ON THE INTERACTION OF TONE AND STRESS IN CONTOUR TONE LANGUAGES: A PROSODIC ACCOUNT

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Abstract

In register tone languages, prominence and tone are related such that prominent (stressed) position and high tone are mutually attracted, as are non-prominent position and low tone. From the available literature, it appears that nothing is known about the relationship between stress and tone in contour tone languages. We examine this question, focusing principally on Tone 2 (T_2) sandhi in Mandarin, because it is uniformly accepted as being triggered by stress. As there is little agreement on the other factors involved in T_2 sandhi, we first undertake an experiment that seeks to better establish the facts. From the acoustic analysis of the results, we argue that T_2 sandhi applies only when T_2 syllables occur in unstressed position. We briefly extend our examination to the other three tone sandhi processes in Mandarin and conclude that all tone sandhi processes in the language are stress-driven: stress governs the realization of tone such that prominence makes tone high and rise and non-prominence makes tone level. We conclude more generally that a bipartite relationship holds between stress and tone in contour tone languages: there is a correlation between high/(low) register and the presence/(absence) of stress, and a correlation between contour/(level) tone and the presence/(absence) of stress.

1. Introduction.

Prosodic systems can be broadly divided into two types: tone systems and stress systems. There are, however, a range of systems intermediate between these two extremes, languages in which tone and stress co-occur (Hyman 2006). In register tone languages of this profile, a relationship holds between prominence and tone as follows: stressed position attracts high tone and high tone attracts stress (Liberman 1975, Selkirk 1984, 1995, Goldsmith 1987); low tone attracts non-prominence and non-prominent position attracts low tone (de Lacy 1999, 2002, 2007).

To our knowledge, nothing is known about the relationship between stress and tone in contour tone languages. Since contour tone languages represent the other major type of tone language in the world and both contour and level tones exist in such languages, understanding of the interaction between tone and stress remains incomplete until an examination of such languages is undertaken.

In this paper, we explore this understudied topic through a comprehensive look at stress–tone interaction in Mandarin. We focus on Mandarin for two reasons. First, Mandarin has an extensive tonal inventory that includes both level and contour tones and, among contours, both rising and falling tones. Second, Mandarin is perhaps the most widely studied contour tone language in the world (see Chen 2000 and references therein); the existing literature thus provides a valuable resource from which to launch an investigation into the relationship between prominence and tone.

To examine how tone and stress interact, it is of course essential to consider how tone is affected by varying the prosodic context. To this end, we focus on tone sandhi, tonal alternations that occur in connected speech (Chen 2000). We concentrate principally on Tone 2 (T_2) sandhi, as it is the only tone sandhi process in Mandarin that is uniformly accepted as being triggered by stress. Unfortunately, however, controversies exist concerning the factors involved in T_2 sandhi. We thus undertake an experiment that seeks to better establish the facts. The empirical observations that the experiment yields are quite uniform and from these we argue that T_2 sandhi applies only when T_2 syllables occur in prosodically non-prominent (unstressed) positions. We briefly extend our examination to the other three tone sandhi processes in Mandarin and conclude that all tone sandhi processes in the language are stress-driven: stress governs the realization of tone such that prominence makes tone high and rise and non-prominence makes tone level. We conclude more generally that a bipartite relationship holds between stress and tone in contour tone languages: there is a correlation between high/(low) register and the presence/(absence) of stress, and a correlation between contour/(level) tone and the presence/(absence) of stress.

The paper is structured as follows. In section 2, we introduce Mandarin T_2 sandhi; although there is general agreement that this process is triggered by stress, from the discussion provided, it will become evident that there is significant controversy regarding the other factors involved. Accordingly, after posing a set of research questions in section 3, in section 4, we detail an experiment we undertook which aims to better establish the facts. The results of the experiment, reported in section 5, prove to be quite uniform. Not surprisingly, they reveal that T_2 sandhi is in part sensitive to the tones of the surrounding syllables. In light of this, we provide our views on the tonal structures for the five Mandarin tones in section 6. As we later motivate a formal link between tonal profile and prominence, in sections 7 and 8, we examine Mandarin foot shape and the prosodic structures of di- and tri-syllabic constructions. The experimental results from section 5 are analyzed in section 9 which, in turn, leads to a prosodic licensing account of Mandarin T_2 sandhi, in section 10. In section 11, we briefly examine the three other tone sandhi processes in Mandarin. This analysis, in concert with our account of T_2 sandhi, reveals the formal relation between tone and stress in Mandarin and, we speculate, in contour tone languages more generally.

2. Overview of T_2 sandhi.

We begin with an overview of tone sandhi in Mandarin. Mandarin has five tones which are standardly described as follows: T_1 (high level), T_2 (high rising), T_3 (low dipping), T_4 (high falling) and T_0 (neutral tone).[1] All morphemes are monosyllabic and each morpheme underlyingly bears tone: lexical morphemes are underlyingly specified for T_1 to T_4; function morphemes bear T_0.

Mandarin has four tone sandhi processes: T_0 sandhi, T_3 sandhi, *yi-bu-qi-ba* sandhi and T_2 sandhi (e.g. Chao 1968). For the first three, there is little dispute about the factors involved (see further section 11.2). This is not the case for T_2 sandhi. As a first attempt, we can describe T_2 sandhi as simplification of T_2 (high rising) to T_1 (high level) when unstressed in medial position in a trisyllabic construction. However, there are unresolved questions regarding most aspects of this process. To highlight the extent of the disagreement in the literature, Table 1 summarizes the findings of four proposals: Chao (1968), supplemented by Chen (2000) and Duanmu (2007); Luo & Wang (1981); Wu (1984); and Chang (1992).[2] As can be seen, disagreements concern both the conditions that must hold for T_2 sandhi to apply as well as the tonal change that T_2 undergoes.[3]

	Chao (1968), Chen (2000), Duanmu (2007)	Luo & Wang (1981)	Wu (1984)	Chang (1992)
Conditions:				
3σ constructions only	yes	yes	yes	no
Hierarchical structure			[[σ σ] σ]	
Stress as trigger	yes	yes		yes
Speech rate	conversational speech			fast speech
Initial syllable	T_1 T_2	T_1 T_2 T_3 T_4	T_1 T_2	T_1 T_2 T_4
Final syllable	T_1 T_2 T_3 T_4	T_1 T_2 T_3 T_4	when T_1 T_4, $T_2 \rightarrow T_1$; when T_2 T_3, $T_2 \rightarrow T_4$	T_1 T_2 T_3 T_4
Tonal change:	T_1	T_1	T_1 T_4	T_1

Table 1.
Factors relevant for T_2 sandhi

Concerning the domain in which T_2 sandhi applies, all researchers agree that the process targets the medial syllable in trisyllabic constructions. Chang (1992), however, states that T_2 sandhi can target the final syllable in disyllabic constructions as well.

Wu (1984) is the only researcher to address the role that the hierarchical structure of trisyllabic constructions may play. He concludes that T_2 sandhi is principally attested in left-branching ([[σ σ] σ]) rather than right-branching ([σ [σ σ]]) constructions. From the examples he provides, it is evident that the difference corresponds to word-internal versus phrase-level structure: left-branching structures are morphologically-complex words; right-branching structures are phrases.

If T_2 sandhi targets the medial syllable in trisyllabic constructions, the affected T_2 (high rising) has the potential to be in foot dependent position. It is perhaps not surprising, then, that all researchers who examine the factor of stress agree that T_2 sandhi is triggered when the syllable bearing T_2 is unstressed (Luo & Wang 1981, Chang 1992, Chen 2000, Duanmu 2007). The agreement, however, appears to end there. Luo & Wang do not discuss how stress is assigned in Mandarin so we cannot glean anything further from their proposal. Chen (2000) uses T_2 sandhi to support a right-prominent rhythmic structure for Mandarin although an account of T_2 sandhi like his seems equally possible when assuming a trochaic foot as in Chang (1992) and Duanmu (2007). Indeed, if Mandarin is trochaic and if Wu's observations about branching are correct, then the second syllable in a left-branching structure would be in foot dependent position. We return to this below.

If stress can be affected by speech rate, it would not be surprising to find that some researchers, namely Chao (1968) and Chang (1992), consider speech rate to be relevant to the application of T_2 sandhi. Chao remarks that T_2 sandhi is attested in what he terms conversational speech but not in deliberate speech. Chang claims that T_2 sandhi is attested in fast speech, but she does not mention whether this should be equated with Chao's conversational speech.

Turning to the tonal profile of the syllables surrounding the targeted T_2 (high rising), significant variation is observed across researchers. Luo & Wang's (1981) proposal is the most permissive: they consider T_2 sandhi to apply when both the initial and final syllables bear any tone except T_0 (neutral tone). Other researchers have concluded that the profile of the initial syllable is more restricted: Chang (1992) states that an initial T_3 (low dipping) rarely triggers T_2 sandhi, something which is considered to be outright forbidden by Chao (1968) and Wu (1984) as well. The latter researchers also do not consider an initial T_4 (high falling) to be a potential trigger.

Regarding the tonal change that T_2 (high rising) undergoes, all researchers agree that the contour of T_2 is simplified into a level tone, namely T_1 (high level). Wu's (1984) proposal, however, is more restricted: T_1 results only when the final syllable bears T_1 (high level) or T_4 (high falling); T_2 is otherwise changed into T_4.

3. Research questions.

We have observed that there is disagreement regarding virtually all of the factors involved in T_2 sandhi. In light of this, we undertake an experiment that strives to better establish the facts. The empirical and theoretical questions that we address in the experiment and ensuing analysis are as follows.

(1) *Empirical questions*

a. Does T_2 sandhi apply in disyllabic as well as in trisyllabic constructions?
b. Does speech rate play a role in the application of T_2 sandhi?
c. Does hierarchical structure play a role in the application of T_2 sandhi?
d. What are the tones carried by the initial and final syllables which trigger T_2 sandhi?
e. What is the sandhi form of T_2?

(2) *Theoretical questions*

a. What kind of stress system does Mandarin have, and how does footing and prosodic structure more generally interact with T_2 sandhi?
b. If T_2 sandhi is induced when the T_2 syllable lacks stress, why are other tones not subjected to similar sandhi processes in this environment?

We turn to the design of the experiment in the next section.

4. An experiment on T_2 sandhi.

Surprisingly, no experiment, to our knowledge, has been undertaken which specifically targets T_2 sandhi in Mandarin. This may, in part, be responsible for the disagreement observed across researchers as to the factors involved in this sandhi process.

Dreher et al. (1969) and Wu (1984) report on experiments which examine trisyllabic constructions, but both experiments were designed to test these constructions with several types of tonal combinations: the medial syllable ranged from T_1 to T_4. For both papers, it is difficult to assess how robust the findings are for T_2 sandhi: Dreher et al. include only 16 forms with medial T_2 (high rising) and Wu does not indicate how many constructions in his experiment were relevant for T_2 sandhi. A further complication for both studies is that most other factors were not controlled, which may, of course, have impacted the results.[4]

Concerning the design of the present experiment, factors relevant to both stimulus shape and subject profile were taken into consideration.

4.1. Methods. In the following sections, we present the experimental design through discussion of the factors that were controlled.

4.1.1. Language-internal factors. In order to test whether T_2 sandhi is attested in disyllabic as well as in trisyllabic constructions, both kinds of constructions were included in the experiment. The tones present on the syllables preceding and following the targeted T_2 syllable were controlled. For trisyllabic stimuli, the hierarchical structure of the construction was also controlled.

Since an initial or final T_0 (neutral tone) has never been reported to trigger T_2 sandhi, constructions with these tones were not included. The trisyllabic stimuli used in the experiment are those with the medial syllable set to T_2 and the initial and final syllables ranging from T_1 to T_4. Both left-branching ([[σ σ] σ]) and right-branching ([σ [σ σ]]) structures were included because these constructions minimally contrast as far as the relationship of the medial syllable to surrounding syllables is concerned. The left-branching structures were words of the shape $[[N\ N]\ N]_N$ or $[[A\ N]\ N]_N$; the right-branching structures were phrases of the shape $[A\ [N\ N]]_{NP}$ or $[V\ [N\ N]]_{VP}$. This yields a total of 32 stimuli; see (3).

(3) *Trisyllabic constructions*

[[σ	σ]	σ]	[σ	[σ	σ]]
T_1	T_2	T_1	T_1	T_2	T_1
T_2		T_2	T_2		T_2
T_3		T_3	T_3		T_3
T_4		T_4	T_4		T_4

For disyllabic constructions, in order to determine whether it is the initial or final syllable that triggers T_2 sandhi, eight constructions were included with T_2 located in initial or final position, as shown in (4). All of these stimuli were morphologically-complex words.

(4) *Disyllabic constructions*

T_2	T_1	T_1	T_2
	T_2	T_2	
	T_3	T_3	
	T_4	T_4	

Taken together, the trisyllabic and disyllabic constructions yield a total of 40 stimuli. All stimuli contained commonly used words in Mandarin.

Turning to the syllable bearing T_2 (high rising), the segments in the onset and rhyme of this syllable were controlled as follows. Consonants usually have an effect on the pitch carried by the following vowel (see Hombert 1978). Because voiceless unaspirated stops and affricates become voiced in Mandarin in the onset of an unstressed syllable (Luo & Wang 1981), we limited the initial consonant of the T_2 syllable to voiceless aspirated. Although the Mandarin vowel inventory contains both monophthongs and diphthongs, the latter are inherently longer than the former (Feng 1985); in order to limit variation in the length of the rhyme across stimuli to the extent possible, the rhyme of the medial vowel was restricted to monophthongs, /i u a/.[5]

In addition, as syllables in phrase-final position are usually lengthened in Mandarin (Feng 1985, Wang & Wang 1993) and this may have an effect on T_2 sandhi, the stimuli were placed in the carrier sentence in (5) in order to minimize any lengthening effect on their final syllables.

(5) [ʂ̥uu$_1$ ʂ̥aŋ$_4$ məi$_2$ jəu$_3$ __ __ __ san$_1$ kɤ$_4$ tsii$_4$]
book up no have __ __ __ three CL character
'There are no three characters __ __ __ in the book.'

Finally, the syllable immediately following the stimuli in the carrier sentence was also controlled in order to minimize any influence it could have on the preceding syllable. The morpheme [san_1] 'three' was chosen since it bears T_1 (high level) and its initial consonant is a sibilant, both of which rarely affect the pitch of the preceding syllable.

4.1.2. Language-external factors. Two major language-external factors that may have an effect on T_2 sandhi are the profile of the subjects participating in the experiment and the rates at which the stimuli are spoken.

Concerning the subjects, data were collected from three female native speakers of Mandarin who were 38 years old at the time of testing and had the same level of education (BA or higher). All subjects were born in Harbin and had lived in this city continuously since they were born. Harbin was selected because the dialect spoken in this city is quite homogeneous and is considered to be the most representative of Standard Chinese (Ying 2002).[6]

To ensure that speech rate could be examined, subjects were asked to read each sentence at three different speech rates: fast, moderate and slow.[7] The goal was to be able to compare speech rates both within and across speakers. In order to best control a given speech rate across items, each subject read all 40 sentences at one speech rate before going through the list again at a different speech rate.

Each of the three speakers read 40 sentences at three different speech rates yielding a total of 360 data points for analysis.

4.1.3. Recording conditions. The stimuli were recorded in a professional music studio in Harbin. Recording conditions were controlled across subjects.

4.1.4. Phonetic analysis. The stimuli were first isolated from the carrier sentence. The pitch contour of the syllables carrying T_2 (high rising) was then examined in pitch tracking graphs, narrow band spectrograms as well as pulse intervals in expanded waveforms. All phonetic analysis was conducted in Praat (Boersma & Weenink 2010).

5. Results.

Before we present the experimental results, recall the empirical questions introduced in (1) as follows: (a) Does T_2 sandhi apply in disyllabic as well as in trisyllabic constructions? (b) Does speech rate play a role in the application of T_2 sandhi? (c) Does hierarchical structure play a role in the application of T_2 sandhi? (d) What are the tones carried by the initial and final syllables which trigger T_2 sandhi? (e) What is the sandhi form of T_2? In the following sections, we present the findings in answer to each of these questions.

5.1. Disyllabic constructions. Recall that two types of disyllabic constructions were included in the experiment: half had an initial T_2 (high rising) syllable and half a final T_2 syllable. In the constructions with T_2 in initial position, T_2 remains as a rising pitch in all three speakers' productions at all three speech rates. The only exception was one token spoken by Speaker 1 in fast speech shown in (6). We return to this example in section 9.3.3.

(6) /$tɕ^hii_2$ p^hau_2/ → [$tɕ^hii_1$ p^hau_2] 'cheong-sam' (woman's gown in Qing Dynasty)

In the constructions with T_2 in final position, T_2 similarly always keeps its citation tone, for all speakers' productions at all three speech rates. No speaker variation was observed.

In answer to question (1a), the experimental results indicate that T_2 sandhi is not attested in disyllabic constructions contra Chang (1992).

