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TONAL STRENGTH

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By

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ABSTRACT

TONAL STRENGTH IN TIANJIN TONE SANDHI

By

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The Tianjin dialect of the People's Republic of China is unique in that it has a complex interaction of four tone sandhi rules.

In this paper, I have analyzed two and three-syllable strings. I have attempted to uncover what dictates when tone sandhi applies and what determines where it will change to. I have done this by analyzing the freedom of occurrence of tones in their respective strings and by analyzing the tones in terms of pitch frequency gain.

The results indicate that the four tones of Tianjin may be a part of a strength hierarchy. All the outputs of Tianjin tone sandhi in two and three-syllable strings, limited by two constraints that I have proposed, can all be explained by the tonal strength hierarchies. The implications of tonal strength and how it can explain tonal phenomena in other languages is yet to be determined.

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1. Introduction

1.1 Purpose

The purpose of this paper is to analyze Tianjin tone sandhi (TTS) from a new point of view. Previous analyses have concentrated solely on the issues of 1) rule directionality, 2) rule ordering, and 3) the prosodic domains of TTS. They have not, however, dealt with the issue of what exactly might dictate and determine TTS, but rather have dealt with what specific problems TTS presents to analysis. My hypothesis is that TTS is not dissimilatory in nature, as has been generally accepted in the past, but is in fact motivated (for the most part) by what I have called "tonal strength." This hypothesis, when applied to the tone sandhi processes of many other languages, may yield a new understanding of the function of tones.

In this paper, I will limit my discussion to TTS in two and three-syllable strings. Rule ordering and rule directionality will be discussed, but I will refer the reader to Chen (1987) and Hung (1987) for their discussion on the prosodic domains of TTS.

1.2 The Tianjin Dialect

The Tianjin dialect is a dialect of the Chinese language. It is spoken in the metropolis of Tianjin, located in Tianjin province, in the People's Republic of China.

Tianjin is 120 km southeast of Beijing, the capital of China.

The Tianjin dialect and Mandarin are mutually intelligible. They both have four tones, the major difference being that the Tianjin dialect has no high level tone [55], but rather has a low falling tone [21]. The complete inventory of the Tianjin tones is as follows:

(1)	[21]	Low Falling	Tone A
	[45]	Rising	Tone B
	[213]	Falling-Rising	Tone C
	[53]	High Falling	Tone D

I will refer to these tones as A, B, C, and D in my discussion in order to remain consistent with other authors.

1.3 Background

There are four tone sandhi rules in the Tianjin dialect. They are:

(2) 21 ->213/___21
(3) 213->45 /___213
(4) 53 ->21 /___53
(5) 53 ->45 /___21

They can be restated as:

(6) AA->CA
(7) CC->BC
(8) DD->AD
(9) DA->BA

These rules have been referred to in previous articles by their input strings, so (6) is the AA rule or AAR, (7) is CCR, (8) is DDR, and (9) is DAR.

Here are some examples of TTS applying on two-syllable strings:

```
(10) AA->CA
     gao  shan            'high mountain'
     21   21
     213  21               by AAR

(11) CC->BC
     xi  lian             'wash face'
     213 213
     45  213               by CCR

(12) DD->AD
     jing zhong           'net weight'
     53   53
     21   53               by DDR

(13) DA->BA
     kan  shu             'read book'
     53   21
     45   21               by DAR
```

Whenever the conditions for TTS are not fulfilled, TTS does not apply. From this we know the original tone of each syllable. For example, whenever 'gao' (considered to bear tone A) occurs before a syllable bearing tones B, C, or D, 'gao' remains tone A.

There are seven three-syllable strings where either more than one TTS rule applies to the string at the same time, or where the application of one TTS rule on the string feeds another, or in other words, provides input for another

TTS rule to apply. When TTS rules apply to these three-syllable strings, their application seems to be inconsistent. Examples of each are presented below:

```
(14) AAA->ACA
     kai  fei  ji        'fly airplane'
     A    A    A
     A    C    A          by AAR

(15) DDD->DAD->BAD
     suo  liao  bu       'plastic sheet'
     D    D     D
     D    A     D         by DDR
     B    A     D         by DAR

(16) CCC->BCC->BBC
     li  fa  suo         'barber shop'
     C   C   C
     B   C   C            by CCR
     B   B   C            by CCR

(17) CAA->CCA->BCA
     bao  wen  bei       'thermo cup'
     C    A    A
     C    C    A          by AAR
     B    C    A          by CCR

(18) ADD->AAD->CAD
     xin  dian  shi      'new television'
     A    D     D
     A    A     D         by DDR
     C    A     D         by AAR

(19) DDA->ADA->ABA
     zuo  dian  che      'take tram'
     D    D     A
     A    D     A         by DDR
     A    B     A         by DAR

(20) DAA->DCA
     zi  zun  xin        'self respect'
     D   A    A
     D   C    A           by AAR
```

In (14), it appears that AAR is applying from right to left because its input is the last two syllables of the AAA string. DDR also appears to be applying from right to left because in (15), its input is the last two syllables of the DDD string. DDR also feeds, or in other words, provides input for DAR to apply. In (16), CCR appears to be applying iteratively from left to right. In (17), AAR feeds CCR. In (18), DDR feeds AAR. In (19), application appears to be from left to right, or another interpretation would be that DDR precedes DAR. Finally, in (20), AAR applies preventing DAR from applying. One might argue that this shows that AAR precedes DAR.

In any case, the problems of rule directionality and rule ordering presented by the data above have been the main issues of discussion in previous articles. I will touch on these issues but the main focus of this study will be tonal strength and how it dictates and determines Tianjin tone sandhi.

2. Previous Analyses

2.1 Li and Liu

Li and Liu's 1985 article in Zhongguo Yuwen, "Tone Sandhi in the Tianjin Dialect," was the first to introduce the Tianjin tone sandhi phenomenon to the linguistic world.

In the article, Li and Liu present the four TTS rules, (6)-(9), together with a fair amount of data showing TTS applying to two, three, and four-syllable strings. The two and three syllable strings are not subdivided but the four-syllable strings are. They are subdivided into 2+2 word groupings, 1+3 word groupings and 3+1 word groupings dependent upon the internal structure of the strings. The data that Li and Liu present shows that in the 2+2 word groupings, TTS applies as it does in two-syllable strings to each two-word group, but that TTS does not apply between these two two-word groups, in other words, TTS does not apply to the second and third words in these four-syllable strings. They go on to show that TTS applies to three-word groups of both 1+3 and 3+1 word groupings the same as it does in three-syllable strings and furthermore that TTS does apply between the first and second word in the 1+3 word groupings and the third and fourth word in the 3+1 word groupings.

2.2 Matthew Y. Chen

Chen has published two articles on the Tianjin tone sandhi phenomenon. The first was a 1986 article, "The Paradox of Tianjin Tone Sandhi," and the second was a 1987 article, "A Symposium on Tianjin Tone Sandhi: Introductory Remarks."

