

**Juncture Phrasing Thresholds:**  
**A constraint-based approach to speech rate effects**  
**on Mandarin tone sandhi**

by

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B.A., University of Victoria, 2005

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# APPROVAL

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**Degree:** Master of Arts

**Title of Thesis:** **Juncture Phrasing Thresholds:  
A constraint-based approach to speech  
rate effects on Mandarin tone sandhi**

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## ABSTRACT

This thesis investigates the effect of speech rate on Mandarin tone sandhi. This effect is argued to be the result of hypothesized thresholds on the duration of junctural units that lie between phonological phrases. A new type of constraint,  $*\text{WrapSD}(n_{\text{msec}})$ , is proposed that assigns a violation to every juncture that exceeds a specified durational threshold. The  $*\text{WrapSD}(n_{\text{msec}})$  constraints are incorporated within recent constraint-based approaches to phonological phrasing and shown to be superior to alternative approaches that require either cyclic rule application or constraint re-ranking. This approach also leads to an empirical exploration of four new sentence types, which are documented with eleven native Mandarin speakers and shown to be consistent with juncture thresholds.

# DEDICATION

To my grandma, my parents and to all the people I love.

*“Measure what is measurable, and make measurable what is not so.”*

– Galileo Galilei (1564-1642)

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# 1. Introduction

## 1.1 Themes

This thesis is about the effects of speech rate on phonological processes, and in particular, those processes tied to the formation of phonological phrases. The empirical focus of the thesis is Mandarin tone sandhi, and how speech rate determines different patterns of tonal neutralization in the language. In Mandarin, a faster speech rate results in a larger number of tonal neutralizations, but the specific patterns of neutralization depend on a host of phonological, morpho-syntactic and timing factors. In this work, I attempt to define a model that integrates all of these factors into a single grammar of tone sandhi.

The theoretical background for the proposal involves a set of assumptions in Optimality Theory (Prince & Smolensky, 1993), as well as some crucial assumptions from End-Based theories of phonological phrasing (Selkirk, 1984a, 1984b; 1986 et seq.). In particular, I apply the OT implementation of End-Based phrasing developed in detail in (Selkirk, 1995; Truckenbrodt, 1995, 1999). My work is a contribution to this theory because I show that by introducing reference to timing information, complex patterns of tone sandhi that depend on speech rate can be explained.

Timing information is encoded in demibeats, and, following (Selkirk, 1984b), I assume that pause durations are represented by silent demibeats, i.e., the timing

units between words. I consider a quantitative way in which OT constraints on phrasing can refer to silent demibeats, and ultimately argue that the following principle can be used to explain the facts of Mandarin tone sandhi.

(1) Juncture Phrasing Thresholds (JPT)

Junctures within a given phonological phrase must not exceed a language-particular juncture timing threshold.

I propose a new set of constraints,  $*\text{WrapSD}(n_{\text{msec}})$ , within an OT version of the End-Based theory to explain the speech rate effects on Mandarin tone sandhi. The analysis of the juncture timing thresholds,  $*\text{WrapSD}(n_{\text{msec}})$ , looks at every phonological phrase. In every phonological phrase, it looks at every juncture and restricts the time value of each juncture that goes above certain thresholds.

(2)  $*\text{WrapSD}(n_{\text{msec}})$

Junctures between two elements with a value equal to or greater than (n) milliseconds cannot be in the same phonological phrase. Assign one violation for every juncture that exceeds the threshold (n).

To illustrate the juncture timing thresholds, I flesh out an example below to show how the silent demibeats at each juncture are assigned, and how the constraint,  $*\text{WrapSD}(n_{\text{msec}})$ , I propose interprets timing information using the silent demibeats.

X is a common denominator for rate of speech, and the way to assign Xs is based on the morpho-syntactic structure. The juncture between two words within a simple noun phrase (A+N etc.) receives one X, whereas the juncture between

the verb and the noun phrase receives two Xs. The juncture between the subject noun phrase and the verb phrase gets three Xs. We assign a ( $n_{\text{msec}}$ ) to the X; the more Xs there are, the longer duration the ( $n_{\text{msec}}$ ) is. I will explain the principles underlying this approach in more detail in Chapter 3.

In the following example, each X is 150 msec at the slowest speech rate. The juncture between two words within the noun phrase *Lao & Li* ‘Lao-Li’ and *hao & jiu* ‘good wine’ is 150 msec. Since the juncture between the verb and the noun phrase complement has longer pause duration than the juncture within the noun phrase, it receives two Xs, and it is 300 msec. The juncture between the noun phrase subject and the verb phrase has the longest pause duration: it receives three Xs, and it is 450 msec.

(3) Illustration of junctures and the assignment of silent demibeats

‘Lao-Li buys good wine.’

老	李	買	好	酒
Lao	Li	mai	hao	jiu
Lao	Li	buy	good	wine
x	<u>x</u>	x	<u>xx</u>	x
	150	<u>xxx</u>	300	<u>x</u>
		450		150

In the juncture timing thresholds, different speech rates are determined by a scale of time values. If the time value of the juncture between two elements is longer than the limit, then the two elements must be separated into two separate domains. The juncture timing thresholds correspond to the alignment and wrap constraints, and allow tonal patterns for speech rates to be directly derived. The details are as follows:

The scale of time values I use here are 300 msec, 200 msec, and 100 msec. One violation is given when the pause duration of the juncture is above the particular time value. The candidate (c) gets two violations of \*Wrap<sub>300</sub> because the juncture between *Li* & *mai* ‘Li & buy’ is above 300 msec, and the juncture between *mai* & *hao* ‘buy & good’ is 300msec. The candidate (a) is the preferred pattern for the slowest pattern, Adagio. Therefore, WrapXP must rank below \*Wrap<sub>300</sub>, as shown in (4), or the winning candidate will be the candidate (c), which is predicted as the pattern for fast speech rate, presto. In (4), the square brackets show the lexical phrases of the sentence, and the brackets show the phonological phrases of the sentence.

(4) Illustration of \*WrapSD( $n_{msec}$ )

[0 <sub>x</sub> 0] <sub>xxx</sub> [0 <sub>xx</sub> [0 <sub>x</sub> 0]]			*Wrap 300	.....	WrapXP
X=150 (slow/adagio)	a.	→(0 <sub>x</sub> 0) <sub>xxx</sub> (0) <sub>xx</sub> (0 <sub>x</sub> 0)			*
	b.	(0 <sub>x</sub> 0) <sub>xxx</sub> (0 <sub>xx</sub> 0 <sub>x</sub> 0)	*!		
	c.	(0 <sub>x</sub> 0 <sub>xxx</sub> 0 <sub>xx</sub> 0 <sub>x</sub> 0)	**!		

This set of constraints covers restrictions on the timing information at junctures for different speech rates. Language-particular differences in their morpho-syntactic structure and phonological structure result from language-particular rankings. For example, if a language requires each lexical phrase to be wrapped into one single domain, then WrapXP must rank high, unlike the case in Mandarin.

The rest of this thesis is organized as follows. Below (in Section 1.2), I motivate the research by reviewing prior work on speech rate effects, identifying a set of key problems that I will attempt to overcome with the theory of Juncture Phrasing Thresholds. In 1.3, I lay out a set of assumptions about the prosodic analysis of sentences and the impact of syntax on the prosodic analyses, which are important in both describing tone sandhi and formulating the new proposal. Chapter 2 documents the problems I attempt to account for in the thesis, reviews the basic empirical patterns for Mandarin tone sandhi, as well as some new patterns that I have explored in this research. Finally, chapter 3 introduces and pursues the theory of Juncture Phrasing Thresholds.

## 1.2 Motivating the research

In this section, I motivate the primary research objective of the thesis by highlighting some of the problems with prior research on speech rate effects relevant to tone sandhi. The goal is to try to identify a set of problems that any theory of speech rate effects should account for, and project ahead to chapter 3, where these problems are addressed.

### 1.2.1 Cyclic approach

Generally speaking, tonal pattern is believed to illustrate the basic effect of speech rates on tone sandhi, and I will describe the tone 3 sandhi rule and speech rate effect in detail in Chapter 2.

(5) Tone 3 Sandhi Rule (Duanmu, 2000, 2007)

In a sequence of two tone 3s, change the first tone 3 to tone 2. It applies from left to right.

(6) Illustration of tone 3 sandhi

T3+T3 → T2+T3

小狗

Xiao3 gou3 → xiao2 gou3 ‘puppy’

很好

Hen3 hao3 → hen2 hao3 ‘very good’

Tone 3 sandhi applies differently in different speech rates. Different rates cause different domains for tone 3 sandhi rule. For instance, in the fastest speed, presto, tone 3 sandhi applies from left to right to the entire sentence. In the slowest



speed, adagio, tone 3 sandhi only applies to the smallest domains defined in terms of the syntactic structure, which will be discussed later in this section.

(7) Speech rate effects on tone sandhi (from slow to fast)

老	李	買	好	酒	
Lao-Li	mai	hao	jiu		'Lao Li buys good wine.'
Lao-Li	buy	good	wine		
3	3	3	3	3	Tonal inputs
2	3	3	2	3	Adagio
2	2	3	2	3	Moderato
2	3	2	2	3	Allegro
2	2	2	2	3	Presto

In cyclic phonology, these different domains can be derived as a function of the different levels of structure at which tone sandhi is applied. In particular, (Cheng, 1973) assumes that the transformational cycle (Chomsky & Halle, 1968, 1991; Chomsky, Halle, & Lukoff, 1956) accounts for tone sandhi application. To understand how it works, we need to first understand what the transformational cycle is. The cycle assumes that phonological rules apply in a set of stages. The levels are defined by progressively larger units, and the cycle goes as follows: the phonological rules first apply on the maximal strings that contain no brackets (i.e. noun phrases). After all relevant rules have applied, the innermost brackets are deleted, and the rules then reapply to maximal strings that contain no brackets (i.e. verb phrases), and, again, innermost brackets are deleted after this application; and so on. The cycles end only when the maximal domain of phonological processing is reached. The cyclic analysis is applied to the following data:

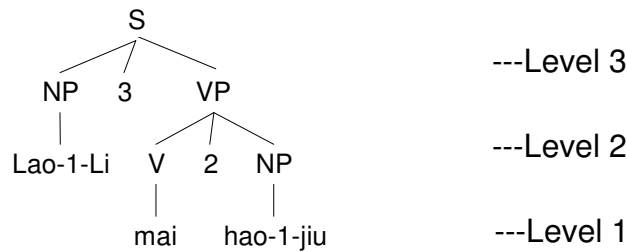
(8) The cyclical analysis of tone sandhi domains

	老 李	買 好 酒				
	Lao-Li	mai hao	jiu		'Lao Li buys good wine.'	
	Lao-Li	buy good	wine			
	[	]NP[	[	]NP]VP	Structure	
	3	3	3	3	Tonal inputs	
(a)	(2	3)	(3)	(2	3)	Cycle 1
(b)	(2	3)	(3	2	3)	Cycle 2
(c)	(2	2	3	2	3)	Cycle 3

In cycle 1, tone 3 sandhi first applies to the smallest domains as in (8a), which are the syllables within noun phrases. The pattern of *adagio* is derived. In cycle 2, the brackets are deleted, and tone 3 sandhi rule is reapplied to the larger domain, but the tonal pattern remains the same. In cycle 3, the brackets are deleted, and tone 3 sandhi then reapplies to the entire phrase. In this cycle, the maximal domain of phonological processing is reached. The pattern of *moderato* is derived.

(Cheng, 1973) applies this cyclical approach to the well-known problem of Mandarin tone sandhi. The numbers 1, 2, 3, etc. are assigned in the tree structures in (9) to indicate a rule domain based on the depth of syntactic boundaries. Using it, we can account for the different possible pronunciations. For example, in slow speech, the tone 3 sandhi rule applies only to depth 1. In faster speech, the rule applies at both depth 1 and depth 2. In even faster speech, the rule applies at both depths 1 and 2, and then is reapplied at depth 3. In the fastest speech, the rule applies simultaneously at all three depths.

