work + certificate*) only can undergo tonal substitution; 结婚证 (/tɕɪʔ5 xuən53 tsən34/, *to marry + certificate*), on the other hand, can undergo either tonal substitution or partial sandhi. The factors that influence the different sandhi behaviors are not clear, and it is possible that lexical frequency and semantic transparency may have an effect here, as we have seen in Shanghai.

(22) *The variant sandhi application of Wuxi trisyllables*

Examples	Tonal substitution	Partial sandhi
工作证 /koŋ53 tsɔʔ5 tsən34/ *work permit*	[koŋ43 tsɔʔ43 tsən34]	

结婚证 /tɕɪʔ5 xuən53 tsən34/ *marriage certificate*	[tɕɪʔ3 xuən55 tsən31]	[tɕɪʔ3 xuən55 tsən34]

Moreover, Yan (ms.) calculated the counts of trisyllables that can apply both substitution sandhi and partial sandhi based on Wang (2008)'s word list of 505 trisyllables. The judgment was made by a 28-year-old female native Wuxi speaker. She was asked to judge the acceptability of applying sandhi and partial sandhi to each lexical item. The results showed that for the 1+2 structure, 92% of the 13 [V N] could undergo both substitution sandhi and partial sandhi, and the rest could only undergo partial sandhi; while 14% of the 85 [M N] could have variable forms, and the rest could only undergo substitution sandhi. For 2+1 [M N], 11% of them could undergo both substitution sandhi and partial sandhi, and 89% of them could only undergo substitution sandhi. Therefore, in 1+2 structures, [M N] tends to undergo tonal substitution more readily than [V N] — a finding similar to that in Shanghai. However, 1+2 [M N] and 2+1 [M N] items may not differ significantly in sandhi application, which is in contrast with the Shanghai pattern.

In general, unlike Shanghai, there is only a very limited literature on variation in Wuxi trisyllabic tone sandhi. Previous studies indicate that Wuxi trisyllabic tone sandhi application is affected by syntactic structure and morpheme length. What roles lexical frequency and semantic transparency play is still unknown. Considering the fact that Wuxi tone sandhi pattern is also left-dominant like Shanghai, lexical and semantic properties may also influence sandhi application of Wuxi trisyllables, but further study is necessary to understand its nature.

2.3 Shanghai & Wuxi tone sandhi comparison

From the discussion above, it is clear that Shanghai and Wuxi differ in tone sandhi patterns. But whether the different sandhi patterns influence the nature of tone sandhi variability has not been investigated. In what follows, I review previous productivity studies that shed light on the relationship between the tone sandhi pattern and sandhi application and use these findings as a basis for hypotheses on how the variation findings in Shanghai and Wuxi may differ.

Nonce probe tests in which speakers are asked to respond to novel words in environments that facilitate the application of phonological processes may provide evidence for the productivity of phonological processes (Berko, 1958; Bybee & Pardo, 1981; Hayes, Zuraw, Siptár, & Londe, 2009; Hayes & White, 2013; Zuraw, 2007, among other). Recent productivity studies have shown that the Chinese sandhi patterns are not entirely productive in novel words. Most of these studies have been conducted in right-dominant sandhi systems, such as Taiwanese (Hsieh, 1970; Wang, 1993; Zhang & Lai, 2008; Zhang, Lai, & Sailor, 2011), Mandarin (Zhang & Lai, 2010), and Tianjin (Zhang & Liu, 2011). These studies indicate that opacity[10] has an effect on sandhi productivity, as Taiwanese tone sandhi, which involves a circular chain shift, is not entirely productive, while transparent sandhi processes in Mandarin and Tianjin have been shown to be more productive. Dialects with left-dominant sandhi that have been tested include Shanghai (Zhang & Meng, 2016) and Wuxi (Yan & Zhang, in press).

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[10] A phonological rule P, A → B / C__D, is opaque if the surface structures are any of the following: (a) instance of A in the C__D environment, or (b) instance of B derived by P in environments other than C__D (Kiparsky, 1973).

Zhang & Meng (2016) investigated the productivity of Shanghai left-dominant sandhi in both disyllabic real and novel items. They found that overall, left-dominant tonal extension was relatively productive. For [M N] words, f0 comparisons between real and novel words showed that the pitch contour over the disyllabic novel [M N] words represented the contour of the base tone of the first syllable, just like in real [M N] words; this suggests a productive application of rightward tonal extension. On the other hand, for [V N] phrases, the pitch contour of novel [V N] phrases preserved the base tonal contours of the two syllables, just like in real [V N] phrases. One additional interesting finding is that there were significantly more cases of left-dominant tonal extension in novel [V N] phrases than real ones across the tonal combinations (Zhang, personal communication).

Yan & Zhang (in press) examined the productivity of Wuxi disyllabic tone sandhi, focusing on the tonal combination of three non-checked Yin tones. As we can see in (23), these three Yin tones are involved in a circular chain shift in tonal substitution: before spreading to the disyllable, the falling tone 53 on the first syllable needs to be substituted by a dipping contour; the dipping tone 323 needs to be substituted by a rising contour, and the rising tone 34 needs to be substituted by a falling contour. Therefore, these sandhi patterns are combinations of both transparent spreading, which has been shown to be relatively productive as in Shanghai, and opaque substitution, which has been shown to be relatively unproductive as in Taiwanese.

(23) *Tonal combinations under investigation:*

σ2 / σ1	T1 [53]	T3 [323]	T5 [34]	Examples
T1 [53] (A)	43+34 (B)			新鲜 (sin53 siɪ53) *fresh*
T3[323] (B)	33+44 (C)			胆小 (tɛ323 siɔ323) *coward*
T5[34] (C)	55+31 (A)			奋斗 (fən34 tɛi34) *to fight for*

A → B
↖ ↙
C

The results showed that unlike Shanghai, Wuxi tonal substitution is not fully productive in novel disyllable items regardless of the syntactic structure: when the first syllable was an accidental gap in the Wuxi syllabary, the speakers tended to simply spread its base tone rather than the expected substituted tone.

The productivity comparison between Shanghai and Wuxi shows that the different sandhi patterns in the two dialects lead to different productivity patterns, i.e., phonological transparency leads to productivity, as in Shanghai, while opacity results in unproductivity of the phonological process, as in Wuxi. Yan & Zhang (in press) argued that the surface forms of existing words that exhibit the opaque patterns are listed in the lexicon (Zuraw, 2000), while transparent patterns can be derived by markedness-faithfulness interaction. The lexically-listed opaque patterns in Wuxi may be more influenced by lexical frequency compared to the transparent patterns in Shanghai. Given the authors' personal observation that novel [V N] phrases apply more left-dominant tonal extension than real [V N] phrases in the Shanghai productivity experiment (Zhang & Meng, 2016), if we consider novel [V N] phrases as extremely low-frequency phrases, then infrequent [V N] items in Shanghai may be more likely to apply left-dominant tonal extension than frequent ones, while frequent [V N] items tend to apply right-dominant tonal reduction more readily. Due to the lexical listedness of the tone sandhi patterns in Wuxi (Yan & Zhang, in press), frequent [V N] items in Wuxi may be more likely to apply left-dominant tonal substitution than infrequent ones.

Furthermore, unlike Shanghai's pattern extension, Wuxi's tonal substitution pattern may be determined by the second syllable, indicating a trace of right-dominance (Chan & Ren, 1989). Yan (ms.) also found that in Shanghai 1+2 [M N] items are more likely to undergo tonal extension than 2+1 [M N] items, but in Wuxi 1+2 and 2+1 [M N] items do not differ significantly. Given these, when applying sandhi to trisyllables with different morpheme length combinations (1+2 [M N] versus 2+1 [M N]), the two dialects may behave differently. In particular, 1+2 [M N] items in Shanghai, due to its stronger left-dominance in the sandhi domain and therefore a greater tendency for stress clashes if it is parsed as two domains, may be more likely to apply left-dominant sandhi than 2+1 [M N] items. On the other hand, the trace of right-dominance in Wuxi may cause 2+1 [M N] items to have a stress clash if it is parsed as two domains, in which case, 2+1 [M N] items in Wuxi would tend to undergo left-dominant sandhi in one domain. Also, due to the left-dominant tonal substitution pattern, 1+2 [M N] items in Wuxi tend to apply sandhi in one domain as well. Hence, the difference between 1+2 and 2+1 [M N] items in Wuxi may be smaller than that in Shanghai.

2.4 Summary

To summarize, the existing literature suggests that lexical frequency, syntactic structure, semantic transparency, and morpheme length may all have an effect on Shanghai tone sandhi application. However, the intuition-based descriptions have not been tested experimentally with native speakers. On the other hand, in Wuxi, the effect of syntactic structure was only observed in a disyllabic productivity test, and the syntactic effect on trisyllables was based on the judgment of one speaker. Whether lexical frequency, semantic transparency and morpheme length influence Wuxi tone sandhi application is unclear. The current study aims to provide us with a better understanding on Shanghai and Wuxi tone sandhi variation.

By examining both Shanghai and Wuxi dialects, we can also examine whether the findings in Wuxi parallel those in Shanghai. Given that Wuxi and Shanghai both have left-dominant sandhi, the effects of lexical frequency, semantic transparency, syntactic structure, and morpheme length on Wuxi tone sandhi variation may be similar to those on Shanghai. However, based on the results of productivity tests and the sandhi patterns, these factors may pattern differently in the two dialects, e.g., lexical frequency may have different influences on the two dialects.

In the next chapter, the effects of the factors that are related to variable tone sandhi application on general morpho-phonological processes will be reviewed.

Chapter III: FACTORS AFFECTING TONE SANDHI APPLICATION

In this chapter, we will review how lexical frequency influences variable processes, how semantic transparency affects compound processing and how it is related to sandhi application, and how syntactic structure and morpheme length affect variable sandhi application.

3.1 Lexical frequency

Frequency effects on phonological variation have been widely documented in different languages. Phonological processes of simplification or reduction often affect frequent words more than infrequent words. In this section, we will first review processes that are more likely to apply to words with high frequencies, including consonant and vowel deletion or reduction, then discuss variable processes which influence the least frequent words more often, including the regularization of English past tense and French liaison application.

One well-studied case of lexical frequency effect is English *t/d* deletion in cluster-final position. This process is considered to be a gestural reduction process: as the articulatory gesture for the coronal stop gradually reduces (Browman & Goldstein, 1990), the perception of the consonant becomes more easily obscured by phonetic contexts, and lexical items with coronal stops would gradually restructure. Bybee (2000) proposed that the more frequently a word is used, the more reduced the word would become, especially in phonetic environments that are felicitous to deletion. In her study, she selected 2,049 word tokens with /-Ct/ or /-Cd/ coda from Santa Ana (1991)'s corpus of Chicano English and investigated the rate of *t/d* deletion. Based on Francis & Kučera (1982)'s frequency data, words with an appearance of 35 times per million or above were considered as high frequency, and those with an appearance below 35 times per million were considered as low frequency. The result showed that the rate of *t/d* deletion in Chicano English was significantly higher in high-frequency words than in the low-frequency words.

Coetzee (2009a) further examined the interaction between lexical frequency and English *t/d* deletion by studying Columbus English *t/d* deletion in three conditions, including Pre-vocalic, Pre-consonantal, and Pre-pausal contexts. 20,145 words were selected from the Buckeye Corpus (Pitt, Dilley, Johnson, Kiesling, Raymond, Hume, & Fosler-Lussier, 2007). The lexical frequencies came from CELEX (Baayen, Piepenbrock, & Gulikers, 1995), and were log-transformed. The results showed that the deletion rate was the highest in Pre-consonantal position, followed by Pre-vocalic and Pre-pausal, however, there was a positive correlation between frequency and deletion rate in all three conditions. It indicates that except for phonological properties, lexical frequency also has an effect on the variation in *t/d* deletion rate, i.e., phonological reduction processes are constrained by both phonetic contexts and frequency.

Coetzee (2009b) conducted another rating experiment on English *t/d* deletion with a group of six southeastern Michigan subjects. 15 mono-morphemic English words with an [-st] coda cluster were selected and divided into two lists based on the average frequency in Kučera & Francis (1967). Words with higher frequencies than the average were in the high-frequency list, and words with lower frequencies than the average were in the low-frequency list. The stimuli were placed in the sentence-final position, and *t/d* occurred in Pre-vocalic, Pre-consonantal, and Pre-pausal contexts. Forty-five sentences were presented in written form to the participants, and they were asked to rate to what extent they would pronounce the sentences without the /t/ in a casual speech situation on a 10-point rating scale. Ratings were averaged by item, and a repeated-measure ANOVA was conducted with frequency (high, low) and context (Pre-vocalic, Pre-consonantal, Pre-pausal) as independent variables. There was a significant effect for both frequency and context, but no interaction between the two factors. It suggests that both grammatical and nongrammatical factors have effects on *t/d* deletion, but each effect is independent. In other words, regardless of lexical frequency, deletion is the most likely to apply in pre-consonantal position, and the least in phrase-final position; words with higher frequency are more likely to apply deletion across different contexts. In conclusion, Coetzee (2009a, 2009b) argued for the necessity of considering both grammar and frequency when analyzing a variable process. Grammar plays the primary role of setting the limits of variation in different contexts, and lexical frequency only determines how the variation can be realized within the parameters set by the grammar.

Similar to English, Dutch also has optional *t* deletion and shows the same interaction between frequency and deletion rate. Goeman & van Reenen (1985) discussed the Dutch *t* deletion in final consonant clusters in present and past tense forms based on the Uit den Boogaart (UitdB) corpus (1975). They found that in both present and past tense forms, *t* deletion applied more often for words with high frequencies. For example, the word *wast* 'wash-3SG PRESENT' had a frequency UitdB of 2, and *moest* 'must-3SG PRESENT' was 160, the corresponding deletion rates were 14% *versus* 42%. This observation provides further evidence that lexical frequency influences the variable consonant deletion process.

There are also other consonant reduction processes that apply more often in high-frequency words. Kawahara (2011a) investigated the devoicing of voiced geminates in Japanese loanwords using a naturalness rating task. In Japanese loanword phonology, geminates can optionally devoice if they co-occur with another voiced obstruent, but singletons do not devoice in the same condition. For example, ba**dd**o → ba**tt**o 'bad' is legal, but re**dd**o → *re**tt**o 'red' is illegal, nor is gi**b**u → *gi**p**u 'give'. The participants were asked to rate the naturalness of the devoicing of singletons and geminates in various contexts. The stimuli were all real Japanese loanwords, presented in katakana orthography (used for loanwords). Amano & Kondo (2000)'s Japanese lexical corpus was used to count the frequencies of the stimuli. The results showed that there was a significant correlation between lexical frequency and naturalness rating in the geminates. The devoicing of high-frequency words was rated to be more natural. Kawahara (2011b) further confirmed the lexical frequency effect on Japanese geminate devoicing in loanword with a larger set of data.

Furthermore, the effect of lexical frequency on variation is also found in vowel reduction. Hooper (1976) examined the relationship between English vowel reduction and word frequency based on Francis & Kučera (1982)'s frequency counts. The results showed that words with higher frequency were more likely to have vowel reduction. For instance, the production of high-frequency words such as *every* (a frequency of 492 times per million) tends to have no schwa; intermediate-frequency words such as *salary* (a frequency of 51 times per million) tend to have syllabic [ɹ̩], and low-frequency words such as *artillery* (a frequency of 11 times per million) tend to maintain the schwa and the [r].

Similar results have been found in other languages as well. Racine & Grosjean (2002) investigated schwa deletion in Swiss French by asking native speakers to tell four stories with words that have optional schwa deletion. To predict the rate of schwa deletion, they calculated the correlation coefficients of seven factors, including lexical frequency, the frequencies of the variants (the token frequencies of lexical items that undergo schwa deletion and those do not), consonant context (the consonants preceding and following the schwa), force of articulation (the co-articulatory effects of consonants preceding and following the schwa), the deletion rate of the preceding word, articulation rate, and discursive rate (the rate of speech deviated from the topics of the stories). They found that there was a correlation between lexical frequency and the rate of schwa deletion: words with higher lexical frequency applied more schwa deletion.

On the other hand, some variable processes are more likely to apply to less frequent words. For instance, Hooper (1976) examined the application of English regular past tense. The results showed that regular past tense tends to apply more to low-frequency words: for example, the past tense form of the lower frequency *weep* could be variably *weeped* or *wept*. while *kept* is consistently used as the past tense form for *keep*, a highly frequent word. She argued that that the pattern is due to analogical change influencing low-frequency words first.

French liaison has a similar frequency effect (Bybee, 2001). Liaison refers to a situation in which a word-final consonant occurs before a vowel-initial word, while in other environments the word-final consonant does not appear. Liaison application is obligatory in determiners and clitic pronouns, such as *vos* [z] *enfants* 'your children' and *nous* [z] *avons* 'we have', and is considered to be variable in other contexts, including plural /-z/ in noun-adjective constructions, person/number endings, a small set of prenominal adjectives in the masculine singular, plurals of the same adjectives, prepositions, adverbs, particles, and fixed phrases (Tranel, 1981; Morin & Kaye, 1982). For instance, the consonant [t] is optional in the preposition *pendant* in *pendant un mois* 'for a month'. Ågren (1973) showed that among the forms of the verb *être* 'to be' in his data, the percentages of liaison could be predicted by the token frequencies in that high-frequency forms had high percentage of liaison. However, there were two exceptions. Low-frequency present particle *étant* had a high percentage of liaison (76%), while the more frequently used first person singular particle indicative form *suis* had a lower percentage of liaison (47%). Ågren (1973) explained that in the former case, *étant* + Past Particle, 4 out of 7 liaison cases were the fixed phrase *étant entendu* 'being understood', and in the latter case, *je suis* 'I am' might be reduced to [ʃɥi] that was not compatible with liaison.

Bybee (2001) further analyzed the variation pattern of French liaison, and argued that no liaison is the regular form in French. There are two constructions[11] for the plural noun-adjective expressions, one is the more general plural determiner + noun + adjective, the other is plural determiner + noun + -z- + [Vowel]-adjective, which specifically applies to vowel-initial adjectives (Morin & Kaye, 1982). Moreover, the type frequency of the first

[11] "Construction" here refers to a sequence of semantically or functionally related morphemes or words when they are used together (Bybee, 2001).

construction is higher than that of the second one, suggesting that the first construction is more productive. Therefore, the loss of liaison in the first construction is considered to be the more general schema for the speakers, while the second construction with [z] preceding vowel-initial adjectives is more restricted. Therefore, Bybee (2001) claimed that the loss of liaison is the regular form in French, and liaison is the irregular form. When variation is observed in cases with vowel-initial adjectives, speakers tend to choose the more general schema for lower frequency items. She further examined the inflected forms of the verb *être* 'to be', which behave differently with respect to liaison application. High-frequency forms are more likely to have the liaison consonant than low-frequency ones, since the more specific liaison construction is preserved by frequency. For a low-frequency form, the irregular liaison may be difficult to access compared to a high-frequency form. Therefore, regular non-liaison tends to apply.

To explain why alternation occurs across word boundaries, Bybee (2001) proposed a usage-based solution. Processing units are formed for words that are often used together, in which case, they will be retrieved as a chunk rather than be gathered morpheme by morpheme or word by word each time they are used. Phonological change may create variant forms of words and hence alternation in a large chunk of utterance. She further claimed that usage frequency can determine syntactic constituency, as Bybee & Scheibman (1999) found that items that commonly co-occur have a tighter constituent structure than those that are less used together. Semantic and functional properties determine what are used together in utterances, but usage frequency determines the constituency.

Overall, earlier research has shown that there is a correlation between lexical frequency and variable processes, either in a positive direction or a negative one. For regular sound changes, such as English *t/d* deletion, or grammaticizing phrases that undergo extreme reduction, such as *I am going to* reducing to *I'm gonna* [ˈaimə̃ɾ̃ə], these processes are more likely to apply in high-frequency items. For analogical change that involves the minimization of alternation, such as English regular past tense and French liaison, the processes are more conservative in more frequent items (Bybee & Thompson, 2000; Bybee, 2001; Phillips, 2001). According to Bybee (1985, 2001), some items from the regular patterns of the language are excluded by such a conserving frequency effect. High-frequency items have a high level of lexical strength, in which case, they are firmly established as individual patterns. Even though general patterns take place in the language, these high-frequency items are less likely to alter. The strong lexical strength of the frequently used items leads to easier access and more resistance to certain forms of change.

These studies have provided a foundation for the current study on the effect of lexical frequency on tone sandhi variation. Based on the literature, phonological reduction tends to apply to more frequent words, and more frequent phrases are more resistant to regularization. If so, for [M N] words in Shanghai, spreading tone sandhi, which reduces tonal contour complexity and the number of tonal contrasts in the sandhi domain, may apply to high-frequency words more often, i.e., the more frequent an [M N] item is, the more likely it applies the sandhi form. For [V N] phrases, high-frequency [V N] phrases may be more resistant to the more general sandhi form and, therefore, keep the irregular no sandhi form, while low-frequency ones may have the tendency to minimize the alternation and undergo regular tone sandhi. In other words, more frequent [V N] phrases may prefer no sandhi application, while less frequent ones may prefer tone sandhi. This corresponds to our prediction based on the productivity results discussed in §2.3. On the other hand, for Wuxi, due to its lexically-listed opaque patterns, more frequent items will be more likely to undergo the substitution sandhi regardless of the syntactic structure.

3.2 Semantic transparency

The semantic transparency of a compound refers to whether the compound can be comprehended through its constituent morphemes or must be represented as a whole in the mental lexicon. For example, the meaning of *bedroom* can be easily inferred from *bed* and *room*; however, the meaning of *hogwash* 'nonsense' cannot be directly derived from *hog* and *wash*. Therefore, the compound *bedroom* is semantically transparent while *hogwash* is semantically opaque (Libben, Gibson, Yoon, & Sandra, 2003). Earlier literature has shown that semantic transparency plays an important role in compound processing. The connection between semantic transparency and tone sandhi variation will be discussed after a brief review of previous studies on semantic transparency.

Several studies have shown that semantically transparent and opaque compounds are processed differently. Sandra (1990) examined the influence of semantic transparency on Dutch speakers' compound processing using a visual semantic priming paradigm. The results showed that semantically related constituents only primed semantically transparent compounds (e.g., *death* primed *birthday*), but not opaque compounds (e.g., *moon* did not prime *Sunday*). Sandra argued that only the constituents of semantically transparent compounds are activated during a morphological decomposition procedure. Zwitserlood (1994) further investigated the same issue with compounds serving as primes and constituents serving as targets. The task was to make lexical decisions on the constituents immediately after seeing the compounds. The results showed that both semantically transparent and opaque compounds primed the constituents. In the second experiment, Zwitserlood made a distinction between fully opaque compounds (*klokhuis*, 'core of an apple', literally = clock + house) and partial opaque compounds (*drankorgel*, 'a drunk', literally = drink + organ) and used a semantic priming paradigm. The experiment found priming effects for transparent and partial opaque compounds, but not for fully opaque and pseudo compounds (e.g., *boycott*). It was concluded that there was no connection between fully opaque compounds and their constituents at the semantic level.

Based on the above findings, Libben (1998) argued that both transparent and opaque compounds are processed through morphological decomposition at the lexical representation level. The lack of semantic-priming effect on opaque compounds resulted from the absence of connections between opaque compounds and their constituents at the semantic level. For instance, *deadline* can activate the lexical representations of *deadline*, *dead*, and *line*. The lexical representation of *deadline* is linked to its semantic representation as a whole word, but there are no direct connections between the lexical representation of *deadline* and the semantic representations of *dead* and *line.* In this case, although activating *dead* and *line* at the lexical level could activate their semantic meanings, there is still no direct connection with *deadline*. He analyzed the data from an aphasic patient to support the argument that he proposed. The patient exhibited a curious pattern of semantic impairment. She was unable to give superordinate terms to characterize lexical items, for example, using *furniture* to characterize *chair*, *table*, and *sofa*. She also could not make semantic classification. For example, when she was given *tulip*, *carnation*, *rose*, and *oak*, and asked to point out which one of these did not belong, she chose *carnation* instead of the correct target *oak*. Her reasoning was that ‘because it comes in a can’.[12] The patient was presented with 120 existing compounds and 120 pseudo compounds (e.g., *redberry*) in a lexical decision test. There was a significant difference between real and pseudo compounds in her response, indicating that she was not treating all compounds as if they were newly constructed. When interpreting real compounds, she tended to produce transparent reading (e.g., *birdhouse* “a house for a bird,” *blueprint* “a print that is blue”). When interpreting real opaque compounds, she mixed the constituent meanings and whole-word representation. For example, for the word *yellowbelly*, her interpretation was “a yellow stomach … a chicken”. Libben argued that the patient failed to inhibit meanings of the constituents at the semantic level from interfering with the interpretation of the compounds.

Libben et al. (2003) investigated the processing of English nominal compounds (head-final) by conducting a word recognition task and a visual priming task. The compounds were classified in four categories according to the semantic transparency of the two constituents: TT (transparent-transparent, e.g., *bedroom*), OT (opaque-transparent, e.g.,

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[12] Carnation is a brand of food products, which is well known for its evaporated milk that is sold in a can.

chopstick), TO (transparent-opaque, e.g., *doughnut*), and OO (opaque-opaque, e.g., *deadline*). The word recognition task compared the reaction time between normal and broken compound (*bedroom* versus *bed room*). The results showed that TT and OT compounds were responded to more quickly, indicating that morphological headedness may have an effect on compound processing. Also, all compounds took longer to be recognized when they were presented in separate forms. They suggested that all compounds had their own representations at the lexical level. The priming task had three types of primes, for example, for the word *hogwash*, the neutral prime is *tree*, the initial prime is *hog*, and the final prime is *wash*. The findings were consistent with those in the first task: although all compounds could be primed by their constituents, compounds with transparent heads (TT and OT) were easier to process than compounds with opaque heads (OO and TO). OO compounds had the longest response time, followed by the TO compounds; TT and OT compounds showed similar priming patterns. Libben et al. (2003) concluded that both initial and final constituents primed all types of compounds, but compounds with opaque heads were more difficult to process. Therefore, when considering compound processing, we need to consider the opacity of individual morphemes, their positions, and their semantic roles in the whole compound.

Fiorentino & Fund-Reznicek (2009) tested the priming effect for the non-head morpheme and head morpheme on compound processing via a mask priming study (Foster & Davis, 1984). Two experiments were conducted. Experiment 1 investigated the priming effect of non-head morpheme. In a mask priming task, each trial starts with a 500 ms forward mask (e.g., #####), and the number of # is equal to the letter-length of the following prime. The visual representation of the prime in lower-case will then appear for 50 ms, and followed by the target in upper-case instantly. The target will remain on the screen until the participant responds or a 2500 ms timeout is reached (Forster, 1999, 2003; Masson & Isaak, 1999). For example, *honeymoon* is the masked prime, and the non-head constituent *honey* is the target. The trial would be ######### – honeymoon – HONEY. The approach facilitates the activation of morphological information, but the prime lasts so briefly that the participant will not be aware of the presence or activate the semantic information. The results showed that there was no significant difference between the transparent and opaque compound conditions, but a significant priming effect for the non-head constituent in general. This suggests that morpho-orthographic segmentation effects apply to masked compounds. Experiment 2 examined the priming effect of head morpheme, and ######### – honeymoon – MOON is a possible trial. The results were consistent with those in Experiment 1, suggesting that masked English compound primed its constituent regardless of semantic transparency or headedness. This is in accordance with the results of Experiment 1 in Zwitserlood (1994). The finding indicates that morpheme-level representation during initial visual word recognition is fundamental in lexical processing.

Marelli & Luzzatti (2012) conducted a lexical decision task and an eye-tracking task to test the effects of frequencies, headedness, and semantic transparency in Italian nominal compound processing, including both head-final and head-initial compounds. The results of the first experiment showed that there were significant interactions among frequencies, headedness, and semantic transparency of the constituent, suggesting that frequency facilitated the response for transparent and head-final compounds. The second experiment is a sentence reading task using eye-tracking paradigm. The results paralleled the findings of the first experiment. High-frequency words elicited shorter total fixation time than low-frequency words. With the same degree of semantic transparency, head-final compounds are easier to process than head-initial compounds in Italian. Marelli & Luzzatti (2012) confirmed the effect of semantic transparency in Italian compound processing, and showed that the headedness effect mainly emerged for the rightmost constituent.

These psycholinguistic studies showed that although transparent and opaque compounds are both processed through morphological decomposition at the lexical representation level, semantic transparency still plays an important role in compound processing at the semantic level. Based on these results, it is hypothesized that if the word form of an opaque compound is connected with its semantic representation as a whole unit, then the sandhi domain will be the whole unit. In this case, semantically opaque compounds will be more likely to apply tone sandhi in one tonal domain. On the other hand, for semantically transparent compounds, there are connections between the semantic representation of the word form and the semantic representation of the morphological constituents in the compound. Activation of the constituents at the lexical level could activate the transparent compound. It is therefore hypothesized that transparent compounds may have a stronger tendency to apply tone sandhi in two separate tonal domains. The role of semantic transparency on tone sandhi variation will be further investigated in the experiments.

3.3 Syntactic structure

There are a large number of models for the nature of the syntax-phonology interface (Beckman & Pierrehumbert, 1986; Cooper & Paccia-Cooper, 1980; Elordieta, 2008; Hayes, 1989; Kaisse, 1985; Nespor & Vogel, 1986; Odden, 1987, 1994, 1996, 2000; Pierrehumbert & Beckman, 1988; Selkirk, 2011; among other). These theories can be categorized into two main groups (Elordieta, 2008). One is the Direct Reference Theory, which argued that phonological processes are directly sensitive to syntactic structures. Syntactic information, such as c-command,[13] directly constrains the domains of application for phonological processes (Kaisse, 1985). The other is the Prosodic Hierarchy Theory, which claimed that prosodic structure mediates between syntactic and phonological processes (Chen, 1987; Hayes, 1989; Nespor & Vogel, 1982, 1986; Selkirk, 1986). Under this theory, a sentence is organized with a Prosodic Hierarchy, and the phonology and phonetics of the sentence are defined in terms of the units of Prosodic Hierarchy. The Prosodic Hierarchy includes a set of prosodic constituents, e.g., syllable, foot, prosodic word, phonological phrase, intonational phrase, and utterance (Selkirk, 1981, 1984, 1986; Nespor & Vogel, 1986). Putting aside these theoretical differences, this section simply focuses on phonological processes that are sensitive to syntactic structure.

One example is English phrase stress assignment. According to Chomsky & Halle (1968), local main stress prominence tends to fall on the rightmost constituent within in phrase.

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[13] C-command refers to the situation that word W1 dominates word W2 if W1 is above W2 in the tree.

For example, in the sentence: $_{S}[_{NP}[$A senator from Chicago$]_{NP}$ $_{V}[$won[the last election$]_{VP}]_{S}$, the rightmost constituent *Chicago* in the first noun-phrase (NP) is more prominent than *senator*, within the verb-phrase (VP) the rightmost constituent *election* is more prominent than *won*, and *election* has the greatest prominence in the sentence due to its position. This indicates that the phonological properties of elements in a sentence are related to the syntactic position they appear in (Selkirk, 2011).

Trunkenbrodt (1995, 1999) illustrated the effect of syntactic structure to vowel shortening in two Bantu languages: Kimatuumbi and Chi Mwi:ni. In Kimatuumbi, a long vowel is shortened when it occurs in a word in non XP-final position, as shown in (24). In (24a) the long vowel in *mpúunga* 'rice' becomes a short vowel since the word is not in the final position in the NP, while the long vowel in *baándu* 'people' cannot be shortened, as the word is in the final position of the NP. In the phrase of (24b), neither *mpuungá* 'rice' nor *waabói* 'has-rotted' meets the syntactic environment to apply long vowel shortening because both are the final word in the XP.

(24) a. $[_{N}[$*mpúunga*$]$ *wá* $[$*baándu*$]_{NP}]_{NP}$ → *mpunga wá baándu*
rice of people
'people's rice'

b. $[$*mpuungá*$]_{NP}$ $[$*waabói*$]_{VP}$ → *mpuungá waabói*
rice has-rotted
'The rice has rotted.'

A similar pattern is attested in Chi Mwi:ni. In (25), only the long vowel in *panziize* 'he ran' can be shortened as the word is non-phrase-final. The long vowels in *choombo* 'vessel' and *mwaamba* 'rock' cannot undergo shortening since they are in the final position of the corresponding NP.

(25) [*panziize* [*choombo*]$_{NP}$ [*mwaamba*]$_{NP}$]$_{VP}$ → *panzize choombo mwaamba*
he-ran vessel rock
'he ran the vessel onto the rock'

Chen (1987) provided an analysis of Xiamen Chinese tone sandhi that is governed by syntax. He argued that tone sandhi applies within a domain defined by syntactic categories in Xiamen. For instance, sandhi application differs for predicate modifiers (ad-V) in (26) and sentence modifiers (ad-S) in (27). The symbol '=' indicates cliticization, and '#' indicates tone sandhi domain. As we can see in (26), the ad-Vs *luan-tsu* 'mindlessly' and *k'un-lat* 'diligent' cliticize to the corresponding verbs *kong* 'talk' and *tak-ts'eq* 'study' to form one tone sandhi domain. While in (27), ad-Ss *kai-tsai* 'fortunately' and *tong-lian* 'of course' do not cliticize to the verbs, and hence constitute separate tonal domains.