In his 1987 article, Chen remarks on his 1986 article, saying:

> "In Chen . . . 1986 . . . I reached the unhappy and inelegant conclusion that no conceivable mode of rule application seemed to be compatible with Li-Liu's (1985) data. I demonstrated that neither cyclic application (obeying Strict Cyclicity Condition), nor simultaneous or iterative application in any direction (L to R, or R to L) is capable of generating the attested sandhi patterns (205)."

He goes on to say that the reason that this was so was that he was treating the four TTS rules (6)-(9), as a unified system that applied in a unified way. In his 1987 article, the rules of TTS are presented as individual rules with different modes of application.

The major contribution of the 1987 article is its discussion of morphosyntax and how it relates to TTS and the author's analysis of the prosodic domains of TTS. Chen gives Phrasing/Foot-Formation rules for dividing up longer utterances (of more than three syllables) into feet and phrases that TTS can apply to. Chen shows how different derivations of longer strings can be explained by alternative divisions of the utterance.

2.3 Fu Tan

Tan has also published two articles on this subject. The first was a 1986 article in Zhongguo Yuwen entitled, "More on Tone Sandhi in the Tianjin Dialect." The second was a 1987 article entitled, "Tone Sandhi in the Tianjin Dialect." This was a revision of an earlier 1986 unpublished manuscript.

Tan, in her 1987 article, proposes that all the rules have a specific directionality:

(21)	AAR	R to L
	CCR	L to R
	DDR	R to L
	DAR	unspecified

She also proposes that these rules are ordered in relation to each other:

(22) AAR>CCR

and

AAR>DDR>DAR

She also claims that morphosyntax does not change the way that TTS rules apply. She shows this by giving examples of left and right branching structures with identical tone patterns and showing that the outputs are the same:

(23)	[suo liao] bu	'plastic sheet'
	D D D	
	D A D	by DDR
	B A D	by DAR

(24)	ya [re dai]	'subtropics'
	D D D	
	D A D	by DDR
	B A D	by DAR

On the other hand, she claims that emphasis blocks TTS:

(25)	<u>cai</u>	+	tai	duo	'there is too much <u>vegetable</u>
	<u>D</u>	<u>+</u>	<u>D</u>	<u>A</u>	(not meat)'
	D	+	B	A	by DAR
					(+ indicates blocking of TTS)

The expected output of DDA is ABA, but in (25), the first word, 'vegetable', has contrastive emphasis with 'meat'. This blocks DDR from applying to the first two words, so DAR applies to the last two words. Li and Liu also give a few examples where emphasis blocks TTS.

I will not be covering this issue in my analysis. Read Tan (1987) for her arguments and Chen (1987) for his counter arguments against this position.

2.4 Tony Hung

In a 1987 article, "Tianjin Tone Sandhi: Towards a Unified Approach," Hung attempts to explain the TTS phenomenon in a different manner. This consists of a surface phonotactic constraint called simply, the Tianjin Phonotactic Constraint (TPC), "... which discourages identical low tones [tones A and C] from surfacing in juxtaposition within the same tone group... (279)."

Hung makes no comment on directionality, but rather says TTS rules apply whenever their condition is met subject to TPC. The only ordering that he proposes is that DAR is ordered last.

A rather large portion of the article deals with the domains for TTS which he specifies as the tone group which is mainly conditioned by prosodic structure but is conditioned less by syntactic structure. I have chosen to ignore the prosodic domains for TTS in this paper because I feel that Chen's (1987) and Hung's (1987) hypotheses are sufficiently viable. If the reader is interested in this aspect of TTS, then I refer the reader to the above analyses for a more complete understanding of TTS.

TPC does not, in my opinion, threaten the validity of my discussion. This constraint cannot fully account for the way TTS operates. It accounts to some extent for the motivation behind CCR and AAR, but it does not account for DDR which Hung says is a product of dissimilation or DAR which is not explained in terms of why it occurs at all.

2.5 Zheng-Sheng Zhang

Zhang's 1987 article, "The Paradox of Tianjin: Another Look," does not draw any conclusions very different from those I have already discussed. The main difference between Zhang's and Tan's proposal is that Zhang avoids the extent of Tan's extrinsic ordering just by stating that AAR and DDR precede DAR. He agrees with Tan on directionality, that AAR and DDR apply right to left and CCR applies left to right. He also shows that TTS rules do not apply cyclically on morphosyntactic structures.

The only other thing of major importance in Zhang's article is a refutation of Hung's TPC (see section 2.4 above). He states that TPC must be "global" in order for it to do the work that Hung wants it to do and is therefore too powerful. He shows that Hung's TPC does not disallow low tones in juxtaposition in ADD->AAD->CAD derivations and it does not disallow AAA->CCA alternative derivations (see section 4.4).

2.6 The Data

The data available for the study of TTS is limited. I have pooled all the data from the above mentioned studies of TTS for my data base. However, in many cases, the data is not consistent.

For instance, Li and Liu neglect to give any examples of TTS applying to DAA strings as in example (20). Furthermore, their output for TTS applying to DDD strings is DAD, thus DDD->DAD->*BAD. This means that DAR doesn't apply after DDR in their data. Hung's data agrees with Li and Liu's in this instance.

Tan's and Chen's data, on the other hand, give the output for TTS applying to DDD strings as BAD as in example (15). Moreover, Tan gives her output for TTS applying to ADD strings as AAD and not CAD, as in example (18). Thus ADD->AAD->*CAD. This means that AAR does not apply after DDR in her data.

Zhang has no data of his own, but rather uses both Li and Liu's and Tan's data. But the cited examples for PQR strings DDD and ADD are from Li and Liu's data because his final output for DDD strings is DAD (same as Li and Liu's) and his output for ADD strings is CAD (same as Li and Liu's).

This apparent split in the data base is most likely due to different variants of the Tianjin dialect. Tan admits that there is another dialect of Tianjin where the CAD output for ADD is an alternative. As regards to the output of DDD strings, I have chosen to use the 2-part derivation DDD->DAD->BAD in agreement with Chen and Tan.

The conflicting data does not affect my discussion of Tianjin tone sandhi. The only difference is that the derivations are not carried out to their full extent. It is still true that each string changes to a stronger string, according to my hypothesis. It is interesting to note that the major difference in data concerns whether DAR applies after DDR. DAR is the only rule whose output is 3 strength relation values stronger than its input. See discussion in section 4.4 below. Also see Appendix for complete listing of data sources.

3. Tianjin Tone Sandhi in Two-Syllable Strings

In my discussion of Tianjin tone sandhi (TTS), I will propose a strength hierarchy of tones. I will show that this hierarchy is supported by two criteria; 1) freedom of occurrence of tones and 2) frequency gain. I will also show that these strength hierarchies dictate when TTS occurs and that they determine where and how the input string changes.

3.1 Variables X and Y

Before I discuss TTS in three-syllable strings, I want to discuss Tianjin tone sandhi in its most limited domain, that is, in two-syllable strings. The four basic TTS rules operate minimally in two-syllable strings. The four basic TTS rules are restated below:

(26)	21 ->213/___21	or	AA->CA	AAR
(27)	213->45 /___213	or	CC->BC	CCR
(28)	53 ->21 /___53	or	DD->AD	DDR
(29)	53 ->45 /___21	or	DA->BA	DAR

In order to represent Tianjin two-syllable strings, I want to introduce two variables, X and Y. Let X and Y each represent a mono-syllable. Secondly, let X and Y each represent a maximum of one morpheme. And finally, let X and Y each represent a tone bearing unit (although it is possible in Tianjin for the syllable to bear no phonemic tone at all).

