TONE SPACE AND TONE FEATURES

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1.0 INTRODUCTION

Tone space is the pitch range within which all the tonal contours of a language are confined. In the study of the interrelationship between tone and intonation, it is well known that only part of the voice range is used for tone purposes. J. Shen (1985) points out that intonation affects tonal pitch indirectly through successive tonal ranges. Thus, although tonal range varies constantly, the relationship between successive tones remains constant. X. S. Shen (1990) argues that in Mandarin the intonation baseline as well as the topline is movable, and that the major cue differentiating statement intonation from question intonation does not only lie in the final section of the intonation contour, but rather it is the tone space as a whole that is raised in questions. From this, X. S. Shen suggests that there exist two layers of intonation in Mandarin, an upper layer for questions and a lower layer for statements.

In addition to the raising or lowering of the tone space as a whole, the tone space can also expand or shrink due to different emotions of speech. This phenomenon is observed in N.-C. T. Chang's study of Chengdu Mandarin (1958). Chengdu has four citation tones. Tone I starts between mid-high and mid and rises to high, roughly [35]. Tone II starts somewhere lower than mid and ends between mid-low and low, roughly [31]. In emphatic sentences, Tone I 'remains high-rising and ends yet higher than its normal pitch in an ordinary statement'; Tone II 'falls yet lower'. In sentences implying a dismissal of the topic, 'the range is narrow; therefore the rising and falling of the tones are very slight.'

All the above studies point to the fact that tone space is limited. In fact, such a limit has been recognized in the literature for a long time. It is generally believed that the maximum number of tone levels any language can distinguish is five (Wang 1967; Maddieson 1978b). It is found that the perceptual distance between tones decreases as the number of tones in a system increases (Hombert 1978). But although the recognition of the limit of tone space is not new, there has been no explanation, as far as I know, as to what determines this limit.

This paper deals with three issues concerning the notion of tone space. Section 2 discusses the relationship between tone space and the number of tone heights in a language. Section 3, based on the hypothesis of tonogenesis, attempts to explain the existence of the limit of tone space in terms of the pitch-affecting limit of the consonants. Section 4 discusses the significance of the tone space in the construction of a distinctive feature system of tone.

2.0 TONE SPACE IN RELATION TO THE NUMBER OF TONE HEIGHTS

There are two opposing hypotheses in the literature regarding the relationship between the overall tone space and the number of tone levels in a system. The older hypothesis holds that a language with two levels of tone tends to have a wider space between the two than the space between each of the levels in a four-level system. In other words, with the increase of the number of tone heights, the overall tone space tends to stay the same with the space between each level compacted. This can be called the 'tone-height compression' view. Pike (1948), for example, holds this view. He illustrates the relationship between the overall tone space and the number of tone heights with the following figure:

(1) Tone-height compression (Pike 1948:6):

high ———	high ———	high ———
		mid ———
	mid ———	
		norm ———
low ———	low ———	low ———

A more recent hypothesis holds that the overall tone space is smaller in a system with a smaller number of tone heights than a system with a larger number of tone heights. In other words, tone space tends to expand with the increase of the number of tone heights. This view can be called the 'tone-space expansion' view. Maddieson (1978b) illustrates this view with the measurement of the tone space in six tone languages as shown below:

(2) Tone space as a function of the number of tone heights (Maddieson 1978b)

TWO LEVELS		THREE LEVELS					FOUR LEVELS
SISWATI	KIOWA	YORUBA I	THAI I	THAI II	TAIWANESE	YORUBA II	TOURA
							+50
		+26	+28	+32	+32	+52	+30
+18	+22	+16	+16	+16	+18	+27	+10
+0	+0	+0	+0	+0	+0	+0	+0

(2) shows the difference in Hz between each tone and the lowest tone in each system. This difference demonstrates that tone space tends to expand as the number of tone heights increases. From this, Maddieson concludes that 'A larger number of tone levels occupy a larger pitch range than a smaller number.'

Maddieson's conclusion is supported by Painter (1978). Painter compares the F_0 plots for Sindhi, a non-tone language, with the F_0 plots for two tone languages, Yoruba and Gã, and finds that the Sindhi plots show a small variation about the mean (±5 Hz), while the Yoruba and Gã plots show considerably more variation (20-30 Hz).