(9) Tree structure:



In the analysis, if we apply the tone sandhi rule cyclically, then there will be only one final outcome of the tonal pattern for the sentence meaning various tonal patterns for different speech rates cannot be derived. Therefore, cyclical application requires a “turning-off” mechanism (Kiparsky, 1985; Myers, 1991) and a “skipping” mechanism, which accounts for the reason why different tonal patterns can be derived for different speech rates.

(10) Turning-off mechanism

The “turning-off” mechanism anticipates the Strong Domain Hypothesis (Kiparsky, 1985; Myers, 1991) that all phonological rules can be turned off at any level, but they cannot be turned on after the rules are applied.

(11) Skipping mechanism

The application of phonological rules can be skipped up to a certain level.

Cyclical application cannot explain the fact that the cycle stops at a certain stage, but the application is necessary to stop at a certain stage in order to derive certain tonal patterns for certain speech rate.

(12) Analysis of possible patterns I: turning-off

	老	李	買	好	酒	
	Lao-Li	mai	hao	jiu		'Lao Li buys good wine.'
	Lao-Li	buy	good	wine		
	(3)	(3)	(3)	(3)	(3)	UR
(a)	( <u>2</u> 3)	3	( <u>2</u> 3)			Adagio----off for levels 2, 3
(b)	(2 3)	(3 2 3)				Adagio----off for level 3
(c)	(2 <u>2</u> 3 2 3)					Moderato----end

In (12), adagio is derived by a turning-off application of tone 3 sandhi at the lowest level (first level) as in (12a). Then, when turning-off at the next higher level (second level), we try to reapply tone 3 sandhi to a larger domain (*mai (hao jiu)*) 'buy good wine'. The output stays the same as the pattern for adagio as in (12b) since there is nothing that satisfies the requirements of the tone sandhi rule. At the highest level, moderato is derived by reapplying the tone sandhi rule to the largest domain as in (12c).

Though the turning-off mechanism can account for adagio and moderato patterns, it still cannot account for the additional patterns of allegro and presto. When the speech rate increases, the domain is enlarged, and the tone 3 sandhi application starts at higher levels of the cycle. In order to derive the patterns of allegro and presto, and to explain why the application of tone 3 sandhi does not start at the first cycle, the skipping mechanism is needed.

(13) Analysis of possible patterns II: skipping

	老	李	買	好	酒	
	Lao-Li	mai	hao	jiu		'Lao Li buys good wine.'
	Lao-Li	buy	good	wine		
	(3)	(3)	(3)	(3)	(3)	UR
(a)	( <u>2</u> 3)	( <u>2</u> <u>2</u> 3)				Allegro----Skip level 1
(b)	( <u>2</u> <u>2</u> <u>2</u> <u>2</u> 3)					Presto----Skip levels 1 & 2

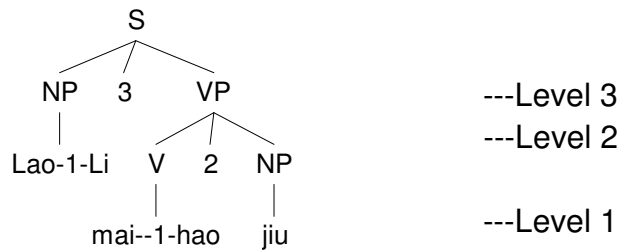
As for allegro, the application skips the first level and starts at the second level. There is no difference between the second turning-off and the third level as in (13a). For presto, the application skips both level 1 and level 2, and directly applies the tone 3 sandhi rule at the highest level as in (13b).

The next example (14) is a different syntactic structure to the previous illustration: this version has exactly the same words, but a different syntactic structure. Comparing the tonal patterns of the two sentences tells us that the application of the tone sandhi rule is affected by morpho-syntactic structure. In the previous example, *hao* means 'good', and it is treated as an adjective that is part of the noun phrase object. However, in the next example, *hao* means 'completing the task' signaled by the first verb, and it is treated as a second verb of a resultative compound verb. According to (Cheng, 1973), there are only two possible tonal patterns: (23)(223) pattern for allegro, and (22223) pattern for presto. One issue is revealed in the structure in (14): the predicted outputs for adagio and moderato cannot be derived.

The following illustration shows that the cyclic approach cannot account for the structure in (14).

Following the turning-off mechanism, the predicted outputs for *adagio* and *moderato* are ungrammatical according to Cheng's logical possible tone patterns for this certain sentence structure, as illustrated in (15).

(14) Tree structure: same words with different sentence structure



(15) Analysis of possible patterns I: same words with different sentence structure (ungrammatical)

	老 李 買 好 酒	
	Lao-Li mai hao jiu	'Lao Li has bought wine.'
	Lao-Li buy good wine	
	* <u>(3)</u> (3) (3) (3) (3)	UR
(a)	( <u>2</u> 3) ( <u>2</u> 3) (3)	Adagio-off for levels 2, 3
(b)	(2 3) (2 <u>2</u> 3)	Moderato--off for level 3

In (15), at the first turning-off level as in (15a), the pattern can be attributed to a slow speech rate, *adagio*. At the second turning-off level as in (15b), the pattern can be attributed to the speech rate of *moderato*, but in fact it is the tonal pattern of *allegro*, an even faster speech rate than *moderato* in Cheng's analysis. It is unclear why Cheng excludes the tonal patterns for both *adagio* and *moderato* in his analysis.

(16) Analysis of possible patterns II: alternative sentence structure (grammatical)

	老	李	買	好	酒	
	Lao-Li	mai hao	jiu			'Lao Li has bought wine.'
	Lao-Li	buy good	wine			
(a)	(2 3	2 2	3)			Allegro----end
(b)	(2 3)	(2 2	3)			Allegro----Skip level 1
(c)	(2 2	2 2	3)			Presto----Skip levels 1 & 2

As for allegro, we have two prosodic analyses, which both derive the same pattern. One way is to turn off at the highest level as in (16a), whereby the pattern for allegro is derived. The other way is to skip the first level and start at the second level as in (16b), however, the derived pattern is exactly the same as the second turning-off level and the third turning-off level. For presto, the application skips both level 1 and level 2 as in (16c), and directly applies the TSR rule at the highest level, which is the same as the process in the original example.

The possible phrasings for two different syntactic structures of one single sentence can be described using cyclical application, which may undergo turning-off or skipping depending on speech rates. If this approach is on the right track, we should expect to get all the predicted results in (15) and (16): (00)(00)(0) pattern in (15a) for the slowest speech rate, adagio; (00)(000) pattern in (16a, b) for allegro; ((00)(000)) pattern in (15b) for moderato; (00000) pattern in (16c) for the fastest speech rate, presto. However, in the analysis of the structure in (14), it predicts a (00)(00)(0) pattern for adagio, which is supposed to be the pattern for allegro; and it predicts a (00000) pattern for moderato, which is supposed to be

the pattern for presto. Since this approach cannot derive all the possible tone patterns, there may be another way to explain the effects of speech rate on tone sandhi that should be simpler and more accurate. These are the problems I would like to address in chapter 3 using OT analysis.

### **1.2.2 Yip's approach**

Speech rate is one important factor that affects the realization of tones. As speech gets faster, phrasing produces into fewer and longer prosodic constituents. Apart from Cheng's analysis in (Cheng, 1973), Yip proposes a tempo-based alternative and domain formation to explain the effect of speech rate on the realization of tones (Yip, 2002). Yip calls both a binary unit and final unary unit a *foot*, and an n-ary unit that encompasses the whole word except the final syllable a *super-foot*. Timing is controlled by the mapping of prosodic units onto timing units, and they are grouped into measures, as [xx]. In a slow speed, each syllable is mapped onto [xx]; in a normal speed, each foot is mapped onto [xx]; in a fast speed, it is the super-foot that is mapped onto [xx].



(17) Illustration:

老	李	買	好	酒	
Lao-Li	mai hao	jiu			'Lao Li buys good wine.'
Lao-Li	buy good	wine			
*3	3	3	3	3	UR
[xx]	[xx]	[xx]	[xx]	[xx]	Slow
(2	3)	(3)	(2	3)	Adagio
[xx]		[xx]	[xx]		Normal
((2	2)	(3)	(2	3))	Moderato
[xx]		[xx]			Fast
(2	3)	(2	2	3)	Allegro
[xx]					Faster
(2	2	2	2	3)	Presto

Yip's analysis shows the importance of foot binarity, timing units, and size of domains; however, it is unclear whether syntactic structure matters, whether the value of timing units changes, and whether the number of syllables affects the formation of domains. Yip's approach and my proposal are similar in the way that we both look at the formation of domains. Yip focuses on foot domains, but it seems that there is no principle relating to morpho-syntactic structure. The differences between our approaches are that I focus on the formation of phonological phrases, and I believe that morpho-syntactic structure plays an important role in the formation of the phonological phrases, which illustrate the speech rate effect on Mandarin tone sandhi.

### 1.2.3 Shih's approach

(Shih, 1986) proposes a prosodic device to reanalyze the problem based on foot formation, which transforms syntactic structure into prosodic structure. This

approach highlights the importance of foot formation and number of syllables on tone sandhi application. She suggests that the tone sandhi rule applies in a prosodic structure, derivable from foot formation, which means disyllabic or longer prosodic units are the minimum domain of tone sandhi rule application.

(18) Illustration of Shih's analysis of Moderato

	老	李	買	好	酒	
	Lao-Li	mai	hao	jiu		‘Lao-Li buys good wine.’
	Lao-Li	buy	good	wine		
(a)	( <u>2</u> 3)	3	( <u>2</u> 3)			cycle 1
(b)	(2 3)	(3	2	3)		cycle 2
(c)	(2 <u>2</u>	3	2	3)		cycle 3

In cycle 1 (18a), we apply tone sandhi across level 1 *Lao-Li* ‘Lao-Li’ and *hao jiu* ‘good wine’. In cycle 2 (18b), the domain of *hao jiu* ‘good wine’ is destroyed, and we apply tone sandhi across level 2 *mai hao jiu* ‘buy good wine’. The output remains the same since there are no adjacent third tones within the domain. Lastly, in cycle 3 (18c), we apply tone sandhi across level 3, and the first of the two adjacent third tones turns into second tone. Therefore, the pattern of moderato is derived.

Shih’s analysis on prosody is similar to my proposal, but instead of looking at each foot, I look at each phonological phrase. Also, Shih’s approach requires recursion, which is not too different from Cheng’s cyclical approach, however, the problem Cheng has still remained. My goal here is to find another way to explain the speech rate effect on tone sandhi without involving recursivity.

### 1.2.4 Recursivity analysis

To implement Shih's approach, (Brooke, Coppola, Lee, & Zhao, 2008) use the NoRecursivity constraint, which restricts recursive structure to be violable, as suggested by (Selkirk, 1995). Such a strategy was also used by (Truckenbrodt, 1995) to analyze tone insertion and shortening in the African language, Kimatumbi. Ranking NoRecursivity low allows multiple embeddings of phonological phrases. To show the ranking effect in the examples below, I will include the constraint, Align-Ph-IP-R, used in (Brooke, et al., 2008), which says "the right edge of each phonological phrase must be aligned with the right edge of an intonational phrase. Assign one violation for each prosodic word that intervenes between a phonological phrase and the right edge of an intonational phrase". This constraint has a similar function as the constraint, WrapS, I will use in my thesis.

As shown in (19), if we rank NoRecursivity low, the winning candidate will be the pattern of moderato. On the other hand, the next example shows that if we rank NoRecursivity high, the winning candidate will be the pattern of adagio.