Next, it is important to understand the relationship of X and Y to each other. Let X always represent the first syllable of a two-syllable string and Y the last syllable in a two-syllable string; therefore the order of these two variables is always XY, never YX. It follows that there can be no other syllables between variables X and Y. They are always adjacent to each other. These variables were designed so that I can more easily refer to the two-syllable string as the XY string and so that I can refer to the first and last syllable of a two-syllable string as X and Y respectively.

3.2 Freedom of Occurrence of Tones in the XY String

The Tianjin dialect has four tones. They are restated below:

(Contrastive Tonal Patterns)	(Tone Labels)
(30) [21]	Tone A
[45]	Tone B
[213]	Tone C
[53]	Tone D

In the discussion that follows I will refer to the tone labels (A, B, C, and D) and not the contrastive tonal patterns of each tone. Therefore X, of the XY string, can bear four possible tones (A, B, C, and D), and Y can also bear four possible tones (A, B, C, and D). That means that there are sixteen possible XY tonal combinations.

Table 1
The Sixteen Possible XY Strings

AA	BA	CA	DA
AB	BB	CB	DB
AC	BC	CC	DC
AD	BD	CD	DD

Since linearity is inherent in my description of the XY string in section 3.1 above, none of the strings in Table 1 are redundant. In other words, an XY string bearing tones A and D in sequence is not equal to an XY string bearing tones D and A in sequence i.e. AD≠DA.

Of these sixteen possibilities, four of them are input strings for TTS rules (26)-(29). They are AA, CC, DD, and DA. This means that when the conditions for tone sandhi are met, these four input strings do not appear as surface strings but rather appear as CA, BC, AD, and BA respectively. Tone sandhi does not occur with any other XY strings. Therefore, in surface strings, AA, CC, DD, and DA do not occur.

Table 1, therefore, can be modified to include only those strings that occur as surface strings:

Table 2
XY Surface Strings

	BA	CA	
AB	BB	CB	DB
AC	BC		DC
AD	BD	CD	

Looking at the X position in surface XY strings, tone B occurs four out of four possible times. In other words, tone B may occur in the X position with any other tone including itself, without becoming part of an input string for tone sandhi. I will refer to this as "freedom of occurrence." Therefore, tone B has a high freedom of occurrence because it occurs four out of four possible times. Additionally, tone C occurs three out of four possible times, tone A occurs three out of four possible times, and finally tone D occurs two out of four possible times, as shown in Table 3:

Table 3
Freedom of Occurrence of X in Surface XY Strings

BY	CY	AY	DY
BA	CA		
BB	CB	AB	DB
BC		AC	DC
BD	CD	AD	

Now looking at the Y position in the surface XY strings, tone B occurs four out of four possible times, tone C occurs three out of four possible times, tone D occurs three out of four possible times, and finally tone A occurs two out of four possible times, as shown in Table 4:

Table 4
Freedom of Occurrence of Y in Surface XY Strings

XB	XC	XD	XA
AB	AC	AD	
BB	BC	BD	BA
CB		CD	CA
DB	DC		

In Table 3 above, both tones C and A occur three out of four possible times in the X position. With only this information, the tones in the X position could be ranked either B-C-A-D or B-A-C-D in terms of freedom of occurrence. In addition, in Table 4, both tones C and D occur three out of four times in the Y position. So in the Y position, the tones could be ranked either B-C-D-A or B-D-C-A. In order to arrive at a ranking for tones regarding freedom of occurrence, one must either concede that there are two possible rankings for each position in the string, or use some additional data to decide upon a ranking. I have decided upon the latter.

If the results of both Tables 3 and 4 are combined, one sees that tone B occurs eight out of eight possible times, tone C occurs six out of eight possible times, tone A occurs five out of eight possible times, and finally tone D also occurs five out of eight possible times. This data shows that, overall, tone B has the greatest freedom of occurrence. In fact, tone B never undergoes tone sandhi. Tone C follows tone B in terms of freedom of occurrence, because it occurs six out of eight possible times in either the X or Y position. This is greater than either tone A or D which both occur five out of eight possible times (see Table 5.c). On this basis I have ranked tone C above tone A in the X position and tone C above tone D in the Y position. The ranking of tones A and D has already been determined by their freedom of occurrence in their respective positions in the XY string.

3.3 The Tone Hierarchy

Table 5
Freedom of Occurrence Hierarchy

```
    a. X Position        b. Y Position        c. Overall
High           B                    B                    B
Freedom of     |                    |                    |
Occurrence     C                    C                    C
               |                    |                   / \
Low            A                    D                  A   D
Freedom of     |                    |
Occurrence     D                    A
```

Table 5 above shows the hierarchy of tones as determined by freedom of occurrence. Table 5.a shows that in the X position, tone B has the highest freedom of occurrence and tone D has the lowest. Similarly in Table 5.b, tone B has the highest freedom of occurrence while tone A has the lowest.

We will see that there is a criterion other than freedom of occurrence for this ranking of the tones.

3.4 Tonal Contours, Frequency Gain, and Tonal Strength

In the Tianjin dialect, there are five phonological pitch levels, [5] being the highest and [1] being the lowest. If the phonological pitch levels within each tone are examined and compared, some interesting results come to light. For example, the phonological pitch levels of tone B are [45]. The tone starts approximately at pitch level [4] and rises to pitch level [5]. This tone has a rising contour. Another way of describing this is that there is an increase in pitch frequency.

The phonological pitch levels within tone C are [213]. It starts at approximately pitch level [2], dips to pitch level [1], and then rises to pitch level [3]. This tone begins with a falling contour but ends with a rising one. There is first a decrease in pitch frequency followed by an increase in pitch frequency.

The phonological pitch levels within tone A are [21]. It starts at approximately pitch level [2] and falls to pitch level [1]. This tone has a low falling contour. Note that the only significant difference between tone C and A is that tone C rises to pitch level [3] after its fall to pitch level [1] and tone A doesn't.

The phonological pitch levels within tone D are [53]. It starts at approximately pitch level [5] and falls to pitch level [3]. Tone D has a high falling contour. Both tones A and D can be described as having a decrease in pitch frequency.

The reason that tones A and D remain distinct, even though they both have a decrease in frequency, is because they are maximally different within the context of a falling tone. Tone D starts at the highest possible pitch level in a five pitch level system, [5], and then falls approximately two pitch levels. Tone A, on the other hand, starts on pitch level [2], the lowest possible starting position for a falling tone and falls to the lowest pitch level, [1].

In Table 6, the tones have been grouped according to their contour. From the discussion above concerning the phonological levels within each tone, it was seen that tonal contours are actually increases or decreases in pitch frequency. Instead of referring to each tone as having an increase or decrease in pitch frequency, I want to propose a single feature which I will call "frequency gain." So any tone that has an increase in pitch frequency will have a positive [+] frequency gain and any tone that has a decrease in pitch frequency will have a negative [-] frequency gain.