(26) a. yi luan-tsu = kong
he mindlessly talk
'He is talking mindlessly'

b. tsit e gin-a # k'un-lat = tak-ts'eq
this CI boy diligent study
'This boy studies hard'

(27) a. gua kai-tsai # tse tsit pan ki
I fortunately take this CI flight
'Fortunately, I am taking this flight'

b. yi tong-lian # t'iang yin bo # e we
he of course listen to his wife E talk
'Of course, he listens to his wife'

Selkirk & Shen (1990) analyzed cases of Shanghai tone sandhi that are regulated by syntactic structure. They argued that a function word does not form its own sandhi domain, but instead cliticizes to the lexical word on the left. (28) shows that due to different syntactic structures, the tone sandhi domains are formed differently (parenthesis indicates tone sandhi domains). A VP with pronominal object *'noN* 'you' and particle *leq* 'has' forms one sandhi domain as in (28a), while a VP with a lexical object *'mo* 'horse' forms two sandhi domains as in (28b). In 'has hit the horse', the function word *leq* 'has' is attached to the lexical word *'mo* 'horse' on the left. Additional examples are listed in (29). In (29a), the function word *'noN* 'you' cliticizes to the left-side verb *peq* 'give' to form one sandhi domain, so the phrase 'give you vegetables' has two sandhi domains; while in (29b) each lexical word forms its own sandhi domain, so the phrase 'give horse grass' has three sandhi domains.

(28) a. (V Pro Prt)
taN 'noN leq
hit you has
'has hit you'

b. (V) (N Prt)
taN 'mo leq
hit horse has
'has hit the horse'

(29) a. (V Pro) (N)
peq 'noN tshe
give you vegetables
'give you vegetables'

b. (V) (N) (N)
peq 'mo tshaw
give horse grass
'give horse grass'

Syntactic structure also has an effect on the variant forms of Mandarin tone sandhi application. As shown in (1a), Tone 3 becomes Tone 2 before another Tone 3 in Mandarin. Zhang (1997) provided a comparison between trisyllables with different syntactic structures, as shown in (30). (30a) is a propositional phrase; it first builds a disyllabic foot from left to right, and applies the T3 sandhi rule, resulting in (T2 T3) T3, then, the unfooted syllable joins the adjacent foot, and the T3 sandhi rule applies again, so the surface representation becomes (T2 T2 T3). On the other hand, (30a) could also have the surface representation T3 (T2 T3). In this case, the unfooted preposition (σ1) can form its own tonal domain, and σ2σ3 form another. The T3 sandhi rule applies to σ2σ3, and σ1 loses the environment of T3 sandhi. The surface representation will be T3 (T2 T3). As Zhang (1997) pointed out, prepositions that are not followed by a pronoun avoid undergoing tone sandhi. If there is no syntactic effect, the surface form T3 (T2 T3) would be illegal, because a monosyllable cannot form an independent sandhi domain. In (30b), the subject-predicate structure can only get (T2 T2 T3) as surface representation. Thus, Mandarin T3 sandhi application is affected by the syntactic structure of the sequence.

(30) *Syntactic effect on Mandarin T3 sandhi*

a. bi gou xiao
   than dog small
   'smaller than a dog'
   T3 T3 T3
→ (**T2** **T2** T3)
→ T3 (**T2** T3)

b. xiao gou pao
small dog run
'the small dog runs'
T3 T3 T3
→ (**T2** **T2** T3)
→ *T3 (**T2** T3)

We have seen that syntactic structure affects phonological processes in different languages, including tone sandhi application. The role of syntactic structure in Shanghai and Mandarin disyllabic sandhi application is documented. The goal of the current study is to uncover how syntactic structure influences Shanghai and Wuxi tone sandhi in both disyllables and trisyllables, and how it interacts with other factors.

3.4 Morpheme length

We have seen that morpheme length affects Shanghai and Wuxi trisyllabic sandhi application in Chapter II. Chinese trisyllables may have different morpheme length patterns: one morpheme that includes all syllables, two morphemes (1+2 or 2+1, where the numbers indicate the numbers of syllables of the concatenating morphemes), or three morphemes (1+1+1). How the morphemes are concatenated often determines the formation of sandhi domain. We will focus on how the morpheme lengths of the trisyllables determined by the morpho-syntax (1+2 or 2+1) influences tone sandhi application.

In addition to Shanghai and Wuxi, the effect of morpheme length on tone sandhi application is also observed in Taiwanese (Duanmu, 1995). Taiwanese tones undergo regular changes in non-phrase-final position (see (1b)). Since the specific pitch value is not of concern, Duanmu (1995) marked the tones occurring in final position as A, B, C, D, E, F, and G, and those on non-final position as A', B', C', D', E', F' and G'. In (31), the 2+1 structure can only apply right-dominant sandhi, while the 1+2 structure can apply both right-dominant and partial sandhi.

(31) *Taiwanese tone sandhi variation*

	1+2		2+1
	ts^hu ting-bin		ts^hing-li be
	house top		thousand kilometer horse
	'top of the house'		'winged steed'
	D C A		A C C
→	D' C' A	→	A' C' C
→	D C' A	→	*A' C C

The sandhi patterns showed that Taiwanese 1+2 structures can form either one or two domains, while the 2+1 structures can only form one domain, as shown in (32).

(32) a. *Taiwanese 1+2 structure*:

D' C' A	D C' A	
(ts^hu ting-bin)	(ts^hu) (ting-bin)	
house top		'top of the house'

b. *Taiwanese 2+1 structure*:

A' C' C	A' C C	
(ts^hing-li be)	*(ts^hing-li) (be)	
thousand-li horse		'winged steed'

Duanmu claimed that compound stress is right-headed in Taiwanese. In the 1+2 structure, there is no stress clash in Taiwanese. Thus, an optional monosyllabic foot on the leftmost allows Taiwanese to form either one or two tonal domains. In the 2+1 structure, if two tonal domains were formed, then there would be a stress clash, which is dispreferred. So Taiwanese can only form one tonal domain for 2+1 structure.

Another piece of evidence comes from Xuzhou Chinese, a dialect spoken in eastern China, which belongs to the Xuhuai sub-dialect area of Northern Chinese (Zhang, 1992). There are four base tones in Xuzhou, MLM, H, LM, and HL. It is also a right-dominant dialect, with two tone sandhi rules, as shown in (33).

(33)*Xuzhou tone sandhi*

a. MLM → LM / ___ MLM
b. MLM → ML / ___ [H/LM/HL]

Zhang (1992) showed that in Xuzhou, right-branching (1+2) structures may apply two forms of tone sandhi optionally, while left-branching (2+1) structures could only apply one sandhi form, as shown in (34).

(34)*Xuzhou tone sandhi variation*

	1+2		2+1
	hei shu-bao		lu-yin ji
	black schoolbag		record machine
	‘black schoolbag’		‘recorder’
	MLM MLM MLM		MLM MLM MLM
	(L to R)		(L to R)
	LM MLM MLM *rule a*		LM MLM MLM *rule a*
	LM LM MLM *rule a*		LM LM MLM *rule a*
→	LM LM MLM	→	LM LM MLM
	(R to L)		(R to L)
	MLM LM MLM *rule a*		MLM LM MLM *rule a*
	ML LM MLM *rule b*		ML LM MLM *rule b*
→	ML LM MLM	→	*ML LM MLM

Zhang (1992) pointed out that the pattern is caused by the direction of sandhi rule application. In 1+2 structures, sandhi rule (33a) can be applied twice from left to right, to get the sandhi form LM LM MLM. Rule (33a) and (33b) can also be applied once from right to left, to get the sandhi form ML LM MLM. On the other hand, 2+1 structure can only apply rule (33a) twice from left to right. He argued that the direction of tone sandhi rule application in 2+1 is obligatory, but optional in 1+2.

The examples above illustrate how morpheme length influences tone sandhi application. Furthermore, from Mandarin data (Duanmu, 1998, 2012), we can see that morpheme length could be influenced by different syntactic structures. [M N] prefers a 2+1 structure, and [V N] prefers a 1+2 structure. This is because in [M N], stress falls on the modifier, and in [V N], stress falls on the noun due to the Nonhead Stress Rule (Cinque, 1993; Zubizarreta, 1998).

Meanwhile, a monosyllabic foot that receives stress is dispreferred. Therefore, [M N] and [V N] prefer different morpheme lengths in Chinese (Duanmu, 1998, 2012).

Based on a random sample of 2,000 monosyllables — one tenth of *Xiandai Hanyu Cidian* (Modern Chinese Dictionary), Huang & Duanmu (2012) found that 70% of Chinese monosyllables have a corresponding disyllabic form. The elasticity of word length causes different morpheme length patterns in Chinese long sequences (Duanmu, 2012). It is reported that in [N N] (noun-noun), a 1+2 structure is dispreferred, and in [V N], a 2+1 structure is dispreferred. The examples in (35) illustrate these preferences.

(35) *Word length preferences*

a. 1+2 is dispreferred in [N N]

2+2	meitan	shangdian	
2+1	meitan	dian	
*1+2	mei	shangdian’	
1+1	mei	dian	
	coal	store	‘coal store’

b. 2+1 is dispreferred in [V N]

2+2	zhongzhi	dasuan	
*2+1	zhongzhi	suan	
1+2	zhong	dasuan	
1+1	zhong	suan	
	plant	garlic	‘to plant garlic’

To obtain a more quantitative result, Duanmu (2012) calculated the token and type frequencies of [N N] and [V N] items in the Lancaster Corpus of Mandarin Chinese (LCMC, McEnery & Xiao, 2004). The token frequency results showed that 55.8% of [N N] was 1+1, 21.8% was 2+2, 21.3% was 2+1, and only 1.1% was 1+2. The type frequency results showed that 63% of [N N] was 1+1, 20.1% was 2+2, 16.2% was 2+1, and 0.8% was 1+2. It is very clear that for [N N], the 1+1 structure is the prevalent one, and 1+2 is disfavored. For [V N], in token counts, 62.8% is 1+1, 19.1% is 1+2, 16.2% is 2+2, and 1.8% is 2+1. The result of the type frequency of [V N] was similar to that of the token frequency: 46.1% is 1+1, 27.3% is 1+2, 24.5% is 2+2, and 2.2% is 2+1. For [V N], the 2+1 structure is dispreferred, and 1+1 is still the dominant one. The preference is also observed in Li, Xu, & Tao (1997)'s *Shanghai Dialect Dictionary*, which has no [V N] in 2+1 structure, and the number of [M N] in 1+2 structure is considerably smaller than that in 2+1 structure.

Considering the interaction between morpheme length and syntactic structure, which cause the extreme paucity of 2+1 [V N] items in Mandarin, this study aims to investigate how morpheme length affects Shanghai and Wuxi [M N] trisyllabic tone sandhi application, and whether there will be an interaction between the effect of morpheme length and dialect. We will compare 2+1 [M N] and 1+2 [M N] to understand the influence of morpheme length in trisyllabic sandhi application.

Chapter IV:EXPERIMENTAL INVESTIGATION OF THE NATURE OF TONE SANDHI VARIATION IN SHANGHAI

4.1 Introduction

In Shanghai Chinese, Xu et al. (1981) claimed that grammatical factors, such as semantic transparency, syntactic structure, and morpheme length, and the usage factor of lexical frequency all influence the variant forms of disyllabic and trisyllabic sandhi application. However, it remains unclear to what extent these factors influence sandhi variation or how they interact with each other in native speakers' behavior. Therefore, this study aims to examine the effects of lexical frequency, semantic transparency, syntactic structure, and morpheme length on tone sandhi variation in Shanghai.

The chapter starts with a statement of the research questions and the predictions. The methodology section that follows discusses how the experiments are designed to address the research questions, including materials, participants and the procedures of each experiment. The methods of data analysis are then presented, followed by the results. The disyllable and trisyllable results are reported separately. Finally, the chapter concludes with a summary of how these factors affect Shanghai tone sandhi variation.

4.2 Research questions

Xu et al. (1981, 1982) indicated that (a) lexical items with high lexical frequency prefer to undergo tonal extension; (b) "closely-connected" (semantically opaque) items prefer to undergo tonal extension; (c) most of modifier-noun ([M N]) only apply tonal extension, and most of verb-noun ([V N]) can undergo both tonal extension and tonal reduction; (d) depending on the "degree of connection" among the morphemes, some trisyllables can only apply partial sandhi, some can only apply tonal extension, and some can have variable forms of tone sandhi. For trisyllables, Xu et al. (1982) claimed that both 1+2 and 2+1 structures can have two forms of sandhi application, while Duanmu (1995) argued that 1+2 items can only apply tonal extension due to a stress clash that would have occurred in the application of partial sandhi. Duanmu's metrical analysis, therefore, suggests that only 2+1 items may have variable forms of sandhi application. In light of these findings, the current hypotheses are that (a) the more frequent the [M N] item is, the more preferred the tonal extension sandhi form is; (b) the more frequent the [V N] phrases are, the more likely the phrases will preserve the irregular tonal behavior, which in this cases is the non-application of sandhi; this is also consistent with Zhang & Meng's (2016) finding that real [V N] phrases undergo no sandhi[14] more often than novel ones; (c) semantically opaque items prefer to undergo tonal extension compared to semantically transparent items; (d) [M N] items prefer to undergo tonal extension more than [V N] items; (e) 1+2 items have a stronger tendency to undergo tonal extension compared to 2+1 items. Moreover, Zhang & Meng (2016) found that Shanghai native speakers were quite sensitive to syntactic structures when applying sandhi in their productivity experiment, with qualitatively different f0 patterns between [M N] and [V N] novel words, while Yan & Zhang (in press) showed only a small syntactic structure effect in the sandhi application in novel

[14] For convenience, right-dominant tonal reduction in Shanghai disyllables is referred to as "no sandhi," since its sandhi behavior is similar to the corresponding sandhi form in Wuxi.

words for Wuxi. Based on these findings, syntactic structure is expected to play a more important role in Shanghai tone sandhi application than in Wuxi.

4.3 Methodology

To shed light on the nature of Shanghai tone sandhi variation, a goodness rating experiment for the variant forms with native Shanghai speakers was conducted in tandem with semantic transparency and subjective frequency ratings from the same speakers. Experiment 1 was a tone sandhi variation goodness rating experiment, and it allowed us to see which sandhi form was preferred by speakers for each lexical item in the experiment; Experiment 2 was a subjective frequency rating experiment, which examined the estimated frequency of all stimuli; and Experiment 3 was a semantic transparency rating experiment, which investigated the estimated semantic transparency of all stimuli. All experiments included the same set of disyllables and trisyllables, which are further discussed in §4.3.1. The sandhi variation goodness rating experiment was run first in order to minimize the potential influence from other tasks, as the results of variation goodness are the main interest of the current study. The rating results of Experiment 1 were treated as the dependent variable, and those of Experiment 2 and 3 were used as independent variables. The procedures of the experiments and design criteria are provided in §4.3.3 to §4.3.5.

4.3.1 Materials

There were two sets of stimuli, one was disyllabic lexical items, and the other was trisyllabic items. All of the stimuli were chosen from the *Shanghai Dialect Dictionary* (Li et al., 1997). For the disyllabic set, 10 [M N] and 10 [V N] items were included for each tonal combination. The 3 non-checked tones T1, T2, T3 in Shanghai were tested, so there were nine tonal combinations (3*3=9), resulting in 180 disyllabic stimuli (20*9 tonal combinations=180). For the trisyllabic words, tones on σ2 and σ3 were not controlled. Due to word length preference, there were 20 2+1 [M N] trisyllables for each tone on σ1 (20*3=60), with the tone on σ1 being T1, T2, T3. For 1+2 structure, there were 20 [M N] and 20 [V N] trisyllables for each tone on σ1 (40*3=120). In total, there were 180 trisyllabic stimuli.

The 180 disyllables and 180 trisyllables were divided into 5 lists, and the participants were divided into 5 groups in lieu of the traditional Latin Square design. There were two considerations for this design. First, to avoid repetition effects, each participant needed to be tested on different stimuli in different experiments. Second, if the stimuli were divided into 3 lists, each experiment would consist of 60 disyllables and 60 trisyllables. The duration of the whole task would be too long for the participants to focus, especially when they had to listen to variant forms of sandhi for each stimulus in Experiment 1. Therefore, the stimuli were divided into 5 lists in this study. How each word list was assigned to each subject group is shown in Table 1. For example, Subject Group 1 saw Word List 1 in Experiment 1, Word List 2 in Experiment 2, and Word List 3 in Experiment 3. That is to say, the subjects would not see the same words in different experiments, and each subject needed to judge 36 disyllables and 36 trisyllables in each experiment. For the 180 disyllables, the same morpheme occurred a maximum of 3 times in the entire word list; for the 180 trisyllables, the same morpheme occurred a maximum of 5 times. The entire stimulus list of Shanghai is given in Appendix A.

Table 1. The distribution to word lists of all the subjects

Subject	Experiment 1	Experiment 2	Experiment 3
Group 1	List 1	List 2	List 3
Group 2	List 2	List 3	List 4
Group 3	List 3	List 4	List 5
Group 4	List 4	List 5	List 1
Group 5	List 5	List 1	List 2

All stimuli were recorded in the Anechoic Chamber at the University of Kansas, using a Marantz PMD-671 solid state recorder and an Electrovoice 767 microphone placed on the desk in front of the speaker. The Shanghai stimuli were recorded by a 24-year-old male native speaker. The stimuli for Experiment 2 (frequency rating) and Experiment 3 (semantic transparency rating) were recorded first, and the speaker was asked to read the stimuli as naturally as possible without considering the tone sandhi variation. Afterwards, the speaker was asked to produce the two variant forms for each stimulus for Experiment 1 (variation goodness rating) with the guidance of a Shanghai early learner who was phonetically trained. The Shanghai experiments were conducted in the Phonetics Laboratory of Shanghai University.

4.3.2 Participants

Seventy native speakers of Shanghai Chinese participated in this study, including 35 males and 35 females. All participants were born and raised in the urban districts of Shanghai, ranging from 18 to 26 years old, with an average age of 22, and they were all living in Shanghai at the time of the experiments. Participants were either undergraduate or graduate students at Shanghai University, and none of them had speech or hearing impairment according to their self-reports. All participants provided background information (see Appendix C), and all took the three experiments in sequence. They were paid $10 for their participation.

4.3.3 Experiment 1: Variant forms goodness rating

Experiment 1 aims to investigate the speakers' goodness ratings of the two variant sandhi forms, i.e., tonal extension and no sandhi in Shanghai disyllables, and tonal extension and partial sandhi in Shanghai trisyllables.

In the experiment, the participants wore a pair of headphones, and sat in front of a computer and a mouse. At the beginning, the participants were given the following instruction and listened to it in Shanghai Chinese, and the researcher made sure that the participants had no confusion about the task.

> Hello! Welcome to our study. The purpose of the study is to investigate word properties in Shanghai. In this part of the experiment, you will hear two different pronunciations of one word. You will first see a word on the screen, for example, *vest*, and two speaker icons. Please click on the

> speaker icon on the top first, and you will hear the first pronunciation in the headphones. Then, please consider if you were to say this word, how likely you would be to say it like the recording you just heard. Give a rating on a 4-point scale from 0 to 3 using the mouse: 0 means 'I never say it in this way', and 3 means 'I always say it in this way'. You can also give ratings between 0 and 3. Please make the judgment based on your own preference. After this, please click on the bottom speaker icon, listen to the second pronunciation, and give a rating according to your preference.

Four practice trials — two [M N] and two [V N] items — were given after the instruction. In the experiment, the participants rated the disyllables first, and then the trisyllables. The instruction was repeated at the beginning of the trisyllabic portion of the experiment. The procedure for one trial of Experiment 1 is illustrated in Figure 1. The interval between each trial was 500 ms. The experiment took about 20 minutes.

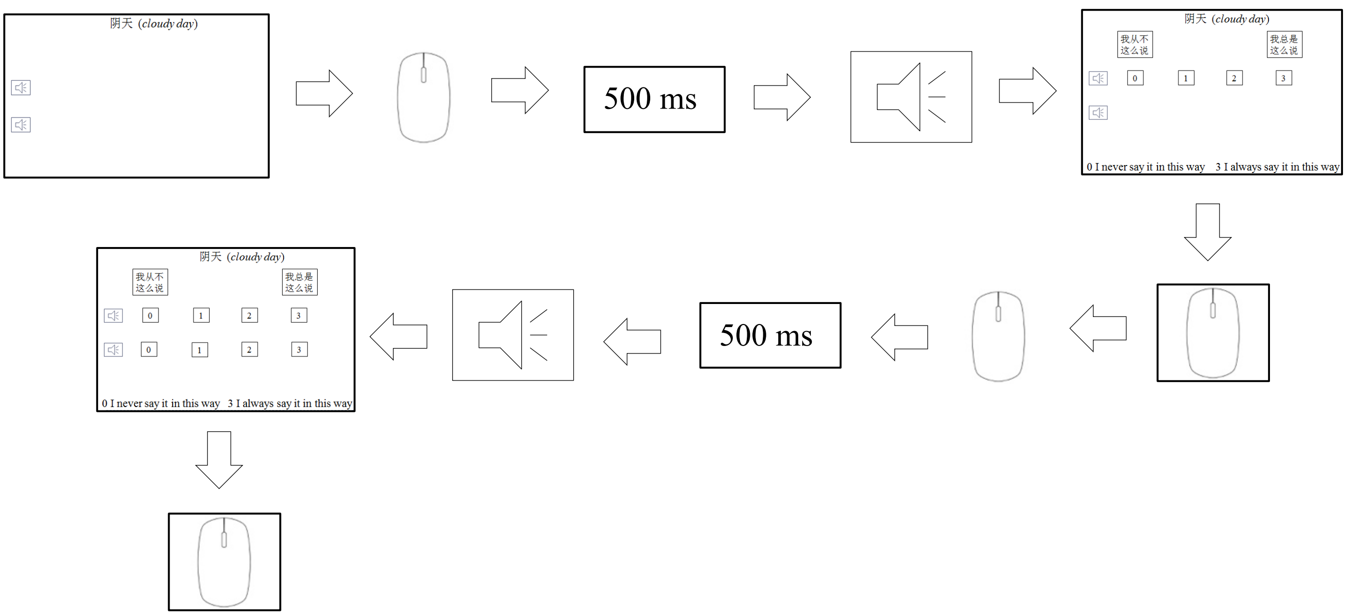

Figure 1. The flowchart of one trial of Experiment 1, the mouse figure in a square is where ratings are given, and the mouse figure without a square represents a click to listen to the sound files (the English translation will not be presented to the participants).

Recall that in disyllabic tone sandhi, some items can undergo both tonal extension and no sandhi in Shanghai, and in trisyllables, both tonal extension and partial sandhi can apply to a single item. The order of hearing the two forms was counterbalanced. That is to say, for half of the [M N] and [V N] items, participants heard the tonal extension form first, and for the other half, the no sandhi or partial sandhi form first. In addition, a 4-point scale was adopted here as the subjects would be forced to judge the goodness of the item without the option of choosing the middle point on the scale. Otherwise, a series of psychological studies have shown that the coefficient of reliability was independent of the number of scales (Bendig, 1953, 1954; Brown, Wilding, & Coulter, 1991; Komorita, 1963; Matell & Jacoby, 1972; Wakita, Ueshima, & Noguchi, 2012), and a 4-poing scale is considered to be adequate.

4.3.4 Experiment 2: Lexical frequency rating

Experiment 2 aims to examine the lexical frequency of all stimuli. The frequency-rating task was conducted mainly because there is no existing corpus of Shanghai Chinese. Balota, Pilotti, & Cortese (2001) collected subjective frequency ratings for 2,938 monosyllabic English words from a group of 574 college students (average age: 19.5 years, range 17-29 years) and a group of 1,590 adults of varying ages and educational background (average age: 40.4 years, range 14-84 years). The data from the latter group were collected via the internet. Additionally, 90 older adults (average age: 73.4 years, range 61-80) were asked to judge a random sample of 480 of these words. All subjects rated the words according to the estimated frequency of encounters on a 7-point scale from ‘never encountered’ to ‘encountered several times a day’. The young and old groups also gave ratings for the encountered frequency of each word in four additional dimensions, including reading, hearing, writing, and speaking. The results showed that there was a tight correlation between subjective frequency estimates and objective log frequency estimates (Kučera & Francis, 1967; CELEX Dutch Center for Lexical Information, 1995), ranging between .78 and .83. These correlations were larger than those between Toglia & Batting (1978)’s subjective familiarity ratings and the same objective log frequency estimates, which were ranged between .53 to .62. It suggested that subjective frequency ratings were more accurate in reflecting actual exposure to the stimuli than subjective familiarity ratings. Therefore, instead of using a Mandarin corpus whose frequency calculation might differ from those of Shanghai, we decided to collect subjective frequency ratings in Shanghai to serve as an estimate for the relative frequency of exposure to a word in the dialect.

In Experiment 2, the subjects wore a pair of headphones, and sat in front of a computer and a mouse. At the beginning, the participants were given the following instruction and listened to it in Shanghai Chinese, and the researcher made sure that the participants knew how to do the task.

> In Shanghai, some words are often used in everyday life, and some words are rarely used. In this part of the experiment, you will hear a word in the

headphones, for example, *fruit*. Please consider the usage of the word in daily life, and give a rating on a 4-point scale from 0 to 3 using the mouse: 0 means ‘this word is rarely used’, and 3 means ‘this word is often used’. You can also give ratings between 0 and 3. Please make the judgment based on your own usage situation.

Since Shanghai Chinese shares the same writing system with Mandarin, to avoid the influence of Mandarin, the participants did not see the Chinese characters, but only heard the stimuli in Experiment 2. Four practice trials, two [M N] and two [V N] items were given after the instruction. In the experiment, the participants rated the disyllables first, and then the trisyllables. The instruction was repeated at the beginning of the trisyllabic portion of the experiment. The procedure for one trial is shown in Figure 2. The interval between each trial was 500 ms. Experiment 2 took about 10 minutes.

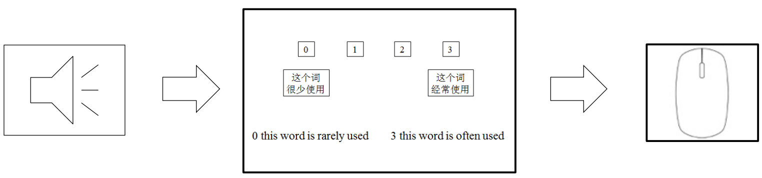

Figure 2. The flowchart of one trial of Experiment 2, the mouse figure in a square is where a rating is given (the English translation will not be presented to the subjects).

4.3.5 Experiment 3: Semantic transparency rating

Experiment 3 aims to measure the semantic transparency of all stimuli. We only measured the transparency of the entire compound, for two reasons: first, the semantic transparency measure of the constituents (the contribution of the meaning of the constituents to the meaning of the whole compound) has been shown to significantly correlate with the compound transparency measure (Kuperman, Bertram, & Baayen, 2008; Marelli & Luzzatti, 2012); second, compound transparency ratings could indicate how well the combination of the constituents represent the compound meaning, while constituent transparency ratings measure the semantic similarity between the meaning of the compound and those of the constituents. Given that the current study aims to examine the role of semantic transparency in variant forms of tone sandhi, and tone sandhi applies to the whole compound instead of the constituents, only compound transparency ratings were measured.

In the experiment, the subjects wore a pair of headphones, and sat in front of a computer and a mouse. At the beginning, the participants were given the following instruction in Shanghai Chinese, and the researcher made sure that the task was clear to the subjects.

> In Shanghai, the meanings of some words can be told from the characters that the word comprises easily, and the meanings of some words cannot. In this part of the experiment, you will hear a word in the headphones, for example, *sofa*. The word will also appear on the screen. Please consider to what extent the meaning of the whole word is predictable from the meanings

of its parts, and give a rating on a 4-point scale from 0 to 3 using the mouse: 0 means ‘cannot tell the meaning of the word from the characters’, and 3 mean ‘can tell the meaning of the word from the characters very clearly’. For example, the meaning of *sofa* (沙发, /su53 faʔ55/, *sand* + *to send out*) cannot be told from the meanings of the two characters, so you may choose 0; the meaning of *bedsheet* (床单, /zɑ̃13 tɛ53/, *bed* +*sheet*) can be told from the meanings of the two characters very clearly, so you may choose 3. You may also give ratings between 0 and 3. Please make the judgment based on your own preference.

During the experiment, the subjects saw the characters of the stimulus on the screen, and then they heard its recording. They needed to give a rating after the recording was heard. Four practice trials, two [M N] and two [V N] items were given after the instruction. The four practice trials were composed of two 0-point items and two 3-point items. The procedure of one trial is shown in Figure 3. The interval between each trial was 500 ms. Experiment 3 took about 10 minutes.

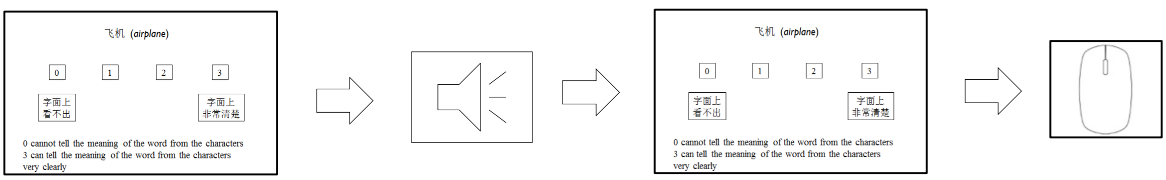

Figure 3. The flowchart of one trial of Experiment 3, the mouse figure in a square is where a rating is given (the English translation will not be presented to the subjects).

4.4 Data analysis

Due to the different nature of disyllables and trisyllables, the two sets of data were analyzed separately. Two types of analysis were conducted for each set. The first analysis examines the preference for the tonal extension sandhi form for a particular item by a particular subject. The rating for no/partial sandhi[15] was subtracted from the rating for tonal extension for that subject. Therefore, the scale of this measure ranges from 3 to -3, in which a positive value indicates a preference for tonal extension for this particular item by this subject, a negative value indicates a preference for no/partial sandhi, and zero suggests no preference between the two types of forms. The ratings of frequency and semantic transparency were first averaged across different subjects, hence, each lexical item has an average frequency rating and an average semantic transparency rating from all subjects that rated the item. The two ratings were then arcsine-transformed to remove skewness of the data set according to the formula in (36a). Since $arcsine\sqrt{x}$ can only be applied to numbers that lie in [0, 1], and the rating scale ranges from 0 to 3, we needed to divide the raw value of the rating by 3. The arcsine-transformed data were then centered at the median to reduce the collinearity of the variables using (36b) (Jaeger & Kuperman, 2009; Jaeger, Graff, Croft, & Pontillo, 2011; Kraemer & Blasey, 2004; Zuur, Ieno, & Elphick, 2010).[16]

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[15] "No sandhi" applies to disyllables, and "partial sandhi" applies to trisyllables. We considered them as the same type for convenience, as they were both contrasted with the tonal extension sandhi.

[16] Given that the data were not normally distributed, the median was used as a more appropriate estimate of the center of the distribution.

(36) a. $Rating_{TRANS} = arcsine\sqrt{Rating_{RAW}/_3}$

b. $Rating_{CEN\,i} = Rating_{TRANS\,i} - \widetilde{Rating}_{TRANS}$

The Variance Inflation Factor (VIF) was used to test the collinearity between lexical frequency ratings and semantic transparency ratings in both disyllables and trisyllables. Multicollinearity diagnosis showed that the VIF values between the two variables were reduced from 50 – 150 to below 4 after transformation and centering, which are considered as nonproblematic (Jaeger & Kuperman, 2009; Montgomery & Peck, 1992; Zuur et al., 2010).

The variable of sandhi preference was then modeled with Linear Mixed-Effects models with participant and item as random effects, and syntactic structure ([M N], [V N]), lexical frequency rating, and semantic transparency rating as fixed effects in the disyllabic data. For trisyllables, to examine the effect of syntactic structure, Linear Mixed-Effects models were run on all 1+2 structures, with participant and item as random effects, and syntactic structure ([M N], [V N]), lexical frequency rating, and semantic transparency rating as fixed effects. To examine the effect of morpheme length, Linear Mixed-Effects models were run on the [M N] data, with participant and item as random effects and morpheme length (1+2, 2+1), lexical frequency rating, and semantic transparency rating as fixed effects.

The other analysis aimed to investigate how each lexical item patterns in sandhi application by averaging the ratings across all subjects. That is to say, each item would have four averaged ratings: the rating for the tonal extension sandhi form, the rating for the no/partial sandhi form, the lexical frequency rating, and the semantic transparency rating. We also subtracted the rating for no/partial sandhi from the rating for tonal extension to derive the variable of sandhi preference. The ratings of frequency and semantic transparency were arcsine-transformed and centered as mentioned above.

For the 180 disyllables, Multiple Linear Regressions were run with sandhi preference as the dependent variable, and syntactic structure ([M N], [V N]), lexical frequency rating, semantic transparency rating as predictors. For the 180 trisyllables, the effects of syntactic structure and morpheme length also needed to be analyzed separately. To investigate the effect of syntactic structure, Multiple Linear Regressions were run on all 1+2 structures, with the sandhi preference as the dependent variable, and syntactic structure ([M N], [V N]), lexical frequency, and semantic transparency rating as predictors. To investigate the effect of morpheme length, Multiple Linear Regressions were run on the [M N] data, with the sandhi preference as the dependent variable and morpheme length (1+2, 2+1), lexical frequency, and semantic transparency rating as predictors.

4.5 Results

4.5.1 Disyllables

For disyllables, the results of Mixed-Effects models are first reported, followed by the results of Multiple Linear Regression models.

4.5.1.1 ***Mixed-Effects models***

In order to characterize the effects of different factors on Shanghai disyllabic sandhi application and generalize the findings to larger populations of subjects and items, Linear

Mixed-Effects models were used, with syntactic structure, frequency rating, and semantic transparency rating as fixed effects and subject and item as random effects. For frequency rating, the higher the value is, the more frequent the item is rated. For the rating of semantic transparency, a high value indicates that the item is semantically transparent, and a low one indicates that the item is semantically opaque. The model with the interaction was significantly better than the other simpler models without the interaction based on the results of log-likelihood comparisons. The parameter estimates for the model with the interaction between the three fixed effects are listed in Table 2. The model treated [M N] item as the baseline for the effect of syntactic structure.