Maddieson's conclusion is partly supported and partly refuted by Hombert's study (1978). Hombert develops a model in which the notion of minimum articulatory difficulty and maximum perceptual distance is used quantitatively to predict the phonetically optimal tone systems from universal phonetic considerations.[1] Based on this model, a perceptual experiment is carried out to determine the perceptual distance between the two closest tones as a function of the number of tones in the system. The number of tones ranges from two to eight. The following two findings are of particular interest to our discussion here (p.140): (i) The distance between high and low is smaller in a two-tone system than in a system with a greater number of tones, suggesting tone-space expansion; (ii) Tone space does not expand with the same rate as the number of tones increases from three to four, or from four to five. Rather, as the number of tones increases, the perceptual distance between tones tends to decrease, suggesting tone-height compression.

The result of Hombert's experiment thus suggests that both tone-space expansion and tone-height compression are at work when the number of tones increases in a system. This result is in line with historical evidence which shows that languages with a large number of tones are unstable and that merger between tones is likely to occur (Haudricourt 1961). In a system of tone features, then, both expansion and compression should be incorporated. We will return to this issue in Section 4.

3.0. THE LIMIT OF TONE SPACE

One of the findings of Hombert's study (1978) discussed above is that as the number of tones in a system increases, the minimum perceptual distance between each tone decreases. With respect to this tendency, Hombert remarks:

> The flattening of the curve obtained for seven and eight tone systems indicates some sort of saturation in the tone space. A huge number of tone systems are then found to be perceptually equivalent. This implies high instability. These data are in agreement with the fact that it is extremely rare to find tone languages with seven or eight tones using only F_0 to distinguish these tones.

The saturation of the tone space suggests that there is a limit as to how far tone space can expand. Without such a limit, there will be no saturation, no instability, and no merger; and the number of tone heights will not be limited to five. In fact, the idea that tone space is limited is assumed in almost all the works dealing with tone. As early as 1930, Chao wrote with respect to his famous tone-letter notation which divides the tone space into five levels, 'as the intervals of speech-tones are only relative intervals, the range 1-5 is taken to represent only ordinary range of speech intonation, to include cases of moderate variation for logical expression, but not to include cases of extreme emotional expression.' Here, a clear distinction is made between tone space and the voice pitch range. But although the limit of tone space is generally assumed in the literature, the reason for such a limit, as far as I know, has not been explicitly explained. This section explores this issue along the lines of the tonogenesis hypothesis (Haudricourt 1954, 1961; Matisoff 1970, 1973).

The tonogenesis hypothesis assumes that tonal distinctions originate historically from consonantal distinctions. In many Southeast Asian languages, the tonogenesis process consists of two stages. In the first stage, syllable-final consonants gave rise to three types of tonal contours. More specifically, a syllable-final glottal stop gave rise to a rising contour; a syllable-final sonorant gave rise to a mid level tone; and a syllable-final -h gave rise to a falling contour.[2]

(3) Pattern of tonogenesis (Haudricourt 1954)

pɑʔ	>	pɑ́
pɑ	>	pɑ
pɑh	>	pɑ̀

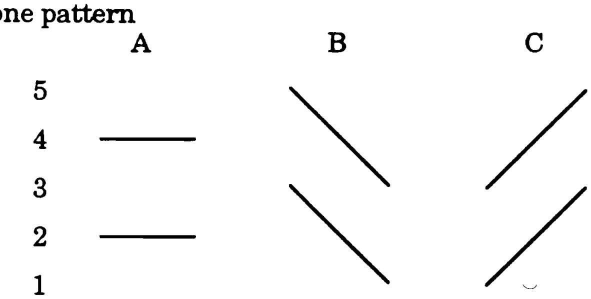
In the second stage, syllable-initial consonants induced tonal split, such that each of the former three tones split into a higher and a lower variant, giving rise to a six-tone system. An ideal system with a two-way split is represented by the Fengxian dialect spoken in a suburb of Shanghai, where no tone overlapping occurs. In (4), A, B, and C represent three historically older tones, each of which has split into two tones in modern Fengxian, conditioned by two different types of syllable initials, which are represented by I and II.

(4) Two-way tone split in Fengxian (Pan 1982:368)

i) Tone values

	A	B	C
I	53	44	35
II	31	22	13

ii) Tone pattern



Since tone split is conditioned by syllable initials, the limit of the tone-space expansion can be explained in terms of the pitch-affecting limit of the initials. Data from various phonetic experiments can be interpreted as supporting the existence of such a limit.

Hombert (1975) studies the effect of voicing on F_0 at different frequency ranges in Yoruba. Yoruba is a tone language with three contrasting tones: high, mid, and low. (5) shows the time course of F_0 variation after voiced and voiceless unaspirated velar stops produced by two Yoruba speakers.

