

# No More Conflicting Directionality: Metrical Conditions on Tianjin Chinese Trisyllabic Tone Sandhi

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## 1 Introduction

Tianjin Chinese (hereafter Tianjin) exhibits complex interactions among its disyllabic tone sandhi rules, leading to both left-to-right and right-to-left rule applications in trisyllabic sequences (e.g. Chen 1986, X. Wang 2003, Lin 2008). Which directionality to adopt for each particular sequence is arbitrary and cannot be accounted for by any known principles. In addition, some disyllabic tone sandhi rules do not always apply in trisyllabic sequences. The present study addresses these two issues of inconsistency in Tianjin trisyllabic tone sandhi: conflicting directionality in rule application, and rule underapplication.

Tianjin has four lexical tones: T1(21), T2(45), T3(213/214) and T4(54) (Li & Liu 1985). The transcriptions are given in “Chao numbers”. A speaker’s tonal range from low to high is represented by a numerical scale from “1” to “5” (Chao, 1968). Six disyllabic tone sandhi rules have been reported, as shown in (1) and (2).

(1) The four traditional disyllabic tone sandhi rules (Li & Liu 1985)

	Tone Sandhi Rules	Examples	Glosses
a. T1+T1	T1+T1 → <b>T3</b> +T1	fei ji (21.21) → fei ji (213.21)	‘airplane’
b. T3+T3	T3+T3 → <b>T2</b> +T3	mai ma (213.213) → mai ma (45.213)	‘buy horse’
c. T4+T1	T4+T1 → <b>T2</b> +T1	jiao shi (54.21) → jiao shi (45.21)	‘teacher’
d. T4+T4	T4+T4 → <b>T1</b> +T4	jiao shou (54.54) → jiao shou (21.54)	‘professor’

(2) The two newly reported tone sandhi rules (Wee 2004, Zhang & Liu 2011)

	Tone Sandhi Rules	Examples	Glosses
a. T3+T2	T3+T2 → <b>T1</b> +T2	fen hong (213.45) → fen hong (21.45)	‘pink’
b. T3+T4	T3+T4 → <b>T1</b> +T4	kuan dai (213.54) → kuan dai (21.54)	‘entertain’

Tianjin trisyllabic tone sandhi traditionally refers to seven sequences potentially involving two applications of the traditional disyllabic sandhi rules in (1). With two new disyllabic tone sandhi reported in Wee (2004) as in (2), there should be eight more trisyllabic sequences with potentially two applications of disyllabic tone sandhi, but no acoustic experiments and phonological analysis have been conducted on these new trisyllabic sequences.

This study starts with a multi-speaker acoustic study for the purposes of checking, confirming or modifying, if necessary, the disyllabic and trisyllabic tone sandhi patterns based on young Tianjin Chinese speakers’ speech. Since there have been reports on variation and change in Tianjin tone sandhi (Shi & P. Wang 2004, Zhang & Liu 2011), to document the current state of the tone sandhi patterns from a homogeneous group of speakers is crucial to setting the foundation for a phonological explanation. Our acoustic analysis includes all 15 trisyllabic patterns based on all the six disyllabic tone sandhi patterns ever reported.

For the phonological analysis, the first issue to resolve is conflicting directionality in rule application.

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\* For helpful comments and suggestions through various stages of this study, we thank Karthik Durvasula, the Michigan State University Phonology-Phonetics Research Group, and participants at MidPhon 21 and AMP 2016.

To derive the attested outputs, in some trisyllabic sequences, the disyllabic sandhi rules have to apply from left to right, but in some other sequences, the rules have to apply from right to left, as shown in (3), where UR = underlying representation and SR = surface representation.

- |     |    |  |    |  |
|-----|----|--|----|--|
| (3) | a. | Some patterns are derived left to right              | b. | Some patterns are derived right to left              |
|     |    | $T3+T3+T3 \rightarrow T2+T2+T3$                      |    | $T1+T1+T1 \rightarrow T1+T2+T1$                      |
|     |    | Left to Right $\rightarrow$ <i>Attested output</i>   |    | Right to Left $\rightarrow$ <i>Attested output</i>   |
|     |    | UR $T3+T3+T3$  |    | UR $T1+T1+T1$  |
|     |    | T3+T3 rule $\underline{T2+T3+T3}$                    |    | T1+T1 rule $T1+\underline{T2+T1}$                    |
|     |    | T3+T3 rule $\underline{T2+T2+T3}$                    |    | T1+T1 rule -----                                     |
|     |    | SR $T2+T2+T3$  |    | SR $T1+T2+T1$  |
|     |    | Right to Left $\rightarrow$ <i>Unattested output</i> |    | Left to Right $\rightarrow$ <i>Unattested output</i> |
|     |    | UR $T3+T3+T3$  |    | UR $T1+T1+T1$  |
|     |    | T3+T3 rule $T3+\underline{T2+T3}$                    |    | T1+T1 rule $\underline{T2+T1+T1}$                    |
|     |    | T3+T3 rule -----                                     |    | T1+T1 rule $T2+\underline{T2+T1}$                    |
|     |    | SR $*T3+T2+T3$                                       |    | SR $*T2+T2+T1$                                       |