(19) The effect of ranking NoRecursivity: low ranking results moderato pattern

[00] <sub>NP</sub> [0 [00] <sub>NP</sub> ] <sub>VP</sub>	Align-Ph-IP-R	NoRecursivity
→(00(0(00)))		**
(00)(0)(00)	*!***	

(20) The effect of ranking NoRecursivity: high ranking results adagio pattern

[00] <sub>NP</sub> [0 [00] <sub>NP</sub> ] <sub>VP</sub>	NoRecursivity	Align-Ph-IP-R
(00(0(00)))	*!*	
→(00)(0)(00)		***

(Brooke, et al., 2009) argue for a need to involve recursion to explain the result of the pattern of moderato. However, with this approach, it does not directly relate to the effect of speech rate with tone sandhi. Therefore, I will not discuss the effect of recursivity in depth, but seek better alternatives in my thesis.

### 1.2.5 The goals of the project

My goals for the project are:

1. To use OT constraints to derive a structure for Mandarin tone sandhi domain at the phrasal level that accounts for patterns of different speech rates;
2. To investigate a simpler analysis than the prior approaches to make predictions for various tonal patterns;
3. To use my theory of Juncture Phrasing Thresholds to explore new data.

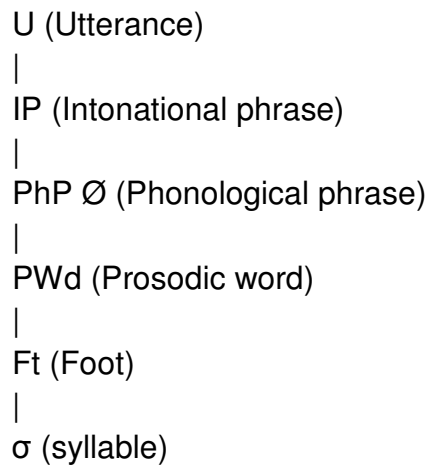
## **1.3 Theoretical assumptions**

In this subsection, I lay out the theoretical assumptions that are required to understand and investigate the problem of speech rate effects on Mandarin tone sandhi. An important aspect of any analysis of this problem is the characterization of the domains for tone sandhi. Prosodic hierarchy theory proposes that these domains are the same as certain prosodic categories. Below I show the various factors that predict the edges of phonological phrases, which in turn define Mandarin tone sandhi domains.

### **1.3.1 Phonological phrases**

In the last 30 years, a great deal of research has focused on phonological processes within the word. However, an important research tradition has been concerned with phonological rules that apply in a larger sentence, such as tonal neutralization in Chinese languages. One of the important problems in this research is predicting the phonological domains for these rules. A basic assumption is a hierarchical layering of prosodic categories (Nespor & Vogel, 1982, 1983, 1986; Selkirk, 1980). The hierarchical layering means each prosodic category is dominated by the other. Each category may serve as domains for the application of rules.

(21) Prosodic Hierarchy



In my thesis, I will assume hierarchical layering, and focus on deriving domains for phonological rules at the level of phonological phrase.

There are several factors that affect the formation of a phonological phrase. One important factor is syntactical structure. A theory that accounts for the role of syntax is End-Based Theory for phonological phrases (Selkirk, 1986). Under this theory, the edges of phonological phrases correspond to the edges of syntactic phrases. The edges of the phonological domain are mapped to the right or left edge of syntactic constituents at a particular level in the syntactic tree. The phonological phrase is also sensitive to lexical and functional categories. A number of researchers (Hale & Selkirk, 1987; Selkirk, 1986, 1995; Selkirk & Shen, 1990) have argued that only the edges of lexical categories, such as noun phrase, verb phrase, and adjective phrase, can trigger an insertion of a phonological phrase boundary. The remaining function words, such as pronoun, will be grouped with the preceding lexical phrase.

This approach has been applied to Xiamen Chinese (Chen, 1987). In this language, a full noun phrase subject or an adjective phrase inside of a noun phrase is followed by a phonological boundary, whereas a pronoun subject is grouped with the following verb phrase, forming one single phonological phrase.

(22) Tonal domain: lexical category (noun phrase) in Xiamen Chinese

[        ]NP [                                ]NP [                                ]VP  
 kai-kih        tsin tsue lang        leq san-po  
 (beach)        (very many people)        (Asp walk )  
 'Many people are taking a walk on the beach.'

(23) Tonal domain: lexical category (adjective phrase) in Xiamen Chinese

[ [        ]AP ]DP [                                ]VP  
 Ang e        k'a sik  
 (red) (e) (more ripe)  
 'The red ones are riper.'

(24) Tonal domain: functional category (pronoun) in Xiamen Chinese

[        ]DP [                                ]VP  
 Yi        sia k'a kin  
 (he write more fast)  
 'He writes faster.'

The prosodic hierarchy and End-Based theory are the two important approaches to deriving phonological domains that can be applied in Chinese. The application of tone sandhi, or tonal neutralization at sentence level, is constrained by phonological domains. (Hale & Selkirk, 1987; Truckenbrodt, 1995, 1999) have worked on deriving the domains of tone rules (tone groups) in several tone languages, such as Papago, Chi Mwi:ni, Chicheŵa, and Kimatuumbi. These tone

groups are aligned with syntactic phrases. Some (Hale & Selkirk, 1987; Truckenbrodt, 1995, 1999) assume those tone groups are phonological phrases, while others, such as (Chen, 1987), believe that tone groups are distinct from phonological phrases. For instance, Chen applies the theory of edge-alignment to Xiamen Chinese, and shows how the syntactic structure affects the formation of tone groups. In my thesis, I will assume that tone groups are the same as phonological phrases, since they are both derived from syntactic phrases. As shown in (25), phonological phrases align with the right edge of lexical phrases.

(25) Edge-alignment in Xiamen Chinese

[            ]NP [                            ]NP [                            ]VP  
 (hai-kih)Ø    (tsin tsue    lang)Ø (leq san-po)Ø  
 beach            very many people    ASP walk  
 'Many people are taking a walk on the beach.'

The End-Based theory of (Selkirk, 1986, 1995) has, in many cases, successfully accounted for the formation of phonological phrases cross-linguistically; examples are Shanghai Chinese (Selkirk & Shen, 1990) and Chi Mwi:ni (Selkirk, 1986). However, this approach predicts more phonological phrases than is needed in some cases, such as in adjoined structures. In order to prevent the XPs from inserting a phonological phrase after every XP, Truckenbrodt argues for a need of another constraint: a constraint on the wrapping of XPs (Truckenbrodt, 1995, 2007).



(26) Left alignment of XP (AlignXPLt)

Left edge of each lexical XP is aligned with the left edge of a phonological phrase.

(27) Wrapping of XP (WrapXP)

For each lexical XP there is a phonological phrase that contains the XP.

AlignXPLt formalizes the interaction of syntactical and prosodic boundaries, whereas WrapXP requires the XP to be a single phonological phrase.

In Tohono O’odham, the effect of Wrap XP accounts for the reason why in (28) there is a boundary between the subject *wakial* ‘cowboy’ and the VP ‘*at g wisilo cepos* ‘branded the calf’, while there is no boundary between the verb *cepos* ‘branded’ and the object *wisilo* ‘calf’. WrapXP requires the whole VP to be a single phonological phrase, but this violates AlignXPLt. WrapXP must be ranked higher than AlignXPLt. I will propose a new theory based on these two constraints to account for timing effects in the formation of Mandarin tone sandhi domains.

(28) Tohono O’odham

[	]	NP	[		[				]	NP	]	VP
(H LL)Ø			(L			HHH	H L	)Ø				
wakial			‘at		g	wisilo	cepos					
cowboy			AUX		DET	calf	branded					
‘The cowboy branded the calf.’												

### 1.3.2 Background on Mandarin syntax

Mandarin is an S-V-O language, and includes both head-initial and head-final phrase structure rules. Mandarin can be either head-final or head-initial for most

categories, with the exception of noun phrases: Mandarin noun phrases are head-final. Mandarin is head-initial only at the lowest level of expansion, allowing a variety of peripheral phrases to occur in the pre-head position. Only complements are after the head (Huang, 1982).

(29) Basic syntactic structure in Mandarin

S	Adv	PP	V	O
張三	昨天	在 學校	看見了	李四
[ZhangSan]NP	[[zuotian]AP	[zai [xuexiao]NP]PP	[kanjian-le]V	[Lisi]NP]VP
ZhangSan	yesterday	at school	see-ASP	Lisi
'ZhangSan saw Lisi at school yesterday.'				

Since phonological domains are only derived from lexical categories, it is important to understand the differences between lexical category and functional category. (Napoli, 1993) has summarized several ways to determine whether a word belongs to a lexical category or functional category. In general, lexical categories are semantically rich, which means they have more than one semantic meaning, event or content. Also, lexical categories assign theta-roles to their complements; for instance a verb assigns a theta-role to its object. Lexical categories allow taking more than one argument, such that a verb can assign both agent and theme to its arguments. Also, lexical categories are stressed under most circumstances. Lastly, lexical categories are open class, meaning that new elements can always be added. On the other hand, functional categories are characterized by the lack of these traits. They are not semantically rich, they do not generally assign a theta-role to their complements, except for

certain prepositions, they are not stressed under most circumstances, and they are in a closed class.

If we apply these assumptions to several categories in Mandarin, we can see that only nouns, verbs, and adjectives are lexical categories, while determiners, classifiers, DE, as well as prepositions are function words. For example, nouns and verbs are semantically rich, they receive or assign a theta-role, and they are stressed in most cases. On the other hand, determiners (including determiners, demonstrators, and quantifiers), classifiers (including classifiers and measure words) and the modifier marker DE are not semantically rich, they do not assign theta-roles, they are unstressed in most cases, and they form a closed class. However, the question of whether a preposition is a lexical category or a functional category is debatable. Prepositions seem to pattern like lexical categories, but there are many cases where prepositions are not rich in meaning, and they are not able to assign any theta-role. Therefore, here we will treat preposition as a functional category.

Applying these lexical and functional category assumptions to Mandarin, similar to Xiamen Chinese, we can see the difference between noun phrases and pronouns in terms of grouping of phonological phrase ( $\emptyset$ ).

(30) Subject is a possessive pronoun (ta-de 'his'): no boundary between the subject and the verb phrase

他的 跑 很 快  
[ ]DP [ ]VP  
ta-de pao hen kuai  
(he-DE run very fast)Ø  
'His [run] runs very fast.'

(31) Subject is a complex NP: a boundary between the subject and the verb phrase

他的 狗 跑 很 快  
[ ]DP [ ]VP  
ta-de gou pao hen kuai  
(he-DE dog)Ø (run very fast)Ø  
'His dog runs very fast.'

In Mandarin Chinese, a full NP subject is generally followed by a phonological boundary, but that is not the case for subject pronouns, since pronouns are function words. Also, there is no phonological boundary between the subject and the predicate because possessives also belong to a functional category. This shows that the rule of edge alignment only applies to lexical categories, and not to functional categories in Mandarin. This also explains why only lexical categories receive phonological boundaries, but not functional categories. Instead, similar to the prosodic structure grouping in Shanghai Chinese (Selkirk & Shen, 1990), function words in Mandarin normally group with a lexical item on their right.

## **2. Tone sandhi in Mandarin**

### **2.1 Tone 3 sandhi rule in Mandarin**

Mandarin tone sandhi has been specifically investigated by (Cheng, 1973; Duanmu, 2000, 2007; Shih, 1986; Yip, 2002). The prior research suggests that speech rate effect and morpho-syntactic structure are a factor in the application of tone sandhi. The sample in this prior work is limited. In order to ensure that the generalization on Mandarin tone sandhi is a true fact of the language, I will find additional evidence for the role of the speech rate effect on tone sandhi to support the prior research.