5.2. Trisyllabic constructions. T_2 sandhi was robustly attested in trisyllabic constructions under certain conditions. One of these conditions was speech rate; we discuss this first.

5.2.1. Speech rate. Each speaker was quite uniform in her productions for a given speech rate. There was, however, some variation across speakers. Speaker 3 always spoke faster than the other two subjects. Her moderate speech rate was equivalent in duration to the fast speech rate of the other speakers: the stimuli for her moderate speech and for the other two speakers' fast speech fell within the range of 500-690ms. We will thus group Speaker 3's moderate speech with the two other speakers' fast speech and label all of these utterances as 'fast speech'.[8]

In response to question (1b), we observe that T_2 sandhi is attested in fast speech only (within the range of 500-690ms), consistent with the findings of Chang (1992). In moderate and slow speech, T_2 (high rising) keeps its citation tone intact. This is not surprising if differences in speech rate reflect differences in prosodic structure: it is only in fast speech that medial T_2 lacks stress and undergoes T_2 sandhi.

5.2.2. Sandhi form of T_2. Before turning to the other factors that potentially affect T_2 sandhi, we briefly discuss the sandhi form of T_2 (high rising), question (1e). Because T_2 sandhi is attested in fast speech only and the targeted syllable is in unstressed position, it is not surprising that our experimental results reveal that the process involves simplification of T_2 to a level pitch. We will follow common practice in indicating the sandhi form of T_2 as T_1 (high level); in reality, however, we observe that the sandhi form is either high or mid: it is high level (equivalent to T_1) after another T_1 or T_2 (high rising) and mid level after T_4 (high falling).[9]

5.2.3. Hierarchical structure. Turning to (1c), the question of whether hierarchical structure plays a role in the application of T_2 sandhi, recall that the trisyllabic stimuli included both left- and right-branching structures (words and phrases respectively). A summary of the results, organized into columns by hierarchical structure, is given in Figure 1. The stimuli are arranged in blocks, A-D, according to the tone of the first syllable. The tonal patterns enclosed in the boxes are those where T_2 sandhi is attested. Those in boldface are where variation across speakers is observed. Four of the variable patterns are contained inside the relevant box; this indicates that two of the three speakers displayed T_2 sandhi in their outputs, suggesting that this is the preferred pattern.[10] For the fifth variable pattern, T_2 sandhi was attested only in one speaker's outputs and, thus, it is not boxed.

	[[σ σ] σ]	[σ [σ σ]]
A.	T_1 T_2 T_1	T_1 T_2 T_1
	T_1 T_2 T_2	**T_1 T_2 T_2**
	T_1 T_2 T_3	T_1 T_2 T_3
	T_1 T_2 T_4	T_1 T_2 T_4
B.	T_2 T_2 T_1	T_2 T_2 T_1
	T_2 T_2 T_2	T_2 T_2 T_2
	T_2 T_2 T_3	T_2 T_2 T_3
	T_2 T_2 T_4	T_2 T_2 T_4
C.	T_3 T_2 T_1	T_3 T_2 T_1
	T_3 T_2 T_2	T_3 T_2 T_2
	T_3 T_2 T_3	T_3 T_2 T_3
	T_3 T_2 T_4	T_3 T_2 T_4
D.	T_4 T_2 T_1	**T_4 T_2 T_1**
	T_4 T_2 T_2	T_4 T_2 T_2
	T_4 T_2 T_3	**T_4 T_2 T_3**
	T_4 T_2 T_4	T_4 T_2 T_4

Figure 1.
Summary of experimental results

As can be seen from the figure, the hierarchical structure of the constructions alone cannot predict whether or not T_2 sandhi will apply. Rather, it interacts with the tonal profile of the surrounding syllables. In view of this, we turn now to discuss the role of the initial and final syllables. We will revisit the issue of hierarchical structure in section 5.2.6.

5.2.4. Tonal profile of initial syllable. Turning to question (1d), a glance at Figure 1 reveals that the tone carried by the initial syllable has a significant effect on the application of T_2 sandhi; the tone carried by the final syllable seems to play a less important role.

An initial T_1 (high level) triggers T_2 sandhi in all of the left-branching trisyllabic constructions, as can be seen in the first column for A in Figure 1. Representative examples are provided in (7). The medial T_2 (high rising) is realized as a level pitch which we indicate as T_1 (as per section 5.2.2). Importantly, the vowel which undergoes T_2 sandhi is realized as short; we discuss this further in section 9.2.

(7c) reveals that variation is observed across speakers when the final syllable bears T_3 (low dipping). The preferred pattern appears to be the sandhi output, displayed by Speakers 2 and 3 (S2 and S3).[11] We address speaker variation more concretely in sections 9.3.3 and 9.3.4.

(7) *[[σ₁ σ₂] σ]*

a.	/tʂʷuu$_1$ pʰii$_2$ pau$_1$/	→	[tʂʷuu$_1$ pʰi$_1$ pau$_1$]	‘handbags made of pig skin’
b.	/tʂən$_1$ tʂʰaa$_2$ pʰai$_2$/	→	[tʂən$_1$ tʂʰa$_1$ pʰai$_2$]	‘scout platoon’
c.	/kʷan$_1$ tʂʰaa$_2$ sʷo$_3$/	→	[kʷan$_1$ tʂʰa$_1$ sʷoo$_3$]	‘Observation Office’ (S2 & S3)
		→	[kʷan$_1$ tʂʰaa$_2$ sʷo$_3$]	(S1)
d.	/kʷan$_1$ tʂʰaa$_2$ ʂau$_4$/	→	[kʷan$_1$ tʂʰa$_1$ ʂau$_4$]	‘sentry post’

For right-branching structures, the second column for A in Figure 1 indicates that T_2 sandhi is attested when the final syllable bears T_1 (high level) as shown in (8a), but not when this syllable bears T_3 (low dipping) and T_4 (high falling); see (8c-d).[12] Speakers vary when the final syllable bears T_2 (high rising), as the examples in (8b) show, with no application of T_2 sandhi seeming to be the preferred pattern.

(8) *[σ$_1$ [σ$_2$ σ]]*
a. /ɕəu$_1$ p^{h}ii$_2$ pau$_1$/ → [ɕəu$_1$ p^{h}i$_1$ pau$_1$] 'to repair leather handbags'
b. /xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$/ → [xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$] 'black teapot' (S2 & S3)
→ [xəi$_1$ tʂ^{h}a$_1$ x^{w}uu$_2$] (S1)
c. /k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$/ → [k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$] 'to run a tea house'
d. /tʂ^{h}ii$_1$ tʂ^{h}aa$_2$ tan$_4$/ → [tʂ^{h}i$_1$ tʂ^{h}aa$_2$ tan$_4$] 'to eat tea eggs'

In sum, as far as an initial T_1 (high level) is concerned, both the tones carried by the final syllable and the hierarchical structure of the constructions are relevant for the application of T_2 sandhi: left-branching structures always undergo T_2 sandhi; right-branching structures only display T_2 sandhi when the final syllable bears T_1 (high level).

Turning to B in Figure 1, those cases where the initial syllable bears T_2 (high rising), T_2 sandhi is attested across the board, regardless of the tones carried by the final syllable as well as the hierarchical structure of the stimuli. Furthermore, no speaker variation is attested. Representative examples are in (9) and (10).

(9) *[[σ$_2$ σ$_2$] σ]*
a. /pai$_2$ p^{h}ii$_2$ ʂ^{w}uu$_1$/ → [pai$_2$ p^{h}i$_1$ ʂ^{w}uu$_1$] 'white covered book'
b. /wəi$_2$ tɕ^{h}ii$_2$ p^{h}an$_2$/ → [wəi$_2$ tɕ^{h}i$_1$ p^{h}an$_2$] 'encirclement chess board'
c. /tʂ^{h}əŋ$_2$ tʂ^{wh}uu$_2$ fa$_3$/ → [tʂ^{h}əŋ$_2$ tʂ^{wh}u$_1$ faa$_3$] 'multiplication and division'
d. /n^{j}əu$_2$ p^{h}ii$_2$ tai$_4$/ → [n^{j}əu$_2$ p^{h}i$_1$ tai$_4$] 'belt made of calf skin'

(10) *[σ$_2$ [σ$_2$ σ]]*
a. /pai$_2$ p^{h}ii$_2$ fuu$_1$/ → [pai$_2$ p^{h}i$_1$ fuu$_1$] 'white skin'
b. /x^{w}əŋ$_2$ tɕ^{h}ii$_2$ p^{h}au$_2$/ → [x^{w}əŋ$_2$ tɕ^{h}i$_1$ p^{h}au$_2$] 'red cheong-sam'
c. /pai$_2$ p^{h}uu$_2$ ts^{h}au$_3$/ → [pai$_2$ p^{h}u$_1$ ts^{h}au$_3$] 'white club grass'
d. /lan$_2$ p^{h}ii$_2$ k^{wh}uu$_4$/ → [lan$_2$ p^{h}i$_1$ k^{wh}uu$_4$] 'blue leather pants'

C in Figure 1 reveals that the constructions with an initial T_3 (low dipping) are the mirror image of those with an initial T_2 (high rising). No T_2 sandhi is ever attested, regardless of hierarchical structure and the tone carried by the final syllable. There is also no variation observed across speakers. Examples are provided in (11) and (12).

(11) *[[σ$_3$ σ$_2$] σ]*
a. /ʂəu$_3$ t^{h}ii$_2$ ɕaŋ$_1$/ → [ʂəu$_3$ t^{h}ii$_2$ ɕaŋ$_1$] 'suitcase'
b. /k^{h}au$_3$ tʂ^{h}aa$_2$ t^{wh}an$_2$/ → [k^{h}au$_3$ tʂ^{h}aa$_2$ t^{wh}an$_2$] 'delegation of investigation'
c. /tɕan$_3$ tʂ^{h}aa$_2$ ʂ^{w}u$_3$/ → [tɕan$_3$ tʂ^{h}aa$_2$ ʂ^{w}u$_3$] 'Inspection Bureau'
d. /tsau$_3$ tʂ^{h}aa$_2$ t^{j}an$_4$/ → [tsau$_3$ tʂ^{h}aa$_2$ t^{j}an$_4$] 'dim-sum restaurant'

(12) *[σ$_3$ [σ$_2$ σ]]*
a. /x^{w}au$_3$ tɕ^{h}ii$_2$ ʂii$_1$/ → [x^{w}au$_3$ tɕ^{h}ii$_2$ ʂii$_1$] 'a good rider'
b. /ɕau$_3$ p^{h}aa$_2$ tʂ^{wh}əŋ$_2$/ → [ɕau$_3$ p^{h}aa$_2$ tʂ^{wh}əŋ$_2$] 'a small reptile'
c. /ləŋ$_3$ tʂ^{h}aa$_2$ ʂ^{w}əi$_3$/ → [ləŋ$_3$ tʂ^{h}aa$_2$ ʂ^{w}əi$_3$] 'cold tea'
d. /mai$_3$ tʂ^{h}aa$_2$ ʂ^{w}uu$_4$/ → [mai$_3$ tʂ^{h}aa$_2$ ʂ^{w}uu$_4$] 'to buy tea plants'

Consider, finally, the patterns in D in Figure 1, those with an initial T_4 (high falling). The first column indicates that T_2 sandhi is attested in left-branching constructions when the final syllable carries T_1 (high level) or T_2 (high rising); see the examples in (13a-b). Speakers vary when the final syllable bears T_3 (low dipping) as shown by the examples in (13c), and no T_2 sandhi is ever attested when the final syllable bears T_4 (high falling), as exemplified in (13d).

(13) *[[σ$_4$ σ$_2$] σ]*

a.	/x^{w}au$_4$ tɕ^{h}ii$_2$ ɕəŋ$_1$/	→ [x^{w}au$_4$ tɕ^{h}i$_1$ ɕəŋ$_1$]	‘curiosity’	
b.	/ʂii$_4$ t^{h}ii$_2$ tɕii$_2$/	→ [ʂii$_4$ t^{h}i$_1$ tɕii$_2$]	‘test collections’	
c.	/lai$_4$ p^{h}ii$_2$ kəu$_3$/	→ [lai$_4$ p^{h}i$_1$ kəu$_3$]	‘rascal’	(S1 & S3)
		→ [lai$_4$ p^{h}ii$_2$ kəu$_3$]		(S2)
d.	/tii$_4$ t^{wh}uu$_2$ ts^{h}ɤɤ$_4$/	→ [tii$_4$ t^{wh}uu$_2$ ts^{h}ɤɤ$_4$]	‘atlas’	

The second column for D in Figure 1 reveals that in right-branching constructions with an initial T_4 (high falling), T_2 sandhi is uniformly attested when the final syllable carries T_2 (high rising) or T_4 (high falling), as shown in the examples in (14b) and (14d). Variation is observed when this syllable bears T_1 (high level) or T_3 (low dipping), as can be seen in (14a) and (14c). Interestingly, in the latter two cases, when no T_2 sandhi is attested, special emphasis on the medial syllable can be detected, which is manifested by a wider pitch range and longer duration (see also Luo & Wang 1981).

(14) *[σ$_4$ [σ$_2$ σ]]*

a.	/p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$/	→ [p^{h}ai$_4$ tɕ^{h}i$_1$ p^{j}əŋ$_1$]	‘to engage soldiers in a surprise attack’	(S1 & S3)
		→ [p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$]		(S2)
b.	/taa$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$/	→ [taa$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$]	‘cello’	
c.	/tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$/	→ [tɕəu$_4$ tɕ^{h}i$_1$ p^{h}u$_3$]	‘used chess manual’	(S1& S3)
		→ [tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$]		(S2)
d.	/x^{w}aa$_4$ t^{wh}uu$_2$ x^{w}aa$_4$/	→ [x^{w}aa$_4$ t^{wh}uu$_2$ x^{w}aa$_4$]	‘to draw a picture’	

In short, similar to what was observed with initial T_1 (high level), in the case of initial T_4 (high falling), both the tones carried by the final syllable and the hierarchical structure of the trisyllabic constructions affect the application of T_2 sandhi.

The results for the initial syllable in trisyllabic constructions can be briefly summarized as follows. An initial T_2 (high rising) triggers T_2 sandhi across the board, while an initial T_3 (low dipping) never does. Initial T_1 (high level) and T_4 (high falling) both trigger T_2 sandhi on occasion, depending on the hierarchical structure of the constructions and the tonal profile of the final syllable.

5.2.5. Tonal profile of final syllable. The final syllable has an effect on T_2 sandhi only when the initial syllable bears T_1 (high level) or T_4 (high falling) as shown in A and D in Figure 1. We thus limit the discussion to cases where the initial syllables have these profiles.

When the final syllable bears T_1 (high level), it virtually always triggers T_2 sandhi regardless of the hierarchical structure of the stimuli. Examples are provided in (15) and (16). Variation across speakers is found with a final T_1 (high level) and an initial T_4 (high falling) in right-branching structures (see D in the second column in Figure 1). T_2 sandhi was not attested in Speaker 2’s speech, (16b), and in this case, special emphasis was detected on the medial syllable.

(15) *[[σ σ$_2$] σ$_1$]*

a.	/tʂ^{w}uu$_1$ p^{h}ii$_2$ pau$_1$/	→ [tʂ^{w}uu$_1$ p^{h}i$_1$ pau$_1$]	‘handbags made of pig skin’
b.	/x^{w}au$_4$ tɕ^{h}ii$_2$ ɕəŋ$_1$/	→ [x^{w}au$_4$ tɕ^{h}i$_1$ ɕəŋ$_1$]	‘curiosity’

(16) *[σ [σ$_2$ σ$_1$]]*

a.	/ɕəu$_1$ p^{h}ii$_2$ pau$_1$/	→ [ɕəu$_1$ p^{h}i$_1$ pau$_1$]	‘to repair leather handbags’	
b.	/p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$/	→ [p^{h}ai$_4$ tɕ^{h}i$_1$ p^{j}əŋ$_1$]	‘to engage soldiers in a surprise attack’	(S1 & S3)
		→ [p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$]		(S2)

A final T_2 (high rising) behaves differently in that hierarchical structure is relevant. Final T_2 regularly triggers T_2 sandhi in left-branching constructions (see A and D in the first column of Figure 1), as seen in the examples in (17). It seldom does, however, in right-branching constructions (see A and D in the second column of Figure 1), as shown in (18).

(17) *[[σ σ$_2$] σ$_2$]*
a. /tʂən$_1$ tʂ^{h}aa$_2$ p^{h}ai$_2$/ → [tʂən$_1$ tʂ^{h}a$_1$ p^{h}ai$_2$] 'scout platoon'
b. /ʂii$_4$ t^{h}ii$_2$ tɕii$_2$/ → [ʂii$_4$ t^{h}i$_1$ tɕii$_2$] 'test collections'

(18) *[σ [σ$_2$ σ$_2$]]*
a. /xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$/ → [xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$] 'black teapot' (S2 & S3)
→ [xəi$_1$ tʂ^{h}a$_1$ x^{w}uu$_2$] (S1)
b. /taa$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$/ → [taa$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$] 'cello'

When the final syllable bears T_3 (low dipping), variation across speakers is typically observed, as can be seen in (19)-(20).

