Speakers Treat Transparent and Opaque Alternation Patterns Differently — Evidence from Chinese Tone Sandhi

Jie Zhang

1. Introduction

1.1. Opacity

The study of opacity has had a long tradition in generative phonology. Kiparsky (1973: p.79) defined two types of opacity for a phonological rule, as in (1). The first type is also known as underapplication opacity, and the opaque rule is non-surface-true; the second type is also known as overapplication opacity, and the opaque rule is non-surface-apparent (e.g., Bakovic 2007).

(1) Opacity: A phonological rule P of the form A → B / C __ D is *opaque* if there are surface structures with any of the following characteristics:
   (a) Instance of A in the environment C __ D;
   (b) Instance of B derived by P in environments other than C __ D.

In the rule-based framework, opacity can generally be derived by ordering the opaque rule before another rule that could either set up or destroy the application of the opaque rule (but see Bakovic 2007, 2011, who advocates the decoupling of opacity and rule ordering). In a surface-oriented theory like Optimality Theory (OT; Prince and Smolensky 1993/2004), however, opacity poses significant challenges. Without modification to the theory, neither underapplication nor overapplication opacity can be straightforwardly derived. A number of general solutions for opacity have been proposed within OT, including the Sympathy Theory (McCarthy 1999), Stratal OT (Kiparsky 2000, Nazarov and Pater 2017), OT with Candidate Chains (OT-CC; McCarthy 2007), and Serial Markedness Reduction (Jarosz 2014, 2016). Solutions for specific types of opacity have also been proposed, including using constraint conjunction (Kirchner 1996), *MAP constraints (Zuraw 2007), and PRESERVE-CONTRAST constraints (Lubowicz 2003) for chain shifts and Output-Output Correspondence for paradigmatic-levelling induced opacity (Benua 1997).

Empirically, however, we know relatively little about how and what speakers learn about opaque patterns, and the limited number of studies returned inconsistent results. Using the artificial language learning paradigm, Ettlinger (2008) and Kim (2012) showed that opacity is learnable and may even be preferred under certain conditions. But wug test results have shown that an overapplied vowel raising rule in Polish (Sanders 2003) and a circular chain shift tone sandhi pattern in Taiwanese Southern Min (Hsieh 1970, Wang, 1993, Zhang et al. 2011) are not fully productive, and results from auditory priming experiments showed little evidence for abstract underlying root consonants in an opaque analysis of Tiberian Hebrew alternation (Sumner 2003).

The goal of this paper is to explore how native speakers internalize transparent and opaque alternation patterns in their language by using wug tests, auditorily primed lexical decision tasks, and rating tasks. Therefore, the contribution here is more in line with the experimental work mentioned above. But it is hoped that the experimental data, especially those that allow a direct comparison between

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transparent and opaque patterns, can also provide strong guidance for the theoretical analysis of opacity. The patterns of interest in this paper are tone sandhi patterns in various dialects of Chinese, with a particular focus on circular chain shifts, which involve underapplication opacity. This is an especially challenging type of opacity analytically, as the circular nature of the chain shift determines that the pattern cannot be resolved by mechanisms that take into account of perceptual distance (e.g., *MAP). Moreton (2004), in fact, provides a formal proof that this type of pattern cannot be computed by traditional OT). Moreover, circular chain shifts are relatively well-attested in tone sandhi patterns in Chinese dialects.

The hypotheses are that circular chain shift patterns lack full productivity synchronically and forms that involve this type of opacity are lexically listed with the sandhi tones; transparent patterns that are tested with the same methods, however, show a different pattern in that they are generally productive under wug tests and transparent forms are listed in their base tones. If these hypotheses find support in the experimental results, it will indicate that a general solution for opacity is neither required nor desirable in OT, as it will make wrong predictions for speakers' experimental behavior for circular chain shift opacity. What this type of opacity needs, instead, is a morphological/lexical account. The greater message behind these studies is that theoretical advances can find guidance in experimental studies that shed light on how speakers internalize different types of alternation.

1.2. Tone Sandhi

Tone sandhi refers to tonal alternation conditioned by the phonological environment in which the tone appears, such as the adjacent tones or the prosodic position of the tone. Tone sandhi is well-attested and well-documented in Chinese dialects, and the contour-rich tonal inventories in Chinese present a particularly fertile ground for intricate tone sandhi patterns.

Tone sandhi patterns can be generally classified as "right-dominant" or "left-dominant" depending on the edge of the sandhi domain that preserves the base tone (Yue-Hashimoto 1987, Chen 2000, Zhang 2007, 2014). It has been argued that these two types of tone sandhi have different typological properties in that, typically, right-dominant sandhi involves paradigmatic tone change, while left-dominant sandhi involves tone spreading (Yue-Hashimoto 1987, Zhang 2007). Right-dominant sandhi is exemplified by Mandarin, Hailu Hakka, and Taiwanese Southern Min in (2). The Mandarin T3 sandhi (2a) is triggered by a following third tone (Chao 1968, Duanmu 2007); the Hailu Hakka (2b) (Chung 1992) and Taiwanese Southern Min (2c) (Cheng 1968, Du 1988) sandhi patterns are both triggered by being in non-phrase-final positions, and the Taiwanese pattern is also characterized by chain shifts.

(2) Right-dominant tone sandhi patterns:
- (a) Mandarin: 213 → 35 / __ 213
- (b) Hailu Hakka: 13 → 33 / __ X
- (c) Taiwanese Southern Min: 51 → 55 → 33 ← 24 / __ X
  ↖ ↙
  21

Left-dominant sandhi is exemplified with patterns from Shanghai Wu and Wuxi Wu in (3). In Shanghai Wu (3a), the tone on the first syllable is spread across the disyllabic word, neutralizing the tone on the second syllable (Zee and Maddieson 1980, Xu et al. 1981, Xu and Tang 1988, Zhu 1999, 2006). In Wuxi Wu (3b), the tone on the first syllable is first substituted by another tone, then the substituted tone is spread across the disyllabic word — a special type of left-dominance as the base tone on the first syllable is not preserved in sandhi, but nonetheless determines the surface tone pattern of the disyllabic word (Chan and Ren 1989, Xu 2007). This type of tone sandhi is sometimes referred to as pattern substitution.

(3) Left-dominant tone sandhi patterns:
- (a) Shanghai Wu: 51-X → 55-31
- (b) Wuxi Wu: 53-X → 43-34

We focus on two sets of comparisons in this paper. The first is a set of right-dominant tone sandhi comparisons, for which native speakers' behaviors on the circular chain shift pattern in Taiwanese Southern Min are compared to those on the transparent substitution patterns in Mandarin and Hailu Hakka. The other is a set of left-dominant tone sandhi comparisons, for which the transparent spreading pattern of Shanghai Wu is pitted against the sandhi pattern in Wuxi Wu, which will be shown to involve the combination of a circular chain shift and transparent spreading.

The right-dominant tone sandhi comparisons include wug tests and auditorily primed lexical decision tasks and are discussed in section 2. The left-dominant tone sandhi comparisons include wug tests and variability rating tasks and are discussed in section 3; a brief discussion of the diachrony of the Shanghai and Wuxi tone sandhi patterns is given in this section as well. Section 4 provides a sketch of the analysis of the tone sandhi pattern in Wuxi Wu. Section 5 concludes the paper.

2. Right-Dominant Tone Sandhi Comparisons

2.1. Wug tests

2.1.1. Taiwanese Southern Min

We start with the tone sandhi pattern in Taiwanese Southern Min. Tone sandhi occurs on nonfinal syllables of syntactically defined tone sandhi domains (see Chen 1987 and Lin 1994 on the tone sandhi domains of a very closely related dialect — Xiamen), and the sandhi follows the pattern in (2c) on non-checked (open or sonorant-closed) syllables.[1] A number of studies have indicated that Taiwanese tone sandhi is indeed structure-preserving and hence opaque (Du 1988, Lin 1988, Peng 1997, Tsay et al. 1999, Myers and Tsay 2008). Moreover, Chang's (2013) corpus study of six non-attriting native Taiwanese speakers' speech showed that, after accounting for dialectal variation and known lexical exceptions, the tone sandhi patterns in (2c) applied with rates well over 90% in natural speech.