Table 2. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Shanghai disyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.485	(-0.090)	27.764	< 2e-16 ***
syntactic structure VN	-4.109	(-0.123)	-33.480	< 2e-16 ***
frequency	0.897	(-0.336)	2.674	0.008 **
transparency	0.300	(-0.339)	0.885	0.377
syntactic structure VN : frequency	-1.790	(-0.422)	-4.241	3.62e-05 ***
syntactic structure VN : transparency	-1.441	(-0.453)	-3.181	0.002 **
frequency : transparency	-1.292	(-1.519)	-0.850	0.396
syntactic structure VN : frequency : transparency	3.309	(-1.759)	1.881	0.062
Random Effects (σ)				
Residual	1.162			
item	0.732			
subject	0.191			
N	2520			
RMSE	1.162			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

Table 2 shows that there is an effect of syntactic structure. With a negative coefficient value (-4.109), [V N] items have significantly lower values of sandhi preference than [M N] items do, which is in accordance with our prediction. The coefficient for the frequency effect for [M N] items is .897, while that for [V N] items is .897 - 1.790 = -.893, i.e., frequency has a positive effect on [M N] disyllables, but a negative effect on [V N] disyllables. Furthermore, the interaction between syntactic structure and semantic transparency is also significant. For [M N] items, there is no effect of semantic transparency, while for [V N] items, there is a negative effect, .300 - 1.441 = -1.141, i.e., semantically more transparent [V N] disyllables prefer the no sandhi form more than semantically less transparent ones.

To further investigate the influences of frequency and semantic transparency on [M N] and [V N] items, two separate Mixed-Effects models were used with lexical frequency rating, semantic transparency rating as fixed effects and subject and item as random effects. According to log-likelihood comparisons, for both [M N] and [V N] disyllables, the model with the frequency by semantic transparency interaction was not significantly different from the model without the interaction. The Mixed-Effects model without the interaction for [M N] and [V N] disyllables are listed in Table 3 and Table 4.

Table 3. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Shanghai [M N] disyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.499	(0.057)	43.692	< 2e-16 ***
frequency	0.839	(0.196)	4.282	4.69e-05 ***
transparency	0.224	(0.196)	1.143	0.256
Random Effects (σ)				

Residual	0.860
item	0.414
subject	0.225
N	1260
RMSE	0.860

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

For [M N] items, lexical frequency has a significant effect on sandhi preference. The positive coefficient (.839) indicates that more frequent [M N] items prefer to undergo tonal extension more than less frequent ones. This again agrees with our prediction as well as the results of the Mixed-Effects model with all disyllabic data. Consistently, there is no semantic transparency effect on [M N] items.

Table 4. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Shanghai [V N] disyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	-1.592	0.121	-13.150	< 2e-16 ***
frequency	-0.916	0.329	-2.785	0.007 **
transparency	-1.247	0.383	-3.255	0.002 **
Random Effects (σ)				
Residual	1.349			
item	0.959			
subject	0.408			
N	1260			
RMSE	1.349			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

For [V N] disyllables, lexical frequency and semantic transparency both influence the sandhi preference significantly. With negative coefficients for frequency (-0.916) and semantic transparency (-1.247), these results confirm the findings in the Mixed-Effects models with all disyllables. In contrast to [M N] items, more frequent [V N] items tend to prefer the no sandhi form more. The negative coefficient for semantic transparency indicates that semantically more transparent [V N] items prefer the no sandhi form more than semantically less transparent [V N] items.

Figure 4 shows the predicted models for frequency and semantic transparency effects on sandhi preference, which provides a visual for the coefficient values we discussed above.

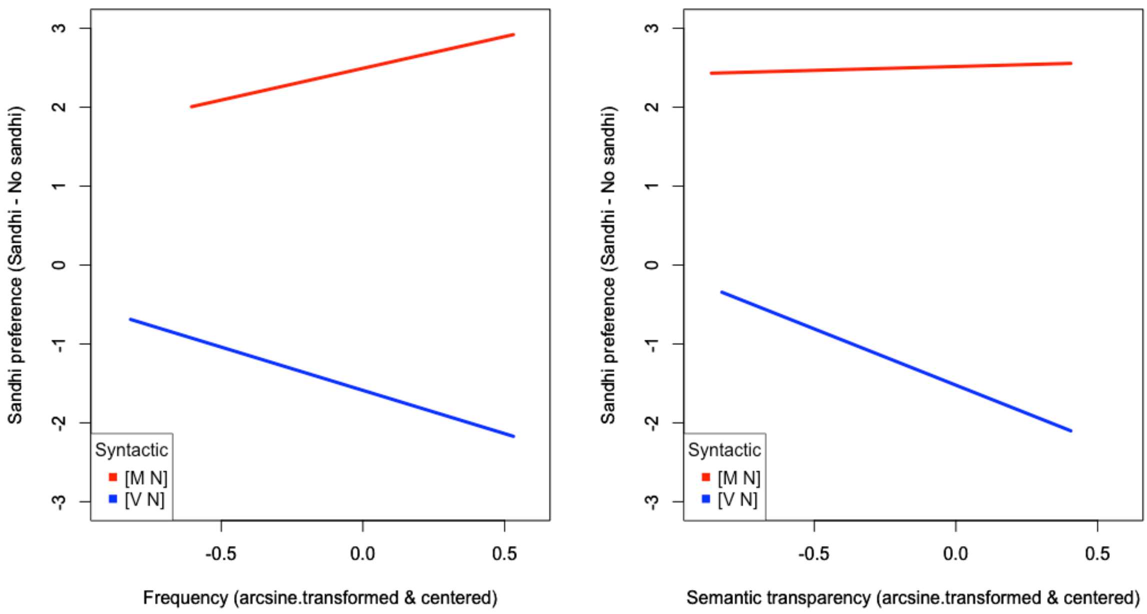

Figure 4. The predicted effects of lexical frequency (left) and semantic transparency (right) in Shanghai disyllabic sandhi preference.

As we can see in Figure 4, for [M N] disyllables, the more frequent it is, the more likely it prefers the tonal extension sandhi form; but there is no semantic transparency effect. For [V N] disyllables, both frequency and semantic transparency have a negative effect on the sandhi application: more frequent [V N] disyllables prefer the no sandhi form more, and semantically more transparent [V N] disyllables prefer the no sandhi form more.

4.5.1.2 ***Multiple linear regression***

To investigate how the sandhi application of each lexical item patterns depends on the syntactic structure, lexical frequency, and semantic transparency, the sandhi preference of each disyllable was plotted against the two continuous predictors, frequency and semantic transparency ratings. Figure 5 shows the distribution of sandhi preference of [M N] and [V N] disyllables depending on the lexical frequency rating with separate regression lines for [M N] and [V N] disyllables. The directions of the two regression lines are in accordance with the predicted lines of the Mixed-Effects models in Figure 4 (left).

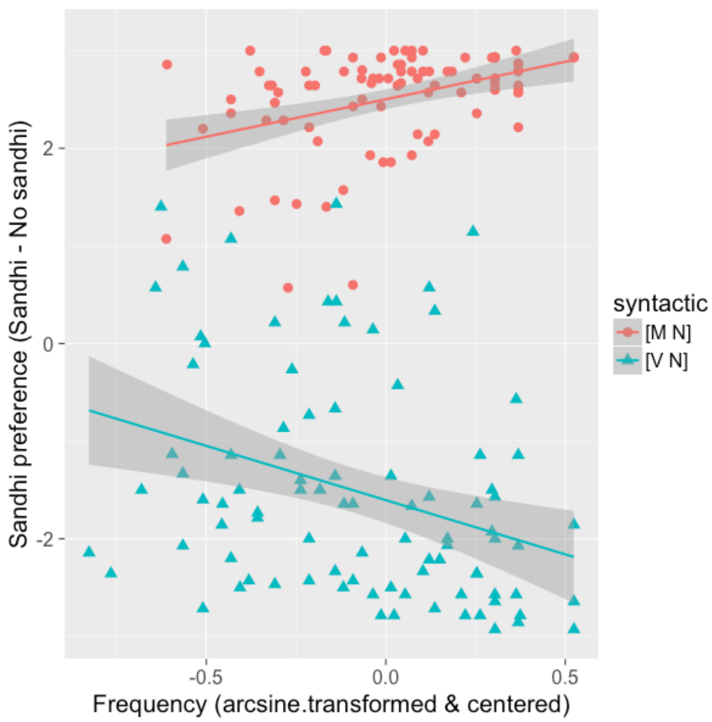

Figure 5. The distribution of sandhi preference of Shanghai disyllables when the predictor is lexical frequency rating.

In general, [M N] items prefer to undergo tonal extension more than [V N] items regardless of the lexical frequency ratings. This is consistent with the results of the Mixed-Effects models. As shown in Figure 5, the more frequent an [M N] disyllable is, the more likely it prefers to undergo tonal extension; on the other hand, speakers are more likely to apply no sandhi for high-frequency [V N] disyllables. A *t*-Test showed that [M N] (M = .02, SD = .26) disyllables had significantly higher frequency ratings than [V N] disyllables (M = -.08, SD = .34), t (168) = 2.21, p = .03.

Figure 6 shows the distribution of sandhi preference of [M N] and [V N] disyllables depending on semantic transparency rating with separate regression lines for [M N] and [V N]. The directions of the two regression lines are consistent with the predicted lines of the Mixed-Effects models in Figure 4 (right).

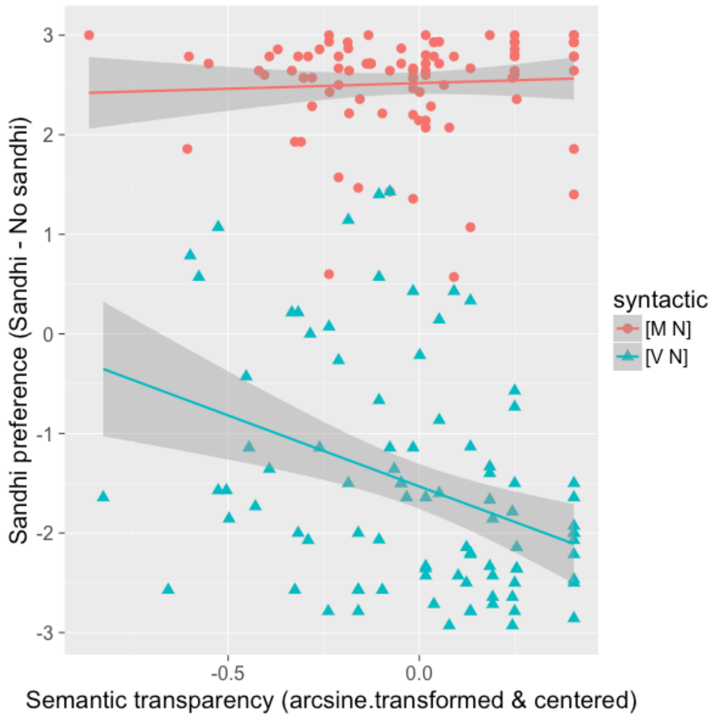

Figure 6. The distribution of sandhi preference of Shanghai disyllables when the predictor is semantic transparency rating.

Figure 6 suggests that semantic transparency does not have an effect on [M N] disyllables, but a negative effect on [V N] disyllables. Semantically transparent [V N] items prefer the no sandhi form more than semantically opaque ones, which is consistent with our prediction and the results of Mixed-Effects models. A *t*-Test indicated that [M N] (M = -.04, SD = .26) and [V N] (M= -.01, SD = .29) did not differ significantly on the ratings for semantic transparency, t (177) = -.51, p = .60.

Two Linear Regression Models, with sandhi preference as dependent variable and syntactic structure, frequency rating, semantic transparency rating as predictors, were run to examine whether the effects of the predictors would be driven by the different frequencies between [M N] and [V N] disyllables: one with all data, one excluding the first quartile of all

[V N] items with the lowest frequencies. In the trimmed data, a *t*-Test showed that [M N] (*M* = .02, *SD* = .26) and [V N] (*M* = .06, *SD* = .24) items no longer differed in lexical frequencies, *t* (151) = -1.18, *p* = .24. Log-likelihood comparisons of different models showed that in both data sets, the best model was the one with all three predictors and interactions. Both models treated [M N] disyllable as the baseline for the effect of syntactic structure. The results of the two regression models turned out to be consistent. Therefore, we report the statistics based on all data, as listed in Table 5.

Table 5. Sandhi preference predicted by syntactic structure, frequency and semantic transparency for Shanghai disyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.495	(-0.086)	28.862	< 2e-16 ***
syntactic structure VN	-4.131	(-0.123)	-33.585	< 2e-16 ***
frequency	0.872	(-0.335)	2.602	0.010 *
transparency	0.316	(-0.335)	0.945	0.346
syntactic structure VN : frequency	-1.765	(-0.421)	-4.192	4.42e-05 ***
syntactic structure VN : transparency	-1.442	(-0.451)	-3.201	0.002 **
frequency : transparency	-1.281	(-1.520)	-0.843	0.400
syntactic structure VN : frequency : transparency	3.234	(-1.760)	1.838	0.068
N	180			
RMSE	0.797			
R^2	0.874			
adj R^2	0.869			

* p <0.05** p <0.01*** p <0.001

Table 5 shows that in the model with all data, the three predictors explain a significant proportion of the variance in sandhi preference (R^2 = .874, F (7, 172) = 171.200, p < .001). There are main effects of syntactic structure and lexical frequency, i.e., syntactic structure significantly predicts sandhi preference, as does lexical frequency. [V N] disyllables have significantly lower sandhi preference values than [M N] disyllables (mean value of sandhi preference: [M N]: 2.50, [V N]: -1.64). With a positive β weight (.872), high-frequency items prefer to undergo the tonal extension form more than low-frequency items in general. These are in accordance with our observation in Figure 5. There is also a syntactic structure by lexical frequency interaction, indicating that the significance of the main effects for syntactic structure and lexical frequency is irrelevant, and the interaction is further probed below. On the other hand, syntactic structure also interacts with semantic transparency, suggesting that the effect of semantic transparency on sandhi preference is different for [M N] and [V N] disyllables.

Next, Linear Regression Models were built separately for [M N] and [V N] disyllables, with lexical frequency and semantic transparency as predictors. For both types of disyllables, the model without the frequency by semantic transparency interaction and the model with the interaction did not differ significantly based on log-likelihood comparisons. We therefore report the simpler models without the interaction here. The results of [M N] data are listed in Table 6, and those of [V N] are listed in Table 7.

Table 6. Sandhi preference predicted by frequency and semantic transparency for Shanghai [M N] disyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.510	(-0.051)	49.620	< 2e-16 ***
frequency	0.810	(-0.195)	4.154	7.62e-05 ***
transparency	0.249	(-0.194)	1.284	0.202
N	90			
RMSE	0.475			
R^2	0.168			

adj R^2	0.149

* p <0.05** p <0.01*** p <0.001

For [M N] disyllables, Table 6 shows that there is a main effect of lexical frequency. With a positive β weight (.810), the value of sandhi preference increases when frequency rating increases one standard deviation and semantic transparency rating is held constant, i.e., more frequent [M N] items prefer tonal extension more than less frequent ones as we predicted. However, there is no effect of semantic transparency on [M N] disyllabic sandhi application.

Table 7. Sandhi preference predicted by frequency and semantic transparency for Shanghai [V N] disyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	-1.607	(0.112)	-14.309	< 2e-16 ***
frequency	-0.932	(0.330)	-2.825	0.006 **
transparency	-1.245	(0.385)	-3.231	0.002 **
N	90			
RMSE	1.034			
R^2	0.203			
adj R^2	0.184			

* p <0.05** p <0.01*** p <0.001

For [V N] items, both lexical frequency and semantic transparency have a significant effect on sandhi preference, and both are negative. The value of sandhi preference decreases when frequency rating increases one standard deviation and semantic transparency rating is held constant, and it decreases when semantic transparency rating increases one standard deviation and frequency rating is held constant. This suggests that for a [V N] disyllable, the more frequent and more semantically transparent it is, the more preferred the no sandhi form is.

In all, syntactic structure, lexical frequency, and semantic transparency all have an effect on Shanghai disyllabic sandhi application. [M N] disyllables prefer tonal extension more than [V N] disyllables, and [V N] disyllables prefer the no sandhi form more. Lexical frequency has a positive effect on [M N] disyllables, but a negative one on [V N] ones. Semantic transparency only affects [V N] disyllables, and goes in the same direction as we predicted, i.e., semantically opaque [V N] disyllables prefer to undergo tonal extension more than semantically transparent ones.

4.5.2 Trisyllables

In trisyllables, an additional predictor was included — the morpheme length. Due to the word length preference in Shanghai, the trisyllable data set only consisted of sixty 1+2 [M N] items, sixty 1+2 [V N] items, and sixty 2+1 [M N] items as mentioned earlier. Therefore, to investigate the effect of syntactic structure and morpheme length, we needed to separate the trisyllable data. The effect of syntactic structure was investigated using all 1+2 items, and the effect of morpheme length was investigated using all [M N] items. In this section, we present the results of the syntactic structure effect first, then the results of the morpheme length effect.

4.5.2.1 ***Syntactic structure***

Similar to the disyllables, the syntactic structure effect of trisyllables was probed via Mixed-Effects models and Multiple Linear Regression models.

4.5.2.1.1 Mixed-Effects models

To examine how trisyllables pattern depending on the syntactic structure, lexical frequency, and semantic transparency and generalize the findings to larger populations of subjects and items, Linear Mixed-Effects models were used, with syntactic structure, frequency rating, and semantic transparency rating as fixed effects and subject and item as random effects. The model with the syntactic structure by frequency interaction was significantly better than the other models without the interaction based on the results of log-likelihood comparisons. The model including the third fixed effect of semantic transparency was not significantly different from the model with the two fixed effects, syntactic structure and frequency rating, and their interaction. The parameter estimates for the model with the interaction between syntactic structure and frequency are listed in Table 8. [M N] trisyllable was treated as the baseline for the effect of syntactic structure.

Table 8. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Shanghai 1+2 trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.144	0.195	11.001	< 2e-16 ***
syntactic structure VN	-3.528	0.264	-13.390	< 2e-16 ***
frequency	1.805	0.568	3.179	0.002 **
syntactic structure VN : frequency	-1.933	0.805	-2.403	0.018 *
Random Effects (σ)				
Residual	1.193			
item	1.348			
subject	0.190			
N	1680			
RMSE	1.193			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

Table 8 indicates that there is an effect of syntactic structure. [V N] trisyllables have significantly lower values of sandhi preference than [M N] ones, which is in accordance with the results of the disyllables. The coefficient for the frequency effect for [M N] items is 1.805, while for [V N] items it is 1.805 - 1.933 = -.128. That is to say, frequency has a positive effect on [M N] items, and a negative effect on [V N] items. The more frequent a [M N] trisyllable is, the more likely it prefers to undergo the tonal extension sandhi form, while the more frequent a [V N] trisyllable is, the more likely it prefers the partial sandhi form.

To further investigate the influences of frequency on 1+2 [M N] and [V N] trisyllables, two separate Mixed-Effects models were used with lexical frequency as a fixed effect and subject and item as random effects. According to log-likelihood comparisons, for both [M N] and [V N] items, the model with the frequency by semantic transparency interaction, the model without the interaction, and the model with only frequency were not significantly different from each other. Therefore, the simplest model with frequency as the predictor is used here. The effects of lexical frequency in the Mixed-Effects model for [M N] and [V N] items are listed in Table 9 and Table 10.

Table 9. Fixed effect estimates (top) and variance estimates (bottom) for results of sandhi preference in Shanghai 1+2 [M N] trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.157	(0.119)	18.066	< 2e-16 ***
frequency	1.900	(0.330)	5.757	3.38e-07 ***
Random Effects (σ)				
Residual	1.187			
item	0.380			
subject	0.722			

N	840
RMSE	1.187

* p ≤0.05** p ≤0.01*** p ≤0.001

For 1+2 [M N] trisyllables, lexical frequency has a significant effect on sandhi preference. The positive coefficient indicates that more frequent 1+2 [M N] trisyllables prefer the tonal extension sandhi form more than less frequent ones. This again agrees with the results of the Mixed-Effects model shown in Table 8, as well as the results of [M N] disyllables. Unlike [M N] disyllables, there is no semantic transparency effect on [M N] trisyllables.

Table 10. Fixed effect estimates (top) and variance estimates (bottom) for results of sandhi preference in Shanghai 1+2 [V N] trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	-1.384	(0.232)	-5.957	1.45e-07 ***
frequency	-0.169	(0.701)	-0.242	0.81
Random Effects (σ)				
Residual	1.144			
item	0.248			
subject	1.758			
N	840			
RMSE	1.144			

* p ≤0.05** p ≤0.01*** p ≤0.001

For 1+2 [V N] trisyllables, there is no frequency effect on the sandhi preference. It seems that neither frequency nor semantic transparency affects sandhi preference of 1+2 [V N] items.

Figure 7 (left) shows the predicted models for frequency effect on the [M N] and [V N] trisyllabic sandhi preference, and the predicted models for semantic transparency effect are plotted on the right side of Figure 7.

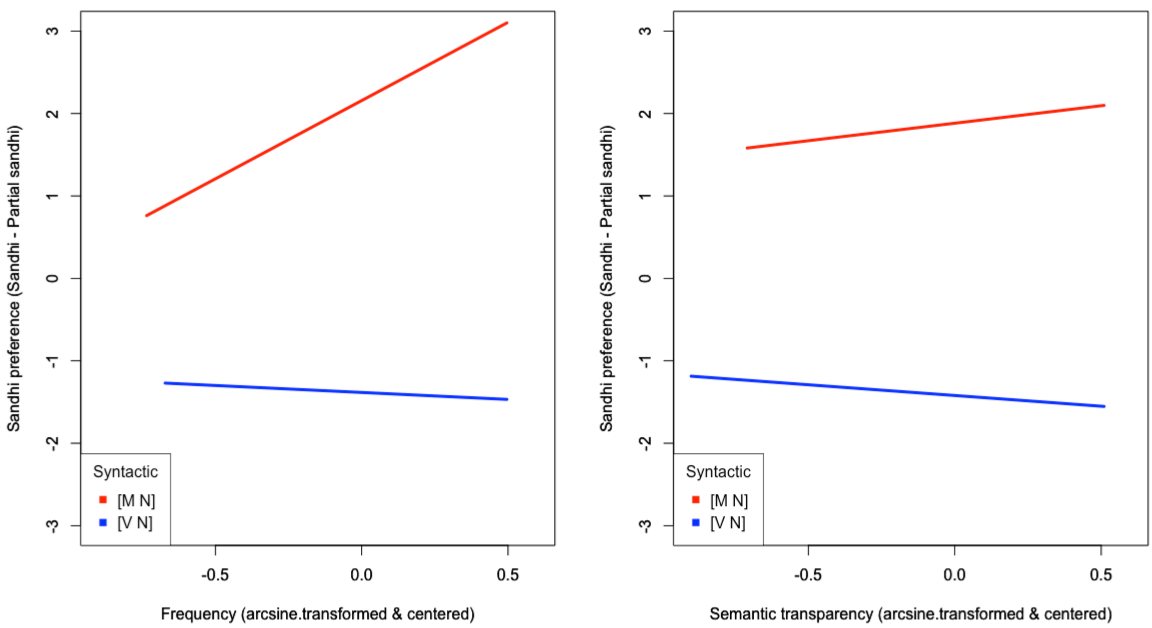

Figure 7. The predicted effects of lexical frequency (left) and semantic transparency (right) in Shanghai 1+2 [M N] and [V N] trisyllabic sandhi preference.

As shown in Figure 7, for 1+2 [M N] trisyllables, there is a significant effect of lexical frequency, i.e., a more frequent 1+2 [M N] item prefers the tonal extension sandhi form; there is a numerically positive coefficient for semantic transparency effect but the effect is not statistically significant. For 1+2 [V N] trisyllables, neither frequency nor semantic transparency effect is significant, although the coefficients are both negative.

4.5.2.1.2 Multiple linear regression

To obtain a more straightforward picture of how 1+2 [M N] and [V N] trisyllables behave in sandhi preference, all 1+2 items were plotted against the two continuous predictors — frequency and semantic transparency ratings. Figure 8 shows the distribution of sandhi preference of [M N] and [V N] trisyllables depending on the lexical frequency rating, with separate regression lines for [M N] and [V N]. The directions of the two regression lines are in accordance with the predicted lines of the Mixed-Effects models in Figure 7 (left).

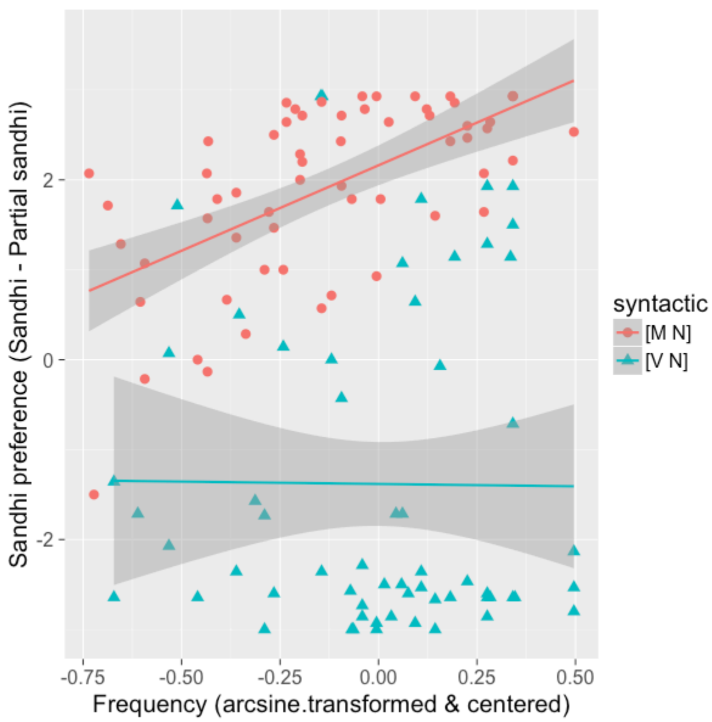

Figure 8. The distribution of sandhi preference of Shanghai 1+2 trisyllables when the predictor is lexical frequency rating.

1+2 [M N] trisyllables prefer to undergo tonal extension more than 1+2 [V N] trisyllables in general. This is consistent with our prediction, the results of the above

Mixed-Effects models, as well as the disyllable results. However, the distribution of sandhi preference in trisyllables is not as tightly clustered as that in disyllables (Figure 5), i.e., there is more variability in trisyllabic sandhi application. As shown in Figure 8, the more frequent an [M N] trisyllable is, the more likely it prefers to undergo tonal extension; on the other hand, there seems to be no frequency effect on [V N] trisyllables. Moreover, a *t*-Test showed that [M N] (M = -.13, SD = .31) items had significantly lower frequency ratings than [V N] (M = 0, SD = .30), t (118) = -2.35, p = .02.

Figure 9 shows the distribution of sandhi preference of [M N] and [V N] trisyllables depending on the semantic transparency rating, with separate regression lines for [M N] and [V N]. The direction of the regression line of 1+2 [M N] trisyllables is similar to the predicted line of the Mixed-Effects model in Figure 7 (right), while the slope of the regression line of 1+2 [V N] trisyllables seems to be steeper than that of the predicted line of the Mixed-Effects model in Figure 7 (right).

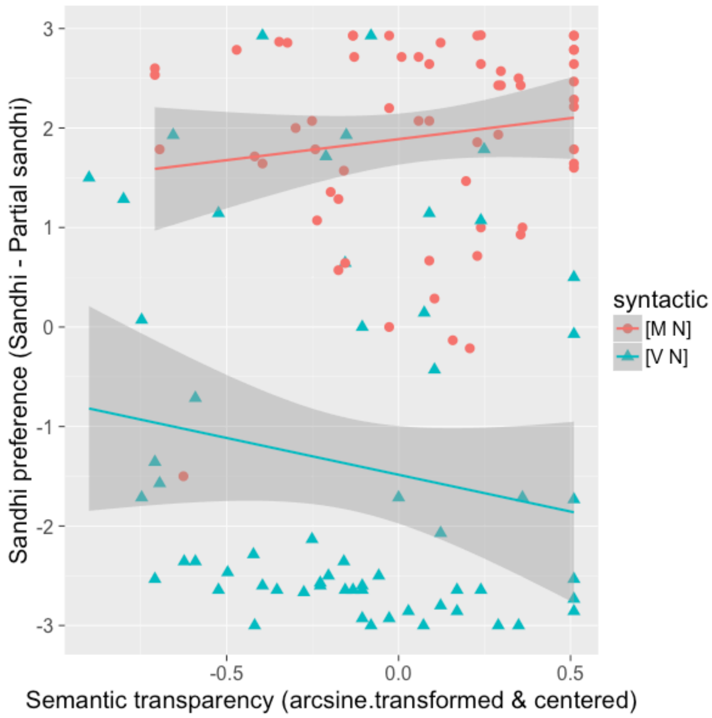

Figure 9. The distribution of sandhi preference of Shanghai 1+2 trisyllables when the predictor is semantic transparency rating.

Figure 9 suggests that, like in [M N] disyllables there is no semantic transparency effect on tone sandhi application in 1+2 [M N] trisyllables. There is a negative effect on 1+2 [V N] trisyllables. Semantically transparent [V N] items prefer the partial sandhi form more than semantically opaque ones, which is consistent with our prediction as well as the results in the disyllable data. [M N] (M = .06, SD = .35) and [V N] (M= -.14, SD = .38) trisyllables differed significantly on the ratings for semantic transparency, t (117) = 3.02, p = .003, based on the result of a t-Test.

Three Linear Regression Models, with sandhi preference as dependent variable and syntactic structure, frequency rating as predictors, were run to examine whether the effects of the predictors were driven by the different frequencies and semantic transparencies between

[M N] and [V N]: one with all data, one excluding the first quartile of all 1+2 [M N] items with the lowest frequencies, and one excluding the first quartile of all 1+2 [V N] items with the lowest semantic transparencies. In the two trimmed data sets, a *t*-Test for frequency rating showed that [M N] (*M* = .01, *SD* = .22) and [V N] (*M* = 0, *SD* = .30) trisyllables no longer differed in lexical frequencies, *t* (102) = .22, *p* = .83; a *t*-Test for semantic transparency rating indicated that [M N] (*M* = .06, *SD* = .35) and [V N] (*M* = .3, *SD* = .27) trisyllables were not different in semantic transparencies either, *t* (103) = .53, *p* = .60. Log-likelihood comparisons showed that the best models conducted for the three data sets were the models without the predictor semantic transparency, and only with the syntactic structure by frequency interaction. All three models treated [M N] item as the baseline for syntactic structure. The results of the three regression models turned out to be consistent. Therefore, we report the statistical results based on all 1+2 items, as list in Table 11.

Table 11. Sandhi preference predicted by syntactic structure and frequency for Shanghai 1+2 trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.161	(0.195)	11.090	< 2e-16 ***
syntactic structure VN	-3.543	(0.265)	-13.370	< 2e-16 ***
frequency	1.899	(0.582)	3.263	0.001 **
syntactic structure VN : frequency	-1.952	(0.842)	-2.318	0.022 *
N	120			
RMSE	1.391			
R^2	0.607			
adj R^2	0.597			

* p <0.05** p <0.01*** p <0.001

Table 11 shows that in the model with all 1+2 items, the two predictors explain 60.7% of the variance in sandhi preference ($R^2 = .607$, F (3, 116) = 59.700, $p < .001$). There are main effects of syntactic structure and lexical frequency, i.e., syntactic structure significantly predicts sandhi preference ($\beta = -3.543$, $p < .001$), as does lexical frequency ($\beta = 1.899$, $p < .01$). The sandhi preference value of [V N] trisyllables is significantly lower than that of [M N] trisyllables (mean value of sandhi preference: [M N]: 1.91, [V N]: -1.38). With a positive β weight (1.899), the value of sandhi preference increases when frequency rating increases one standard deviation. That is to say, high-frequency items prefer the tonal extension sandhi form more compared to low-frequency items. There is also a syntactic structure by lexical frequency interaction, indicating that the significance of the main effects for syntactic structure and lexical frequency is irrelevant, and the interaction is further examined below. Finally, the effect of semantic transparency is not significant, suggesting that semantic transparency does not influence Shanghai 1+2 trisyllabic sandhi application.

Next, Linear Regression Models were conducted separately in 1+2 [M N] and [V N] trisyllabic data, with lexical frequency as predictor. This is because: first, there is no semantic transparency by sandhi preference interaction in the model reported above; second, for both types of trisyllables, the model with only frequency as the predictor was not significantly different from those more complicated models based on the results of log-likelihood comparisons. We therefore report the simple models with only one predictor here. The results of [M N] data are listed in Table 12, and those of [V N] are listed in Table 13.

Table 12. Sandhi preference predicted by frequency for Shanghai 1+2 [M N] trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.161	(0.110)	19.568	< 2e-16 ***
frequency	1.899	(0.330)	5.757	3.41e-07 ***
N	60			
RMSE	0.788			
R^2	0.364			

* *p* <0.05** *p* <0.01*** *p* <0.001

Table 13. Sandhi preference predicted by frequency for Shanghai 1+2 [V N] trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	-1.382	(0.233)	-5.939	1.72e-07 ***
frequency	-0.052	(0.788)	-0.066	0.947
N	60			
RMSE	1.802			
R^2	0.000			

* *p* <0.05** *p* <0.01*** *p* <0.001

For [M N] items, Table 12 shows that there is a main effect of lexical frequency. With a positive β weight (1.899), the value of sandhi preference increases when frequency rating increases one standard deviation, i.e., more frequent 1+2 [M N] trisyllables prefer the tonal extension sandhi form more than less frequent ones as we predicted, and this is also consistent with the [M N] disyllable results. For 1+2 [V N] items, there is no effect of lexical frequency, as shown in Table 13.