The second issue to resolve is rule underapplication. Some disyllabic tone sandhi rules do not apply in some trisyllabic sequences even when their sandhi conditions are satisfied. For example, the attested output of  $T4+T4+T4$  is  $T4+T1+T4$ . From neither direction can this attested output be derived. If the directionality of rule application goes from left to right, the output would be  $*T1+T1+T4$ . If the directionality goes from right to left, the output would be  $*T2+T1+T4$ . To derive the attested output, either from left to right or right to left, one of the relevant disyllabic rules must not apply even when its sandhi condition is satisfied, as the example in (4) illustrates.

- |     |                                |                                |                                       |
|-----|--------------------------------|--------------------------------|---------------------------------------|
| (4) | Underapplication in $T4+T4+T4$ |                                |                                       |
|     | a.                             | Left to right rule application |                                       |
|     |                                | UR                             | $T4+T4+T4$                            |
|     |                                | T4+T4 rule                     | $\underline{T4+T4+T4}$ no application |
|     |                                | T4+T4 rule                     | $T4+\underline{T1+T4}$ application    |
|     |                                | SR                             | $T4+T1+T4$                            |
|     | b.                             | Right to left rule application |                                       |
|     |                                | UR                             | $T4+T4+T4$                            |
|     |                                | T4+T4 rule                     | $T4+\underline{T1+T4}$ application    |
|     |                                | T4+T1 rule                     | $\underline{T4+T1+T4}$ no application |
|     |                                | SR                             | $T4+T1+T4$                            |

We propose an analysis of Tianjian trisyllabic tone sandhi in which metrical structure and disyllabic sandhi rules interact, and demonstrate that Tianjin tone sandhi rules apply consistently from left to right when both metrical and tonal complexity conditions are satisfied, thereby removing the need for conflicting directionality.

In what follows, we report the acoustic study and its results in §2, and present our phonological analysis in §3. The final section concludes the paper.

## 2 Acoustic study

The acoustic study examines not only trisyllabic tone sandhi, but also lexical tones and disyllabic tone sandhi. Lexical tones were studied first because the changes in lexical tones would affect disyllabic and trisyllabic tone sandhi, and disyllabic tone sandhi provides the baseline for trisyllabic tone sandhi.

The experiments were divided into three parts: lexical tones in monosyllabic words, disyllabic sequences and trisyllabic sequences. The data from the four traditional disyllabic tone sandhi rules and the two newly reported ones were all collected and analyzed. Since the main purpose this study is to investigate how disyllabic tone sandhi interacts in trisyllabic sequences, we only analyzed the trisyllabic sequences that involve potentially two applications of disyllabic tone sandhi. The experiments on trisyllabic sequences

contain three parts. The first part was done to confirm the seven traditional trisyllabic sequences (T1+T1+T1, T1+T4+T4, T3+T1+T1, T3+T3+T3, T4+T1+T1, T4+T4+T1, T4+T4+T4). The second part investigated eight trisyllabic patterns, which also potentially involve two applications of disyllabic tone sandhi on the condition that the newly reported rules (2a) and (2b) exist. The third part examined the X+T4+T1, T4+T1+X and T4+T1+N patterns (X = any tone, N = metrically weak neutral tone), with the purpose of testing the potential influence on tone sandhi application from metrical structure.

If the two newly reported tone sandhi patterns in (2a) and (2b) exist, more trisyllabic sequences would involve potentially two applications of disyllabic tone sandhi. For example, a sequence like T3+T4+T4 potentially contain two applications of disyllabic tone sandhi patterns because it satisfies the sandhi conditions of the T3+T4 rule and the T4+T4 rule, as shown in (5). This pattern has not been studied before, so either output through left-to-right or right-to-left application potentially exists.

- (5) The potential derivations of T3+T4+T4
- |                       |                   |
|-----------------------|-------------------|
| a. From left to right |                   |
| UR                    | T3+T4+T4          |
| T3+T4 rule            | <u>T1</u> +T4+T4  |
| T4+T4 rule            | T1+ <u>T1</u> +T4 |
| SR                    | T1+T1+T4          |
| b. From right to left |                   |
| UR                    | T3+T4+T4          |
| T4+T4 rule            | T3+ <u>T1</u> +T4 |
| T3+T4 rule            | -----             |
| SR                    | T3+T1+T4          |

Regarding the third part, X. Wang (2003) found that the T4+T1 rule applies in any X+T4+T1 sequences, but not in T4+T1+X ones. This point is also reported in Li & Chen (2016). We also investigated the T4+T1+N sandhi pattern since we had hypothesized that the inconsistent applications of the T4+T1 rule in different positions could be related to metrical structure. The metrical structure of a trisyllabic sequence should change when the last syllable is a metrically weak neutral tone. If the behaviors of T4 differ in T4+T1+X and T4+T1+N, we have good reasons to attribute the difference to metrical structures.