(5) Pitch variations after [k] and [g] in Yoruba (Hombert 1975:44)

	TIME IN MSEC							
	0	20	40	60	80	100	150	200
HIGH TONE								
after [k]	186.1	176.3	174.7	175.4	175.8	175.2	174.0	172.7
after [g]	142.6	159.0	166.1	171.0	173.8	175.6	175.2	172.3
MID TONE								
after [k]	164.9	151.6	149.2	149.0	148.4	148.8	148.4	147.8
after [g]	134.3	145.1	148.3	149.5	150.6	151.5	150.7	149.6
LOW TONE								
after [k]	153.0	137.0	132.6	128.2	123.9	120.2	115.0	106.6
after [g]	121.6	130.7	130.9	129.7	126.3	122.4	117.8	113.6

This experiment shows that 'the perturbation caused by a voiced consonant on a following high tone or by a voiceless consonant on a following low tone is greater than the effect of these two series of consonants on a mid tone' (Hombert 1977:178). This means that the more the tone space expands, the stronger the opposite forces to balance the expansion.

A similar tendency exists in Siamese (Gandour 1974), where it is found that the raising effect of the voiceless consonants is at its weakest at the top of the tone space, and the lowering effect of the voiced consonants is at its weakest at the bottom of the tone space. Siamese has five tones, High, Mid, Low, Rising, and Falling. (6) shows the averaged F_0 values after voiceless and voiced stops for three tones. The onset value refers to the initial fundamental frequency value after the release of the stops; the peak value refers to the highest fundamental frequency value after the release of voiced stops. The result shows that 'the distance of the fall in pitch...varies depending on the initial height on the following vowel. The longer falls in pitch tend to occur before lower pitch heights, the shorter falls in pitch before higher pitch heights' (Gandour 1974:343).

(6) Pitch values after voiced and voiceless stops in Siamese (Gandour 1974:342)

	[p t]	[b d]	
	onset	onset	peak
High	146	123	132
Mid	136	120	126
Low	136	109	114

The Yoruba and Siamese examples show that although the impact of initial voicing on the F_0 of the following vowel is evident at different frequency ranges, the effectiveness of such an impact differs according to the pitch height of the vowel. The raising effect of the voiceless consonants is weaker on a higher tone than on a lower tone; conversely, the lowering effect of the voiced consonants is weaker on a lower tone than on a higher tone. Such correlations between pitch and voice clearly suggest the existence of a limit beyond which a voiceless/voiced distinction ceases to affect pitch.

Not only does a voicing distinction affect pitch, but pitch variation also affects the perception of voicing. Experimental studies of the latter also suggest that pitch variations caused by a voicing distinction are limited.

Haggard, *et al.* (1970) conduct a perceptual experiment to determine the effect of F_0 on the perception of the voiced/voiceless distinction. The test material is a synthesized syllable ambiguous between [bi] and [pi]. Superimposed on the initial 55 msec of this syllable are three F_0 trajectories, falling, level, and rising. These trajectories start at 308, 201, and 145 Hz, respectively, and all terminate at 201 Hz. The initial section is followed by the steady-state vowel, the F_0 of which is at 201 Hz for 50 msec and then gradually falls to 165 Hz. The perceptual experiment shows that the high falling trajectory generates more [p] responses, the low rising trajectory more [b] responses, and the level pitch generates an equal frequency of [b] and [p].

Massaro and Cohen (1977) conduct a series of perceptual tests to evaluate the effects of frication duration, voice onset time, and F_0 on the perception of voicing. In their experiments, synthesized [si] and [zi] are presented to a number of subjects. Massaro and Cohen demonstrate that as the F_0 value at the vowel onset increases, there is an increased chance that the synthesized sounds are perceived as starting with an [s]. (7) shows the result of their 1977 experiment.

(7) The effect of F_0 values on the perception of voicing (Massaro and Cohen 1977:379)

	F_0 (Hz)			
Subject	163	183	206	224
1	.33	.40	.58	.69
2	.27	.43	.61	.73
3	.24	.44	.56	.69
4	.34	.45	.56	.64
5	.31	.43	.55	.72
6	.28	.39	.55	.80
Average	.30	.42	.57	.71

These two perceptual experiments demonstrate that given a wide enough range, pitch variation can help to determine the status of voicing or even override a voicing distinction. The significance of this is that the effect of consonants on pitch can be counterbalanced by the effect of pitch on consonants.