(19) *[[σ σ$_2$] σ$_3$]*
a. /k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_3$/ → [k^{w}an$_1$ tʂ^{h}a$_1$ s^{w}oo$_3$] 'Observation Office' (S2 & S3)
→ [k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_3$] (S1)

b. /lai$_4$ p^{h}ii$_2$ kəu$_3$/ → [lai$_4$ p^{h}i$_1$ kəu$_3$] 'rascal' (S1 & S3)
→ [lai$_4$ p^{h}ii$_2$ kəu$_3$] (S2)

(20) *[σ [σ$_2$ σ$_3$]]*
a. /k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$/ → [k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$] 'to run a tea house'
b. /tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$/ → [tɕəu$_4$ tɕ^{h}i$_1$ p^{h}uu$_3$] 'used chess manual' (S1& S3)
→ [tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$] (S2)

Lastly, a final T_4 (high falling) usually does not trigger T_2 sandhi; see (21)-(22). T_2 sandhi is only attested when the initial syllable bears T_1 (high level) in left-branching structures (see A in the first column of Figure 1), as shown in (21a). No speaker variation is attested with a final T_4.

(21) *[[σ σ$_2$] σ$_4$]*
a. /k^{w}an$_1$ tʂ^{h}aa$_2$ ʂau$_4$/ → [k^{w}an$_1$ tʂ^{h}a$_1$ ʂau$_4$] 'sentry post'
b. /tii$_4$ t^{wh}uu$_2$ ts^{h}ɤɤ$_4$/ → [tii$_4$ t^{wh}uu$_2$ ts^{h}ɤɤ$_4$] 'atlas'

(22) *[σ [σ$_2$ σ$_4$]]*
a. /tʂ^{h}ii$_1$ tʂ^{h}aa$_2$ tan$_4$/ → [tʂ^{h}i$_1$ tʂ^{h}aa$_2$ tan$_4$] 'to eat tea eggs'
b. /x^{w}aa$_4$ t^{wh}uu$_2$ x^{w}aa$_4$/ → [x^{w}aa$_4$ t^{wh}uu$_2$ x^{w}aa$_4$] 'to draw a picture'

5.2.6. Hierarchical structure revisited. We have observed that the hierarchical structure of the constructions alone cannot predict whether or not T_2 sandhi will apply. Rather, it interacts with the tonal profile of the surrounding syllables, notably when the initial syllable bears T_1 (high level) or T_4 (high falling). In view of this, in the following discussion, we ignore constructions with an initial T_2 (high rising) and T_3 (low dipping).

The clearest cases in which T_2 sandhi can be seen to be sensitive to hierarchical structure are those constructions where T_2 (high rising) is both preceded by T_1 (high level) and followed by T_4 (high falling), or both preceded by T_4 (high falling) and followed by T_2 (high rising). T_2 sandhi is always attested in left-branching constructions with these tonal profiles and never in right-branching constructions, as a comparison of (23) and (24) reveals.

(23) *[[σ σ] σ]*
a. /k^{w}an$_1$ tʂ^{h}aa$_2$ ʂau$_4$/ → [k^{w}an$_1$ tʂ^{h}a$_1$ ʂau$_4$] 'sentry post'
b. /ʂii$_4$ t^{h}ii$_2$ tɕii$_2$/ → [ʂii$_4$ t^{h}i$_1$ tɕii$_2$] 'test collections'

(24) *[σ [σ σ]]*
a. /tʂ^{h}ii$_1$ tʂ^{h}aa$_2$ tan$_4$/ → [tʂ^{h}i$_1$ tʂ^{h}aa$_2$ tan$_4$] 'to eat tea eggs'
b. /taa$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$/ → [ta$_4$ t^{h}ii$_2$ tɕ^{h}əŋ$_2$] 'cello'

The effect of hierarchical structure on T_2 sandhi can also be seen in certain tonal patterns in which speaker variation is observed. When T_2 (high rising) is both preceded by T_1 (high level) and followed by T_2 (high rising), T_2 sandhi is attested in all three speakers' productions in left-branching constructions, as shown in (25), but only in one speaker's production in right-branching constructions, as shown in (26). We will suggest in section 9.3.3 below that the application of T_2 sandhi in Speaker 1's speech in (26) is due to independent factors.

(25) *[[σ σ] σ]*
/tʂən$_1$ tʂ^{h}aa$_2$ p^{h}ai$_2$/ → [tʂən$_1$ tʂ^{h}a$_1$ p^{h}ai$_2$] 'scout platoon'

(26) *[σ [σ σ]]*
/xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$/ → [xəi$_1$ tʂ^{h}aa$_2$ x^{w}uu$_2$] 'black teapot' (S2 & S3)
→ [xəi$_1$ tʂ^{h}a$_1$ x^{w}uu$_2$] (S1)

Turning to cases where the medial T_2 (high rising) is both preceded by T_1 (high level) and followed by T_3 (low dipping), T_2 sandhi is attested in left-branching constructions in the productions of two speakers, as exemplified in (27), but is never attested in right-branching constructions, as shown in (28).

(27) *[[σ σ] σ]*
/k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_3$/ → [k^{w}an$_1$ tʂ^{h}a$_1$ s^{w}oo$_3$] 'Observation Office' (S2 & S3)
→ [k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_3$] (S1)

(28) *[σ [σ σ]]*
/k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$/ → [k^{h}ai$_1$ tʂ^{h}aa$_2$ k^{w}an$_3$] 'to run a tea house'

Figure 2 summarizes the experimental results for hierarchical structure. Y indicates that T_2 sandhi is attested, V stands for variation across speakers where T_2 sandhi is attested in two speakers' productions, and an empty cell indicates that no T_2 sandhi is attested or that it is only attested in one speaker's productions.

Initial syllable	Hierarchical structure	Final syllable			
		T_1	T_2	T_3	T_4
T_1 (high level)	[[σ σ] σ]	Y	Y	V	Y
	[σ [σ σ]]	Y			
T_2 (high rising)	[[σ σ] σ]	Y	Y	Y	Y
	[σ [σ σ]]	Y	Y	Y	Y
T_3 (low dipping)	[[σ σ] σ]				
	[σ [σ σ]]				
T_4 (high falling)	[[σ σ] σ]	Y	Y	V	
	[σ [σ σ]]	V		V	

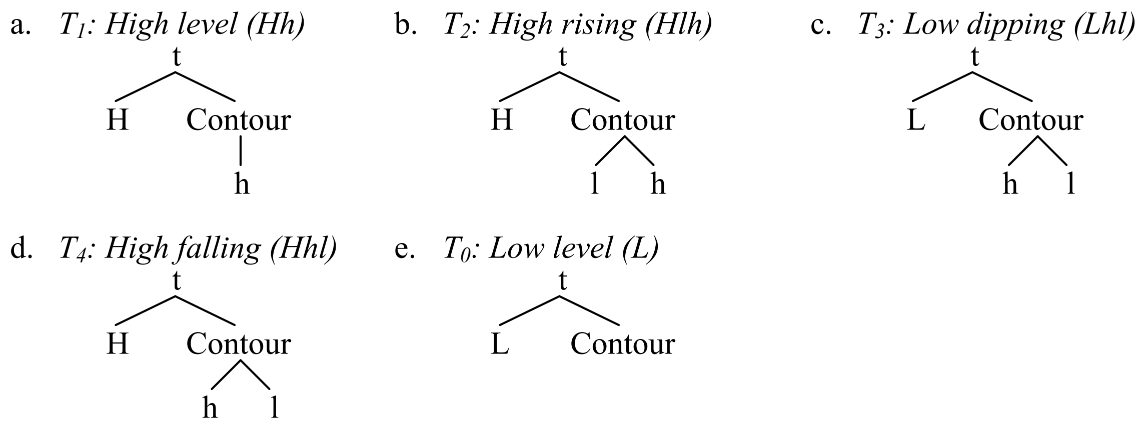
Figure 2.
Hierarchical structure in T_2 sandhi

5.2.7. Summary. Although the empirical findings of the experiment are quite uniform, we have observed that T_2 sandhi is highly complex. The process is not attested in disyllabic constructions; in trisyllabic constructions, its application is sensitive to speech rate, to the tones of both the initial and final syllables, and to the hierarchical structure of the constructions; and finally, the sandhi form of T_2 is a level pitch, either high or mid.

With answers to the five empirical questions that were introduced in (1), we turn now to the theoretical questions in (2): (a) what kind of stress system does Mandarin have, and how does footing and prosodic structure more generally interact with T_2 sandhi? (b) If T_2 sandhi is induced when the T_2 syllable lacks stress, why are other tones not subjected to similar sandhi processes in this environment? We will address (2a) first, as the answer to (2b) rests on the answer to this question. However, before we delve into Mandarin prosodic structure, we detail our assumptions about how tone is formally expressed. This is an essential first step as our assumptions about tonal complexity will be an important element in our analysis of the prosodic underpinning of T_2 sandhi.

6. Mandarin tonal structure.

We propose the structures for Mandarin tones in (29). We adopt Bao's (1990, 1999) model for formally expressing tone in contour tone languages where tone is represented by independent register and contour nodes organized under a tonal node t. H and L mark register; [h] and [l] are tonal features. Register specifies the relative pitch of a tone, while contour specifies the tonal profile over the tone bearing unit.

(29)


The tonal features of T_1, T_2 and T_4 in (29) are consistent with the analyses of Yip (1980) and Duanmu (2007). Our structure for T_3, however, departs from early work (Chao 1968; see also Woo 1969, Shih 1997) in that the 'dip' (hlh) is not part of the underlying representation we assume, because this complex contour only surfaces in limited contexts (see further sections 7 and 8.1). We also differ from the position of Yip (1980) and Duanmu (1999) who propose that T_3 is underlyingly a level tone, because T_3 always surfaces at least with a falling profile.

Turning finally to T_0, following Yip (1980), we propose that it is a low register tone that lacks tonal features (for alternative representations, see e.g. Lin 1992, Wang 1997). We have specified T_0 for low register because it never bears stress. Indeed, we will propose in section 7 that there is a formal link between register and stress in Mandarin: low register tones, T_0 (L) and T_3 (as Lhl), cannot appear in foot head position. The absence of tonal features for T_0 is motivated by the observation that its tonal specification is determined by the preceding syllable (see further section 11.2.1). More generally, we regard the presence of tonal features to be the defining property of lexical morphemes as opposed to function morphemes in Mandarin.

The structures in (29) reveal that T_2 is the only rising tone in Mandarin. In fact, its representation as Hlh makes it highly marked (as per Yip's 2002 criteria). We will argue below that its marked status is what triggers T_2 sandhi when certain prosodic conditions hold. In the following section, we detail our assumptions about prosodic structure.

7. Mandarin stress.

We assume that prosodic constituents are organized into the hierarchy in (30) (e.g. Selkirk 1980, 1986, McCarthy & Prince 1986, 1995, Nespor & Vogel 1986). Our main focus in this section is on foot shape.

(30) *Prosodic hierarchy (partial)*

Phonological Phrase (PPh)
|
Prosodic Word (PWd)
|
Foot (Ft)
|
Syllable (σ)
|
Mora (μ)

Although there is general agreement that T_2 sandhi is induced when the T_2 syllable lacks stress, exactly how stress works in Mandarin is a thorny issue. We follow Yip (1980, 1995) and Duanmu (1990, 1993, 2007) in regarding Mandarin as a weight-sensitive language. We accept their position that T_0 (L) syllables are uniformly light and T_2 (Hlh) syllables, uniformly heavy. However, in contrast to their view that T_3 syllables are heavy, we consider these syllables to be light.[13] Departing from Yip and Duanmu further, we propose that syllables with other tonal profiles, T_1 (Hh) and T_4 (Hhl), vary in their weight. Our position is summarized in (31) (for detailed discussion of Mandarin weight sensitivity, see Qu 2007).

(31)

Heavy syllables	*Light syllables*
	T_0 (Lh)
T_1 (Hh)	T_1 (Hh)
T_2 (Hlh)	
	T_3 (Lhl)
T_4 (Hhl)	T_4 (Hhl)

We adopt the view that Mandarin feet are trochaic. To our knowledge, this has never been in dispute (among those who assume that Mandarin has feet). Although many researchers point out that final syllables in Mandarin are prominent (Chao 1968, Lin et al. 1984, Chen 2000), it has not been proposed that this is due to a right-aligned iambic foot because it is also widely recognized that the initial syllable receives stress (following Chao 1951, 1968). In view of this, we suggest that initial prominence is due to a left-aligned trochee. Final prominence, however, we attribute to a final lengthening effect, a commonly observed process across languages (Hayes 1995).

Concerning the type of trochee that Mandarin builds, we assume that this foot is optimally uneven (following Goad et al. 2003, Goad & White 2006). In spite of the fact that uneven trochees are cross-linguistically marked (Hayes 1995), they have been shown to play a central role in the grammars of other languages as well (e.g. Bani-Hassan Arabic (Kenstowicz 1994), Kambera (van der Hulst & Klamer 1996), Tondano and Mohawk (Piggott 1998) and Seleyarese, Central Slavic and Mohawk (Mellander 2002)). Following Duanmu (2007), more specifically, we propose that stressed syllables in Mandarin are always heavy; this leads to $(\sigma_{\mu\mu}\sigma_{\mu})$ as well as $(\sigma_{\mu\mu})$ feet as well-formed to the exclusion of $*(\sigma_{\mu}\sigma_{\mu})$. The adoption of uneven trochees contrasts with proposals for left-headed quantity-sensitive unbounded feet (Yip 1990, 1995), moraic trochees (Duanmu 1990, 1993), syllabic trochees (Feng 1995, 2001, 2006; see also Chang 1992) and 'dual trochees' (Duanmu 2007).[14] However, it is consistent with the observation that duration is the principal phonetic correlate for Mandarin stress (Lin et al. 1984). We provide phonological support for $('\sigma_{\mu\mu}\sigma_{\mu})_{Ft}$ over $('\sigma_{\mu}\sigma_{\mu})_{Ft}$ in section 8 below. More detailed discussion for uneven trochees as optimal in Mandarin can be found in Qu (2007).

Although we have stated that initial prominence is due to a left-aligned trochee, stress does not always fall on the initial syllable in a PWd. The lack of consistent word-initial stress is in part responsible for proposals in the literature that word-level stress in Mandarin is indeterminate (Kratochvil 1974, J. Li 1957, W. Li 1981, Yin 1982, Xu 1982, Hoa 1983, Duanmu 2007) or that the language lacks word-level stress altogether (Gao & Shi 1963, Yip 1980). We suggest that there are illusory effects in the language which have led to such proposals and which instead arise from the different prosodic structures assigned to disyllabic words in combination with the effect of final lengthening (see Qu 2007 for detailed discussion). Following from the proposal that Mandarin strives to build uneven trochees, stress falls, we contend, on the leftmost heavy syllable in a PWd. The location of this syllable depends on tonal profile, as per (31), and will be further elaborated on in section 8.

Finally, we propose that the rightmost PWd in a PPh bears primary stress (cf. Kratochvil 1974, Duanmu 1998). As per Hayes (1995), we assume that phrase-level stress is assigned by ENDRULE(RIGHT).

8. Prosodic structures.

As we are concerned with disyllabic and trisyllabic constructions in this work, we turn now to examine the prosodic structures of these two types of constructions.

8.1. Disyllabic constructions. Our focus in this subsection will be on disyllabic constructions. This will lead, in section 9.1, to an explanation for why T_2 sandhi is not attested in constructions of this size.

In section 4.1.1, we mentioned that the disyllabic constructions under focus are all morphologically-complex words. Although they are composed of two lexical morphemes, we will show below that these constructions form single PWds that contain exactly one stressed syllable.

When considering the relative weight of the two syllables in a disyllabic word, the four profiles in (32) are all theoretically possible.

(32) a. $\sigma_{\mu\mu}\ \sigma_{\mu\mu}$
b. $\sigma_{\mu\mu}\ \sigma_{\mu}$
c. $\sigma_{\mu}\ \sigma_{\mu\mu}$
d. $\sigma_{\mu}\ \sigma_{\mu}$

Recall from (31) that we regard syllables carrying T_3 (Lhl) and T_0 (L) as light. Thus, for the profile in (32d), four tonal combinations are a priori possible, as shown in (33).[15]

(33) *Options for $\sigma_{\mu}\ \sigma_{\mu}$*
a. $T_3\ T_3$
b. $T_3\ T_0$
c. $T_0\ T_3$
d. $T_0\ T_0$

However, if Mandarin stressed syllables are always heavy, these tonal profiles are predicted not to surface intact. This prediction proves to be correct.

Concerning (33a), T_3 sandhi applies and the initial T_3 (Lhl) is changed into T_2 (Hlh), a heavy syllable (see further section 11.2.2). For (33b), the initial T_3 is not realized as Lhl but instead as Lhlh (as mentioned in note 13), a tonal profile that can only be borne by a heavy syllable. Turning to (33c-d), neither profile is attested in Mandarin.