To test the productivity of the different tone sandhis in the pattern, we used a method similar to the ones used by Hsieh (1970, 1975, 1976) and Wang (1993). Specifically, we elicited the production of two types of disyllabic words from native speakers: real words and novel words. The real words were existing words that all participants were familiar with. The novel words were composed of an accidental gap syllable and an existing noun, where the first syllable was cued as a novel verb in a discourse context. For the real words, the participants heard the two syllables in their base tones separated by 800ms and were asked to produce the two syllables together as a word as naturally as possible. For the novel words, the participants heard the novel syllable pronounced in its base tone twice and the noun in its base tone once in the discourse set-up; they were then asked to produce the V-N combination as a word as naturally as possible. Twenty-five real words and twenty-five novel words were elicited from the participants. The first syllable included all five unchecked tones, while the second syllable had a 33 tone in all test words. Twenty-six native Taiwanese speakers with a mean age of 38.5 participated in the experiment in Taiwan.

An initial inspection of the production data indicated that the participants' responses on the first syllables were categorically one of the five unchecked tones. The tones on the first syllables were then transcribed by a team of three researchers consisted of one bilingual Taiwanese/Mandarin speaker and two native Mandarin speakers, all of whom are phonetically trained. The transcriptions were then classified into "Correct_Sandhi" if the syllable underwent the expected sandhi according to (2c), "No_Sandhi" if the syllable was pronounced with the base tone, or "Others" if the participant provided any other response.

The percentages of the three types of responses for the real and novel words are given in Figure 1. Linear Mixed-Effects analyses were conducted with word type (real vs. novel) and the base tone on the first syllable (24, 33, 21, 51, 55) as fixed effects and participant, participant by word type, and item as random effects. Likelihood ratio comparisons showed that for "Correct_Sandhi" rate, adding word type (χ^2=66.91, p<.001) and σ1 base tone (χ^2=45.68, p<.001) successively into the model both improved the

1 On checked syllables (stop-closed syllables), the tonal inventory comprises a high level tone 4 and a low level tone 2. In sandhi contexts, if the syllable ends in -p, -t, -k, 4 → 2, and 2 → 4; if the syllable ends in -ʔ, the glottal stop is lost, and 4→2, 2 → 51.

model, but adding the interaction term did not (χ^2=6.17, p=.187). For "No_Sandhi" rate, however, the model with the interaction is the best (χ^2=11.97, p=.018), and separate analyses for real and novel words showed that σ1 base tone has no effect in real words, but a significant effect in novel words, with the 24→33 sandhi eliciting significant fewer "No_Sandhi" responses than the other sandhis.

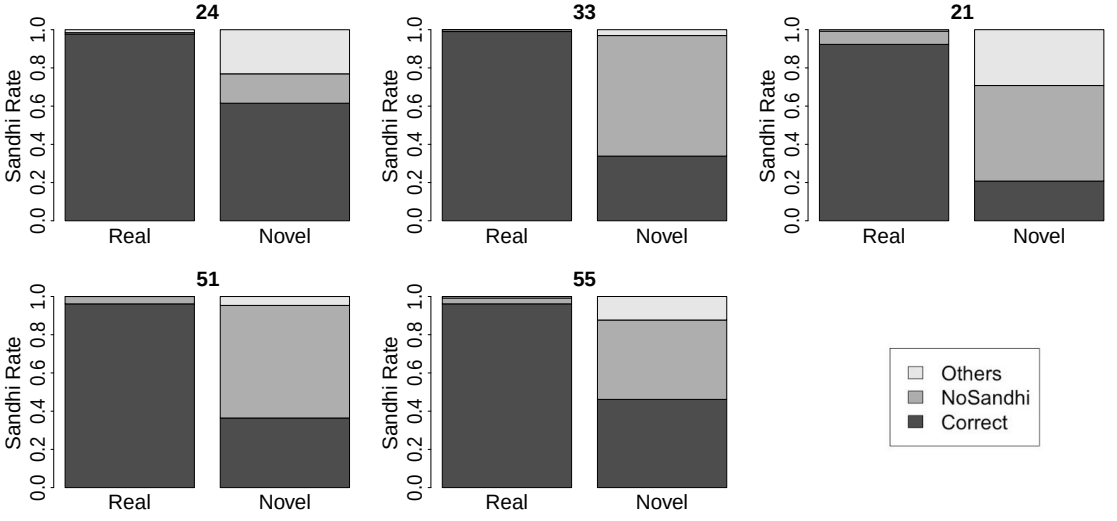

Figure 1. Tone sandhi results on the first syllable of disyllabic real and novel words in Taiwanese Southern Min.

These results showed that none of the opaque tonal substitution processes in Taiwanese Southern Min is entirely productive, and the participants' responses often have no sandhi application. The phonotactically motivated sandhi 24→33, however, has an edge in productivity over the other sandhis in that it is less likely for the participants to respond with the no sandhi form. These results are consistent with earlier wug test results on Taiwanese tone sandhi and provide evidence that the tone sandhi patterns in Taiwanese, especially the ones in the circular chain shift, should be accounted for by allomorph listing of existing syllables and/or morphemes.

However, a caveat to the interpretation of the results above is that the results may be due to a task effect, in that the participants were simply unwilling to apply tone sandhi in a novel word context. To address this concern, the opaque tone sandhi in Taiwanese Southern Min needs to be compared with transparent tone sandhi patterns under similar wug test methods. The next two subsections discuss the wug test results on transparent tone sandhis in Mandarin and Hailu Hakka that provide this comparison.

2.1.2. Mandarin

The productivity of the T3 sandhi pattern in Mandarin (2a) was investigated in Zhang and Lai (2010). The experiment tested the production of real words as well as four types of nonce words — pseudo words in which both syllables were existing morphemes, but the combinations were nonwords, and novel words in which the first syllable, the second syllable, or both syllables were accidental gaps in the syllabary. Participants heard the two syllables in their base tones separated by 800ms and produced the two syllables together as a word as naturally as possible. Thirty native speakers of Beijing Mandarin ranging from 19 to 37 years of age participated in the experiment in Beijing.

The production data showed that the T3 sandhi consistently applied in all nonce word types, as shown in Figure 2. Comparisons of the f0 curves indicated that there was incomplete application of the sandhi in nonce words, as the pitch pattern of the sandhi tone in nonce words showed more base tone properties (lower and later turning point) than in real words (see Zhang and Lai (2010) for more details). But the productivity of tone sandhi in Mandarin clearly patterns very differently from that in Taiwanese

Southern Min, indicating that the categorical failure of tone sandhi application in novel words in Taiwanese cannot be simply due to the task.[2]

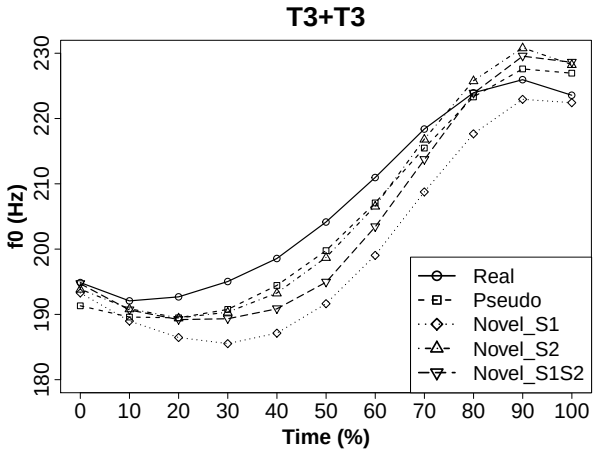

Figure 2. F0 results for the first syllable of disyllabic real words and four types of nonce words in Mandarin.