Table 6
Tonal Contour Groupings

Rising Contour	Falling-Rising Contour	Falling Contour
Tone B	Tone C	Tone A Tone D
[+] Frequency Gain	[- +] Frequency Gain	[-] Frequency Gain

Therefore, since tone B has an increase in pitch frequency, it can be understood as having a positive [+] frequency gain. Tones A and D, on the other hand, can be understood as both having a negative [-] frequency gain since both have a decrease in pitch frequency. Tone C, however, is a combination of both a decrease and increase in pitch frequency in that order. So to accurately represent tone C, it can be understood as having both negative and positive frequency gain represented as [-+]. Therefore tone C is ranked between tone B and tones A and D because it shares features with both. If it is understood that the tones shown in Table 6 (left to right) are in descending order {[+] to [-]} in terms of frequency gain, then the result is an ordering equivalent to that of freedom of occurrence (Table 5).

Another way of understanding this ordering is that freedom of occurrence directly correlates with frequency gain. Therefore, if a tone has a positive [+] frequency gain (tone B for instance), then it will have a high freedom of occurrence. In other words, a tone that has a positive [+] frequency gain resists change and is therefore stronger than a tone that has a negative [-] frequency gain (tones A or D for instance) which are most subject to change. I will refer to this as "tonal strength." Tone C falls in between these two extremes because it has both negative and positive [-+] frequency gain.

The fact that both tones A and D have negative [-] frequency gain correlates with the ordering of these two tones in the strength hierarchy which can either be A-D (X position) or D-A (Y position). Their ultimate ordering is dependent upon their position in the XY string. This will be explained in detail in section 3.5.

This phenomenon of tonal strength may be related to perception, in that increases in pitch frequency are often perceived as being stressed. This factor may account for why increases in pitch frequency are stronger than decreases in pitch frequency.

3.5 The Tone Matrix

It was shown in section 3.2 that freedom of occurrence ordered the tones as B-C-A-D in the X position and B-C-D-A in the Y position. These tones were placed in freedom of occurrence hierarchies in section 3.3. In section 3.4, it was shown that pitch frequency gain ordered the tones in the same way. These hierarchies, presented in Tables 5 and 6 can now be understood as strength hierarchies, tone B being the strongest and tones A and D being the weakest. To further illustrate this, I will use the X hierarchy for the horizontal axis in a matrix, and I will use the Y hierarchy for the vertical axis in a matrix. I will also show by using strength relation values how tonal strength dictates and determines tone change.

Y \ X	B	C	A	D
B	BB	CB	AB	DB
C	BC	CC	AC	DC
D	BD	CD	AD	DD
A	BA	CA	AA	DA

Figure 1
The Tone Matrix

Figure 1 above shows the sixteen possible XY tonal combinations. Those underlined, AA, CC, DD, and DA, do not occur as surface strings, but rather undergo tone sandhi.

XY string AA becomes CA by AAR, CC becomes BC by CCR, and DD becomes AD by DDR. In Figure 1 above, output strings CA, BC, and AD all appear immediately to the left of their input strings AA, CC, and DD respectively. DA does not become AA as might be predicted by Figure 1, but rather becomes BA. Before this can be explained, replacement within the matrix must be discussed.

3.5.1 Replacement Within the Matrix

I have proposed that tonal strength both dictates and determines Tianjin tone sandhi: (1) an XY string will change if the XY tonal combination has a low strength relation value and (2) the input string will change to an output string that is stronger than the original input string. To show this, in Figure 2, I have assigned number values to each tone in each hierarchy ranging from 4 to 1, 4 being the strongest and 1 being the weakest. The strength of each XY string is then determined by the sum of the values of the X and Y tone.

In the tonal matrix, strings that undergo tone sandhi may only be replaced within the horizontal row which they occupy. This is because the tone in the X position is the one that changes. The tone in the Y position always remains the same. In other words, replacement occurs along the X hierarchy and not the Y hierarchy because the tone in the X position is the one that changes, not the tone in the Y position. See Figure 2:

X Y	B 4	C 3	A 2	D 1
B 4	BB 8	CB 7	AB 6	DB 5
C 3	BC 7	CC 6	AC 5	DC 4
D 2	BD 6	CD 5	AD 4	DD 3
A 1	BA 5	CA 4	AA 3	DA 2

Figure 2
The Tonal Matrix with Strength Values

The number values of each XY string in Figure 2 above are strength relation values. Notice that AA, DD, and DA are the weakest XY strings (strengths 3, 3, and 2 respectively) and therefore change. An explanation of why CC changes will be given in section 3.6. Also notice that each string changes to a stronger output string; AA->CA is a change from 3 to 4, DD->AD is a change from 3 to 4, and DA->BA is a change from 2 to 5.

The output of XY input string DA does not change to the next strongest string as do the others, but this can be explained in the following manner. If DA's output were the next strongest string, then the output would be XY string AA which is also an input string. AA would also undergo tone sandhi and the final output of DA would be CA, the same output string for AA. Therefore input strings DA and AA would have the same output, CA. In fact, if DA were to become CA, then tone D of the input string DA would undergo tone sandhi twice. First it would change to A and then it would change to C. I propose the following constraint[1]:

(31) TTS Constraint 1:

A tone may only undergo tone sandhi once.

This constraint would prohibit DA from becoming CA through AA. However, it would not prohibit DA from becoming CA without any transition through AA. But the problem would still remain that DA and AA would both have the same outputs, namely CA. Although this situation is not at all impossible, a language would reasonably avoid this merger if there were a feasible alternative.

The only alternative left is for DA to become BA, which is in fact the case. This means that the output string of DA is three strength relation values higher than its input string, but the fact remains that the output string has a stronger value than the input string. Moreover, the fact that DA becomes BA doesn't violate TTS Constraint 1 because there is no transition through other tones. TTS Constraint 1 will be discussed in more detail in section 4.4, below.

3.6 The Tonal Matrix Graph

The Tonal Matrix Graph (see Figure 3) is a graphic representation of each tone and each of the XY string tonal combinations. It is presented in the same manner as the