Such a balancing force has both diachronic and synchronic consequences on phonological systems cross-linguistically. Maddieson (1978a) has a summary of consonantal changes conditioned by pitch. The following are some examples taken from that study. In Korana, spoken in South Africa, */g/ and perhaps other voiced consonants have become devoiced when followed by high tones. In Kuwaa spoken in Liberia, /k͡p/ is realized as [g͡b] before a low tone. In Tankhur Naga spoken in North-Eastern India, /p, t, k/ become voiced intervocalically especially before a low tone.

To summarize, the above studies all point to the fact that the effect of consonants on the pitch of vowels is limited to a narrow range. To explain the limit of tone space in terms of the limit of consonant effect is not to deny that tone space can also be affected by active pitch control. Since different emotions may either expand or reduce the width of tone space, the actual tone space varies constantly in actual speech. But since this kind of variation is synchronic and does not permanently affect tone space, it should not be considered as a determining factor of the limit to tone space.

4.0 TONE SPACE AND TONE FEATURES

As far as the relationship between tone space and the number of tone heights is concerned, previously proposed tone-feature systems are either based on the 'tone-height compression' view, or the 'tone-space expansion view'. Representative of the former approach is Wang's system (1967), which contains seven features as shown below:

(8) Wang's feature system (Wang 1967)

	1	2	3	4	5	6	7	8	9	10	11	12	13
	˥	˩	˦	˨	˧	˧˥	˩˧	˥˧	˧˩	˥˧˥	˧˩˧	˧˥˧	˩˧˩
[contour]	–	–	–	–	–	+	+	+	+	+	+	+	+
[high]	+	–	+	–	–	+	–	+	–	+	–	+	–
[central]	–	–	+	+	+	–	–	–	–	–	–	–	–
[mid]	–	–	–	–	+	–	–	–	–	–	–	–	–
[rising]	–	–	–	–	–	+	+	–	–	+	+	+	+
[falling]	–	–	–	–	–	–	–	+	+	+	+	+	+
[convex]	–	–	–	–	–	–	–	–	–	–	–	+	+

As seen in (8), the feature [high] plays a pivotal role in Wang's system: it divides the tone space into two sub-ranges, within which all contour tones are confined. That is, a contour tone is either [+high] or [–high], and no contours cross the mid pitch line. With respect to tone space, Wang says, "No matter how many tones a language has, the voice pitch traverses approximately the same overall range... The greater the number of distinct tones in the paradigm, the narrower the phonetic range of each tone would be" (1967:100). This view can be illustrated with the following figure, which is based on figure 2 in Wang's paper (1967:101):

(9) Tone-height compression expressed in distinctive features

<table>
<tr><th>2 levels</th><th>3 levels</th><th>4 levels</th><th>5 levels</th></tr>
<tr><td rowspan="5">+high</td><td rowspan="3">+high
–central</td><td rowspan="2">+high
–central</td><td>+high
–central
–mid</td></tr>
<tr><td rowspan="3">+high
+central
–mid</td></tr>
<tr><td rowspan="3">+high
+central</td></tr>
<tr><td rowspan="4">+central</td></tr>
<tr><td rowspan="2">–high
+central
+mid</td></tr>
<tr><td rowspan="5">–high</td><td rowspan="3">–high
+central</td></tr>
<tr><td rowspan="3">–high
+central
–mid</td></tr>
<tr><td rowspan="3">–high
–central</td></tr>
<tr><td rowspan="2">–high
–central</td></tr>
<tr><td>–high
–central
–mid</td></tr>
</table>

The immediate consequence of this formulation is that the same features cover different pitch ranges in different paradigms. The range covered by [+central] grows with the increase of the number of tone heights within a paradigm. The feature [+high] covers half of the total range in paradigms with two and four levels, but less than half in paradigms with three and five levels. In other words, the features [high] and [central] do not have fixed values with respect to tone space. It is therefore unclear how the variation of [high] can be reconciled with the fact that this feature functions to restrict all the tonal contours within half of the tonal tone space in (8).