**2.1 Tokens** The wordlist contains three parts: (i) forty monosyllabic words, ten for each of the four lexical tones; (ii) 60 disyllabic sequences, ten for each of the six disyllabic tone sandhi patterns; (iii) 144 trisyllabic sequences, 8 for each of the 15 trisyllabic combinations potentially containing two applications of disyllabic tone sandhi, and 4 for each of the X+T4+T1, T4+T1+X and T4+T1+N patterns. All test words were common words based on frequency counts in the Modern Chinese Frequency Dictionary (1986).

Although previous studies on Tianjin tone sandhi have not shown morpho-syntactic influences on tone sandhi patterns, morpho-syntactic effects were still taken into consideration when test words were selected. All test patterns have different parts of speech, and trisyllabic sequences have both left-branching and right-branching structures.

**2.2 Participants** A total of 16 native Tianjin speakers (M=8, F=8) took part in the experiment. All participants were born and brought up in the six inner-city districts of Tianjin, have been living in Tianjin, and speak both Tianjin and Standard Chinese in their daily lives. They were undergraduates of Tianjin Normal University, and their average age at the time of recording was 21.2.

**2.3 Experimental procedure** All test words were written on cards and the speakers read the words out at random order. All the spoken tokens were recorded in Praat (Boersma & Weenink 2013) in a quiet room in Tianjin. After an interview lasting about 60 minutes per participant, all participants had a ten minute break. The recording of the wordlist started after the break. The recording took place in three sections: first the monosyllabic words, then the disyllabic ones and finally the trisyllabic ones. The participants had a five-minute break between each section. Only one token was written on each card, and each token was read one time by each participant. For each speaker, the order of the cards in each section was randomized by hand.

**2.4 Data analysis** All acoustic analyses were conducted in Praat (Boerma and Weenink, 2013), and the acoustic data were manually annotated. The F0 at every 10% of the rhyme duration was extracted, giving eleven F0 measurements for each syllable. A disyllabic or trisyllabic token was not used if the second or the third syllable was judged by us as a neutral tone (J. Wang 2002, Lu & J. Wang 2012), because in such words, the first syllable in disyllabic sequences and the second syllable in trisyllabic sequences do not undergo tone sandhi (J. Wang 2002). For each participant, all the valid tokens for each test tone pattern were averaged, and therefore each participant contributed only one set of F0 values for analyses. For each tone, the raw F0 of any of the eleven points was normalized, using the formula in (6) (Shi, 1986).  $\text{Log}_x$  is the testing point.  $\text{Log}_{\max}$  is the highest value of the average value of all points and  $\text{log}_{\min}$  is the lowest value of the average value of all points. The normalized results were recorded on a 0-5 numerical scale, with 0-1, 1-2, 2-3, 3-4, and 4-5 corresponding to 1-5 in Chao numbers respectively.

(6) Normalization Formula:  $F0_{\text{normalized}} = \{[\text{Log}_x - \text{Log}_{\min}] / [\text{Log}_{\max} - \text{Log}_{\min}]\} \times 5$

**2.5 Results of lexical tones and disyllabic sequences** The results of Tianjin lexical tones are given in Table 1. The tonal inventory contains two falling tones, a dip-rising tone and a rising tones. T1 is a falling tone in the lower register and T4 is a falling tone in the higher register. T3 is a dip-rising tone in the lower register and T2 is a rising tone in the higher register. Our results differ from the traditional description in that T1 now has a pitch value of 41 instead of 21 (cf. §1 and (1)). The same change has also been reported by Zhang & Liu (2011).

Table 1 Results of Tianjin lexical tones

Tone number	T1	T2	T3	T4
Chao number (pitch value)	41	45	214	53

The results of disyllabic tone sandhi are given in (7) and (8). The T1+T1, T3+T3 and T4+T1 rules in (7a-c) apply consistently in all tokens for all speakers. The output of T1+T1 is T2+T1, instead of T3+T1 in traditional descriptions, which is in agreement with Zhang & Liu (2011). The T4+T4 rule has become obsolete, which is in agreement with Gao and Lu (2003), Shi & Wang (2004), Zhang & Liu (2011), but X. Wang (2015) has found that the T4+T4 → T1+T4 sandhi pattern in (1d) still exists among old speakers.

