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Tone Sandhi and Tonal Coarticulation in Tianjin Chinese

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Abstract

We present in this article an acoustic study on tone sandhi and tonal coarticulation in Tianjin Chinese. Our results indicate that Tianjin tone sandhi is likely influenced by Standard Chinese and is undergoing a number of changes, causing variations and exceptions to the sandhi patterns, and the majority of the sandhis are non-neutralizing, contra traditional descriptions. Tonal coarticulation in Tianjin exhibits a number of well-known cross-linguistic properties: progressive assimilation, regressive dissimilation, a greater progressive effect, and a number of High/Low asymmetries. Despite the dissimilatory properties observable from both tone sandhi and tonal coarticulation, they seem to have different characteristics, indicating different sources for the two processes.

1. Introduction

Chinese languages are known for their intricate tone patterns. Detailed acoustic studies of Chinese tone patterns, however, have primarily focused on Standard Chinese (SC) or the Beijing dialect on which SC is based with notably few exceptions [e.g., Taiwanese: Lin, 1988; Peng, 1997; Zhenhai: Rose, 1990; Tianjin: Shi, 1990; Shanghai: Zee and Maddieson, 1980; Zhu, 1999]. This study reports the acoustic patterns of tone in Tianjin Chinese, a dialect spoken in the city of Tianjin 65 miles to the southeast of Beijing. Despite its similarity to SC, Tianjin has a considerably more complex pattern of tone sandhi – phonological alternations of tones due to tonal, prosodic, or morphosyntactic environments in which the tones appear [Chen, 2000; Zhang, 2010] – than SC. Moreover, tone sandhis in Tianjin exhibit a fair amount of variation, making an already complex picture even more puzzling. One of the goals of this research, therefore, is to provide a comprehensive picture of the tone sandhi pattern in disyllabic words in Tianjin through a multispeaker acoustic study.

Beyond tone sandhi, the acoustic realization of tones also exhibits gradient variations depending on the preceding and following tones. This process is known as tonal

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Table 1. Various transcriptions of tones in non-sandhi contexts in Tianjin Chinese

	Tone 1	Tone 2	Tone 3	Tone 4
Li and Liu [1985]	21	45	213	53
Shi [1987], Yang et al. [1999]	21	45	13	53
Shi [1990]	11	55	24	53
SC cognate	55	35	213	51

The transcriptions are given in 'Chao numbers', whereby a speaker's tonal range from low to high is represented by a numerical scale from '1' to '5'. Contour tones are denoted by number concatenations; e.g., '24' indicates a rising tone in the mid range [Chao, 1948, 1968].

coarticulation. Tonal coarticulation is relatively well studied cross-linguistically, and universal tendencies as well as language-specific properties have been identified. In particular, languages are known to share assimilatory progressive tonal coarticulation, whereby a tone partially assimilates to the preceding tone, and the effect of this coarticulation is relatively large, but languages differ with respect to the degree of regressive tonal coarticulation – the influence of a tone on the preceding tone – and whether this coarticulation is assimilatory or dissimilatory [SC: Ho, 1976; Shih, 1988; Shen, 1990; Xu, 1994, 1997, 1999, 2001; Taiwanese: Cheng, 1968; Lin, 1988; Peng, 1997; Vietnamese: Han and Kim, 1974; Brunelle, 2003, 2009; Thai: Abramson, 1979; Gandour et al., 1992a, b, 1994; Potisuk et al., 1997]. Another goal of this research is to situate Tianjin in the typology of tonal coarticulation and provide a further test to both the universal and language-specific properties of this phonetic phenomenon.

The rest of the paper is organized as follows. We start with a review of the two literatures on Tianjin tone sandhi and cross-linguistic tonal articulation. We then move on to our study on the tone pattern in Tianjin, starting with the methodology, followed by results on tone sandhi and tonal coarticulation, respectively. Discussions on how the results shed light on theoretical and methodological issues are then provided. The final section provides concluding remarks and points out directions for future research.

2. Tone Sandhi in Tianjin Chinese

2.1. Tones in Non-Sandhi Contexts

Tianjin has four phonemic tones that appear in non-sandhi contexts (citation tones), which include monosyllabic words and the final syllable of polysyllabic words. They correspond to the four tones in SC. The phonetic transcriptions of these tones differ from source to source, and representative transcriptions along with the transcriptions of their SC cognates are given in table 1. Chen [2000], relying on Shi's [1990] experimentally based transcriptions, argued that these tones should be interpreted as L (T1), H (T2), LH (T3), and HL (T4). We will use Chen's [2000] notation as a convenient shorthand here without committing ourselves to representing the tones phonologically as such. When confusion arises, T1, T2, T3, and T4 will be used instead.

2.2. Tone Sandhi in Disyllabic Words

In disyllabic words, the initial syllable may undergo tone sandhi in Tianjin. Four sandhi processes are traditionally identified [Li and Liu, 1985; Shi, 1986; Yang et al., 1999; Chen, 2000], as given in (1).

(1) Traditional descriptions of tone sandhi in Tianjin:

a. T1 + T1 → T3 + T1: L + L → LH + L
b. T3 + T3 → T2 + T3: LH + LH → H + LH
c. T4 + T1 → T2 + T1: HL + L → H + L
d. T4 + T4 → T1 + T4: HL + HL → L + HL

It is worth noting that depending on how the tones in the inventory are transcribed (table 1), the phonological analysis for the sandhi pattern may be drastically different. For example, in the transcriptions by Shi [1987], Yang et al. [1999], and Li and Liu [1985], T1 is considered a contour tone, while Shi [1990] and Chen [2000] treat it as a level tone. Consequently, the T4 + T1 sandhi can be interpreted as resulting from either a markedness ban against two falling tones or against two adjacent low pitch targets, and the structural change can be interpreted as either the metathesis of two contour features or simply the deletion of one of them.

The T3 + T3 sandhi in (1b) is cognate to the 'Third-Tone Sandhi' in SC, which also changes a T3 to a T2 before another T3. This sandhi corresponds to a historical sandhi pattern dated back to the 16th century [Mei, 1977]: *Shang* + *Shang* → *Yangping* + *Shang*, where *Shang* and *Yangping* refer to the historical tonal categories from which T3 and T2 descended, respectively. Consequently, the sandhi has cognates in many other Northern Chinese dialects regardless of the current pitch values of the two tonal categories, e.g., Luoyang [He, 1993], Jinan [Qian and Zhu, 1998] and Taiyuan [Wen and Shen, 1999]. The other three sandhis are not attested in SC, nor do they have extensive synchronic counterparts in other dialects or diachronic traditions to the best of our knowledge.

Shi [1988] was the first to note that the four sandhi processes in (1) apply with different propensities in Tianjin. He based his argument on both the numbers of exceptions of the sandhis and the likelihood with which the base-tone combinations may surface as the result of tone sandhi in longer sequences. Under these criteria, the sandhis are ordered as follows with respect to their 'strength': T3 + T3 > T1 + T1 > T4 + T4 > T4 + T1.

Shi and Wang [2004] recorded disyllabic words of the four sandhi combinations from 204 Tianjin speakers and investigated the differences among different age groups in 10-year increments in their applications of the sandhis. They tabulated the application of each sandhi for the different age groups according to the following questions: for T1 + T1 → T3 + T1, whether the sandhi tone was indeed T3 in Tianjin or closer to T2 in Tianjin and T1 in SC, which have a higher pitch; for T3 + T3 → T2 + T3, whether the sandhi tone was phonetically T2 in Tianjin (45) or T2 in SC (35); and for T4 + T1 → T2 + T1 and T4 + T4 → T1 + T4, whether the sandhis applied or not. Their results showed that: (a) younger speakers had a higher percentage of T1 + T1 → T2 + T1 sandhi than older speakers (close to 100% for <20 years to around 50% for >70 years); (b) younger speakers' sandhi tone for T3 + T3 → T2 + T3 was phonetically closer to T2 in SC than older speakers' (around 80% SC T2 for <20 years to around 10% for >70 years); (c) the T4 + T1 sandhi had a tendency to apply with greater regularity among younger speakers (close to 100% application for <20 years to around 60% for >70), and (d) the T4 + T4 sandhi had generally disappeared among younger speakers (close to 0% application for <20 years to around 40% for >70 years). These tendencies were also reflected in the pitch tracks drawn from 2 old (>60 years), 2 middle-aged (30–59 years), and 2 young (<29 years) speakers.

The change of the sandhi tone from T3 to T2 for the T1 + T1 sandhi was also discussed in detail by Lu [1997, 2004], who reported a sociolinguistic study of 40 speakers of different ages, occupations, and districts of Tianjin on their application of the sandhi in di- and trisyllabic words and phonetic pitch values for 2 of these speakers. The sociolinguistic study showed that younger speakers used the T2 sandhi tone more frequently than older speakers (56% for <25 years, 43% for 25–50 years, and 1% for >50 years), but the usage of T2 was not strongly correlated with the occupation or geographic location of the speakers. The 2 speakers in the phonetic study both had frequent use of the T2 sandhi tone impressionistically, and pitch measurements confirmed that their sandhi tone fell in the T2 range.

The disappearance of the T4 + T4 sandhi was echoed in a sociolinguistic study reported in Liu and Gao [2003] and Gao [2004], which sampled 104 speakers from an inner city district of Tianjin with different ages, occupations, and educational levels and recorded both a wordlist and a free conversation from each speaker. Results showed that the T4 + T4 sandhi applied with a lower rate in wordlist reading (37.06% for free conversation; 12.5% for disyllabic wordlist, 11.2% for trisyllabic wordlist) and for speakers that were younger (around 10% for <20 years to around 50% for >70 years), had white-collar jobs (less than 5% for teachers to around 50% for factory workers) and higher education levels (around 10% for college-educated to around 50% for elementary-school-educated). The authors credited the change of this sandhi behavior to the influence of SC, which has a similar T4 (51) that does not undergo sandhi before another T4.

Wee [2004] reported two additional tone sandhis for Tianjin, as given in (2). These sandhis are similar to the 'Half-Third Sandhi' in SC, whereby the falling-rising T3 is realized as its first half before a tone other than T3 (213 + T → 21 + T, T≠213). But the Tianjin sandhis are neutralizing according to Wee's [2004] report (neutralization of T3 and T1 in the sandhi contexts), while the SC 'Half-Third Sandhi' is allophonic (21 is not in the tonal inventory of SC). Ma and Jia [2006] conducted both acoustic and perceptual studies on these two sandhis and showed that neither is truly neutralizing: the sandhi tones partially preserve the rising property of T3, and listeners could identify the difference between T1 and T3 in the sandhi contexts with an accuracy rate of over 85%.