In short, $\sigma_{\mu}\,\sigma_{\mu}$ disyllabic constructions do not surface in Mandarin. Initial T_3 syllables become heavy; initial T_0 syllables cannot be augmented and are thus altogether absent.[16] In view of this, (32) must be revised as in (34) to reflect the attested patterns for Mandarin disyllabic constructions.

(34) a. $\sigma_{\mu\mu}\,\sigma_{\mu\mu}$
b. $\sigma_{\mu\mu}\,\sigma_{\mu}$
c. $\sigma_{\mu}\,\sigma_{\mu\mu}$
d. $*\sigma_{\mu}\,\sigma_{\mu}$

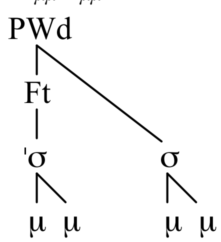
In contrast to (34d), (34a-c) are all attested. In the following lines, we provide the prosodic structures that we assume for each of these constructions.

When disyllabic constructions are composed of two heavy syllables, as in (34a), two feet should be formed because of WEIGHT-TO-STRESS: heavy syllables are stressed (definition from Kager 1999:172). However, an overriding constraint, NONFINALITY: no prosodic head is final in PWd (Kager 1999:165), prohibits the final syllable from forming a foot. The resulting prosodic structure for this type of construction is shown in (35a). Stress is correctly realized only on the first syllable.

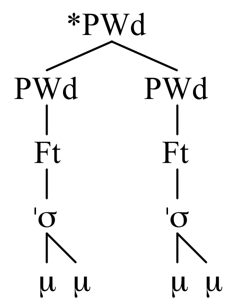
Even though the disyllabic constructions under consideration are composed of two lexical morphemes, the optimal parse contains a single PWd, as mentioned above. If these morphemes were instead parsed into a compound-like structure, as in (35b), the final syllable would be footed, given the nonexhaustivity restriction on extrametricality (Hayes 1995:58). The result would be an output where both syllables in the construction are stressed. This is ruled out by *CLASH: no stressed syllables are adjacent (Kager 1999:165).[17] In view of the fact that disyllabic words contain only one stressed syllable, we do not consider parses with two PWds further.

(35) *Input:* $\sigma_{\mu\mu}\,\sigma_{\mu\mu}$

a.

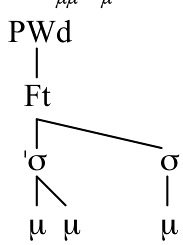


b.



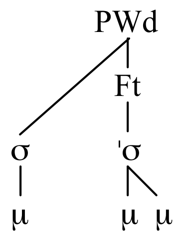
When disyllabic constructions have the shape in (34b), one foot is formed because Mandarin favors uneven trochees. See (36).

(36) *Input:* $\sigma_{\mu\mu}\,\sigma_{\mu}$



Finally, for disyllabic constructions with the shape in (34c), the initial syllable is left unparsed because it cannot head the foot due to WEIGHT-TO-STRESS, in combination with a ban on degenerate feet. The final syllable thus forms a foot unto itself; it cannot, of course, be extrametrical, as in (35a), because of the nonexhaustivity restriction on extrametricality. The structure is provided in (37).

(37) *Input:* $\sigma_{\mu}\ \sigma_{\mu\mu}$



WEIGHT-TO-STRESS is highly ranked in Mandarin. Aside from contexts where NONFINALITY must be respected, heavy syllables always appear in prosodic head position. In the next section, we will observe that this constraint plays an important role in trisyllabic constructions as well.

8.2. Trisyllabic constructions. Because we are concerned with trisyllabic constructions with a medial T_2 (Hlh) and T_2 syllables are invariably heavy, our focus in this section will be on the prosodic structures of trisyllabic constructions with medial heavy syllables. With this restriction in place, there are theoretically four possible combinations of heavy and light syllables, as can be seen in (38).

(38)
a. $\sigma_{\mu\mu}\ \sigma_{\mu\mu}\ \sigma_{\mu\mu}$
b. $\sigma_{\mu\mu}\ \sigma_{\mu\mu}\ \sigma_{\mu}$
c. $\sigma_{\mu}\ \sigma_{\mu\mu}\ \sigma_{\mu\mu}$
d. $\sigma_{\mu}\ \sigma_{\mu\mu}\ \sigma_{\mu}$

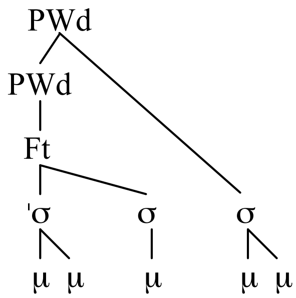
Since Mandarin trisyllabic constructions can be either left- or right-branching, we consider each of the options in (38) for these two types of constructions independently.

8.2.1. Left-branching constructions. In section 4.1.1, we mentioned that the left-branching constructions under focus are words, not phrases. Recall as well from section 7 that Mandarin PWd-level stress falls on the leftmost heavy syllable in this domain. As observed with disyllabic constructions, left-branching trisyllabic constructions contain only one stressed syllable; thus, all parses considered below will contain only one stressable PWd. In contrast to the disyllabic constructions, however, left-branching trisyllabic constructions all involve an adjunction structure to reflect the constituency involved.

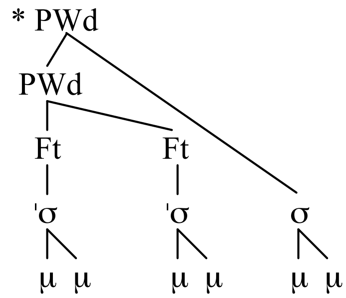
Regarding the profile in (38a) where all three syllables are underlyingly heavy, one foot is built rather than two, as can be seen in comparing (39a) with the illicit (39b). (39b) is non-optimal due to the stress clash that results. Stress clash is not observed in (39a) because the final heavy syllable cannot be footed, in order to satisfy NONFINALITY. As the first two syllables are parsed into a single foot, the rhyme of the second syllable must shorten, given that it is in foot-dependent position. The result is an uneven trochee. Stress correctly falls on the initial syllable.

(39) *Input: [[$\sigma_{\mu\mu}$ $\sigma_{\mu\mu}$] $\sigma_{\mu\mu}$]*

a.



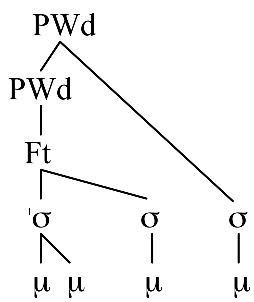
b.



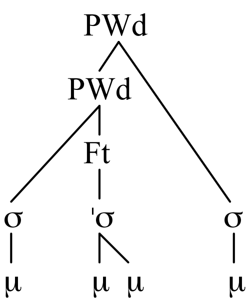
For the profile in (38b) where the final syllable is instead light, two prosodic structures emerge as optimal, those in (40a-b), because of the building of uneven trochees in combination with the ban on degenerate feet. The alternative structure in (40c) is illicit due to the presence of stress clash. The critical difference between (40a) and (40b) is the profile of the medial syllable. In the former construction, it is in foot-dependent position and so must shorten. In the latter construction, it is in head position because the initial syllable, which has shortened, is organized directly by the PWd.[18] Both (40a) and (40b) are attested, as will be shown in section 9.2.1.

(40) *Input: [[$\sigma_{\mu\mu}$ $\sigma_{\mu\mu}$] σ_{μ}]*

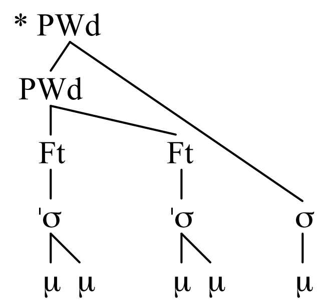
a.



b.

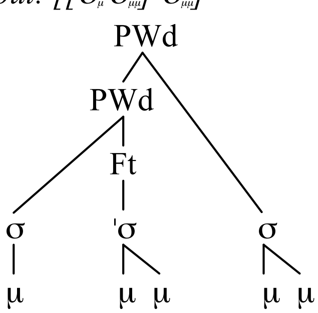


c.



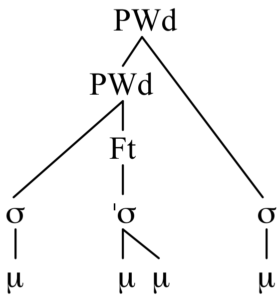
Turning to the pattern in (38c) where the initial syllable is light and final syllable heavy, the medial heavy syllable occurs in head position as shown in (41). Satisfaction of NONFINALITY and the ban on degenerate feet are responsible for this structure.

(41) *Input: [[σ_{μ} $\sigma_{\mu\mu}$] $\sigma_{\mu\mu}$]*



Finally, when the medial heavy syllable is surrounded by two light syllables as in (38d), the structure in (42) below arises because of the ban on degenerate feet and WEIGHT-TO-STRESS.

(42) *Input: $[[\sigma_{\mu}\ \sigma_{\mu\mu}]\ \sigma_{\mu}]$*



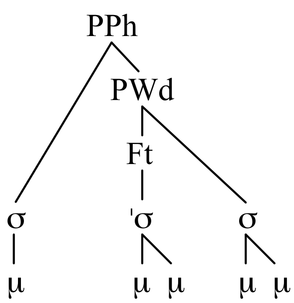
To briefly summarize, whether the input medial syllable occupies head position in the foot and thereby remains heavy or whether it ends up in foot dependent position and must shorten is tied to the weight of the surrounding syllables. We will see the significance of this for T_2 sandhi after considering the possible structures for right-branching constructions.

8.2.2. Right-branching constructions. In section 4.1.1, we pointed out that right-branching constructions are phrases. Recall further, from section 7, that phrasal stress in Mandarin is determined by ENDRULE(RIGHT).

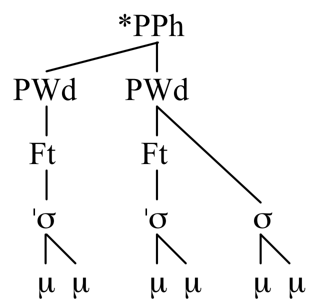
Concerning the pattern in (38a), with three heavy syllables in the input, the medial heavy syllable is in head position as seen in (43a). The initial syllable must link directly to the PPh and so the vowel is shortened. The alternative in (43b), where the initial syllable maintains its weight and thereby heads its own foot, is illicit because of the stress clash that arises. The parse in (43a) also holds for the pattern in (38c), that where the initial syllable is light in the input.

(43) *Input: $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu\mu}]]$ or $[\sigma_{\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu\mu}]]$*

a.



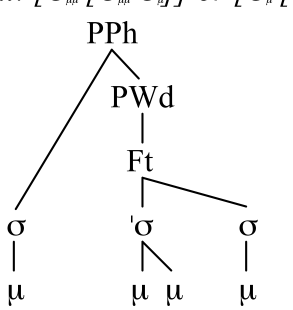
b.



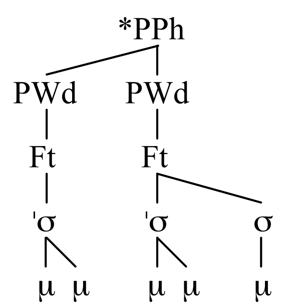
Turning to (38b), a construction where the final syllable is light, the medial syllable also ends up in head position with the final syllable as its dependent as seen in (44a). The initial syllable is shortened as it links directly to the PPh, as was the case in (43a). The alternative in (44b), where the weight of the initial syllable remains intact, is illicit because of stress clash. The same structure holds for (38d), where the initial syllable is light in the input.

(44) *Input: $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu}]]$ or $[\sigma_{\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu}]]$*

a.

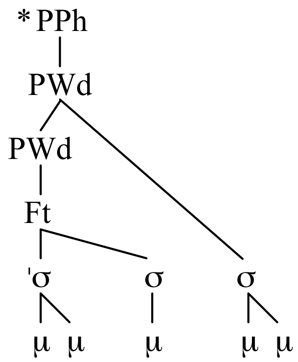


b.

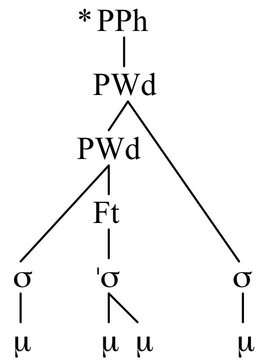


Although right-branching constructions are phrases, the optimal forms in (43a) and (44a) reveal that these constructions nevertheless can contain only one PWd, as was seen for the left-branching constructions which form words discussed in the preceding section. In constructions with both types of branching, the single PWd parse arises as optimal because stress clash is not tolerated in Mandarin (but see note 17). Given this parallel between left- and right-branching constructions, we must address what rules out the parse in (45a) for input $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu\mu}]]$ and the parse in (45b) for input $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu}]]$. (45a) is parallel to the optimal structure for $[[\sigma_{\mu\mu}\ \sigma_{\mu\mu}]\ \sigma_{\mu\mu}]$ in (39a); (45b) is parallel to the optimal structure for $[[\sigma_{\mu\mu}\ \sigma_{\mu\mu}]\ \sigma_{\mu}]$ in (40b).

(45) a. *Input:* $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu\mu}]]$



b. *Input:* $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu}]]$



The representations in (45) are ruled out, we contend, because the prosodifications that result do not respect the hierarchical structure of the input: the syllables (morphemes) that compose a phrase must be prosodically grouped together so as to reflect their constituency. The parses in (45), where the first two syllables form a unit (foot), are inconsistent with the right-branching inputs $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu\mu}]]$ and $[\sigma_{\mu\mu}\ [\sigma_{\mu\mu}\ \sigma_{\mu}]]$.

Because of the isomorphism that holds between the hierarchical and prosodic structures of phrases, the medial heavy syllable always occupies foot head position, regardless of the weight of the surrounding syllables. This, we will see, accounts for why T_2 sandhi applies less frequently in right-branching structures than in left-branching structures.

In view of the prosodic structures provided in this and the preceding sections, we turn now to an analysis of the experimental results on T_2 sandhi.

9. Experimental results revisited.

In section 5, we presented the results of our experiment on T_2 sandhi. The principal findings are repeated here: (i) T_2 sandhi does not apply in disyllabic constructions; (ii) T_2 sandhi is attested in trisyllabic constructions with an initial T_2 (Hlh) regardless of the hierarchical structure of the construction; (iii) T_2 sandhi is not observed in trisyllabic constructions with an initial T_3 (Lhl) regardless of hierarchical structure; (iv) variation across speakers is found when the final syllable bears T_3; (v) the hierarchical structure of the construction is relevant when the initial syllable bears either T_1 (Hh) or T_4 (Hhl); and (vi) the sandhi form of T_2 (Hlh) is a level pitch. Through a discussion of each of these findings, we argue that T_2 sandhi applies when T_2 occurs in prosodically non-prominent (unstressed) position.

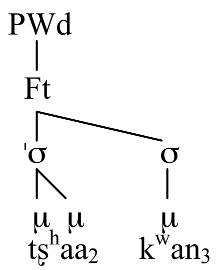
In section 8, we discussed the prosodic structures available for Mandarin disyllabic and trisyllabic constructions. The general properties of these structures are summarized as follows. Heavy syllables in disyllabic constructions always appear in head position. In left-branching trisyllabic constructions, the medial heavy syllable occupies foot-dependent position except when the initial syllable is light; when the final syllable is light, two structures are possible: the medial syllable can be in head or dependent position. In right-branching trisyllabic constructions, the medial heavy syllable always occupies the head position, regardless of the weight of the surrounding syllables.

In the following sections, we provide an analysis of the experimental results by making reference to specific structures presented in section 8. We then turn to address the various contexts in which T_2 sandhi under- or over-applies as per these structures.

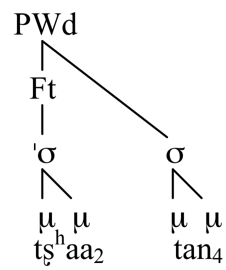
9.1. T_2 sandhi and disyllabic constructions. In section 5.1, we presented the results of our experiment for disyllabic constructions. We observed that T_2 sandhi does not apply in constructions of this shape: T_2 remains as a rising pitch in the productions of all speakers (one exception aside; see section 9.3.3). In the following lines, we provide an explanation for this observation that stems from the prosodic structures proposed in section 8.1 for disyllabic constructions.

Recall that the disyllabic stimuli included in the experiment either have an initial T_2 or a final T_2. When the initial syllable bears T_2 (Hlh), two prosodic structures are possible depending on the weight of the final syllable. When the final syllable bears T_3 (Lhl) which is light, a single foot is formed ((36) above) with the initial T_2 syllable in foot-head position, as shown in (46a). When the final syllable is T_1 (Hh), T_2 (Hlh) or T_4 (Hhl), which are heavy, one foot is formed as in (46b); the second syllable cannot form a foot without violating NONFINALITY ((35a) above). In both cases, word-level stress falls on T_2, the leftmost heavy syllable and, thus, no T_2 sandhi applies.