(7) The results of the four traditional disyllabic tone sandhi

	Tone Sandhi Rules	Examples	Glosses
a. T1+T1	T1+T1 → <b>T2</b> +T1	fei ji (41.41) → fei ji (45.41)	‘airplane’
b. T3+T3	T3+T3 → <b>T2</b> +T3	mai ma (214.214) → mai ma (45.214)	‘buy horse’
c. T4+T1	T4+T1 → <b>T2</b> +T1	jiao shi (54.41) → jiao shi (45.41)	‘teacher’
d. T4+T4	T4+T4 → T4+T4	jiao shou (54.54) → jiao shou (54.54)	‘professor’

(8) The results of the two newly reported disyllabic tone sandhi

	Tone Sandhi Rules	Examples	Glosses
a. T3+T2	T3+T2 → <b>21</b> +T2	fen hong (213.45) → fen hong (21.45)	‘pink’
b. T3+T4	T3+T4 → <b>21</b> +T4	kuan dai (213.54) → kuan dai (21.54)	‘entertain’

The normalized results of the first tones in the outputs of both T3+T2 and T3+T4 in (8) are 21, rather than a categorical lexical tone in Table 1. Although the overall value is different from the value of the lexical tone T3(214), this process can be considered a case of tonal reduction due to the insufficient duration on a non-final syllable (Zhang & Liu 2011), i.e., the duration is too short to realize the final rise of T3(214). Besides, the pitch graph of the sandhi tone in the T3+T2 and T3+T4 patterns is similar to that of the lexical T3 (214). The normalized result 21 can be interpreted as the first half of T3 (214).

**2.6 Results of the fifteen trisyllabic sequences** Table 2 shows the results of all tested trisyllabic sequences, and the directionality indicated in the table refers to the directionality of rule application that can derive the attested outputs.

Table 2 Results of 15 trisyllabic sequences

a. The seven traditional sequences			b. The eight new sequences		
Inputs	Outputs	Directionality	Inputs	Outputs	Directionality
T1+T4+T4	T1+ <b>T1</b> +T4	left→right	T1+T3+T2	T1+ <b>2I</b> +T2	left→right
T3+T1+T1	T3 <sup>1</sup> + <b>T2</b> +T1	left→right	T3+T3+T2	<b>T2</b> + <b>2I</b> +T2	left→right
T3+T3+T3	<b>T2</b> + <b>T2</b> +T3	left→right	T4+T3+T2	T4+ <b>2I</b> +T2	left→right
T1+T1+T1	T1+ <b>T2</b> +T1	right→left	T1+T3+T4	T1+ <b>2I</b> +T4	left→right
T4+T1+T1	T4+ <b>T2</b> +T1	right→left	T3+T3+T4	<b>T2</b> + <b>2I</b> +T4	left→right
T4+T4+T1	T4+ <b>T2</b> +T1	right→left	T3+T4+T1	<b>2I</b> + <b>T2</b> +T1	left→right
*T4+T4+T4	T4+ <b>T1</b> +T4	Neither	T3+T4+T4	<b>2I</b> + <b>T1</b> +T4	left→right
			T4+T3+T4	T4+ <b>2I</b> +T4	left→right

The seven traditional trisyllabic sequences show inconsistent directionality: three outputs can be derived through left-to-right rule application, three from right to left, and the last one can not be derived from either direction and can only be accounted for by rule underapplication, as shown in (4) earlier. Note that the underlined T1+T1, T4+T4 and T4+T1 in Table 2 undergo tone sandhi when they are right-aligned in a trisyllabic sequence but not when they are left-aligned. This generalization will become relevant to our phonological analysis.

In young speakers' speech, the T4+T4 rule does not apply in disyllabic words, but interestingly, it still applies in trisyllabic sequences. The asymmetry suggests that T4 can undergo tone sandhi when it is in a weak metrical position in a larger grammatical/prosodic domain<sup>2</sup>.

The eight new trisyllabic sequences do not show irregular directionality as all rule applications can go from left to right. The newly reported T3+T2 and T3+T4 rules can apply no matter whether they are left-aligned or right-aligned in a trisyllabic sequence, which is different from T1+T1 and T4+T4, as well as T4+T1.

