A Phonetic and Acoustic Investigation of the Concept of Tone Space

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ABSTRACT

This study is an attempt to explore tone space across tone systems via a phonetic and acoustic investigation. Three Chinese dialects (Mandarin, Jinanese and Cantonese), having different tonal inventory sizes or different tonal contrasts, were initially involved in the experiment. Eight bilingual speakers, four for Mandarin and Jinanese and four for Mandarin and Cantonese, were selected for making the recordings. The investigation in an idealized situation, and within the type of tone languages in East Asia provides us with cogent evidence in illustrating the concept of tone space. Phonetically speaking, tone space, known as pitch range, varies across tone systems. Contrary to previous reports, tone space does not necessarily expand with an increase of tonal inventory size. On the other hand, the transformed acoustic data from this study have also substantiated the previous claim that, tone space can be regarded as uniform across some tone languages from a phonological perspective.

1. INTRODUCTION

The term of tone space has been widely used in the literature of tonal research, though an explicit definition on tone space has never been specifically proposed, either phonologically or phonetically. When used in phonology, tone space, which is commonly recognized as voice pitch, is assumed to be uniform across languages in a manner similar to vowel space, regardless of how many tones a language has, or whether it has any at all [10, 12]. This is convenient and may be accurate when referring to the phonological features of tone and intonation. However, when talking about the phonetic value of tone space, other views have been proposed. For instance, it is often stated that tone space tends to expand in a system with the increase of the number of tone heights [7, 6]. Moreover, the expansion of tone space is formulated in two ways: (1) starting from the center and expanding outwards; or (2) starting from one border of the tone space and expanding beyond the other [4]. These statements, however, seem to lack exact and reliable evidence. In addition, knowledge from previous studies does not appear to uncover the underlying mechanism for tonal production or to solve the problems of phonetic tonal behavior reported by earlier researchers, e.g., the problem concerning tonal variation which first arose in an engineering application. Studies, especially those cross-language ones and from a phonetic angle, are needed to further delineate these issues in a more systematic manner. This served as the basis for designing the present acoustic experiment with a view towards offering a preliminary discussion on the concept of tone space and other related topics.

2. METHOD

2.1 MATERIAL

It is assumed in this study that both tonal inventory size and tonal shape are critical to tone space. Hence, during the design of the experiment, three Chinese dialects, Mandarin, Jinanese and Cantonese, with either different tonal inventory sizes or different tonal contrasts, were initially involved. Table 1 lists the three tonal paradigms in tone number, a qualitative description and a five-degree scale transcription [1, 13]. It is known that in the phonological tone system of Cantonese, there are three other checked tones, besides the six long tones listed in the table. The three checked tones are usually recognized as short High, Mid, and Low level tones, respectively. Previous phonetic studies have revealed that postvocalic consonants have an effect on the F_0 of the preceding vowels [8, 6]. To parallel the comparison of the tones among the three dialects, however, the influence of the three short tones on the Cantonese tone space is to be discussed in future publications.

Dialect	Number	Description	Numeric scale
M	Tone 1	high level	55
	Tone 2	high rising	35
	Tone 3	falling-rising	214
	Tone 4	high falling	51
J	Tone 1	falling-rising	213
	Tone 2	high falling	42
	Tone 3	high level	55
	Tone 4	low falling	21
C	Tone 1	high level	55
	Tone 2	high rising	35
	Tone 3	mid level	33
	Tone 4	low falling	21
	Tone 5	low rising	23
	Tone 6	low level	22

Table 1: Summary of the paradigms of citation tones in Mandarin, Jinanese and Cantonese.

Because it is known that different syllable structures may also influence the tone space, two syllables were chosen for the recordings of each dialect. For Mandarin and

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Jinanese, the two syllables were /shi/ and /yan/ (Pinyin), while those for Cantonese were /si/ and /ian/ (Jyutping). The testing utterances associating with these syllables were all minimally distinguished by tone in each dialect. Chinese characters for the two syllables in Mandarin and Jinanese are the same, while the characters for Cantonese syllable /si/ are the same as for Mandarin and Jinanese. The characters for /ian/ are different from those for /yan/ in Mandarin and Jinanese, but are similar in pronunciation.