(46) *Initial T_2*

a. 

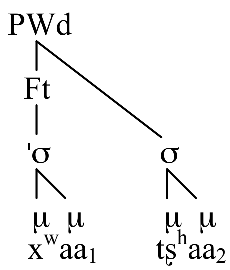
‘tea house’

b. 

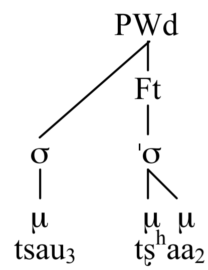
‘tea egg’

When the T_2 (Hlh) syllable occurs in word-final position, there are similarly two prosodic structures available ((35a) and (37) above). If the initial syllable is heavy – T_1 (Hh), T_2 (Hlh) or T_4 (Hhl) – the T_2 syllable is not footed, as shown in (47a), and T_2 sandhi does not apply. When the initial syllable is light, T_3 (Lhl), word-level stress falls on the T_2 syllable, as it is the leftmost heavy syllable in the PWd; see (47b). Since T_2 is again in foot head position, T_2 sandhi does not apply.

(47) *Final T_2*

a. 

‘jasmine tea’

b. 

‘dim-sum’

Before turning to trisyllabic constructions, we must address why heavy-heavy inputs with T_2 (Hlh) in second position are not parsed as heavy-light trochees, as in (46a). The effect would be that T_2 sandhi applies. This parse fatally violates faithfulness to the tonal features of T_2. Although we will see that faithfulness can be violated in a similar situation in left-branching trisyllabic constructions, $[[\sigma_{\mu\mu}\sigma_{\mu\mu}]\sigma_{\mu\mu}]\rightarrow[[\sigma_{\mu\mu}\sigma_{\mu}]\sigma_{\mu\mu}]$, the critical difference between disyllabic and left-branching trisyllabic constructions is that an additional foot well-formedness constraint, *CLASH, factors into the assessment of the latter. This must be satisfied at the expense of faithfulness to T_2 and it is this that triggers T_2 sandhi in these longer constructions.

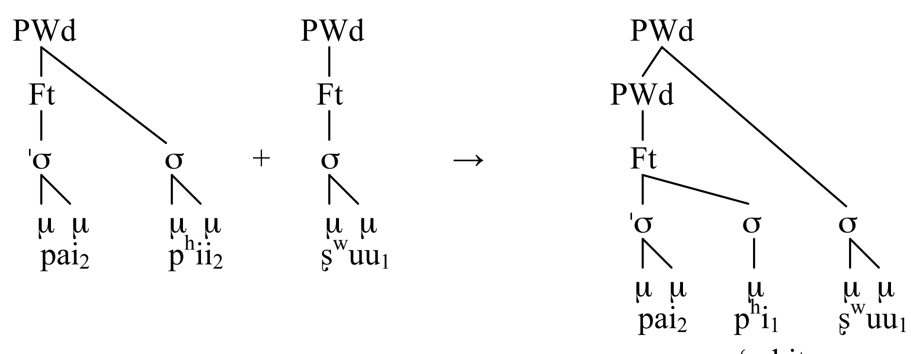
To sum up, the structures shown for disyllabic constructions in (35)-(37) revealed that heavy syllables are restricted to foot-head position. Since syllables bearing T_2 (Hlh) are heavy, they always occupy head position in constructions of this shape, as shown in (46)-(47). The result is that no T_2 sandhi will ever be attested in disyllabic constructions, regardless of whether the T_2 syllable occurs in initial or final position.

9.2. T_2 sandhi and trisyllabic constructions. Recall that T_2 sandhi is attested more commonly in left-branching constructions than in right-branching constructions. Recall further that hierarchical structure has no impact on the application of the process when the initial syllable is T_2 (T_2 sandhi applies across the board) or T_3 (T_2 sandhi is not attested). From the prosodic structures posited above, it will become evident that we predict that T_2 sandhi should be limited to applying in left-branching constructions, although the tone (and therefore weight) of surrounding syllables must also be factored in. This approach will lead to an explanation for the absence of T_2 sandhi in left-branching constructions with initial T_3 (Lhl), but not for the over-application of T_2 sandhi in right-branching constructions with initial T_2 (Hlh). The latter will be addressed in section 9.3.5.

9.2.1. T_2 sandhi and left-branching constructions. We consider trisyllabic constructions with left-branching structures first. When the initial syllable is heavy, the medial heavy syllable typically ends up in foot-dependent position in the output ((39) and (40a) above). The situation where this does not always hold is when the final syllable is light. In this situation, two structures are possible ((40a-b) above) which differ in the weight of the medial syllable. Following from this, if T_2 sandhi applies when T_2 (Hlh) occurs in non-prominent position, it should always be attested when the initial syllable is heavy; and variation across speakers should be observed when the final syllable is light because of the presence of more than one parse for constructions of this shape.

Returning to the experimental results, these predictions hold for the most part. When the input consists of three heavy syllables, T_2 sandhi applies when the initial and final syllables bear T_1 (Hh), T_2 (Hlh) or T_4 (Hhl).[19,20] Consider the example in (48) (compare (39a)).[21] When a morpheme is added to the right of a disyllabic word with a final T_2 syllable (see (35a)), this syllable loses its extrametrical status because of the peripherality condition on extrametricality (Hayes 1995: 57). The likely alternative would thus be $(pai_2)_{Ft}$ $(p^hii_1)_{Ft}$ $ʂ^wuu_1$, but this form contains a stress clash. This forces the medial syllable to become light, resulting in an uneven trochee. T_2 sandhi thus applies.

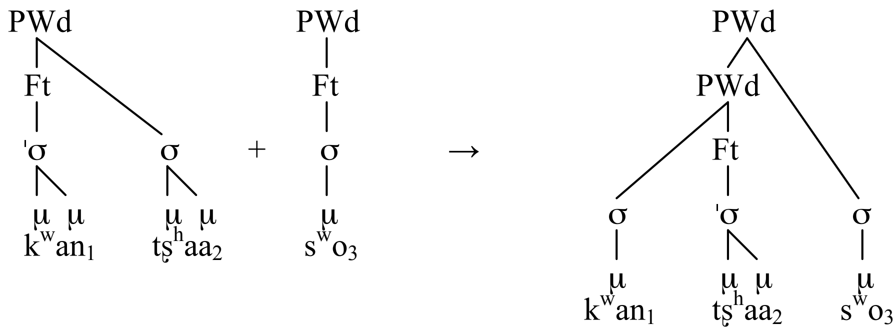
(48)



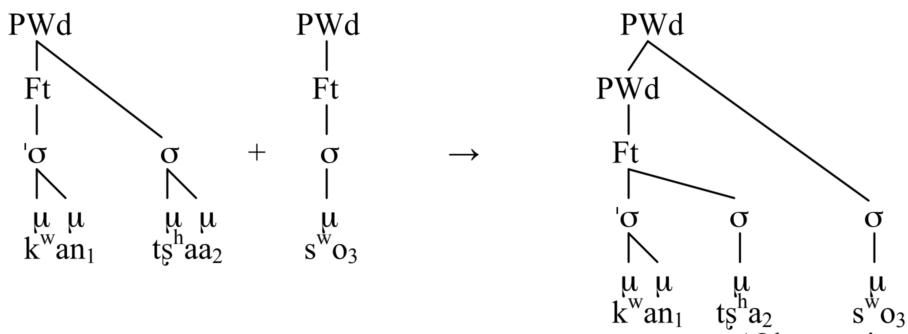
'white covered book'

Speaker variation is observed when the final syllable is light, that is, T_3 (Lhl). This is because, as discussed earlier, two prosodic structures are possible for input heavy-heavy-light strings: light-heavy-light ((40b) above) and heavy-light-light ((40a) above)). Consider (49). In (49a), the medial T_2 ends up in foot-head position and T_2 sandhi does not apply. However, to avoid clash, the initial syllable must then become light and is parsed directly by the PWd. In (49b), the analysis for the medial T_2 syllable is the same as that in (48) and T_2 sandhi thus applies. Concerning the two possibilities in (49), since a sequence of light-heavy-light syllables is more rhythmic than a sequence of heavy-light-light, we speculate that (49a) may be more commonly attested than (49b). This is consistent with what we observed although our group of speakers is small.

(49) a.



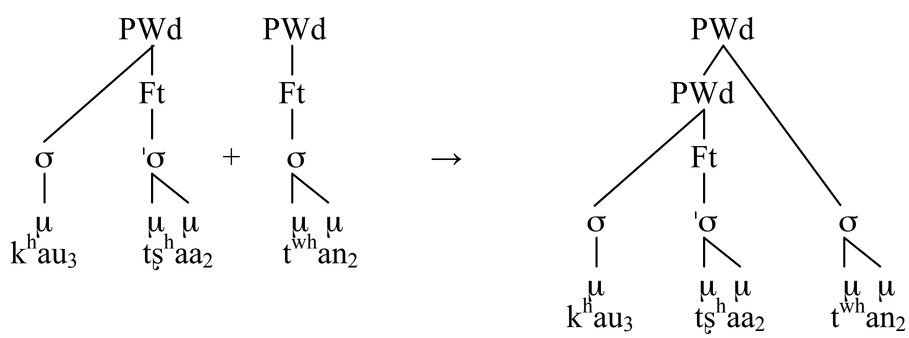
b.



‘Observation Office’

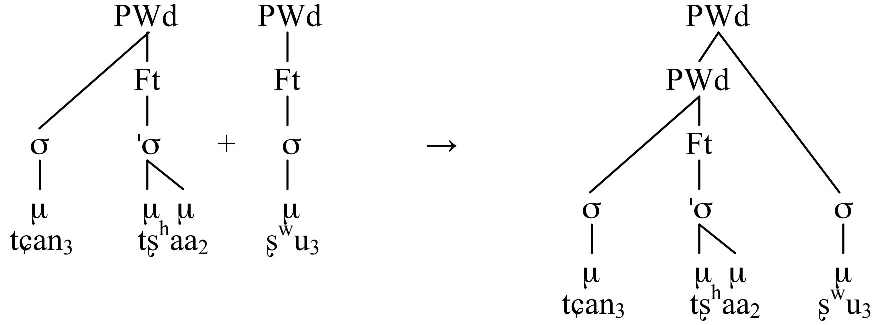
Let us briefly consider the final possibility, cases where the input contains an initial light syllable, namely T_3 (Lhl). In words of this profile, a medial heavy syllable will always be parsed as such in the output, regardless of the weight of the following syllable ((41) and (42) above). As a result, no T_2 sandhi should be attested. This is consistent with the experimental results, as shown in (50a-b).

(50) a.



‘delegation of investigation’

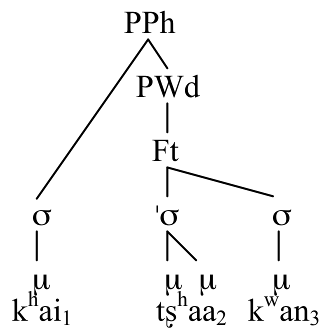
b.



'Inspection Bureau'

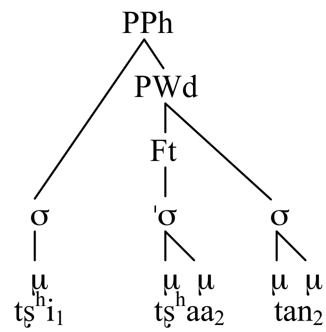
9.2.2. T_2 sandhi and right-branching constructions. We turn now to trisyllabic constructions with right-branching structures. Recall that in constructions of this type, the medial heavy syllable always occurs in prosodic head position, regardless of the status of the surrounding syllables ((43) and (44) above). This predicts that no T_2 sandhi should be attested. For the most part, this prediction holds true. Consider the representations in (51). Recall that the stimuli with right-branching structures are phrases. If Mandarin phrasal stress is assigned by ENDRULE(RIGHT), the medial T_2 syllable in these constructions will always receive phrasal stress, regardless of the status of the final syllables, light (as in (51a)) or heavy (as in (51b)).

(51) a.



'to run a tea house'

b.



'to eat tea eggs'

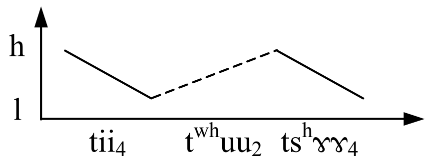
Unexpectedly, T_2 sandhi does apply when the tonal pattern is [σ_1 [σ_2 σ_1]] and, in some tokens, with [σ_1 [σ_2 σ_2]], [σ_4 [σ_2 σ_1]] and [σ_4 [σ_2 σ_3]]. It also applies when the initial syllable bears T_2. We address these cases of over-application in section 9.3.

To sum up, our analysis can be briefly stated as follows: T_2 sandhi does not apply when T_2 syllables are stressed, that is, when they appear in head position; it does apply when these syllables are forced into dependent position where they surface as unstressed. In the next section, we discuss other factors which obscure the (non)application of T_2 sandhi as per this analysis.

9.3. Under- and over-application of T_2 sandhi. Given the prosodic account of T_2 sandhi developed here, there are contexts where T_2 sandhi is predicted to apply but fails to and other contexts where it is predicted not to apply but nevertheless does. In this section, we provide explanations for each of these cases of under- and over-application.

9.3.1. Under-application in [[σ_4 σ_2] σ_4]. Recall from sections 5.2.4 and 5.2.5 that T_2 sandhi fails to apply in left-branching structures with the tonal profile [[σ_4 σ_2] σ_4]. We attribute this under-application of T_2 sandhi to the influence of the pitch of the surrounding syllables. As T_4 (Hhl) is high falling (i.e., the pitch starts high and ends low) and T_2 (Hlh) is high rising (the pitch starts low and ends high), when a T_2 is surrounded by T_4 syllables, it serves as a perfect transition from the initial T_4 to the final T_4, as shown by the dotted line in (52). In short, T_2 sandhi may well be applying here, but its application has been disguised.

(52) *[[σ$_4$ σ$_2$] σ$_4$]*



‘atlas’

9.3.2. Over-application in [σ$_1$ [σ$_2$ σ$_1$]]. Concerning the over-application of T$_2$ sandhi, we begin with structures with the tonal profile σ$_1$ σ$_2$ σ$_1$. Although, as predicted, T$_2$ sandhi applies in left-branching structures of this profile, it also unexpectedly applies in right-branching structures (e.g. /ɕəu$_1$ p^{h}ii$_2$ pau$_1$/ → [ɕəu$_1$ p^{h}i$_1$ pau$_1$] ‘to repair leather handbags’). We propose that, in this case, T$_2$ sandhi over-applies because of physiological factors that govern the production of tone.

Hirose (1997) observes that pitch differences arise from adjusting the mass and stiffness of the vocal folds. The activity of the crico-thyroid muscle increases to raise pitch and decreases to lower pitch.[22] Contracting the crico-thyroid muscle leads to pitch rise. As a result, the effective mass of the vocal folds decreases and their stiffness increases.

In constructions with the tonal pattern [σ$_1$ [σ$_2$ σ$_1$]], T$_2$ (Hlh) is surrounded by two T$_1$ (Hh) syllables. The production of this tonal pattern requires the crico-thyroid muscle to be contracted first, then expanded and then contracted again. In fast speech, this process is difficult to implement, similar to arresting vocal fold vibration in the production of intervocalic voiceless stops. The low tone of T$_2$ (Hlh) is thus realized as high (Hh) when surrounded by two high tones, as shown in (53a). In fact, the process of a low tone becoming high when surrounded by high tones, (53b), is cross-linguistically common, as observed by Kisseberth & Odden (2003) for many Bantu languages.

(53) a. $T_2 \rightarrow T_1 / T_1$ __ T_1 (Hlh → Hh / Hh __ Hh)
b. low → high / high __high

We thus regard the application of T$_2$ sandhi in this particular case as resulting from purely physiological constraints on tone production, in contrast to the prosodically-conditioned T$_2$ sandhi process attested in other environments, as discussed above.

9.3.3. Over-application in [σ$_1$ [σ$_2$ σ$_2$]]. There are three other right-branching structures where T$_2$ sandhi unexpectedly applies – [σ$_1$ [σ$_2$ σ$_2$]], [σ$_4$ [σ$_2$ σ$_1$]] and [σ$_4$ [σ$_2$ σ$_3$]] – but in each of these cases, speaker variation is observed. We begin with [σ$_1$ [σ$_2$ σ$_2$]], constructions with two structurally-adjacent T$_2$ syllables. The pattern of variation observed is in (54).