**2.7 Results of X+T4+T1, T4+T1+X and T4+T1+N** We analyzed the X+T4+T1 pattern and the T4+T1+X pattern to investigate whether the T4+T1 rule does not apply in T4+T1+X but applies in X+T4+T1, as discussed in X. Wang (2003) and also reported later in Li & Chen (2016). In addition, the trisyllabic sequences ending in a neutral tone and a non-neutral tones have different stress patterns. Since we have hypothesized that the inconsistent rule application is sensitive to metrical structure, the different stress patterns in trisyllabic sequences ending in neutral tone and non-neutral tones are expected to produce different outputs. If the trisyllabic sequence ends in a full tone, the third syllable is the most prominent (see §3.1 below). If the trisyllabic sequence ends in a neutral tone, the third syllable is the weakest since the neutral tone is weaker than any of the four full lexical tones. The results indicate that the output of T4+T1+N is indeed different from the outputs of T4+T1+X. In T4+T1+N, the T4+T1 rule applies although it is left-aligned.

X+T4+T1 includes T1+T4+T1, T2+T4+T1, T3+T4+T1 and T4+T4+T1. The second syllables of the outputs of these four sequences are all changed to the rising tone T2(45), indicating the T4+T1 rule applies in these trisyllabic sequences when T4+T1 is right-aligned. The F0 Hertz results of T1+T4+T1 → T1+T2+T1 are given in Figure 1 as an example to illustrate the right-aligned X+T4+T1 pattern, where we see the high rising sandhi tone T2(45) in the middle rather than the original high falling T4(53). The F0 hertz results of T4+T1+T1 are given in Figure 2 as an example to represent the left-aligned T4+T1+X pattern, where we see that the first tone T4(53) does not undergo sandhi and stays as a high falling tone. In the T4+T1+N structure, however, the left-aligned T4+T1 rule applies. As shown in Figure 3, T4(53)

<sup>1</sup> Phonetically, this is a reduced T3 with the ending point much lower than fully realized T3 (214). It also shows much inter-speaker and intro-speaker variation.

<sup>2</sup> There is an on-going tone change in Tianjin. The application rates of the T4+T4 rule are very low among young Tianjin speakers, but are comparatively high among old Tianjin speakers, which indicates that the application of the T4+T4 rule is decreasing (X. Wang 2015). Although the T4+T4 sandhi pattern almost disappears among young speakers in their wordlist reading style, it still exists in the same speakers' less careful interview style (X. Wang 2015). This can explain why in our acoustic data, the T4+T4 rule does not apply in disyllabic sequences, but still applies in trisyllabic ones.

becomes a high rising tone T2(45) in T4+T1+N, which demonstrates that the left-aligned T4+T1 rule undergoes tone sandhi only when the last syllable is a neutral tone.

In sum, the results of our acoustic study indicate the crucial role metrical structure may play in accounting for Tianjin trisyllabic tone sandhi.

Figure 1 The output of  $T1+T4+T1 \rightarrow T1+T2+T1$

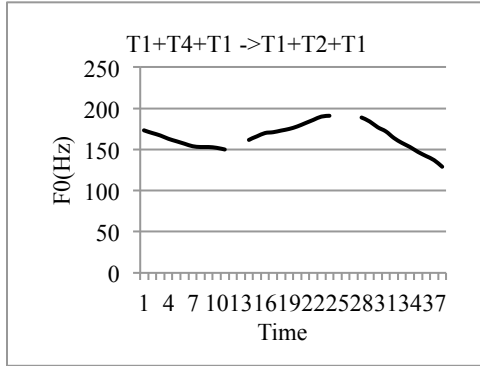


Figure 2 The output of  $T4+T1+T1 \rightarrow T4+T2+T1$

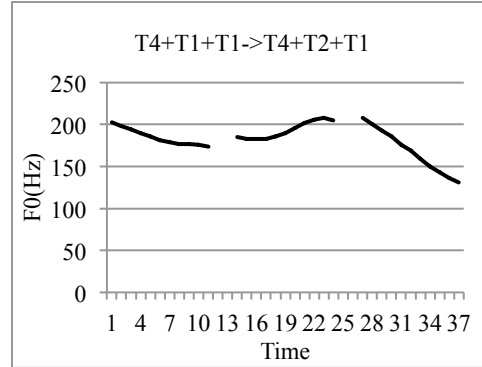
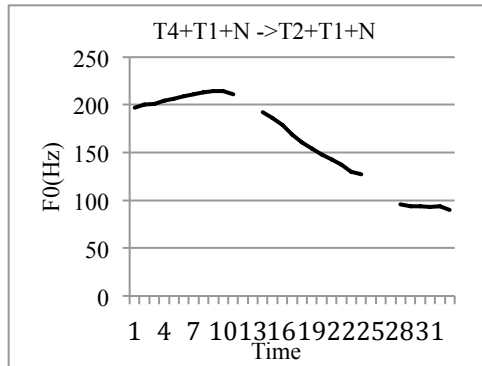


Figure 3 The output of  $T4+T1+N \rightarrow T2+T1+N$



### 3 Phonological analysis

The relation between metrical structure and tone sandhi has been discussed in many studies (Wright 1983, Duanmu 1995, Chan 1985, Wang & Lin 2016, among others). This is in agreement with the view that prosodic prominence and tonal complexity are correlated (Hyman 2007, Yip 2002:27-30). Contour tones occur more freely in stressed syllables than unstressed syllables, with no language display the opposite pattern (Zhang 2002).