2.2 RECORDING

Tokens of eight repetitions of each item were written individually on cards, using Chinese characters to represent the segments and tones. To minimize the physiological factor, which is largely known to influence the voice pitch, eight bilingual speakers were chosen for the recording. Four of them were bilinguals of Mandarin and Cantonese, two females (Fmc1, Fmc2) and two males (Mmc1, Mmc2), while another four were of Mandarin and Jinanese, also, two females (Fmj1, Fmj2) and two males (Mmj1, Mmj2). During the recording, carrier sentences were used in order to keep a relatively consistent reading style, a relatively equal speaking rate, and to balance the stress pattern. For Mandarin and Jinanese, the carrier sentence was " wo3 yao4 nian4 … gei3 ni3 ting1" (I am going to read … for you to listen). For Cantonese, the carrier sentence was " ngo5 jiu3 duk6 … bei2 nei5 teng1" (I am going to read … for you to listen). Recordings for the Mandarin and Cantonese speakers were completed in the Phonetics Laboratory of the City University of Hong Kong. Those for Mandarin and Jinanese speakers were completed in the recording booth of the Jinan Radio Broadcasting Station.

2.3 F_0 EXTRACTION AND PROCESSING PROCEDURE

All of the vocalizations by the eight speakers were digitized at a sampling rate of 10kHz at the Phonetics Laboratory of the City University of Hong Kong, by using Kay CSL Model 4300B. F_0 was computed directly from the waveform, using a CSL algorithm that employs a time domain approach in pitch analysis, with a nonoverlapping variable frame length. The onset of the target pitch curve is defined as the starting point of the first normal period that often coincides with the vertical striations in the second and higher formants. Tonal offset is defined either as the last F_0 value for some clear-cut utterances, or as the cessation of the second and higher formants of the vowel in a simultaneous display of a wide-band spectrogram, with a scale from 0-4Khz [5]. Only pitch curves of the target items were extracted and saved. The raw pitch curve for each testing item from the acoustic analysis was saved as a file in a NSP format. Each file contained the following raw data: (1) a frame number representing each sampling point; (2) the time location on the screen of each point; and (3) the fundamental frequency value of each point on the pitch curve. The raw data obtained from CSL were processed with a computer program in Matlab written by the senior author. The processing procedure of each pitch curve included the following steps. Firstly, zero values, irregularly appearing on the pitch curve, were eliminated. Secondly, the original pitch curve was smoothed by using the method of three-point averaging. Thirdly, the duration of each pitch curve was normalized by uniformly extracting 20 points, with the original starting and ending points in place. If the sampling points were less than 20, an interpolation procedure was implemented. An extra-incorporated program (in Matlab) was used to average eight repetitions for each speaker of each testing item/language.

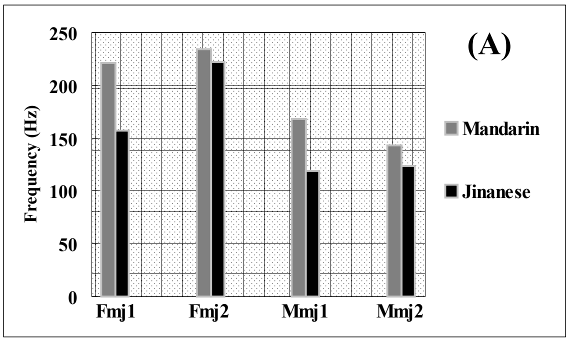
Results for individual speakers were directly represented with fundamental frequency values. To enhance the comparability of the varieties of acoustic data between-language for typological and universal purposes [3], the normalization method of z-score for F_0 was adopted. This method expresses an observed F_0's dispersion away from a mean F_0 value. The following is the standard formula used for calculating the z-score value of an F_0 value [11],

$$Z_i = (x_i - m) / s$$

where $\mathbf{x_i}$ is an observed F_0 value, **m** is the mean F_0 value, and **s** is the standard deviation of a given sample.