An addition issue to consider in the comparison between the opaque sandhi in Taiwanese Southern Min and the transparent sandhi in Mandarin is the nature of the tone sandhi trigger: albeit both right-dominant, the Taiwanese sandhi pattern is triggered by position, while the Mandarin T3 sandhi is triggered by a specific following tone. This difference determines that the sandhi tone appears more often than the base tone in Taiwanese Southern Min, but less often than the base tone in Mandarin. Therefore, the productivity difference may have a frequency-based account, in that Taiwanese speakers have less evidence that the alternation is due to a base tone to sandhi tone mapping than Mandarin speakers. To complete the argument that it is indeed opacity that causes categorical unproductivity, I discuss a productivity study of a sandhi pattern in Hailu Hakka that is both positionally triggered and transparent in the next subsection.

2.1.3. Hailu Hakka

Hailu Hakka has a tonal inventory of 53, 44, 13, 21, and 33 on non-checked syllables. The only tone sandhi attested on this type of syllables is the one in (2b) — a neutralizing sandhi that turns 13 into 33 in nonfinal positions of tone sandhi domains (see Chung 1992 for more details on the tone sandhi domains). The productivity of this tone sandhi has been investigated by Zhang et al. (2016).

Participants provided production data for 16 real words and 16 novel words of 13-33 or 13-53 base tone combinations. The novel words were M-N or V-N combinations where the first syllable was an accidental gap syllable and was set up as either a novel modifier or a novel verb, and the second syllable was an existing noun. Like in the Taiwanese experiment, for the real words, the participants heard the two syllables in their base tones separated by 800ms and were asked to produce the two syllables together as a word as naturally as possible; for the novel words, the participants heard the novel syllable pronounced in its base tone twice and the noun in its base tone once in the discourse set-up; they were then asked to produce the M-N or V-N combination as a word as naturally as possible. Nineteen native speakers with a mean age of 58.6 participated in the experiment in Hsinchu, Taiwan.

2 The method of the wug test in Mandarin is not identical to that in Taiwanese Southern Min, as the Mandarin participants were not given sentential contexts for the nonce words. But given that the higher productivity of tone sandhi Mandarin was elicited under a more adverse condition for sandhi productivity than Taiwanese, the comparison provides an even stronger argument against the task effect interpretation for the lack of sandhi productivity observed in Taiwanese.

The normalized f0 results for the first syllable of the 13-X disyllables are given in Figure 3. Growth curve analysis (Mirman 2014) with orthogonal quadratic polynomials was used to compare the f0 curves of real and novel words. The result showed no difference between the two curves in the intercept, the linear term, or the quadratic term, indicating that the tone sandhi applied productively to the novel words.

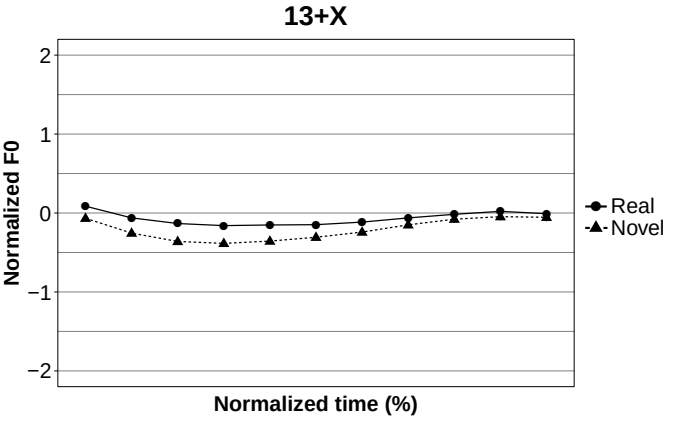

Figure 3. F0 results for the first syllable of disyllabic real and novel words in Hailu Hakka.

2.1.4. Interim Summary

The productivity comparison among the three right-dominant tone sandhi patterns in Taiwanese Southern Min, Mandarin, and Hailu Hakka strongly suggests that the unproductivity of the tone sandhi patterns in Taiwanese is due to the circular chain shift that the sandhi is involved in, not the positional nature of the sandhi trigger (which translates into a higher frequency of the sandhi tone in discourse), or the nature of the experimental task itself. In other words, phonological opacity plays a crucial role in determining how native speakers internalize tone sandhi: transparent sandhis are likely derived through productive phonological derivations from the base tone, while opaque sandhis are likely due to allomorph listings of existing syllables and/or morphemes (see Tsay and Meyers 1996 for a similar view). Phonotactic motivations, however, could give the sandhi a productive edge even if it is opaque, as shown in the 24 → 33 sandhi result in Taiwanese.

Further converging evidence for this theoretical stance can be sought in the processing of words that undergo different types of tone sandhi. In the following section, a series of studies that further investigates the nature of these right-dominant tone sandhi patterns from the perspective of spoken word recognition is discussed. The goal is to address the question whether the speakers' phonological knowledge that we deduced from the wug tests is consistent with what they use in the process of spoken word recognition.

2.2. Auditorily Primed Lexical Decision

In auditory lexical decision, participants judge whether an experimental item they hear is a word or not. The latency with which the participants respond "yes" to a word is influenced by properties of the word itself, such as its frequency, as well as the exposure to an earlier item (prime). The types of priming effects that have been demonstrated in the literature include phonological priming (e.g., *mean* primes *bean*), semantic priming (e.g., *table* primes *chair*), and morphological priming (e.g., *government* primes *govern*).

What is particularly relevant for the current investigation is that there is a body of evidence from priming that suggests that listeners can access the abstract phonological representation in processing when there is predictable phonological alternation such as place assimilation and voicing assimilation (e.g., Lahiri et al. 1990, Gaskel and Marslen-Wilson 1996, Luce et al. 2001, Gow 2001, 2002). For instance, Gow (2001) showed that an item that has undergone regressive place assimilation (e.g., *gree[m] beans*) primes the unassimilated form in isolation (e.g., *green*). Lahiri et al.'s (1990) study on the Dutch

pronominal clitic /*dər*/ is especially telling. When attached to a verb that ends in an obstruent, the obstruent-d cluster can undergo either cluster devoicing or regressive voicing assimilation under variable prosodic parsing of the combination. Lahiri et al. showed that when the UR of the verb has a voiceless obstruent at the end, the verb-clitic combination with cluster devoicing has a greater priming effect on the verb in isolation (e.g., [kœs-tər] primes [kœs], UR=/kœs/), as expected; but when the UR of the verb has a voiced obstruent at the end, the combination with regressive voicing assimilation has a greater priming effect on the verb in isolation, even though the verb in isolation undergoes final devoicing ([kiz-dər] primes [kis], UR=/kiz/).

We used a similar method to test the representation of disyllabic words with right-dominant tone sandhi that listeners access in spoken word recognition. But instead of using the disyllabic words as primes, we used them as targets, as monosyllables are typically bound morphemes, not individual words in Chinese, and are therefore not ideal for lexical decision judgments. The general method is auditory lexical decision with auditory priming to test whether the disyllable is primed by a monosyllable sharing the base tone or the sandhi tone of the first syllable. By comparing the priming behavior of disyllables undergoing transparent and opaque sandhis, we can investigate whether the two types of sandhis are processed differently in spoken word recognition, as predicted by our wug test results. Data from Taiwanese Southern Min, Mandarin, and Hailu Hakka are reported in the following three subsections.

2.2.1. Taiwanese Southern Min

We start with the priming study of two of the tone sandhi patterns in Taiwanese Southern Min, 51 → 55 and 24 → 33, reported in Chien et al. (2017). Recall that both sandhi patterns are opaque, but 24 → 33 can potentially be motivated by a phonotactic generalization. Eighteen words undergoing each of these sandhis were used as targets (e.g., */piŋ^{51}-tsun^{24}/* 翻船 'to capsize a boat'). Each target was preceded by three types of monosyllabic primes by 250ms in a Latin-square design: underlying prime (e.g., */piŋ^{51}/* 翻 'to capsize'), surface prime (e.g., */piŋ^{55}/* 冰 'ice'), and control prime (e.g., */piŋ^{21}/* 併 'to combine'). Sixty filler words and ninety-six nonwords with a balanced mixture of tones and prime types were also included in the experiment. The participants needed to judge whether the disyllable is a word or not in Taiwanese as quickly and as accurately as possible upon hearing the prime and the target. Thirty-six native Taiwanese listeners in the age range of 30-55 participated in the experiment in Taiwan.