(54) /xəi$_1$ tʂ̩^{h}aa$_2$ x^{w}uu$_2$/ → [xəi$_1$ tʂ̩^{h}a$_1$ x^{w}uu$_2$] ‘black teapot’ (S1)
→ [xəi$_1$ tʂ̩^{h}aa$_2$ x^{w}uu$_2$] (S2 & S3)

We propose that the application of T$_2$ sandhi in this construction in Speaker 1’s grammar is induced by the Obligatory Contour Principle (OCP) (Leben 1973, McCarthy 1986). Two questions immediately arise. One, why is the OCP only triggered by adjacent T$_2$ syllables and not with tones of other profiles? Two, are disyllabic constructions where two T$_2$ syllables are similarly structurally adjacent as they are in [σ$_1$ [σ$_2$ σ$_2$]] subject to the OCP in Speaker 1’s grammar as well?

We begin with the OCP restriction to T$_2$ syllables. Across languages, OCP effects are most commonly observed with marked features (or marked feature values) (e.g. Itô & Mester 1986, McCarthy 1989 on marked laryngeal features; Pierrehumbert 1993, Coetzee & Pater 2008 on marked place features). Here, we show that T$_2$ is the most marked tone in Mandarin (see section 10.1 for further discussion). Consider Yip’s (2002) cross-linguistic markedness observations for tone in (55).

(55) a. High tones are more marked than low tones.
b. Contour tones are more marked than level tones.
c. Rising tones are more marked than falling tones.

If we combine these observations into a markedness scale, we arrive at (56) for Mandarin.[23]

(56) T_2 (Hlh) > T_4 (Hhl) > T_1 (Hh) > T_3 (Lhl) > T_0 (L)

In short, OCP effects are only observed with adjacent T_2 syllables, because T_2 is the most marked tone in Mandarin.

Turning to disyllabic constructions with adjacent T_2 syllables, recall that T_2 sandhi is only attested in one form, repeated below in (57). As expected from (54), this form is produced by Speaker 1.

(57) /tɕ^{h}ii$_2$ p^{h}au$_2$/ → [tɕ^{h}ii$_1$ p^{h}au$_2$] 'cheong-sam' (S1)
→ [tɕ^{h}ii$_2$ p^{h}au$_2$] (S2 & S3)

Since this is the only disyllabic form in the experiment that underwent T_2 sandhi, it is evident that something other than prosodically-conditioned T_2 sandhi is responsible for the simplification to T_1, namely the OCP. Clearly, the grammar of Speaker 1 is slightly different from the grammars of the other two subjects in this respect.[24]

9.3.4. Over-application in $[\sigma_4\ [\sigma_2\ \sigma_1]]$ and $[\sigma_4\ [\sigma_2\ \sigma_3]]$. Speaker variation is also unexpectedly attested in right-branching constructions with an initial T_4 (Hhl) and a final T_1 (Hh) or T_3 (Lhl). T_2 sandhi over-applies in the grammars of Speakers 1 and 3. The examples are repeated in (58).

(58) a. /p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$/ → [p^{h}ai$_4$ tɕ^{h}i$_1$ p^{j}əŋ$_1$] 'to engage soldiers in a surprise attack' (S1 & S3)
→ [p^{h}ai$_4$ tɕ^{h}ii$_2$ p^{j}əŋ$_1$] (S2)

b. /tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$/ → [tɕəu$_4$ tɕ^{h}i$_1$ p^{h}u$_3$] 'used chess manual' (S1& S3)
→ [tɕəu$_4$ tɕ^{h}ii$_2$ p^{h}u$_3$] (S2)

We propose that the application of T_2 sandhi in the productions of Speakers 1 and 3 is due to the quality of the surrounding vowels, rather than to prosodic factors. The prosodic structure of these constructions should be that in (44a) where the initial syllable is shortened and linked to the PPh and the medial syllable is in foot head position. In both (58a) and (58b), however, the quality of the vowels in the first two syllables makes this difficult to attain: the initial syllables contain diphthongs, which are inherently more difficult to shorten than monophthongs, and the medial syllables, the vowel /i/, which is shorter than other monophthongs in Mandarin (Feng 1985). Stressing the medial /i/ in the constructions in (58a) and (58b) thus requires a concerted lengthening because, as mentioned earlier, duration has been experimentally shown to be the principal phonetic correlate of stress in Mandarin (Lin et al. 1984). If this account of over-application of T_2 sandhi is correct, when it fails to apply, as in Speaker 2's productions, special emphasis should be observed on the second syllable containing stressed [ii] when it follows a syllable containing a diphthong. This is precisely what was attested in Speaker 2's productions of both constructions in (58).[25]

9.3.5. A greater role for OCP: Over-application in right-branching constructions with initial T_2. The preceding sections on under- and over-application of T_2 sandhi have revealed that T_2 sandhi is a complex process with many factors at play. In addition to the role that stress and prosodic structure more generally plays in the process, we have seen that other factors, both phonological and phonetic, can influence the process: the OCP, the pitch of surrounding syllables and vowel quality. If we remove these non-prosodic effects on T_2 sandhi, we arrive at the following observations.

For initial T_1 (Hh) and T_4 (Hhl), prosodically-conditioned T_2 sandhi applies in left-branching constructions but not in right-branching constructions, as shown in (59). The difference between (59) and A and D in Figure 1 (section 5.2.3) is that all cases of [σ [σ σ]] have been moved out of the class of prosodically-conditioned T_2 sandhi contexts. For initial T_1, [σ_1 [σ_2 σ_1]] has been removed as T_2 sandhi was argued to over-apply due to physiological factors which govern the realization of tone (section 9.3.2). For initial T_4, [σ_4 [σ_2 σ_1]] and [σ_4 [σ_2 σ_3]] have similarly been removed, as T_2 sandhi was argued to over-apply due to vowel quality considerations (section 9.3.4). And finally, for left-branching constructions, [[σ_4 σ_2] σ_4] has been removed as the application of T_2 sandhi was argued to be disguised due to the quality of the surrounding tones (section 9.3.1). The overall result is that hierarchical structure can be seen to play a significant role in the application of T_2 sandhi, consistent with Wu (1984).

(59) *Prosodically-conditioned T_2 sandhi with initial T_1 and T_4*

a.	✓ [$\sigma_{1/4}$ σ_2] σ_1]	b.	✗ [$\sigma_{1/4}$ [σ_2 σ_1]]
	✓ [$\sigma_{1/4}$ σ_2] σ_2]		✗ [$\sigma_{1/4}$ [σ_2 σ_2]]
	✓ [$\sigma_{1/4}$ σ_2] σ_3]		✗ [$\sigma_{1/4}$ [σ_2 σ_3]]
	✓ [$\sigma_{1/4}$ σ_2] σ_4]		✗ [$\sigma_{1/4}$ [σ_2 σ_4]]

In contrast to initial T_1 and T_4, for initial T_2 (Hlh), the role for hierarchical structure is less clear, as T_2 sandhi applies across the board, that is, in both left- and right-branching constructions; see (60).[26] Furthermore, no variation across speakers is observed.

(60) *T_2 sandhi with initial T_2*

a.	✓ [σ_2 σ_2] σ_1]	b.	✓ [σ_2 [σ_2 σ_1]]
	✓ [σ_2 σ_2] σ_2]		✓ [σ_2 [σ_2 σ_2]]
	✓ [σ_2 σ_2] σ_3]		✓ [σ_2 [σ_2 σ_3]]
	✓ [σ_2 σ_2] σ_4]		✓ [σ_2 [σ_2 σ_4]]

In this section, we attribute application of T_2 sandhi with initial T_2 in right-branching structures to the OCP. That is, its application in (60b) is another case of over-application.

In section 9.3.3, we argued that the OCP is responsible for over-application of T_2 sandhi in Speaker 1's productions of [σ_1 [σ_2 σ_2]] and [σ_2 σ_2]. We appealed specifically to structural adjacency, that the OCP comes into play when the second and third syllables in right-branching constructions both bear T_2, the most marked tone in Mandarin. In (60), however, reference to structural adjacency is not necessary: whenever the initial two syllables bear T_2, T_2 sandhi applies. Consequently, T_2 sandhi over-applies in the right-branching structures in (60b): its application is not prosodically-conditioned here. Concerning the left-branching structures in (60a), we assume that T_2 sandhi is prosodically-conditioned here, as it is in (59a), although, of course, the OCP could also account for T_2 sandhi applying in constructions of this profile.

In short, (60) can be revised as in (61) which is exactly parallel to (59).

(61) *Prosodically-conditioned T_2 sandhi with initial T_2*

a.	✓ [σ_2 σ_2] σ_1]	b.	✗ [σ_2 [σ_2 σ_1]]
	✓ [σ_2 σ_2] σ_2]		✗ [σ_2 [σ_2 σ_2]]
	✓ [σ_2 σ_2] σ_3]		✗ [σ_2 [σ_2 σ_3]]
	✓ [σ_2 σ_2] σ_4]		✗ [σ_2 [σ_2 σ_4]]

9.4. T_2 sandhi as a prosodically-conditioned process. We have now isolated the contexts in which T_2 sandhi applies as a prosodically-conditioned process. T_2 sandhi which applies in non-prosodically-conditioned contexts has been accounted for through other means, as have cases where the process seemingly under-applies. In view of this, Figure 1 (from section 5.2.3) has been revised as Figure 3, by removing T_2 sandhi that is conditioned by factors other than prosodic structure. As in Figure 1, tonal patterns which are boxed are those where T_2 sandhi applies as a prosodically-conditioned process; those in boldface are where variation across speakers is observed. The patterns which differ from Figure 1 are marked with a dot: [σ_1 [σ_2 σ_1]] is now outside the box (over-application due to physiological factors which govern the realization of tone), as are [σ_4 [σ_2 σ_1]] and [σ_4 [σ_2 σ_3]] (over-application due to vowel quality) and [σ_2 [σ_2 $\sigma_{1\text{-}4}$]] (over-application due to OCP); and [σ_4 [σ_2 σ_4]] is now inside the box (application disguised due to quality of surrounding tones).

	[[σ σ] σ]	[σ [σ σ]]
A.	T_1 T_2 T_1	• T_1 T_2 T_1
	T_1 T_2 T_2	**T_1 T_2 T_2**
	T_1 T_2 T_3	T_1 T_2 T_3
	T_1 T_2 T_4	T_1 T_2 T_4
B.	T_2 T_2 T_1	• T_2 T_2 T_1
	T_2 T_2 T_2	• T_2 T_2 T_2
	T_2 T_2 T_3	• T_2 T_2 T_3
	T_2 T_2 T_4	• T_2 T_2 T_4
C.	T_3 T_2 T_1	T_3 T_2 T_1
	T_3 T_2 T_2	T_3 T_2 T_2
	T_3 T_2 T_3	T_3 T_2 T_3
	T_3 T_2 T_4	T_3 T_2 T_4
D.	T_4 T_2 T_1	• **T_4 T_2 T_1**
	T_4 T_2 T_2	T_4 T_2 T_2
	T_4 T_2 T_3	• **T_4 T_2 T_3**
	• T_4 T_2 T_4	T_4 T_2 T_4

Figure 3.
T_2 sandhi as a prosodically-conditioned process

As can be seen, prosodically-conditioned T_2 sandhi is entirely tied to hierarchical structure. The medial syllable in left-branching constructions strives to be in foot-dependent position in order to avoid stress clash, as discussed in sections 8.2.1 and 9.2.1. Recall from section 2 that in the previous literature, there is lack of consensus on the role that hierarchical structure and the tonal profile of the syllables surrounding T_2 play in the application of T_2 sandhi. It should now be clear that these factors play a defining role in this tone sandhi process. However, we have proposed that this is because these are the factors that influence the construction of Mandarin prosodic structure.

This concludes our discussion of the theoretical questions posed in (2a) (section 3): what kind of stress system does Mandarin have, and how does footing and prosodic structure more generally interact with T_2 sandhi? Concerning question (2b) (if T_2 sandhi is induced when the T_2 syllable lacks stress, why are other tones not subjected to similar sandhi processes in this environment?), we have addressed this in part but provide more detailed discussion of this question in the next section.

10. Prosodic licensing account of T_2 sandhi.

It has been argued in the preceding sections that T_2 sandhi is attested whenever a syllable bearing T_2 occurs in dependent (unstressed) position. However, we have not provided a broader explanation for why tone sandhi does not target T_4 (Hhl), a tone that, like T_2, is a high register contour tone. In this section, we provide an account of the restriction to T_2, one which appeals to prosodic licensing, in particular to licensing asymmetries between heads and dependents (Harris 1997, Dresher & van der Hulst 1998).

10.1. Markedness of Mandarin tones. Our analysis of T_2 sandhi has argued that tonal profile is one of the factors involved in this process because it is tone that influences the construction of Mandarin prosodic structure. That is, tonal profile is intimately connected with syllable weight which, in turn, means that certain tones are restricted to specific positions within the foot. In this section, we will argue that this restriction follows independently from the markedness of a given tonal profile. This, in turn, will lead to an explanation for why it is only T_2 that undergoes sandhi in foot-dependent position.

Recall from section 9.3.3 that we proposed the scale for Mandarin tones in (63). This was compiled from the markedness observations in (62) from Yip (2002). Both are repeated below.

(62) a. High tones are more marked than low tones.
b. Contour tones are more marked than level tones.
c. Rising tones are more marked than falling tones.

(63) T_2 (Hlh) > T_4 (Hhl) > T_1 (Hh) > T_3 (Lhl) > T_0 (L)

Let us first make a small modification to (63). There seems to be no evidence to support the markedness of T_4 over T_1 in Mandarin. Rather, the behavior of these two tones indicates that they are equally marked. First, the experimental results on T_2 sandhi reveal that initial T_1 and T_4 behave in parallel fashion. Second, in *yi-bu-qi-ba* sandhi, both T_1 and T_4 are targeted, as will be discussed in section 11.2.3. In view of this, we revise the scale in (63) to that in (64).

(64) T_2 (Hlh) > T_4 (Hhl), T_1 (Hh) > T_3 (Lhl) > T_0 (L)
|————————μμ————————|
|————————μ————————|

Although the markedness scale in (63)/(64) is derived from the markedness observations in (62), we have proposed that there is an additional link between markedness and syllable weight, indicated below (64) (see earlier (31)).[27] This, in turn, governs the distribution of tones within the foot, shown in (65).

(65) *Distribution of Mandarin tones within the foot*

Ft

$\sigma_{\mu\mu}$	σ_{μ}
T_2 (Hlh)	
T_4 (Hhl)	T_4 (Hhl)
T_1 (Hh)	T_1 (Hh)
	T_3 (Lhl)
	T_0 (L)

As discussed in section 9.3.3, T_2 (Hlh) is the most marked tone as per (62a-c); it is invariably borne by heavy syllables and is thereby restricted to prominent (foot-head) position in (65). At the other end of the scale in (64), T_3 (Lhl) and T_0 (L), as the only low register tones in Mandarin, are the least marked as per (62a). Consequently, they are always carried by light syllables and can only occur in non-prominent (non-head) position in (65). Tones in the middle of the scale in

(64), T_1 and T_4, high register tones without contour or with unmarked contour, are only moderately marked; they can freely occur in both head and non-head positions with their tonal profile intact, although their weight varies accordingly.[28]

10.2. Head-dependent asymmetries. With this background in mind, we turn now to address why a process like T_2 sandhi – which simplifies complex tones in non-head position – only targets T_2; in particular, why does T_4 not similarly undergo simplification? Our explanation for the restriction of tonal simplification to T_2 appeals to the theory of prosodic licensing. In this theory, an asymmetrical relationship holds between heads and dependents. Prosodic heads support more complex structures than non-heads (Harris 1997); and the dependent in any constituent cannot be more complex than its head (Dresher & van der Hulst 1998). We refer to this as the prosodic licensing principle; see (66).

(66) *Prosodic licensing principle*
  a. Prosodic heads support more complex structures than non-heads (Harris 1997)
  b. Dependents cannot be more complex than their heads (Dresher & van der Hulst 1998)

In (66), the complexity we have in mind is tonal complexity (markedness), as per (64). Taken together, (66) rules out cases where the dependent has a more marked tone than its head; and while (66) prefers a head to have a more marked tonal profile than its dependent, it does not preclude cases where head and dependent carry tones of equal complexity, as long as the tones involved are those that can appear in both head and dependent position as per (65). In view of this, let us consider the experimental results. We limit the discussion to the high register tones, T_2 (Hlh), T_4 (Hhl) and T_1 (Hh).

Since T_2 is the most marked tone in Mandarin, it can only be carried by heavy syllables, as we have seen. Accordingly, when it appears in foot-dependent position, as in medial position after a heavy syllable (T_1 (Hh), T_4 (Hhl) or T_2 (Hlh)) in left-branching constructions, it must shorten and T_2 sandhi thereby applies: the marked contour of T_2 is simplified: it changes from rising to level.

We turn now to the critical cases, initial H register tones followed by T_1 (Hh) or T_4 (Hhl) in medial position in left-branching constructions. Why does tone sandhi not apply in these cases? When we introduced T_2 sandhi in section 2, we mentioned that Mandarin has four tone sandhi processes: T_0 sandhi, T_3 sandhi, *yi-bu-qi-ba* sandhi and T_2 sandhi (Chao 1968). We will argue in section 11.2 that, in addition to T_2 sandhi, the three other sandhi processes are also triggered by stress. As will be seen, *yi-bu-qi-ba* sandhi affects a subset of morphemes bearing T_1 and T_4 but what is absent from Mandarin are tone sandhi processes applying to T_1 and T_4 more generally. This suggests that these tones, T_1 (Hh) and T_4 (Hhl), can appear in both head and dependent position with their tonal profiles intact. This is indeed the case.

