MUSICAL INTERVALS OF TONES IN CANTONESE ENGLISH

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Abstract

It has been shown that the relative pitch levels of Cantonese tones closely correspond to musical intervals (MIs) [1]. Given that an emerging tone language, Cantonese English, has developed tone under the substrate influence of Cantonese, this paper examines the correspondence between the newly emerged tones and MIs, and how the musical analogy relates to those established for Cantonese.

The fundamental frequencies of the tones produced by six speakers of Cantonese English were extracted with Praat, then time-normalized across rhymes. The mean values of the interval points of two tones were expressed in terms of ratio, then matched with the closest MI on the musical scale.

This paper demonstrates that the pitch levels of tones in Cantonese English correspond to MIs, given the converging ranges of MIs for different speakers and similar MIs of different tone pairs for different speakers. It also shows that the MIs of tones in Cantonese English are related to the corresponding tone pairs for Cantonese. The viability of MI as a means to understand the tonal system of non-tonal languages whose speakers' native language is tonal extends the link between the use of pitch in speech tones and music.

Index Terms: tone and music, musical interval, frequency ratio, Cantonese English, Hong Kong English

1. Introduction

To record the principal phonetic characteristic of lexical tone, i.e. fundamental frequency (F0), Chao developed the 5-level transcription of tonal pitch variation（五度標記法）with the use of sliding-pitchpipes [2]. When the pitch of the pitchpipe matches the pitch of the linguistic tone, the pitch values of a linguistic tone (the starting and ending points, also a turning point between the two if any) can be notated on a staff. The major advantage of this method is that the relativity of pitch, and therefore spatial relationship among lexical tones, could be recorded musically. The tones are represented phonologically on a tone scale with five numeric values from 1 to 5, a method usually adopted for Chinese languages [3]. Echoing Chao's method of notating the lexical tones via a musical means, this paper explores how linguistic tones can be understood in terms of musical intervals (MIs) based on the phonetic data obtained in Cantonese English.
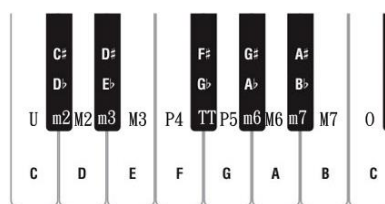

Figure 1: *MIs from C on piano keyboard [1]*

A MI is a perceptual distance of pitch, expressed in form of a ratio to show the distance between two adjacent notes on a scale. Figure 1 shows a chromatic scale on a piano keyboard. Different MIs are expressed in abbreviated forms: unison (U), minor (m), major (M), perfect (P), tritone (TT) and octave (O).

Let the leftmost C be an anchor key, one step up counts as one semitone. Moving from C to C♯ involves one semitone, and its MI is a minor second. Two semitones or one whole tone is involved when moving from C to D, and the corresponding MI is a major second. The longer the distance, the more the semitones involved, and the bigger the MI. Notably, the difference between two keys is relative in terms of MI. For example, the distance from C to E and from E to G♯ is the same: the MIs are both major thirds, with four semitones. As relativity of pitch is a core characteristic of phonemic tone, MI serves as a link to understand linguistic tones musically.

The MIs of linguistic tones can be obtained by calculating the frequency ratios of the tone pairs in a tone inventory, a method particularly useful for describing intervals in both Western and non-Western music. The absolute pitch of one tone is expressed in the form of a ratio to another tone. The ratios can then be matched with the closest MI on the musical scale. It has been shown that the pitch intervals of Cantonese tones closely correspond to the number of semitones derived from the MIs [1]. Given that Cantonese English has developed tone under the substrate influence of Cantonese, is there a musical basis or analogue to the tone inventory of this emerging tone language? If so, how does the musical basis or analogue relate to that for Cantonese?

Cantonese English is an emerging language which owns its distinctiveness in many linguistic aspects that are worth paying attention to for the sake of providing a neutral and unbiased description [4]. Many phonological aspects of Cantonese English have been studied so far [5-9]. Specifically, the use of pitch in Cantonese English, unlike tones in Cantonese, is perceptually distinct but carries a low functional load, with few if any minimal pairs in normal speech. This paper refers to this systematic use of pitch as tone, and examines the relationship among these tones, as described in recent works like [6, 10-13].