However, in both Figure 8 and Figure 9, the sandhi preference of [V N] trisyllables, represented by blue triangles, seems to have a bimodal distribution. The Kernel Density of 1+2 [V N] trisyllables is plotted in Figure 10, from which we can observe that the distribution is bimodal.

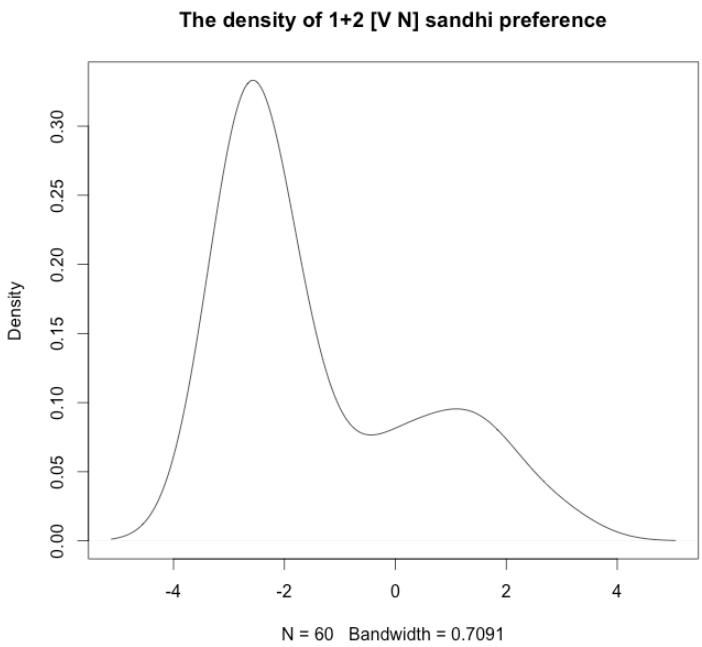

Figure 10. Density of sandhi preference of 1+2 [V N] trisyllables.

Considering the bimodality of 1+2 [V N] items' sandhi preference, we separated the data for further analysis. Based on visual inspection on Figure 8 and Figure 10, we chose -1 as the dividing line between the two peaks. We ran two Linear Regression models on the 1+2 [V N] items with high sandhi preference values (above -1) and those with low sandhi preference values (below -1). For both [V N] data sets, the best model for sandhi preference was the one with lexical frequency as the lone predictor. The results of 1+2 [V N] trisyllables that prefer to undergo tonal extension are listed on the top of Table 14, and the results of those that prefer to undergo partial sandhi are listed on the bottom.

Table 14. Sandhi preference predicted by frequency for Shanghai 1+2 [V N] trisyllables in two data sets.

Prefer sandhi [V N]				
	Estimate	(S.E.)	*t*	*p*
(Intercept)	1.021	0.247	4.129	0.0007 ***
frequency	0.270	0.882	0.306	0.763
N	19			
RMSE	1.075			
R^2	0.005			
Prefer partial sandhi [V N]				
(Intercept)	-2.502	(0.063)	-39.812	< 2e-16 ***
frequency	-0.537	(0.208)	-2.577	0.014 *
N	41			
RMSE	0.402			
R^2	0.146			

* p <0.05** p <0.01*** p <0.001

For those 1+2 [V N] trisyllables that have high preference values for the tonal extension sandhi form, frequency effect is not significant. For those items that have low preference values for tonal extension, there is a significant negative effect of lexical frequency on sandhi preference. This finding is similar to that in [V N] disyllables, and it will be further discussed in §4.6.

In conclusion, 1+2 [M N] and [V N] trisyllables differ in sandhi preference. Similar to disyllables, 1+2 [M N] trisyllables prefer to undergo the tonal extension sandhi form, and 1+2 [V N] items prefer the partial sandhi form. Lexical frequency has a positive effect on 1+2 [M N] items. As a result of the bimodal distribution of sandhi preference for 1+2 [V N] trisyllables, frequency has a negative effect on 1+2 [V N] trisyllables that prefer the partial sandhi form, but not on those that prefer the sandhi form. There is no semantic transparency effect on 1+2 trisyllables.

4.5.2.2 ***Morpheme length***

Both Mixed-Effects models and Multiple Linear Regression models were used to examine the morpheme length effect in Shanghai trisyllabic tone sandhi application.

4.5.2.2.1 Mixed-Effects models

To investigate how trisyllables pattern depending on morpheme length, lexical frequency, and semantic transparency, Linear Mixed-Effects models were used with morpheme length, frequency rating as fixed effects and subject and item as random effects. Based on the results of log-likelihood comparisons, the model with the morpheme length by frequency interaction was significantly better than the other simpler models. Adding the third fixed effect, semantic transparency rating, did not significantly improve the model. The parameter estimates for the model with the interaction between the two fixed effects are listed in Table 15. The model treated 1+2 [M N] item as the baseline for morpheme length effect.

Table 15. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Shanghai 1+2 and 2+1 [M N] trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.157	0.112	19.340	< 2e-16 ***
morpheme length 2+1	-0.083	0.136	-0.614	0.541
frequency	1.880	0.295	6.381	4.1e-09 ***
morpheme length 2+1: frequency	-1.052	0.494	-2.130	0.035 *
Random Effects (σ)				
Residual	1.126			
item	0.635			

subject	0.438
N	1680
RMSE	1.126

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

Table 15 indicates that there is an effect of lexical frequency. More frequent [M N] items prefer the tonal extension form more than less frequent ones. This is in accordance with our prediction and the disyllables results. The coefficient for the frequency effect for 1+2 items is 1.880, while that for 2+1 items is 1.880 - 1.052 = .828. This suggests that the slope for 1+2 items is steeper than that for 2+1 items.

To further look into the morpheme length by frequency interaction, two separate Mixed-Effects models were used with lexical frequency rating as a fixed effect and subject and item as random effects. According to log-likelihood comparisons, for both 1+2 and 2+1 [M N] items, the model with the frequency by semantic transparency interaction was not significantly different from the model without the interaction or the model with only frequency. Therefore, the simplest model with frequency as the fixed effect is used here. The effects of lexical frequency in the Mixed-Effects models for 1+2 and 2+1 [M N] items are listed in Table 9 and Table 16.

As shown in §4.5.2.1.1, for 1+2 [M N] trisyllables, lexical frequency has a positive effect on sandhi preference, and semantic transparency does not play a role in 1+2 [M N] trisyllabic sandhi application.

Table 16. Fixed effect estimates (top) and variance estimates (bottom) for the model result of sandhi preference in Shanghai 2+1 [M N] trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	-1.384	(0.232)	-5.957	1.45e-07 ***
frequency	-0.169	(0.701)	-0.242	0.81
Random Effects (σ)				
Residual	1.144			
item	0.248			
subject	1.758			
N	840			
RMSE	1.144			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

For 2+1 [M N] trisyllables, there is no frequency effect on sandhi preference. The predicted models for frequency effect on 1+2 and 2+1 [M N] items' sandhi preference are presented in Figure 11 (left), and the predicted models for semantic transparency effect are also shown in Figure 11 (right).

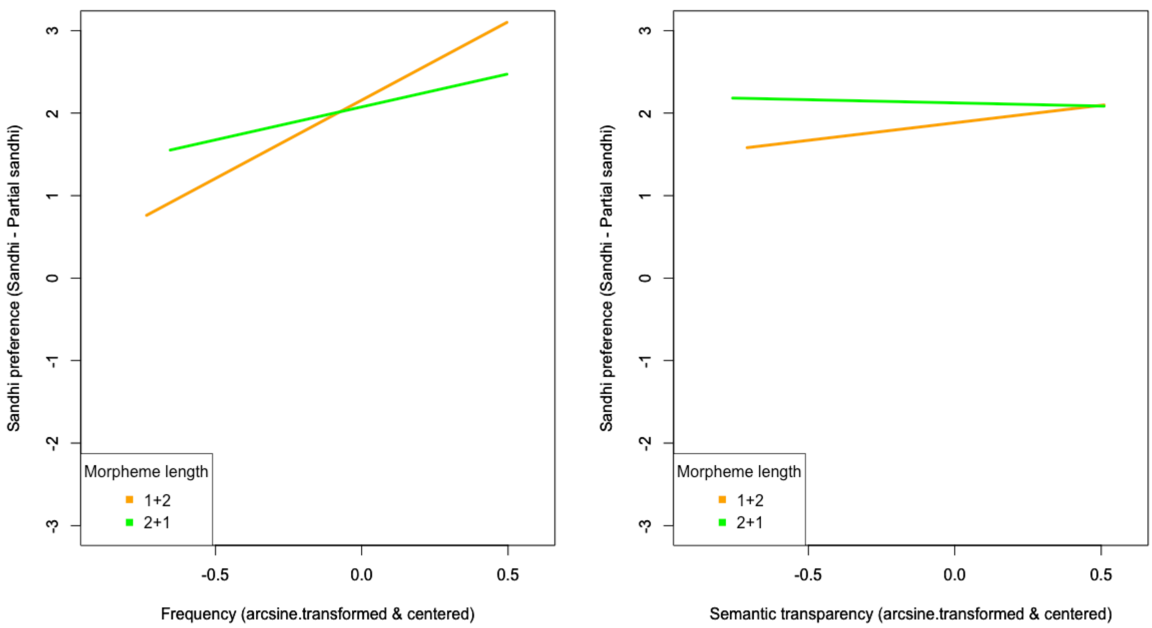

Figure 11. The predicted effects of frequency (left) and semantic transparency (right) in Shanghai 1+2 and 2+1 [M N] trisyllabic sandhi preference.

Generally speaking, there is no difference between 1+2 and 2+1 [M N] trisyllables in term of sandhi preference. On the left side of Figure 11, we can see that both 1+2 and 2+1 [M N] trisyllables are positively influenced by lexical frequency, however, as shown in the Mix-Effects models, the slope of 1+2 items is steeper than that of 2+1 items. On the right side of Figure 11, semantic transparency does not influence 2+1 [M N] items, and seems to have a positive effect on 1+2 [M N]. But neither of them is statistically significant.

4.5.2.2.2 Multiple linear regression

The sandhi preference of all [M N] items was plotted against the two continuous predictors — frequency and semantic transparency ratings. Figure 12 shows the distribution of sandhi preference of 1+2 and 2+1 trisyllables depending on lexical frequency rating, with separate regression lines for 1+2 and 2+1 structures, the directions of which are very similar to those of the predicted lines in the Mixed-Effects models in Figure 11 (left).

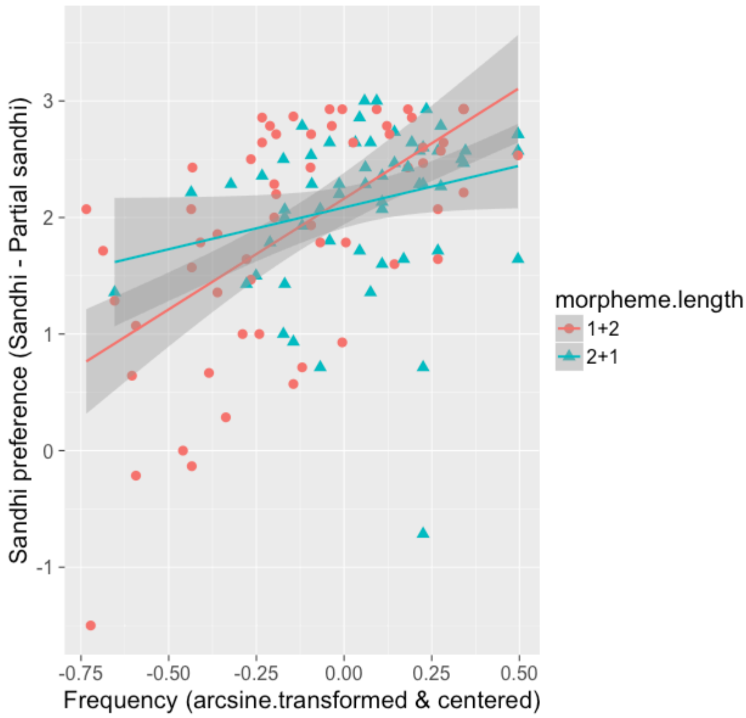

Figure 12. The distribution of sandhi preference of Shanghai [M N] trisyllables when the predictor is lexical frequency rating.

For frequency effect, since these are all [M N] trisyllables, both 1+2 and 2+1 [M N] items prefer the tonal extension sandhi form. This is consistent with our prediction, the Mixed-Effects models results, as well as the disyllable results. However, the frequency predictor on 1+2 [M N] items has a steeper slope than that on 2+1 [M N] ones; this indicates that frequency affects 1+2 [M N] items more than 2+1 [M N]. This may be caused by the low-frequency 1+2 items (on the left corner of Figure 12). A *t*-Test indicated that 1+2 [M N] (M = -.13, SD = .31) and 2+1 [M N] (M = .06, SD = .23) had significantly different frequencies, t (109) = -3.79, $p < .001$.

Figure 13 shows the distribution of sandhi preference of 1+2 and 2+1 [M N] trisyllables based on semantic transparency ratings, with separate regression lines for 1+2 and 2+1 items.

These regression lines have the same direction as the predicted lines in the Mixed-Effects models in Figure 11 (right).

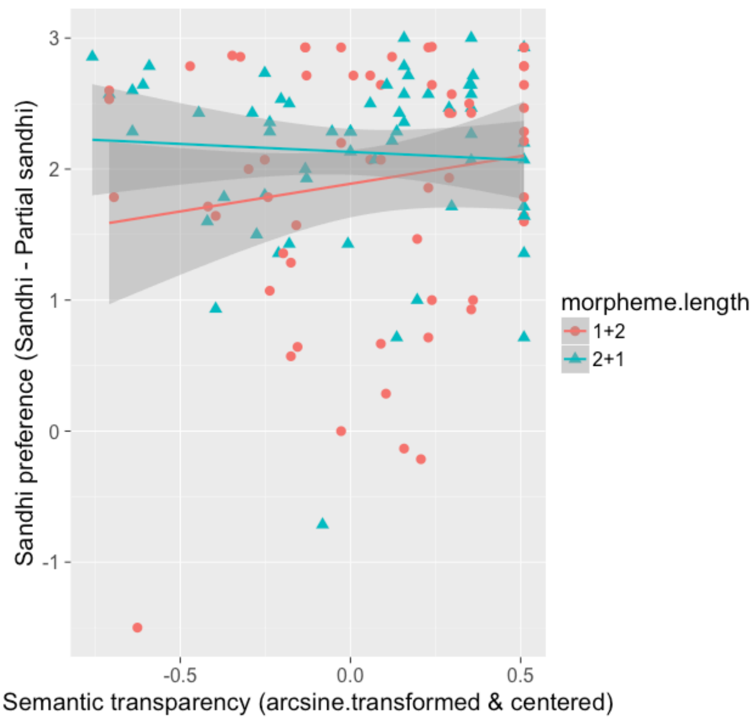

Figure 13. The distribution of sandhi preference of Shanghai [M N] trisyllables when the predictor is lexical semantic transparency rating.

For the rating of semantic transparency, due to the ceiling effect of all [M N] items, there seems to be little semantic transparency effect. A *t*-Test showed that 1+2 [M N] (M = .06, SD = .35) and 2+1 [M N] (M = .02, SD = .35) did not differ significantly in semantic transparencies, t (118) = .66, p = .51.

Two Linear Regression Models, with sandhi preference as dependent variable and syntactic structure, frequency rating as predictors, were run to examine whether the effects of the predictors were driven by the different frequencies between 1+2 and 2+1 [M N] items: one with all data, one excluding the first quartile of all 1+2 [M N] items with the lowest frequencies. In the trimmed data set, a *t*-Test for frequency rating showed that 1+2 [M N] (*M* = .01, *SD* = .22) and 2+1 [M N] (*M* = .06, *SD* = .30) trisyllables no longer differed in lexical frequencies, *t* (95) = -1.08, *p* = .28. Log-likelihood comparisons of different models showed that in all data, the best model was the one with the morpheme length by lexical frequency interaction, while in the trimmed data, the best one was the one without the interaction. The results of the two regression models are listed in Table 17, with the all-data result on the top and the trimmed-data result on the bottom. Both models treated 1+2 [M N] items as the baseline for morpheme length effect.

Table 17. Sandhi preference predicted by morpheme length and frequency for Shanghai [M N] trisyllables in two data sets.

All data				
	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.161	(0.102)	21.267	< 2e-16 ***
morpheme length 2+1	-0.075	(0.140)	-0.538	0.592
frequency	1.899	(0.304)	6.257	6.8e-09 ***
morpheme length 2+1: frequency	-1.183	(0.506)	-2.338	0.021 *
N	120			
RMSE	0.725			
R^2	0.279			
adj R^2	0.260			
Trimmed data				
(Intercept)	2.220	(0.099)	22.489	< 2e-16 ***
morpheme length 2+1	-0.149	(0.132)	-1.134	0.260
frequency	0.967	(0.283)	3.421	0.0009 ***
N	105			
RMSE	0.662			
R^2	0.107			
adj R^2	0.090			

* p <0.05** p <0.01*** p <0.001

For the all-data results, the two predictors explain a significant proportion of the variance in sandhi preference (R^2 = .279, F (3, 116) = 14.970, p < .001). There is a main effect of lexical frequency, suggesting that the value of sandhi preference increases with one standard deviation increase of frequency. Morpheme length and lexical frequency also interact significantly. This indicates that the effects of lexical frequency are different for 1+2 and 2+1 items, which requires separate analyses for the two types of structures. However, different from our prediction, there is no main effect of morpheme length (mean value of sandhi preference: 1+2: 1.91, 2+1: 2.13). 1+2 [M N] items do not have stronger preferences for the tonal extension sandhi form than 2+1 [M N] items.

The bottom of Table 17 shows that in the model with trimmed data, where low-frequency 1+2 [M N] trisyllables are excluded to reach frequency balance, the two predictors also explain a significant proportion of the variance in sandhi preference (R^2 = .107, F (2, 102) = 6.112, p = .003). A log-likelihood comparison test suggested that there was no significant difference between the model with the interaction and the one without, hence, the simpler model without the interaction is reported here. There is a main effect of lexical frequency. With a positive β weight (0.967), the value of sandhi preference increases when frequency rating increases one standard deviation. That is to say, high-frequency items prefer the tonal extension sandhi form more than low-frequency items. These are in accordance with our prediction, the results of disyllables, as well as those of 1+2 trisyllables. But in the trimmed data without low-frequency 1+2 [M N] items, the interaction between morpheme length and frequency disappears. Therefore, the interaction occurring in the model with all data may be caused by the different frequencies between 1+2 and 2+1 [M N] items. To get a better understanding of how frequency affects 1+2 and 2+1 [M N] items, two Linear Regression models were conducted separately. The results are shown in Table 18 and Table 19.

Table 18. Sandhi preference predicted by frequency for Shanghai 1+2 [M N] trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.161	(0.110)	19.568	< 2e-16 ***
frequency	1.899	(0.330)	5.757	3.14e-07 ***
N	60			
RMSE	0.788			
R^2	0.364			

* *p* <0.05** *p* <0.01*** *p* <0.001

Table 19. Sandhi preference predicted by frequency for Shanghai 2+1 [M N] trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.086	(0.088)	23.829	<2e-16 ***
frequency	0.716	(0.366)	1.954	0.056
N	60			
RMSE	0.656			
R^2	0.062			

* *p* <0.05** *p* <0.01*** *p* <0.001

As shown in Table 18 and Table 19, there is a significant effect of frequency for 1+2 [M N] items, but only a marginal effect for 2+1 [M N] items. Given the results of the model with trimmed data, the frequency effect on 1+2 [M N] items may be driven by the low frequency items. Therefore, for 1+2 and 2+1 [M N] items with same frequencies, frequency does not affect sandhi preference differently. Furthermore, there is no morpheme length effect on the preference of sandhi application, which is inconsistent with our prediction, but consistent with the Mixed-Effects model results in §4.5.2.2.1.

In conclusion, there is no statistical difference between the sandhi application preference between 1+2 and 2+1 [M N] items. Frequency appears to influence 1+2 [M N] items more compared to 2+1 [M N] items, but this may have resulted from the different frequencies between the two types of trisyllables.

4.6 Discussion

In the Shanghai data, the sandhi applications of disyllables and trisyllables pattern differently and are influenced by different factors.

For disyllables, the results support hypothesis (a): [M N] disyllables prefer to apply tonal extension compared to [V N] disyllables, as shown in both Mixed-Effects models and Multiple Linear Regressions. For Hypothesis (b), the results show that frequency influences [M N] and [V N] disyllables in different ways: lexical frequency has a positive effect on the preference of applying tonal extension for [M N] disyllables, but a negative effect for [V N] ones. This indicates that lexical frequency interacts with syntactic structure in Shanghai disyllabic tone sandhi application. [M N] disyllables with high lexical frequencies tend to apply tonal extension, while the higher the frequency a [V N] disyllable has, the less preferred tonal extension is. Hypothesis (c) finds partial support in our results: there is only an effect of semantic transparency for [V N], whereby semantically more opaque [V N] disyllables have a stronger preference for the tonal extension sandhi form than semantically transparency ones.

Overall, the results suggest that disyllabic tone sandhi application in Shanghai is primarily determined by syntactic structure, as the robustness of its effect, especially in [M N] compounds, overwhelms any semantic transparency effect. The lexical frequency effect functions differently based on syntactic structures: a more frequent [M N] disyllable that usually undergoes tone sandhi has a greater tendency to undergo tonal extension, while a more frequent [V N] disyllable has a stronger tendency for no sandhi. According to Bybee (2001), high-frequency forms are resistance to regularization, such as the cases of English past tense regularization and the loss of liaison in French. In the current case, high-frequency [V N] disyllables tend to resist tonal change, and low-frequency [V N] disyllables tend to undergo the regular tonal extension sandhi.

For trisyllables, the results again support hypothesis (a): 1+2 [M N] trisyllables prefer to apply tonal extension than 1+2 [V N] trisyllables, suggesting a strong syntactic structure effect. Hypothesis (b) receives partial support: lexical frequency has a positive effect on the preference of applying tonal extension for 1+2 [M N] trisyllables, but no effect for 1+2 [V N] trisyllables. We can see that for 1+2 [V N] trisyllables that prefer to undergo partial sandhi, there is still a negative frequency influence. This indicates that lexical frequency interacts with syntactic structure in Shanghai trisyllabic tone sandhi application as well. 1+2 [M N] trisyllables with high lexical frequencies tend to apply tonal extension, while there seems to be some other factors that cause the bimodal distribution of 1+2 [V N] trisyllabic sandhi application, which the current study is not designed to investigate. Hypothesis (c) does not find support in the trisyllabic results: there is no effect of semantic transparency for trisyllables.

There is also no evidence to support Hypothesis (d). Even with the same frequency, 1+2 and 2+1 [M N] items do not differ in sandhi application. The participants do not have a stronger preference for applying tonal extension for 1+2 [M N] items than for 2+1 [M N] items. In all, the results indicate that similar to the disyllables, trisyllabic tone sandhi application in Shanghai is also mainly determined by syntactic structure. Lexical frequency has an effect on sandhi application of 1+2 [M N] trisyllables, but not on that of 1+2 [V N] or 2+1 [M N] items. For 1+2 [V N] trisyllables, the lack of general frequency effect may be caused by the bimodal distribution of sandhi preference, and there seems to be some other factors that make the speakers prefer tonal extension for some [V N] trisyllables and partial sandhi for some others. [V N] trisyllables that prefer to undergo partial sandhi behave similarly to [V N] disyllables in that lower frequency items are more likely to regularize towards the spreading sandhi form and hence show a stronger preference for the spreading sandhi form; for the [V N] trisyllables that prefer to undergo the spreading sandhi, they behave like words and show similar frequency behavior to [M N] forms in that higher frequency items are stronger preference for the spreading sandhi form.

Both the disyllabic and trisyllabic results indicate that lexical frequency effect interacts with syntactic structure. Although [M N] disyllables have significantly higher lexical frequency ratings than [V N] ones, and [M N] trisyllables have statistically lower frequency ratings than [V N] ones, frequency is not the determinant of sandhi application. That is because, first, after balancing the frequency ratings of [M N] and [V N] items, a frequency by syntactic structure interaction is still observed; second, high-frequency [M N] and [V N] items have different tendencies for sandhi application, i.e., more frequent [M N] words prefer the sandhi form and more frequent [V N] phrases prefer the no sandhi form. Therefore, the finding in Shanghai does not support the argument that usage frequency determines constituency (Bybee, 2001); Shanghai tone sandhi application is regulated by the grammatical factors, such as the transparency of the sandhi pattern and syntactic structure.

One point worth noting is that in the sandhi form goodness rating experiment, the participants listened to two sandhi forms, while in the frequency and semantic transparency rating experiments, they only heard one form[17] of sandhi for each stimulus. To examine whether the ratings for lexical frequency and semantic transparency may be affected by the sandhi preference of a particular participant, we conducted Pearson's correlation tests between sandhi preference values and frequency ratings and between sandhi preference values and semantic transparency ratings by each subject. By averaging across the items, four average ratings were derived for each participant: one for the sandhi forms, one for the no/partial sandhi forms, one for lexical frequency, and one for semantic transparency. For each participant, the average rating for the no/partial sandhi forms was then subtracted from the average rating for the sandhi forms to get the average sandhi preference value. Correlation tests were then run between the values of sandhi preference and the ratings for lexical frequency and between the values of sandhi preference and the ratings for semantic transparency. These tests allow us to see whether a participant's frequency and semantic transparency ratings were influenced by the

[17] For disyllables, all [M N] items participants heard in frequency and semantic transparency rating experiments are tonal extension sandhi form, and 88 out of 90 [V N] items they heard are no sandhi form. For trisyllables, 118 out of 120 [M N] items participants heard are tonal extension sandhi form, and 51 out of 60 [V N] items they heard are partial sandhi form.

specific sandhi variants that the participant heard and this participant's general sandhi preference. Given that the forms of sandhi participants heard in [M N] items are different from those they heard in [V N], we tested the correlation in [M N] and [V N] items separately.

In [M N] disyllables, the values of sandhi preference and the ratings for lexical frequency are not correlated, r (68) = .09, p = .46, and the values of sandhi preference and the rating for semantic transparency are not correlated either, r (68) = .11, p = .35. In [V N] disyllables, there is no correlation between the values of sandhi preference and the ratings for lexical frequency (r (68) = .08, p = .49), or between the values of sandhi preference and the ratings for semantic transparency (r (68) = .07, p = .58).

In [M N] trisyllables, there is no correlation between the values of sandhi preference and frequency ratings (r (68) = .04, p = .73), or between the values of sandhi preference and semantic transparency ratings (r (68) = .15, p = .22). In [V N] trisyllables, the values of sandhi preference are not correlated with frequency ratings (r (68) = -.05, p = .69), but are correlated with semantic transparency ratings (r (68) = -.29, p = .02).

To look into the correlation between the values of sandhi preference and semantic transparency ratings in [V N] trisyllables, we plotted the seventy subjects' data in Figure 14. There is no outlier for the values of sandhi preference nor semantic transparency ratings. This indicates that the forms that the participants heard did have an effect on their ratings for semantic transparency in [V N] trisyllables. Considering that the sandhi form of 51 out of 60 [V N] trisyllables they heard was the partial sandhi form, the participants that prefer the sandhi form have a tendency to rate the semantic transparency of the lexical items relatively low, indicating that the items are semantically opaque, while those that prefer the partial sandhi form tend to rate the semantic transparency high. Even though there is this correlation, the results of Mixed-Effects models and Multiple Linear Regression models are consistent with each other, suggesting that the findings could be generalized to larger populations of subjects and items.

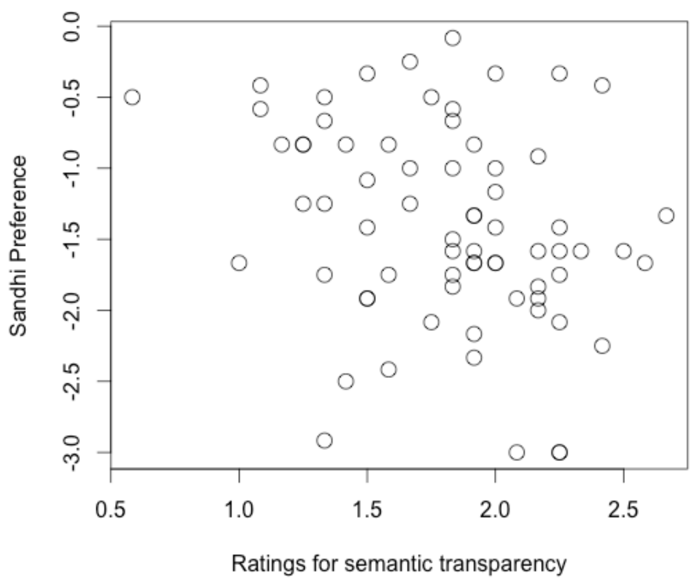

Figure 14. The distribution of the values of sandhi preference predicted by the ratings for semantic transparency in [V N] trisyllables for Shanghai participants.

In all, syntactic structure effect is operative in the variant forms of Shanghai disyllabic and trisyllabic sandhi application, i.e., the sandhi process is constrained by syntactic structures. [M N] items prefer the tonal extension form, while [V N] items prefer the no/partial sandhi form. Lexical frequency has different influences on sandhi application in different syntactic structures. For [M N] items that have a tendency to undergo tonal extension, a phonological reduction process, the sandhi form is preferred by more frequent items, as these items are treated as phonological words. For [V N] items, given that they are treated as phrases, alternation of the verbal form becomes relevant, and higher frequency items showed stronger resistance against regularizing towards the sandhi form and therefore a stronger preference towards the no/partial sandhi form. The semantic transparency effect only appears in [V N] disyllables in a negative direction. [M N] disyllables showed a ceiling effect in the application of tonal extension; for trisyllables, the semantic transparency effect of the whole item may be overridden by other factors, such as the frequency and semantic transparency of the morphological constituents, and so forth. Finally, no morpheme length effect was found in trisyllabic sandhi application.

Chapter V: EXPERIMENTAL INVESTIGATION OF THE NATURE OF TONE SANDHI VARIATION IN WUXI

5.1 Introduction

In Wuxi Chinese, Xu (2007) mentioned in passing that grammatical factors such as semantic transparency and syntactic structure and non-grammatical factors such as lexical frequency can both influence the variable disyllabic sandhi application. For trisyllabic sandhi application, Wang (2008) is the only source that I am aware of that provided a description. Therefore, compared to Shanghai, we know even less about the nature of tone sandhi variation in Wuxi. The tone sandhi patterns of the two dialects are similar in that both dialects have left-dominant sandhi, but they differ in the mode of sandhi application: Shanghai applies tonal extension, while Wuxi applies tonal substitution. In the latter, speakers need to use a substituted tone before applying tonal extension. Productivity tests also show that Shanghai, with phonologically transparent tone sandhi, behaves differently from Wuxi, which has a phonologically opaque sandhi circle. Not only are we unclear about the nature of variation in Wuxi tone sandhi application, it is also unknown whether transparent and opaque sandhi patterns may differ in the pattern of variation. This study aims to examine the effects of lexical frequency, semantic transparency, syntactic structure, and morpheme length on tone sandhi variation in Wuxi and compare the results to those of Shanghai.

This chapter first proposes the research questions of the study and lays out the predictions. The methodology section discusses the materials, participants and the procedures of each experiment. The data analysis method is then stated, followed by the results. The disyllabic and trisyllabic results are reported separately. The chapter closes by a discussion of how lexical frequency, semantic transparency, syntactic structure, and morpheme length influence Wuxi tone sandhi variation. The comparison between Shanghai and Wuxi is provided in Chapter VI.

5.2 Research questions

For the effects of semantic transparency and syntactic structure, Xu (2007) indicated that some [V N] disyllables with a "close connection" between the components only apply tonal substitution, and some [V N] disyllables could apply either tonal substitution or no sandhi. Yan (ms.) found that syntactic structure also has an effect on 1+2 trisyllables, i.e., 1+2 [M N] items tend to apply tonal substitution more readily than 1+2 [V N] items. Moreover, Yan & Zhang's (in press) wug test results showed that the opaque substitution pattern is not fully productive in novel words, which suggests a frequency effect and is consistent with their contention that the opaque sandhi patterns are lexically listed. Based on these limited resources, we hypothesize that in Wuxi, (a) [M N] items prefer to undergo tonal substitution more than [V N] items; (b) high-frequency items prefer tonal substitution more than low-frequency ones; (c) semantically opaque items have a stronger tendency to undergo tonal substitution than semantically transparent items; and (d) 1+2 [M N] items prefer tonal substitution more than 2+1 ones, but the difference between 1+2 and 2+1 [M N] trisyllables may be smaller than that in Shanghai, given that Wuxi tonal substitution has been argued to have a trace of right-dominance (Chan & Ren, 1989).

5.3 Methodology

To explore the nature of Wuxi tone sandhi variation, we conducted three experiments with native Wuxi speakers as we did with native Shanghai speakers, including a goodness rating experiment for the variant forms together with subjective frequency and semantic transparency ratings from the same speakers. Experiment 1 was a tone sandhi variation goodness rating experiment that informed us that for each lexical item in the experiment, which sandhi form was preferred by the speakers; Experiment 2 was a subjective frequency rating experiment, which investigated the frequency of all stimuli; and Experiment 3 was a semantic transparency rating experiment, which examined the semantic transparency of all stimuli. All experiments included the same set of disyllables and trisyllables, which are further discussed in §5.3.1. The rating results of Experiment 1 were treated as the dependent variable, and those of Experiment 2 and 3 were used as independent variables. The procedures of the experiments and design criteria were identical to the Shanghai experiments.