The logged reaction times (logRT) for the correct responses, trimmed to exclude those falling outside two standard deviations from the mean for each participant, were analyzed using Linear Mixed-Effects models with sandhi and prime type as fixed effects and participant and item as random effects.

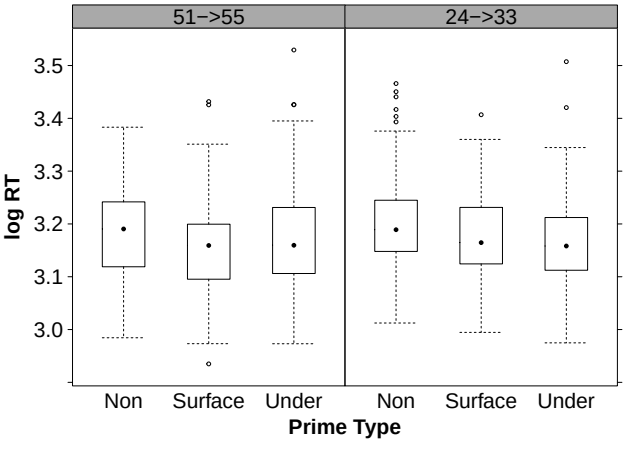

Figure 4. LogRT results for disyllables undergoing the 51 → 55 and 24 → 33 tone sandhis in Taiwanese Southern Min, separated by the underlying prime (Under), surface prime (Surface) and control prime (Non) conditions.

The logRT results are shown in Figure 4. A significant interaction between sandhi and prime type motivated separate analyses for 51 → 55 and 24 → 33. For 51 → 55, only the surface primes elicited significant facilitation compared to the control primes (β=-.030, SE=.007, t=-4.45, p<.001), while the underlying primes did not (β=-.011, SE=.007, t=-1.66, p=.097). For 24 → 33, however, both the underlying and the surface primes elicited significant priming (underlying primes: β=-.036, SE=.006, t=-5.68, p<.001; surface primes: β=-.023, SE=.006, t=-3.65, p<.001).

2.2.2. Mandarin

An auditory priming study of the tonally-triggered transparent T3 sandhi in Mandarin was reported in Chien et al. (2016). Thirty disyllabic T3 sandhi words were used as targets, and in a Latin-square design, each target was preceded by an underlying (T3) prime, a surface (T2) prime, or a control prime, all of which shared the same segments with the first syllable of the word. Sixty filler words and ninety nonwords with a balanced mixture of tones and prime types were also included in the experiment. Thirty-three native Taiwan Mandarin listeners participated in the experiment in Taiwan.

The logRT results, given in Figure 5, showed that only the underlying primes elicited significant facilitation compared to the control primes (β=-.030, SE=.005, t=-6.36, p<.001), while the surface primes did not (β=-.0005, SE=.005, t=-.10, p=.920).

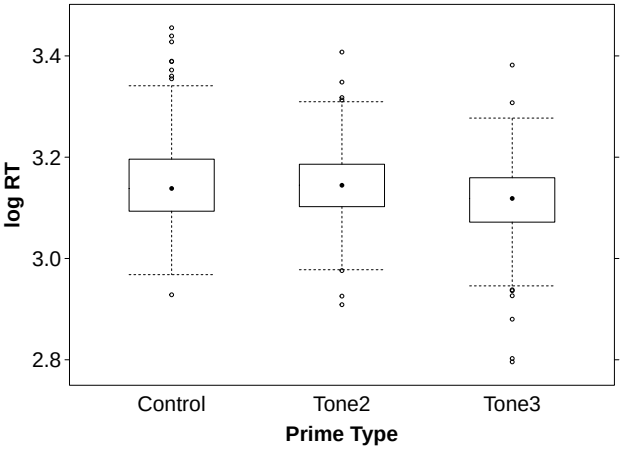

Figure 5. LogRT results for T3 sandhi words in Mandarin, separated by the underlying prime (T3), surface prime (T2) and control prime conditions.

2.2.3. Hailu Hakka

Zhang et al. (2016) discussed a priming study of the positionally-triggered transparent sandhi 13 → 33 / __ X in Hailu Hakka. Twenty disyllabic 13-X words were used as targets, and in a Latin-square design, each target was preceded by four types of monosyllabic primes, the first three of which shared the same segments as the first syllable of the word: underlying prime (13), surface prime (33), segmental prime (a tone other than 13 or 33), and unrelated prime (different syllable from the first syllable with a tone other than 13 or 33). Eighty filler words and one hundred nonwords with a balanced mixture of tones and prime types were also included in the experiment. Thirty-two native Hailu Hakka listeners participated in the experiment in Hsinchu, Taiwan.

The logRT results, given in Figure 6, showed that, compared to the unrelated primes, all prime types that shared the same segments as the first syllable of the words elicited significant priming, a finding consistent with earlier literature (e.g., Sereno and Lee 2015). But compared to the segmental primes, only the underlying primes elicited faster reaction time (β=-.003, SE=.010, t=-2.602, p=.0096), while the surface primes did not (β=-.011, SE=.010, t=-1.072, p=.284). As the segmental primes in Hailu Hakka correspond to the control primes in the Taiwanese and Mandarin experiments, the results here are similar to the Mandarin results, but different from the Taiwanese results.

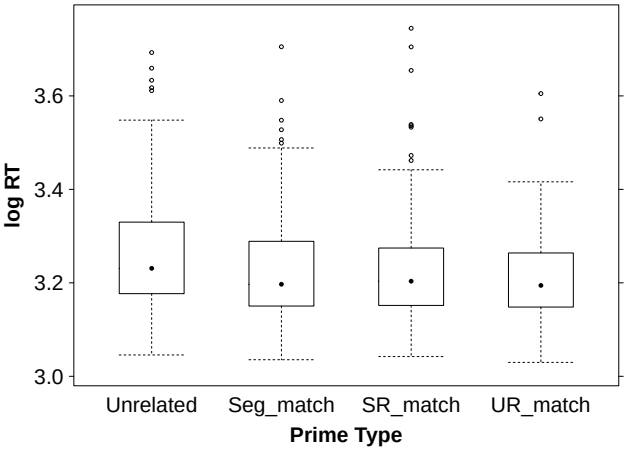

Figure 6. LogRT results for the 13 → 33 sandhi words in Hailu Hakka, separated by the underlying prime (UR_match), surface prime (SR_match), segmental prime (Seg_match), and unrelated prime conditions.

2.2.4. Interim Summary

The results of the auditory priming experiments in Taiwanese, Mandarin, and Hailu Hakka show that a disyllabic word undergoing a right-dominant transparent tone sandhi (Mandarin, Hailu Hakka) is consistently primed by a syllable that is segmentally identical to the first syllable carrying the base tone, a word undergoing an opaque tone sandhi with a potential phonotactic motivation (Taiwanese 24 → 33) can be primed by either the base tone or the sandhi tone, and a word undergoing an opaque tone sandhi in a circular chain shift is only primed by the sandhi tone. These results match the productivity gradation observed in the wug tests and provide converging evidence that transparent tone sandhis involve productive phonological processes from the base tone, while opaque sandhis involve allomorph listings of existing syllables and/or morphemes.

3. Left-Dominant Tone Sandhi Comparisons

3.1. Wug tests

3.1.1. Shanghai Wu

The tone sandhi pattern for disyllabic compounds with a non-checked syllable in initial position in Shanghai Wu is given in (4) (Zee and Maddieson 1980, Xu et al. 1981, Xu and Tang 1988, Zhu 1999, 2006). As previously stated, the general sandhi pattern can be characterized as the rightward spreading of the tone on the initial syllable over the compound domain.