The goals of this paper are to find out the correspondence between the new tones and MIs, and examine how the musical analogy relates to those established for Cantonese. The first working hypothesis is that the pitch levels of tones in Cantonese English correspond to the MIs. This predicts that the ranges of MIs for different speakers should display a convergent pattern, and the MIs of different tone pairs for different speakers should be similar. The second working hypothesis is that the MIs of tones in Cantonese English are related to those for Cantonese. This predicts that there are corresponding tone pairs in Cantonese English and Cantonese.

2. Linguistic tone and musical tune

2.1. Relativity in tone and tune

The relationship between language and music has been shown to be multifold. In recent works on tone-melody mapping, the

conformity between lexical tone and melody in vocal songs has been the focus [14-22]. Both speaking and singing involve vocalization and manipulation of pitch, but composition of songs sometimes requires fixed pitch notation while pitch in speech tones is a relative concept in principle. Depending on the pitch of the adjacent, or even neighboring, tones in speech, the interpretation of tones may vary. If the pitch of the adjacent or neighboring tones is lower, the target tone will be perceived as a higher tone. Likewise, higher pitch of the adjacent or neighboring tones makes the target tone a lower tone [23]. Relativity is an important characteristic not only of speech tone, but also of musical tone because not everyone, even musicians, has absolute pitch, and many people sing songs with the right intervals but not at the fixed pitch transcribed in the musical notation. They need to attune their instruments and the pitch of their voice with the help of tuning devices.

2.2. Cantonese tones and musical intervals

Since relativity of pitch is crucial to the link between tone and tune, one would expect correspondence between the frequency ratios of tones in speech and tones in sung melody. [19] used a ratio called High-Low Quotient for each of the twenty Chinese languages by dividing the F0 of the highest pitch level with the F0 of the lowest pitch level articulated by a given speaker of each language. Instead of only using the highest and lowest F0, [22] identified six pitch intervals (1-2, 1-3, 1-5, 2-3, 2-5 and 3-5) in Cantonese and calculated the frequency ratios involved when transiting from one pitch level to another with single utterance data by five speakers from [24]. Though both studies claimed that the frequency ratios did not align with the musical intervals neatly, the values were close and seemed to show patterns.

[1] proposed an MI analysis for speech tones in Cantonese similar to the one adopted by this paper. It collected F0 data of Cantonese tones and calculated the frequency ratios for all of the seven tone pairs in Cantonese (T1:T3, T1:T6, T1:T4, T2:T5, T3:T6, T3:T4 and T6:T4) from multiple utterances produced by six speakers. Since the frequency ratio and the MI share the same way of calculation using the equation $\frac{F0x}{F0y}$, the frequency ratio for the speech tones is named as MI.
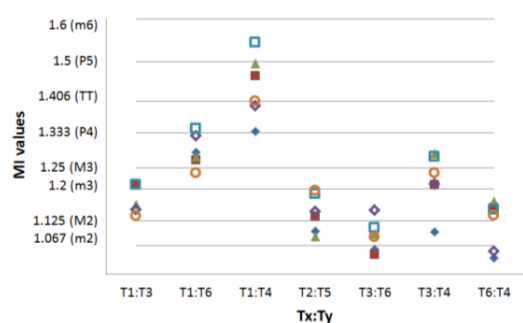

Figure 2: *Cantonese MIs of all subjects [1].*

Figure 2 shows the MIs identified for the six subjects. F/M1 to M/F3 represent fe/male speakers numbered 1 to 3 respectively. It was found that the minimal distance between two tones in Cantonese is a minor second for the tone pair of T3:T6, with pitch levels 3-2. The maximal distance between two tones in Cantonese is a perfect fifth, which is found for the tone pair of T1:T4, with pitch levels 5-1. This coincided with

the findings in tone-melody mapping, where a tonal transition from 5-1 is found to be mapped onto a musical interval of a perfect fifth [20, 22]. Figure 2 demonstrates that MI is a possible scale to portray tones in a tone inventory produced by multiple speakers, and to display the spatial relationship between different tone pairs in each speaker's tonal space.

2.3. Musical intervals and semitones

MIs allow tonal analysis be done without committing to specific tuning systems which divide an octave slightly differently, thus avoiding small yet possibly significant effects of such differences on the interpretation of the spatial relationship of the tones in a tone inventory. Comparison of linguistic tones can be obtained through MI ratios ranging from 1 to 2 in an octave. Switching from one tuning system to another can be done by changing the ratios which the MIs are based on.