In this section, we show that metrical structure and tonal complexity can account for the application inconsistency in T4+T1, T4+T4, and T1+T1, and the application consistency in T3+T2, T3+T3 and T3+T4 in Tianjin trisyllabic sequences, and claim that the inconsistent directionality and underapplication issues discussed in §1 can be resolved. The inconsistent application of the T4+T1, T4+T4 and T1+T1 rules when they are right-aligned and left-aligned can also be explained when metrical structures are considered. Our proposed analysis can be summarized as follows: (i) the directionality of rule application is consistently from left to right; (ii) a T1(41) or T4(53) occupying a foot head does not undergo tone sandhi; (iii) the most complex tone T3(213) does not undergo tone sandhi only when it occupies the prosodic head or primary stress. Since metrical structure is a key factor in resolving the two issues in Tianjin trisyllabic tone sandhi, Tianjin trisyllabic metrical structures will be introduced first in the next subsection, followed by additional subsections on different aspects of and evidence for our proposed analysis.

**3.1 Tianjin metrical structures** For a disyllabic sequence, the foot is right-headed as tone sandhi applies only to the first syllable within the disyllabic foot. Tianjin trisyllabic metrical structure (Huang, Yan & Lu 2005) has been claimed to be [secondary stress, weak, primary stress] when the last syllable is not a neutral tone, as given in (9), in which 1 stands for the primary stress, 2 stands for the secondary stress and 3 stands for the weakest syllable. Morpho-syntactic structures are irrelevant in this metrical pattern.

(9) Tianjin trisyllabic metrical pattern

$\sigma$	$\sigma$	$\sigma$
(x)	(x	x)
(x		x)
		x
tu	shu	guan (library)
2	3	1

However, trisyllabic sequences ending in a neutral tone have a different metrical structure since neutral tone is unstressed or extrametrical. The duration of a neutral tone is only about half of the duration of a full tone (J. Wang 2002, Lu & J. Wang 2012). The metrical structure of a trisyllabic sequence ending in a neutral tone is shown in (10).

(10) Tianjin trisyllabic metrical structure with a final neutral tone

$\sigma$	$\sigma$	$\sigma_N$
(x	x)	<x>
		x

**3.2 Directionality issue resolved** The seemingly irregular directionality does not exist if metrical structure is taken into consideration. Of all the fifteen trisyllabic sequences we have analyzed, only three are derived from right to left (T1+T1+T1, T4+T1+T1 and T4+T4+T1). One crucial generalization is that for these three sequences to derive the attested outputs, the tone of the first syllable cannot be changed even when its sandhi condition is satisfied. Traditional analyses with right-to-left application can block the application of the left-aligned sandhi rule, but results in conflicting directionality with the majority of other trisyllabic sequences. Our metrically-conditioned analysis maintains that the application directionality is consistently from left to right, and a T1 or T4 occupying a foot head does not undergo tone sandhi. The derivations of these three sequences are given in (11-13), where MS = metrical structure.

(11) T1+T1+T1  $\rightarrow$  T1+T2+T1 with left to right rule application

UR	T1+T1+T1	
MS	(x) (x	x)
	(x	x)
		x
L to R	<u>T1+T1</u> +T1	no application
	T1+ <b>T2</b> +T1	application
SR	T1+ <b>T2</b> +T1	

The first T1 in (11) does not change even when its sandhi context is satisfied because it is on secondary stress, i.e. on a foot head. The T1+T1 rule applies only when the first T1 is on a weak syllable, as in the right-aligned T1+T1. By the same token, in (12) and (13), T4 in the first syllable does not undergo tone sandhi even though its sandhi context is satisfied because it is on a foot head, not on a weak position. The right-aligned T1+T1 in (12) and T4+T1 in (13) undergo tone sandhi when the T1 in (12) and T4 in (13) occupy the weak position of the metrical structure, i.e. the middle syllable.

(12)  $T4+T1+T1 \rightarrow T4+T2+T1$  with left-to-right rule application

UR	T4+T1+T1	
MS	(x) (x x)	
	(x x)	
	x	
L to R	<u>T4+T1</u> +T1	no application
	T4+ <b>T2</b> +T1	application
SR	T4+ <b>T2</b> +T1	

(13)  $T4+T4+T1 \rightarrow T4+T2+T1$  with left-to-right rule application

UR	T4+T4+T1	
MS	(x) (x x)	
	(x x)	
	x	
L to R	<u>T4+T4</u> +T1	no application
	T4+ <b>T2</b> +T1	application
SR	T4+ <b>T2</b> +T1	

Since tone sandhi rules for all other trisyllabic sequences are applied from left to right, with these three sequences reanalyzed with left-to-right rule application, the conflicting directionality in Tianjin trisyllabic tone sandhi in the traditional analysis disappears when metrical structure is taken into consideration.