(4) Shanghai Wu tone sandhi for non-checked syllables:
T1-X: 51-X → 55-31
T2-X: 34-X → 33-44
T3-X: 13-X → 11-13

Zhang and Meng (2016) reported a wug test experiment on tone sandhi in Shanghai Wu. Similar to the Taiwanese and Hailu Hakka experiments, participants in the Shanghai experiment also provided production data for real and novel disyllabic words, but the novel disyllables were only cued as modifier-noun (M-N) combinations, as V-Ns are generally phrases in Shanghai in which tone sandhi either does not apply or only applies variably (see section 3.2 for more details). All tonal combinations were tested in Zhang and Meng (2016), but we only focus on the combinations between 51 and the two tones on non-checked syllables with a voiceless onset (51, 35) here due to space limitation. Forty-eight speakers with a mean age of 24.6 from the urban regions of Shanghai participated in the experiment.

An initial inspection of the production data indicated that a classification of the responses into "sandhi" vs. "no sandhi" would be difficult. Therefore, we opted to measure the f0 of the two syllables using Yi Xu's *ProsodyPro* Praat script and conducted growth curve analyses (Mirman 2014) using orthogonal quadratic polynomials to compare the f0s between real and novel words. The normalized f0 results for 51-51 and 51-35 are given in Figure 7.

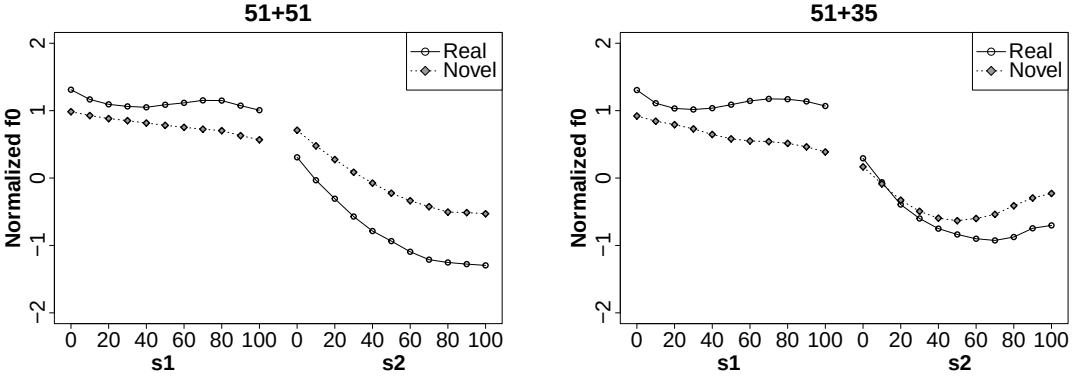

Figure 7. F0 results for disyllabic real and novel words in /51-51/ and /51-35/ base tone combinations in Shanghai Wu.

The overall shapes of the f0 curves in Figure 7 show a falling contour over the two syllables for both real and novel words, indicating that the spreading sandhi is generally productive. Growth curve analyses, however, showed a difference in f0 between real and novel words on both syllables. There appear to be stronger traces of the base tones in the novel words than in the real words; e.g., the second syllable has a higher fall in 51-51 and a greater rise in 51-35 in the novel words. This suggests that the lack of full productivity of the spreading pattern in Shanghai, if any, lies in the gradient phonetic realization of the sandhi, a pattern quite different from the categorical non-application observed in Taiwanese Southern Min, but very similar to the observation in Mandarin.

3.1.2. Wuxi Wu

Wuxi is a Wu dialect closely related to Shanghai. The pattern substitution sandhis in Wuxi involving non-checked syllables with a voiceless onset are given in (5) (Chan and Ren 1989, Xu 2007).

(5) Wuxi Wu tone sandhi for non-checked syllables with a voiceless onset:
T1-X: 53-X → 43-34
T3-X: 323-X → 44-55
T5-X: 34-X → 55-31

If we do not ascribe theoretical significance to the small transcription differences between 323 and 434 and between 45 and 34, we can divide the sandhi pattern in Wuxi into two distinct aspects: an opaque circular substitution pattern T1 → T3 → T5 → T1 and the subsequent transparent spreading of the substituted tone. Wuxi Wu, therefore, has elements of both opacity and transparency. The productivity of the Wuxi tone sandhi pattern was tested by Yan and Zhang (2016a), and I summarize the results for T1-X, a cognate of the Shanghai T1-X pattern, here.

Production data were elicited for real words and two types of nonce words — pseudo words in which both syllables were existing morphemes, but the combinations were nonwords, and novel words in which the first syllable was an accidental gap syllable cued as a novel modifier or a novel verb and the second syllable was a common noun. For the real and pseudo words, participants heard the two syllables in their base tones separated by 800ms and were then asked to produce the two syllables together as a word as naturally as possible. The novel words were elicited in the same way as in Taiwanese, Hailu Hakka, and Shanghai. Both M-N and V-N items were used in Wuxi, as unlike Shanghai, no clear difference in sandhi production between M-N and V-N was documented in the

descriptive literature (but see Yan 2016). Twenty native speakers with a mean age of 27 participated in the experiment in Wuxi.

Both an acoustic analysis of f0 and the transcription and categorization of the sandhi patterns were conducted for the production data. The acoustic f0 results for 53-53, 53-323, and 53-34 are provided in Figure 8.

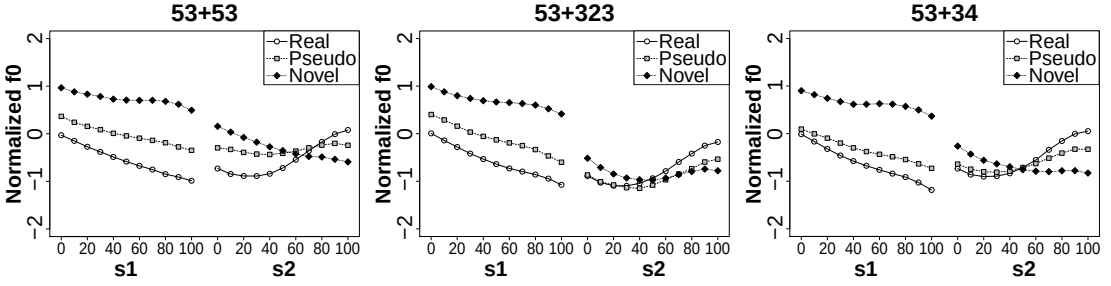

Figure 8. F0 results for disyllabic real and novel words in /53-53/, /53-323/, and /53-34/ base tone combinations in Wuxi Wu.

The f0 pattern here is markedly different from that in Shanghai Wu. There are large differences in f0 on both syllables between real and novel words. The graphs indicate that the substitution sandhi only occurred in the real words; in the novel words, the initial fall was spread instead, and there are also traces of the base tones in the surface tone patterns, e.g., the low dipping on the second syllable of 53-323. The f0 pattern of the pseudo words lie in between the real and novel words. For statistical comparisons of the f0 curves, see Yan and Zhang (2016a).

The results of the transcription and classification of the sandhi patterns by a phonetically trained native Wuxi speaker are given in Figure 9. These results further support the conclusions drawn from the f0 results. The real words underwent the pattern substitution sandhi, as expected. But there is only a very low percentage of correct substitution in novel words, mirroring the Taiwanese tone sandhi pattern in 2.1.1. The majority of the responses was classified as having the extension pattern, and "unchanged", where both syllables kept the base tone, and "partially unchanged", where at least one of the syllables kept the base tone, also accounted for a good portion of the data. This is similar to the Shanghai spreading pattern observed in 3.1.1. For pseudo words, both the correct substitution rate and the extension rate lie between those of real words and novel words, indicating that the circular tonal substitution is not only due to the listing of the substituted tone for existing syllables and/or morphemes, but also the listing of the disyllabic tone patterns of existing words, as without the latter, the difference between real and pseudo words cannot be accounted for. Readers are again referred to Yan and Zhang (2016a) for statistics on these results.