(2) Additional tone sandhis in Tianjin:

a. T3 + T2 → T1 + T2: LH + H → L + H

b. T3 + T4 → T1 + T4: LH + HL → L + HL

The tone sandhi pattern in Tianjin disyllabic words, therefore, is quite complex. This is not only because more sandhi processes are present in the dialect than in SC, but also because there is considerable variation in the sandhi pattern, and the pattern is likely undergoing changes due to influence from SC. The nature of the sandhi processes as neutralizing, as traditionally assumed in the literature, has also been put to doubt by recent research. What the previous research is lacking, however, is detailed acoustic measurements and statistical analyses of sandhi applications by multiple speakers – the large-scale studies by Shi and Wang [2004], Lu [1997, 2004], Liu and Gao [2003] and Gao [2004] only reported percentages of categorical tone sandhi applications without phonetic details of f0 information for all the speakers. Moreover, in our preliminary exploration of the sandhi patterns with a native consultant, we often found it difficult to classify whether a sandhi applied or not and whether the sandhi tone was one or another tone in the Tianjin tonal inventory. Therefore, we believe that a multispeaker acoustic study that clarifies the current state of the tone sandhi pattern in Tianjin will make an additional contribution to its understanding. In particular, we seek to address the following questions: (a) What are the acoustic realizations of tones in non-sandhi (monosyllabic) contexts in Tianjin? (b) In the sandhi contexts, do the tone sandhis result in complete tonal neutralization? (c) What is the nature of variation in the sandhi processes in Tianjin?

3. Tonal Coarticulation

The effect of context on the surface realizations of tones is not limited to tone sandhi. In the absence of such phonological effects, the adjacent tones also have a coarticulatory effect on the acoustic realization of a tone. Conceptually, tonal coarticulation differs from tone sandhi in that tonal coarticulation is a gradient phonetic effect and highly variable across speech rates and styles, while tone sandhi is categorical, oftentimes neutralizing, and stable across speech rates and styles. In reality, these distinctions are sometimes difficult to maintain. For example, speech-rate-related tone sandhi variation has been reported for SC [Shih, 1986; Zhang, 1997] and the Northern Wu dialect Nantong [Ao, 1993]. Tonal coarticulation may also be neutralizing. In SC trisyllabic words, the progressive coarticulatory effect of an initial High (T1) or Rise (T2) on a following Rise may cause the Rise to neutralize with a High, especially in fast speech [Chao, 1968]. In Tianjin disyllabic words, however, the tone patterns allow us to maintain a relatively clear distinction between the two, and we will discuss the patterns in (1) and (2) under the rubric of 'tone sandhi' and other contextual tonal variations under the rubric of 'tonal coarticulation'.

Detailed acoustic studies of tonal coarticulation can be found for SC [Ho, 1976; Shih, 1988; Shen, 1990; Xu, 1994, 1997, 1999, 2001], Taiwanese [Cheng, 1968; Lin, 1988; Peng, 1997], Vietnamese [Han and Kim, 1974; Brunelle, 2003, 2009], and Thai [Abramson, 1979; Gandour et al., 1992a, b, 1994; Potisuk et al., 1997]. These studies have focused on the following questions regarding the properties of tonal coarticulation: (a) Is the direction of tonal coarticulation progressive or regressive? (b) If both progressive and regressive tonal coarticulations exist, are there differences in the size of the two effects? (c) Is tonal coarticulation assimilatory or dissimilatory in either direction? (d) Are there differences in how High and Low tones participate in tonal coarticulation either as a trigger or a target? Table 2 summarizes the findings of these studies on these issues.

With the exception of Lin's [1988] study on Taiwanese, which did not find a regressive effect, all studies have found that tonal coarticulation is bidirectional. With the exception of Abramson's [1979] 1-speaker study on Thai, the magnitude of progressive coarticulation is consistently reported to be larger than that of regressive coarticulation. The duration with which the effect persists is also generally greater in progressive coarticulation, but Brunelle [2003, 2009] found that for both Northern and Southern Vietnamese, regressive coarticulation, though weaker in magnitude, has a longer effect duration. Progressive coarticulation is found in all studies to be assimilatory in nature.

Table 2. A cross-linguistic comparison of properties of tonal coarticulation

	SC	Taiwanese	Vietnamese	Thai
Progressive or regressive	both	both	both	both
Effect magnitude	P > R	P > R	P > R	P > R
Assimilatory or dissimilatory	P: assimilatory; R: assimilatory/ dissimilatory	P: assimilatory; R: assimilatory/ dissimilatory	P: assimilatory R: assimilatory	P: assimilatory; R: dissimilatory
H/L asymmetry	P assimilation trigger: H > L P assimilation target: H > L R dissimilation trigger: L > H	R dissimilation trigger: L > H	P assimilation trigger: H > L	R dissimilation trigger: L > H

P = Progressive; R = regressive.

The nature of regressive coarticulation, however, may be specific to language or even to particular tones in a language. Vietnamese is reported to have assimilatory regressive coarticulation, while most studies on Thai have reported dissimilatory regressive coarticulation, especially the effect of a Low tone on the preceding tone with a high offset. For Taiwanese, Cheng [1968] and Peng [1997] both found the regressive effects to be primarily assimilatory, but Peng [1997] also noticed dissimilatory effects for the level target tones in that the pitch of the high-level and mid-level tones is higher when the following tone has a low onset. For SC, the dissimilatory raising of a preceding high target by a low-onset tone has been noted by multiple studies [Shih, 1986; Shen, 1990; Xu, 1994, 1997], but Shih [1986] and Shen [1990] have also reported assimilatory tendencies in regressive coarticulation, such as the raising of the offset of the preceding tone by high-onset tones [Shen, 1990]. A common theme, however, is that a Low tone is more likely to have a dissimilatory effect on a preceding High than a High tone on a preceding Low. Another High/Low asymmetry in the small typology is that a High tone, especially a high offset of a rising tone, induces a greater carryover effect than a Low tone. This is seen in both Han and Kim's [1974] study of Vietnamese and Xu's [1994, 1997] studies of SC. Finally, Xu [1997] also showed that High targets are more likely than Low targets to undergo progressive assimilation in SC.

Another goal of our study on Tianjin, therefore, is to contribute to the typology of tonal coarticulation by providing an additional case study. The investigation is framed around the four questions on the properties of tonal coarticulation raised earlier in the hopes to shed further light on the nature of this phenomenon.

It is also of particular interest to study both the tone sandhi and tonal coarticulation in the same language acoustically to potentially address the differences and relationship between the two phenomena. As we mentioned earlier, the distinction between the two can be blurry sometimes. Moreover, from typological studies of tone and tone sandhi such as Hyman and Schuh [1974], Maddieson [1977], Yue-Hashimoto [1987], Bao [1992], Chen [1991, 1992, 1996, 2000], Hyman [2007] and Zhang [2007], we have learned that tone sandhi has much in common with tonal coarticulation in its typological characteristics. For example, tone spreading, whereby a tone is realized on a neighboring syllable, is the 'most basic tonal process' [Hyman, 2007, p. 6], and it has the following cross-linguistic properties: it is predominantly progressive [Hyman and Schuh, 1974; Hyman, 2007; Zhang, 2007], and it is more likely to be triggered by a High tone than a Low tone [Maddieson, 1977; Hyman, 2007]. Regressive polarization/dissimilation that turns a High tone in an H-L sequence into a contrastive Superhigh is also cross-linguistically common [Hyman, 2007]. For Chinese languages, their tone sandhi systems can be generally classified as either 'left-dominant' or 'right-dominant,' where 'left' or 'right' refers to the edge syllable in the tone sandhi domain that must maintain the original base tone [Yue-Hashimoto, 1987; Chen, 2000; Zhang, 2007]. Zhang [2007] argued that there is an asymmetry between the two types of sandhis, in that left-dominant sandhi usually involves the extension of the initial tone rightward, while right-dominant sandhi tends to involve local tone changes of the nonfinal syllables that result in contour simplification and neutralization. Sandhi patterns that have been analyzed as the dissimilation of either the contour or the register feature [e.g., in Bao, 1990, 1999; Chen, 2000] are predominantly found in right-dominant systems; Tianjin is an illustration of this. All these tone sandhi patterns find parallels in patterns of tonal coarticulation discussed above. It is therefore reasonable to consider tonal coarticulation as a precursor to at least some of the tone sandhi patterns, much in the same way as vowel-to-vowel coarticulation is a precursor to vowel harmony [Przezdziecki, 2005]. An acoustic study that encompasses both the tone sandhi and tonal articulation patterns of a language will therefore at least encourage the conversation regarding the relation between the two, if not provide any definitive answers to the question.

4. Method

4.1. Stimuli Construction

We designed our study to investigate the tones on both monosyllables and all disyllabic tonal combinations in Tianjin. The monosyllables provide the baseline for the tonal inventory, and the disyllables allow for the study of tone sandhi and tonal coarticulation.

Sixteen monosyllabic words, four for each of the four tones, and 64 disyllabic words, four for each of the 16 di-tone combinations, were selected from a corpus of written Chinese compiled from online resources by Da [2004]. All test words were common words based on frequency counts in the corpus. Due to the limited availability of syllables with sonorant onsets, all syllables in the selected words started with an obstruent onset for ease of word selection and frequency control. Additionally, all syllables were without an onglide to allow easy identification of the rhyme and avoid the thorny issue of whether the onglide is tone-bearing in Chinese [Duanmu, 2007; Lin, 2007]. The selection of obstruent onsets came with its sacrifices, however. First, aspiration in the onset of the second syllable effectively increases the duration between the two rhymes. Therefore, the tonal coarticulatory effect between the two syllables may be affected to different degrees depending on the presence or absence of this aspiration. Second, onset aspiration has been reported to affect the initial pitch of the following vowel in both tone [Gandour, 1974; Zee, 1980a; Shi, 1998; Xu and Xu, 2003; Lai, 2004; Francis et al., 2006; Lee, 2010; Lai and Chen, 2011] and non-tone languages [Jeel, 1975; Kagaya and Hirose, 1975; Cho et al., 2002; Kang and Guion, 2008; Lee, 2010]. Although the direction of the effect is controversial: for example, Xu and Xu [2003] showed a raising effect for unaspirated consonants in Mandarin, while Lai and Chen [2011] showed the opposite effect, this potential confound cannot be ignored. These confounds are further considered in the data analysis. Additional information on the selection of the stimuli and the entire word list are given in the 'Appendix'.

To minimize prosodic boundary effects on tonal realization, we embedded all words in carrier sentences. For each word, four carrier sentences were used, which cross-classified the heights of the end pitch before the word (H vs. L) and the beginning pitch after the word (H vs. L) to balance the coarticulation effects from the carrier sentence. The numbers of syllables in all carrier sentences were matched. For monosyllabic targets, the four carrier sentences in (3) were used, and for disyllabic targets, the four carrier sentences in (4) were used.