To see the role of the speech rate effect on tone sandhi, let us first look at the basic properties of tones and the basic rule of tone 3 sandhi in Mandarin. In the examples given in this thesis, I underline the tones that have undergone the application of tone 3 sandhi. Each tone suffixed to each syllable, which is given in Pinyin, indicates the lexical tone of the syllable. Also, “S” refers to the syllable(s) in the subject position; “V” refers to the verb of the sentence; and “O” refers to the syllable(s) in the object position. Those letters not only indicate the category of each syllable, but also show the number of syllables within a phrase and a sentence. For example, (SSVOO) indicates that the pattern of the sentence is a transitive structure with disyllabic subject, monosyllabic verb and disyllabic object.

There are four tones in Mandarin Chinese, which I refer to by the numbers 1, 2, 3 and 4. Tone 1 is a high level tone, tone 2 is a rising tone, tone 3 is a falling and rising tone, and tone 4 is a falling tone (Chao, 1968; Duanmu, 2000, 2007). My goal here is not to analyze features of the tones, so I will not discuss the details of the tones.

Tone 3 sandhi is a type of phonological process in Mandarin (Duanmu, 2000, 2007; Shih, 1986). Tone 3 becomes tone 2 when it occurs before another tone 3. If tone 3 is followed by a tone other than tone 3, tone 3 becomes a half tone 3, (3'). The duration of the half tone 3 is not a full tone. It is shorter than the full tone 2, changed from a full tone 3. Tone 3 sandhi can apply in any syntactic domain; it can also apply to a word, a compound, or a phrase as shown by the examples in (32) to (34) (Duanmu, 2007). The example in (35) is a case of a tone 3 changing into a half tone 3. I believe that a tone 2 changing from a tone 3 and a half tone 3 are two different phonological processes. I will briefly discuss the difference between them in 3.4.

(32) Word

螞 蟻

ma3 yi3 'ant'

2 3

(33) Compound

米 酒

mi3- jiu3 'rice wine'

2 3

(34) Phrase

你 好

ni3 hao3 'how are you?'

2 3

(35) Case of half tone 3

美 妙

Mei3-miao4 'amazing'

3' 4

Tone 3 sandhi can have more than one outcome from the same input. Later in my thesis, I will show how these possible patterns are determined by speech rates. As shown in (36), there are two possible tone patterns for one single verb phrase, *mai hao jiu* 'to buy good wine'.

(36) Illustration of trisyllabic verb phrase

買 好 酒

[mai3 [hao3 jiu3]] 'to buy good wine'

buy good wine

(a) (3) (2 3) pattern 1

(b) (2 2 3) pattern 2

(37) Alternative structure of trisyllabic verb phrase

買 好 酒 'bought wine'

[[mai3 hao3] jiu3]

buy - asp wine

((2 2) 3) pattern 1

Tone 3 sandhi is sensitive to syntactic branching. In (36), *mai* 'buy' is a monosyllabic verb, and *hao jiu* 'good wine' is a noun phrase complement. Tone 3

sandhi only applies once: either applying once on *hao* ‘good’ as (3)(23) in (36a) or applying on both *mai* ‘buy’ and *hao* ‘good’ as (223) in (36b). The pattern in (37) has the same sequence of words as in (36), but with different structures: *mai hao* ‘has bought’ is a compound verb in (37). Tone 3 sandhi rule applies twice: applying on *mai* ‘buy’ first, and then applying on *hao* ‘asp’ as ((22)3). This means that morpho-syntactic structure influences the formation of phonological phrases. Two sentences, which have exactly the same number of syllables, may result in different tonal patterns when they have different syntactic structures.

Tone 3 sandhi is optional in certain cases, such as between two binary branches of a syntactic tree. For example, in (38), *Lao-Li* ‘Lao-Li’ is a compound noun, and *mai shu* ‘buy books’ is a verb phrase. Tone 3 sandhi may or may not to apply between *Li* ‘Li’ and *mai* ‘buy’ for some speakers.

(38) A sentence with disyllabic subject, a monosyllabic verb, a monosyllabic object

	老	李	買	書	
	[[Lao3 Li3][mai3 shu1]]				‘LaoLi buys books.’
	Lao	Li	buy	book	
(a)	<u>2</u>	3	3	1	pattern 1
(b)	<u>2</u>	<u>2</u>	3	1	pattern 2

The phrase below is a noun phrase. Though both (38) and (39) contain four syllables, tone 3 sandhi must apply between *zhi* ‘paper’ and *lao* ‘old’, since *zhi lao*-ying ‘paper eagle’ is a compound noun. The juncture within a noun phrase is smaller than the juncture between the verb and the noun phrase. This difference



shows that the application of tone sandhi is sensitive to morpho-syntactic structure.

(39) Illustration of noun phrase containing four syllables

	小	紙	老	鷹	
	[xiao3 [zhi3 [lao3-ying1]]] 'small paper eagle'				
	Small paper old eagle				
	* <u>2</u>	3	3	1	
(a)	3	<u>2</u>	3	1	pattern 1
(b)	<u>2</u>	<u>2</u>	3	1	pattern 2

Syntactic structure alone cannot fully predict the outcome of tone 3 sandhi because different tone patterns may occur in the same general tree structure. The two examples below have the same general tree structure, but they are realized in different levels. One is a sentence and the other one is a phrase. The first example, (40), is a sentence, and tone 3 sandhi may or may not be applied between the two monosyllabic verbs, *xiang* 'want to' and *mai* 'buy'. On the other hand, the second example, (42), is a noun phrase, and since *zhi lao-ying* 'paper eagle' is a compound noun, tone 3 sandhi must apply between *zhi* 'paper' and *lao* 'old'. The juncture between *xiang* 'want to' and *mai* 'buy' in (40) is longer than the juncture between *zhi lao-ying* 'paper eagle' in (42); therefore, tone 3 sandhi needs to not apply in the case of (40), but its application is necessary in the case of (42).

(40) A sentence with a monosyllabic subject, a disyllabic verb, a monosyllabic object

我 想 買 書

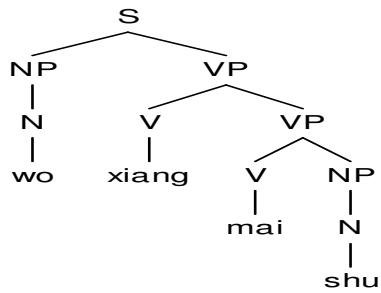
[wo3 [xiang3 [mai3 shu1]]]

'I want to buy a book.'

I want buy book

- (a) 2 3 3 1 pattern 1  
 (b) 2 2 3 1 pattern 2

(41) Syntactic structure for (40)



(42) Illustration of noun phrase containing four syllables

小 紙 老 鷹

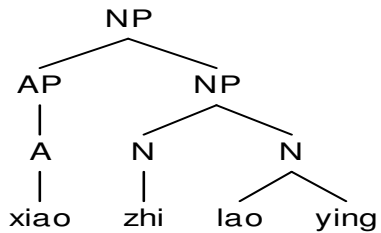
[xiao3 [zhi3 [lao3-ying1]]] 'small paper eagle'

Small paper eagle

\*2 3 3 1

- (a) 3 2 3 1 pattern 1  
 (b) 2 2 3 1 pattern 2

(43) Syntactic Structure for (42)



Flat structure, such as phone digits in (44), seems to form domains of disyllabic pairs from left to right. This shows that binarity is also a factor in the application of tone 3 sandhi.

(44) Illustration of flat structure

	五	五	五	五	
	wu3	wu3	wu3	wu3	'five-five-five-five'
(a)	( <u>2</u>	3)	( <u>2</u>	3)	pattern 1
(b)	( <u>2</u>	<u>2</u>	<u>2</u>	3)	pattern 2

The effect of emphasis also affects the application of tone 3 sandhi. In (45a), without emphasizing the second verb, *mai* 'buy', the phrase breaks into two phonological phrases, resulting from the need for binarity. However, when the second verb, the capitalized *mai* 'buy', is emphasized, as shown in (45b), it will be in the same domain; and its complement, *gu-piao* 'stocks', and the first verb, *xiang* 'want', will stand by themselves. This shows that the effect of prominence outranks the need for binarity. This factor will not be discussed in this thesis, but will be explored in later study.

(45) Neutral (a) and Emphasis on the verb *mai* 'buy' (b)

(a)	想	買	股	票	
	Xiang3	mai3	gu3	paio4	'want to buy stocks'
	want	buy	stocks		
	[2	3]	[3	4]	
(b)	想	買	股	票	
	Xiang3	MAI3	gu3	paio4	'want to buy stocks'
	want	buy	stocks		
	*[2	3]	[3	4]	
	[3]	[2	3	4]	

## 2.2 Investigation of additional syntactic constructions

*Lao-Li mai hao jiu* 'Lao-Li buys good wine' is a well-known example (Cheng, 1973; Duanmu, 2000, 2007; Shih, 1986; Yip, 2002) that illustrates the effect of speech rate on tone sandhi in Mandarin. I would like to provide additional data to make sure my proposed approach accounts for general facts of the language. There are three principles I would like to point out along with the new sets of data: (a) the rules of left alignment and WrapXP, (b) the role of binarity, (c) the role of size of a phonological phrase.

Also, instead of having the speech rates scaled as *adagio*, *moderato*, *allegro* and *presto*, I will simplify the speech rates into slow, normal and fast. Since the difference between *moderato* and *allegro* is too small to analyze, I will treat both *moderato* and *allegro* as the normal speech rate. The issue of *moderato* speech will be discussed in 3.4.

Moreover, I understand that every speaker has his/her own definition of each speech rate, as well as understanding of syntactic structure and phonological structure; therefore, I will not measure the values of each speech rate. In order to minimize the possible variations, I have tried to do as best as possible in my pilot experiment to ensure the consistency across speakers in terms of their speech rates.

In my pilot experiment, there are a total of eight subjects and one subject who records the sample stimuli for the training section in the study. They are all native

Mandarin speakers from Taiwan. I first provided a training section for subjects. They listened to a sample recording to familiarize three different speech rates. Subjects were instructed to make sure that their slow speed is not so slow that they produce syllable by syllable, and their fast speed is not so fast that people cannot understand the sentences. Also, at the end of the experiment, I studied their files to make sure that their performances were consistent.

The syntactic structure of the well-known example, *Lao-Li mai hao jiu* ‘Lao-Li buys good wine’, shown in (46), is a transitive sentence with a disyllabic noun phrase subject, a monosyllabic verb and a disyllabic noun phrase complement. My additional data will include a set of examples that has exactly the same syntactic structure and number of syllables as this example. This is to ensure that the speech rate effects on tone sandhi do not apply to a limited data sample.

(46) Additional data 1: no effect on phonetic difference

(a) 小美 踩手錶

Xiao3-mei3 cai3 shou3-biao3      ‘Xiao-mei steps on the watch’

Xiao-mei      step watch

2      3      3      2      3      slow

2      3      2      2      3      normal

2      2      2      2      3      fast

(b) 小紫煮水餃

Xiao3-zi3 zhu3 shui3-jiao3      ‘Xiao-zi makes dumpling’

Xiao-zi      cook dumpling

2      3      3      2      3      slow

2      3      2      2      3      normal

2      2      2      2      3      fast

(c)小虎補美語					
Xiao3-hu3	bu3	mei3-yu3			'Xiao-hu takes English'
Xiao-hu	take	English			
<u>2</u>	3	3	<u>2</u>	3	slow
<u>2</u>	3	<u>2</u>	<u>2</u>	3	normal
<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	3	fast

According to the pilot experiment, the tonal patterns of the sentences above are identical to the pattern of the well-known example. This supports the approach of forming phonological phrases in Mandarin.