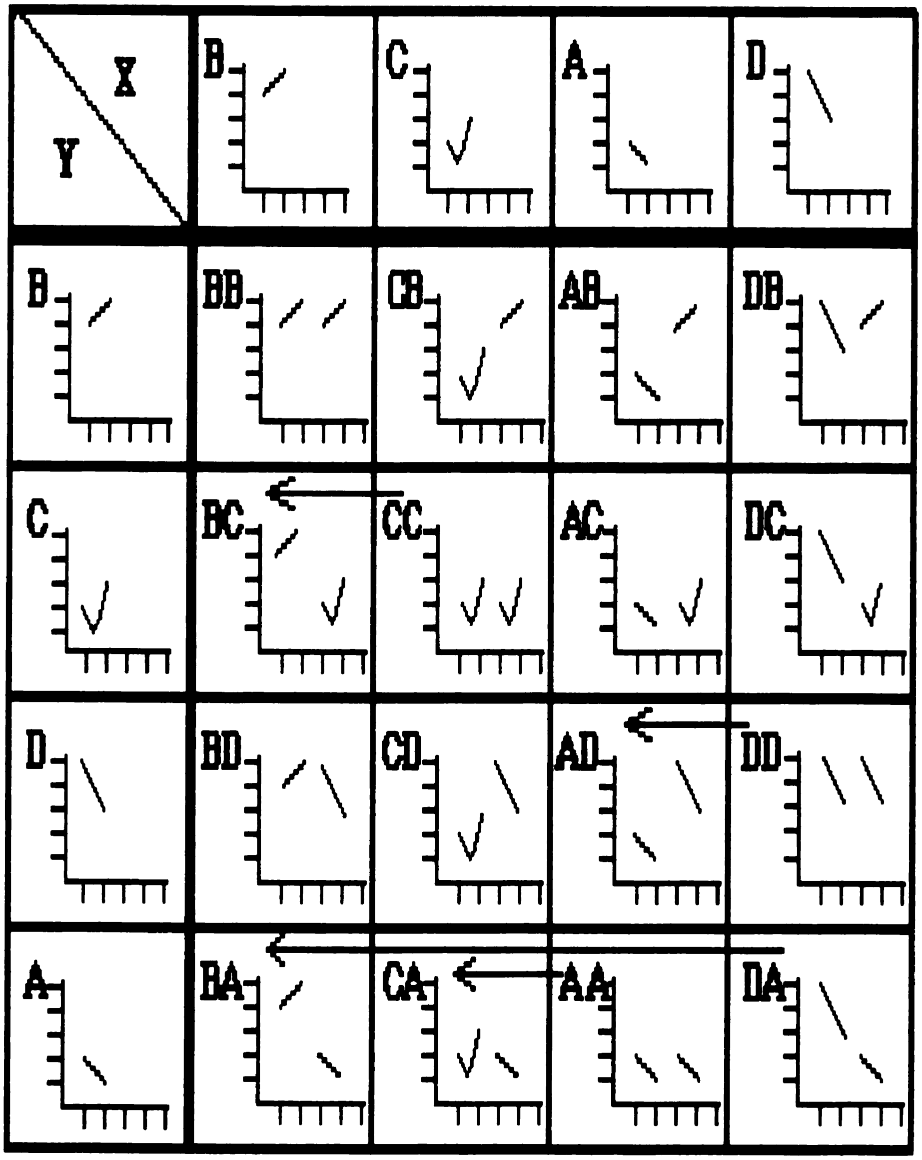

Figure 3
The Tonal Matrix Graph

matrices above. The horizontal axis of the matrix is the tonal strength hierarchy for the X position of the XY string. The vertical axis of the matrix is the tonal strength hierarchy for the Y position.

For each graph in the matrix, the vertical axis represents pitch frequency and the horizontal axis represents time. It must be understood that in reference to time, that there have been no real time measurements of these tones, but in this present analysis this point is irrelevant. In the outer periphery of the matrix where tone B is either in the X or Y position, none of these XY strings are input strings for tone sandhi. This is, in my opinion, because tone B is a member of each XY string. Tone B is the strongest tone (because it only has positive [+] frequency gain) and therefore these XY strings are resistant to change.

Moving in one layer of the matrix where tone C is in either the X or Y position (but not in combination with tone B), the only XY tonal combination which is an input string for tone sandhi is CC. In the other strings, tone C is in the X or Y position in combination with either tones A or D. Because C is second on the strength hierarchy, these XY strings are resistant to change. Note that in each of these combinations, there is an increase in pitch frequency.

It has been suggested by Chen that the CC->BC tone sandhi rule is applicable in all Mandarin dialects,[2] which may be true, but it is still important to realize that CC still changes to the next strongest XY tonal combination. One explanation of why this XY string is an input for tone sandhi, even though it has a strength relation value of 6, is that it is the most complex of all the XY tonal combinations in that there is a lot of information packed in a small amount of time. In a relatively short time span, there is first a decrease in pitch frequency immediately followed by an increase, then another decrease immediately followed by another increase. The intuitions of most native speakers support this explanation of complexity in that two C tones in a row are simply difficult to pronounce.

Finally moving in another layer on the matrix which consists of XY strings AA, AD, DD, and also including DA, these XY tonal combinations only consist of falling tones, or in other words, only those that have negative [-] frequency gain. This is the weakest section of the matrix (see Figure 2) and the three weakest XY strings are indeed input strings for tone sandhi, AA, DD, and DA. AD is not an input string for tone sandhi although it consists of two falling tones. This is because tone A is stronger in the X position than in the Y position and because tone D is stronger in the Y position than in the X position. The XY string DA, the weakest of all the strings having a strength relation value of 2, is actually a continuous decrease in frequency starting at pitch level [5] and falling to pitch level [1]. The XY string AD, on the other hand is not a continuous decrease in frequency. Tone A ends at pitch level [1] and then tone D starts at pitch level [5]. Although this juncture is not voiced, in fact, none of them are, there is a difference of 5 pitch levels.

It has also been suggested by Chen[3] and Hung[4] that Tianjin tone sandhi is dissimilatory in nature. If this is true, then why doesn't the XY string BB change? And furthermore, why does the XY string DA change at all? My explanation of tonal strength is consistent with these facts.

3.7 Summary

I introduced two variables, X and Y, to represent the two-syllable string in TTS. Then I proposed a strength hierarchy for tones supported by two criteria: 1) I showed the freedom of occurrence of each Tianjin tone in the X or Y position in the XY string. These tones were then placed in a hierarchy in regards to freedom of occurrence. 2) Then I compared the phonological pitch levels of each Tianjin tone and placed them in a hierarchy in regards to frequency gain. Then I showed that the freedom of occurrence and the frequency gain hierarchies were consistent with each other and could be referred to as strength hierarchies. Then I constructed a matrix using the X and Y position tonal strength hierarchies for variables and I showed that each XY string changes to a stronger XY string and that the weaker strings (excluding CC) were the XY strings that changed. This matrix was then reformulated in the form of a tonal graph matrix where it was apparent that the weakest XY strings (those with strength relation values of 3 and 2) were combinations of falling tones.

In the next section, I will discuss how tone sandhi operates in three-syllable strings.

4. Tianjin Tone Sandhi in Three-Syllable Strings

4.1 Variables P, Q, and R

In this section I want to discuss how TTS operates in three-syllable strings. In order to represent the three-syllable string, I need to introduce three new variables, P, Q, and R. The variables P, Q, and R represent the same thing as variables X and Y (see section 3.1). However, the relationships among these three variables are different in that P always represents the first syllable of a three-syllable string, Q always represents the medial syllable of a three-syllable string, and R always represents the final syllable of a three syllable string. Again, these variables are only used so that I can more easily represent the three-syllable string as the PQR string and so that I can refer to the first, medial, and final syllables of a three-syllable string as P, Q, and R respectively.

I decided to use three different variables rather than add just one variable, Z, to the XY string because I wanted to make it clear when, for example, I am referring to the first syllable in a three syllable string: this is P and not X.