(3) Carrier sentences for monosyllabic target words:

a. wo njan (T4, L offset) ____ tʂɤ (T4, H onset) kɤ tsɨ
I read ____ this measure-word character
'I read the character ____.'

b. wo njan (T4, L offset) ____ kei (T3, L onset) tʰa tʰiŋ
I read ____ to him listen
'I read ____ for him to listen to.'

c. wo tu (T2, H offset) ____ tʂɤ (T4, H onset) kɤ tsɨ
I read ____ this measure-word character
'I read the character ____.'

d. wo tu (T2, H offset) ____ kei (T3, L onset) tʰa tʰiŋ
I read ____ to him listen
'I read ____ for him to listen to.'

(4) Carrier sentences for disyllabic target words:

a. wo njan (T4, L offset) ____ tʂɤ (T4, H onset) kɤ tsʰɨ
I read ____ this measure-word word
'I read the word ____.'

b. wo njan (T4, L offset) ____ liɑŋ (T3, L onset) kɤ tsɨ
I read ____ two measure-word character
'I read the two characters ____.'

c. wo tu (T2, H offset) ____ tʂɤ (T4, H onset) kɤ tsʰɨ
I read ____ this measure-word word
'I read the word ____.'

d. wo tu (T2, H offset) ____ liɑŋ (T3, L onset) kɤ tsɨ
I read ____ two measure-word character
'I read the two characters ____.'

The verb 'to read' ([njan, T4] or [tu, T2]) is at the right edge of a sandhi domain and thus not affected by the tone of the first syllable of the target word. The monosyllabic targets or the second syllable of the disyllabic targets also do not belong to the same sandhi domain as the following syllable in the carrier due to both the focus of the targets in the subjects' reading of the sentences and the fact that the targets and the following syllable do not form a word.

The three syllables to the right of the target words, however, do form a sandhi domain and could potentially undergo tone sandhi. For the carriers for the monosyllabic targets, the two contexts have the base tone combinations T4 + T4 + T4 ([tʂɤ kɤ tsɨ], 'this character') and T3 + T1 + T1 ([kei tʰa tʰiŋ], 'for him to listen to'). According to Li and Liu's [1985] description, these base tone combinations should become T2 + T1 + T4 and T2 + T3 + T1, respectively, as a result of right-to-left applications of disyllabic sandhis (T4 + T4 + T4 → T4 + T1 + T4 → T2 + T1 + T4; T3 + T1 + T1 → T3 + T3 + T1 → T2 + T3 + T1). But the Tianjin consultant that we hired to help with the stimuli construction did not apply these sandhis but pronounced these sequences unsandhied. Our experimental participants also did not apply these sandhis in the carriers. As we will see in the 'Results' section, this is due to the facts that the T4+T4 sandhi has indeed become obsolete [Liu and Gao, 2003; Gao, 2004; Shi and Wang, 2004], and the surface form of T1 + T1 has shifted from T3 + T1 to T2 + T1 [Lu, 1997, 2004; Shi and Wang, 2004]. The Half-Third sandhi that affects the T3 + T2 sequence [Wee, 2004] did apply to the first syllable of base T3 + T1 + T1, but this sandhi did not affect the onset of the first syllable.

For the carriers for the disyllabic targets, the two right-hand contexts have the base tones T4 + T4 + T2 ([tʂɤ kɤ tsʰɨ], 'this word') and T3 + T4 + T4 ([liɑŋ kɤ tsɨ], 'two characters'), which should become T1 + T4 + T2 and T3 + T1 + T4, respectively, according to Li and Liu [1985]. But again due to the disappearance of the T4 + T4 sandhi, the onset of the first syllable remained intact.

4.2. Participants

A total of 12 native speakers of Tianjin (6 male, 6 female) participated in the experiment. All speakers were from the six inner-city districts of Tianjin and used both Tianjin and SC in their daily lives. The average age of the speakers at the time of the recording was 34.3, and their age distribution was as follows: 20–24: n = 3; 25–29: n = 4; 30–39: n = 1; 40–49: n = 2; 50 and above: n = 2. The distribution is therefore skewed towards younger speakers. Nine of these speakers were living in the Kansas City area of the US when they were recorded, and the other 3 were living in Tianjin. Besides the matched numbers of male and female speakers and the requirement that the speakers be from the inner-city districts of Tianjin, no other factors were considered in the speaker sampling.

4.3. Experimental Procedure

Test words in carrier sentences were given to each speaker on printed sheets. Each sheet contained only one word in the four carrier sentences; there were therefore 16 sheets for monosyllables and 64 sheets for disyllables. For each speaker, the orders of the sheets for the monosyllables and disyllables were randomized by hand. The speakers were instructed to read each sentence twice, and the recording took place in three sections: first the monosyllables, then half the disyllables, and then the other half of the disyllables. There was a 5-min break between sections. The speakers from Kansas were recorded in an anechoic chamber in the Phonetics and Psycholinguistics Laboratory of the University of Kansas using a Marantz solid state recorder PMD 671 sampling at 22.05 kHz and an Electro-Voice RE-20 microphone. The speakers from Tianjin were recorded in a quiet room in the Phonetics Laboratory of the Department of Chinese Language and Literature at Nankai University using the same model of solid state recorder and an EV N/D 767a microphone.

4.4. Data Analysis

All acoustic analyses of the data were conducted in Praat [Boersma and Weenink, 2009]. For all syllables in the test words, we took an f0 measurement at every 10% of the rhyme duration using Yi Xu's TimeNormalizedF0 Praat script [Xu, 2005, predecessor of ProsodyPro, Xu, 2005–2011], giving eleven f0 measurements for each syllable. TimeNormalizedF0 uses the automatic vocal pulse marking by Praat as well as a trimming algorithm that removes spikes and sharp edges [see Appendix 1 of Xu, 1999, for additional information on the trimming algorithm]. The Maxf0 and Minf0 parameters in the script as well as the octave-jump cost were adjusted for each speaker, and the f0 measurements were hand-checked against narrow-band spectrograms in Praat. The two repetitions of a test sentence were both used, and their f0 values averaged. The f0 values of a test word in the four carrier sentences were then further averaged. Therefore, for each test word, each speaker only contributed one set of f0 values for statistical analyses. A disyllabic token was not used if its second syllable was judged by the authors as a stressless syllable, as in these words, the first syllable never undergoes sandhi, and the tone of the stressless syllable is determined by the tone of the first syllable. For detailed descriptions of the tonal behavior of stressless syllables in Tianjin, see Jiang [1994] and Wang [2002].

5. Results

5.1. Monosyllables

The f0 results of the four tones in monosyllables averaged across the 12 speakers are given in figures 1 and 2. Figure 1 provides the results in Hertz, while figure 2 provides the results in a normalized 0–5 numerical scale, which can be interpreted in the tradition of Chao [1948, 1968], whereby the intervals 0–1, 1–2, 2–3, 3–4, and 4–5

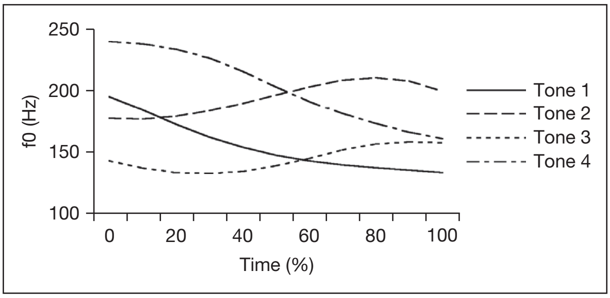


Fig. 1. f0 results in Hertz of the four tones in monosyllables.

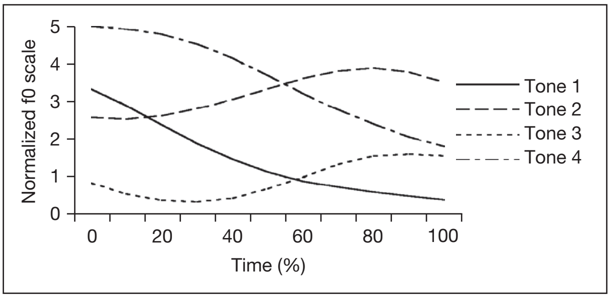


Fig. 2. f0 results of the four tones in monosyllables on a normalized 0–5 numerical scale.

correspond to 1–5 in Chao numbers, respectively. For each speaker, the normalized f0 value of any of the 11 points for each tone is calculated as in (5), in which $f0_{min}$ and $f0_{max}$ refer to the minimum and maximum f0 values in Hertz in that speaker's averaged f0 data for the four tones [Shi, 1986].

(5) f0 normalization:

$$f0_{normalized} = \frac{\log_{10} f0 - \log_{10} f0_{min}}{\log_{10} f0_{max} - \log_{10} f0_{min}} \times 5$$

The raw and normalized f0 results show essentially the same pattern: phonetically, the tonal inventory of Tianjin is comprised of two rising and two falling tones. The two tones that have been interpreted as L (T1) and H (T2) by Chen [2000] have considerable f0 movements. From the normalized f0 graphs, the four tones correspond to 41, 34, 12, and 52 in Chao numbers. Given the similarity between the f0 results in Hertz and the numerical scale, we only report the statistical analyses based on Hertz.

5.2. Disyllables – Tone Sandhi

We report in this section tone sandhi behavior in disyllables. All six tonal combinations that have been reported to have tone sandhi in the literature in (1) and (2) are discussed under 'tone sandhi'. We first report the average f0 patterns across all speakers for each tonal combination. For each speaker, the f0 data for each tonal combination were derived from all tokens for the tonal combination, regardless of whether the token undergoes the sandhi per the rules in (1) and (2). This is because whether a tonal combination has undergone the sandhi categorically, incompletely, or has not undergone the sandhi at all was often difficult to determine. We have therefore chosen to include all tokens in the graphs first, then comment on the types of variations observed for each tonal combination later.