Let us examine this more concretely. When the initial tone is T_2 (Hlh) and the medial tone is T_1 (Hh) or T_4 (hl), no problem arises. T_2 is more complex, as per (64), and can thus be followed by any tone of lesser complexity, including T_1 and T_4, as all of these tones can be carried by light syllables. T_2 could also be followed by T_2, without violating (66); however, this tone is restricted to heavy syllables, as we have seen, and thus T_2 sandhi must apply independent of (66).

When both the initial and medial tones are T_1 and/or T_4, (66) is similarly not violated, as these tones are of equal complexity. As long as T_1 and T_4 can be borne by both heavy and light syllables, as we have proposed, then they are correctly predicted not to undergo sandhi when in medial position.

In short, (66) does not rule out tones of equal tonal complexity in head and dependent positions in the foot, as long as these tones respect the weight constraints of the Mandarin foot. Consequently, processes like T_2 sandhi are not inadvertently predicted to target tonal profiles other than T_2.

11. Relationship between stress and tone in Mandarin.

Thus far, this paper has focused on the prosodic factors underlying T_2 sandhi. In this final section, we examine the broader relationship that holds between stress and tone in Mandarin and, we conjecture, in contour tone languages more generally. In section 11.1, we propose that a relation holds between high register and prominence (stress) and between low register and non-prominence (absence of stress). A relation also exists between rising contour and prominence, and between level tone and non-prominence. In section 11.2, we argue that it is stress that regulates the realization of tone. We propose that Mandarin sandhi processes are all triggered by stress: prominent position makes tone high and rise; non-prominent position makes tone level.

11.1. Static relations between stress and tone. The static relations that hold between stress and tone in Mandarin can be discerned from the markedness scale in (64) above. Since Mandarin is a contour tone language, the relations that hold are of two types: there is a relation between stress and register; and there is a relation between stress and contour.

Concerning the relation between stress and register, all high register tones, T_1 (Hh), T_2 (Hlh) and T_4 (Hhl), both level and contour, can occur in prosodic head position. By contrast, low register tones, both level T_0 (L) and contour T_3 (Lhl), can only occur in non-head position. There is thus a relation between low register and non-prominent position and between high register and prominent position, consistent with what is observed in register tone languages: high tone is correlated with prominence (Liberman 1975, Selkirk 1984, 1995, Goldsmith 1987) and low tone with non-prominence (de Lacy 1999, 2002, 2007).

As far as the relation between stress and contour is concerned, rising tone (T_2) only occurs in prosodic head position. When a rising tone occurs in non-prominent position, it becomes a level tone (as in T_2 sandhi). This indicates that there is a relation between rising contour and prominent position and between level tone and non-prominent position.

11.2. Dynamic relations between stress and tone. The markedness scale in (64) pairs tone with weight (and thus stress) in Mandarin. However, it tells us nothing about how tone and stress interact with each other dynamically. In the following sections, we address this question.

Meredith (1990) proposes that Mandarin stress is determined solely by tone. Chang (1992) partly adopts this proposal and suggests further that T_4 attracts stress while T_3 repels it. However, neither researcher provides sufficient evidence to support the proposal, thus leaving open the question as to why it is tone that determines stress rather than stress that determines the realization of tone.

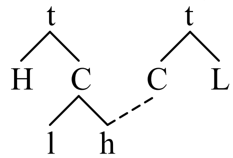
In this paper, we take the opposite position to that of Meredith and Chang: we argue that it is stress that determines the realization of tone. The evidence comes from tone sandhi, not just from T_2 sandhi but from all of the tone sandhi processes in Mandarin. Prominent position makes tone high and rise and non-prominent position makes tone level.

Recall that there are four tone sandhi processes in Mandarin: T_0 sandhi, T_3 sandhi and *yi-bu-qi-ba* sandhi, in addition to T_2 sandhi. As far as T_2 sandhi is concerned, we have shown that whenever T_2 (Hlh) syllables are unstressed, the rising contour becomes level. As all researchers who factor prosodic considerations into their analysis agree that this sandhi process is triggered by stress, nothing further needs to be added here. We briefly consider T_0 sandhi before turning to examine T_3 sandhi and *yi-bu-qi-ba* sandhi.

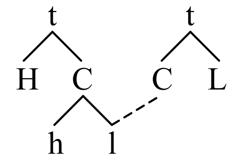
11.2.1. T_0 sandhi. Recall from section 6 that we specify T_0 (L) for register only, that is, as lacking tonal features. This is because we regard T_0 sandhi as a process where T_0 syllables, which are always unstressed, acquire their tone from the adjacent head. T_0 always surfaces as a mid or low level tone, as expected if there is a relation between level tone and non-prominent position. (67) shows that if the rightmost tonal feature from the foot head spreads onto T_0, the correct results obtain: [tsɨ$_0$] surfaces as mid (Lh) in (67a) and as low (Ll) in (67b).

(67) *T_0 sandhi*

a. (ˈh^{w}uu$_2$ tsɨ$_0$)$_{Ft}$ 'beard'



b. (ˈtən$_4$ tsɨ$_0$)$_{Ft}$ 'stool'



11.2.2. T_3 sandhi. We turn now to examine T_3 sandhi and, following this, *yi-bu-qi-ba* sandhi in greater detail. We argue that in both cases, stress is the trigger: in prominent position, tones become high and rising.

As alluded to in section 8.1, in T_3 sandhi, T_3 (Lhl) becomes T_2 (Hlh) when it occurs before another T_3 (Lhl). Yip (2002:180-181) regards T_3 sandhi as OCP-driven dissimilation. However, OCP effects are usually observed when marked features are adjacent and T_3 falls near the unmarked end of the markedness scale for Mandarin (section 10.1). Dell (2004) proposes that T_3 sandhi is likely induced by stress; he suggests that T_3 sandhi is a process of neutralization in which the first T_3 neutralizes with T_2 (Hlh) when unstressed. (Dell (2004) considers Mandarin to have a right-prominent rhythmic structure.) This, however, raises a new question as to why T_3 (Lhl) would change from a less marked to a more marked tone when lacking stress.

In this section, we provide evidence that T_3 sandhi is indeed induced by stress, but recall that in our view, Mandarin builds trochees with main stress left-aligned with the PWd, in contrast to the position taken by Dell (2004). The first piece of evidence that T_3 sandhi is induced by stress comes from the examples provided by Cheng (1968), reproduced in (68).

(68) a. hao$_3$ proˈfessor 'good professor'
|
Lhl → Hlh

b. hao$_3$ ˈstudent 'good student'
|
Lhl

As can be seen, T_3 sandhi applies in (68a) when the syllable under focus is followed by an unstressed syllable, but it does not apply in (68b) when the following syllable is stressed. Since the examples contain loanwords from English and high pitch is one of the main cues for English stress, Cheng (1968) suggests that it may be more accurate to regard T_3 sandhi as being triggered by low pitch. However, as was pointed out in section 11.1, low pitch is usually linked to prosodically non-prominent position. If T_3 sandhi is triggered by a following low pitch, the T_3 syllable which undergoes this sandhi process must occur in a prominent position. In other words, T_3 (Lhl) becomes T_2 (Hlh) when it is stressed.

The second piece of evidence that T_3 sandhi is stress-induced comes from the application of this sandhi process in larger domains. Cheng (1973) and Shih (1997) observe that the sentence in (69) consisting of a sequence of five T_3 syllables has more than one reading. (This sentence contains three words: Lao$_3$ Li$_3$, mai$_3$, hao$_3$ jiu$_3$.)

(69) *Underlying*

Lao$_3$ Li$_3$	mai$_3$	hao$_3$ jiu$_3$	'Old Li buys good wine'
Old Li	buy	good wine	

Attested outputs

a. Lao$_2$ Li$_3$ mai$_3$ hao$_2$ jiu$_3$
b. Lao$_2$ Li$_2$ mai$_3$ hao$_2$ jiu$_3$
c. Lao$_2$ Li$_3$ mai$_2$ hao$_2$ jiu$_3$
d. Lao$_2$ Li$_2$ mai$_2$ hao$_2$ jiu$_3$

Shih (1997: 85) mentions that the last reading, output (69d), is the least favoured and is sometimes rejected outright by speakers. This is expected under a stress-based account of T$_3$ sandhi: it is highly unlikely that all of the (non-final) syllables in a sentence would be equally stressed (i.e., bearing T$_2$) in normal speech. On our account, this violates *CLASH.

As far as output (69b) (as well as (69d)) is concerned, where the second syllable *Li$_3$* undergoes T$_3$ sandhi, this will never apply according to the intuitions of the first author because *Li$_2$* and *Li$_3$* are different family names. If T$_3$ sandhi were to apply, misunderstanding would arise. This leaves outputs (69a) and (69c) as the most natural readings. Nothing particular needs to say about (69a): the initial syllables of the two multimorphemic words undergo T$_3$ sandhi as expected. For output (69c), the third syllable *mai$_3$* undergoes T$_3$ sandhi because it is under focus and, thus, must bear stress.

It is not surprising that T$_3$ (Lhl) becomes rising when under stress. Recall from (64) that the syllables bearing T$_3$ are light. In order for them to occur in prosodic head position, they must become heavy. However T$_3$ (Lhl) cannot be lengthened without changing the pitch contour. This is because T$_3$, as Lhl, has reached the lowest point in the available pitch range. When longer duration is available for this syllable, its pitch can therefore only rise. Accordingly, T$_3$ (Lhl) becomes T$_2$ (Hlh) when stressed phrase-internally. In phrase-final position, where even longer duration is available, it becomes Lhlh, as mentioned earlier.

11.2.3. Yi-bu-qi-ba *sandhi. Yi-bu-qi-ba* sandhi refers to the tonal change that the morphemes /jii$_1$/ 'one', /puu$_4$/ 'not', /tɕ^{h}ii$_1$/ 'seven' and /paa$_1$/ 'eight' undergo when followed by another morpheme bearing T$_4$ (Hhl), as shown by the following examples.[29] As can be seen, no matter whether the targeted syllable is underlyingly T$_1$ (Hh) or T$_4$ (Hhl), it becomes T$_2$ (Hlh) when occurring in word-initial (stressed) position.

(70) a. /jii$_{Hh}$ p^{jh}an$_{Hhl}$/ → [jii$_{Hlh}$ p^{jh}an$_{Hhl}$] 'one + CLASSIFIER'
b. /puu$_{Hhl}$ tɕ^{wh}yy$_{Hhl}$/ → [puu$_{Hlh}$ tɕ^{wh}yy$_{Hhl}$] 'not go'
c. /tɕ^{h}ii$_{Hh}$ kɣɣ$_{Hhl}$/ → [tɕ^{h}ii$_{Hlh}$ kɣɣ$_{Hhl}$] 'seven + CLASSIFIER'
d. /paa$_{Hh}$ m^{j}an$_{Hhl}$/ → [paa$_{Hlh}$ m^{j}an$_{Hhl}$] 'eight + CLASSIFIER'

Chang (1992) suggests that *yi-bu-qi-ba* sandhi is likely induced by stress. However, she follows Meredith (1990) in regarding T$_4$ (Hhl) as the most prominent tone in Mandarin. Her account thus fails to explain why this tone becomes less prominent (T$_2$) when it occurs in stressed position.

Under the prosodic licensing account of T$_2$ sandhi presented here, this problem can be straightforwardly resolved. Recall from (64) that T$_2$ (Hlh) is the only tone that is more marked than T$_4$ (Hhl) and T$_1$ (Hh). Accordingly, in *yi-bu-qi-ba* sandhi, when both T$_1$ and T$_4$ are targeted to undergo change when stressed, T$_2$ (Hlh) is the only possible output. Note that *yi-bu-qi-ba* sandhi is different from T$_3$ sandhi, as in the latter, the initial light syllable becomes heavy when stressed. In *yi-bu-qi-ba* sandhi, by contrast, the initial syllable is already heavy; thus, in this sandhi process, the head is only made more prominent (more marked), as per (66a).

In sum, we have proposed that all tone sandhi processes in Mandarin are triggered by stress. In T$_2$ sandhi, non-prominent position makes rising contours become level, while in T$_3$ sandhi and *yi-bu-qi-ba* sandhi, prominent position makes tone (either level or contour) become high and rising. In T$_0$ sandhi, T$_0$ surfaces as a level tone through assimilation from both level and contour tones in head position, which is as expected if there is a relation between level tone and non-prominent position. We contend that the only possible explanation for all of these patterns is that (absence of) stress determines the realization of tone.

12. Concluding remarks.

The goal of this paper was to examine the relationship between tone and stress in contour tone languages. Mandarin T_2 sandhi was focused on because there is uniform agreement that it is triggered by stress and because T_2 (Hlh) is a contour tone. To disambiguate the factors involved in this sandhi process, an experiment was performed. Although only three subjects were tested, the results were relatively uniform, suggesting that the generalizations found may hold quite widely.

As far as foot shape is concerned, we argued that Mandarin builds uneven trochees. We suggested that the different prosodic structures that disyllabic words have, combined with a phrase-final lengthening effect, are responsible for the divergent proposals in the literature concerning word-level stress. On our view, word level stress always falls on the leftmost heavy syllable.

Stemming from the experimental results and constraints on Mandarin prosodic structure, we showed that in T_2 sandhi, a rising tone becomes level whenever the syllable bearing this tone loses stress. We proposed that T_2, as the most marked tone in Mandarin, can only be licensed in head position. The prosodic licensing account of T_2 sandhi further explained why only T_2 (Hlh) and not T_4 (Hhl), another high register contour tone, undergoes sandhi when it occurs in non-prominent position.

Based on the distribution of Mandarin tones within the foot, we suggested that there is a relation between high register and prominence, between low register and non-prominence, between rising contour and prominence, and between level tone and non-prominence in contour tone languages. Although the relation found between register and prominence is consistent with what has been observed for register tone languages, we extended the proposal to contour as well.

The relations between register and prominence and between contour and prominence are static relations that hold between tone and stress. In discussing the dynamic interactions that hold, we argued that it is stress which determines the realization of tone. Prominent positions make tone high and rising, as in Mandarin T_3 sandhi and *yi-bu-qi-ba* sandhi; non-prominent positions make tone level, as in T_2 sandhi.

The proposal we have put forward is, of course, based on results from a single contour tone language only. Clearly, a range of languages must be examined in future work in order to validate the broader findings of both the static and dynamic relations that hold between prominence and tone.

References

Bao, Zhiming. 1990. *On the nature of tone*. Cambridge, MA: MIT dissertation.

Bao, Zhiming. 1999. *The structure of tone*. Oxford: Oxford University Press.

Boersma, Paul, and David Weenink. 2010. Praat: doing phonetics by computer (version 5.1.38) [computer program]. http://www.praat.org/.

Chao, Yuen Ren. 1951. The Cantian idiolect: an analysis of the Chinese spoken by a twenty-eight-months-old child. *Semitic and oriental studies,* ed. by Walter J. Fischel, 27-44. Berkeley: University of California Press.

Chao, Yuen Ren. 1968. *A grammar of spoken Chinese*. Berkeley: University of California Press.

Chang, Laura Mei-Chih. 1992. *A prosodic account of tone, stress, and tone sandhi in Chinese languages*. Honolulu: University of Hawai'i dissertation. [Published, Taipei: Crain, 1993.]

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

Cheng, Chin-chuan. 1968. English stresses and Chinese tones in Chinese sentences. *Phonetica* 18.77-88.

Cheng, Chin-chuan. 1973. *A synchronic phonology of Mandarin Chinese*. The Hague: Mouton.

Coetzee, Andries, and Joe Pater. 2008. Weighted constraints and gradient restrictions on place co-occurrence in Muna and Arabic. *Natural Language & Linguistic Theory* 26.289-337.

de Lacy, Paul. 1999. *Tone and prominence*. University of Massachusetts, Amherst, MS. [Rutgers Optimality Archive, no. 333.]

de Lacy, Paul. 2002. The interaction of tone and stress in Optimality Theory. *Phonology* 19.1-32.

de Lacy, Paul. 2007. The interaction of tone, sonority, and prosodic structure. *The Cambridge handbook of phonology,* ed. by Paul de Lacy, 281-307. Cambridge: Cambridge University Press.

Dell, François. 2004. On unwarranted claims about stress and tone in Beijing Mandarin. *Cahiers de linguistique – Asie Orientale* 33.33-63.

Dreher, John J., Elaine L. Young, and Pao Chen Lee. 1969. Mandarin triplet contours. *Research Communication* 107. Huntington Beach, CA: Douglas Advanced Research Laboratories.

Dresher, Elan, and Harry van der Hulst. 1998. Head-dependent asymmetries in prosodic phonology: visibility and complexity. *Phonology* 15.317-52.