5.3.1 Materials

There were two sets of stimuli, one was disyllabic, and the other was trisyllabic. All of the stimuli were chosen from Xu (2007), Wang (2008), and the *Wuxi Dialect Dictionary* (Xiang, 2008). The 3 non-checked Yin tones T1, T3, T5 were tested. For the disyllabic set, 10 [M N] and 10 [V N] items were included for each tonal combination, which resulted in 180 stimuli (20*9 tonal combinations =180). For the trisyllabic set, tones on σ2 and σ3 were not controlled, but checked tones were avoided. Due to word length preference, there were 20 2+1 [M N] items for each tone on σ1 (20*3=60), with the tone on σ1 being T1, T3, T5. For the 1+2 structure, there were 20 [M N] and 20 [V N] items for each tone on σ1 (40*3=120). In total, there were 180 trisyllabic stimuli.

The 180 disyllables and 180 trisyllables were divided into 5 lists, and the participants were divided into 5 groups, as shown in Table 1. Participants would not see the same words in different experiments, and each subject needed to judge 36 disyllables and 36 trisyllables in each experiment. For the 180 disyllables, the same morpheme occurred a maximum of 3 times in the entire word list; for the 180 trisyllables, the same morpheme occurred a maximum of 5 times. The entire stimulus list of Wuxi is given in Appendix B.

All stimuli were recorded in the Anechoic Chamber at the University of Kansas, using a Marantz PMD-671 solid state recorder and an Electrovoice 767 microphone placed on the desk in front of the speaker. The Wuxi stimuli were recorded by a 28-year-old female native speaker with phonetic training. The stimuli for Experiment 2 (frequency rating) and Experiment 3 (semantic transparency rating) were recorded first, and the speaker was asked to read the stimuli as naturally as possible without considering the tone sandhi variation. Afterwards, the speaker was asked to produce the two variant forms for each stimulus for Experiment 1 (variation goodness rating). The Wuxi experiments were conducted in a quiet office in Wuxi.

5.3.2 Participants

Seventy-one native speakers of Wuxi Chinese participated in this study, including 35 males and 36 females. All participants were born and raised in the urban districts of Wuxi until 18 years old, ranging from 21 to 35 years old, with an average age of 27, and they were all living in Wuxi at the time of the experiments. None of them had speech or hearing impairment according to their self-reports. All participants provided background information (see Appendix C), and all took the three experiments in sequence. They were paid $10 for their participation.

5.3.3 Procedures

Wuxi participants took the three experiments in the same order as the Shanghai participants. Experiment 1 was a variation goodness rating experiment, in which participants heard tonal substitution sandhi form and no/partial sandhi form for each lexical item. It took about 20 minutes. Experiment 2 was a lexical frequency rating experiment. Participants were asked to rate the frequency for each lexical item, and it took about 10 minutes. Experiment 3 was a semantic transparency rating experiment, which asked the participants to rate the semantic transparency for each item. It also took about 10 minutes. In the experiments, the participants wore a pair of headphones, and sat in front of a computer and a mouse. At the beginning of each experiment, the participants listened to the instruction in Wuxi, and the researcher made sure that the participants had no confusion about the task. The procedures were the same as those in Shanghai.

5.4 Data analysis

Disyllables and trisyllables were analyzed separately, and both Mixed-Effects models and Multiple Linear Regression models were used for each set. The rating for no/partial sandhi form was subtracted from the rating for tonal substitution sandhi form to get a value of sandhi preference. Lexical frequency rating and semantic transparency rating were arcsine-transformed and centered at the median as in Shanghai.

For disyllables, the dependent variable is sandhi preference in both Mixed-Effects models and Multiple Linear Regressions, and the independent variables are syntactic structure ([M N], [V N]), frequency rating, and semantic transparency rating. For trisyllables, the dependent variable is still sandhi preference, but the stimuli were split according to the syntactic structure and morpheme length. In 1+2 items, the independent variables included syntactic structure ([M N], [V N]), frequency rating, and semantic transparency rating. In [M N] items, we investigated the independent variables of morpheme length (1+2, 2+1), frequency, and semantic transparency ratings.

5.5 Results

5.5.1 Disyllables

To be consistent with the report of the Shanghai results, we first present the results of the Mixed-Effects models, and then discuss the results of the Multiple Linear Regression models.

5.5.1.1 ***Mixed-Effects models***

In order to examine the effects of the different factors on Wuxi disyllabic sandhi application and be able to generalize the findings to larger populations of subjects and items, Linear Mixed-Effects models were used, with syntactic structure, frequency rating, and semantic transparency rating as fixed effects and subject and item as random effects. For frequency rating, the higher the value is, the more frequent the item was rated. For the rating of semantic transparency, a high value indicates that the item is semantic more transparent, and a low values indicates the item is semantic more opaque. The model with the interaction among the three fixed effects was significantly better than the other simpler models without the interaction based on the results of log-likelihood comparisons. The parameter estimates for the model with the interaction among the three fixed effects are listed in Table 20. The model treated [M N] item as the baseline for the effect of syntactic structure.

Table 20. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of Wuxi sandhi preference in disyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.577	(0.095)	27.138	< 2e-16 ***
syntactic structure VN	-1.673	(0.131)	-12.744	< 2e-16 ***
frequency	0.425	(0.312)	1.365	0.174
transparency	0.358	(0.391)	0.914	0.362
syntactic structure VN : frequency	0.535	(0.456)	1.174	0.242
syntactic structure VN : transparency	-1.826	(0.512)	-3.569	0.0005 ***
frequency : transparency	-2.166	(1.254)	-1.727	0.086
syntactic structure VN : frequency : transparency	0.784	(1.610)	0.487	0.627
Random Effects (σ)				
Residual	1.165			
item	0.774			

subject	0.271
N	2556
RMSE	1.165

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

These results show that there is an effect of syntactic structure. With a negative coefficient value (-1.673), [V N] items have significantly lower values of sandhi preference than [M N] items, which is consistent with our prediction. There is no frequency or semantic transparency effect, however, there is an interaction between syntactic structure and semantic transparency. For [M N] items, there is no effect of semantic transparency, while for [V N] items, there is a negative effect, .358 - 1.826 = -1.468, i.e., semantically transparent [V N] disyllables disfavor the tonal substitution sandhi form compared to semantically opaque [V N] items.

Given the interaction between syntactic structure and semantic transparency, two separate Mixed-Effects models were conducted to further examine the different behaviors of [M N] and [V N] disyllables. For [M N] disyllables, the best model was the model with the frequency by semantic transparency interaction based on log-likelihood comparisons; for [V N] disyllables, the model without the frequency by semantic transparency interaction turned out to be significantly better than other models.

Table 21. Fixed effect estimates (top) and variance estimates (bottom) for Wuxi sandhi preference in disyllabic [M N].

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.571	(0.059)	43.413	< 2e-16 ***
frequency	0.428	(0.183)	2.338	0.022 *

transparency	0.340	(0.230)	1.483	0.142
frequency : transparency	-2.186	(0.736)	-2.970	0.004 **
Random Effects (σ)				
Residual	0.803			
item	0.438			
subject	0.237			
N	1278			
RMSE	0.803			

* *p* ≤0.05** *p* ≤0.01*** *p* ≤0.001

For [M N] disyllables, lexical frequency has a significant effect. A positive coefficient (.428) indicates that high-frequency [M N] disyllables prefer to undergo tonal substitution. The interaction between lexical frequency and semantic transparency is also significant (-2.186), suggesting that the more semantically transparent an [M N] disyllable is, the smaller the effects of frequency on sandhi preference is.

Table 22. Fixed effect estimates (top) and variance estimates (bottom) for Wuxi sandhi preference for disyllabic [V N].

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	0.854	(0.125)	6.804	5.63e-10 ***
frequency	0.979	(0.431)	2.272	0.026 *
transparency	-1.311	(0.408)	-3.211	0.002 **
Random Effects (σ)				
Residual	1.405			
item	1.007			
subject	0.427			
N	1278			
RMSE	1.405			

* *p* ≤0.05** *p* ≤0.01*** *p* ≤0.001

For [V N] disyllables, there are significant effects for both frequency and semantic transparency. The positive coefficient (.979) for frequency indicates that more frequent [V N] disyllables in Wuxi prefer to undergo tonal substitution compared to less frequent ones, and the negative coefficient (-1.311) on semantic transparency suggests that semantically transparent [V N] disyllables tend to prefer the no sandhi form more than semantically opaque [V N] disyllables.

Figure 15 shows the predicted models for frequency and semantic transparency effects on sandhi preference and provides a visual for the coefficient values we discussed above.

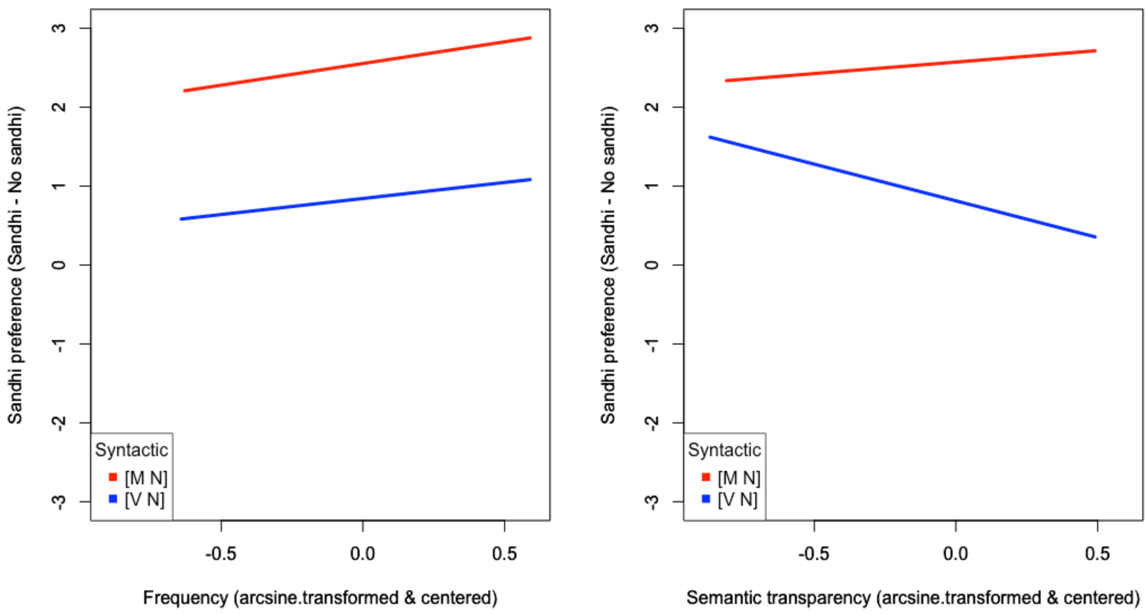

Figure 15. The predicted effects of lexical frequency (left) and semantic transparency (right) in Wuxi disyllabic sandhi preference.

As shown in Figure 15, for [M N] disyllables, the more frequent it is, the more likely it prefers the tonal substitution sandhi form; but there is no semantic transparency effect. For [V N] disyllables, frequency also has a positive effect on the sandhi application: more frequent [V

N] disyllables prefer the tonal substitution sandhi form more; semantic transparency has a negative effect: semantically transparent [V N] disyllables prefer to apply the no sandhi form.

5.5.1.2 ***Multiple linear regression***

To see how the sandhi application of each lexical item depends on syntactic structure, lexical frequency, and semantic transparency, the sandhi preference of each disyllable was plotted against the two continuous predictors, frequency and semantic transparency ratings. Figure 16 shows the distribution of sandhi preference of [M N] and [V N] disyllables depending on the lexical frequency rating, with separate regression lines for [M N] and [V N]. The directions of the two regression lines are in accordance with the predicted lines of the Mixed-Effects models in Figure 15 (left).

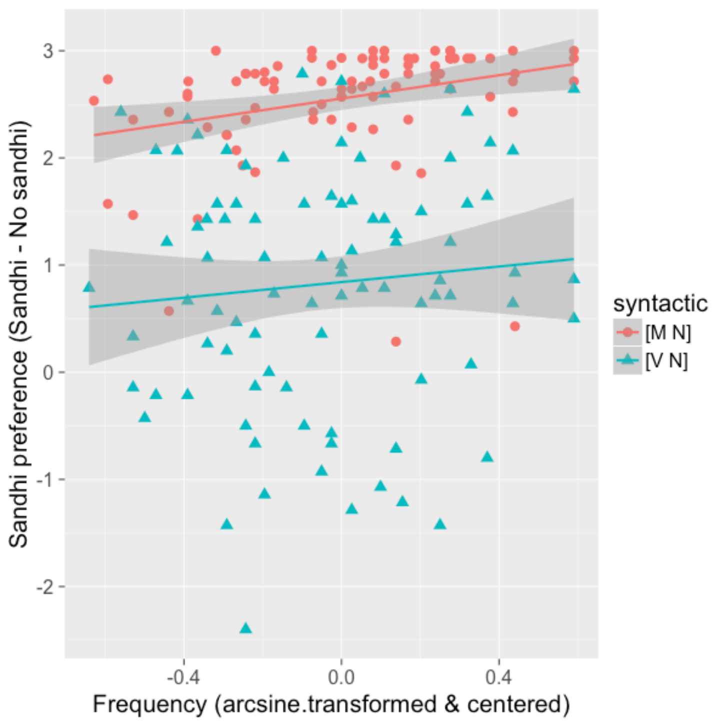

Figure 16. The distribution of sandhi preference of Wuxi disyllables when the predictor is lexical frequency rating.

In general, [M N] disyllables prefer to undergo tonal substitution more than [V N] disyllables regardless of the lexical frequency ratings. This is consistent with the prediction and the results of the Mixed-Effects models. As shown in Figure 16, speakers were more likely to apply tonal substitution for high-frequency [M N] and [V N] disyllables. A *t*-Test showed that there was no significant difference between the frequency ratings for [M N] (M = .02, SD = .29) disyllables and [V N] disyllables (M = -.05, SD = .29), t (178) = 1.45, p = .15.

Figure 17 shows the distribution of sandhi preference of [M N] and [V N] disyllables depending on semantic transparency rating, with separate regression lines for [M N] and [V N]. The directions of the two regression lines are consistent with the predicted lines of the Mixed-Effects models in Figure 15 (right).

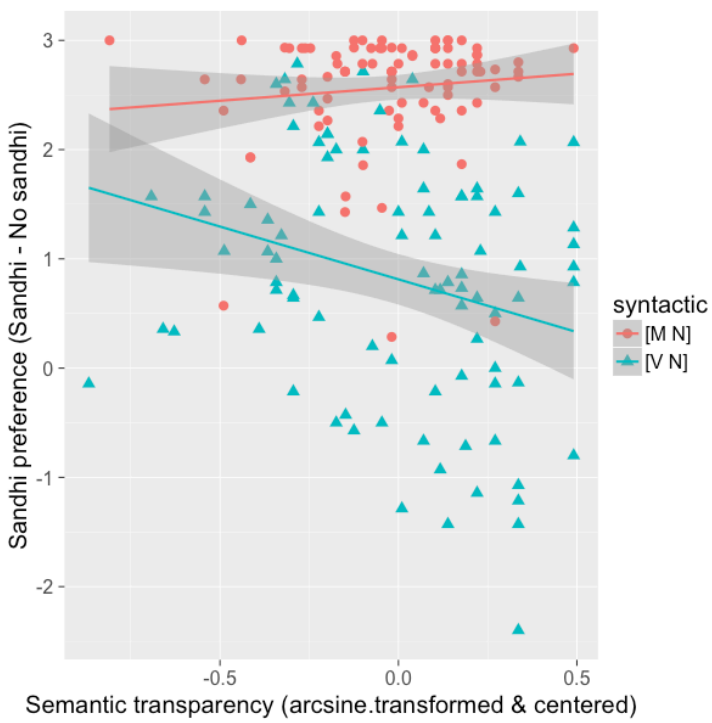

Figure 17. The distribution of sandhi preference of Wuxi disyllables when the predictor is semantic transparency rating.

In Figure 17, it seems that there is no semantic transparency effect on [M N] disyllables, but a negative effect on [V N] disyllables. Semantically transparent [V N] items, which have higher values of semantic transparency ratings, prefer to undergo no sandhi more than semantically opaque ones, which is consistent with our prediction and the results of Mixed-Effects models. A *t*-Test indicated that [M N] ($M = -.03$, $SD = .23$) and [V N] ($M = -.01$, $SD = .31$) did not differ significantly on the ratings for semantic transparency, $t\ (164) = -.49$, $p = .63$.

Multiple Linear Regression models were run to see how the three factors influenced Wuxi disyllabic sandhi application. The dependent variable is the value of sandhi preference, and the independent variables are syntactic structure, lexical frequency rating, and semantic transparency rating. Log-likelihood comparisons of different models showed that the best model was the one with all three independent variables and their interaction. The results of the regression model are listed in Table 23, and [M N] disyllable was treated as the baseline for the effect of syntactic structure.

Table 23. Sandhi preference predicted by syntactic structure, frequency and semantic transparency for Wuxi disyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.578	(0.090)	28.740	< 2e-16 ***
syntactic structure VN	-1.675	(0.132)	-12.714	< 2e-16 ***
frequency	0.425	(0.311)	1.366	0.174
transparency	0.310	(0.391)	0.792	0.430

syntactic structure VN : frequency	0.513	(0.457)	1.123	0.263
syntactic structure VN : transparency	-1.799	(0.513)	-3.508	0.0006 ***
frequency : transparency	-2.306	(1.254)	-1.839	0.068
syntactic structure VN : frequency : transparency	0.911	(1.611)	0.566	0.572
N	180			
RMSE	0.836			
R^2	0.565			
adj R^2	0.547			

* p <0.05** p <0.01*** p <0.001

Table 23 shows that the three predictors explain a significant portion of the variance in sandhi preference ($R^2 = .565$, $F(7, 172) = 31.860$, $p < .001$). There is a main effect of syntactic structure, i.e., syntactic structure significantly predicts sandhi preference. [V N] disyllables have significantly lower sandhi preference values than [M N] disyllables (mean value of sandhi preference: [M N]: 2.56, [V N]: .82). There is also a syntactic structure by semantic transparency interaction, indicating that the effect of semantic transparency on sandhi preference is different for [M N] and [V N] disyllables. Hence, it is necessary to separate [M N] and [V N] disyllables for further analysis.

Based on the results of log-likelihood comparisons, we found that for [M N] disyllables, the model with the frequency by semantic transparency interaction was significantly better than the model without the interaction; for [V N] disyllables, there was no significant difference between the model with the interaction and the model without. The results of [M N] data with the frequency by semantic transparency interaction are listed in Table 24, and those of [V N] data without the interaction are listed in Table 25.

Table 24. Sandhi preference predicted by frequency and semantic transparency for Wuxi [M N] disyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.578	(0.052)	49.307	< 2e-16 ***
frequency	0.425	(0.182)	2.344	0.021 *
transparency	0.310	(0.228)	1.358	0.178
frequency : transparency	-2.306	(0.731)	-3.154	0.002 **
N	90			
RMSE	0.487			
R^2	0.189			
adj R^2	0.161			

* p <0.05** p <0.01*** p <0.001

Table 24 shows that there is a significant effect of lexical frequency for [M N] disyllables. With a positive β weight (.425), the value of sandhi preference increases when frequency rating increases one standard deviation and semantic transparency rating is held constant, i.e., high-frequency [M N] items prefer to undergo tonal substitution as we predicted, which is also consistent with the results of Mixed-Effects models in §5.5.1.1. There is also an interaction between lexical frequency and semantic transparency on [M N] disyllabic sandhi application. This indicates that the semantic transparency effect on sandhi preference depends on lexical frequency, i.e., for semantically more transparent [M N] disyllables, the effects of frequency on sandhi preference is smaller (negative β weight) than semantically less transparent ones.

Table 25. Sandhi preference predicted by frequency and semantic transparency for Wuxi [V N] disyllables.

	Estimate	(S.E.)	*t*	*p*

(Intercept)	0.853	(0.115)	7.405	7.89e-11 ***
frequency	0.959	(0.430)	2.228	0.028 **
transparency	-1.342	(0.405)	-3.318	0.001 **
N	90			
RMSE	1.078			
R^2	0.120			
adj R^2	0.100			

* *p* <0.05** *p* <0.01*** *p* <0.001

For Wuxi [V N] disyllables, both lexical frequency and semantic transparency have significant effects on sandhi preference, but in different directions. The value of sandhi preference increases when frequency rating increases one standard deviation and semantic transparency rating is held constant, and it decreases when semantic transparency rating increases one standard deviation and frequency rating is held constant. This indicates that for a [V N] disyllable, the more frequent and less semantically transparent it is, the more preferred the tonal substitution sandhi form is.

Above all, syntactic structure, lexical frequency, and semantic transparency all have effects on Wuxi disyllabic sandhi application. [M N] disyllables prefer to undergo tonal substitution more than [V N] disyllables, and [V N] disyllables prefer the no sandhi form more. Lexical frequency has a positive influence on both [M N] and [V N] disyllables. Semantically opaque [V N] disyllables prefer the tonal substitution sandhi form more, while the effect of semantic transparency in [M N] disyllables is regulated by the effect of lexical frequency.

5.5.2 Trisyllables

Due to the inclusion of the additional predictor, morpheme length, as well as the nature of the stimuli, we separated the data according to the predictors under investigation. The syntactic structure effect was examined using all 1+2 items; and the morpheme length effect was examined using all [M N] items. Both Mixed-Effects models and Multiple Linear Regression models were conducted to probe the two effects, as we did in Shanghai.

5.5.2.1 ***Syntactic structure***

As just stated, the data used for the analysis of syntactic structure effect consist of all 1+2 items. Similar to the disyllables, the syntactic structure effect of trisyllables was investigated via Mixed-Effects models and Multiple Linear Regression models.

5.5.2.1.1 Mixed-Effects models

To investigate how trisyllabic sandhi application depends on the syntactic structure, lexical frequency, and semantic transparency ratings, Linear Mixed-Effects models were used with syntactic structure, frequency rating as fixed effects and subject and item as random effects. Based on the results of log-likelihood comparisons, the model with the syntactic structure by frequency rating interaction was not significantly better than the other simpler models. Including a third fixed effect of semantic transparency did not significantly improve the model. The parameter estimates for the model without the interaction between the two fixed effects — syntactic structure and frequency rating — are listed in Table 26. The model treated 1+2 [M N] item as the baseline for the syntactic structure effect.

Table 26. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Wuxi 1+2 trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.352	(0.108)	21.742	< 2e-16 ***
syntactic structure VN	-2.385	(0.143)	-16.699	< 2e-16 ***
frequency	0.788	(0.311)	2.538	0.013 *
Random Effects (σ)				
Residual	1.368			
item	0.693			
subject	0.311			
N	1704			
RMSE	1.368			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

Table 26 shows that there is an effect of syntactic structure. [V N] trisyllables have significantly lower values of sandhi preference than [M N] ones do, which is consistent with the results of the disyllables. The coefficient for the frequency effect for [M N] items is .788. That is to say, frequency has a positive effect on [M N] items. More frequent 1+2 [M N] trisyllables prefer the tonal substitution sandhi form more. However, there is no frequency effect for 1+2 [V N] trisyllables.

The predictions of the models were plotted in Figure 18, with the effect of frequency on the left and the effect of semantic transparency on the right.

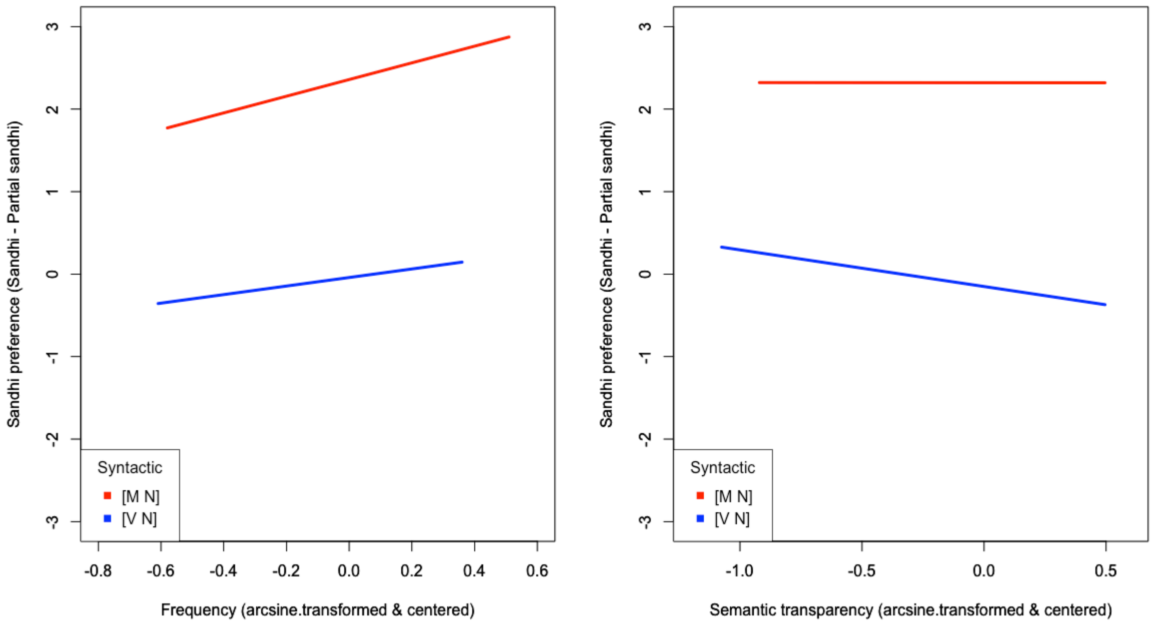

Figure 18. The predicted effects of lexical frequency (left) and semantic transparency (right) in Wuxi 1+2 [M N] and [V N] trisyllabic sandhi preference.

As shown in Figure 18, for 1+2 [M N] trisyllables, there is a significant effect of lexical frequency, i.e., more frequent 1+2 [M N] item prefer to undergo tonal substitution more; semantic transparency does not influence 1+2 [M N] trisyllables. For 1+2 [V N] trisyllables, neither frequency nor semantic transparency effect is statistically significant. The numerical trends that frequency affects 1+2 [V N] trisyllables positively, and semantic transparency affects them negatively, however, are consistent with the patterns as we have seen in disyllables (Figure 15).

5.5.2.1.2 Multiple linear regression

To see how individual 1+2 [M N] and [V N] trisyllables behave in sandhi preference more directly, all 1+2 items were plotted against lexical frequency and semantic transparency ratings. Figure 19 shows the distribution of sandhi preference of 1+2 [M N] and [V N] trisyllables depending on the lexical frequency rating, with separate regression lines for [M N] and [V N]. The directions of the two regression lines are consistent with the predicted lines of the Mixed-Effects models in Figure 18 (left).

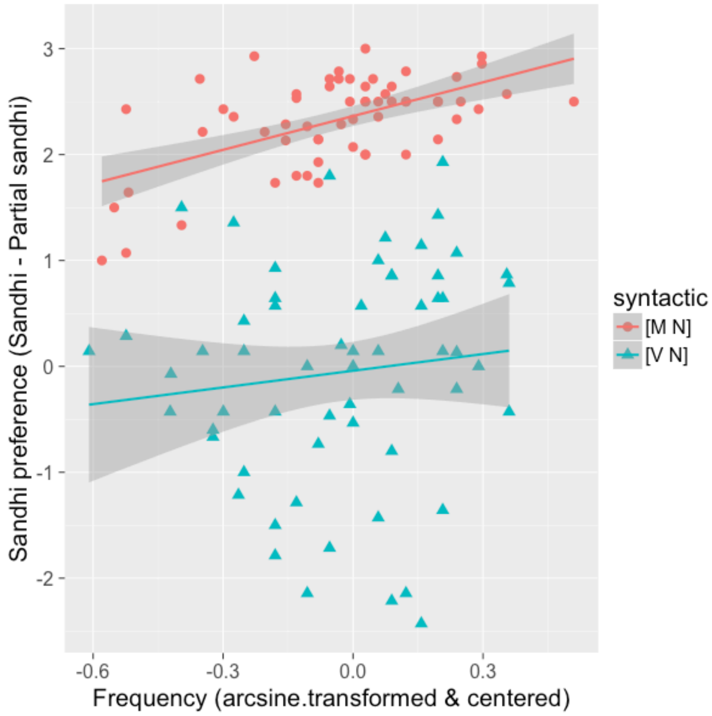

Figure 19. The distribution of sandhi preference of Wuxi 1+2 trisyllables when the predictor is lexical frequency rating.

1+2 [M N] trisyllables are more likely to undergo tonal substitution than 1+2 [V N] trisyllables in general. This is in accordance with our prediction, the results of the previous Mixed-Effects models, as well as the disyllable results. However, the distribution of 1+2 [V N] trisyllables sandhi preference is not as tightly clustered as that in disyllables (Figure 16), i.e., there is more variability in the sandhi application for 1+2 [V N] trisyllables. As shown in Figure 19, the more frequent a 1+2 [M N] trisyllable is, the more likely it prefers to undergo tonal substitution; on the other hand, there seems to be a smaller frequency effect on 1+2 [V N] trisyllables. Moreover, a *t*-Test showed that the frequency ratings for 1+2 [M N] (M = -.04, SD = .23) and 1+2 [V N] (M = -.03, SD = .23) trisyllables did not differ significantly, t (118) = -.18, p = .86.

Figure 20 shows the distribution of sandhi preference of [M N] and [V N] disyllables depending on the semantic transparency rating, with separate regression lines for [M N] and [V N]. The directions of the regression lines are similar to the predicted lines of the Mixed-Effects models in Figure 18 (right).

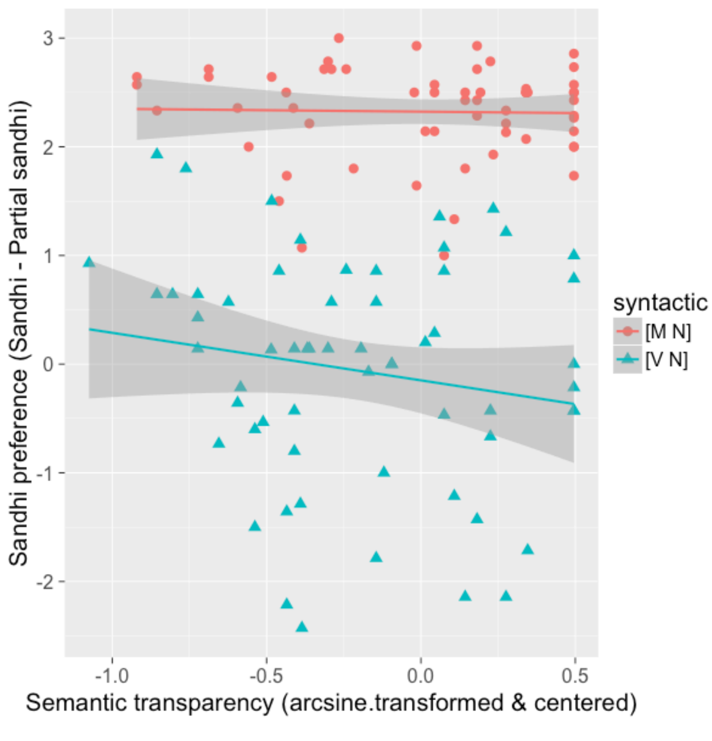

Figure 20. The distribution of sandhi preference of Wuxi 1+2 trisyllables when the predictor is semantic transparency rating.

In Figure 20, semantic transparency does not regulate the sandhi application of 1+2 [M N] trisyllables, but have a negative influence on 1+2 [V N] items. Semantically transparent [V N] items prefer partial sandhi more than semantically opaque ones, which is consistent with our prediction as well as the results in disyllable data. However, based on the result of a *t*-Test, 1+2 [M N] trisyllables (*M* = .02, *SD* = .41) had significantly higher ratings for semantic transparency than 1+2 [V N] trisyllables (*M*= -.21, *SD* = .41), *t* (118) = 3.05, *p* = .003.

Two Linear Regression Models were constructed to examine whether the effects of the predictors would be driven by the different semantic transparencies between [M N] and [V N] trisyllables: one with all data, one excluding the first quartile of all [V N] items with the lowest semantic transparency ratings. In the trimmed data, a *t*-Test showed that 1+2 [M N] (*M* = .02, *SD* = .41) and [V N] (*M* = -.04, *SD* = .32) items no longer differed in semantic transparency, *t* (103) = .88, *p* = .38. Log-likelihood comparisons of different models showed that in both data sets, the best model was the one with syntactic structure and lexical frequency. Adding a third predictor of semantic transparency did not significantly improve the model. Both models treated 1+2 [M N] trisyllable as the baseline for the effect of syntactic structure. The results of the two regression models turned out to be consistent. Therefore, we report the statistics based on all data, as listed in Table 27.

Table 27. Sandhi preference predicted by syntactic structure and frequency for Wuxi 1+2 trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.353	(0.102)	23.117	< 2e-16 ***
syntactic structure VN	-2.386	(0.143)	-16.685	< 2e-16 ***

frequency	0.797	(0.309)	2.581	0.011 *
N	120			
RMSE	0.783			
R^2	0.708			
adj R^2	0.703			

* p <0.05** p <0.01*** p <0.001

Table 27 shows that in the model with all 1+2 items, the two predictors explain 70.8% of the variance in sandhi preference ($R^2 = .708$, $F(2, 117) = 141.900$, $p < .001$). There are main effects of syntactic structure and lexical frequency, i.e., syntactic structure significantly predicts sandhi preference ($\beta = -2.386$, $p < .001$), as does lexical frequency ($\beta = .797$, $p < .05$). 1+2 [V N] trisyllables have significantly lower sandhi preference values than that of 1+2 [M N] trisyllables (mean value of sandhi preference: [M N]: 2.32, [V N]: -.06). With a positive β weight (0.797), the value of sandhi preference increases when frequency rating increases one standard deviation. That is to say, higher-frequency items prefer the tonal substitution sandhi form more. Similar to the results of the Mixed-Effects models, there is no syntactic structure by frequency interaction.