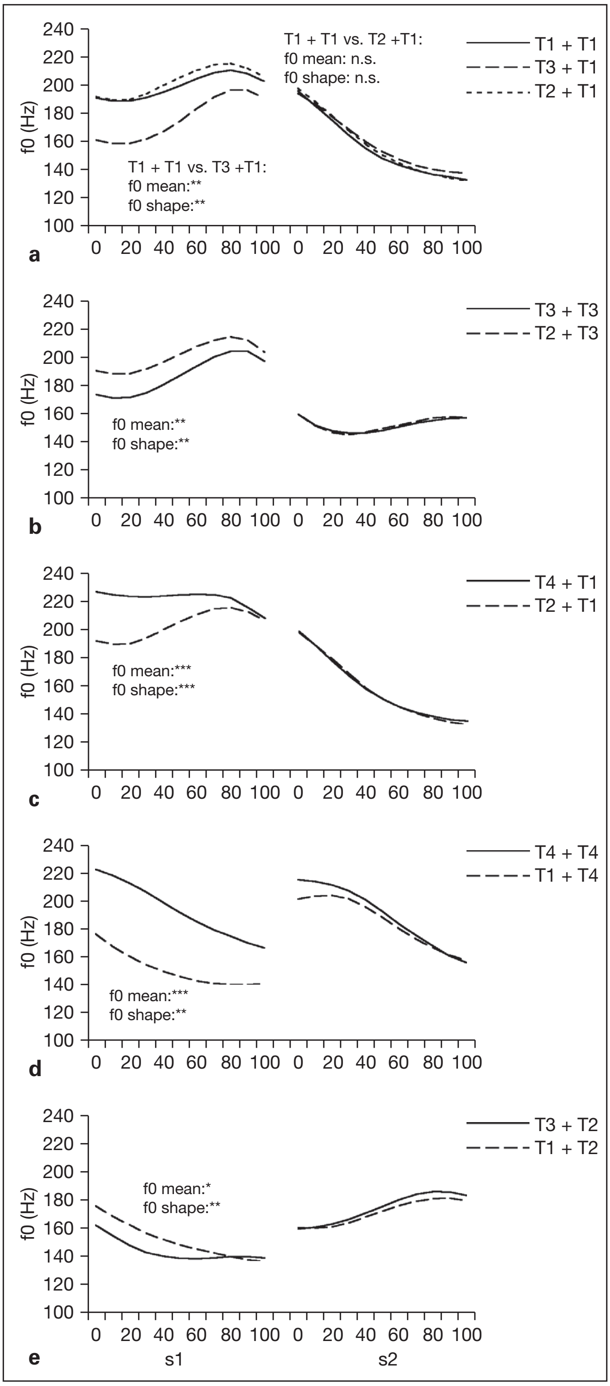
Figure 3 reports the f0 patterns for base tone targets T1 + T1, T3 + T3, T4 + T1, T4 + T4, T3 + T2, and T3 + T4. For each graph, the f0 of the tonal combination that the target is reported to neutralize with is superimposed on the target f0. For example, the T1 + T1 graph (fig. 3a) has three f0 tracks as it has been reported to neutralize with either T3 + T1 or T2 + T1. A two-way Repeated Measures ANOVA was conducted to compare the f0 of the first syllable between the target and the tonal combination it reportedly neutralizes with, with Tone (2 levels) and Data Point (11 levels) as independent variables. A significant main effect of Tone would indicate that the two f0 curves have different means, and a significant interaction between Tone and Data Point would indicate that the two f0 curves have different shapes. Huynh-Feldt adjusted values were used to correct for sphericity violations. The ANOVA results are summarized in table 3, and significance results for f0 mean and f0 shape are indicated in figure 3a as well.

The T1 + T1 sandhi (fig. 3a) applies consistently in all tokens for all speakers except for those in which the second syllable is stressless and hence not used in the analysis. The statistical results show that the sandhi tone for T1 + T1 is acoustically neutralized with T2, not T3 as the traditional descriptions indicate. This agrees with Shi and Wang's [2004] and Lu's [1997, 2004] descriptions for younger speakers of Tianjin. However, a closer look at each individual's results shows that this change is not yet complete. Among our 12 speakers, only 7 have a complete merger between T1 + T1 and T2 + T1, 4 others' sandhi tone lies between T2 and T3, and 1 speaker still maintains the T3 sandhi tone.

The T3 + T3 sandhi (fig. 3b), which corresponds to the Third-Tone Sandhi in SC, also applies consistently in all tokens. But our statistics show that the sandhi is not acoustically neutralizing: the sandhi tone is overall lower than T2, nor does it have the same shape as T2. This, again, agrees with the results of Shi and Wang [2004]. Individually, only 2 of our 12 speakers showed a complete merger between T2 and sandhi T3, while the other 10 showed a clear difference between the two tones.

The T4 + T1 sandhi (fig. 3c) is also clearly non-neutralizing acoustically. There is a highly significant difference between T2 and the sandhi T4 in both f0 mean and f0 shape: T2, though sometimes transcribed as a level High by fieldworkers, is in fact a rising tone, while the sandhi T4 here is a true High level tone. The exceptional behavior of this sandhi discussed in Shi [1988] and Shi and Wang [2004] was attested in 2 of our speakers, who failed to apply this sandhi to a subset of the words, but the other 10 speakers applied this sandhi consistently. The words that the sandhi did not apply to differed between the 2 speakers, indicating lexicalized behavior.

In agreement with Shi [1988], Shi and Wang [2004], Liu and Gao [2003] and Gao [2004], the T4 + T4 sandhi (fig. 3d) has indeed become obsolete. The 'sandhi' tone shares much resemblance to T4 in the second syllable and is considerably higher in pitch than T1 – the tone that it supposedly neutralizes with according to earlier reports. Among our speakers, 9 did not show any trace of the sandhi in any words, while the


T1 + T1 vs. T2 +T1:
f0 mean: n.s.
f0 shape: n.s.
T1 + T1
T3 + T1
T2 + T1
T1 + T1 vs. T3 +T1:
f0 mean:**
f0 shape:**
f0 (Hz)
a
T3 + T3
T2 + T3
f0 mean:**
f0 shape:**
b
T4 + T1
T2 + T1
f0 mean:***
f0 shape:***
c
T4 + T4
T1 + T4
f0 mean:***
f0 shape:**
d
T3 + T2
T1 + T2
f0 mean:*
f0 shape:**
e
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s2

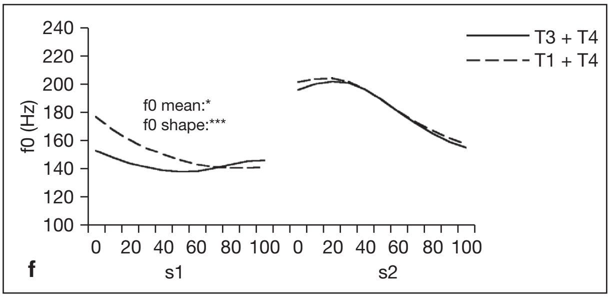

Fig. 3. f0 patterns for base tone combinations: T1 + T1 (**a**), T3 + T3 (**b**), T4 + T1 (**c**), T4 + T4 (**d**), T3 + T2 (**e**), and T3 + T4 (**f**). f0 patterns of the tonal combinations that each of these has been reported to neutralize with are superimposed in the figures. Each pitch track represents an average across 12 speakers. f0 mean and f0 shape comparisons are indicated in the figures: n.s. = no significant difference; significant differences: *p < 0.05, **p < 0.01, ***p < 0.001.

Table 3. ANOVA results for the f0 comparisons between f0 of the first syllable of disyllabic targets and f0 of the first syllable of the tonal combinations they reportedly neutralize with

	Tone (f0 mean)	Data point	Tone × Point (f0 shape)
T1 + T1 vs. T3 + T1	F(1.000, 11.000) = 21.236, p = 0.001	F(2.404, 26.444) = 19.928, p < 0.001	F(1.649, 18.140) = 10.366, p = 0.002
T1 + T1 vs. T2 + T1	F(1.000, 11.000) = 1.224, p = 0.292	F(1.935, 21.280) = 11.952, p < 0.001	F(1.407, 15.472) = 0.760, p = 0.440
T3 + T3 vs. T2 + T3	F(1.000, 11.000) = 16.451, p = 0.002	F(1.635, 17.980) = 11.741, p = 0.001	F(2.599, 28.592) = 8.089, p = 0.001
T4 + T1 vs. T2 + T1	F(1.000, 11.000) = 24.445, p < 0.001	F(2.049, 22.540) = 5.275, p = 0.013	F(1.343, 14.776) = 20.660, p < 0.001
T4 + T4 vs. T1 + T4	F(1.000, 11.000) = 32.042, p < 0.001	F(1.048, 11.530) = 23.852, p < 0.001	F(1.469, 16.163) = 9.437, p = 0.004
T3 + T2 vs. T1 + T2	F(1.000, 11.000) = 8.552, p = 0.014	F(1.165, 12.816) = 31.114, p < 0.001	F(1.325, 14.570) = 12.444, p = 0.002
T3 + T4 vs. T1 + T4	F(1.000, 11.000) = 7.992, p = 0.016	F(1.169, 12.856) = 15.825, p = 0.001	F(1.255, 13.802) = 19.904, p < 0.001

other 3 applied the sandhi to a subset of the words. The words that underwent the sandhi again differed among the speakers.

The two Half-Third Sandhis (fig. 3e, f) show similar patterns: both sandhi tones preserve a small rise from the original T3, and consequently, neither sandhi results in complete neutralization with T1. The sandhis, therefore, seem to be gradient reactions to insufficient duration on nonfinal syllables to realize a full rising tone [Zhang, 2002; Zhang and Lai, 2010]. Due to this gradient nature, it is particularly difficult to decide categorically whether a given token has undergone the sandhi or not. Our result agrees with Wee [2004] in that there is indeed tone sandhi in the T3 + T2 and T3 + T4 contexts, but agrees with Ma and Jia [2006] in that the sandhis are non-neutralizing, at least acoustically.

In summary, we have observed the following two properties of tone sandhi in Tianjin. First, some of the sandhi patterns either have undergone or are undergoing changes, and there is a fair amount of variation. In particular, the output of the T1 + T1 combination is now acoustically merged with T2 + T1, the T4 + T4 sandhi has generally become obsolete, and two Half-Third sandhis have emerged. The variation on whether a sandhi applies is observable on both interspeaker and intraspeaker levels for virtually all sandhis. Second, statistically, with the exception of T1 + T1 → T2 + T1, all sandhis are acoustically non-neutralizing, contra traditional descriptions. However, there are also variations in whether a sandhi is neutralizing and what it neutralizes with on both interspeaker and intraspeaker levels, as we have seen for T1 + T1 and T3 + T3.

5.3. Disyllables – Tonal Coarticulation

5.3.1. Carryover Effects

The data for progressive tonal coarticulation (carryover effects) come from the surface tonal realizations for all 16 disyllabic tonal combinations, as shown in figure 4. For each graph in figure 4, the tone of the second syllable is held constant while the tone on the first syllable varies, which organizes the 16 tonal combinations into four quadruplets and allows the effects of the first syllable on the second syllable to be seen. Given that the pitch tracks represent surface tonal realizations, the effects of tone sandhi have been taken into account. The pitch patterns in the graphs are averages across the 12 speakers.

To investigate the carryover effects quantitatively, for each quadruplet, the end pitch of the first syllable was classified into High (H), Mid (M), or Low (L) depending on its surface realization, as indicated in figure 4, and the effects of this classification on the pitch values at the beginning, mid point, and end of the second syllable were evaluated by one-way repeated measures ANOVAs with Huynh-Feldt adjusted values. The ANOVA results are summarized in table 4, and significance values are indicated in figure 4 as well.