The following data set, (48), shows the importance of the roles of left alignment and WrapXP. The syntactic structure in (48) is the additional example on two syntactic structures of one single sentence. As mentioned in 1.2.1, one structure is (SSVOO), and the alternate one is (SSVVO). Their formation of phonological phrases is different. This new set should show the rules of left alignment. In (48a) and (48b), in the slow speed, the predicted phonological phrases are (SS)<sub>NP</sub>, (V)<sub>VP</sub> and (OO)<sub>NP</sub> since the left edge of each lexical phrase needs to be aligned. On the other hand, in (48c) and (48d), in the slow speed, following the rule of left alignment, the predicted phonological phrases are (SS)<sub>NP</sub>, (VV)<sub>VP</sub> and (O)<sub>NP</sub>. Also, in the prior research, there are only two possible tone patterns: one is allegro, (23)(223); the other is presto, (22223). However, I believe that there must be a pattern for a slow speed, adagio. I would like to see if the new approach predicts the pattern for a slow speech rate. Following the rule for the formation of phonological phrases, the slow pattern of the alternative structure of the well-

known example should be (23)(23)(3). The first hypothesis I test on is as stated in (47) below.

(47) Hypothesis 1: I expect that phonological phrases are formed by left-aligning each phonological phrase with each lexical phrase.

(48) Additional data 2: a & b are (SSVOO); c & d are (SSVVO)

(a) 小美烤好餅

Xiao3-Mei3 kao3 hao3 bing3 'Xiao-Mei bakes good cookies.'

xiao-mei bake good cookies

2 3 3 2 3 slow

2 3 2 2 3 normal

2 2 2 2 3 fast

(b) 小虎煮好米

Xiao3-Hu3 zhu3 hao3 mi3 'Xiao-Hu makes good rice.'

Xiao-hu cook good rice

2 3 3 2 3 slow

2 3 2 2 3 normal

2 2 2 2 3 fast

(c) 小美烤好餅

Xiao3-Mei3 kao3-hao3 bing3 'Xiao-Mei baked cookies.'

Xiao-mei bake-asp cookies

2 3 2 3 3 slow

2 3 2 2 3 normal

2 2 2 2 3 fast

(d) 小虎煮好米

Xiao3-Hu3 zhu3-hao3 mi3 'Xiao-Hu makes good rice.'

Xiao-hu cook-asp rice

2 3 2 3 3 slow

2 3 2 2 3 normal

2 2 2 2 3 fast

The results are identical to the well-known example, except for the slow pattern of (48c) and (48d). For the structure of (SSVVO), the slow pattern (23233) is

considered as an ungrammatical pattern in the prior research. However, the subjects in my pilot experiment pronounce it as (23233). Following the rule of left alignment, the result of the slow pattern agrees with the predicted pattern, and the complete analysis will be shown in 3.3.2.

The reason why it is considered ungrammatical may be that the underlined tone 3 in (23233) is realized as a half tone 3. Some may treat the half tone 3 as a tone 2 since it sounds closer to a tone 2, and some may treat it as a tone 3 since it sounds closer to a tone 3; it will depend on an individual's production and perception.

Moreover, the next hypothesis I test on is stated in (49), which requires the role for foot binarity for the formation of phonological phrases.

(49) Hypothesis 2: I expect that when there is odd number of syllables within a phrase formed by its syntactic rule, Foot Binarity constraint is required to form a phonological phrase.

The set of examples in (51) shows the need for binarity. The syntactic structure in (51) is a transitive structure with a monosyllabic subject. There are only four syllables (SVOO). Because of the rules of left alignment and WrapXP, "S" and "V" should belong to different phonological phrases. However, this outcome in the slow speech rate turns out to be tonal pattern that does not exist. Therefore, the "S" and the "V" should be in one single phonological phrase. This shows the role of binarity on tone sandhi. Disyllabic word is preferred to be the minimal size for a phonological phrase. For example, in (51), the (3)(223) pattern should be



the pattern for the slow speed since there should be a break between the monosyllabic subject and the monosyllabic verb. However, according to the pilot experiment, the pattern for the normal speed is (23)(23). Therefore, binary effect should outrank the other factors, such as the morpho-syntactic structure. The complete analysis will be shown in 3.3.2.

(50) Structure of additional data 3: transitive monosyllabic subject

[ ] <sub>NP</sub>	[	[	] ] <sub>NP</sub>	] ] <sub>VP</sub>
S	V	O	O	

(51) Additional data 3: transitive monosyllabic subject

(a) 你踩手錶

Ni3 cai3 shou3-biao3 'You step on the watch'

You step watch

2 3 2 3 slow/normal

2 2 2 3 fast

(b) 我煮水餃

Wo3 zhu3 shui3-jiao3 'I make dumpling'

I cook dumpling

2 3 2 3 slow/normal

2 2 2 3 fast

(c) 馬咬小虎

Ma3 yao3 xiao3-hu3 'Ma bites Xiao-hu'

Ma bite Xiao-hu

2 3 2 3 slow/normal

2 2 2 3 fast

The last hypothesis I test on is stated in (52), which looks at syllable numbers within a sentence.

(52) Hypothesis 3: I expect that there is no limit for the number of syllables within one sentence, only if the formation of phonological phrases follows the left-alignment constraint and Foot Binarity constraint with equal footing.

The set of data in (54) shows the preference for size of each phonological phrase. The syntactic structure in (54) is still a transitive structure, but with a disyllabic verb. There are six syllables (SSVVOO). Following the rules of left alignment and WrapXP, the phonological phrases in the normal speed should be (SS)(VVOO). However, the preferred tonal pattern for the normal speed is (SS)(VV)(OO), which is the same as the pattern in the slow speed. One phonological phrase containing four syllables seems too long to produce, and the sizes between (SS) and (VVOO) are not balanced. Therefore, speakers tend to minimize them into two phonological phrases, and prefer the tonal pattern for the normal speed to be (SS)(VV)(OO). This shows the effect of maximum and minimum numbers of syllables. This is also related to the effect of binarity that disyllabic words are preferred. The complete analysis will be shown in 3.3.2.

(53) Structure of additional data 4: transitive disyllabic verb

[	]NP	[		[	]NP]VP
S	S	V	V	O	O

(54) Additional data 4: transitive disyllabic verb

(a) 小美想踩手錶

Xiao3-mei3 xiang3-cai3 shou3-biao3 'Xiao-mei wants to step on the watch'

Xiao-mei      want-step      watch

<u>2</u>	3	<u>2</u>	3	<u>2</u>	3	slow/normal
<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	3	fast

(b) 小紫想煮水餃

Xiao3-zi3 xiang3-zhu3 shui3-jiao3 'Xiao-zi wants to make dumpling'

Xiao-zi want-cook dumpling

2 3 2 3 2 3 slow/normal

2 2 2 2 2 3 fast

(c) 小虎想補美語

Xiao3-hu3 xiang3-bu3 mei3-yu3 'Xiao-hu wants to take English'

Xiao-hu want-take English

2 3 2 3 2 3 slow/normal

2 2 2 2 2 3 fast

The factors of binarity and size of syllables can be explained by a binary constraint and the new set of constraints, \*WrapSD( $n_{msec}$ ), which will be introduced, illustrated and discussed in 3.2.

## 2.3 Summary of the empirical findings

The pilot experiment shows as follows:

1. The tonal patterns of the first additional data in (46) are identical to the pattern of the well-known example, *Lao-Li mai hao jiu* 'Lao-Li buys good wine';
2. The left-alignment plays an important role on phrasing, which agrees with the hypothesis 1 in (47);
3. Binarity affects phrasing, which agrees with the hypothesis 2 in (49);
4. Different number of syllables within one sentence does not affect phrasing. However, one phonological phrase containing more than three syllables prefers to be broken into two separate phonological phrases. The size of each phonological phrase should be equal/ balanced, and this result agrees with the hypothesis 3 in (52).

## 3. The proposal

### 3.1 Preliminary assumptions

In this subsection, I first review some basic assumptions of my approach, including (Selkirk, 1984a, 1984b)'s theory of Silent Demibeat Addition and relevant constraints, which must be addressed before I introduce and pursue my proposed approach, the theory of Juncture Phrasing Thresholds.

#### 3.1.1 The theory of Silent Demibeat Addition

In order to ensure that the size of a tone sandhi domain varies depending on the speech rate, we need a set of new constraints to complete the analysis. I adopt (Selkirk, 1984a, 1984b)'s theory of Silent Demibeat Addition (SDA) to create a new set of  $WrapSD(n_{msec})$  constraints. Selkirk argues that if syntactic timing is properly represented in terms of the grid, then it may be expected that syntactic structure is sensitive to the syllable-to-grid alignment of an utterance. Also, it would be affected by the alignment of demibeats. Selkirk uses the silent demibeat approach to explain the relation between speech rate and tone sandhi rule application, which is also discussed in (Shih, 1986).

##### (55) Silent Demibeat Addition (SDA)

Add a silent demibeat at the end of the metrical grid aligned with (a) a word; (b) a word that is the head of a nonadjunct constituent; (c) a sentence, and (d) a daughter phrase of S.

(56) Illustration

[		]NP	[		[[		]AP		]NP]VP
小	美		烤	好	餅				
Xiao-Mei			kao	hao	bing				'Xiao-Mei bakes good cookies.'
Xiao-Mei		bake	good	cookies					
***	***	*	**	*	*	*	****		
(a)	(a,b,d)		(a,b)	(a)			(a,b,c,d)		

The way to assign the silent demibeats is as shown above. We first add a silent demibeat at the end of each word. Second, we add one more silent demibeat at the end of the head of the NP subject, the head of the VP, and the head of the NP object. Then, we add one silent demibeat at the end of the sentence. Finally, we add one silent demibeat at the end of the daughter phrases of the sentence, which are the NP subject and the VP.

Given a particular speech rate, an idealized time value is assigned to the silent demibeats. For example, we assign more time value to the silent demibeat at slower speeds and less time value to the silent demibeat at faster speeds.

Applying SDA theory to Mandarin, tone sandhi rules need a particular number of silent demibeats between words and phrases, and the phrase breaks across which tone sandhi applies. The phonological phrase grows larger as speech rate increases. The duration of silent demibeat is arbitrary in the examples I use below. In order to address the problems in a concrete way, specific timing value will be assigned to ( $n_{msec}$ ). Since the purpose here is to show how speech rate effect predicts tone sandhi patterns but not the speech rate itself, I will assume

what I have broken down as follows. At the slowest speed, each silent demibeat is ( $n_{\text{msec}}$ ), and at the faster speed, each silent demibeat is ( $2n/3_{\text{msec}}$ ); whereas at the fastest speed, each silent beat is only ( $n/3_{\text{msec}}$ ). The number of silent demibeats is based on the syntactic constituent, as shown in (57) (i.e., whether it occurs between elements in a word, phrase, or sentence). The number of silent demibeats on the edge between two words and within one phrase must be less than the number of silent demibeats on the edge between two phrases.

I adopt Selkirk's (Selkirk, 1984a, 1984b) analysis in the following example. Each X, ( $n_{\text{msec}}$ ), is 150msec. For adagio, each X is 150msec. The boundary between "Lao & Li: Lao Li" and "hao & jiu: good wine" is at depth 1, the smallest unit, so each of them only receives one silent beat, which values 150 msec at adagio rate. The boundary between "mai & hao jiu: buy good-wine" is at depth 2, so it receives two silent beats, which values 300 msec. The boundary between "Lao-Li & mai hao jiu" is at depth 3, so it receives three silent beats, which values 450 msec.

For allegro, each X is 100msec, and for presto, each X is 50msec. The assignment of the number of silent demibeats for both allegro and presto is the same as for adagio, as shown in (57).

(57) Illustration of SDA application in Mandarin

老	李	買	好	酒	
Lao	Li	mai	hao	jiu	'Lao-Li buys good wine.'
x	<u>x</u>	x	<u>xxx</u>	x	<u>xx</u>
	150		450		300
	100		300		200
	50		150		100
					50
					<u>xxxxx</u>
					(adagio)
					(allegro)
					(presto)

### 3.1.2 Constraints

In the spirit of (Selkirk, 1986), and the proposed constraint in OT by (Truckenbrodt, 1995, 2007), I assume that left or right alignment constraint governs the distribution of phonological phrases in Mandarin.