4.2 Freedom of Occurrence of Tones in the PQR String

Since there are three positions in the PQR string, there are 64 possible tonal combinations as in Table 7:

Table 7
The 64 Possible PQR Strings

AAA	BAA	CAA	DAA
AAB	BAB	CAB	DAB
AAC	BAC	CAC	DAC
AAD	BAD	CAD	DAD
ABA	BBA	CBA	DBA
ABB	BBB	CBB	DBB
ABC	BBC	CBC	DBC
ABD	BBD	CBD	DBD
ACA	BCA	CCA	DCA
ACB	BCB	CCB	DCB
ACC	BCC	CCC	DCC
ACD	BCD	CCD	DCD
ADA	BDA	CDA	DDA
ADB	BDB	CDB	DDB
ADC	BDC	CDC	DDC
ADD	BDD	CDD	DDD

Of the 64 possibilities, 27 are input strings for TTS. Therefore, these 27 PQR strings do not appear as surface strings. These are underlined in Table 7 above. The freedom of occurrence for each tone can be figured in the same manner that it was in section 3.2 above.

4.3 Tone Hierarchies in the PQR String

The hierarchies that result are as follows:

Table 8
Freedom of Occurrence Hierarchies

a. P Position		b. Q Position		c. R Position		d. Overall	
B	12/16	B	16/16	B	12/16	B	40/48
C	9/16	C	9/16	C	9/16	C	27/48
A	9/16	A	6/16	D	9/16	A	22/48
D	7/16	D	6/16	A	7/16	D	22/48

To the right of each tone in the hierarchies are the freedom of occurrence ratios for that tone. The highest freedom of occurrence possible for each tone in a given position is 16; therefore the overall ratio is 48 because there are three positions. To understand the hierarchies above, it is necessary to remember that the input for any TTS rule is a two-syllable string, thus in the PQR string there is an overlapping of two two-syllable strings.

(32) XY
 XY

The hierarchy for the P position (Table 8.a) of the PQR string is the same as that for the X position in an XY string. Moreover, the hierarchy for the R position (Table 8.c) is the same as that for the Y position in the XY string. But the hierarchy for the Q position (Table 8.b) is indeterminate. Where tones A and D were clearly ordered depending on their position in either X or Y of the XY string, the freedom of occurrence of tones A and D is the same in the Q position of a PQR string. This is because the Q position, example (32), is both the X and Y position at the same time. If the overall hierarchy (Table 8.d) is referred to, tones A and D still have the same freedom of occurrence. It would appear that an arbitrary decision needs to be made regarding the ordering of the Q position hierarchy. For the moment, I will use the hierarchy as listed in Table 8.b, B-C-A-D, without explanation. However, it will be explained in section 4.7.

4.4 The 27 PQR Input Strings and Their Outputs

If two assumptions are made, then the output of each PQR string can be predicted. The first assumption is that all the rules apply uniformly from left to right. The second assumption is that in TTS, whenever the condition for a rule is met, then the rule applies. Therefore, in a PQR string where both PQ and QR meet the condition for tone sandhi, then it is predicted that TTS will apply first to the PQ string and then the QR string, if possible.

By the second assumption, it is also possible for a QR string to feed, or in other words, provide input for a PQ string. A PQ string, however, cannot provide input for a QR string because it is the tone that occupies the P position that changes and P is not part of the QR string.

It is also possible that after tone sandhi operates on the PQ string that QR is still an input string for TTS, in which case TTS occurs.

In Table 9.a below is a complete listing of the 27 PQR input strings and their predicted outputs according to the two assumptions:

Table 9.a
Predicted Outputs of the 27 Input PQR Strings
(*: Incorrect Outputs)

1.*AAA->CAA->CCA->BCA
2. BAA->BCA
3. CAA->CCA->BCA
4.*DAA->BAA->BCA
5. AAB->CAB
6. DAB->BAB
7. AAC->CAC
8. DAC->BAC
9. AAD->CAD
10. DAD->BAD
11. CCA->BCA
12. CCB->BCB
13. ACC->ABC
14. BCC->BBC
15. CCC->BCC->BBC
16. DCC->DBC
17. CCD->BCD
18. ADA->ABA
19. BDA->BBA
20. CDA->CBA
21. DDA->ADA->ABA
22. DDB->ADB
23. DDC->ADC
24. ADD->AAD->(CAD)[5]
25. BDD->BAD
26. CDD->CAD
27.*DDD->ADD->AAD->CAD

Of the predicted outputs for the 27 PQR strings, only three of them are incorrect, numbers 1, 4, and 27. Their actual outputs are:

Table 9.b
Actual Outputs

1. AAA->ACA
4. DAA->DCA
27. DDD->DAD->(BAD)

The data in Table 9.b seem to indicate that AAR and DDR operate from right to left in three syllable strings, because these strings (AAA and DDD) are the only strings where AAR and DDR have the opportunity to operate on PQ and QR of the PQR string at the same time, and the outputs show that it is the QR string that TTS applies to. But this, in fact, does not prove conclusively that AAR and DDR operate from right to left. TTS Constraint 1 (introduced in section 3.5.1) can explain this. TTS Constraint 1 says that a tone may only undergo tone sandhi once. If AAR and DDR were to operate on PQ of AAA and DDD respectively, then the tone in the P position would undergo tone sandhi twice (see Table 9.a, 1 and 27). This is an unacceptable output, so to prevent this, AAR and DDR operate on the QR string instead.

There is more data to support TTS Constraint 1. In fast speech, these alternative outputs have been attested (see Appendix):

```
(33)  AAA->CAA->CCA ->*BCA
      kai  fei  ji     'fly airplane'
      A    A    A
      C    A    A
      ------------
      C    C    A

(34)  ji guan qiang    'machine gun'
      A  A     A
      C  A     A
      ------------
      C  C     A

(35)  fei ji shi       'airplane expert (pilot)'
      A   A  A
      C   A  A
      ---------
      C   C  A
```

These outputs show that AAR is applying left to right, that is, on the PQ position first and then the QR position. The resulting CCA strings in (33), (34), and (35) above, appear to be able to undergo TTS again, but that there is no change may be attributed to TTS Constraint 1. That is because tone A in (33), (34), and (35), has already become tone C and therefore they cannot change again.

Hung(1987) gives the following example:

```
(36)  DDD->ADD->AAD ->*CAD
      fu jiao shou    'associate professor'
      D  D    D
      A  D    D
      ------------
      A  A    D
```

It is unclear in Hung's discussion whether this is an alternative output for a DDD string or not. He labels it with a question mark [?], but he has also labeled the previous example (an AAA->CAA->CCA output) in the same manner although he has just stated that this reading is acceptable in fast/casual speech. He may have been referring to (36) above as unacceptable in normal speech, but not in fast/casual. If this is the case, then there is evidence that DDR applies left to right in fast casual speech also and that it also follows TTS Constraint 1.

We may understand the results as follows. In normal speech, the speaker looks further ahead than in fast casual speech. In AAA->ACA of normal speech, it is possible that the speaker realizes, obviously not in a conscious way, that if he accepts PQ for tone sandhi, then the output will be a violation of TTS Constraint 1, so the speaker skips PQ and accepts QR. But in AAA->CAA->CCA of fast/casual speech, the speaker does not take time or is not careful to look that far ahead and accepts PQ as an input string for tone sandhi. When the speaker reaches CCA of the derivation, he realizes that if he continues, he will violate TTS Constraint 1, so he accepts CCA as the surface string.