Our results indicate that carryover coarticulation is generally assimilatory. The only exception is in the T + T1 quadruplet, where a High offset of the first syllable induces lower pitches on the second syllable than a Mid offset. We do not have a reasonable interpretation for this result except noting that the difference between H and M on the first syllable is relatively small, and the effect does not show a progression from large to small as the second syllable unfolds as expected for progressive coarticulation. For the other three quadruplets, assimilatory coarticulation is the most prominent at the onset of the second syllable and gradually decreases towards the end of the second syllable. The duration through which coarticulation sustains differs according to the tone on the second syllable, from 100% of the duration for T + T2 to around 50% for T + T4 and to less than 50% for T + T3. One interpretation is that a High pitch target is more susceptible to coarticulatory raising by a preceding High. This is consistent with two previously established trends of coarticulation: a High tone is both a better trigger [Han and Kim, 1974; Xu, 1994, 1997] and a better target [Xu, 1997] of carryover effects than a Low tone.

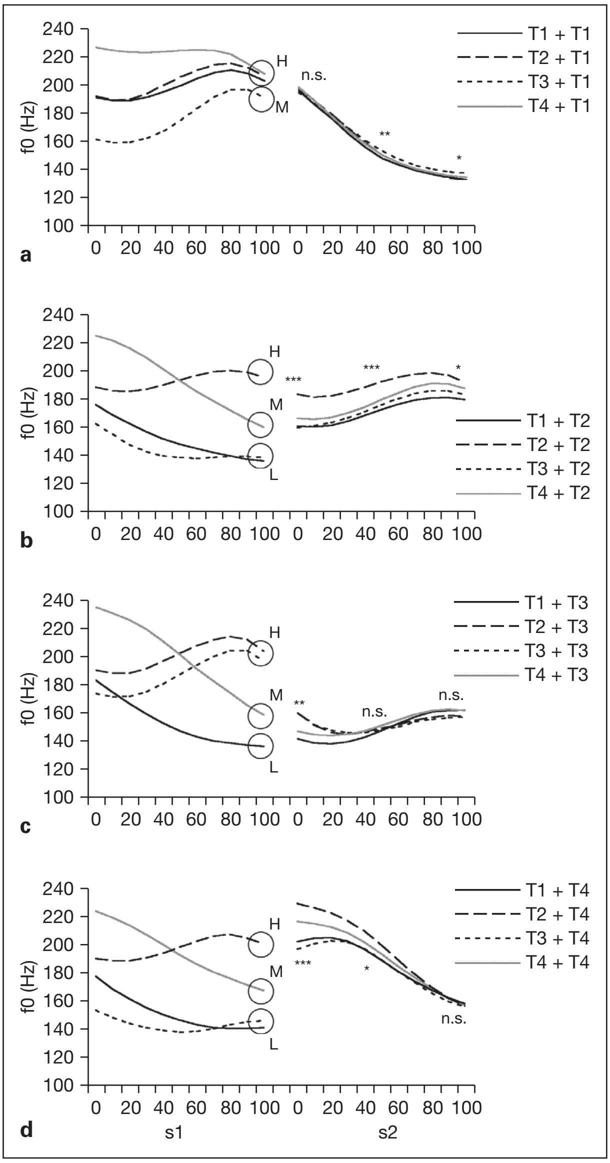

Fig. 4. Carryover tonal coarticulation effects shown in four graphs, each of which represents the surface tonal realizations of a quadruplet in which the tone on σ2 is kept constant and the tone on σ1 varies: σ2 = T1 (**a**); σ2 = T2 (**b**); σ2 = T3 (**c**); σ2 = T4 (**d**). Effects of tone sandhi have been taken into account. Each pitch track represents an average across 12 speakers. The end pitch of σ1 is classified into H, M, and L, and its effects on the beginning, mid point, and end pitches of σ2 are indicated in the figures: n.s. = significant effect, significant effects: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 4. ANOVA results for the effects of the end pitch of σ1 on the beginning, mid point, and end pitches of σ2 based on the classification of σ1 end pitch as H, M, or L

	σ2 position		
	beginning	mid point	end
T + T1 H: T = T1, T2, T4 M: T = T3	F(1.000, 11.000) = 0.915, p = 0.359	F(1.000, 11.000) = 9.975, p = 0.009 H < M: p = 0.009	F(1.000, 11.000) = 7.313, p = 0.021 H < M: p = 0.021
T + T2 H: T = T2 M: T = T4 L: T = T1, T3	F(1.886, 20.748) = 33.927, p < 0.001 H > M: p < 0.001 H > L: p < 0.001 M = L: p = 0.202	F(1.828, 20.105) =13.488, p < 0.001 H > M: p = 0.002 H > L: p = 0.005 M = L: p = 0.488	F(2.000, 22.000) = 5.075, p = 0.015 H = M: p = 0.649 H > L: p = 0.033 M = L: p = 0.233
T + T3 H: T = T2, T3 M: T = T4 L: T = T1	F(2.000, 22.000) = 10.384, p = 0.001 H > M: p = 0.020 H > L: p = 0.009 M = L: p = 0.469	F(1.565, 17.217) = 0.509, p = 0.566	F(1.581, 17.396) = 1.154, p = 0.326
T + T4 H: T = T2 M: T = T4 L: T = T1, T3	F(2.000, 22.000) = 15.088, p < 0.001 H = M: p = 0.108 H > L: p = 0.002 M > L: p = 0.011	F(2.000, 22.000) = 3.679, p = 0.042 H = M: p = 0.335 H = L: p = 0.104 M = L: p = 0.808	F(1.687, 18.560) = 0.015, p = 0.973

When the effect is significant, post-hoc pairwise comparisons are also given.

In order to investigate the possible influence of σ2 (syllable 2) onset consonants on carryover coarticulation, we measured the rhyme-to-rhyme duration between the two syllables in our data, which included both the closure and aspiration portions of the σ2 onset consonant. The effect of the H-M-L classification on this duration was evaluated by one-way repeated measures ANOVAs with Huynh-Feldt adjusted values. The duration results are given in figure 5, and the ANOVA results are summarized in table 5. The results show that for T + T1, T + T2, and T + T4, there is no significant difference in rhyme-to-rhyme duration among the H, M, and L groups based on σ1 offset, indicating that the pitch differences on σ2 among the H, M, and L groups are unlikely to be caused by different degrees of coarticulation that resulted from different σ2 onset consonants. For T + T3, the L group has a significantly longer rhyme-to-rhyme duration than both the H and M groups (H = M < L), but the pitch effect at the onset of σ2 is H > M = L, which does not match up with the durational pattern.

As previously mentioned, the feature of aspiration is also a possible confound in the f0 results. In our word list, there are proportionally more words with an aspirated σ2 onset for the H category for T + T1, the L category for T + T2, the L category for T + T3, and the H and M categories for T + T4 (see 'Appendix' for the full word list). Therefore, the aspiration feature does not consistently favor either the H or the L category. The general assimilatory effect observed in carryover coarticulation, then, cannot be due to the effect of aspiration, regardless of the direction of the effect.

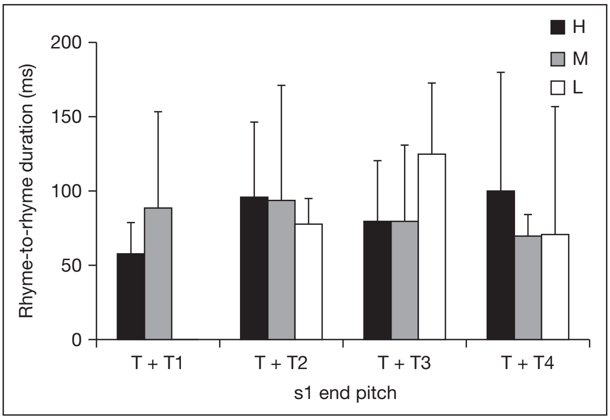

Fig. 5. The effects of the end pitch of σ1 on rhyme-to-rhyme duration based on the classification of σ1 end pitch as H, M, or L for T + T1, T + T2, T + T3, and T + T4, respectively. For T + T1, H = T1, T2, T4, M = T3; for T + T2, H = T2, M = T4, L = T1, T3; for T + T3, H = T2, T3, M = T4, L = T1; for T + T4, H = T2, M = T4, L = T1, T3. The y axis represents the rhyme-to-rhyme duration in milliseconds, which includes both the closure and the aspiration of σ2 onset. The error bars represent one standard deviation.

Table 5. ANOVA results for the effects of the end pitch of σ1 on rhyme-to-rhyme duration based on the classification of σ1 end pitch as H, M, or L

	Rhyme-to-rhyme duration
T + T1 H: T = T1, T2, T4 M: T = T3	F(1.000, 11.000) = 3.437, p = 0.091
T + T2 H: T = T2 M: T = T4 L: T = T1, T3	F(1.920, 21.121) = 0.705, p = 0.500
T + T3 H: T = T2, T3 M: T = T4 L: T = T1	F(1.440, 15.844) = 12.599, p = 0.001 H = M: p = 1.000 H < L: p=.009 M < L: p=.010
T + T4 H: T = T2 M: T = T4 L: T = T1, T3	F(2.000, 22.000) = 1.329, p = 0.285

When the effect is significant, post-hoc pairwise comparisons are also given.