**3.3 Underapplication issue resolved** The attested output of  $T4+T4+T4$  is  $T4+T1+T4$ . To derive the attested output, either from left to right or from right to left, one of the relevant disyllabic sandhi rules must not apply, as shown in (14), repeated from (4).

(14) Underapplication in  $T4+T4+T4$

- a. Left to right rule application
 

UR	T4+T4+T4	
T4+T4 rule	<u>T4+T4</u> +T4	no application
T4+T4 rule	T4+ <b>T1</b> +T4	application
SR	T4+ <b>T1</b> +T4	
- b. Right to left rule application
 

UR	T4+T4+T4	
T4+T4 rule	T4+ <b>T1</b> +T4	application
T4+T1 rule	<u>T4+T1</u> +T4	no application
SR	T4+ <b>T1</b> +T4	

To derive the attested output, the  $T4+T1$  or  $T4+T4$  rule does not apply even though their tone sandhi conditions are satisfied. This underapplication issue can be resolved because  $T4$  or  $T1$  does not undergo tone sandhi when they are on a foot head (i.e. has a secondary stress). Our metrically-conditioned analysis is illustrated in (15), which follows the same analysis as in the previous subsection.

(15)  $T4+T4+T4 \rightarrow T4+T1+T4$  with left-to-right rule application

UR	T4+T4+T4	
MS	(x) (x x)	
	(x x)	
	x	
L to R	<u>T4+T4</u> +T4	no application
	T4+ <b>T1</b> +T4	application
SR	T4+ <b>T1</b> +T4	

When T4+T4 is left-aligned, the first T4 is on a stressed syllable/foot head, and hence cannot undergo tone sandhi. On the other hand, for the right-aligned T4+T4, the middle T4 in the trisyllabic sequence is on the weak syllable, and thus can undergo tone sandhi.

**3.4 Generalizations and further evidence for the metrical effects** X. Wang (2003) found that the T4+T1 rule does not apply when it is left-aligned, but duly applies when it is right-aligned. The present study expands this same generalization to both T1+T1 and T4+T4 rules; that is, the three T4+T1, T1+T1 and T4+T4 rules do not apply when they are left-aligned, but apply when they are right-aligned. The acoustic results of Li & Chen (2016) also show that T1+T1 and T4+T1 sandhi apply only when they are right-aligned, but they do not explain why. The left-aligned patterns are exactly those requiring right-to-left rule application and/or blocking rule application in the traditional analysis. The derivations in (16) show how metrical structure can account for this discrepancy, using T4+T1 as the example.

(16)	a. Left-aligned patterns	b. Right-aligned patterns
	UR    T4+T1+X	UR    X+T4+T1
	<u>T4+T1</u> +X	X+ <u>T2</u> +T1
	no rule application	rule application
	SR    T4+T1+X	SR    X+ <b>T2</b> +T1
	(x) (x x)	(x) (x x)
	(x    x)	(x    x)
	x	x

When T4+T1 is left-aligned in a trisyllabic sequence, T4 is on a stressed syllable/foot head, and therefore T4 does not undergo tone sandhi. When T4+T1 is right-aligned, T4 is on a weak syllable, and undergoes tone sandhi.

Further evidence for the metrical effects on Tianjin trisyllabic tone sandhi comes from trisyllabic sequences with a final neutral tone. In a T4+T1+N sequence where the metrical structure becomes [weak-strong-weak], left-aligned T4+T1 does undergo tone sandhi since T4 is in a weak position. The metrical structure of T4+T1+N is different from that of T4+T1+X as the neutral tone is unstressed or extrametrical. The metrical structure of trisyllabic sequences ending with a neutral tone was given in (10) earlier, and is restated here as (17) for ease of reference.

(17)	Tianjin trisyllabic metrical structure with a final neutral tone		
	σ	σ	σ <sub>N</sub>
	(x	x)	<x>
		x	

We take T4+T1+X and T4+T1+N as examples in (18) to show how differences in metrical structures affect the application of Tianjin tone sandhi. In both T4+T1+X and T4+T1+N patterns, T4+T1 is left-aligned. What is interesting is that T4 undergoes tone sandhi in T4+T1+N but remains unchanged in T4+T1+X. The application versus non-application follows our analysis in which T1 and T4 undergo tone sandhi only when they occupy a weak syllable. Since the metrical structure of T4+T1+N is different from that of T4+T1+X, in T4+T1+N, T4 is on a weak syllable, and undergoes tone sandhi.