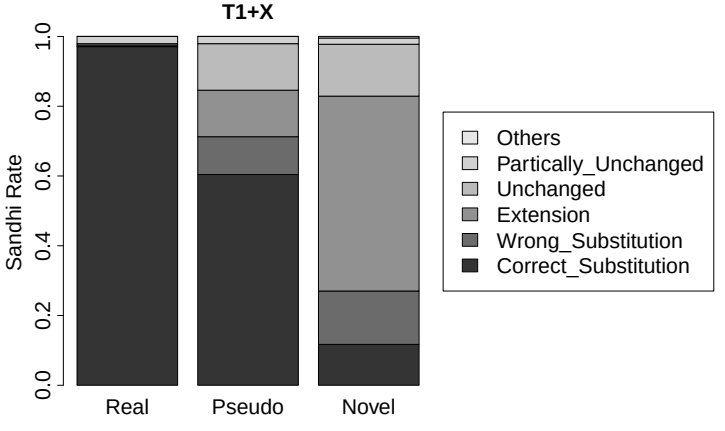

Figure 9. Tone sandhi classification results for disyllabic real, pseudo, and novel words in /T1-X/ (i.e., /53-53/, /53-323/, and /53-34/) base tone combinations in Wuxi Wu.

The f0 and the classification results together indicate that the two aspects of Wuxi tone sandhi have different productivity properties: similar to Taiwanese Southern Min, tonal substitutions in a chain shift lack full productivity and often categorically fail to apply to novel words; and similar to Shanghai, transparent spreading, either from the base tone or from the substituted tone, is generally productive, but may apply incompletely in a phonetically gradient fashion. The behavior of the pseudo words provides evidence that the circular chain shift sandhi pattern results from both the listing of the tonal patterns for the disyllabic words and the allomorph listing of tones for existing syllables and/or morphemes.

3.1.3. Interim Summary

The Shanghai vs. Wuxi Wu comparison in left-dominant tone sandhi makes the same point as the Mandarin/Hakka vs. Taiwanese comparison in right-dominant tone sandhi: circular chain shift undermines the productivity of the pattern and its analysis should rely on morphological/lexical mechanisms such as allomorph and lexical listing; transparent patterns, on the other hand, are generally productive and should be derived from phonological mechanisms such as the ranking of faithfulness and markedness constraints.

An alternative explanation for the productivity difference between Shanghai and Wuxi tone sandhi is that the propensities for tone spreading in Shanghai and pattern substitution in Wuxi are different. Variability patterns discussed in the descriptive literature indicate that this explanation is unlikely to be viable, as the tone spreading pattern in Shanghai in fact has more restrictions in the morphosyntactic combinations it applies to and hence applies with less regularity than pattern substitution in Wuxi. Moreover, the different behavior of the two aspects of Wuxi sandhi cannot be accounted for by frequency as both aspects are simultaneously involved in the sandhi process in Wuxi words.

In the next subsection, a more detailed look at the variation patterns of the two types of tone sandhi in Shanghai and Wuxi Wu is provided and it is shown that the variation patterns furnish further converging evidence for the lexicality of opaque tonal substitution in a chain shift.

3.2. Variation Patterns in Shanghai and Wuxi Tone Sandhi

The descriptive literature reports a fair amount of variation in tone sandhi in both Shanghai Wu (Xu et al., 1981, Xu and Tang 1988) and Wuxi Wu (Xu 2007) in phrasal contexts such as V-N combinations. The Shanghai examples in (6) illustrate the relation between semantic compositionality and tone sandhi application in V-N combinations: semantically opaque forms such as idiomatic expressions favor tone sandhi application, while semantically transparent forms favor the no-sandhi form. The Wuxi examples in (7) illustrate a similar pattern. M-N combinations, however, were reported to undergo tone sandhi consistently in both dialects.

(6) Examples of tone sandhi variation in Shanghai Wu (Xu et al. 1981: p. 148):

Examples	Tone sandhi	No sandhi	Gloss
拔河 /bɑʔ12-u13/ *to pull-river*	[bɑʔ11-u13]		'tug of war'
拔草 /bɑʔ12-tsʰɔ34/ *to pull-grass*	[bɑʔ11-tsʰɔ13]	[bɑʔ12-tsʰɔ34]	'to weed'
拔树 /bɑʔ12-zɨ13/ *to pull-tree*		[bɑʔ12-zɨ13]	'to pull out a tree'

(7) Examples of tone sandhi variation in Wuxi Wu (Xu 2007: p. 68):

Examples	Tone sandhi	No sandhi	Gloss
倒霉 /tɐ323-mɛ13/ *to pour-mold*	[tɐ44-mɛ55]		'to have bad luck'
倒酒 /tɐ323-tɕiɐɤ323/ *to pour-wine*	[tɐ44-tɕiɐɤ55]	[tɐ323-tɕiɐɤ323]	'to pour wine'

These patterns indicate that, for both Shanghai and Wuxi, the more word-like a disyllable is, the more likely it will undergo tone sandhi (for the wordhood of M-Ns and phrasehood of V-Ns in Chinese, see Duanmu 2007 and Xu 2018). But given the opacity difference between the two sandhi patterns and their productivity difference shown by the wug test results, a hypothesis worthy of investigation is whether Wuxi V-Ns show more lexicalized properties than Shanghai. In the context of tone sandhi variation, this translates into two questions: (a) Do V-Ns have a greater tendency to undergo tone sandhi in Wuxi than Shanghai? (b) Does frequency have the same effect on tone sandhi application in Wuxi and Shanghai?

The hypothesis for (a) is that, since tonal substitution in the chain shift needs to be listed (either lexically or allomorphically) in Wuxi, even for V-Ns, V-Ns in Wuxi should be more word-like than Shanghai and hence undergo tone sandhi more readily. The hypothesis for (b) is more complex. Bybee (2001) argues that there are two types of frequency effects on the application of phonological processes. The first type is that word-level reduction processes are more likely to apply to higher-frequency items. For instance, post-tonic schwa deletion in English is more likely to apply to higher-frequency items like *mem[ə]ry* than lower-frequency items like *mamm[ə]ry* (Zwicky 1972). The second type is that paradigmatic leveling effects based on other related forms are more likely to occur in lower-frequency items. For instance, irregular past tense in English is more likely to be regularized in lower-frequency items like *weep/wept/weeped* than higher-frequency items like *keep/kept/*keeped* (Hooper 1976). Bybee (2001) also showed that, in French, in phrasal contexts in which liaison is optional, liaison consonants are less likely to appear in lower-frequency combinations (Tranel 1981, Morin and Kaye 1982). She argued that this is because the form without the liaison consonant is the regular form due to its wider distribution; lower-frequency forms are hence more likely to regularize towards this form in paradigmatic leveling. Based on these effects, the hypothesis is that for M-Ns, given that they are words in both Shanghai and Wuxi, we should expect higher-frequency ones to undergo tone sandhi more readily in both dialects (if tone sandhi variation is found); for V-N phrases, however, we would only expect a positive correlation between frequency and sandhi application in Wuxi due to V-Ns' lexicality in the dialect, but for Shanghai, we expect the frequency correlation with sandhi application to be the opposite, i.e., *lower*-frequency items should be more likely to undergo tone sandhi, as the sandhi form, due to its applicability in all grammatical combinations, is the "regular" form, and paradigmatic leveling should level towards this form.

Due to the lack of corpus data in Shanghai and Wuxi, Yan (2016) conducted a set of rating experiments in both Shanghai and Wuxi Wu to test these hypotheses, including a goodness rating experiment for the two variant forms (one with tone sandhi, one without) of 180 M-Ns and 180 V-Ns as well as a semantic transparency and a subject frequency rating experiment for these items. Seventy native Shanghai speakers (35F, 18-26 years old) and seventy-one native Wuxi speakers (36F, 21-35 years old) participated in the experiments in Shanghai and Wuxi, respectively. See Yan (2016) and Yan and Zhang (2016b) for additional details on the experimental design.