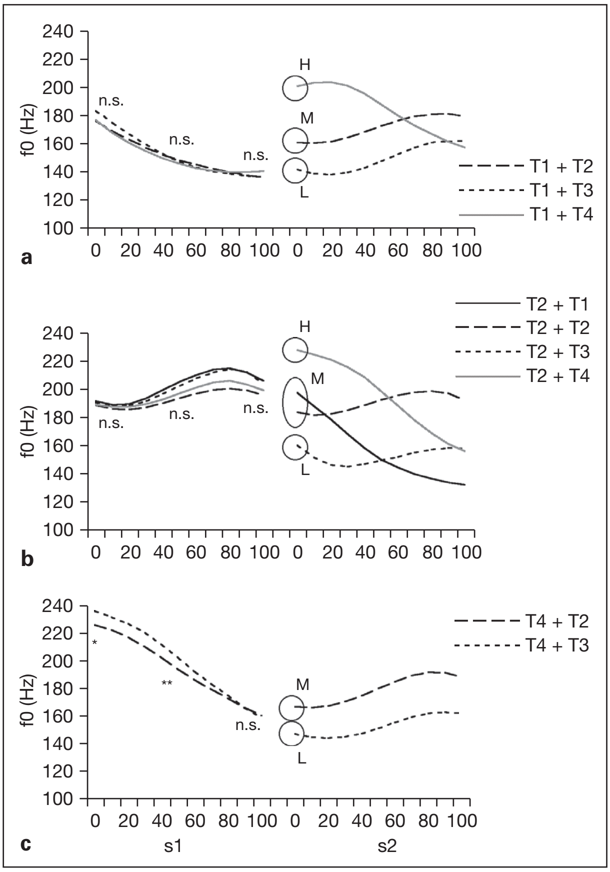

Fig. 6. Anticipatory tonal coarticulation effects shown in three graphs, each of which represents the surface tonal realizations of a tonal combination grouping in which the tone on σ1 is kept constant and the tone on σ2 varies: σ1 = T1 (**a**); σ1 = T2 (**b**); σ1 = T4 (**c**). None of the tonal combinations involves tone sandhi. Each pitch track represents an average across 12 speakers. The beginning pitch of σ2 is classified into H, M, and L, and its effects on the beginning, mid point, and end pitches of σ1 are indicated in the figures: n.s. = no significant effect, significant effects at *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

5.3.2. Anticipatory Effects

Due to the right-dominant nature of tone sandhi in Tianjin, the data for regressive tonal coarticulation (anticipatory effects) can only come from surface tonal realizations for the tonal combinations to which sandhi does not apply. Among the ten such tonal combinations, T3 + T1 is not informative as this is the only combination for which T3 surfaces unsandhied and therefore cannot provide comparisons of how T3 varies depending on the following tone. The nine useful tonal combinations were organized into three groups: T1 + T (T = T2, T3, T4), T2 + T (T = T1, T2, T3, T4) and T4 + T (T = T2, T3), which allows the effect of the second syllable on the first syllable to be investigated. The pitch patterns of these three tone groupings are given in figure 6. The pitch patterns in the graphs are again averages across the 12 speakers.

Table 6. ANOVA results for the effects of the beginning pitch of σ2 on the beginning, mid point, and end pitches of σ1 based on the classification of the beginning pitch of σ2 as H, M, or L

	σ1 position		
	beginning	mid point	end
T1 + T H: T = T4 M: T = T2 L: T = T3	F(2.000, 22.000) = 3.073, p = 0.067	F(1.901, 20.910) = 0.965, p = 0.393	F(1.747, 19.220) = 3.557, p = 0.054
T2 + T H: T = T4 M: T = T1, T2 L: T = T3	F(2.000, 22.000) = 0.230, p = 0.797	F(1.963, 21.594) = 2.720, p = 0.089	F(1.121, 12.331) = 0.943, p = 0.362
T4 + T M: T = T2 L: T = T3	F(1.000, 11.000) = 9.332, p = 0.011 M < L: p = 0.011	F(1.000, 11.000) = 11.162, p = 0.006 M < L: p = 0.006	F(1.000, 11.000) = 0.342, p = 0.570

When the effect is significant, post-hoc pairwise comparisons are also given.

For each grouping, we classified the beginning pitch of the second syllable into H, M, or L, as indicated in figure 6. The H, M, and L here have no direct relation with the H, M, and L in the carryover effects. The effects of this classification on the pitch values at the beginning, mid point, and end of the first syllable were evaluated by one-way repeated measures ANOVAs with Huynh-Feldt adjusted values. The ANOVA results are summarized in table 6, and significance values are indicated in figure 6 as well.

The effects of regressive coarticulation, as we can see, are considerably weaker than progressive coarticulation. A significant anticipatory effect is only attested when the first syllable has a T4 – a high falling tone, with the following two observations. First, the effect is dissimilatory, as a Low onset for the second syllable causes a higher pitch on the first syllable than a Mid onset. Second, this dissimilatory effect is the most obvious for a High target on the first syllable, even though this High tone is at the beginning of the syllable and thus farther away from the affecting tone. Both of these observations have been made for regressive coarticulation in other languages, for example, in closely related SC [Xu, 1997].

It is also worth noting that in the T2 + T comparisons, if we group the tonal combinations not according to the beginning pitch, but according to the overall pitch height of the second syllable into High (T2 + T2, T2 + T4) and Low (T2 + T1, T2 + T3), then the pitch of the second syllable does have a significant dissimilatory effect on the pitch of the mid and end points of the first syllable: mid point: $F(1.000, 11.000) = 10.307$, $p = 0.008$; end point: $F(1.000, 11.000) = 5.489$, $p = 0.039$. The effect on the beginning of the first syllable is still not significant: $F(1.000, 11.000) = 0.742$, $p = 0.408$. This dissimilatory effect is consistent with the observation above that a High tone is more susceptible to anticipatory dissimilation.

The possible influence of σ2 onset consonants on anticipatory coarticulation was investigated by the effect of the H-M-L classification of the beginning pitch of σ2 on

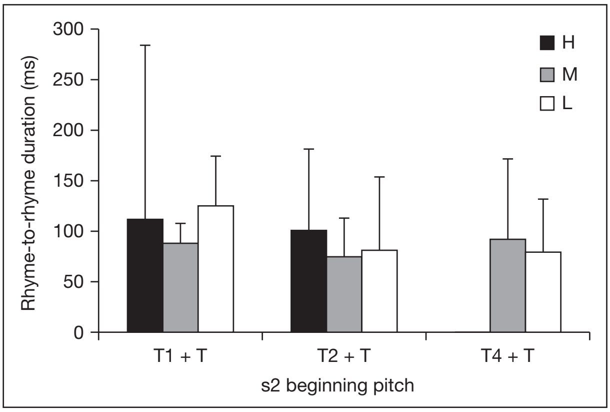

Fig. 7. The effects of the beginning pitch of σ2 on rhyme-to-rhyme duration based on the classification of the beginning pitch of σ2 as H, M, or L for T1 + T, T2 + T, and T4+T, respectively. For T1 + T, H = T4, M = T2, L = T1; for T2 + T, H = T4, M = T1, T2, L = T3; for T4 + T, M = T2, L = T3. The y axis represents the rhyme-to-rhyme duration in milliseconds, which includes both the closure and the aspiration of σ2 onset. The error bars represent one standard deviation.

Table 7. ANOVA results for the effects of the beginning pitch of σ2 on rhyme-to-rhyme duration based on the classification of the beginning pitch of σ2 as H, M, or L

	Rhyme-to-rhyme duration
T1 + T H: T = T4 M: T = T2 L: T = T3	F(1.049, 11.538) = 0.536, p = 0.487
T2 + T H: T = T4 M: T = T1, T2 L: T = T3	F(2.000, 22.000) = 0.991, p = 0.387
T4 + T M: T = T2 L: T = T3	F(1.000, 11.000) = 0.771, p = 0.399

When the effect is significant, post-hoc pairwise comparisons are also given.

rhyme-to-rhyme duration. The duration results are given in figure 7, and the repeated measures ANOVA results are summarized in table 7. The results show that there is no significant difference in this duration among the H, M, and L groups based on σ2 onset pitch for any of the coarticulatory comparisons, indicating that the pitch differences on σ1 among the H, M, and L groups are unlikely to be caused by different degrees of coarticulation that resulted from different σ2 onset consonants.

Given that the known effect of aspiration on f0 is on the vowel following it, it is unlikely that aspiration (aside from the duration that it contributes) has a direct influence on anticipatory coarticulation. But it is still possible that it can mask the true f0 onset intended by the following tone, which may then affect our interpretation of anticipatory coarticulation. To investigate this possibility, we again tabulated the number of test words with an aspirated σ2 onset in each set of tonal combinations for the coarticulatory comparisons. It turns out that there are proportionally more words with an aspirated σ2 onset for the M category for both T1 + T and T2 + T, and there are no such words for either the M or L category for T4 + T. Given that aspiration does not consistently favor either H or L, and that we only observed dissimilatory anticipatory coarticulation in T4 + T, we conclude that the confounding effect of aspiration in our anticipatory coarticulation result is minimum.

5.3.3. Coarticulation Summary

To echo the questions raised earlier on the direction, magnitude, assimilatory or dissimilatory nature, and High/Low asymmetries of tonal coarticulation, we summarize our findings in Tianjin as follows. The coarticulation effect is bidirectional, with progressive coarticulation being primarily assimilatory and regressive coarticulation being primarily dissimilatory. Progressive coarticulation generally has a greater magnitude than regressive coarticulation, but the effect duration is more related to the tones involved than directionality. High tones are better triggers and targets of progressive assimilation and better targets of regressive dissimilation, and Low tones are better triggers of regressive dissimilation. All of these properties are attested in the closely related SC, and they generally agree with the cross-linguistic tendencies established in the small typology summarized in section 3.

6. Discussion

6.1. Monosyllables

Our results on citation tones in Tianjin differed from existing transcriptions in table 1 in a number of respects: T1 has a higher f0 onset and consequently a more pronounced fall; T2 and T3 both have an overall lower pitch than expected, and T2 also has a more pronounced rise; T4, on the other hand, has a lower f0 offset and hence also a more pronounced fall. We surmise that some of these differences may have stemmed from the influence of SC and the Beijing dialect. For instance, the lower f0 of T2 may have resulted from assimilation to T2 (35) in SC, which has a lower f0 than traditional Tianjin, and the lower f0 offset of T4 may have also come from the more drastic fall of T4 (51) in SC. The cause of the f0 onset raising for T1 is less clear, but may have also stemmed from the higher f0 onset of the corresponding T1 (55) in SC. The fact that the offset of T1 still remains low despite the high offset of T1 in SC, then, may be due to the need to maintain the contrast between T1 and T2 in Tianjin. In other words, tones in Tianjin may be influenced by the corresponding tones in SC, but only to the extent that the contrasts are still clearly maintained.

As likely as the SC influence interpretation is, it is important to recognize that without data from different age groups in both Tianjin and SC (or Beijing), our experiment was simply not designed to directly test the hypothesis regarding the influence of SC on Tianjin. This interpretation was therefore only offered as a speculative scenario that has led to the differences between our citation tone results and the traditional descriptions, and whether it can withstand rigorous experimental testing awaits future research.

6.2. Disyllables – Tone Sandhi

Our disyllabic tone sandhi results verified a number of changes in the sandhi pattern previously reported: the surface form of T1 + T1 has shifted from T3 + T1 to T2 + T1 à la Lu [1997, 2004] and Shi and Wang [2004]; the T4 + T4 sandhi has generally become obsolete [Liu and Gao, 2003; Gao, 2004; Shi and Wang, 2004], and two Half-Third Sandhi patterns have emerged [Wee, 2004]. It is likely that these changes have also come from the influence of SC.