(18)	a. <u>T4+T1</u> +N → <b>T2</b> +T1+N	b. <u>T4+T1</u> +X → <u>T4</u> +T1+X
	UR    T4+T1+N	UR    T4+T1+X
	<u><b>T2</b></u> +T1+N	<u>T4</u> +T1+X
	rule application	no rule application
	SR <b>T2</b> +T1+N	SR    T4+T1+X
	σ    σ    σ <sub>N</sub>	σ    σ    σ
	(x) (x) <x>	(x) (x) (x)
	x	(x    x)
		x

**3.5 Tonal Complexity** Our proposed analysis raises a question regarding the consistent application of T3+T3, T3+T2 and T3+T4. These three rules, all involving T3 in the sandhi position, always apply from left to right in a trisyllabic sequence no matter whether they are left-aligned or right-aligned. We propose that the different behavior of T3 from that of T1 and T4 can be attributed to the difference in tonal complexity.

According to Yip (2002: 27-30), the tonal complexity order is rising, falling, high and low, as shown in (19), where > = more complex than.

- (19) Order of tonal complexity (Yip 2002:27-30)  
Rising > Falling > High > low

Tianjin T3 in Chao number is 214, as opposed to simple falling tones T1 (41) and T4 (53). We suggest that as the most complex tone in Tianjin, T3 keeps its full tonal contour only when it occupies the prosodic head, i.e. the third syllable with the primary stress. Therefore, T3 in either the first or second syllable in a trisyllabic sequence consistently undergo tone sandhi in a left-to-right application. The derivations in (20) illustrate the differences in behavior between T3 and T4.

- |      |                                 |                                    |
|------|---------------------------------|------------------------------------|
| (20) | a. Left-aligned patterns        | b. Left-aligned patterns           |
|      | UR    T3+T3+T3                  | UR    T4+T1+X                      |
|      | <u>T2+T3</u> +T3    application | <u>T4+T1</u> +T1    no application |
|      | T2+ <u>T2+T3</u>                | T4+ <u>T2+T1</u>                   |
|      | SR <b>T2+T2</b> +T3             | SR    T4+ <b>T2</b> +X             |
|      | (x) (x) (x)                     | (x) (x) (x)                        |
|      | (x)    (x)                      | (x)    (x)                         |
|      | x                               | x                                  |

When T3+T3 is left-aligned, the first T3 is not the prosodic head. Since T3 is the most complex tone in Tianjin, it loses its underlying tone whenever it is not occupying a prosodic head. T4 is less complex than T3 and it can keep its underlying tone unless it is on a weak syllable. This difference in tonal complexity can account for why T3 always undergoes tone sandhi no matter whether it is left-aligned or right-aligned, but whether T4 and T1 undergo tone sandhi is sensitive to their metrical position in a trisyllabic sequence.

## 4 Conclusions

The results of our acoustic study show that (i) the pitch value of T1 has changed from 21 to 41 and T4+T4 disyllabic tone sandhi does not exist in young speakers' speech, (ii) the new set of trisyllabic sequences that were not studied before all display left-to-right rule application, (iii) only three sequences require right-to-left rule application in a traditional analysis, and (iv) the underapplication issue in T4+T4+T4 remains.

Our phonological analysis concludes that the seemingly irregular directionality in Tianjin trisyllabic tone sandhi application disappears if metrical structures and differences in tonal complexity are taken into consideration. We argue that in Tianjin trisyllabic sequences, tone sandhi applications consistently go from left to right. Metrical conditions and tonal complexity can account for the application discrepancies in directionality and rule underapplication. T1 and T4 do not lose their underlying tones unless they are on the unstressed syllable, and that is why the T1+T1, T4+T4 and T4+T1 do not undergo tone sandhi when they are left-aligned in a trisyllabic sequence. When they are right-aligned in a trisyllabic sequence, the first tones are on the weak syllable and hence undergo tone sandhi. This metrical account is further supported by a trisyllabic sequence with a final neutral tone, which renders the first syllable unstressed and leads to tone sandhi application at the left edge. The consistent applications of the T3+T3, T3+T2 and T3+T4 rules regardless of edge alignment in a trisyllabic sequence are attributed to tonal complexity. As the most complex tone in Tianjin, T3 routinely undergoes tone sandhi unless it occupies the prosodic head (i.e. the third syllable with the primary stress).

Tianjin trisyllabic tone sandhi has long been considered a difficult and complex system to analyze (Li & Liu 1985, Chen 1986, Chen 2000, Lin 2008, among others). Our study not only illuminates the true

nature of Tianjian tone sandhi patterns, but also provides a case study where metrical structure and tonal properties interact to influence tone sandhi rule applications beyond the typical disyllabic domain.

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