(58) AlignXPLt/AlignXPRt

The left/right edge of each lexical XP must be aligned with the left/right edge of a phonological phrase. Assign one violation for each lexical XP whose left/right edge does not coincide with the left/right edge of a phonological phrase.

Another type of constraint that is relevant to the current analysis is WrapXP, from (Truckenbrodt, 1995)'s account of phonological phrase. The idea of WrapS is an extension of WrapXP, which wraps the whole sentence into one single phonological phrase, instead of lexical phrases. This will be further discussed in 3.3 and as below.



(59) WrapXP

Each lexical XP should be contained within a single phonological phrase.  
Assign a violation for each lexical XP that is not contained within a single phonological phrase.

(60) WrapS

Each sentence should be contained within a single phonological phrase.  
Assign a violation for each sentence that is not contained within a single phonological phrase.

However, these constraints do not directly address the effect of speech rate on tone sandhi. They only show the impact of syntax on prosody. As shown above, in the formation of domains for a disyllabic subject transitive sentence, *adagio* (=slow) has the phrasing (00)(0)(00), *allegro* (=normal) has the phrasing as (00)(000) and *presto* (=fast) has the phrasing as (00000). *Moderato* pattern is omitted, for simplification. I apply these constraints to the example below to try to derive a structure for Mandarin tone sandhi domain at the phrasal level.

(61) Three basic speech rates

老 李 買 好 酒

Lao-Li mai hao jiu 'Lao-Li buys good wine.'

Lao-Li buy good wine

(00)(0)(00) Adagio (=slow)

(00)(000) Allegro (=normal)

(00000) Presto (=fast)

When WrapS is ranked above both WrapXP and AlignXPLt, the tonal pattern of the fast speech rate (00000) is predicted. This shows that, in the fast speech rate, a whole sentence prefers to be in one single phonological phrase, which is more

important than aligning each lexical phrase into separate phonological phrases. This causes the violation of WrapS. This also shows the idea that a faster speech rate results in a larger number of tonal neutralizations, and a larger size of phonological phrase.

(62) WrapS >> WrapXP; AlignXPLt: fast pattern

	WrapS	WrapXP	AlignXPLt
(00)(0)(00)	*!	*	
(00)(000)	*!		*
→(00000)			**

Similar to the result above, when WrapXP ranks above WrapS, and the two wrapping constraints rank above the alignment constraint, the tonal pattern of the fast speech rate (00000) is derived. The pattern for slow speed is out because the verb phrase breaks into two phonological phrases. The pattern for normal speed is out because the next higher ranked constraint, WrapS, requires the whole sentence to be in one single phonological phrase. Therefore, with an alternative ranking, the tonal pattern of fast speech rate is derived.

(63) WrapXP>> WrapS>> AlignXPLt: fast pattern

	WrapXP	WrapS	AlignXPLt
(00)(0)(00)	*!	*	
(00)(000)		*!	*
→(00000)			**

However, if we only switch the rankings of WrapS and AlignXPLt, the winning candidate changes to the tonal pattern of the normal speech rate (00)(000). Again, the pattern for slow speed is out because breaking the verb and its

complement into two separate phonological phrases is not preferred. Since the pattern for the fast speed does not align with the left edge of the VP and the complement NP, it is out. Therefore, we get the tonal pattern of normal speech rate.

(64) WrapXP >> AlignXPLt >> WrapS: normal pattern

	WrapXP	AlignXPLt	WrapS
(00)(0)(00)	*!		*
→(00)(000)		*	*
(00000)		**!	

The last possible ranking is to rank AlignXPLt above both WrapS and WrapXP, and the tonal pattern of slow speech rate is derived. This shows that, in the slow speech rate, aligning each phonological phrase with each lexical phrase is preferred, and this shows the idea that a slower speech rate results in a smaller number of tonal neutralizations and a smaller size of phonological phrase.

(65) AlignXPLt >> WrapS; WrapXP: slow pattern

	AlignXP Lt	WrapS	WrapX P
→(00)(0)(00)		*	*
(00)(000)	*!	*	
(00000)	**!		

After the illustration above, we know that there is no single ranking that accounts for the tone sandhi effects on the three basic speech rates. The three basic constraints, WrapXP, WrapS and AlignXPLt, only address the relation between morpho-syntax and prosody, but not the relation between tone sandhi and

speech rates. Therefore, I attempt to develop one analysis to account for the effects of speech rate on phonological phrases. The Juncture Phrasing Thresholds should provide new predictions, and specific analysis that explains the relation between speech rate effect and application of tone sandhi will be provided in 3.2.

### 3.2 The theory of Juncture Phrasing Thresholds (JPT)

Following (Selkirk, 1984a, 1984b)'s theory of Silent Demibeat Addition, I consider that OT constraints on phrasing can refer to silent demibeats, and argue for the following principle to explain the speech rate effects on Mandarin tone sandhi.

(66) Juncture Phrasing Thresholds (JPT)

Junctures within a given phonological phrase must not exceed a language-particular juncture timing threshold.

I propose a set of constraints,  $*\text{WrapSD}(n_{\text{msec}})$ , using the assumption of the wrapping constraint to explain the effect of speech rates on Mandarin tone sandhi.  $\text{WrapXP}$  and  $\text{WrapS}$  can account for phonological phrases, but they do not show the relation between speech rate and phonological phrase. On the other hand,  $*\text{WrapSD}(n_{\text{msec}})$  looks at every phonological phrase to find the largest juncture and to restrict timing units that go above certain thresholds.

(67)  $*\text{WrapSD}(n_{\text{msec}})$

Junctures between two elements with a value equal to or greater than (n) milliseconds cannot be in the same phonological phrase. Assign one violation for every juncture that exceeds the threshold (n).

The scale of values of (n) milliseconds I propose here are 300 msec, 200 msec, and 100 msec, and these intervals are arbitrary. In real speech, (n) may be any value of milliseconds. However, in order to address the problems in a concrete way, I lay down a scale for these intervals that is sufficient for explaining the

problems. One violation is given when pause duration of the largest juncture is above any of these particular time values.

Turning back to the prior research on speech rate effects relevant to tone sandhi, there are three problems I would like to address in the next section with some illustration of the new proposed constraint and the other relevant constraints that I have discussed in 3.1.2 on various examples.

First, as mentioned in 1.2.2, (Yip, 2002)'s analysis that relies on foot structure is similar to my approach, such that there exists the importance of binarity, timing units and number of syllables in each domain. However, Yip does not explain the effect of speech rates on tone sandhi in terms of the morpho-syntactic structure, which I consider to be another important factor in my proposal.

Second, the cyclic approach seems to have difficulty accounting for the following contrasts. As mentioned in 1.2.1, the cyclical application requires "turning-off" and "skipping". The result of "turning-off" is to turn off a phonological rule at a certain level, and the result of "skipping" is to skip a phonological rule up to a certain level. These two mechanisms are used to describe why different tonal patterns are derived for different speech rates. However, this approach seems arbitrary, since there is no specific rule that relates to speech rates for the application of turning-off and the application of skipping.

(68) Illustration on the cyclic approach: a transitive with a disyllabic subject

[ σ σ ]NP		[ σ [ σ σ ]NP]VP		
小 虎		補 美 語		
Xiao-hu		bu mei-yu		'Xiao-hu takes English class.'
Xiao-hu		take English		
( <u>2</u> 3)		3 ( <u>2</u> 3)		slow-off for levels 2, 3
( <u>2</u> 3)		(3 <u>2</u> 3)		slow-off for level 3/1 skip
( <u>2</u> <u>2</u> )		3 <u>2</u> 3)		normal-end
( <u>2</u> <u>2</u> )		<u>2</u> <u>2</u> 3)		fast-1 & 2 skip

(69) Illustration on the cyclic approach: a transitive with a monosyllabic subject

[ σ ]NP		[ σ [ σ σ ]NP]VP		
虎		補 美 語		
Hu		bu mei-yu		'Hu takes English class.'
Hu		take English		
* (3)		3 ( <u>2</u> 3)		slow-off for levels 2, 3
* (3)		(3 <u>2</u> 3)		slow-off for level 3/1 skip
( <u>2</u> 3		<u>2</u> 3)		normal-end
( <u>2</u> <u>2</u> )		<u>2</u> <u>2</u> 3)		fast-1 & 2 skip

The difference between (68) and (69) is that the subject of (68) is disyllabic and the subject of (69) is monosyllabic. By applying the turning-off and skipping mechanisms to both (68) and (69), it results in wrong tonal patterns in (69). Therefore, the applications of turning-off and skipping cannot fully account for the tone sandhi effect on speech rate. There is no principled way to explain why they do not exist. This result also shows that the cyclic approach has difficulty controlling the need for foot binarity. The pattern of (0)(000) is not preferred.

Lastly, Selkirk's theory of SDA itself has difficulty accounting for the previous contrasts, as well: it seems to be ruling out the (0)(000) pattern in SVOO, but allowing for the (00)(0)(00) pattern in SSVOO.

(70) Illustration on the SDA approach: a transitive with a disyllabic subject

[ σ σ ]NP	[ σ [ σ σ ]NP]VP	
小 虎	補 美 語	
Xiao- hu	bu mei-yu	‘Xiao-hu takes English class.’
Xiao- hu	take English	
* * * ***	* ** * * *	****
<u>2</u> 3	3 <u>2</u> 3	slow
<u>2</u> 3	<u>2</u> <u>2</u> 3	normal
<u>2</u> <u>2</u>	<u>2</u> <u>2</u> 3	fast

(71) Illustration on the SDA approach: a transitive with a monosyllabic subject

[ σ ]NP	[ σ [ σ σ ]NP]VP	
虎 補 美 語		
Hu bu mei-yu	‘Hu takes English class.’	
Hu take English		
* ***	* ** * * *	****
*3	3 2 3	slow
*3	2 2 3	normal
2	2 2 3	fast

In both structures, the juncture between the verb *bu* ‘take’ and the NP *mei-yu* ‘English’ receives two silent demibeats. Following the alignment and wrapping constraints, we expect that they have the same tonal patterns. However, the tonal patterns for slow speed and normal speed in (71) are ungrammatical. This shows that the morpho-syntactic structure alone is not enough to account for the



tone sandhi effect on speech rate; rather there are other factors that affect the formation of phonological phrases.

Therefore, we cannot depend solely on morpho-syntactic structure or phonological structure to predict the effect of tone sandhi. My goal in the next section is to apply my theory of Juncture Phrasing Thresholds, which is more direct than the cyclic approach and the recursive approach, and is applied to a larger data set to account for all of these factors in this single grammar of tone sandhi.

### **3.3 Illustration of the theory of Juncture Phrasing Thresholds**

In chapter 1, I discussed the speech rate effect on tone sandhi with simple transitive sentences. In chapter 2, I extended the discussion to a more complicated set of data. In this subsection, I will first apply the Juncture Phrasing Thresholds to the structure of the well-known tone sandhi data set, and to three different syntactic constructions. My goal here is to define a model that integrates all of the phonological and morpho-syntactic factors into a single grammar of tone sandhi with a single ranking without any re-ranking.

#### **3.3.1 The structure of the well-known data**

First, I will apply my proposed constraint and the other relevant ones to the structure of the well-known tone sandhi example, a transitive sentence with a disyllabic subject, a monosyllabic verb and a disyllabic object. The constraints I am using here are as follows: *WrapXP*; *WrapS*; *AlignXPLt* and *\*WrapSD*( $n_{msec}$ ). These constraints were defined in (58), (59) and (60) in 3.1.2, and (67) in 3.2.