3. RESULTS AND DISCUSSION

Generally speaking, tone space and voice pitch are not the same. Voice pitch indicates the extent of pitch variation during speech, in both tone and non-tone languages. In phonetics, however, tone space appears to be more closely allied with voice pitch. Furthermore, when dealing with some types of tone languages, tone space can be referred to as pitch range that contains all of the tones in a system. It has been commonly recognized that voice pitch varies considerably according to a variety of other factors, such as tongue height, degree of supraglottal closure, intonation, contrastive accent, speaker's mood and voice intensity. In the present study, however, the authors intend primarily to investigate the relationship among tonal inventory size, tonal contrast and tone space. To achieve this goal, all other factors influencing the voice pitch, were kept as balanced as possible. Therefore, the divergence of different tone systems is primarily due to, either the tonal inventory size, tonal contrast, or both.



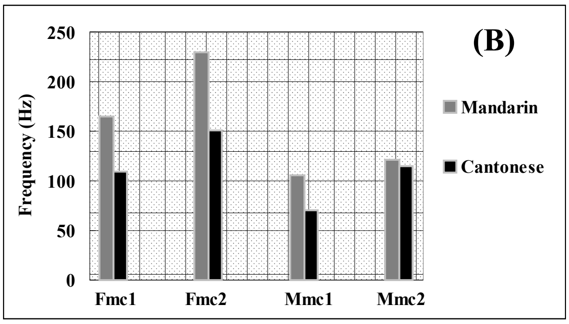


Figure 1: Comparisons of the average pitch range by individual speakers of: (A) Mandarin and Cantonese; (B) Mandarin and Cantonese

Figures 1 shows the average pitch range of each individual speaker with both dialects in either of the two pairs. Graph A illustrates the comparison between pitch ranges for Mandarin and Jinanese. It can be seen that the difference in pitch range varies among different speakers. The difference for speakers Fmj1 and Mmj1 is considerable, while that for speakers Fmj2 and Mmj2 is comparatively small. Mandarin and Jinanese have the same tonal inventory size, though the pitch range for the two tone systems is different. This indicates that different tonal contrast may influence the pitch range. Moreover, the four Mandarin and Jinanese bilinguals show the same trends, i.e. the pitch range for Mandarin being wider than that for Jinanese. Graph B represents the same comparison between Mandarin and Cantonese. Similarly, the four speakers showed various degrees of divergence with the pitch ranges for Mandarin and Cantonese. Except for speaker Mmc2, the difference is quite evident. It should be noted, however, that Mandarin has a smaller inventory size, but takes a wider pitch range than Cantonese. This is congruous across all four speakers. The present researchers did not predict such an outcome. Mandarin consistently takes a wider pitch range than Jinanese or Cantonese. Figure 2 shows the comparisons of the average frequency values of the four speakers.

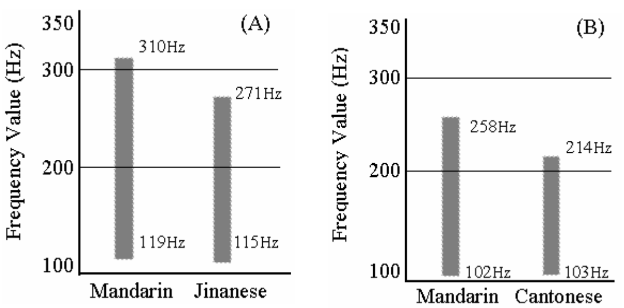


Figure 2: Comparisons of the average pitch range across speakers for each pair of dialects

In the literature of phonetic studies on tone space, there is agreement that pitch range tends to be larger with the increase of tonal heights [6, 7, 9]. Data obtained from the present study, appear to be in conflict with previous findings. Cantonese has a greater number of tones than Mandarin but with a smaller pitch range. However, the authors can't easily refute the previous conclusions, because their studies may be dealing with a different type of tone languages. In conclusion, it is safe to assert, according to the data from the present study, that tone space does not always tend to expand with the increase of tone numbers. This is true at least with a certain type of tone languages.

In the literature, there are two assumptions regarding the way that tone space expands. The first one assumes that tone space starts from one border and expands beyond the other. An alternate view suggests that it starts in the center and expands outward. The present study provides persuasive evidence in support of the former view. Tone space expands from one border, beyond the other. More specifically, tone space tends to extend toward the high register, while the bottom of tone space stays the same. The data in figure 2 illustrate this. It can be seen that the pitch range may undergo considerable variation between the two tone systems, while the bottom values consistently stay nearly the same. Table 2 lists the average pitch range of individual speakers with both of their dialects. It is obvious, that for each speaker, the top frequency values consistently vary greatly, while the bottom ones are very close, often less than 10Hz difference. In this regard, data obtained from the male speakers were more consistent than those recorded from the female speakers.