This shows that TTS Constraint 1 is stronger than assumption two, in other words, prohibiting tone sandhi from applying twice to a given tone is more important than that a string undergo tone sandhi, even when the condition for tone sandhi is met.

The fact that DAA becomes DCA rather than BAA->BCA can be explained in the following manner. AAR, CCR, and DDR all produce outputs which are one strength relation value stronger than their input strings. DAR, however, is the only TTS rule which produces an output string that is three strength relation values stronger than its input string.

All the previous analyses agree that DAR is ordered last. This may be understood as a consequence of the strength relations as follows: those rules that produce outputs one strength relation value stronger than their input strings (AAR, CCR, and DDR) must apply before a rule (DAR) that produces an output three strength relation values stronger than its input string. Granted, this is another way of saying DAR is ordered last, but it is an explanation of why this is so. I will call this TTS Constraint 2:

(37) TTS Constraint 2:

> A rule that produces an output string one strength relation value stronger than its input string must apply before a rule that produces an output string more than one strength relation value stronger than its input string.

Tan (1987:232) provides the following example:

(38) DAA->DCA
dian deng guan 'electric light turn-off'
D A A
D C A by AAR

The application of AAR in (38) has prevented DAR from applying. But Tan (1987:232) also provides another derived form:

(39) DAA->BAA ->*BCA
dian deng guan
D A A
B A A by DAR

In (39), DAR has applied first, AAR cannot apply now due to TTS Constraint 2. This also shows that TTS Constraint 2 is stronger than assumption two, in other words, it is more important that no other rule apply after DAR (which strengthens its output string by three strength relation values) than that a string undergo tone sandhi, even when the condition for tone sandhi is met.

4.5 Exceptional Surface Strings

In section 2.6, I discussed the inconsistency of the data. There is another type of inconsistency in the data, which I did not mention before, which I will refer to as "exceptional." These are examples given by the various authors of surface strings that do not seem to follow the previously discussed patterns. These exceptional surface strings are idiosyncratic in nature in that they only appear in specific lexical items. Some examples are given below:

```
(40)  DDA->*ADA->*ABA
      xia dian che        'descend tram car'
      D   D    A
      D   B    A           by DAR

(41)  ADD ->*AAD->*CAD
      yi yuan jin         'hospital is near'
      A  D    D            no change
```

In (40), the PQ position of the PQR string DDA has been skipped and the QR position has been accepted. In (41), there is no change where one would expect it to occur. There are a few other examples similar to these but they are idiosyncratic in nature as well. The unproductiveness of these patterns, in that they are limited to a few specific lexical examples, indicates that they do not invalidate the present analysis, which seems to hold for the vast majority of the data. These could be considered in the same category as idioms.

4.6 The Three-Dimensional Tonal Matrix

In order to represent TTS in three-syllable strings, a three-dimensional matrix (in other words a matrix with three sets of variables) may be used. The variables are the tonal hierarchies for the P, Q, and R positions. See Table 8.

Figure 4 is a three-dimensional representation of all the PQR strings and their relationships to each other. The P position of the PQR string is represented by the vertical axis of Figure 4. The R position of the PQR string is represented by the horizontal axis that is perpendicular to the P position axis. The Q position of the PQR string is represented by the horizontal axis that is perpendicular to the R position axis.

The lightly shaded areas in Figure 4 (and in Figures 5 and 6) are PQR input strings. The darker shades areas are also PQR input strings, but they are the seven input strings presented in section 1.3. That means that they are subject

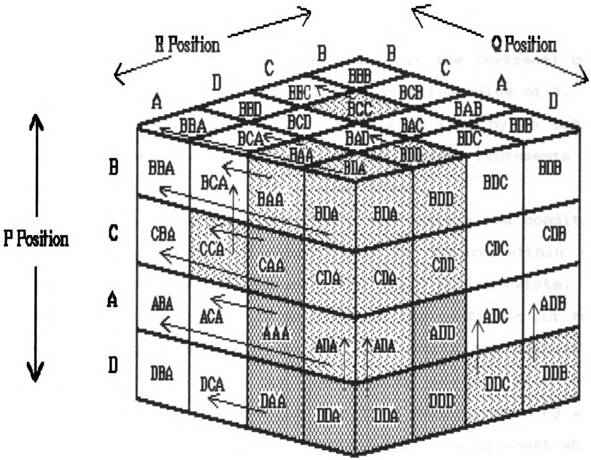

Figure 4
The Three-Dimensional Tonal Matrix

to more than one TTS rule or that after application of the first TTS rule, the output feeds another TTS rule.

The BBB string, in the uppermost corner of Figure 4, has the strongest strength relation value, 12, if values form 4-1 are assigned for each place in the hierarchy, 4 being the strongest. The DDA string, in the lowermost corner, is the weakest with a strength relation value of 3. In Figure 4, any replacement of an input string by an output string leftward or upward of one space represents an increase in tonal strength of one value.

In any PQR string where only PQ fulfills the condition for tone sandhi, replacement will be upward within the vertical plane and row in which the input string exists. In any PQR string where only QR fulfills the condition for tone sandhi, replacement will be leftward within the horizontal plane and row in which the input string exists. If both PQ and QR fulfill the condition for tone sandhi, then PQ will undergo tone sandhi first (vertical plane replacement-which I will refer to as VPR in the tables below) and then QR will undergo tone sandhi (horizontal plane replacement-HPR) except in cases where TTS Constraints 1 and 2 apply.

In Figure 4, 13 PQR input strings and their outputs are visible. They are listed below. The numbers refer to the strings as listed in Tables 9.a and 9.b:

Table 10
Explanation of Replacement in Figure 4

1.	AAA->ACA	TTS Constraint 1/HPR
2.	BAA->BCA	HPR
3.	CAA->CCA->BCA	HPR and VPR
4.	DAA->DCA	TTS Constraint 2/HPR
11.	CCA->BCA	VPR
14.	BCC->BBC	HPR
18.	ADA->ABA	HPR
19.	BDA->BBA	HPR
20.	CDA->CBA	HPR
21.	DDA->ADA->ABA	VPR and HPR
22.	DDB->ADB	VPR
23.	DDC->ADC	VPR
25.	BDD->BAD	HPR

A violation of TTS Constraint 1 would be represented in Figure 4 by an 'S'-like replacement path. This can be seen in Figure 4 by looking at the AAA string. Instead of HPR, it would first have VPR, thus *AAA->CAA->CCA->BCA.

A violation of TTS Constraint 2 would be represented in Figure 4 by a DAR input string being replaced by another input string. This can be seen by looking at the DAA string if it first had VPR to BAA instead of HPR to DCA.

Figure 5 is the same as Figure 4 except that it has been split open in order to see the inside. In order to get the correct orientation, compare the BBB string in Figure 5 to the BBB string in Figure 4.