Multiple linear regressions were conducted to investigate how each experimental item's sandhi preference, defined as the average difference between the rating of the sandhi form and the rating of the no-sandhi form for all participants, is affected by morphosyntactic structure (M-N vs. V-N), semantic transparency, and lexical frequency. For both Shanghai and Wuxi, the best model is the full model with all interactions. For Shanghai, there is a highly significant morphosyntactic structure effect, with the M-N items preferring the sandhi form more than the V-N items (t=-33.480, p<0.001); there are also significant interactions between structure and semantic transparency (t=-3.181, p<0.01) as well as between structure and frequency (t=-4.241, p<0.001). For Wuxi, there is a highly significant morphosyntactic structure effect in the same direction as Shanghai (t=-12.744, p<0.001); there is a significant interaction between structure and semantic transparency (t=-3.569, p<0.001), but not between structure and frequency (t=-1.174, p>.05).

The relation between sandhi preference and semantic transparency for Shanghai and Wuxi is given in Figure 10. The morphosyntactic structure effect in both dialects can be clearly seen in the graphs. Moreover, a comparison between the two graphs indicates that the effect is stronger in Shanghai. In other words, V-Ns behaved more similarly to M-Ns in Wuxi than in Shanghai, supporting our hypothesis that V-Ns in Wuxi have more lexical properties and prefer to undergo tone sandhi more than in Shanghai.

Further regression analyses indicate that, for both Shanghai and Wuxi, semantic transparency does not have a significant effect on sandhi preference for M-N, but has a significant negative effect on sandhi preference for V-N (the more semantically transparency a form is, the less preferred the sandhi form is).

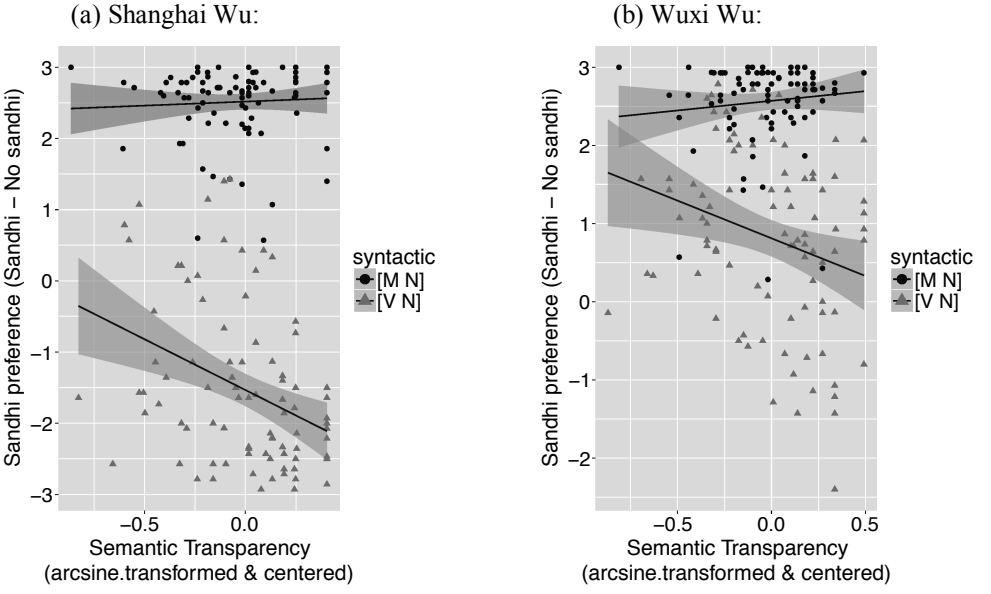

Figure 10. The relation between tone sandhi preference and semantic transparency in (a) Shanghai Wu and (b) Wuxi Wu.

The relation between sandhi preference and frequency for Shanghai and Wuxi is given in Figure 11. For M-N, frequency has a positive effect on sandhi preference for both dialects, but for V-N, frequency only has a positive effect on sandhi preference in Wuxi, but a negative effect in Shanghai. This again supports our hypothesis that V-Ns are word-like in Wuxi, but phrase-like in Shanghai. Therefore, frequency has a word-level reduction type effect on tone sandhi in Wuxi, but a phrase-level paradigmatic leveling type effect in Shanghai.

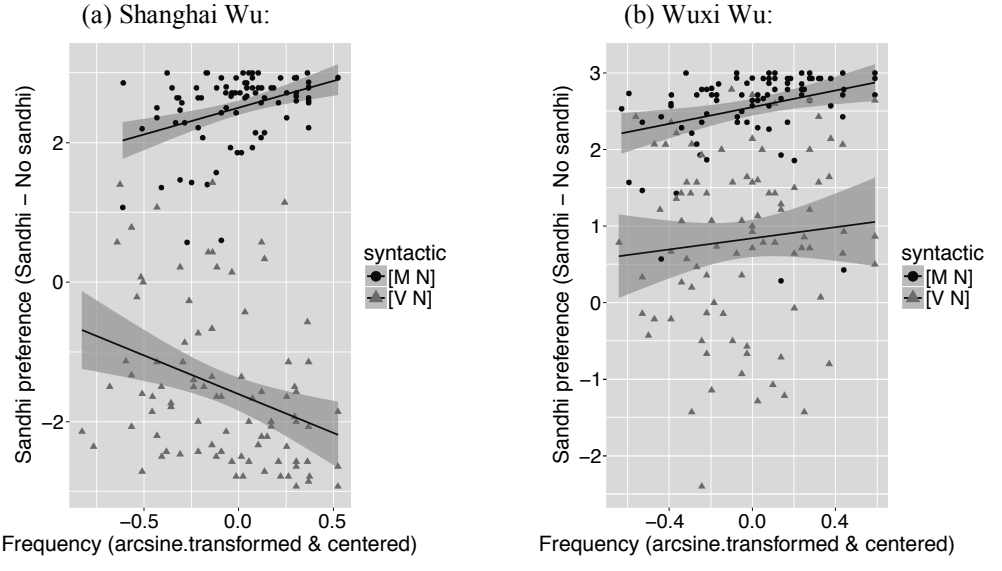

Figure 11. The relation between tone sandhi preference and frequency in (a) Shanghai Wu and (b) Wuxi Wu.

For more detailed statistical results, readers should consult Yan (2016) and Yan and Zhang (2016b). But I hope that the general result is clear: both the greater preference for sandhi application in V-N in Wuxi and the different frequency effects on sandhi application in V-N between Wuxi and Shanghai indicate that Wuxi tone sandhi forms have more lexical properties. This provides further converging evidence for the lexical/allomorph listing analysis for the circular chain shift tone sandhi pattern.

3.3. The Diachrony of Shanghai and Wuxi Tone Sandhi

As two closely related Wu dialects, a comparison between Shanghai and Wuxi in their tonal inventories, given in (8), indicates that the Wuxi system is diachronically more conservative, as it has preserved more of the historical tonal distinctions from Middle Chinese.[3]

(8) Shanghai and Wuxi Wu tonal inventory comparison: *Ping, Shang, Qu, Ru* refer to the four historical tonal categories in Middle Chinese (*Ru* tones occur on syllables closed by a stop coda); *Yin* and *Yang* refer to syllables with voiceless and voiced initials, respectively.

Shanghai

	Yin	*Yang*
Ping	51	13
Shang	34	
Qu		
Ru	5	12

Wuxi

	Yin	*Yang*
Ping	53	113
Shang	323	13
Qu	34	113
Ru	5	13

According to Ballard (1988) and Chan and Ren (1989), the substitution + spreading pattern in Wuxi tone sandhi is the combined result of tone sandhi patterns from two diachronic stages. At an earlier stage, the edge of phonological prominence was the right edge, and the tone sandhi pattern was a typologically common right-dominant pattern where the nonfinal syllables undergo paradigmatic tonal substitution. At a later stage, the prominent edge shifted to the left; the substituted tone then spread to the right, as is typical for a left-dominant tone sandhi pattern. Present-day Wuxi is also reported to have a spreading pattern of tone sandhi. But the spreading pattern only applies to a limited number of structures such as reduplicated verbs, resultative verbs, and number + classifiers (Chan and Ren 1989). Comparing Wuxi and Shanghai, then, it is more accurate to state that their difference lies not in whether tone sandhi is pattern substitution or spreading categorically, but in that Shanghai has simply expanded the contexts of the spreading tone sandhi to all phonological words.