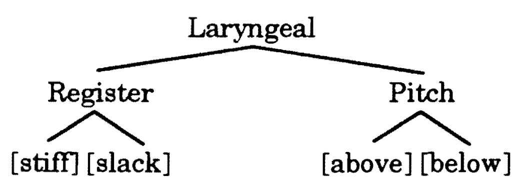
Representative of the 'tone-space expansion' view is Maddieson (1970). As seen above, Maddieson argues against the 'tone-height compression' view, claiming instead that with the addition of tone height, tone space expands. His system captures tone-space expansion, but cannot express tone-height compression:

(10) Tone-space expansion expressed in distinctive features (Maddieson 1970)

	[Raised]	[Lowered]	[Extreme]
extra high	+	–	+
high	+	–	–
mid	–	–	–
low	–	+	–
extra low	–	+	+

As seen in Section 2, since both tone-space expansion and tone-height compression occur as the result of tone split (i.e., the increase of tone height), a more accurate system should reflect both expansion and compression. One such system is proposed by Duanmu (1990), although Duanmu does not discuss the relationship between tone space and the number of tone heights:

(11) Duanmu's model (1990)



In (11), all the four features are binary. Combinations of [stiff] and [slack] yields a maximum number of three registers, each of which can be divided into three pitch levels yielded by the combinations of the features [above] and [below]. Duanmu's system thus allows nine contrastive tone heights, which is nevertheless not attested in any language.

As we have seen in Section 3, historical tone split may lead to the saturation of the tone space and hence tone merger. This is due to the limit of tone space, which may be the reason why there is no language that distinguishes nine contrastive tone heights. Thus, in the construction of a feature system for tone, the limit of tone space must be taken into consideration.

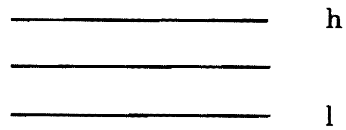
One such system is proposed in Fu (1994a, b; 1995), where both tone-space expansion and tone-height compression are taken care of, and the number of contrastive tone heights is limited to five. This system identifies three registers, with each register further divisible into three tone heights.[3] A key characteristic of this system is to allow register overlapping such that no more than five contrastive tone heights can be generated. This system is constructed as follows.

First, the system consists of two privative features [high] and [low], to be used at both the register tier and the tone tier. These two features are defined as in (12):

(12) The definition of tone features
[high] = to raise the pitch level by one and only one step from the neutral reference pitch.
[low] = to lower the pitch level by one and only one step from the neutral reference pitch.

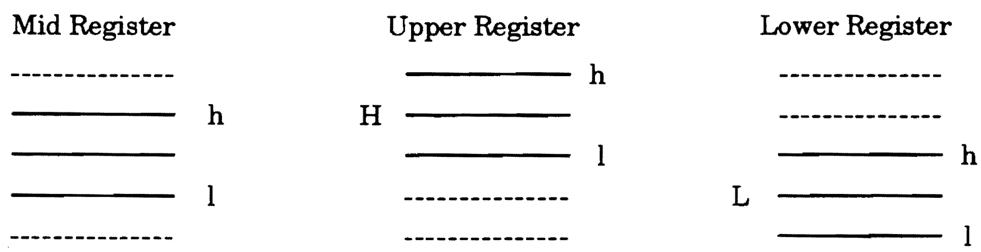
Second, to represent the pattern of tonogenesis given in (3), the two features are applied at the tone tier, giving (13), where the mid tone is left unspecified.

(13) The representation of tonogenesis



Third, to represent the tone split given in (4), the two features are applied at the register tier, giving (14). As the mid tone is unspecified in (13), the mid register is also unspecified in (14).

(14) The representation of register split



In this system, tone-space expansion is captured by the fact that both tonogenesis and tone split are represented as an enlargement of the tonal pitch range. Tone-height compression is captured by register overlapping, as shown in (14), where the mid register partially overlaps with both the upper and the lower registers. Theoretically, this overlapping follows from the definition of the tone feature given in (12). In this way, no more than five contrastive tone heights can be generated by the system.

NOTES

1 'A system was considered perceptually optimum for a given set of input parameters (i.e., number of tones and set of weighting factors) when it was found to have the greatest DMIN [minimal distance] after all possible tone systems with N tones were compared. In other words, the chosen perceptual criteria was to keep the two closest tones of a given system maximally apart.' (Hombert 1978:135).

2 For verifications of this type of tonogenesis, see Matisoff (1970, 1973), Mei (1970, 1982), Henderson (1982), and Manaster-Ramer (1986). For amendment of Haudricourt's scheme of tonogenesis, see Sagart (1986, 1988).

3 For the evidence of the existence of three registers, see Chao (1928), Li, *et al.* (1959), Haudricourt (1961), Pulleyblank (1978), Xiong (1979), Edmondson (1992), and Shi (1992).

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