Duanmu, San. 1990. *A formal study of syllable, tone, stress and domain in Chinese languages*. Cambridge, MA: MIT dissertation.

Duanmu, San. 1993. Rime length, stress, and association domains. *Journal of East Asian Linguistics* 2.1-44.

Duanmu, San. 1998. Wordhood in Chinese. *New approaches to Chinese word formation: morphology, phonology and the lexicon in modern and ancient Chinese*, ed. by Jerome L. Packard, 135-96. Berlin: Mouton de Gruyter.

Duanmu, San. 1999. Metrical structure and tone: evidence from Mandarin and Shanghai. *Journal of East Asian Linguistics* 8.1-38.

Duanmu, San. 2007. *The phonology of Standard Chinese.* 2nd edn. Oxford: Oxford University Press. [1st edn., 2000.]

Feng, Long. 1985. Duration of initials, finals and tones in Beijing dialect. *Working Papers in Experimental Phonetics,* ed. by Lin Tao, 131-95. Beijing: Beijing University Press.

Feng, Shengli. 1995. *Prosodic structure and prosodically-constrained syntax in Chinese*. Philadelphia: University of Pennsylvania dissertation.

Feng, Shengli. 2001. *Minimal word in Mandarin Chinese*. Lawrence: University of Kansas, ms. [Rutgers Optimality Archive, no. 507.]

Feng, Shengli. 2006. Hanyu yunlü yufa yanjiu *[The study of Mandarin prosodic syntax]*. Beijing: Beijing University Press.

Fromkin, A. Victoria (ed.) 1978. *Tone: a linguistic survey*. New York: Academic Press.

Gao, Mingkai, and Anshi Shi. 1963. *Yuyanxue kailun [Introduction to linguistics]*. Beijing: Zhunghua Shudian.

Goad, Heather, and Lydia White. 2006. Ultimate attainment of L2 inflection: effects of L1 prosodic structure. *Second Language Research* 22.243-68.
Goad, Heather, Lydia White, and Jeffrey Steele. 2003. Missing inflection in L2 acquisition: defective syntax or L1-constrained prosodic representations? *Canadian Journal of Linguistics* 48.243-63.
Goldsmith, John. 1987. Tone and accent, and getting the two together. *BLS* 13.88-104.
Goldsmith, John (ed.) 1995. *The handbook of phonological theory.* Oxford: Blackwell.
Harris, John. 1997. Licensing inheritance: an integrated theory of neutralisation. *Phonology* 14.315-70.
Hayes, Bruce. 1995. *Metrical stress theory: principles and case studies*. Chicago: University of Chicago Press.
Hirose, Hajime. 1997. Investigating the physiology of laryngeal structures. *The handbook of phonetic sciences*, ed. by William J. Hardcastle and John Laver, 116-36. Oxford: Blackwell.
Hoa, Monique. 1983. *L'accentuation en pékinois.* Paris: Editions Langages Croisés.
Hombert, Jean-Marie. 1978. Consonant types, vowel quality, and tone. In Fromkin 1978, 77-112.
Hulst, Harry van der, and Marian Klamer. 1996. The uneven trochee and the structure of Kambera roots. *Dam Phonology: HIL Phonology Papers II*, ed. by Marina Nespor & Norval Smith. The Hague: Holland Academic Graphics.
Hyman, Larry. 2006. Word-prosodic typology. *Phonology* 23.225-57.
Itô, Junko, and Ralf-Armin Mester. 1986. The phonology of voicing in Japanese: theoretical consequences for morphological accessibility. *Linguistic Inquiry* 17.49-73.
Kager, René. 1999. *Optimality Theory.* Cambridge: Cambridge University Press.
Kenstowicz, Michael. 1994. *Phonology in generative grammar*. Oxford: Basil Blackwell.
Kisseberth, Charles, and David Odden. 2003. Tone. *The Bantu languages*, ed. by Derek Nurse and Gérard Philippson, 59-70. London: Routledge.
Kratochvil, Paul. 1974. Stress shift mechanism and its role in Peking dialect. *Modern Asian Studies* 8.433-458.
Leben, William. 1973. *Suprasegmental phonology*. Cambridage, MA: MIT dissertation.
Li, Jinxi. 1957. *Guoyu cidian yuanxu [Original preface for national language dictionary]* in Hanyu cidian [The dictionary of Mandarin]. Originally published (1937) as Guoyu cidian [National language dictionary]. Beijing: Shangwu Yinshu Guan.
Li, Weimin. 1981. Shilun qingsheng he zhongyin [On neutral tone and stress]. *Zhongguo Yuwen* 1.35-40.
Liberman, Mark. 1975. *The intonational system of English*. Cambridge, MA: MIT dissertation.
Lin, Hua. 1992. *On the nature of Mandarin tone and tone sandhi.* Victoria, BC: University of Victoria dissertation.
Lin, Maocan, Jingzhu Yan, and Guohua Sun. 1984. Beijinghua liangzizu zhengchang zhongyin de chubu shiyan [A preliminary experiment on normal stress in Beijing Mandarin bisyllabic expressions]. *Fangyan* 1.57-73.
Luo, Changpei, and Jun Wang. 2002. *Putong yuyinxue gangyao* [Outline of general phonetics]. 2nd edn. Beijing: Shangwu Yinshuguan. [1st edn., 1981.]
McCarthy, John. 1986. OCP effects: Gemination and antigemination. *Linguistic Inquiry* 17.207-63.
McCarthy, John. 1989. Linear order in phonological representation. *Linguistic Inquiry* 20.71-99.
McCarthy, John, and Alan Prince. 1986. *Prosodic morphology*. University of Massachusetts, Amherst and Brandeis University, ms.
McCarthy, John, and Alan Prince. 1995. Prosodic morphology. In Goldsmith 1995, 318-66.
Mellander, Evan W. 2002. *A prosodic theory of prominence and rhythm*. Montreal, QC: McGill University dissertation.
Meredith, Scott. 1990. *Issues in the phonology of prominence*. Cambridage, MA: MIT dissertation.
Nespor, Marina, and Irene Vogel. 1986. *Prosodic phonology*. Dordrecht: Foris.
Pierrehumbert, Janet. 1993. Dissimilarity in the Arabic verbal roots. *Proceedings of the North East Linguistic Society* 23, ed. by Amy Schafer, 367-81. Amherst, MA: GLSA.

Piggott, Glyne L. 1998. Foot form and the parsing of weightless syllables. *CLS 34: Main session*, ed. by M. Catherine Gruber, Derrick Higgins, Kenneth Olson, and Tamra Wysocki, 315-32. Chicago: Chicago Linguistic Society.
Prince, Alan, and Paul Smolensky. 1993. *Optimality Theory: constraint interaction in generative grammar.* Rutgers University and University of Colorado Boulder, ms. [Published 2004, Oxford: Blackwell.]
Selkirk, Elisabeth O. 1980. The role of prosodic categories in English word stress. *Linguistic Inquiry* 11.563-605.
Selkirk, Elisabeth O. 1984. *Phonology and syntax: the relation between sound and structure.* Cambridge: MIT Press.
Selkirk, Elisabeth O. 1986. On derived domains in sentence phonology. *Phonology Yearbook* 3.371-405.
Selkirk, Elisabeth O. 1995. The prosodic structure of function words. *Papers in Optimality Theory* (University of Massachusetts Occasional Papers 18), ed. by Jill Beckman, Laura Walsh Dickey, and Suzanne Urbanczyk, 439-69.
Schuh, Russell G. 1978. Tone rules. In Fromkin 1978, 77-112.
Shih, Chilin. 1997. Mandarin third tone sandhi and prosodic structure. In Wang & Smith 1997, 81-123.
Wang, Jialing. 1997. The representation of the neutral tone in Chinese Putonghua. In Wang & Smith 1997, 157-83.
Wang, Jialing, and Norval Smith (eds.) 1997. *Studies in Chinese phonology*. Berlin: Mouton de Gruyter.
Wang, Jun, and Lijia Wang. 1993. Putonghua duoyijie ci yinjie shichang fenbu moshi [The types of relative length of syllables in polysyllabic words in Putonghua]. *Zhongguo Yuwen* 2.112-116.
Woo, Nancy. 1969. *Prosody and phonology.* Cambridge, MA: MIT dissertation.
Wu, Zongji. 1984. Putonghua sanzizu biandiao guilü [Tone sandhi of tri-syllabic expressions in Standard Mandarin]. *Zhongguo Yuyan Xuebao* 2.70-92.
Wu, Zongji, and Maocan Lin. 1989. *Shiyan yuyinxue gaiyao* [An outline of experimental phonetics]. Beijing: Higher Education Press.
Xu, Shirong. 1982. Shuangyinjie ci de yinliang fenxi [A quantitative analysis of disyllabic words]. *Yuyan Jiaoxue yu Yanjiu* 2.4-19.
Yan, Jingzhu, and Maocan Lin. 1988. Beijinghua sanzizu zhongyin de shengxue biaoxian [The acoustic manifestation of stress in Beijing Mandarin trisyllabic expressions]. *Fangyan* 3.227-37.
Yin, Zuoyan. 1982. Guanyu Putonghua shuangyi changyong ci qingzhongyin de chubu kaocha [A preliminary study of accents and atonics in disyllabic words in common use]. *Zhongguo Yuwen* 3.168-73.
Ying, Shichao. 2002. Harbin hua shi he Beijing hua zui wei jiejin de yizhong teda chengshi fangyan [Harbin dialect is a super city dialect most representative of Mandarin]. *Hanyu yufa xiuci lunji*, ed. by Shichao Ying, 311-30. Beijng: China Social Science Press.
Yip, Moira. 1980. *The tonal phonology of Chinese*. Cambridge, MA: MIT Dissertation, [Published, New York: Garland, 1990.]
Yip, Moira. 1995. Tone in East Asian languages. In Goldsmith 1995, 476-94.
Yip, Moira. 2002. *Tone*. Cambridge: Cambridge University Press.

Endnotes

[1] The descriptions in the text originally come from Chao (1968:25-26). Note though that Chao treats T_0 as non-contrastive, as derived from other tones when unstressed; this is also the position of Yip (1980).

[2] Chen and Duanmu adopt Chao's observations but amend his proposal by including the additional trigger of stress.

[3] A further issue concerns whether the process involves assimilation (Chen 2000, Duanmu 2007) or neutralization (Chang 1992). We discuss this very briefly in section 5.2.2.

[4] Wu controlled for hierarchical structure; Dreher et al. did not. In neither study was the segmental profile of the medial syllable controlled; nor were the speakers controlled for dialect and speech rate, as well as register in the case of Wu.

[5] Note, though, that all stressed syllables must be heavy in Mandarin and so monophthongs in stressed open syllables are realized as long (Lin et al. 1984, Yan & Lin 1988).

[6] We did not select participants from Beijing because the inhabitants of this city are increasingly heterogeneous due to the large number of migrants who have moved there from other parts of China. This may, of course, have an effect on the dialects spoken in this city and thus on the application of T_2 sandhi.

[7] Subjects were asked to control their speech rates by themselves. As will be discussed in section 5.2.1, only stimuli that fell within a fixed range for duration were compared in the analysis.

[8] Speaker 3's fast speech is only taken into consideration for stimuli which were produced with similar duration to those produced by the other two speakers. Most of her trisyllabic constructions in fast speech had a duration of less than 500ms. In all of these cases, the medial T_2, regardless of factor, underwent tone sandhi. Some of the affected syllables were realized with a level pitch and others with a falling pitch, consistent with Wu (1984).

[9] Although the rising contour of T_2 cannot be licensed in unstressed syllables in medial position, at the same time, all syllables must bear some tone to be well-formed: we thus assume that the neutralized T_2 syllable acquires the rightmost tonal feature from the preceding vowel, yielding a level tone. In the interest of space, we do not provide a fully fleshed out analysis of the sandhi form of T_2; nevertheless, it should be evident from the brief sketch here that we assume an account involving both neutralization and assimilation. Neutralization alone has been proposed by Chang (1992) and assimilation alone by Chen (2000) and Duanmu (2007). Both types of approaches, however, face empirical challenges.

[10] Of course, one must be cautious in drawing conclusions about which pattern, presence or absence of sandhi, is preferred based on data from only two out of three speakers. We will see later, however, that the analysis does indeed predict as optimal the patterns displayed by the two speakers in each of the cases of variation.

[11] T_3 carried by a long vowel is realized as low dipping, while T_3 carried by a short vowel is low falling (see further section 7).

[12] Note that the vowels in the initial syllables in (8b) (for Speakers 2 and 3) and (8c-d) are shortened, although we have only transcribed this for the monophthong in (8d); shortening is discussed further in sections 8.2.2 and 9.2.2.

[13] In utterance-final position and before T_0 (L), T_3 (Lhl) is realized as Lhlh which we regard as heavy (see further notes 16 and 17 and section 11.2.2).

[14] Duanmu's dual trochee permits feet to be complex at both syllabic and moraic levels. In effect, it yields feet that are either HH or HL in shape.

[15] Even though T_1 and T_4 can be light, they are not included in (33) since they can also appear as heavy with the same tonal profile, as is evident from (31).

[16] The two-way (heavy vs. light) split in (31) may be too coarse. It may well be the case that T_0 syllables are moraless, in contrast to the other light syllables in Mandarin that are monomoraic. This would account for their inability to be augmented when in initial position in $\sigma_\mu \sigma_\mu$ disyllabic constructions. In addition, the Lhlh allotone of T_3 may actually be trimoraic. As

mentioned in note 13, this allotone only occurs before T_0 and utterance-finally. If T_0 is moraless, then disyllabic constructions composed of T_3 (as Lhlh) + T_0 would be trimoraic paralleling the number of moras found in uneven trochees. That is, although somewhat unorthodox, Mandarin would strive to build feet with three moras. Related to this, note that T_3 does not surface as Lhlh before another T_3 (Lhl) which would yield the illicit foot $*(\sigma_{\mu\mu\mu}\,\sigma_{\mu})_{Ft}$ under this analysis. Instead, it changes into bimoraic T_2.

17 To our knowledge, clash is never tolerated in Mandarin (except in emphatic speech; see e.g. (69c) below). Adjacent stresses are ruled out within PWds (as in (39b)), across PWds in compounds (as in (35b)) and across PWds in phrases (as in (43b)).

18 The vowels in left-edge adjuncts in Mandarin must be short, whether they are licensed by the PWd, as in (40b), or by the PPh, as in (43a) below. This is because domain-initial syllables that are heavy must be stressed in Mandarin.

19 In addition to T_1, T_2 and T_4, the final syllable can also bear T_3 which surfaces as Lhlh when heavy (see note 13), for example: /k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_3$/ → [k^{w}an$_1$ tʂ^{h}a$_1$ s^{w}oo$_{Lhlh}$] 'Observation Office' (S2 & S3). Compare [k^{w}an$_1$ tʂ^{h}aa$_2$ s^{w}o$_{Lhl}$] (S1) where T_3 surfaces as light, Lhl, and T_2 sandhi does not apply.

20 Counter to expectation, T_2 sandhi is not attested when the medial T_2 is surrounded by two T_4 syllables. We address this case of under-application in section 9.3.1.

21 In the interest of clarity, we have provided two-step structures for the trisyllabic constructions in sections 9.2.1 and 9.2.2. The appropriate structures can also be arrived at non-derivationally, as was shown earlier in sections 8.2.1 and 8.2.2.

22 Other muscles are also involved in pitch lowering; see Hirose (1997) for details.

23 This scale will be revised slightly in section 11.1.

24 We must consider why the OCP is operative only in [σ_1 [σ_2 σ_2]] in Speaker 1's productions, and not in [σ_3 [σ_2 σ_2]] and [σ_4 [σ_2 σ_2]]. We reason that this is due to the tonal profiles of T_3 (Lhl) and T_4 (Hhl). The end point for both tones is low which is the starting point for T_2 (Hlh); it should thus be relatively easy for speakers to maintain the contour required for T_2 in this context, in spite of the OCP violation that results. T_1, by contrast, is Hh; it should be harder to produce the rising pitch required for T_2 following T_1, especially in fast speech.

25 Note that there is no over-application of T_2 sandhi in right-branching constructions with the following tonal profiles: [σ_1 [σ_2 σ_3]] and [σ_1 [σ_2 σ_4]]. This is presumably because, in the examples in our experiment, the medial vowel in these constructions was [aa].

26 We exclude from discussion constructions with initial T_3 (Lhl): recall that they never display T_2 sandhi.

27 Recall from note 16 that we have suggested that T_0 may be moraless. Once this issue has been examined more systematically, it may be that (64) must be revised to reflect this.

28 T_4 (Hhl) isn't phonetically realized in exactly the same manner in head and dependent position. Not surprisingly, the contour is less steep in foot-dependent position, but the contour is nevertheless still present, unlike in the case of T_2.

29 The morpheme /jii1/ 'one' is realized as T_4 (Hhl) when occurring before morphemes bearing tones other than T_4 (Hhl).