In all, for Wuxi 1+2 trisyllables, syntactic structure has a significant effect on sandhi application, i.e., [M N] trisyllables prefer to undergo tonal substitution more than [V N] trisyllables. Lexical frequency also affects 1+2 [M N] items positively, but has no influence on 1+2 [V N] items. More frequent 1+2 [M N] trisyllables tend to undergo tonal substitution more than less frequent ones. Finally, there is no semantic transparency effect on Wuxi trisyllabic sandhi application.

5.5.2.2 ***Morpheme length***

The data used for the analysis of morpheme length effect consist of all [M N] items. Both Mixed-Effects models and Multiple Linear Regression models were run to investigate the morpheme length effect in Wuxi trisyllabic tone sandhi application.

5.5.2.2.1 Mixed-Effects models

To investigate how morpheme length affects trisyllabic sandhi application together with lexical frequency and semantic transparency, Linear Mixed-Effects models were used with morpheme length, frequency rating, and semantic transparency rating as fixed effects and subject and item as random effects. Based on the results of log-likelihood comparisons, the model with the morpheme length by frequency interaction was not significantly better than the other simpler models. Adding a third fixed effect of semantic transparency did not significantly improve the models. The parameter estimates for the model without the interaction are listed in Table 28; 1+2 items were treated as the baseline for morpheme length.

Table 28. Fixed effect estimates (top) and variance estimates (bottom) for multi-level model results of sandhi preference in Wuxi 1+2 and 2+1 [M N] trisyllables.

Fixed effect	Coefficient	SE of estimate	*t*	*p*
(Intercept)	2.352	(0.088)	26.663	< 2e-16 ***
morpheme length 2+1	-0.283	(0.099)	-2.851	0.005 **
frequency	0.789	(0.222)	3.561	0.0005 ***
Random Effects (σ)				
Residual	1.095			
item	0.456			
subject	0.448			
N	1704			
RMSE	1.095			

* $p \leq 0.05$** $p \leq 0.01$*** $p \leq 0.001$

Table 28 indicates that there are main effects of morpheme length and lexical frequency. Given the negative coefficient (-.283), 2+1 [M N] trisyllables has a smaller sandhi preference values for the tonal substitution sandhi form than 1+2 [M N] trisyllables. The significant effect of lexical frequency indicates that more frequent 1+2 [M N] items prefer to undergo tonal substitution more than less frequent ones. This is in accordance with our prediction and the previous finding in §5.5.2.1. Considering that there is no interaction between morpheme length and frequency, the effect of lexical frequency on the sandhi application in 2+1 [M N] trisyllables is not different from that in 1+2 [M N] trisyllables.

Figure 21 shows the predictions of the models, the effect of frequency is presented on the left, and that of semantic transparency is on the right.

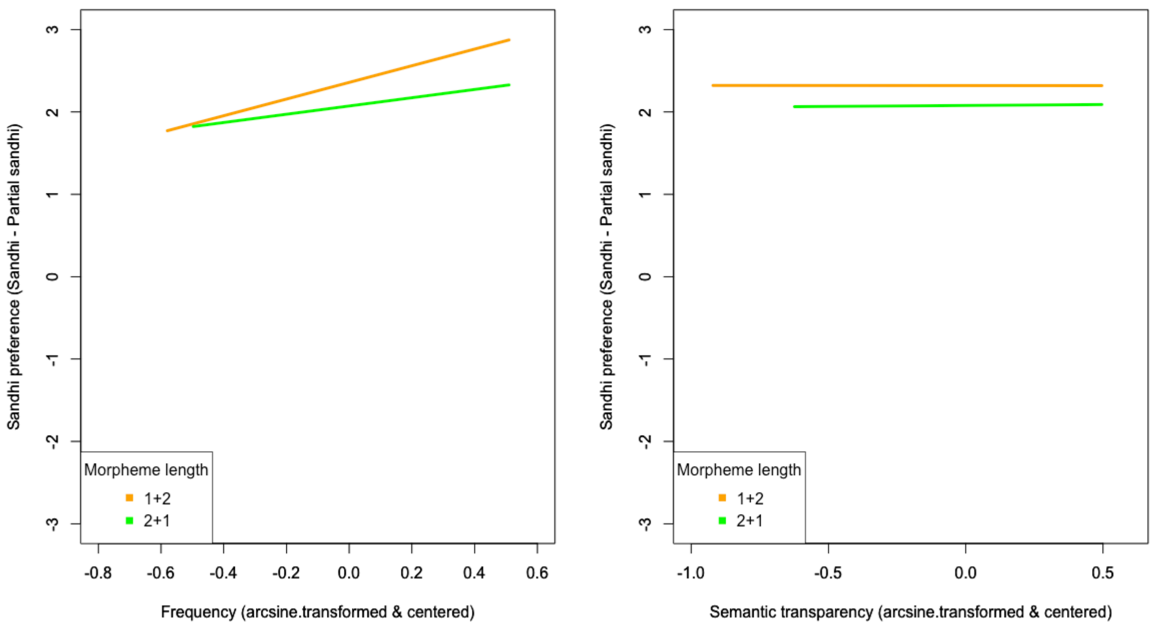

Figure 21. The predicted effects of lexical frequency (left) and semantic transparency (right) in Wuxi 1+2 and 2+1 [M N] trisyllabic sandhi preference.

In general, 1+2 [M N] items prefer to undergo tonal substitution more compared to 2+1 [M N] items. For 1+2 [M N] trisyllables, there is a significant effect of lexical frequency, while semantic transparency does not play a role in its sandhi application. For 2+1 [M N] trisyllables, frequency appears to have a positive effect, but is not statistically significant, and semantic frequency has no effect on its sandhi preference. For [M N] trisyllables, semantic transparency may not be relevant for sandhi application.

5.5.2.2.2 Multiple linear regression

We plotted the sandhi preference of all [M N] trisyllables against two continuous predictors — lexical frequency and semantic transparency ratings. Figure 22 shows the distribution of sandhi preference of 1+2 and 2+1 trisyllables depending on lexical frequency rating, with separate regression lines for 1+2 and 2+1 [M N] items, the directions of which are very similar to those of the predicted lines in the Mixed-Effects models in Figure 21 (left).

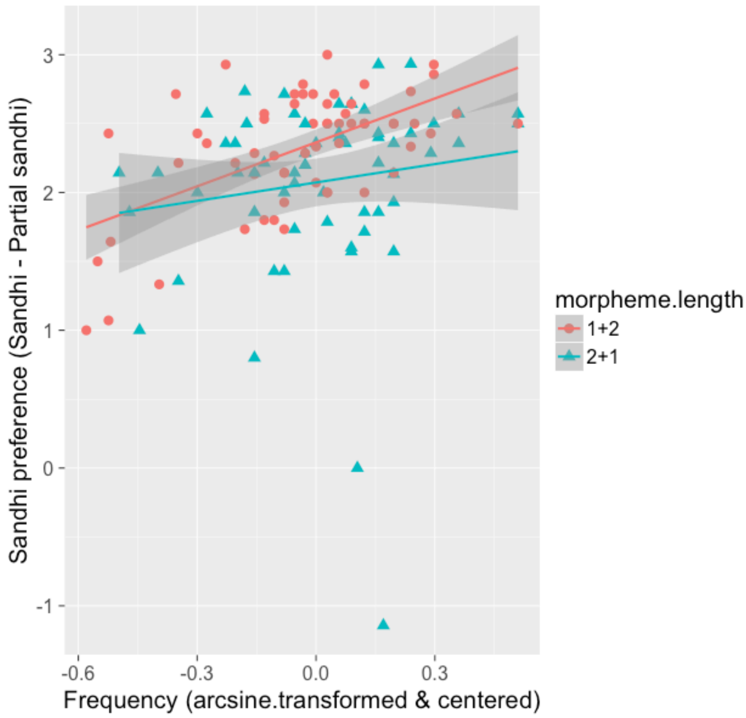

Figure 22. The distribution of sandhi preference of Wuxi [M N] trisyllables when the predictor is lexical frequency rating.

For frequency effect, since these are all [M N] trisyllables that prefer the tonal substitution sandhi form, the data points are clustered on the top of Figure 22. This is consistent with our prediction, the Mixed-Effects models results in §5.5.2.2.1, as well as the disyllable results. However, the red line representing 1+2 [M N] items is above the blue line representing 2+1 [M N] items, suggesting that 1+2 [M N] trisyllables prefer to undergo tonal substitution more than 2+1 [M N] trisyllables. A *t*-Test indicated that 1+2 [M N] (M = -.04, SD = .23) and 2+1 [M N] (M = .01, SD = .22) trisyllables did not differ significantly in frequencies, t (118) = -1.20, p = .23.

Figure 23 shows the distribution of sandhi preference of 1+2 and 2+1 [M N] trisyllables depending on semantic transparency rating, with separate regression lines for 1+2 and 2+1 [M

N]. The regression lines have the same direction as the predicted lines in the Mixed-Effects models in Figure 21 (right).

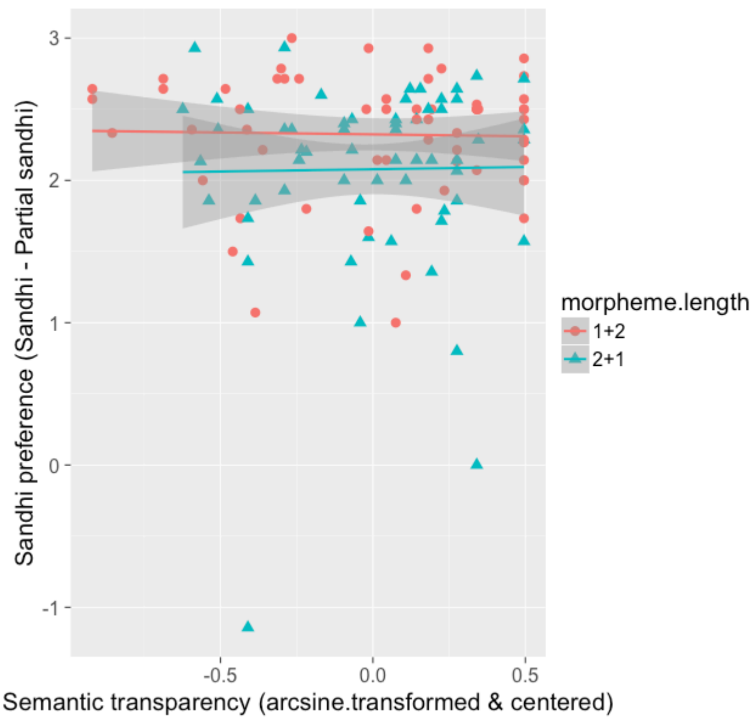

Figure 23. The distribution of sandhi preference of Wuxi [M N] trisyllables when the predictor is lexical semantic transparency rating.

For the rating of semantic transparency, the regression lines for 1+2 and 2+1 [M N] trisyllables are two parallel horizontal lines, indicating that there is little semantic transparency effect on sandhi preference for [M N] trisyllables. A *t*-Test showed that semantic transparency did not differ significantly for 1+2 [M N] (*M* = .02, *SD* = .41) and 2+1 [M N] (*M* = -.01, *SD* = .30) trisyllables, *t* (109) = .44, *p* = .66.

Multiple Linear Regression models were run to see how the three factors influenced Wuxi [M N] trisyllabic sandhi application. The dependent variable was the value of sandhi preference, and the independent variables were morpheme length, lexical frequency, and semantic transparency ratings. Log-likelihood comparisons between different models showed that the model with the morpheme length by frequency interaction and the model without the interaction did not differ significantly. Adding a third predictor of semantic transparency did not improve the model significantly. Therefore, the results of the regression model with morpheme length and lexical frequency as predictors are listed in Table 29, and 1+2 items were treated as the baseline for morpheme length.

Table 29. Sandhi preference predicted by morpheme length and frequency for Wuxi [M N] trisyllables.

	Estimate	(S.E.)	*t*	*p*
(Intercept)	2.352	(0.070)	33.543	< 2e-16 ***
morpheme length 2+1	-0.284	(0.099)	-2.863	0.005 **
frequency	0.771	(0.217)	3.548	0.0006 ***
N	120			
RMSE	0.539			
R^2	0.138			
adj R^2	0.124			

* p <0.05** p <0.01*** p <0.001

Table 29 indicates that the two predictors explain a significant proportion of the variance in sandhi preference ($R^2 = .138$, $F(2, 117) = 9.391$, $p < .001$). There is a main effect of morpheme length, suggesting that morpheme length significantly predicts sandhi preference. 2+1 [M N] trisyllables have significantly lower sandhi preference values than 1+2 [M N] trisyllables (mean value of sandhi preference: 1+2: 2.32, 2+1: 2.08). There is also a frequency main effect, indicating that high-frequency [M N] trisyllables prefer tonal substitution more than low-frequency ones.

In conclusion, for Wuxi trisyllables, both syntactic structure and morpheme length have an effect on sandhi application. 1+2 [M N] items prefer the tonal substitution sandhi form more than 1+2 [V N] items, and 1+2 [M N] items also prefer tonal substitution more than 2+1 [M N] items. Lexical frequency only affects 1+2 [M N] trisyllables positively, but not 2+1 [M N] or 1+2 [V N] items. Finally, semantic transparency is irrelevant for Wuxi trisyllabic sandhi application.

5.6 Discussion

In the Wuxi data, the sandhi applications of disyllables and trisyllables are influenced by different factors.

For disyllables, the results support Hypothesis (a): [M N] disyllables prefer to undergo tonal substitution more than [V N] disyllables, as shown in both Mixed-Effects models and Multiple Linear Regressions; the results also support Hypothesis (b): frequency has a positive influence on [M N] and [V N] disyllables, indicating that regardless of the syntactic structure, Wuxi disyllables with high lexical frequencies prefer tonal substitution more than those with low lexical frequencies. For Hypothesis (c), the results show that there is only an effect of semantic transparency for [V N] disyllables — semantically more opaque [V N] disyllables have a stronger preference for the tonal substitution sandhi form than semantically less opaque ones. In addition, there is no frequency or semantic transparency rating difference between [M

N] and [V N] disyllables, therefore, the different sandhi preference between [M N] and [V N] cannot be due solely to a frequency or semantic transparency effect. It further confirms that syntactic structure affects Wuxi disyllabic sandhi application. Overall, the results suggest that disyllabic tone sandhi application in Wuxi is determined by both syntactic structure and lexical frequency. The ceiling effect of tonal substitution application for [M N] disyllables has potentially overwhelmed any semantic transparency effect. Even though there is a syntactic structure effect on tonal substitution application, [M N] and [V N] disyllables are influenced by lexical frequency in the same direction, potentially due to the nature of tonal substitution: a more frequent disyllabic lexical item has easier access to the lexical entry with tonal substitution (Zuraw 2000) and therefore has a stronger preference for the tonal substitution sandhi form.

For trisyllables, the results again support Hypothesis (a): 1+2 [M N] trisyllables prefer to apply tonal substitution more than 1+2 [V N] trisyllables, and their frequencies do not differ significantly, suggesting a strong syntactic structure effect. Hypothesis (b) finds partial support: lexical frequency has a positive effect on the preference of applying tonal substitution for 1+2 [M N] trisyllables. Numerically, more frequent 1+2 [V N] and 2+1 [M N] trisyllables prefer the tonal substitution sandhi form more, however, the effects are not statistically significant. Hypothesis (c) does not receive support in Wuxi trisyllables results: semantic transparency does not affect trisyllabic sandhi application, although for 1+2 [V N] items, the effect of semantic transparency ratings has a negative coefficient value, which is consistent with that in disyllabic [V N] results. For Hypothesis (d), as predicted, 1+2 [M N] trisyllables prefer tonal substitution more than 2+1 [M N] trisyllables. It seems that the speakers do have a preference for applying more tonal substitution for 1+2 [M N] items than for 2+1 [M N] items. In all, the results indicate that similar to the disyllables, trisyllabic tone sandhi application in Wuxi is also mainly determined by syntactic structure. Lexical frequency has an effect on sandhi application in 1+2 [M N] trisyllables, but the positive coefficients and β weights of lexical frequency for 1+2 [V N] and 2+1 [M N] items are not statistically significant. The effect of semantic transparency did not show up in Wuxi trisyllabic data. It is possible that other factors, such as the semantic transparency of the constituents, are also involved in trisyllabic sandhi application. Finally, there is a morpheme length effect in Wuxi trisyllabic tone sandhi. For 1+2 [M N] trisyllables, due to the left-dominance, a stress clash would result if there were two tonal domains. Hence, speakers prefer to form one tonal domain and apply the substitution sandhi form for 1+2 [M N] items more than for 2+1 [M N] items.

As we did in Shanghai, to make sure that the ratings for lexical frequency and semantic transparency are not affected by the form participants heard, we conducted Pearson's correlation tests between sandhi preference values and frequency ratings, and between sandhi preference values and semantic transparency ratings by each participant. By averaging across the items, four average ratings were derived for each participant: one for the sandhi form, one for the no/partial sandhi form, one for lexical frequency, and one for semantic transparency. For each participant, the average rating for no/partial sandhi forms was then subtracted from the average rating for sandhi forms to get the average sandhi preference value. Correlation tests were then run between the values of sandhi preference and the ratings for lexical frequency, and between the values of sandhi preference and the ratings for semantic transparency. These tests allow us to see whether a participant's frequency and semantic transparency ratings were influenced by the specific sandhi variants that the participant heard and this participant's general sandhi preference. Given that the forms of sandhi participants heard in [M N] items and in [V N] items are different, we tested the correlation in [M N] and [V N] items separately.[18]

In [M N] disyllables, the values of sandhi preference and the ratings for lexical frequency are correlated, r (69) = .25, p = .04, while the values of sandhi preference and the ratings for semantic transparency are not correlated, r (69) = .17, p = .16. In [V N] disyllables, there is no correlation between the values of sandhi preference and ratings for lexical frequency (r (69) = -.01, p = .93), or between the values of sandhi preference and ratings for semantic transparency (r (69) = .09, p = .45).

In [M N] trisyllables, there is no correlation between the values of sandhi preference and frequency ratings (r (69) = -.11, p = .38), but there is a correlation between the values of sandhi preference and the ratings for semantic transparency (r (69) = .25, p = .03). In [V N] trisyllables, the values of sandhi preference are not correlated with frequency ratings (r (69) = -.04, p = .76), or with semantic transparency ratings (r (69) = -.23, p = .06).

There are two significant correlations, one in [M N] disyllables and one in [M N] trisyllables. First, for the correlation between the values of sandhi preference and lexical frequency ratings in [M N] disyllables, we plotted the seventy-one subjects' data in Figure 24.

[18] For disyllables, all [M N] items participants heard in frequency and semantic transparency rating experiments are tonal substitution sandhi form, and 21 out of 90 [V N] items they heard are no sandhi form. For trisyllables, all [M N] items participants heard are tonal substitution sandhi form, and 35 out of 60 [V N] items they heard are partial sandhi form.

There are several participants who generally provided low ratings for lexical frequency, and three of them are the outliers,[19] as shown in the boxplot in Figure 25 (left). There is also one outlier for the values of sandhi preference, who did not have a preference for the substitution sandhi form like other participants, as shown in Figure 25 (right). If we exclude these outliers, then there is no longer a correlation between the values of sandhi preference and the ratings for lexical frequency (*r* (65) = .10, *p* = .43). This indicates that in general, the participants' preference towards the forms that they heard did not have an effect on their ratings for frequency.

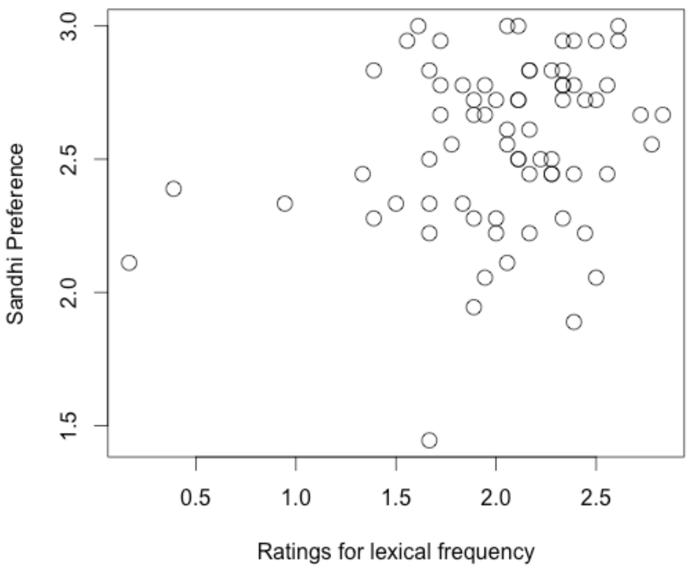

Figure 24. The distribution of the values of sandhi preference predicted by the ratings for lexical frequency in [M N] disyllables for Wuxi participants.

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[19] Here we adopt the definition of outlier as any data point that is more than 1.5 interquartile ranges below the first quartile or above the third quartile.

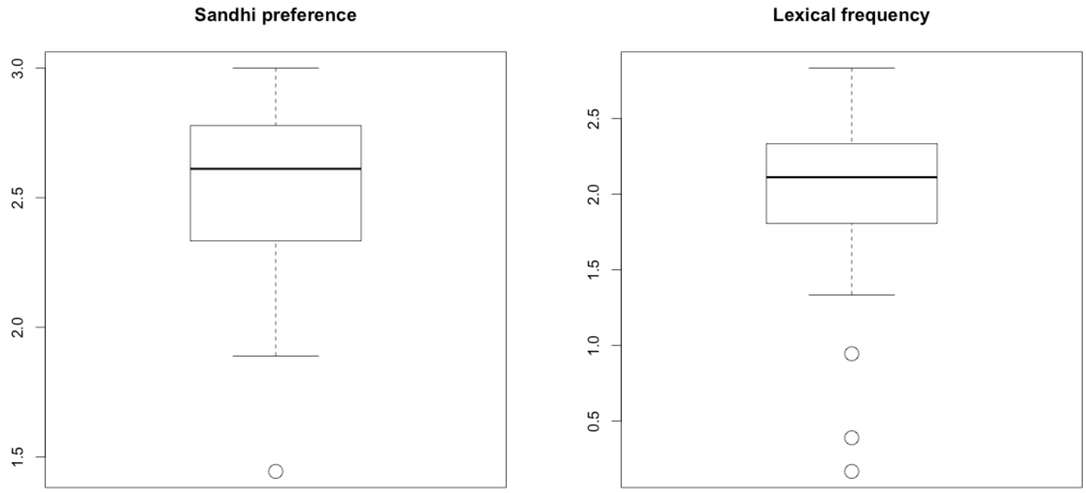

Figure 25. The boxplots of sandhi preference values (left) and lexical frequency ratings (right) in [M N] disyllables for Wuxi participants.

Second, the values of sandhi preference and ratings for semantic transparency in [M N] trisyllables are also correlated. All seventy-one subjects' data were plotted in Figure 26. There is one participant who rated semantic transparency low, as shown in Figure 27. If we exclude this outlier, then the values of sandhi preference and the ratings for semantic transparency no longer correlate (r (68) = .23, p = .06). This suggests that for most of the participants, their preference towards the forms that they heard did not influence the semantic transparency ratings they gave for the forms. Considering that the results of Mixed-Effects models and Multiple Linear Regression models are consistent with each other, it does not seem necessary to exclude these participants.

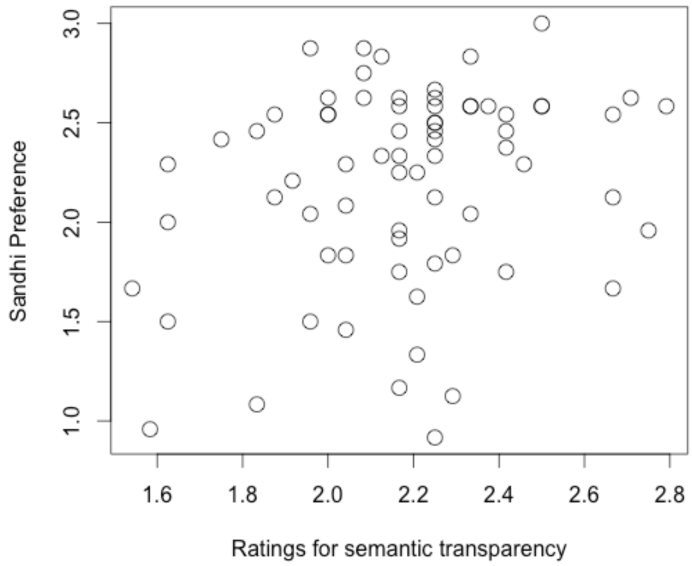

Figure 26. The distribution of the values of sandhi preference predicted by the ratings for semantic transparency in [M N] trisyllables for Wuxi participants.

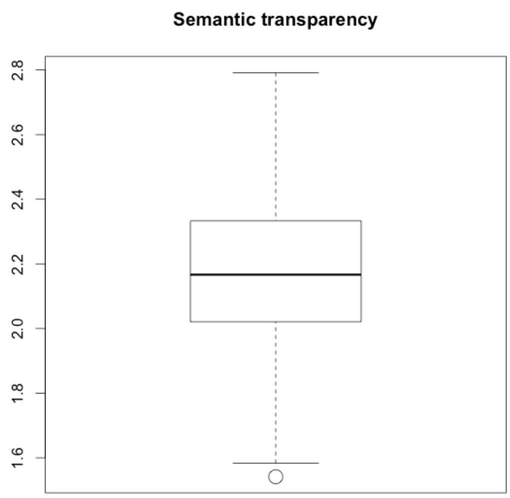

Figure 27. The boxplot of semantic transparency ratings in [M N] trisyllables for Wuxi participants.

In summary, tonal substitution and no/partial sandhi can apply variably in Wuxi disyllables and trisyllables according to native speakers' judgment. [M N] items prefer tonal substitution, and [V N] items prefer the no/partial sandhi form. As a result of lexical listedness, both high-frequency [M N] and [V N] items are more likely to apply the substitution sandhi pattern. Semantic transparency only influences [V N] disyllables, with the semantically opaque items preferring the sandhi form more than the semantically transparent ones. The lack of semantic transparency effect on [M N] disyllables is caused by the ceiling effect in substitution application, and there are other factors influencing trisyllabic sandhi beyond the scope of the current study. Possible factors include the frequency and semantic transparency of the constituents. Finally, Wuxi speakers' awareness of morpheme length suggests that Wuxi nominal compound is left-headed.

Chapter VI:GENERAL DISCUSSION AND CONCLUDING REMARKS

This chapter compares the similarities and differences between Shanghai and Wuxi tone sandhi variation and summarizes the main findings. The directions for future research are also outlined.

6.1 Comparison between Shanghai and Wuxi tone sandhi variation

The comparison between Shanghai and Wuxi disyllabic tone sandhi variation is summarized in Table 30.

Table 30. The comparison of factors affecting Shanghai and Wuxi disyllabic tone sandhi application.

	Shanghai disyllables	Wuxi disyllables
Similarities		
Syntactic structure	[M N] prefers the sandhi form more than [V N].	
Lexical frequency	A positive effect on [M N]	
Semantic transparency	A negative effect on [V N], no effect on [M N]	
Differences		
Syntactic structure	A larger effect	A smaller effect
Lexical frequency	A negative effect on [V N]	A positive effect on [V N]

For disyllables, there are three similarities between Shanghai and Wuxi tone sandhi variation: (a) tone sandhi application is regulated by syntactic structure, and [M N] disyllables prefer the sandhi form more than [V N] disyllables; (b) lexical frequency has a positive effect on [M N] disyllables, i.e., more frequent [M N] disyllables prefer to undergo the sandhi form more than less frequent [M N] items; (c) semantic transparency does not influence [M N] disyllables significantly due to the ceiling effect of [M N] items' preference for the sandhi form, but the more semantically transparent a [V N] item is, the less preferred the sandhi form is. The differences that distinguish Shanghai and Wuxi disyllabic tone sandhi variation are: (a) despite the fact that [M N] and [V N] disyllables behave differently in both dialects, the difference in Wuxi is smaller than that in Shanghai: the coefficient difference between [M N] and [V N] is -4.109 for Shanghai and -1.673 in Wuxi; as the sandhi preference for [M N] is comparable between Shanghai (2.485) and Wuxi (2.577), this difference primarily stems from the different treatment of the [V N] items between the two dialects: [V N] has a negative coefficient (2.485 - 4.109 = -1.624) and hence prefers the no sandhi variant in Shanghai, but a positive coefficient (2.577 - 1.673 = .904) and hence prefers the sandhi variant in Wuxi; (b) Shanghai high-frequency [V N] disyllables prefer the no sandhi form more than low-frequency counterparts, but Wuxi high-frequency [V N] disyllables prefer the sandhi form more than low-frequency counterparts.

Table 31 shows the summary of how each factor influences Shanghai and Wuxi trisyllabic sandhi application.

Table 31. The comparison of factors affecting Shanghai and Wuxi trisyllabic tone sandhi application.

	Shanghai trisyllables	Wuxi trisyllables
Similarities		
Syntactic structure	1+2 [M N] prefers the sandhi form more than 1+2 [V N].	
Lexical frequency	A positive effect on 1+2 and 2+1 [M N]	
Semantic transparency	No effect	
Differences		
Syntactic structure	A larger effect	A smaller effect
Lexical frequency	A negative effect for 1+2 [V N] that prefers partial sandhi	No effect on 1+2 [V N]
Morpheme length	No effect	1+2 [M N] prefer sandhi more

For trisyllables, we found three similarities between Shanghai and Wuxi tone sandhi variation: (a) 1+2 [M N] trisyllables prefer the sandhi form more than 1+2 [V N] trisyllables; (b) high-frequency 1+2 and 2+1 [M N] items have a stronger preference for the sandhi form than low-frequency ones; (c) there is no semantic transparency effect on trisyllabic sandhi application, but semantic transparency does have negative coefficients in the Mixed-Effects models and negative β weights in the Multiple Linear Regressions for 1+2 [V N] items in both dialects. There are also three distinctions between Shanghai and Wuxi trisyllabic tone sandhi variation: (a) similarly to the disyllables, the difference between 1+2 [M N] and [V N] trisyllables is smaller in Wuxi than that in Shanghai; (b) the sandhi preference for 1+2 [V N] items in Shanghai shows a bimodal distribution; for forms that show a strong preference for partial sandhi, frequency has a negative effect on the preference for the sandhi form, similarly to that in the disyllabic forms, but for forms that prefer sandhi, there is no frequency effect; for Wuxi, however, the sandhi preference for 1+2 [V N] items does not have a bimodal distribution, and the effect of frequency for 1+2 [V N] items is not significant; (c) 1+2 [M N] trisyllables prefer to undergo sandhi more than 2+1 [M N] trisyllables in Wuxi; while there is no morpheme length effect in Shanghai [M N] trisyllables. The comparison between Shanghai and Wuxi tone sandhi variation has a number of theoretical implications.

First, sandhi application is primarily affected by syntactic structure in Shanghai and Wuxi. In both dialects, [M N] words tend to apply the sandhi form, and [V N] phrases are more likely to undergo the no/partial sandhi form. However, the syntactic structure effect is larger in Shanghai compared to that in Wuxi. This is compatible with earlier research, since Xu et al. (1981, 1982), Takahashi (2013), and Zhang & Meng (2016) all showed that Shanghai speakers distinguish [M N] and [V N] structures clearly when applying tone sandhi, while syntactic structure effect is rarely documented in Wuxi tone sandhi studies (Cao, 2003; Xu, 2007; Wang, 2008). The current study complements the previous descriptive literature of Wuxi, showing that even though the effect is not as strong as that in Shanghai, Wuxi speakers are still aware of the effect of syntactic structures on the tone sandhi pattern of the lexical items. The difference between Shanghai and Wuxi may be due to the different nature of the sandhi patterns of Shanghai and Wuxi. As mentioned in §2.3, Shanghai's tonal extension is phonologically transparent, while Wuxi's tonal substitution is phonologically opaque. Our results demonstrate that phonologically transparent sandhi is more constrained by syntactic structures, and phonologically opaque sandhi is less sensitive to them.

Crossdialectally, the restriction of transparent tone sandhis to specific syntactic structures is common. For instance, Tangxi, another Wu dialect, behaves similarly to Shanghai in restricting the spreading tone sandhi to [M N], while maintaining the base tones in [V N] combinations (Kennedy, 1953). Wuxi's tonal extension is also restricted to certain syntactic structures, including reduplicated verbs, reduplicated nouns in baby talk, verbs with resultative or directional complement, and expressions of 'number + classifier', as mentioned in §2.2.1. Duanmu (1998) provided a metrical analysis for this pattern in Shanghai. Following Cinque's (1993) Nonhead Stress Rule, when Word 1 (W1) is an argument of Word 2 (W2), W1 is the complement and stress falls on the non-head W1, and when W1 is not an argument of W2, it is a specifier and stress falls on the non-head W2. That is to say, stress falls on the modifier in [M N] compounds, and on the noun in [V N] phrases. This was briefly mentioned in §3.4. In Shanghai [M N] compounds, each word is assigned word stress, so when left-headed compound stress applies to W1, a stress clash occurs. After removing the weaker stress on W2, W2 merges with the adjacent W1. In this case, it forms one tonal domain, and tone sandhi applies. In [V N] phrases, each word is assigned word stress, and when right-headed phrase stress applies to W2, a stress clash occurs. However, even after removing the weaker stress on W1, the unstressed W1 cannot merge with the stressed W2 due to Shanghai's left-dominant tonal spreading pattern. Therefore, it forms two tonal domains, and the base tone in each domain is preserved. This analysis is applicable to all left-dominant sandhis, as we found a syntactic structure effect in both Shanghai and Wuxi sandhi variation. However, the smaller effect in Wuxi suggests that not all phonological processes are constrained by syntactic structures to the same degree. Even though Wuxi speakers may be aware of the effect of syntactic structures implicitly, the opaque substitution pattern is listed in speakers' lexicon regardless of the syntactic structures.