Supporting evidence for the diachronic relation between the Wuxi and Shanghai patterns can be found in a closer examination of the tone sandhi pattern in the older descriptive literature of Shanghai (e.g., Xu et al., 1981), which showed that the spreading pattern in fact has substitutive exceptions. For instance, some /34-X/ words exhibit a [55-31] sandhi form instead of the expected [33-44]. Given that Shanghai /34/ is cognate with Wuxi /323/ and /34/, these substituted exceptions are clearly remnants of the cognate patterns in Wuxi, which has a 34-X → 55-31 sandhi. Interestingly, these descriptions of Shanghai commented that these exceptional patterns in Shanghai were becomingly rare at that time, and our experience working with younger speakers of Shanghai in recent years has indicated that these patterns have become close to non-existent.

These observations in Wuxi and Shanghai all point to a direction of diachronic change: there is a tendency for the opaque substitution pattern to be lost. Clearly, the claim is not that Wuxi will necessarily lose its substitution pattern of tone sandhi eventually, nor that all circular chain shift patterns will be lost. But there does seem to be evidence that the majority-spreading pattern in Shanghai originated from a majority-substitution pattern like in Wuxi, and that the remaining substitution patterns in Shanghai are unstable. These are consistent with our experimental results that tone spreading is more productive than tone substitution and that tone substitution has more lexical/morphological properties. In the bigger picture, this diachronic scenario is also consistent with Kiparsky's (1971) original contention that opacity poses difficulties for the learner, and diachronic change tends to remove it. More recently, Hansson (1999) showed that some instances of underapplication opacity in vowel harmony have been

3 But see Zhang (2014) for the ongoing merger of *Yang* tones in certain populations of Wuxi speakers.

lost in Yowlumne, and Gress-Wright (2010) argued that Early Modern German lost final devoicing for a time when it underapplied due to a vowel apocope process.

4. A Sketch of the Tone Sandhi Analysis for Modifier-Nouns in Wuxi Wu

A complete grammatical model of Wuxi tone sandhi needs to include the interaction between morphosyntax and tonal phonology, the gradient effects of frequency and semantic transparency on tone sandhi application, as well as the tone sandhi patterns for syllables with a voiced onset and for checked syllables. This section only attempts the modest goal of sketching out an analysis for the tone sandhi patterns in modifier-nouns in Wuxi Wu, with the simplifying assumption that tone sandhi applies consistently in these items. But even this simplified grammar needs to account for the following generalizations: (a) in existing M-Ns, the pattern substitution sandhi applies consistently; (b) in novel words, the spreading aspect of the tone sandhi is generally productive, but the substitution aspect of the tone sandhi is considerably less so; (c) tonal substitution has a higher productivity in pseudo words, in which the modifier is an existing modifier in Wuxi. As a descriptively adequate model, the grammar should also be learnable from exposure from existing M-Ns in Wuxi (Yan and Zhang 2016a).

Based on the wug test and rating experiment results above, Yan and Zhang's (2016a) analysis posits that tonal substitution and rightward spreading are accounted for in the grammar differently: substitution is due to lexical/allomorph listing, while spreading is due to markedness and faithfulness interaction.

The observed productivity gradation from real words to pseudo words to novel words in tonal substitution indicates that the grammar requires three levels of listedness with the substituted tone: lexical listing for disyllabic words, allomorph listing from existing syllables, and allomorph listing for tones independent of segmental content. Yan and Zhang (2016a) then assumed that there are USELISTED constraints that force listed forms to be used, modeled after Zuraw (2000). In the MaxEnt model (Goldwater and Johnson 2003, Jäger 2007) in which the grammar and its learning were implemented, however, learning biases were set against promoting the weights of USELISTED constraints for syllable and tonal allomorphs in the form of smaller σ^2s for the Gaussian priors of the default weights of these constraints (Chen and Rosenfeld 2000). Following Zhang (2007), Yan and Zhang (2016a) posited that the markedness constraint that forces tone spreading is a constraint against pronounced contour tones in nonfinal position, and the relevant faithfulness constraints are MAX(TONE) and FAITH-ALIGN-RIGHT (Zhang 2007), which penalizes rightward tone spreading. Yan and Zhang (2016a) fed a MaxEnt learner (Hayes et al. 2009) 189,000,000 words, divided among T1+X, T3+X, and T5+X according to a frequency approximation of T1, T3, and T5 in Wuxi. The grammar learned from this input was then used to make predictions about the behavior of real, pseudo, and novel words. The prediction of the grammar for T1+X is given in Figure 12, which shows that the grammar is able to capture the three generalizations that we set out to capture at the beginning of this section.

For more details of the analysis of Wuxi tone sandhi, see Yan and Zhang (2016a).

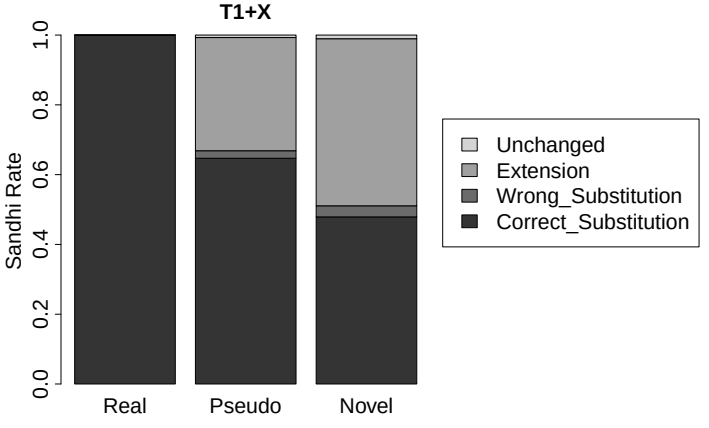

Figure 12. Grammar prediction of the tone sandhi behavior for disyllabic real, pseudo, and novel words in /T1-X/ (i.e., /53-53/, /53-323/, and /53-34/) base tone combinations in Wuxi Wu.

5. Conclusion

Opacity, *prima facie*, poses analytical problems for surface-oriented theories of phonology such as Optimality Theory. The studies on tone sandhi discussed in this paper, however, show that it is worthwhile to understand where the problem truly lies by investigating how speakers internalize opaque patterns via experimental means, especially when opaque patterns can be compared with transparent patterns. The results here indicate that at least a subset of opaque alternation patterns (e.g., those involved in a circular chain shift) calls for an analysis that is morphological/lexical in nature. The difficulty of the synchronic analysis of such patterns, then, shifts from deriving the patterns in general phonological terms to making sure that the analysis is able to reconcile the experimental results with the lexical patterns in the language itself as well as to capture the gradience observed in the experimental data. These experimental studies, therefore, provide not only an empirical basis for formal advances of the theory to test their predictions against, but also a guide for the direction of these advances.

For tone sandhi per se, these complex, often phonetically arbitrary patterns are the results of stages of diachronic change, much of which we are still yet to understand. While we have only focused on one type of tone sandhi pattern — circular chain shift opacity — that can pose potential learning challenges for learners, tone sandhi provides many other opportunities for the study of the limits and biases of phonological learning due to structural complexity, phonetic arbitrariness, variability, and exceptionality. Together with the facts that tone languages, particularly those considered dialectal forms of major languages, are generally understudied, and that tone patterns change relatively quickly diachronically (the existing descriptions of the various stages of Shanghai Wu is a case in point; e.g., see Zhu 2006), I hope that this provides additional incentives for the experimental study of tone languages and the tonal alternation patterns observed in these languages.

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