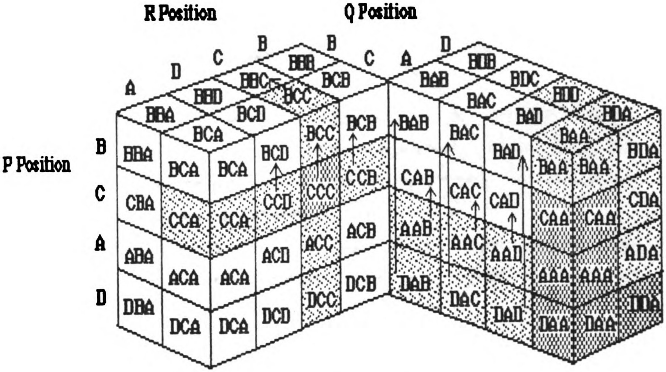

Figure 5
The Three Dimensional Tonal Matrix: Second View

In Figure 5, 9 more PQR input strings and their outputs are visible. They are listed in Table 11 below:

Table 11
Explanation of Replacement in Figure 5

5.	AAB->CAB	VPR
6.	DAB->BAB	VPR
7.	AAC->CAC	VPR
8.	DAC->BAC	VPR
9.	AAD->CAD	VPR
10.	DAD->BAD	VPR
12.	CCB->BCB	VPR
15.	CCC->BCC->BBC	VPR AND HPR
17.	CCD->BCD	VPR

Figure 6 is also the same as Figure 4 except that it has been split open in a different manner. Again, in order to get the correct orientation, compare the BBB string in Figure 4 to the BBB string in Figure 6.

In Figure 6, the remaining 5 PQR input strings and their outputs are visible. They are listed in Table 12 below:

Table 12
Explanation of Replacement in Figure 6

13.	ACC->ABC	HPR
16.	DCC->DBC	HPR
24.	ADD->AAD->(CAD)	HPR and (VPR)
26.	CDD->CAD	HPR
27.	DDD->DAD->(BAD)	TTS Constraint 1/HPR and (VPR)

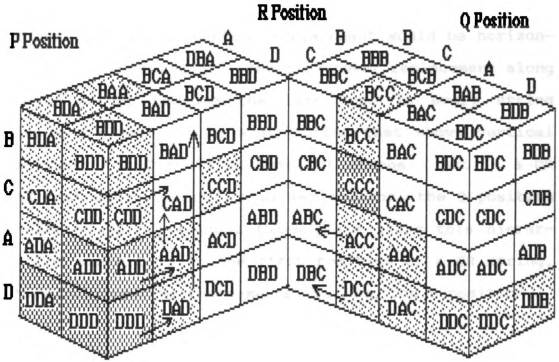

Figure 6
The Three-Dimensional Tonal Matrix: Third View

4.7 Q Position Hierarchy: B-C-A-D or B-C-D-A?

Now that the three-dimensional matrices have been presented, it will be easier to explain why the Q position ordering must be B-C-A-D rather than B-C-D-A. The last tone in each string, Y of the XY string and R of the PQR string, never changes. In the AAA string, for example, if PQ of this string were accepted (I have shown, however, that this is not the case), then replacement would be vertical along the P hierarchy, because the P tone changes. If, on the other hand, QR were accepted, replacement would be horizontal along the Q hierarchy. There is never replacement along the R hierarchy because the last tone in every string remains the same. So in a PQ string that shows vertical replacement, the Q position does not change. But in a QR string that exhibits horizontal replacement, the Q position does change and replacement takes place along this hierarchy. And since Q is in the first position of a QR string, the hierarchy must be the same as that for the P position.

4.8 Summary

I introduced three more variables, P, Q, and R, to represent the three-syllable string in TTS. Then I showed the freedom of occurrence of tones in the PQR string and arranged these in strength hierarchies for each position in the PQR string. Then I took the 27 PQR input strings and explained all of their outputs showing that all the TTS rules apply left to right but that TTS Constraints 1 and 2 limit the position (PQ or QR) of the PQR string that they can apply to. After I discussed exceptional surface strings, I used the tonal strength hierarchies for each position in the PQR string to construct a three-dimensional tonal matrix. Finally, I showed why the ordering of the Q hierarchy must be B-C-A-D and not B-C-D-A.

5. Conclusion

5.1 Summary

In this thesis I have discussed Tianjin tone sandhi in two and three-syllable strings. I have shown that an independently motivated notion of tonal strength may be the explanation for the occurrence of tone sandhi, and I have shown, according to this understanding, that the TTS rules all apply from left to right, and given two constraints which limit the position of the string that TTS rules can apply to.

5.2 Statement of Rules

One implication of this study is that rules (42) and (43) are not restatements of the same phenomenon, as is generally accepted. A rule, for example, like (42) below does not seem to state the facts as accurately as (43) when stating the rules for Tianjin tone sandhi.

(42) x->y/___z

(43) xz->yz

Rule (42) can be restated informally as: x becomes or appears as y in an environment where it occurs before z. In this rule, x changes because it occurs before z. Example (43), on the other hand, can be restated informally as: when x and z occur immediately adjacent to each other, they become or appear as yz. In this rule, x changes because it occurs with z. Rule (43) is a more accurate statement of Tianjin tone sandhi because it is the combination of the two tones e.g. two falling tones occurring in an XY string (excluding AD), that makes the string subject to TTS. It is not the fact that a falling tone occurs before another falling tone that causes it to change as (42) would indicate.

5.3 Tonal Strength: Universal or Language Specific?

That tones may have strength in relation to one another to my knowledge has never been proposed before. To show this empirically is to say something about tones that might be found to have further implications in other languages. It goes without saying that much more research needs to be done on this subject. Tonal languages from different language groups need to be studied and the data needs to be analyzed along the lines I have shown. Only in this way can we find if tonal strength is a parameter for other tone

languages or even universal, or if it is in fact only a phenomenon specific to the Tianjin dialect.

NOTES

[1] Chen (1986:109) refers to a Non-Derived Environment Constraint that is mentioned in Hung (1985): " . . .no TS [tone sandhi] rule of Tianjin may apply to the same syllable more than once in the course of a derivation." Although this is very similar to my TTS Constraint 1, Hung does not mention it in his more recent 1987 paper.

[2] Zhang mentions (1987:260) that Chen told him this through personal communication.

[3] Chen (1986:105).

[4] Hung (1987:278 and footnote 4).

[5] Parentheses are used to indicate that there is conflicting data for the final outputs of these strings. See section 2.6. The parentheses are also used in Tables 9.b and 12.

APPENDIX

APPENDIX

This Appendix provides the sources for all the data used in this paper. I will give the number of the example followed by the author, year of publication, and page number.

(10) Chen:1987:205.

(11) ibid.

(12) ibid.

(13) ibid.

(14) Zhang:1987:248.

(15) Tan:1987:234.

(16) Zhang:1987:249.

(17) Chen:1987:208.

(18) ibid.

(19) Zhang:1987:255.

(20) ibid.

(23) Tan:1987:234.

(24) ibid.

(25) Tan:1987:243.

(33) Zhang:1987:269.

(34) Hung:1987:278.

(35) Hung:1987:283.

(36) Hung:1987:278.

(38) Tan:1987:232.

(39) ibid.

(40) Zhang:1987:261.

(41) ibid.

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