This is consistent with the findings of previous productivity studies, which reveal that phonologically transparent patterns are more productive than phonologically opaque patterns (Zhang & Lai, 2010; Zhang et al., 2011; Zhang & Liu, 2011; Zhang & Meng, 2016; among other). Psycholinguistic studies also show that underlying primes have a facilitation effect for transparent sandhi, such as Mandarin T3 sandhi; and surface primes have a greater facilitation effect than underlying primes in opaque and phonotactically discouraged sandhi, such as Taiwanese 51 → 55 sandhi (phonotactically 51 may occur in the non-phrase final position due to the 21 → 51 sandhi) (Chien, Sereno, & Zhang, 2016a; Chien, Sereno, & Zhang, 2016b). These studies show that transparency facilitates the speakers' learning of the pattern, while opaque patterns are listed in speakers' lexicon. In other words, the speakers' tacit knowledge is different between transparent and opaque patterns. In Shanghai transparent sandhi, [M N] items prefer to form one tonal domain, but [V N] items are more likely to form two tonal domains. Wuxi opaque sandhi is lexically listed, therefore, the sandhi patterns for both [M N] and [V N] items are lexically listed, and therefore less constrained by syntactic structures.

Second, the different degrees of syntactic-structure restriction also explain the finding that [V N] items are influenced by frequency in different directions in Shanghai and Wuxi. In

Shanghai, the lexical frequency effect is related to syntactic structures: a [M N] compound that undergo phonetic reduction has a greater tendency to undergo tonal extension if it has a high frequency, while a [V N] phrase is more resistant against regularization towards tone sandhi if it is frequently used and hence has a stronger preference for the no/partial sandhi form. If this is true for all tone sandhi patterns, then we should observe the same paradigm in Wuxi. However, Wuxi's opaque sandhi is less restricted to syntactic structures and therefore has a greater tendency to be lexically listed as words; therefore, regularization due to alternation minimization is irrelevant, and both frequent [M N] and [V N] items prefer to undergo tonal substitution in Wuxi. In other words, the different frequency effects in Shanghai and Wuxi [V N] items also imply that speakers have different phonological knowledge between transparent and opaque processes.

Third, although semantic transparency plays an important role in compound processing, it only has a moderate influence on tone sandhi application, likely because other factors are more overwhelming. The robustness of the syntactic structure effect erases the semantic transparency effect in [M N] items. For [V N] disyllables, semantically transparent forms have a stronger preference for the no sandhi form than semantically opaque ones in both Shanghai and Wuxi, which agrees with Xu et al. (1981, 1982) and Xu (2007). No significant semantic transparency effect was observed in [V N] trisyllabic sandhi application in either Shanghai or Wuxi. However, this may have been due to the fact that the experiment only measured the semantic transparency of the whole lexical item, and it is possible that the semantic transparency of the constituents may also be involved in trisyllabic sandhi application.

Fourth, our results show that there is no morpheme length effect in Shanghai [M N] trisyllables, even after we balanced the frequencies between 1+2 and 2+1 [M N] trisyllables, suggesting that there is no morpheme length effect in the phonologically transparent tonal extension. This is consistent with Xu et al.'s (1982) description, which claimed that trisyllabic sandhi application depends on the "degree of connection" and "habit of usage" rather than the 1+2 or 2+1 structure. Our results run contrary to the metrical analysis of Duanmu (1995), who proposed that a stress clash would occur if a 1+2 [M N] item forms two tonal domains, hence 1+2 [M N] items prefer to form one tonal domain and undergo sandhi more than 2+1 [M N] items. The current findings indicate that Shanghai speakers do not have a strong preference for sandhi application for 1+2 [M N] items.

However, the morpheme length effect is significant in Wuxi [M N] trisyllables. To avoid stress clash caused by left-dominant sandhi, 1+2 [M N] items in Wuxi are less likely to form two tonal domains, therefore, they prefer to undergo tonal substitution in one tonal domain more than 2+1 [M N] trisyllables. This is inconsistent with our prediction, as we expected the trace of right-dominance in Wuxi pattern substitution to cause a smaller difference in the sandhi preference between 1+2 and 2+1 [M N] trisyllables than in Shanghai. An explanation may be that the tonal combinations involved in the current study all have non-checked Yin tones (T1, T3 and T5) on the first syllables, the sandhi patterns of which are not affected by the tones of the rightmost syllables. In other words, when the first syllable is a non-checked Yang tone T4, checked tones T7 or T8, the lexical item may undergo different sandhi patterns depending on the tone of the rightmost syllable and hence show a trace of right-dominance. But in the tonal combinations tested here, there may not be any trace of right-dominance.

Fifth, Shanghai 1+2 [V N] trisyllables show a bimodal distribution of sandhi preference (Figure 10). Speakers prefer tonal extension for some [V N] trisyllables, while partial sandhi for the others. 19 out of 60 [V N] items prefer to undergo tonal extension, among which, 2 have T1 on the first syllable, 7 have T2 on the first syllable, and 10 have T3 on the first syllable. There seem to be some other criteria that Shanghai speakers use to determine the application of tone sandhi in [V N] forms that the investigation scope of the current dissertation does not cover. But for the items that have a strong preference for the partial sandhi variant, the frequency result is consistent with the disyllabic [V N] items: a higher frequency phrase is more conservative with regard to regular tonal extension and therefore, a stronger preference for the partial sandhi variant. For reference, the list of these [V N] item that prefer sandhi is provided in Appendix D, including the base tone of its first syllable and their lexical frequency and semantic transparency ratings after they were arcsine-transformed and centered.

6.2 Summary of findings

The study in Shanghai tone sandhi variation found that syntactic structure has a primary effect on sandhi application for both disyllables and trisyllables. It overrides the effect of semantic transparency, especially in [M N] disyllables and trisyllables. The nature of the lexical frequency effect in Shanghai is related to the syntactic-category of the item: [M N] items are words and behave more similarly to cases of English *t/d* deletion: the more frequent it is, the more reduction application it prefers. [V N] items, on the other hand, are phrases and more similar to cases of English past tense and French liaison regularization in that more frequent items are more resistant to regularization that minimizes alternation; crucially, we treat the tone sandhi forms as regular forms, as the grammatical descriptors for the constructions that can undergo tone sandhi are more general. Morpheme length effect is overwhelmed by lexical frequency, and overall Shanghai speakers do not have a preference for tonal extension for 1+2 [M N] items compared to 2+1 [M N] items.

The study in Wuxi tone sandhi variation found that syntactic structure determines the tone sandhi application for both disyllables and trisyllables. Due to the lexical listedness of the tonal substitution pattern, both [M N] and [V N] items are treated as words and lexical frequency influences sandhi application in both types of items positively. Semantic transparency effect is only apparent for [V N] disyllables, and semantically more opaque [V N] items prefer tonal substitution more than semantically less opaque ones. Moreover, morpheme length also distinguishes sandhi application between 1+2 and 2+1 [M N] items.

In general, the current dissertation investigates the variation in both transparent and opaque tone sandhi patterns. Using quantitative rating experiments, it shows that tone sandhi variation is regulated by both grammatical factors, such as syntactic structure, morpheme length, phonological opacity, and nongrammatical factors, such as lexical frequency. But crucially, the experimental results also showed that the frequency effects in tone sandhi application is regulated by grammatical factors, as evidenced by the different frequency effects between [M N] and [V N] items in Shanghai as well as between [V N] items in Shanghai and

[V N] items in Wuxi. In addition, the syntactic structure effect cannot be solely accounted for by frequency, contra Bybee (2001), as the [M N] and [V N] items under comparison in our studies generally do not differ in frequency, and when they do, the frequency difference cannot account for the syntactic structure effect alone. The wordhood determines whether there is alternation conditioned by word boundaries, and the minimization of this alternation in phrases is what causes the regularization towards sandhi application in lower frequency [V N] items in Shanghai. This point echoes the position of "grammar dominance" espoused in Coetzee (2009a, 2009b), Coetzee & Pater (2011), Kawahara (2011a, 2011b), Coetzee & Kawahara (2012), among other.

6.3 Future research

With the investigation of Shanghai and Wuxi tone sandhi variation, this dissertation illustrates how syntactic, morphological, and lexical factors condition sandhi application. A number of future directions will increase the impact of the research.

First, it will contribute more to formal phonology if the variability patterns can be formally modeled by a constraint system. The learner will be fed tonal combinations that are representative of the lexicon of Shanghai or Wuxi, and output a grammar that predicts the speakers' behavior. The goal is to allow the weights of the constraints to capture the different effects of syntactic structure, semantic transparency, lexical frequency and morpheme length on the speakers' experimental ratings in Shanghai and Wuxi, and let the differences between Shanghai and Wuxi emerge as the different nature of relevant constraints in the two dialects.

For instance, the opaque sandhi pattern in Wuxi would involve constraints that force listed sandhi forms to be used (see Yan & Zhang, in press, for details), while the transparent sandhi pattern in Shanghai would be derived by markedness and faithfulness interactions.

Second, as the tones studied here include all non-checked Yin tones without the trace of right-dominance in Wuxi, it would be interesting to examine those checked tones and Yang tones that preserve the trace of right-dominant sandhi. If there is a metrical difference between left-dominant and right-dominant sandhis, 1+2 and 2+1 [M N] trisyllables with checked tones and Yang tones on the first syllable would have different preferences for sandhi application. Due to the potential stress clash in 2+1 [M N] trisyllables, 2+1 [M N] items would have a stronger preference to undergo tone sandhi compared to 1+2 [M N] items, which will contrast with the current findings in non-checked Yin tones.

Finally, psycholinguistic priming studies have rarely been conducted in left-dominant sandhi. Given the fact that Shanghai transparent sandhi is constrained to syntactic structures, the priming effects may also be different in [M N] and [V N] items. For Shanghai [V N] disyllables, since the base tone of the monosyllables is preserved in most of the cases, the underlying tone would contribute to word recognition compared to the other irrelevant tones; however, for Shanghai [M N] disyllables, underlying primes would have a weaker facilitation effect on word recognition compared to that on [V N] as a result of the tonal extension pattern. But we may still expect some degree of priming effect from the underlying tone. For Wuxi, on the other hand, due to the opacity of the pattern, the surface substituted tone is expected to have a stronger priming effect than the underlying tone for [M N] (cf. Chien et al., 2016b). For [V N], the priming effect from the underlying tone would be expected to be weaker than that in Shanghai as [V N] items in Wuxi have a stronger preference for the sandhi variant than the [V N] items in Shanghai, as our goodness rating experiments showed.

References

Ågren, J. (1973). Etude sur quelques liaisons facultatives dans le français de conversation radiophonique: fréquence et facteurs, Uppsala: Acta Universitatis Upsaliensis. Studia Romanica Upsaliensia 10.

Amano, S., & Kondo, T. (2000). *NTT database series: Lexical properties of Japanese, 2nd release*. Tokyo: Sanseido.

Anttila, A. (1997). Deriving variation from grammar. In F. Hinskens, R. van Hout, & L. Wetzels, (eds.), *Variation, Change and Phonological Theory*. Amsterdam: John Benjamins, 35-68.

Baayen, R. H., Piepenbrock, R., & Gulikers, L. (1995). The CELEX Lexical Database (CD-ROM). Philadelphia, PA: Linguistic Data Consortium.

Barry, M. (1985). A palatographic study of connected speech processes. *Cambridge papers in phonetics and experimental linguistics* 4.

Bayley, R. (1997). Variation in Tejano English: evidence for variable Lexical Phonology. In C. Bernstein, T. Nunnaly, & R. Sabino, (eds.), *Language Variety in the South Revisited.* Tuscaloosa: University of Alabama Press.

Balota, D. A., Pilotti, M., Cortese, M. J. (2001). Subjective frequency estimates for 2,938 monosyllabic words. *Memory & cognition*; 29(4): 639-647.

Beckman, M., & Pierrehumbert, J. (1986). Intonational structure in English and Japanese. *Phonology Yearbook*, 3: 255-310.

Bendig, A. W. (1953). The reliability of self-ratings as a function of the amount of verbal anchoring and the number of categories on the scale. *Journal of Applied Psychology*, 37: 38-41.

Bendig, A. W. (1954). Reliability and the number of rating scale categories. *Journal of Applied Psychology*, 38: 38-40.

Berko, J. (1958). The child's learning of English morphology. *Word*, 14: 150–177.

Boersma, P., & Hayes, B. (2001). Empirical tests of the Gradual Learning Algorithm. *Linguistic Inquiry*, 32: 45-86.

Boersma, P., & Pater, J. (2008). *Convergence Properties of a Gradual Learner in Harmonic Grammar*. Ms. Amsterdam and Amherst, MA: Meertens Institute and University of Massachusetts Amherst.

Booij, G. E., & Rubach, J. (1987). Postcyclic versus postlexical rules in Lexical Phonology. *Linguistic Inquiry*, 18: 1-44.

Browman, C. P., & Goldstein, L. (1990). Representation and reality: physical systems and phonological structure. *Journal of Phonetics*, 18, 411-424.

Brown, G., Wilding, R. E., & Coulter, R. L. (1991). Customer evaluation of retail salespeople using the SOCO scale: A replication extension and application. *Journal of the Academy of Marketing Science*, 9: 347-351.

Bybee, J. L. (1985). *Morphology: a study of the relation between meaning and form.* Philadelphia: Benjamins.

Bybee, J. L. (2000). The phonology of the lexicon: evidence from lexical diffusion. In M.

Barlow & S. Kemmer, (eds.), *Usage-Based Models of Language*. 65-85. Stanford: CSLI Publications.

Bybee, J. L. (2001). *Phonology and Language Use*. Cambridge: Cambridge University Press.

Bybee, J. L., & Pardo, E. (1981). On lexical and morphological conditioning of alternations: A nonce-probe experiment with Spanish verbs. *Linguistics*, 19, 937-968.

Bybee, J. L., & Scheibman, J. (1999). The effect of usage on degree of constituency: the reduction of don't in American English. *Linguistics*, 37. 575-596.

Bybee, J. L., & Thompson, S. (2000). Three frequency effects in syntax. *Berkeley Linguistics Society* 23.65–85.

Cao, X. Y. (2003). Wuxi fangyan yanjiu. [Studies on Wuxi dialect]. Suzhou: Suzhou University, MA thesis.

Chao, Y. R. (1928). *Xiandai Wuyu de Yanjiu [Studies in the modern Wu dialects]*. Peiping: Hsinghua College Press.

Chao, Y. R. (1930). A system of tone letters. *Le Maitre Phonetique* (3rd series) 45: 24-47.

Chan, M. K.-M., & Ren, H. M. (1989). Wuxi tone sandhi: from last to first syllable dominance. *Acta Linguistica Hafniensia*, 21(2): 35-64.

Chan, M. K.-M. (1991). Contour-tone spreading and tone sandhi in Danyang Chinese. *Phonology*, 8: 237-259.

Chan, M. K.-M. (1995). An autosegmental analysis of Danyang tone sandhi: some historical and theoretical issues. In E. Zee (ed.), *Wuyu Yanjiu [The studies of Wu dialects]*, 145-184, Chinese University of Hong Kong.

Chang, Yufen. (2012). Variation in the Taiwanese tone sandhi circle: language change in progress. *The 41st Annual Conference of New Ways of Analyzing Variation, Indiana University Bloomington, October 25-28*.

Chen, M. Y. (1987). The syntax of Xiamen tone sandhi. *Phonology Yearbook* 4: 109-149.

Chen, M. Y. (2000). *Tone sandhi: patterns across Chinese dialects.* Cambridge: Cambridge University Press.

Chen, Y.-Y. (2008). Revisiting the phonetics and phonology of Shanghai tone sandhi. In *Proceedings of Speech Prosody 2008*, 253-256. Campinas, Brazil.

Cheng, C.-C. (1970). Domain of phonological rule application. In J.M. Sadock & A.L.Vanek, (eds.), *Studies presented to Robert B. Lee by his students*, 39-60. Alberta: Edmonton.

Cheng, C.-C. (1973). *A synchronic phonology of Mandarin Chinese*. The Hauge: Mouton.

Cheng, R. (1968). Tone sandhi in Taiwanese. *Linguistics*, 41: 19-42.

Chien, Y.-F., Sereno, J. A. & Zhang, J. (2016a). Priming the representation of Mandarin Tone3 sandhi words. *Language, Cognition and Neuroscience*, 31(2): 179-189.

Chien, Y.-F., Sereno, J. A. & Zhang, J. (2016b). Priming the representation of Taiwanese tone sandhi words. *The 5th International Symposium on Tonal Aspects of Languages*, Buffalo, New York, May 24-27, 2016.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Chomsky, N. (1970). Remarks on Nominalization. In J. Roderick A. & P.S. Rosenbaum, (eds.), *Readings in English Transformational Grammar*, 184-221. Boston: Ginn.

Cinque, G. (1993). A null theory of phrase and compound stress. *Linguistic* Inquiry, 24(2): 239-297.

Coetzee, A. W. (2004). *What It Means to Be a Loser: Non-Optimal Candidates in Optimality Theory*. Ph.D. dissertation, University of Massachusetts Amherst.

Coetzee, A. W. (2006). Variation as accessing "non-optimal" candidate. *Phonology*, 23: 337-385.

Coetzee, A. W. (2009a). An integrated grammatical/non-grammatical model of phonological variation. In Y.-S. Kang, J.-Y. Yoon, H. Yoo, S.-W. Tang, Y.-S. Kang, Y. Jang, C. Kim, K.-A. Kim, & H.-K. Kang, (eds.), *Current Issues in Linguistic Interfaces. Volume 2*, 267-294. Seoul: Hankookmunhwasa.

Coetzee, A. W. (2009b). Phonological variation and lexical frequency. In A. Schardl, M. Walkow, & M. Abdurrahman, (eds.), *NELS 38: Proceedings of the 38th Meeting of the North East Linguistics Society*. *Volume 1*. Amherst: GLSA. 189-202.

Coetzee, A. W., & Pater, J. (2011). The place of variation in phonological theory. In J. Goldsmith, J. Riggle, & A. Yu (eds.), *The Handbook of Phonological Theory: 2nd Edition*, 401-434. Cambridge: Blackwell.

Coetzee, A. W., & Kawahara, S. (2012). Frequency biases in phonological variation. *Natural Language & Linguistic Theory*, 31: 47-89.

Cooper, W. E., & Paccia-Cooper, J. (1980). Syntax and Speech. Cambridge MA: Harvard University Press.

Dawes, J. (2008). Do data characteristic change according to the number of scale points used?

International Journal of Market Research, 50(1): 61-77.

Duanmu, S. (1995). Metrical and tonal phonology of compounds in two Chinese dialects. *Language*, 71: 225-259.

Duanmu, S. (1998). Wordhood in Chinese. In J. Packard. (eds.), *New Approaches to Chinese Word Formation: Morphology, Phonology and the Lexicon in Modern and Ancient Chinese*, Berlin: Mouton de Gruyter, 135-196.

Duanmu, S. (2007). *The phonology of Standard Chinese*. 2nd Edition. Oxford: Oxford University Press.

Duanmu, S. (2011). Wordhood in Chinese. In B. Wolfgang, Y.G. Gu, Z. Handel, C.-T. J. Huang, & R. Sybesma (eds.), *Encyclopedia of Chinese Language and Linguistics*. Leiden: Brill.

Duanmu, S. (2012). Word-length preferences in Chinese: a corpus study. *Journal of East Asian Linguistics*, 21(1): 89-114.

Dutch Center for Lexical Information. (1995). *The Celex lexical database.* Nijmegen: Dutch Center for Lexical Information.

Efron, B., & Tibshirani, R. (1993). *An Introduction to the Bootstrap*. Chapman and Hall, New York, London.

Ellis, L., & Hardcastle, W. J. (2002). Categorical and gradient properties of assimilation in alveolar to velar sequences: Evidence from EPG and EMA data. *Journal of Phonetics*, 30: 373-396.

Elordieta, G. (2008). An overview of theories of the syntax-phonology interface. *Journal of*

Basque Linguistics and Philology, 42: 209-286.

Fiorentino, R., & Fund-Reznicek, E. (2009). Masked morphological priming of compound constituents. *The Mental Lexicon*, 4(2): 159-193.

Fischer, M. (2005). *A Robbins-Monro type learning algorithm for an entropy maximizing version of stochastic Optimality Theory*. Berlin: Humboldt University, MA thesis.

Forster, K. I. (1999). The microgenesis of priming effects in lexical access. *Brain and Language*, 68, 5-15.

Forster, K. I. (2003). The mechanics of masked priming. In S. Kinoshita & S. Lupker (eds.), *Masked Priming: The State of the Art*. New York: Psychology Press.

Fougeron, C., & Steriade, D. (1997). Does the deletion of French schwa lead to the neutralization of lexical distinctions? *Proceedings of the Eurospeech conference, Rhodes*, 943–946.

Francis, W. N., & Kučera, H. (1982). *Frequency Analysis of English Usage*. Boston: Houghton Mifflin.

Gao, J. (2004). The changing sandhi rules in Tianjin dialect. In J.L. Lu (ed.), *Phonetic and phonological studies on Tianjin dialect*, 193-247. Beijing: Beijing Institute of Technology Press.

Goeman, A. C. M., & van Reenen, P. Th. (1985). Word-Final t-Deletion in Dutch Dialects. The Roles of Conceptual Prominence, Articulatory Complexity, Paradigmatic Properties, Token Frequency and Geographical Distribution. *Vrije Universiteit Working Papers in Linguistics* 16. Amsterdam: Vakgroep Algemene Taalwetenschap Vrije Universiteit.

Guy, G. R. (1991). Contextual conditioning in variable lexical phonology. *Language Variation and Change*, 3: 223-239.

Guy, G. R. (1994). The phonology of variation. In K. Beals (ed.) *CLS 30: Papers from the 30th Regional Meeting of the Chicago Linguistic Society. Volume 2: The Parasession on Variation in Linguistic Theory*, 133-149. Chicago: Chicago Linguistic Society.

Halle, M., & Vergnaud., J.-R. (1987). *An essay on stress*. Cambridge, MA: MIT Press.

Hayes, B. (1989). The prosodic hierarchy in meter. In P. Kiparsky & G. Youmans (eds.), *Rhythm and Meter*, 201-260. Orlando, FL: Academic Press.

Hayes, B. (1995). *Metrical stress theory: Principles and case studies*. Chicago: University of Chicago Press.

Hayes, B. & Abad, M. (1989). Reduplication and syllabification in Ilokano. *Lingua*, 77: 331-374.

Hayes, B., & White, J. (2013). Phonological naturalness and phonotactic learning. *Linguistic Inquiry*, 44: 45–75.

Hayes, B., Zuraw, K., Siptár, P., & Londe, Z. (2009). Natural and unnatural constraints in Hungarian vowel harmony. *Language*, 85: 822–863.

Hooper, J. B. (1976). *An Introduction to Natural Generative Phonology*. New York: Academic Press.

Hsieh, H.-I. (1970). The psychological reality of tone sandhi rules in Taiwanese. *Papers from the 6th meeting of the Chicago Linguistic Society*, Chicago: Chicago Linguistic Society: 489–503.

Huang, J. C.-T. (1984). Phrase structure, lexical integrity, and Chinese compounds. *Journal of the Chinese Language Teachers Association*, 19(2): 52-78.

Huang, L. J., & Duanmu, S. (2012). A quantitative study of elastic word length in Chinese. *The 20th Annual Meeting of the International Association of Chinese Linguistics, Hong Kong Polytechnic University*, August 29-31.

Jaeger, T. F., & Kuperman, V. (2009). *Standards in fitting, evaluating, and interpreting regression models.* UC Davis. Available from http://hlplab.wordpress.com (Presentation give at the Workshop on Ordinary and Multilevel Modeling)

Jaeger, T. F., Graff, P., Croft, W., & Pontillo, D. (2011). Mixed effect models for genetic and areal dependencies in linguistic typology. *Linguistic Typology*, 15: 281-320.

Kaisse, E. (1985). *Connected speech: the interaction of syntax and phonology.* New York: Academic Press.

Kawahara, S. (2011a). Aspects of Japanese loanword devoicing. *Journal of East Asian Linguistics*, 20: 169-194.

Kawahara, S. (2011b). Japanese loanword devoicing revisited: A well-formedness rating study. *NaturalLanguage & Linguistic Theory*, 29: 705–723.

Kennedy, G. A. (1953). Two tone patterns in Tangsic. *Language*, 29(3): 367-373.

Kiparsky, P. (1973). Abstractness, opacity and global rules. In O. Fujimura (eds.), *Three dimensions in phonological theory*, 57–86. Tokyo, Japan: TEC Company.

Kiparsky, P. (1982). Lexical phonology and morphology. In I.-S. Yang (ed.) *Linguistics in the Morning Calm*, 1-91. Seoul: Hanshin.

Kiparsky, P. (1985). Some consequences of Lexical Phonology. *Phonology Yearbook*, 2: 85-138.

Kiparsky, P. (1993). An OT perspective on phonological variation. Handout from *Rutgers Optimality Workshop 1993*, also presented at *NWAV 1994*, Stanford University. Available at http://www.stanford.edu/~kiparsky/Papers/nwave94.pdf.

Kiparsky, P. (2000). Opacity and cyclicity. *The Linguistic Review*, 17:351-365.

Komorita, S. S. (1963). Attitude content, intensity, and the neutral point on a Likert scale. *Journal of Social Psychology*, 61: 327-334.

Kraemer, H. C., & Blaset, C. M. (2004). Centring in regression analyses: a strategy to prevent errors in statistical inference. *International Journal of Methods in Psychiatric Research*, 13(3): 141-151.

Kučera, M., & Francis,W. N. (1967).*Computational analysis of present day American English*. Providence, RI: Brown University Press.

Kuperman, V., Bertram, R., & Baayen, R. H. (2008). Morphological dynamics in compound processing. *Language and Cognitive Processes*, 23: 1089–1132.

Labov, W. (1989). The child as linguistic historian. *Language Variation and Change*, 1:85- 97.

Libben, G. (1994). How is morphological decomposition achieved? *Language and Cognitive Processes*, 9: 369–391.

Libben, G. (1998). Semantic transparency in the processing of compounds: Consequences for representation, processing, and impairment. *Brain and Language*, 61: 30–44.

Libben, G., Gibson, M., Yoon, Y. B., & Sandra, D. (2003). Compound fracture: The role of semantic transparency and morphological headedness. *Brain and Language*, 84: 50-64.

Li, R., Xu, B. H., & Tao, H. (1997). *Shanghai Fangyan Cidian [Shanghai Dialect Dictionary]*. Nanjing: Jiangsu Education Press.

Li, X.-J., & Liu, S.-X. (1985). Tianjin fangyan de liandu biandiao [Tone sandhi in the Tianjin dialect]. *Zhongguo Yuwen [Studies of the Chinese Language]*, 1: 76–80.

Liu, Y.-Z., & Gao, J. (2003). Qu-Qu liandu biandiao guize: shehui yuyanxue bianxiang [FF sandhi rule in Tianjin dialect: A sociolinguistic variable]. Tianjin Shifan Daxue Xuebao—Shehui Kexue Ban [Journal of Tianjin Normal University—Social Sciences], 2003(5): 65–69.

Lu, B. F., & Duanmu, S. (2002). Rhythm and syntax in Chinese: A case study. *Journal of the Chinese Language Teachers Association*, 37.2: 123-136.

Masson, M. E. J., & Isaak, M. I. (1999). Masked priming of words and nonwords in a naming task: Further evidence for a nonlexical basis for priming. *Memory and Cognition*, 27, 399-412.

Marelli, M., & Luzzatti, C. (2012). Frequency effects in the processing of Italian nominal compounds: modulation of headness and semantic transparency. *Journal of Memory and Language*, 66: 644-664.

Mascaró, J. (1976). *Catalan phonology and the phonological cycle.* Ph.D. dissertation, Massachusetts Institute of Technology.

Matell, M. S. & Jacoby, J. (1972). Is there an optical number of alternatives for Likert-scale items? Effects of testing time and scale properties. *Journal of Applied Psychology*, 56(6): 506-509.

McEnery, T. & Xiao, R. (2004). The Lancaster Corpus of Mandarin Chinese: A corpus for monolingual and contrastive language study. In M. T. Lino, M. F. Xavier, F. Ferreire, R. Costa, & R. Silva (eds.), *Proceedings of the Fourth International Conference on Language Resources and Evaluation (LREC) 2004*, 1175-1178. Lisbon, May 24-30.

McMahon, A. M. S. (2000). *Lexical phonology and the history of English*. Cambridge: Cambridge University Press.

Montgomery, D. C., & Peck, E. A. (1992). *Introduction to Linear Regression Analysis*. Wiley, New York.

Morin, Y.-C., & Kaye, K. D. (1982). The syntactic bases for French liaison. *Journal of Linguistics*, 18: 291–330.

Nespor, M., & Vogel, I. (1982). Prosodic domains of external sandhi rules. In H. v.d. Hulst, & N. Smith (eds.), *The Structure of Phonological Representations*, 224-255. Dordrecht: Foris.

Nespor, M., & Vogel, I. (1986). *Prosodic Phonology.* Dordrecht: Foris.

Nolan, F. (1992). The descriptive role of segments: evidence from assimilation. In G.J. Docherty & D.R. Ladd (eds.), *Papers in laboratory phonology II*, 261-280. Cambridge: Cambridge University Press.

Odden, D. (1987). Kimatuumbi phrasal phonology. *Phonology yearbook*, 4: 13-36.

Odden, D. (1994). Syntactic and semantic conditions in Kikongo phrasal phonology. In J. Cole, & C. Kisseberth (eds.), *Perspectives in Phonology*, 167-202. Stanford, CA: CSLI.

Odden, D. (1996). *The Phonology and Morphology of Kimatuumbi: The Phonology of the World's Languages.* Oxford: Clarendon Press.

Odden, D. (2000). The Phrasal Tonology of Zinza. *Journal of African Languages and Linguistics*, 21: 45-75.

Phillips, B. S. (2001). Lexical diffusion, lexical frequency, and lexical analysis. In J. Bybee, & P. Hopper (eds.), *Frequency and the emergence of linguistic structure*, 123-36. Amsterdam: Benjamins.

Phillips, B. S. (2006). *Word Frequency and Lexical Diffusion.* New York: Palgrave Macmillan.

Pierrehumbert, J., & Beckman, M. (1988*). Japanese Tone Structure*. Cambridge MA: The MIT Press.

Pitt, M.A., Dilley, L., Johnson, K., Kiesling, S., Raymond, W., Hume E. & Fosler-Lussier, E. (2007). *Buckeye Corpus of Conversational Speech (2nd release)* [www.buckeyecorpus.osu.edu] Columbus, OH: Department of Psychology, Ohio State University (Distributor).

Prince, A. (1980). A metrical theory for Estonian quantity. *Linguistic Inquiry*, 11: 511-562.

Racine, I. & Grosjean, F. (2002). La production du E caduc facultatif est-elle prévisible? Un début de réponse. *Journal of French Language Studies*, 12: 307-326.

Rose, P. (1990). Acoustics and phonology of complex tone sandhi. *Phonetica*, 47, 1-35.

Rubach, J. (1984). *Cyclic and Lexical Phonology: the structure of Polish*. Dordrecht, The Netherlands: Foris Publications.

Rubach, J. (2008). An overview of lexical phonology. *Language and Linguistics Compass*, 2/3: 456-477.

Sandra, D. (1990). On the representation and processing of compound words: Automatic access to constituent morphemes does not occur. *The Quarterly Journal of Experimental Psychology*, 42a: 529– 567.

Santa Ana, O. (1991). *Phonetic Simplification Processes in the English of the Barrio: A Cross-Generational Sociolinguistic Study of the Chicanos of Los Angeles*. Ph.D. Dissertation, University of Pennsylvania.

Santa Ana, O. (1992). Chicano English evidence for the exponential hypothesis: a variable rule pervades lexical phonology. *Language Change & Variation*, 4: 275-288.

Selkirk, E. O. (1981). On the nature of phonological representation, in J. Anderson, J. Laver and T. Meyers. (eds.), *The Cognitive Representation of Speech*, Amsterdam: North Holland.

Selkirk, E. O. (1984). *Phonology and Syntax: The relation between sound and structure.* Cambridge: MIT Press.

Selkirk, E. O. (1986). On derived domains in sentence phonology. *Phonology* 3, 371-405.

Selkirk, E.O. (2011). The syntax-phonology interface. In J. Goldsmith, J. Riggle, & A. Yu (eds.), *The Handbook of Phonological Theory, 2nd edition*. Oxford: Blackwell Publishing.

Selkirk, E. O. & Shen, T. (1990). Prosodic domains in Shanghai Chinese. In S. Inkelas., & D. Zec. (eds.), *The phonology-syntax connection*, 313-337. Chicago, IL: University of Chicago Press.

Shi, F., & Wang, P. (2004). Tianjinhua shengdiao de xin bianhua [New changes in Tianjin tones]. In F. Shi., & Z.W. Shen. (eds.), *The joy of research: A festschrift in honor of Professor William S.-Y. Wang on his seventieth birthday,* 176-188. Tianjin: Nankai University Press.

Siegel, D. (1974). *Topics in English morphology*. Ph.D. dissertation, Massachusetts Institute of Technology.

Smolensky, P. (1986). Information processing in dynamical systems: Foundations of harmony theory. In D. E. Rumelhart, J. L. McClelland & the PDP Research Group, *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 1: Foundations*. Cambridge, MA: MIT Press/Bradford Books. 194-281.

Smolensky, P., & Legendre, G. (2006). *The harmonic mind: from neural computation to optimality theoretic grammar*. Cambridge, MA: MIT Press.

Tagliaferri, B. (2011). Perception Research Systems Inc. (Paradigm) [Program available online at http://www.paradigmexperiments.com/.]

Takahashi, Y. (2013). *The phonological structure of Shanghai tone sandhi*. Ph.D. dissertation, Tokyo University of Foreign Studies, Tokyo, Japan.

Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms.* Hillsdale, NJ: Erlbaum.