Moreover, in the earlier chapter, I mentioned the importance of binarity. The constraint of foot binarity is necessary in my analysis. The local conjunction constraint, *\*(0)(000)*, is also needed to ensure that size of each phonological phrase in a sentence is fairly equal. When a sentence that violates both *FtBinMin* and *FtBinMax* (each foot must not contain more than two syllables), it also violates the conjoined constraint, *\*(0)(000)*.

(72) FtBinMin (McCarthy & Prince, 1986; McCarthy, 2003)

Each foot must contain at least two syllables. Assign a violation for each foot which does not contain two or more syllables.

(73) \*(0)(000)

The pattern of (0)(000) is not allowed. \*(0)(000) is a local conjunction constraint that is conjoined by FtBinMin and FtBinMax. Assign a violation for each sentence which violates both FtBinMin and FtBinMax.

The ranking is as follows: \*Wrap300, \*(0)(000) and FtBinMin must rank the highest. If \*Wrap300 ranks below the two Wrap constraints, then the result will be the pattern of the fast speech rate (00000), instead of the expected ones. \*(0)(000) needs to rank high to prevent from resulting unbalanced phonological phrases. Also, both WrapXP and WrapS must rank above AlignXPLt and \*Wrap100; otherwise, the result will always be the pattern of the slow speech rate. The alignment constraint must rank the lowest; otherwise, the pattern of the fast speech rate will never be derived.

(74) Ranking:

\*Wrap300; \*(0)(000); FtBinMin>> \*Wrap200>> WrapS; WrapXP  
>>AlignXPLt; \*Wrap100

(75) OT Tableau: X=150 (slow)

$[\sigma\sigma]_{NP}[\sigma[\sigma\sigma]_{NP}]_{VP}$

老 李 買 好 酒

Lao-Li mai hao jiu 'Lao-Li buys good wine.'

Lao-Li buy good wine

$[0_x0]_{xxx}[0_{xx}[0_x0]]$	*Wra p300	*(0) (000)	Ft Bin Mi n	*Wra p200	W r a p S	W r a p X P	A l i g n X P L t	*Wra p100
$\rightarrow(0_x0)_{xxx}(0)_{xx}(0_x0)$			*		*	*		**
$(0_x0)_{xxx}(0_{xx}0_x0)$	*			*!	*		*	***
$(0_x0_{xxx}0_{xx}0_x0)$	**!			**			*	**** *

In the slow speech rate, each phrase tends to break down into the smallest unit. Therefore, the highest interval, \*Wrap300, must rank high to avoid wrapping a large size of juncture of two elements into one single phrase. The pattern (00)(0)(00) is derived as the pattern for the slow speed.

(76) OT Tableau: X=100 (normal)

[0 <sub>x</sub> 0] <sub>xxx</sub> [0 <sub>xx</sub> [0 <sub>x</sub> 0]]	*Wrap300	*(0)(000)	FtBinMin	*Wrap200	Wraps	Wraps	Align	*Wrap100
(0 <sub>x</sub> 0) <sub>xxx</sub> (0) <sub>xx</sub> (0 <sub>x</sub> 0)			*!		*	*		**
→ (0 <sub>x</sub> 0) <sub>xxx</sub> (0 <sub>xx</sub> 0 <sub>x</sub> 0)				*	*		*	***
(0 <sub>x</sub> 0 <sub>xxx</sub> 0 <sub>xx</sub> 0 <sub>x</sub> 0)	*!			**			* *	****

In the normal speech rate, the phrases need to be larger than the size of phrases in the slow speed, but smaller than the size of phrases in the fast speed. When X is lowered from 150<sub>msec</sub> to 100<sub>msec</sub>, junctures go below the thresholds. Again, the highest interval, \*Wrap300, should rank high to avoid deriving the pattern for the fast speed. FtBinMin also plays an important role here: the pattern for the slow speed gets one violation on FtBinMin since the verb itself forms a small unit. Therefore, the pattern (00)(000) is derived as the pattern for normal speech rate.

(77)OT Tableau: X=50 (fast)

[0 <sub>x</sub> 0] <sub>xxx</sub> [0 <sub>xx</sub> [0 <sub>x</sub> 0]]	*Wrap300	*(0) (000)	Ft Bin Min	*Wrap200	W r a p S	W r a p P	A l i g n X P L t	*Wrap100
(0 <sub>x</sub> 0) <sub>xxx</sub> (0) <sub>xx</sub> (0 <sub>x</sub> 0)			*!		*	*		
(0 <sub>x</sub> 0) <sub>xxx</sub> (0 <sub>xx</sub> 0 <sub>x</sub> 0)					*!		* *	
→ (0 <sub>x</sub> 0 <sub>xxx</sub> 0 <sub>xx</sub> 0 <sub>x</sub> 0)							* ** *	

In the fast speech rate, the whole sentence needs to be wrapped into one single unit, and therefore, FtBinMin and WrapS are crucial here for deriving this pattern. By ranking FtBinMin and WrapS high, the patterns for the slow speed and the normal speed are out, and therefore, the pattern (00000) is derived as the pattern for the fast speed.

In order to derive the correct tonal pattern of different speech rates, the wrapping constraints must rank higher than the left alignment constraint. As for the set of \*WrapSD(*n*<sub>msec</sub>) constraints, it seems that the highest value of the (*n*<sub>msec</sub>) must rank the highest to prevent the largest juncture of two elements to be in one single phonological phrase.

### 3.3.2 Additional structures

In order to explore the predictions for other constructions and to define a model to show how speech rate determines different patterns of tonal neutralization in Mandarin, I would like to see if my proposal works well on other syntactic structures.

Following the analysis in 3.3.1, WrapXP and WrapS must rank higher than the left alignment. They cannot rank the highest, otherwise, the pattern for the slow speed or the pattern for the normal speed is derived for the fast speech rate. As for the set of \*WrapSD( $n_{\text{msec}}$ ) constraints, the highest interval, \*Wrap300, must rank the highest to avoid having a large juncture of two elements above the 300 msec threshold to be in one unit. This is crucial for deriving the pattern for the slow speech rate. The lower intervals do not have specific ranking, as long as they stay low. If this model works, this approach should be able to apply to other morpho-syntactic structures.

The ranking works for the transitive structure with a disyllabic subject, a disyllabic verb and a monosyllabic object, as well as for the transitive structure with a disyllabic subject, a disyllabic verb and a disyllabic object.

The only difference between the OT tableau in (75) and the OT tableau in (78) is the predicted pattern for the slow speech rate. They are both transitive sentences with five syllables, but their morpho-syntactic structures are different. The sentence in (75) has a monosyllabic verb and a disyllabic complement NP, while the sentence in (78) has a disyllabic verb and a monosyllabic complement NP.

Therefore, in (75), the pattern (00)(0)(00) is derived for the pattern for the slow speed, while in (78), the pattern (00)(00)(0) is derived for the pattern for the slow speed. Even though (75) and (78) have different phrasing, the ranking stays the same.



(78) OT Tableau:  $[\sigma\sigma]_{NP}[\sigma\sigma[\sigma]_{NP}]_{VP}$

小 美 烤 好 餅

Xiao-Mei kao-hao bing 'Xiao-Mei baked cookies.'

Xiao-mei bake-asp cookies

$[0_x0]_{xxx}[0_x0_{xx}[0]]$	*Wra p300	*(0) (000)	Ft Bin Mi n	*Wra p200	W r a p S	W r a p X P	A l i g n X P L t	*Wra p100
a. X=150 Slow								
$\rightarrow (0_x0)_{xxx}(0_x0)_{xx}(0)$			*		*	*		**
$(0_x0)_{xxx}(0_x0_{xx}0)$	*			*!	*		*	***
$(0_x0_{xxx} 0_x0_{xx}0)$	**!			**			*	**** *
b. X=100 Normal								
$(0_x0)_{xxx}(0_x0)_{xx}(0)$			*!		*	*		**
$\rightarrow (0_x0)_{xxx}(0_x0_{xx}0)$				*	*		*	***
$(0_x0_{xxx} 0_x0_{xx}0)$	*!			**			*	**** *
c. X=50 Fast								
$(0_x0)_{xxx}(0_x0)_{xx}(0)$			*!		*	*		
$(0_x0)_{xxx}(0_x0_{xx}0)$					*!		*	*
$\rightarrow (0_x0_{xxx} 0_x0_{xx}0)$							*	** *

The difference between the OT tableau in (75) and the OT tableau in (79) is the number of syllables. They are both transitive sentences, but the sentence in (75) contains five syllables, while the sentence in (79) contains six syllables. Also, the sentence in (75) has a monosyllabic verb; while the sentence in (78) has a disyllabic verb. Even though they contain different numbers of syllables, the condition does not change, and the ranking stays the same. The reason why the pattern of (00)(0000) is excluded in the analysis below is because the sizes between (00) and (0000) are not balanced, and the second domain seems too long to produce in a normal speed for native speakers. The maximum number of syllables within one phonological phrase in Mandarin does not contain more than three syllables.

(79) OT Tableau:  $[\sigma\sigma]_{NP}[\sigma\sigma[\sigma\sigma]_{NP}]_{VP}$

小 紫 想 煮 水 餃

Xiao-zi xiang-zhu shui-jiao 'Xiao-zi wants to make dumpling.'

Xiao-zi want-cook dumpling

$[0_x0]_{xxx}[0_x0]_{xx}[0_x0]$	*Wrap300	*(0)(000)	FtBinMin	*Wrap200	Wraps	WrappXP	Align	*Wrap100
a. X=150 Slow								
$\rightarrow(0_x0)_{xxx}(0_x0)_{xx}(0_x0)$	*		*	*	*	*	*	***
$(0_x0)_{xxx}0_x0_{xx}0_x0$	***!			***			*	*****
b. X=100 Normal								
$\rightarrow(0_x0)_{xxx}(0_x0)_{xx}(0_x0)$				*	*	*	*	***
$(0_x0)_{xxx}0_x0_{xx}0_x0$	*!		*	***			*	*****
c. X=50 Fast								
$(0_x0)_{xxx}(0_x0)_{xx}(0_x0)$					*!	*	*	*
$\rightarrow(0_x0)_{xxx}0_x0_{xx}0_x0$							*	***

The ranking for the transitive structure with a monosyllabic subject, a monosyllabic verb and a disyllabic object, in particular, must rank \*Wrap 200 above all constraints except for \*Wrap300 and FtBinMin; otherwise, the pattern of normal speech rate cannot be derived.

The subject and the verb in (80) are both monosyllabic words, and the juncture between them supposes to be the largest size of juncture among the other junctures in the sentence. However, because of the binarity effect, they must be wrapped into one single unit. Therefore, the second highest interval in  $*\text{WrapSD}(n_{\text{msec}})$ ,  $*\text{Wrap200}$ , must rank high to allow grouping the large juncture between the subject and the verb into one single unit without wrapping the whole sentence. Therefore, the pattern (00)(00) is derived for the normal speech rate. The patterns of (0)(000) and (0)(0)(00) are included in the OT tableau (80) to show that disyllabic word is preferred in Mandarin, however, they were not produced by the native speakers in my pilot experiment. Neither (0)(000) nor (0)(0)(00) can be the winning candidate. (0)(000) is ruled out by violating  $*(0)(000)$ , and (0)(0)(00) is ruled out by violating  $\text{FiBinMin}$ .

(80) OT Tableau:  $[\sigma]_{NP}[\sigma[\sigma\sigma]_{NP}]_{VP}$

我 煮 水 餃

Wo zhu shui-jiao 'I make dumpling.'