The change from T3 to T2 as the sandhi tone of T1 may have been caused by the lowering of the pitch for both T2 and T3 in the inventory as the potential result of SC influence mentioned above. In Chinese dialects, sandhi tones are often reported to be diachronically more conservative than citation tones [Ting, 1984, 1996], likely due to the higher frequency of usage of the disyllabic forms. For example, the T2 and T3 distinction in the Northern dialect Yinchuan [Zhang, 1984] is only preserved in the sandhi context, but merged in the citation context [Ting, 1996, pp.153–154]. Therefore, if the pitch of the sandhi tone has remained the same while the citation tones T2 and T3 have both become lower, it would cause the sandhi tone to look more like T2 than T3.

The disappearance of the T4 + T4 sandhi attested in our study has been attributed to the influence of SC by Liu and Gao [2003] and Gao [2004], as T4 + T4 does not undergo sandhi in SC. We echo this interpretation here.

The Half-Third Sandhi before T2 and T4 may have come from the Half-Third Sandhi in SC due to the similarity between the two patterns. Yet we cannot rule out the possibility that Tianjin developed this sandhi on its own due to the phonetic nature of the sandhi, as the sandhi reduces a full rising tone to a smaller rise in nonfinal position [Zhang, 2002; Zhang and Lai, 2010].

Similar to the discussion on monosyllables, the influence of SC that we have offered as an interpretation here should be verified with experiments specifically designed to test it, and we leave this as a topic of future research.

Our tone sandhi results also echo the sentiment in Zhang [2010] about the prevalence of variations and exceptions in Chinese tone sandhi patterns. Due to the influence of the dominant dialect SC, the increasingly close contacts among different dialects of Chinese, and the differences between literary and colloquial pronunciations in many Chinese dialects, variations and exceptions are par for the course for tone sandhi as well as many other phonological patterns in Chinese. Our results indicate that this is true for Tianjin as well. The nature of variations attested here is complex as well. With respect to particular lexical items, we have seen variations on both interspeaker and intraspeaker levels. Many language-internal and sociolinguistic factors may have contributed to this complex picture of variation, from lexical frequencies for individual speakers to the speakers' age, geographic background, and educational levels. Our study is unfortunately not of a large enough scale to allow any of these factors to be analyzed in detail, but it at least points to areas that future studies on Tianjin and other dialects of Chinese can investigate. If our result on Tianjin is any indication, the tone sandhi patterns in Chinese dialects overall can provide a fertile ground for our exploration of the speakers' phonological knowledge when variations and exceptions exist – a timely and important issue in phonological theory [Coetzee and Pater, 2011].

Finally, our sandhi results indicate that many of the sandhi patterns are acoustically non-neutralizing, contra traditional descriptions. Similar results have been obtained for the Third-Tone Sandhi in SC. Acoustic studies by Zee [1980b], Shen [1990], and Xu [1993] on SC spoken by mainland speakers showed that the Third-Tone Sandhi did not cause complete neutralization with T2, and the sandhi tone was found to be lower than T2 by anywhere from 3.2 [Xu, 1993] to 17.5 Hz [Zee, 1980b]. Acoustic studies on Taiwan Mandarin returned conflicting results: Peng [2000] found a significant 2.3 Hz difference between T2 and sandhi T3, while Myers and Tsay [2003] showed no significant difference between the two tones. Our results are the first to our knowledge that show the acoustic non-neutralizing nature of the Third-Tone Sandhi in a non-SC dialect, and the magnitude of the acoustic difference is comparable to that of Zee [1980b] for SC. Perception-wise, studies have shown that native speakers cannot distinguish T2 and sandhi T3 in SC [Wang and Li, 1967; Peng, 2000]. Whether the Tianjin T3 + T3 sandhi represents incomplete neutralization perceptually remains a topic for future research.

The acoustic non-neutralization of the Half-Third Sandhi has intriguing phonological consequences. It is interesting to note that the Half-Third Sandhi in Tianjin does not affect T3 before a T1 like it does in SC – the f0 of T3 remains a full rising tone, which can be seen in figures 4 and 6. It is tempting to interpret this sandhi blocking as a classic phonological conspiracy: the application of the sandhi would have resulted in two adjacent low falling tones – an illegal output for Tianjin (recall that T1 + T1 must undergo sandhi). Under this interpretation, it looks like that the influence of SC on Tianjin, if any, is selective in an interesting way: Tianjin only takes something from SC that it can tolerate. But if Half-Third Sandhi is indeed non-neutralizing and returns a low-falling-rising tone, not a low falling tone, then its application before T1 would not violate the markedness conspiracy and should therefore not be blocked. Tone sandhi behavior in trisyllabic sequences T1 + T3 + T2 and T1 + T3 + T4 further adds to this mystery. According to Wee [2004, p. 110], the Half-Third Sandhi applies to T3 in these sequences, effectively creating two adjacent low falling tones on the surface where one of them comes from a sandhied T3, indicating that this combination indeed does not violate the markedness conspiracy. Without a comprehensive study of trisyllabic tone sandhi in Tianjin, we can only offer a conjecture to this conundrum. Wee [2004, p. 112] has shown that in Tianjin, a tonal combination that can potentially undergo tone sandhi cannot surface on the final disyllabic sequence in a sandhi domain, but is sometimes tolerated earlier in the sandhi domain. For example, a base /T2 + T1 + T1/ sequence like *liŋ tɕʰi san* 'zero-seven-three' must undergo sandhi to become [T2 + T3 + T1], while a base /T1 + T1 + T2/ sequence *san san liŋ* 'three-three-zero' can be pronounced with either [T1 + T1 +T2] or [T3 + T1 + T2]. The toleration of a T1 plus a sandhied T3 in the first two syllables of a trisyllabic sequence, but the illegality of it in a disyllable, is then likely due to this asymmetry. The markedness conspiracy should then ban any two low-registered tones.

6.3. Disyllables – Tonal Coarticulation

Our tonal coarticulation results reaffirmed a number of generalizations in the small but growing typology of this phenomenon: the assimilatory nature of carryover effects and the dissimilatory nature of anticipatory effects, the greater magnitude of carryover effects than anticipatory effects, and the asymmetries between High and Low tones as triggers and targets of coarticulation in either direction.

6.4. General Discussion

Our acoustic study on tonal realizations of Tianjin highlights the value of detailed acoustic studies to our understanding of tone patterns, a point also made in Zhang [2010]. The phonetic nature of tones in the inventory of Tianjin has been a contentious issue from the get-go and different researchers have made different assumptions about their representations, often based on impressionistic transcriptions. Our results showed that the citation tones in Tianjin are composed of two falling tones and two rising tones, casting doubt on the analyses of Tianjin tones and tone sandhi based on the two-level and two-contour inventory. Moreover, our results pointed to the ways in which Tianjin tones may have been influenced by the cognate tones of SC such as the lowering of T2 and T3, and these effects provide insight into the behavior of tone sandhi in Tianjin, such as the shift of the surface realizations of T1 + T1 from T3 + T1 to T2 + T1. From the tone sandhi perspective, a categorical and neutralizing nature of tone sandhi is often assumed in dialectological fieldwork in Chinese, and the sandhis are often described as the changes from one tonal category to another. Without detailed acoustic studies, the true nature of at least some of the sandhis as being gradient (both in terms of individual differences and acoustically gradient realization of the sandhis) and non-neutralizing would not have come to the surface.

Despite the gradient and variable nature of many of the tone sandhi processes, it was not difficult to differentiate tone sandhi from tonal coarticulation in Tianjin. This may have been due to the fact that tone sandhi in Tianjin is right-dominant, and regressive tonal coarticulation in Tianjin, like in other languages, is of small magnitude. It is also interesting to note that although many of the tone sandhi processes in Tianjin can be characterized as phonologically dissimilatory in nature, they do not share properties with regressive tonal coarticulation. For example, the T1 + T1 → T3 (T2) + T1 sandhi can be considered as phonological dissimilation between two like tones, but the effect of the sandhi is to turn the Low offset of the first T1 into a High offset, which disagrees with the coarticulation generalization that regressive dissimilation affects High targets more than Low targets. The same is true for T4 + T1 → T2 + T1, which can be considered as the dissimilation between two falling tones, but its raising of the Low offset of T4 again finds no parallel in regressive tonal coarticulation. Therefore, it does not seem the case that the tone sandhi processes in Tianjin are truly rooted in tonal coarticulation.

However, we do not exclude the possibility that there are tone sandhi patterns that are indeed rooted in and may in fact be difficult to tease apart from coarticulation, in particular, left-dominant sandhi patterns that involve spreading. Nor do we wish to deny the possible effects of phonetics on shaping phonological sandhi patterns, such as the leveling of tonal contours and the reduction of tonal inventories on syllables of durational disadvantage [Zhang, 2002] and the minimization of pitch turning points in a prosodic domain [Zhang, 1999; Hyman, 2007].

There have been a number of quantitative models that aim to simulate the behavior of prosodic systems that include tone, intonation, and prosodic strength. These models either directly simulate the movement of the f0 contour by using pitch targets as primitives [e.g., Xu and Wang, 2001; Prom-on et al., 2009] or derive the f0 by simulating the articulatory mechanisms responsible for f0 production [e.g., Kochanski et al., 2003; Kochanski and Shih, 2003; Fujisaki et al., 2005]. Specific parameters in the models for both the primitive targets and how the targets interact with each other can be trained from actual data, and this learning process allows the models to capture tonal coarticulation as well as other phonetic effects in f0 production such as downstepping and the interaction between duration and f0. But the effects of tone sandhi invariably have to be prespecified in these models. This is consistent with the theoretical approach in which the sandhi tone is generated through allomorph selection [Tsay and Myers, 1996; Yip, 2004; Zhang and Lai, 2008; Zhang et al., 2009, 2010] and then undergoes tonal coarticulation. In fact, this is how tonal coarticulation is analyzed in Peng [1997] and in this study (see section 5.3.1 and fig. 4). It is also possible to use these quantitative models to assess whether an ambiguous pattern is better analyzed as tone sandhi or tonal coarticulation by comparing the f0 predictions of two models, one trained with a prespecification for the sandhi tone, one trained without. Although the goal of this research is not to test the quantitative models of prosody on the market, it provides the empirical data that can potentially be used for this purpose; on the other hand, quantitative modeling is also helpful in teasing apart the sources of f0 effects. Progress in our understanding of tonal patterns, therefore, requires not only increased empirical knowledge of tone sandhi, tonal coarticulation, and other f0 effects such as the influence of sentential prosody, focus, speaking rate, etc., but also the explicit modeling of these patterns.