Tranel, B. (1981). *Concreteness in generative phonology: Evidence from French.* Berkeley, CA: University of California Press.

Truckenbrodt, H. (1995). *Phonological phrases: Their relation to syntax, focus, and prominence*. Cambridge: Massachusetts Institute of Technology dissertation.

Truckenbrodt, H. (1999). On the relation between syntactic phrases and phonological phrases. *Linguistic Inquiry*, 30(2): 219-255.

Wakita, T., Ueshima, N., & Noguchi, H. (2012). Psychological distance between categories in the Likert scale: comparing different numbers of options. *Educational and Psychological Measurement*, 72(4): 533-546.

Wang, C. Y., & Lin, Y. H. (2011). Variation in Tone 3 sandhi: the case of prepositions and pronouns. In J.-S. Zhuo (ed.), *Proceedings of the 23rd North American Conference on Chinese Linguistics (NACCL-23) 2011*, 138-155. University of Oregon, Eugene, June 17-19.

Wang, H. S. (1993). Taiyu biandiao de xinli texing [On the psychological status of Taiwanese tone sandhi]. *Tsinghua Xuebao [Tsinghua Journal of Chinese Studies],* 23, 175–192.

Wang, P. (1988). Changzhou fangyan de liandu biandiao [Tone sandhi in the Changzhou dialect]. *Fangyan [Dialects]*, 3: 177–194.

Wang, Y. Z. (2008). Wuxi Fangyan Yuyin Yanjiu. [Studies on the phonological system of Wuxi dialect]. Shanghai: Shanghai University MA thesis.

White, J. (2013). *Bias in Phonological Learning: Evidence from Saltation.* Los Angeles: University of California dissertation.

Xiang, H. (2008). *Wuxi Fangyan Cidian [Wuxi Dialect Dictionary]*. Changchun: Time Literature & Art Publishing House.

Xu, B. H., Tang, Z. Z., & Qian, N. R. (1981, 1982). Xinpai Shanghai fangyan de liandu biandiao I, II, III [Tone sandhi in new Shanghai I, II, III]. *Fangyan [Dialects]*, 1981: 145-155; 1982: 115-128; 1983: 197-201.

Xu, J. Y. (2007). Wuxi Fangyan Shengdiao Shiyan Yanjiu [The experimental research on the tone of Wuxi dialect]. Nanjing: Nanjing Normal University MA thesis.

Yan, H. B., & Zhang, J. (in press). Pattern Substitution in Wuxi Tone Sandhi and Its Implication for Phonological Learning. *International Journal of Chinese Linguistics*.

Yan, H. B. (2014). Trisyllabic tone sandhi patterns in Shanghai and Wuxi Wu. University of Kansas, ms.

Yip, M. (1989). Contour tones. *Phonology*, 6: 149-174.

Yue-Hashimoto, A. O. (1980). Tone sandhi across Chinese dialects. Presented at the 13th International Conference on Sino-Tibetan Language and Linguistics, Charlottesville, Virginia.

Zee, E., & Maddieson, I. (1979). Tone and tone sandhi in Shanghai: Phonetic evidence and phonological analysis. *UCLA Working Papers in Phonetics* 45: 93–129.

Zhang, H. M. (1992). *Topics in Chinese phrasal phonology*. Ph.D. Dissertation, University of California, San Diego.

Zhang, J. (2007). A directional asymmetry in Chinese tone sandhi systems. *Journal of East Asian Linguistics*, 16: 259-302.

Zhang, J., & Lai, Y.-W. (2008). Phonological knowledge beyond the lexicon in Taiwanese double reduplication. In Y.-C. Hsiao, H.-C. Hsu, L.-H. Wee, & D.-A. Ho (eds.), *Interfaces in Chinese phonology: Festschrift in honor of Matthew Y. Chen on his 70th birthday*, 183-222. Taipei: Academia Sinica.

Zhang, J., & Lai, Y.-W. (2010). Testing the role of phonetic knowledge in Mandarin tone sandhi. *Phonology*, 27(1): 153-201.

Zhang, J., Lai Y. W., & Sailor, C. (2011). Modeling Taiwanese speakers' knowledge of tone sandhi in reduplication. *Lingua* 121, 181-206.

Zhang, J., & Liu. J. (2011). Tone sandhi and tonal coarticulation in Tianjin Chinese. *Phonetica* 68(3): 161-191.

Zhang, J., & Meng, Y. L. (2016). Structure-dependent tone sandhi in real and nonce disyllables in Shanghai Wu. *Journal of Phonetics*, 54: 169-201.

Zhang, N. (1997). The avoidance of the third tone sandhi in Mandarin Chinese. *Journal of East Asian Linguistics*, 6: 293-338.

Zheng-Zhang, S. F. (1964). Wenzhou Fangyan de Liandu Biandiao. [Tone Sandhi in Wenzhou Dialect]. *Zhongguo Yuwen [Chinese]*, 2: 106-152.

Zheng-Zhang, S. F. (1980). Wenzhou Fangyan Erweici de Yuyin Bianhua - 1. [Phonological changes in Wenzhou Dialect words with the diminutive suffix - 1] *Fangyan [Dialect]*, 4: 245-262.

Zubizarreta, M. L. (1998). *Prosody, focus, and word order*. Cambridge, MA: MIT Press.

Zuur, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, 1: 3-14.

Zuraw, K. (2000). *Patterned exceptions in phonology*. Ph.D. Dissertation, University of California, Los Angles.

Zuraw, K. (2007). The role of phonetic knowledge in phonological patterning: corpus and survey evidence from Tagalog infixation. *Language*, 83, 277–316.

Zwitserlood, P. (1994). The role of semantic transparency in the processing and representation of Dutch compounds. *Language and Cognitive Processes*, 9: 341–368.

Appendix A: Shanghai stimuli

Disyllables:

Modifier-noun			Verb-noun		
Base tones	Chinese	Gloss	Base tones	Chinese	Gloss
T1+T1 (53+53)	山沟	gully	T1+T1 (53+53)	烧香	to burn incense
	冰糕	ice cream		搬书	to move books
	飞机	airplane		分赃	to divide the spoils
	猪肝	pig liver		蹲坑	to go to toilet
	西装	suit		开花	to blossom
	贪官	corrupted official		抽筋	to cramp
	烟囱	chimney		关灯	to turn off light
	阴天	cloudy day		弯腰	to bend over
	香菇	shii-take		贪多	to bite off more
	方巾	face cloth		兜风	to go for a ride
T1+T2 (53+24)	商品	product	T1+T2 (53+24)	生火	to make a fire
	青菜	bok choy		开矿	to open a mine
	花店	flower shop		催款	to remind to pay
	尿布	diaper		张嘴	to open the mouth
	胎记	birth mark		烧菜	to cook dishes
	冬笋	bamboo shoot		通海	to connect the sea
	衣架	clothes hanger		拎水	to hold water
	春卷	spring roll		交税	to pay tax
	山顶	mountain top		清火	to clean inner fire
	汤罐	soup can		招手	to wave at someone
T1+T3 (53+13)	铅桶	lead barrel	T1+T3 (53+13)	摊床	to make the bed
	车站	station		修桥	to fix the bridge
	粢饭	Ci rice		观潮	to watch the tide
	师母	teacher's wife		招人	to recruit
	乌云	black clouds		医病	to cure the disease
	蛙泳	breast stroke		拖地	to mop the floor
	虾仁	shrimp meat		梳头	to comb the hair
	婚事	marriage stuff		揩油	to take advantage
	金条	gold bar		坍台	to lose face
	边门	side door		添饭	to have more rice
T2+T1 (24+53)	手心	palm	T2+T1 (24+53)	煮汤	to cook soup
	海参	sea cucumber		套圈	to lasso
	假山	rockery		变心	to change mind
	火车	train		打针	to give an injection

	土堆	mound		起风	to blow wind
	苦瓜	bitter melon		报丧	to tell the death of …
	怪胎	freak		赏花	to admire flowers
	剪刀	scissors		看书	to read books
	罩衫	coat		唱歌	to sing songs
	气窗	transom		化妆	to make up
T2+T2 (24+24)	喜酒	wedding party	T2+T2 (24+24)	倒水	to pour water
	小狗	puppy		扫土	to sweep dust
	唱片	music record		做酒	to throw a party
	草纸	toilet paper		报喜	to tell a good news
	彩票	lottery		破费	to spend money
	蟹粉	crab meat		照相	to take a picture
	底板	bottom board		记账	to keep accounts
	圆凳	round chair		进货	to replenish stock
	跳板	jump board		表态	to show the attitude
	次货	bad product		献宝	to present a treasure
T2+T3 (24+13)	顶棚	ceiling	T2+T3 (24+13)	泡茶	to make tea
	蛀虫	moth		退堂	to end the court
	吊桶	bucket		告状	to tell on others
	带鱼	hairtail fish		过夜	to spend the night
	小牛	little ox		拜年	to visit in Spring Festival
	记号	mark		锁门	to lock the door
	笑话	joke		写字	to write characters
	指纹	finger print		散步	to take a walk
	蒜苗	garlic bolt		救命	to save one’s life
	草帽	grass hat		跳绳	to skip rope
T3+T1 (13+53)	皮包	leather handbag	T3+T1 (13+53)	买花	to buy flower
	同乡	countryman		练功	to practice
	棒冰	popsicle		磨刀	to sharpen the knife
	蛋糕	cake		弹筝	to play the zither
	头盔	helmet		坐车	to take the bus
	豆浆	bean milk		背书	to recite
	病根	root of sickness		撞腔	to talk back
	台风	typhoon		舀汤	to get some soup
	雨衣	raincoat		下班	to go off work
	茶杯	teacup		有心	to be considerate
T3+T2 (13+24)	弹性	elasticity	T3+T2 (13+24)	寻宝	to hunt for treasure
	重点	key point		抬腿	to raise leg
	芹菜	celery		赖账	to deny the debt
	旅馆	hotel		填土	to shovel mud

	露水	dew		提款	to deposit money
	饭店	restaurant		买账	to buy someone's point
	棉裤	cotton-padded pants		领奖	to get the prize
	寒假	winter break		还手	to fight back
	藕粉	lotus root powder		办酒	to have a party
	袖套	oversleeve		谢顶	to be balding
T3+T3 (13+13)	大盘	stock grail	T3+T3 (13+13)	汏头	to wash the hair
	旗袍	chi-pao		提成	to deduct a percentage
	象棋	chess		上朝	to go to court (ancient)
	糯米	sticky rice		涂墙	to paint the wall
	跑鞋	running shoes		除尘	to clean up the dust
	排球	volleyball		买琴	to buy some instrument
	护士	nurse		磨洞	to grind a hole
	外行	layman		描红	to copy handwriting
	面盆	basin		淘米	to wash the rice
	眼皮	eyelid		害人	to victimize someone

Trisyllables:

1+2 Structures					
Modifier-noun			Verb-noun		
Base tones on σ1	Chinese	Gloss	Base tones on σ1	Chinese	Gloss
T1 (53)	尖眼睛	sharp eyes	T1 (53)	生毛病	to be sick
	干电池	battery		香面孔	to kiss on the face
	新思想	new idea		夸海口	to brag
	沙喉咙	deep voice		挑头路	to divide the hair
	香肥皂	soap		穿衣裳	to put on clothes
	干点心	dry snacks		摊底牌	to tell the truth
	空地皮	empty land		拉关系	to pull connections
	新社会	new society		招女婿	to have a son-in-law
	天老爷	goodness		抄近路	to take the short cut
	飞蚂蚁	termite		开条斧	to give conditions
	乖心肝	sweetheart		烧小菜	to cook dishes
	新饭店	new restaurant		兜圈子	to be subtle
	汤三鲜	Sanxian soup		吹泡泡	to blow bubbles
	双眼皮	double-fold eyelids		捞外快	to get extra money
	香瓜子	sunflower seed		翻跟斗	to take loops
	抄下巴	lower jaw		开伙仓	to cook

	香莴笋	asparagus lettuce		捂被头	to make the bed warm
	鸡屁股	chicken bottom		扳老酒	to drink alcohol
	单眼皮	mono-eyelids		开夜车	to stay late
	新产品	new product		装胡羊	to play innocent
T2 (24)	小姑娘	little girl	T2 (24)	揿手印	to give finger print
	总指挥	chief commander		打地铺	to sleep on the floor
	短大衣	short jacket		走江湖	to be in society
	好朋友	good friend		写文书	to write legal paperwork
	小馄饨	small wonton		吊胃口	to make people curious
	纸老虎	paper tiger		睏懒觉	to sleep late
	笡对过	to the opposite		板面孔	to have a serious face
	表姐妹	cousin sisters		做人情	to do someone a good turn
	水面筋	elastic flour food		拗手劲	to compete hand strength
	脆麻花	crispy snacks		讲闲话	to chat
	副经理	assistant manager		解厌气	not to be bored
	臭豆腐	sticky toufu		看医生	to see a doctor
	小黄鱼	small yellow-fin tuna		探口风	to sound out someone
	破水缸	broken water jar		叫冤枉	to claim being wronged
	酱乳腐	beancurd in sauce		做生意	to do business
	碎钞票	small changes		打草稿	to draft something
	扁马桶	toilet		打官司	to have a lawsuit
	表兄弟	cousin brothers		赌铜钿	to gamble
	总工会	labor unions		吊盐水	to be injected
	半当中	in the middle		走亲眷	to visit relatives
T3 (13)	老面皮	shameless	T3 (13)	望亲眷	to visit relatives
	洋山芋	sweet potato		谈朋友	to be in a relationship
	蚕宝宝	silkworm		篰三胡	to chat
	米淘箩	rice washing tool		买旧货	to buy vintage
	后半夜	late evening		掼榔头	to buff
	二房东	second landlord		换牙齿	to change teeth
	油墩子	Shanghai snack		赚外快	to make extra money
	甜酒酿	fermented rice		流眼泪	to cry with tears
	大黄鱼	large yellow-fin tuna		寻对象	to find a partner
	皮箱子	leather suitcase		晾衣裳	to dry clothes outside
	油葫芦	one type of cleanser		荡秋千	to sit on a swing
	前两年	past two years		有公事	to have a business
	右半爿	the right side		用心思	to make efforts
	大姆妈	aunt		骂山门	to fight
	前刘海	bang		乘风凉	to sit outside in summer
	弟新妇	little brother's wife		捣糨糊	to mediate

	洋囡囡	baby doll		竖面孔	to be angry
	嫩豆腐	soft toufu		有志气	to be ambitious
	旧报纸	old newspaper		回娘家	to go back mother’s home
	厚被单	thick sheet		磨洋工	to procrastinate

2+1 Structures		
Modifier-noun		
Base tones on σ1	Chinese	Gloss
T1 (53)	穿堂风	wind go through rooms
	温墩水	warm water
	梳妆台	dresser table
	梭子蟹	one type of crab
	三黄鸡	one type of chicken
	宽紧带	elastic band
	玻璃杯	glass
	蜘蛛网	spider web
	西贝货	fake product
	乡下人	countryman
	精神病	psycho
	粢饭团	Ci rice roll
	交杯酒	wedding drinks
	葱油饼	pancake with onion oil
	花样经	variety of ideas
	三轮车	three-wheeler
	酸梅汤	plum drinks
	西瓜虫	watermelon bug
	番茄酱	ketchup
	风凉鞋	sandals
T2 (24)	点心店	snack shop
	靠背椅	backrest chair
	韭菜花	leek flower
	纸板箱	paper box
	钓鱼竿	fish pole
	水仙花	narcissism
	厕所间	bathroom
	驾驶员	driver
	斗鸡眼	fixed eyes
	闯祸胚	someone who always makes trouble
	摆渡口	port

	土地庙	temple
	剃头店	salon
	本地人	local people
	洗衣粉	laundry powder
	四季豆	green bean
	卷心菜	cabbage
	太阳光	sunshine
	小人书	cartoon book
	讨债鬼	someone who always asks for something
T3 (13)	棚户区	poor areas
	厨房间	kitchen
	长生果	peanut
	元宝鱼	Yuanbao fish
	自来火	match
	还潮天	wet climate
	大兴货	fake product
	狐狸精	siren
	五香豆	flavored beans
	条头糕	rice cake
	罗宋汤	Russian soup
	电影院	cinema
	楼梯间	stairway
	售票员	ticket seller
	五斗橱	cabinet with five drawers
	礼拜天	Sunday
	梧桐树	plane tree
	黄梅天	rain season
	喇叭花	trumpet flower
	棉毛衫	underwear tee

Appendix B: Wuxi stimuli

Disyllables:

Modifier-noun			Verb-noun		
Base tones	Chinese	Gloss	Base tones	Chinese	Gloss
T1+T1 (53+53)	三鲜	three delicacies	T1+T1 (53+53)	开窗	to open the window
	飞机	airplane		收工	to finish working
	天窗	scuttle		蹲坑	to go to toilet
	方砖	squared brick		兜风	to go for a ride
	西装	suit		分居	to separate
	砂锅	pot		翻身	to turn over the body
	香灰	incense ash		煲汤	to make soup
	贪官	corrupted official		弯腰	to bend over
	香菇	shii-take		烧香	to burn incense
	书包	backpack		关灯	to turn off the light
T1+T3 (53+323)	东海	East Sea	T1+T3 (53+323)	搬嘴	to talk on people's back
	汤碗	soup bowl		浇水	to water
	钢板	steel board		清火	to clean inner fire
	青草	grass		招手	to wave at someone
	疯狗	crazy dog		摊饼	to make pancakes
	山顶	mountain top		催款	to remind to pay
	春卷	spring roll		通海	to connect the sea
	冬笋	bamboo shoot		生火	to make a fire
	科长	Section Chief		端碗	to hold bowls
	车展	car show		修表	to mend watches
T1+T5 (53+34)	金块	gold chunk	T1+T5 (53+34)	搓背	to scrub the back
	拖布	mop		拖债	not to pay the debt
	衣架	clothes hanger		开店	to open a shop
	胎记	birth mark		交税	to pay tax
	花店	flower shop		烧菜	to cook dishes
	车票	bus/train ticket		收费	to charge
	欢笑	laughter		通信	to communicate
	腥气	the smell of fish		牵线	to make connections
	书费	book fee		撑伞	to hold an umbrella
	中觉	nap		搛菜	to get food
T3+T1 (323+53)	小兵	solider	T3+T1 (323+53)	抢亲	to take other's marriage
	火车	train		赏花	to admire flowers
	好心	good hearted		打呼	to sneeze
	剪刀	scissors		转弯	to make a turn

	响声	sound		起风	to blow wind
	姐夫	big sister's husband		写书	to write a book
	狗圈	dog loop		采花	to pick up flowers
	土堆	mound		把尿	to help kids urinate
	奖金	bonus		打针	to have an injection
	海参	sea cucumber		掸灰	to clean the dust
T3+T3 (323+323)	蟹粉	crab meat	T3+T3 (323+323)	举手	to raise one's hand
	草纸	toilet paper		炒股	to play stocks
	滚水	boiled water		改口	to change one's word
	小腿	calf		摆酒	to have a party
	厂长	factory chief		打鼓	to play the drum
	左手	left hand		洒水	to spray water
	楷体	Kai font		扫土	to sweep the dust
	表姐	big cousin sister		舔碗	to lick the bowl
	小狗	puppy		掌嘴	to slap
	体检	body check		品酒	to taste wines
T3+T5 (323+34)	苦笑	bitter smile	T3+T5 (323+34)	表态	to show the attitude
	紫菜	sea weed		管账	to be in charge of accounts
	表带	watch belt		补课	to have extra classes
	短裤	shorts		写信	to write letters
	板凳	stool		讨债	to ask for debt payment
	诡计	scheme		讲课	to give lectures
	彩票	lottery		剪布	to cut the cloth
	假货	fake product		点菜	to order food
	土布	raw cloth		喘气	to breathe
	手套	gloves		选课	to choose classes
T5+T1 (34+53)	冻疮	chilblain	T5+T1 (34+53)	费心	to be bothered
	罩衫	coat		报丧	to tell the death of …
	汽车	car		放生	to let something alive
	素鸡	vegetarian chicken		拜师	to be student of someone
	气窗	transom		做东	to host
	睏衣	pajamas		戒烟	to quit smoking
	线衫	cardigan		化妆	to make up
	智商	IQ		唱歌	to sing songs
	怪胎	freak		变天	weather to be changed
	唱功	singing skill		绣花	to embroider
T5+T3 (34+323)	跳板	jump board	T5+T3 (34+323)	放狗	to walk dogs
	次品	bad product		敬酒	to drink with someone
	转椅	swivel chair		献宝	to present a treasure
	账本	account book		泡澡	to take a shower

	裤腿	pant legs		救火	to put out a fire
	废纸	waste paper		戴表	to wear a watch
	信纸	letter paper		诉苦	to complain
	碳粉	carbon dust		倒酒	to pour wines
	债主	debt owner		散伙	to separate the group
	废品	waste		吊水	to be injected
T5+T5 (34+34)	概况	general situation	T5+T5 (34+34)	寄信	to send a letter
	怨气	complaint		进货	to replenish stock
	志气	ambitious		睏觉	to sleep
	固态	solid		放假	to have break
	唱片	music record		做账	to make the account
	次货	bad product		送葬	to be in a funeral
	赛制	competition system		破费	to spend money
	界线	boarder		退货	to return merchandise
	歉意	apology		照相	to take a picture
	碎片	pieces		报到	to register the arrival

Trisyllables:

1+2 Structures					
Modifier-noun			Verb-noun		
Base tones on σ1	Chinese	Gloss	Base tones on σ1	Chinese	Gloss
T1 (53)	孙女儿	granddaughter	T1 (53)	搓麻将	to play mahjong
	沙喉咙	deep voice		绷绒线	to collect knitting wool
	花蚊子	mosquito		装死腔	to pretend
	鸡皮肤	uneven skin		穿衣裳	to wear clothes
	干点心	dry snacks		称份量	to weigh
	秋老虎	hot autumn		开伙仓	to cook
	新官人	groom		搓团子	to make sticky rice ball
	香肥皂	soap		抛铜板	to throw the coin
	青面皮	someone who is angry easily		翻跟斗	to take loops
	尖眼睛	sharp eyes		抄近路	to take the short cut
	双胞胎	twins		听调头	to listen to someone
	新饭店	new restaurant		开条斧	to give conditions
	飞蚂蚁	termite		扳字眼	to work on wording
	天老爷	goodness		拼性命	to fight till death
	青蚕豆	green vicia faba		剖肚皮	to cut the belly
	新社会	new society		开夜车	to stay late

	干电池	battery		开洋荤	to have something fancy
	香瓜子	sunflower seed		挑野菜	to get wild herbs
	单眼皮	mono-eyelids		兜远路	to go far roads
	新产品	new product		捞水草	to pick up water grass
T3 (323)	好机会	good opportunity	T3 (323)	拗手劲	to compete hand strength
	水弄堂	water alley		讨新妇	to have a daughter-in-law
	纸老虎	paper tiger		淌眼泪	to cry with tears
	小意思	a piece of cake		打呼噜	to sneeze
	小青头	young rogue		打圆场	to make others comfortable
	假喉咙	fake voice		斩洋绅	to be cheated (business)
	表兄弟	cousin brothers		摆酒水	to have a party
	总指挥	chief commander		板面孔	to show an angry face
	小馄饨	small wonton		讲老空	to chat
	好人家	good family		起迷露	to be foggy
	总书记	general secretary		显本事	to show off
	酒文化	wine culture		解厌气	not to be bored
	小黄鱼	small yellow-fin tuna		打包票	to assure
	短大衣	short jacket		走门路	to get connections
	圆面孔	round face		讲闲话	to chat
	总经理	general manager		解腥气	to get rid of fish smell
	小肚皮	belly		找钞票	to get changes
	总工会	labor unions		懂清头	to be understandable
	表姊妹	cousin sisters		打地铺	to sleep on the floor
	好朋友	good friend		裹馄饨	to wrap wonton
T5 (34)	半当中	in the middle	T5 (34)	倒春寒	to be cold in spring
	副经理	assistant manager		睏晏觉	to sleep late
	素筒肠	intestine made of beancurd		报平安	to tell one’s safety
	破棉鞋	broken cotton-padded shoes		吊胃口	to interest others
	副厂长	assistant factory chief		看好看	to witness a scene
	细棺材	little kids (unfriendly)		拜天地	to be married
	布衣裳	clothes		探口气	to sound out someone
	破信封	broken envelop		揿手印	to give finger print
	副产品	byproduct		做生意	to do business
	布玩具	cloth toy		叹苦经	to complain
	寄女儿	goddaughter		睏中觉	to sleep at noon
	破书包	broken backpack		钉洋钉	to knock in a nail
	副主任	assistant director		做人情	to do someone a good turn
	破床单	broken sheet		倒反账	to charge back
	背当心	middle of the back		凑闹猛	to be in the noise
	胖猪猡	fat pig		放炮仗	to fire firecrackers

	副组长	assistant team leader		做人家	to save money
	酱瓣豆	beans with soy sauce		派用场	to use something
	脆麻花	crispy snack		戴戒指	to wear rings
	太师傅	teacher's teacher		借铜钱	to borrow money

2+1 Structures		
Modifier-noun		
Base tones on σ1	Chinese	Gloss
T1 (53)	飞机场	airport
	乡下人	countryman
	心肝头	sweetheart
	开裆裤	open-seat pants
	垃圾货	bad product
	金花菜	Jinhua vegetable
	冤枉路	wrong road
	收音机	radio
	冬至夜	the evening of December 21st
	酸梅汤	plum drinks
	猪油渣	pork oil residue
	丝瓜巾	bowl wash cloth
	生意经	business idea
	枪毙鬼	someone who behaves really bad
	梭子蟹	one type of crab
	阴沟洞	waste water alley
	尴尬相	awkwardness
	青紫块	bruise
	珍珠米	corn
	风凉话	to say unhelpful things
T3 (323)	海南岛	Hainai island
	讨债鬼	someone who always asks for something
	摆渡船	boat
	广播站	radio station
	海棠糕	rice cake with pink color
	火车票	train ticket
	保险箱	safety box
	普通话	Mandarin
	土地庙	temple
	卷心菜	cabbage
	展览会	exhibition

	保管费	maintenance fee
	水产部	fishery department
	嘴唇瓣	lips
	指南针	compass
	统计表	calculating table
	闯祸胚	someone who always makes trouble
	保证书	certificates
	显微镜	microscope
	酒精厂	alcohol factory
T5 (34)	太师椅	chairs with handles
	纪念品	souvenir
	笑面虎	people who smile but mean
	四季豆	green bean
	太阳光	sunshine
	斗鸡眼	twisted eyes
	靠背椅	backrest chair
	化妆品	cosmetics
	揿书机	stapler
	粽子糖	rice candy
	汽车票	bus ticket
	挂号信	registered letter
	俏档货	popular product
	太平洋	Pacific Ocean
	剃头店	salon
	绣花针	embroidering needle
	见面礼	first-time present
	进口货	imported product
	意见簿	advise notes
	个体户	people who run business by themselves

Appendix C: Language background questionnaire

语言背景问卷

受试者 #:	年龄:	性别: 男 女	习惯用手: 左手 右手
☐ 本科生 ☐ 研究生		____年级	专业:
职业:			

你曾经有过(请勾出所有适用选项): ☐ 视力障碍?

☐ 听力障碍?

☐ 语言障碍?

☐ 学习障碍?

如果你有以上障碍，请详细解释（包括矫正情况）________________________________

---

1. 你的母语是什么? (*可多选*)
汉语普通话
上海/无锡市区话
上海/无锡郊区话: ________________
其他: ______________________

2. 你父亲的母语是什么? (*可多选*)
汉语普通话
上海/无锡市区话
上海/无锡郊区话: ________________
其他: ______________________

3. 你母亲的母语是什么? (*可多选*)
汉语普通话
上海/无锡市区话
上海/无锡郊区话: ________________
其他: ______________________

4. 你5周岁以前，在家里使用什么语言/方言? (*可多选*)
汉语普通话
上海/无锡市区话
上海/无锡郊区话: ________________
其他: ______________________

5. 你6到11周岁的时候，在家里使用什么语言/方言? (*可多选*)
汉语普通话
上海/无锡市区话

上海/无锡郊区话: ________________
其他: ______________________

6. 你12 到 17 周岁的时候，在家里使用什么语言/方言? (*可多选*)
汉语普通话
上海/无锡市区话
上海/无锡郊区话: ________________
其他: ______________________

7a. 你在上海哪个区居住的时间最长？

黄浦区	虹口区	金山区
徐汇区	杨浦区	松江区
长宁区	闵行区	青浦区
静安区	宝山区	奉贤区
普陀区	嘉定区	崇明县
闸北区	浦东新区	

7b. 你在无锡哪个区居住的时间最长？

崇安区	滨湖区	新区
南长区	江阴市	
北塘区	宜兴市	

8. 你…在上海/无锡哪个区或者哪个其他城市居住

…儿童时期?	…青少年时期?	…成年人?

9. 除了上语言类课程, 在…里，你的老师用什么语言/方言教课 (比如，数学、历史等)

… 小学?	… 初中?	… 高中?

10. 请按照习得顺序，列出你会说的语言/方言 (从母语开始)。

1)	2)	3)	4)	5)

11. 请自我评价一下你会说的语言/方言的熟练程度 (*初学者, 低-中级, 中级, 低-高级, 高级, 接近母语, 母语*).

语言/方言					
熟练程度					

12. 请用百分比列出你现在会说的语言/方言在生活中的使用情况 (*全部加起来应为 100%*).

语言/方言					

百分比					

13. 现在，如果有个人的语言/方言背景情况跟你一模一样，你会依次选择用什么语言/方言和他/她交流?分别占你们对话的多少百分比?

语言/方言					
百分比					

Language Background Questionnaire

Participant #:	Age:	Gender: M F	Handedness: Left Right
Year ___ of ☐ undergraduate ☐ graduate studies			Major:
Others:			

Have you ever had (check all that apply): ☐ vision problems?

☐ hearing impairment?

☐ language disability?

☐ learning disability?

If yes to any, please explain (including any corrections) ________________________________

1. What is (are) your native language(s)/ dialect(s)? (*check all that apply*)

Mandarin Chinese

Shanghai/Wuxi Wu (urban)

Shanghai/Wuxi Wu (suburban): ___________

Other: ____________________________

2. What is (are) your first parent's native language(s)/ dialect(s)? (*check all that apply*)

Mandarin Chinese

Shanghai/Wuxi Wu (urban)

Shanghai/Wuxi Wu (suburban): ___________

Other: ____________________________

3. What is (are) your second parent's native language(s) / dialect(s)? (*check all that apply*)

If non-applicable, write NA: _______

Mandarin Chinese

Shanghai/Wuxi Wu (urban)

Shanghai/Wuxi Wu (suburban): ___________

Other: ____________________________

4. What language(s) / dialect(s) were used in your house from birth to 5 years of age? (*check all that apply*)

Mandarin Chinese
Shanghai/Wuxi Wu (urban)
Shanghai/Wuxi Wu (suburban): ___________
Other: ___________________________

5. What language(s) / dialect(s) were used in your house from 6 to 11 years of age? (*check all that apply*)
Mandarin Chinese
Shanghai/Wuxi Wu (urban)
Shanghai/Wuxi Wu (suburban): ___________
Other: ___________________________

6. What language(s) / dialect (s) were used in your house from 12 to 17 years of age? (*check all that apply*)
Mandarin Chinese
Shanghai Wu (urban)
Shanghai Wu (suburban): ___________
Other: ___________________________

7a. In which district of Shanghai did you live for the longest time?

Huangpu	Hongkou	Jinshan
Xuhui	Yangpu	Songjiang
Changning	Minhang	Qingpu
Jing'an	Baoshan	Fengxian
Putuo	Jiading	Chongming
Zhabei	Pudong	

7b. In which district of Wuxi did you live for the longest time?

Chong'an	Binhu	Xinqu
Nanchang	Jiangyin	
Beitang	Yixing	

8. In which district of Shanghai/Wuxi or other cities did you live…

…as a child?	…as a teenager?	…as an adult?

9. Excluding language classes, in what language(s) were you taught (e.g., math, history, etc.) in…

… elementary school?	… middle school?	… high school?

10. Please list your languages in order of acquisition (beginning with native language).

1)	2)	3)	4)	5)

11. Please estimate your global proficiency in all the languages you know (*beginner, low-intermediate, intermediate, low-advanced, advanced, near-native, native*).

Language/ dialect					
Proficiency					

12. Please give the percentage of time you currently use each language (*your percentages should add to 100%*).

Language/ dialect					
Percent					

13. When speaking a language with someone who is equally fluent in all your languages, what percent of the time would you choose to speak each of your languages?

Language/ dialect					
Percent					

Appendix D: Shanghai [V N] pro-sandhi trisyllables

Item	Gloss	Base tone on σ1	Frequency	Semantic transparency
装胡羊	to play innocent	T1	-0.584	-0.628
招女婿	to have a son-in-law	T1	-0.171	0.013
走亲眷	to visit relatives	T2	-0.194	-0.277
走江湖	to be in society	T2	-0.562	-0.092
打官司	to have a lawsuit	T2	0.042	-0.036
解厌气	not to be bored	T2	-0.198	0.039
叫冤枉	to claim being wronged	T2	-0.293	0.194
看医生	to see a doctor	T2	0.142	0.208
做生意	to do business	T2	0.057	0.368
箍三胡	to chat	T3	0.290	-0.781
骂山门	to fight	T3	0.225	-0.681
磨洋工	to procrastinate	T3	0.290	-0.536
谈朋友	to be in a relationship	T3	0.290	-0.472
捣糨糊	to mediate	T3	0.284	-0.405
乘风凉	to sit outside in summer	T3	0.225	-0.033
用心思	to make efforts	T3	-0.145	0.224
荡秋千	to sit on a swing	T3	0.009	0.358
有志气	to be ambitious	T3	-0.405	0.629
晾衣裳	to dry clothes outside	T3	0.105	0.629