I cook dumpling

$[0]_{xxx}[0_{xx}[0_x0]]$	*Wra p300	*(0) (000)	Ft Bin Min	*Wra p200	W r a p S	W r a p X P	A l i g n X P L t	*Wra p100
a. X=150 Slow								
$\rightarrow (0_{xxx}0)_{xx}(0_x0)$	*			*	*	*	*	**
$(0)_{xxx}(0_{xx}0_x0)$	*	*!	*	*	*		*	**
$(0)_{xxx}(0)_{xx}(0_x0)$			**!		*	*		*
$(0_{xxx}0_{xx}0_x0)$	**!			**			*	*** *
b. X=100 Normal								
$\rightarrow (0_{xxx}0)_{xx}(0_x0)$	*			*	*	*	*	**
$(0)_{xxx}(0_{xx}0_x0)$		*	*!	*	*		*	**
$(0)_{xxx}(0)_{xx}(0_x0)$			**!		*	*		*
$(0_{xxx}0_{xx}0_x0)$	*			**!			*	*** *
c. X=50 Fast								
$(0_{xxx}0)_{xx}(0_x0)$					*!	*	*	*
$(0)_{xxx}(0_{xx}0_x0)$		*!	*		*		*	*
$(0)_{xxx}(0)_{xx}(0_x0)$			*!*		*	*		
$\rightarrow (0_{xxx}0_{xx}0_x0)$							*	** *

### 3.3.3 Discussion

After applying my proposal on four different syntactic structures containing a different number of syllables, the system seems to work well, and the problems from the prior research that I pointed out in 3.2 are solved.

In the theory of Juncture Phrasing Thresholds, I adopt (Selkirk, 1984a, 1984b)'s theory of SDA, and give each silent demibeat ( $n_{\text{msec}}$ ) a time value. Different domains that depend on speech rates are determined by juncture thresholds. Each ( $n_{\text{msec}}$ ) falls in a certain range, and leads to certain speech rate. For example, if we set up a scale like in (81), and if the ( $n_{\text{msec}}$ ) of the largest juncture equals 250 msec, then it falls in the second range, and the speech rate is normal.

(81) Scale for speech rates

	Ranges	Speech rates
a.	$\geq 300$ msec	Slow
b.	$< 300$ msec; $> 100$ msec	Normal
c.	$\leq 100$ msec	Fast

In this way, we can derive tonal patterns for different speech rates directly and effectively. In further study, I wish to apply this theory to more complex sentences with various structures, as well as to cases in other languages.

The constraints I account for in this theory show the importance of morpho-syntactic structure on prosody. As illustrated in the previous subsection, the

rankings for the morpho-syntactic based constraints, WrapXP, WrapS and AlignXPLt, affect the results of our analysis. Also, the two wrapping constraints, WrapXP and WrapS, must rank above the alignment constraint, AlignXPLt. They cannot be omitted in the analysis of the tone sandhi effect on speech rate in Mandarin. With the new set of constraints, \*WrapSD( $n_{msec}$ ), how speech rate determines different patterns of tonal neutralization in Mandarin is explained.

Moreover, the new set of constraints, \*WrapSD( $n_{msec}$ ), I proposed shows the importance of the size of junctures. The larger the size of the juncture is, the less possibility the two elements between the juncture is wrapped. Therefore, the higher value of ( $n_{msec}$ ) must be ranked high, and the lower value of ( $n_{msec}$ ) must be ranked low.

The theory of Juncture Phrasing Thresholds does not need to consider the application of cycles, which makes the analysis more direct and less arbitrary. Both (Cheng, 1973) and (Selkirk, 1984a, 1984b) assume that the tone sandhi rules apply cyclically. But as we have illustrated earlier, this approach cannot account for some structures in Mandarin. For example, it can derive the correct pattern for a sentence with a disyllabic subject, a monosyllabic verb and a disyllabic object. However, it cannot derive the correct patterns for a sentence with a disyllabic subject, a disyllabic verb and a monosyllabic object. On the other hand, the theory of Juncture Phrasing Thresholds with foot binarity is able to account for both, as well as other constructions.

In developing the juncture timing based analysis, I have looked at some of the factors, such as timing values, binarity and morpho-syntactic structure, and different phonological phrasings. Different speech rates involve different values of time, which affects the phonological phrasing, as well. Combining the theory of SDA with the requirement of foot binarity in Mandarin, we can solve the problems we have discussed in the last part of 3.2, as shown again below.

(82) Illustration of the SDA approach: a transitive with a disyllabic subject

[ σ σ ]NP	[ σ [ σ σ ]NP]VP	
小 虎	補 美 語	
Xiao- hu	bu mei-yu	‘Xiao-hu takes English class.’
Xiao- hu	take English	
* * *	* ** * * *	****
<u>2</u> 3	3 <u>2</u> 3	slow
<u>2</u> 3	<u>2</u> <u>2</u> 3	normal
<u>2</u> <u>2</u>	<u>2</u> 2 3	fast

(83) Illustration of the SDA approach: a transitive with a monosyllabic subject

[ σ ]NP	[ σ [ σ σ ]NP]VP	
虎 補 美 語		
Hu bu mei-yu	‘Hu takes English class.’	
Hu take English		
* ****	* ** * * *	****
*3	3 <u>2</u> 3	slow
*3	<u>2</u> <u>2</u> 3	normal
<u>2</u>	<u>2</u> 3	fast

According to the pilot experiment, the patterns for slow speed and normal speed should be (00)(00). However, this pattern cannot be derived if we follow the theory of SDA. On the other hand, if we follow the theory of Juncture Phrasing



Thresholds, \*WrapSD( $n_{\text{msec}}$ ) restricts two elements to be wrapped into one single domain. The (0000) pattern has more violations than the (00)(00) pattern. The correct pattern (00)(00) for both slow speed and normal speed can be derived.

Therefore, the theory of Juncture Phrasing Thresholds seems to be more promising than the cyclic approach.

### 3.4 Summary and Implications

I have developed a comprehensive analysis of speech rate effects on Mandarin tone sandhi. The notion of Juncture Phrasing Thresholds has played an important role in describing the various factors of the analysis. First, the theory of Juncture Phrasing Thresholds generalizes a timing scale to restrict the size of each juncture. This shows the relation between the morpho-syntactic structure and the size of each phonological phrase, and shows that the size changes depending on speech rates. Also, the theory of Juncture Phrasing Thresholds does not involve cyclicity, which is arbitrary in that it cannot explain how turning-off and skipping work. In Juncture Phrasing Thresholds, one single ranking can apply to different types of constructions, and there is no re-ranking involved. This seems to be a more promising approach compared to the cyclic approach.

I would like to conclude with a brief discussion of some further issues: the problem of half tone 3, (3'), and the pattern for moderato speech rate. For simplification, I have excluded the discussion of the two issues. I would like to extend the analysis, and to see how the new theory works on the case of half tone 3 and the case of moderato.

I believe that half tone 3 happens only because of the timing duration of each syllable, and the stress assignment within the phrase. (Duanmu, 2000, 2007) notes that a full tone 3 is longer than the other three tones, and he claims that a tone 3 is normally produced as a half tone 3 in the real speech. He has done a

survey where he asked the subjects to read at normal speed 16 expressions that contain a tone 3 in the final position. He used noun phrases that contain a monosyllabic modifier and a monosyllabic noun, and verb phrases that contain a monosyllabic verb and a monosyllabic object, as shown in (84). The results show that most speakers pronounced all of the 16 final tone 3s with half tone 3s. A full final tone 3 is less used in a noun phrase, (84a), than in a verb phrase, (84b), which may be caused by stress assignment within a phrase (Hoa, 1983). Hoa points out that the noun phrase has initial stress, whereas the verb phrase has final stress. This is the reason why the tone 3 syllable in a verb phrase can take a full tone 3, while the tone 3 syllable in a noun phrase prefers to take a half tone 3. The same idea may apply to the case where a tone 3 syllable appears initially. Since tone 3 is longer than the other tones, each tone links to a syllable, and each syllable should have fairly similar timing duration, a full tone 3 cannot be produced in normal speech. The tone 3 syllable can only be produced as a full tone 3 when it is stressed. Therefore, when a tone 3 syllable comes before another tone other than another tone 3, it will normally be produced as a half tone 3. This type of tonal change is completely different from the tonal change for the application of tone 3 sandhi.

Therefore, I first argue that half tone 3 is another level of realization of tonal change, which is different from tone 3 sandhi. The half tone 3 seems to change from one full tone to another, but I think that it is part of the original tone 3. As speech gets faster, time is shortened, and the first tone 3 fails to be realized as a

full tone 3. That is why it becomes a half tone 3, which is different from the process of tonal neutralization. Therefore, the process of a full tone 3 becoming a full tone 2, and the process of a full tone 3 becoming a half tone 3 are different.

If this is true, the current constraints in the theory of Juncture Phrasing Thresholds may not be relevant, and we may need to have another constraint/s to account for this specific issue.

(84) Contrast between [M N] and [V O] for final tone 3

(a) [M N]

賽馬

Sai4 ma3 'a race horse'

race horse

4 (3')/(?3)

(b) [V O]

賽馬

Sai4 ma3 'to race horse'

race horse

4 (3')/(3)

Another issue I would like to address here is the pattern of moderato. I first left this pattern aside in my analysis because I wanted to generalize the basic patterns before moving onto the complicated one. From the prior research, the pattern for moderato exists. However, the result of my pilot experiment shows that the pattern for normal speech rate is the same as the predicted pattern for allegro, a faster speech rate in the prior research.

My theory seems not to be able to derive the pattern for moderato. Since the speed of moderato is between adagio and allegro, I set the value of X as 125

msec. The predicted pattern for moderato in the prior research is (000)(00), without considering cyclicity. However, with the constraints I have so far, and with different rankings, the pattern of (000)(00) still cannot be derived. The illustration is shown in (85) and (86).

(85) The patterns of moderato and allegro

老 李 買 好 酒

Lao-Li mai hao jiu 'Lao Li buys good wine.'

Lao-Li buy good wine

3	3	3	3	3	Tonal inputs
<u>2</u>	<u>2</u>	3	<u>2</u>	3	Moderato
<u>2</u>	3	<u>2</u>	<u>2</u>	3	Allegro

(86) OT Tableau: the case of moderato (X=125)

[0 <sub>x</sub> 0] <sub>xxx</sub> [0 <sub>xx</sub> [0 <sub>x</sub> 0]]	*Wra p300	*(0) (000)	Ft Bin Mi n	*Wra p200	W r a p S	W r a p X P	A l i g n X P L t	*Wra p100
(0 <sub>x</sub> 0) <sub>xxx</sub> (0) <sub>xx</sub> (0 <sub>x</sub> 0)			*		*	*		**
?(0 <sub>x</sub> 0 <sub>xxx</sub> 0) <sub>xx</sub> (0 <sub>x</sub> 0)	*			*	*	*	*	***
(0 <sub>x</sub> 0) <sub>xxx</sub> (0 <sub>xx</sub> 0 <sub>x</sub> 0)	*			*	*		*	***
(0 <sub>x</sub> 0 <sub>xxx</sub> 0 <sub>xx</sub> 0 <sub>x</sub> 0)	**			**			*	****

My explanation is that /i 'Li' in the pattern of moderato may be a half tone 3 instead of a full tone 2. The difference between a full tone 2 and a half tone 3 is

that the pitch contour of a full tone 2 is rising, while the pitch contour of half tone 3 is falling and rising. However, even though a tone 2 and a half tone 3 have distinct pitch shapes, the timing duration of a tone 2 is fairly similar to a half tone 3, people may think that it is a tone 2. Therefore, it may be the case that what people transcribe as a tone 2 on the second syllable in the pattern of moderato is actually a half tone 3. For future research, it may be helpful to have native speakers talk with as many speech rates as possible, and measure the speech rates to see if there are truly four distinct patterns in four different speech rates for tone sandhi application in Mandarin Chinese.

Therefore, in order to distinguish whether there is a difference between the pattern of moderato and the pattern of allegro may require an in-depth study. My goal of the thesis is only to generalize a model that integrates the factors of speech rates, phonological structure and morpho-syntactic structure into a single grammar of tone sandhi in Mandarin.

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