Speaker	*Dialect*	*Pitch range (Hz) bottom ---- top*
Fmj1	M	153 ---- 373
	J	135 ---- 292
Fmj2	M	145 ---- 379
	J	152 ---- 374
Mmj1	M	108 ---- 276
	J	106 ---- 225
Mmj2	M	68 ---- 211
	J	67 ---- 191
Fmc1	M	134 ---- 299
	C	143 ---- 252
Fmc2	M	122 ---- 352
	C	123 ---- 274
Mmc1	M	65 ---- 171
	C	64 ---- 134
Mmc2	M	86 ---- 208
	C	82 ---- 197

Table 2: Average pitch range of each speakers with both dialects

Additional studies were conducted in this study to compare the tone space of different languages in a general linguistic perspective. The acoustic data were normalized, using a z-score method. Normalization is a mathematical analogue of a human's perceptual process. It aims to extract and to specify the invariant acoustic correlates of linguistic features of a particular variety, towards a comparability of varieties, for typological and universal purpose [3]. If the z-score is an appropriate normalization method with tones, from phonetic values to phonological

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abstracts, the present data substantiates the previous phonological claims that, with the increase of the number of tone heights, the overall tone space tends to stay the same [10, 12]. Figures 3 and 4 display the normalized tone space of each dialect. Visually, it is obvious that, with different tonal contrasts (Mandarin and Jinanese), or with different tonal inventory sizes (Mandarin and Cantonese), the tone space is almost uniform across different dialects.

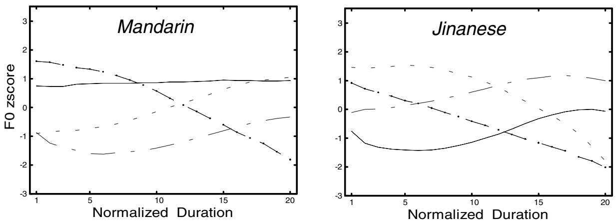

Figure 3: Comparison of normalized tone space of Mandarin and Jinanese by four bilingual speakers

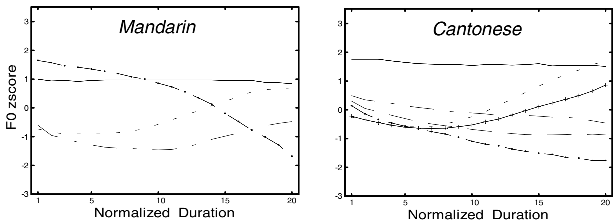

Figure 4: Comparison of normalized tone space of Mandarin and Cantonese by four bilingual speakers

The acoustic data presented above are based on the analysis using syllables /shi/ for Mandarin and Jinanese and /si/ for Cantonese. The results from the same analysis with syllables /yan/, and /ian/ were found to show the same trends in terms of the relationship between tone space and tonal inventory size. Those results, however, are not included in this paper. Because of page limitations, the inter- and intra-speaker variability on the pitch range with different syllable structures, will be included in a future paper.

4. CONCLUSIONS

Data obtained from this phonetic and acoustic investigation indicates that tone space, known phonetically as pitch range, varies across different tone systems. This is manifested by the tone systems with either different tonal inventory sizes or tonal contrasts. In addition, tone space does not always expand with the increase of the tonal inventory size. In specific type of tone languages (e.g. Mandarin and Cantonese), tone space decreases even though the tone system has a larger number of tones. In contrast, the transformed acoustic data from this study support a previous claim, that tone space, indeed, is uniform across languages in phonology, irrespective of different tonal inventory sizes or different tonal contrasts. More studies will have to be undertaken to determine if these results apply to the concept of tone space between tone and non-tone languages. This seems logical because there exists a considerable phonetic difference between tone and non-tone languages as previously reported [2, 9]. These data reported in the present study have also provided cogent evidence for understanding the manner of how tone space varies. Phonetically, the expansion or reduction of pitch range is through the boarder of tone space at the high register, rather than at the low register. These results are not only significant for increasing the knowledge of tonal behavior in linguistics, but also helpful in speech techniques for modeling more accurate and more natural language-specific intonation.

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