An additional issue worth recognizing here is that Tianjin is known for its intricate tone sandhi behavior in trisyllables, a point we already raised in the tone sandhi discussion. Trisyllabic tone sandhi in Tianjin poses serious problems to both rule- and constraint-based phonology due to the conflicting directionality (left-to-right or right-to-left application of disyllabic sandhis) required to derive all sandhi patterns, and a large literature, the most notable of which includes Hung [1987], Tan [1987], Zhang [1987], Milliken et al. [1997], Chen [2000], Wee [2004, 2010], and Lin [2008], has been devoted to it. The analyses in these works, however, are almost exclusively based on impressionistically transcribed data. Although the current work focuses on the tone patterns of disyllables, we believe that the lesson here – that many true properties of tone sandhi, such as whether it involves complete neutralization, variations, and exceptions, can only surface under careful experimental studies – is applicable to trisyllabic studies as well. We hope that our work will inspire experimental studies on tone sandhi in longer sequences in both Tianjin and other Chinese dialects to provide a more solid empirical basis on which theoretical advances can be made.

7. Concluding Remarks

We have presented here an acoustic study on the realizations of tones in Tianjin Chinese with a particular focus on the changes of tones induced by their adjacent tonal contexts. The tone changes are discussed under two different headings – tone sandhi and tonal coarticulation, a traditional classification based on the categoricity of the tone changes. Our tone sandhi study indicated a number of changes to the traditional sandhi patterns, likely due to influence from SC, and that the majority of the sandhis is non-neutralizing in the acoustic sense. In addition, there are interspeaker and intraspeaker variations in both the application of the sandhi and the neutralization properties of the sandhis. Our tonal coarticulation results confirm a number of well-known cross-linguistic properties of tonal coarticulation: the assimilatory nature of carryover effects and the dissimilatory nature of anticipatory effects, the greater magnitude of carryover effects than anticipatory effects, and the asymmetries between High and Low tones in this process, particularly the greater propensity for High to serve as both the trigger and target of carryover assimilation and target of anticipatory dissimilation. Despite the lack of categorical neutralization in tone sandhi, the distinction between tone sandhi and tonal coarticulation is clear, and despite the dissimilatory nature present in both processes, they seem to have different properties, indicating different sources for the two processes.

Our understanding of tone patterns in Tianjin can benefit from future studies in the following areas. First, although we have shown that many of the tone sandhi patterns are acoustically non-neutralizing, we still need perceptual studies to test whether the acoustic differences can be perceived by the listeners. In the case of the categorical shift of T1 + T1 from T3 + T1 to T2 + T1, perceptual studies will also reveal whether this change has been completed, and if so, in which speaker groups. Second, with the presence of variations and exceptions in the sandhi processes, it will be particularly interesting to test the productivity of the sandhis via a 'wug' test [Berko, 1958] to address the question of whether the speakers' knowledge of the tone sandhi patterns follows the lexical patterns in the language, and if not, what are the causes of overlearning (speakers having knowledge that the lexical patterns do not inform them of) and underlearning (speakers being oblivious to certain regularities in the lexicon) [Hayes et al., 2009; Zhang et al., 2009, 2011; Zhang and Liu, 2011]. Third, with results from the current study and the wug test, what does a formal model of Tianjin speakers' knowledge of tone sandhi look like? How do we capture the variations and exceptions, and if certain patterns are overlearned or underlearned from the lexicon, how does a learning model capture these effects? Lastly, what is the nature of the contact effect? We already know that the influence of SC on Tianjin is selective, as evidenced by the avoidance of the Half-Third Sandhi in the T1 context due to the illegality of T1 + T1 in Tianjin. We would also like to know how the frequencies of lexical items as used in Tianjin and SC in the speech community influence the changes in Tianjin as well as how sociolinguistic factors such as the speakers' age, geographic background, and educational levels shape the changes. A model of language contact and change should be able to make predictions on these issues that can be empirically tested.

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Appendix: Additional Stimuli Information

The 16 monosyllabic words were selected from a corpus of written Chinese compiled from online resources by Da [2004], which includes 258,852,642 total Chinese characters (each character is pronounced with one syllable in Chinese). All 16 words have a raw frequency over 20,000. The 64 disyllabic words were selected from the corpus using digram information provided by Da [2004] based on two subcorpora – one of news and one of general fiction. The two subcorpora have a total of 28,278,285 digrams, and the raw digram frequencies of the selected words fall between 166 and 43,521. To ensure that the digrams were indeed high-frequency real words rather than accidentally co-occurring morphemes due to each morpheme's high frequency, the Mutual Information Scores of the selected disyllables provided by Da's [2004] corpora were used as a criterion. The Mutual Information Score is calculated as

$$I(x,y) = \log_2 \frac{p(x,y)}{p(x)p(y)},$$

where *p(x,y)* represents the digram frequency, and *p(x)* and *p(y)* represent the frequencies of the two characters, respectively. A higher Mutual Information Score indicates a higher likelihood for the two characters to co-occur, and hence form real words. A Mutual Information Score greater than 3 indicates that the two words have a strong collocation [Oakes, 1998]. The Mutual Information Scores of our selected disyllables were all above 3.5 when averaged across the two subcorpora.

Due to the lack of corpora based on spoken Tianjin, we used Da's [2004] written Chinese corpus to approximate the frequencies of Tianjin words. There are two justifications for this. First, Tianjin and SC are closely related Northern dialects of Chinese with considerable contact due to geographical proximity. There is hence a considerable overlap in vocabulary between them. Second, different Chinese dialects share the same orthographic tradition. Chinese speakers are thus diglossic in a sense. The Chinese that our Tianjin speakers read and write is essentially the same as written SC. For these two reasons, the words selected from a written Chinese corpus reasonably approximate the knowledge of these words from our Tianjin speakers. Similar points have been made in Zhao and Jurafsky [2009] in defense of their use of an SC written corpus for a Cantonese study.

The full list of monosyllabic and disyllabic words used in the experiment are given below. The transcriptions represent the pronunciation of newer varieties of Tianjin, which have adopted the robust dental (ts, tsʰ, s) vs. retroflex (tʂ, tʂʰ, ʂ) distinctions of SC. Older varieties generally realized both series as dentals.

Monosyllabic word list:

Tone 1	他	[tʰa]	'he'	Tone 2	时	[ʂi]	'time'
	出	[tʂʰu]	'to exit'		及	[tɕi]	'to reach'
	方	[fɑŋ]	'square'		直	[tʂɨ]	'straight'
	心	[ɕin]	'heart'		白	[pai]	'white'
Tone 3	此	[tsʰɨ]	'this'	Tone 4	是	[ʂi]	'to be'
	主	[tʂu]	'main'		个	[kɤ]	measure word
	使	[ʂɨ]	'to let'		去	[tɕʰy]	'to go'
	体	[tʰi]	'body'		四	[sɨ]	'four'

Disyllabic word list:
Tone 1 + Tone X:

Tone 1	攻击	[kuŋ tɕi]	'to attack'	Tone 1	支持	[tʂɨ tʂʰɨ]	'to support'
+	非洲	[fei tʂou]	'Africa'	+	积极	[tɕi tɕi]	'positive'
Tone 1	周刊	[tʂou kʰan]	'weeklies'	Tone 2	非常	[fei tʂʰɑŋ]	'very'
	牺牲	[ɕi ʂən]	'to sacrifice'		侦察	[tʂen tʂʰa]	'to detect'
Tone 1	开始	[kʰai ʂi]	'to begin'	Tone 1	深圳	[ʂən tʂən]	city name
+	基础	[tɕi tsʰu]	'basic'	+	发布	[fa pu]	'to issue'
Tone 3	申请	[ʂən tɕʰiŋ]	'to apply'	Tone 4	颁布	[pan pu]	'to decree'
	清醒	[tɕʰiŋ ɕiŋ]	'clear-headed'		忽视	[xu ʂɨ]	'to ignore'

Tone 2 + Tone X:

Tone 2	袭击	[ɕi tɕi]	‘to attack’	Tone 2	繁荣	[fan ɹuŋ]	‘flourishing’
+	评估	[pʰiŋ ku]	‘to evaluate’	+	辞职	[tʂʰɨ tʂɨ]	‘to resign’
Tone 1	承担	[tʂʰəŋ tan]	‘to take on’	Tone 2	徒刑	[tʰu ɕiŋ]	‘time in jail’
	神舟	[ʂən tʂou]	‘Divine Land’		陶瓷	[tʰɑu tsʰɨ]	‘porcelain’
Tone 2	停止	[tʰiŋ tʂɨ]	‘to stop’	Tone 2	足够	[tsu kou]	‘enough’
+	诚恳	[tʂʰəŋ kʰən]	‘earnest’	+	群众	[tɕʰyn tʂuŋ]	‘the people’
Tone 3	弥补	[mi pu]	‘to make up’	Tone 4	培训	[pʰei ɕyn]	‘to train’
	祈祷	[tɕʰi tɑu]	‘to pray’		淘汰	[tʰɑu tʰai]	‘to eliminate’

Tone 3 + Tone X:

Tone 3	北京	[pei tɕiŋ]	‘Beijing’	Tone 3	改革	[kai kɤ]	‘to reform’
+	始终	[ʂɨ tʂuŋ]	‘always’	+	紧急	[tɕin tɕi]	‘urgent’
Tone 1	走私	[tsou sɨ]	‘to smuggle’	Tone 2	扫除	[sɑu tʂʰu]	‘to eliminate’
	纺织	[fɑŋ tʂɨ]	‘to weave’		警察	[tɕiŋ tʂʰa]	‘police’
Tone 3	反腐	[fan fu]	‘anticorruption’	Tone 3	导弹	[tɑu tan]	‘missile’
+	采访	[tsʰai fɑŋ]	‘to interview	+	恐怖	[kʰuŋ pu]	‘terrifying’
Tone 3	阻止	[tsu tʂɨ]	‘to stop’	Tone 4	保障	[pɑu tʂɑŋ]	‘to ensure’
	感慨	[kan kʰai]	‘to sigh’		储备	[tʂʰu pei]	‘to store up’

Tone 4 + Tone X:

Tone 4	信息	[ɕin ɕi]	‘information’	Tone 4	负责	[fu tsɤ]	‘responsible’
+	竞争	[tɕiŋ tʂəŋ]	‘to compete’	+	涉及	[ʂɤ tɕi]	‘to involve’
Tone 1	汽车	[tɕʰi tʂʰɤ]	‘car’	Tone 2	病毒	[piŋ tu]	‘virus’
	士兵	[ʂɨ piŋ]	‘soldier’		步伐	[pu fa]	‘pace’
Tone 4	政府	[tʂəŋ fu]	‘government’	Tone 4	逝世	[ʂɨ ʂɨ]	‘to pass away’
+	记者	[tɕi tʂɤ]	‘journalist’	+	爆炸	[pɑu tʂa]	‘the explode’
Tone 3	自己	[tsi tɕi]	‘self’	Tone 4	覆盖	[fu kai]	‘to cover’
	彻底	[tʂʰɤ ti]	‘completely’		注册	[tʂu tsʰɤ]	‘to register’

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