One can also divide the MI ratios into smaller logarithmic units like semitones by $\log_2 MI * 12$, and so as cents by $\log_2 MI * 12 * 100$. Adopting a logarithmic unit of measurement will fit the reported logarithmic characteristic in perception [25] and production [26] of pitch in speech.

This paper adopts the just intonation tuning system as provided by 5-limit tuning, where the main intervals and just intervals are found to sound pleasant and well-tuned to most people.

3.   Methodology

Six Cantonese English speakers balanced for gender were chosen as subjects. They were born after 1980 and raised in Hong Kong. Their age ranged from 21 to 32 years old, representing young adult speakers of Cantonese English.

The data was elicited using a wordlist providing a comprehensive coverage of the syllable structure, vowel and consonant inventories, and surface tones of Cantonese English. The criteria for stimulus construction are listed in Table 1 below. 24 target items were randomized with 8 fillers during elicitation.

Table 1. *Criteria for stimulus construction.*

	Description
Syllable structure	(C)V(V/N/C)
Vowel	Syllables mainly contain but not limited to 3 cardinal vowels [i], [a], [u]
Consonant	[t], [b], [ʃ], [m], [k], [l], [s], [g], [n], [p], [ɹ]/[w], [f], [d]
Tone category	M(id), H(igh), Mf(alling), L(ow), Hf

The subjects were asked to produce each word three times in a row so that the basic position (initial, medial or final) of each target item in an utterance was controlled, for instance, *arm-arm-arm*. A total of 2376 target syllables (= 66 target syllables x 3 repetitions x 2 sets x 6 subjects) were recorded. Recordings were made with Praat (ver. 5.3.39) [27] with a sampling frequency of 22050Hz in a sound-proofed recording booth.

F0 tracks of the items in the utterance final position were extracted with Praat, then time-normalized at 10% interval points across the rhyme of each syllable with Praat script ProsodyPro (ver. 4.3) [28]. Based on the above categorization of tones, tone profiles of individual speakers were generated in the form of line graphs. The mean values of the ten interval points of each of the two tones were expressed as a ratio in

order to match with the equivalent ratio for the closest MI. The MI of each tone pair was then used to map the closest MI on the musical scale. For the sake of accuracy, the MIs were expressed in numbers, as in Table 2. Since the tones seemed to be restricted to certain syllable positions in a word, the selection of tones relevant for the calculation of MIs will be discussed in the following section after presenting the Cantonese English tone profiles.

4. Results and discussion

4.1. F0 profiles of subjects

The Cantonese English F0 profile of each subject was generated in form of line graphs like Figure 3. Recall that the words were repeated three times when recorded so as to control the position of the words in an utterance. Only the words in the utterance-final position are used because they display richer materials for tonal analysis. Also, since the placement of tones in Cantonese English seems to be restricted in certain syllable positions of a word, three graphs, from left to right, are used to present the tones occurring in the word-initial, word-medial and word-final positions respectively. H, M and L are each shown by solid, dashed and dotted lines.
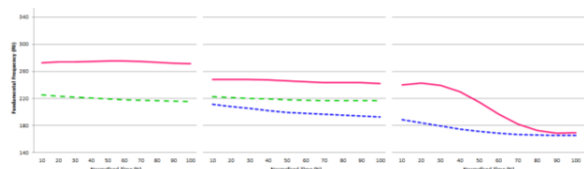

Figure 3: *Cantonese English tone profile of speaker F2.*

As observed above, not all of the five tones surface in all three positions in a word. H and M surface in both word-initial and word-medial positions. In the word-final position, the lower curve is regarded as a boundary L, and the upper curve with a distinguishable falling contour is a H transiting to a boundary L. Additional data shows that the more syllables between the rightmost H and the boundary L, the flatter the slope of each curve. The intervening tones from the rightmost H in a word to the boundary L are excluded from the calculation of MIs. To minimise declination effects, H and M in word-medial position and L in the final position are selected, given that the L only surfaces at the right boundary of a word. Also noticeable from the data is that M only occurs before H, and H only occurs before L. There are some variations concerning the details of the pitch contours, but the patterns described above generally hold across subjects.

4.2. Tones in Cantonese English on MI scale

The pitches of each pair of tones were expressed as a ratio and compared with the pitch ratios for the closest corresponding MIs. The data of speaker F2 is used as an example.

Table 2. *MIs of speaker F2.*

$\overline{T}x{:}\overline{T}y$	$\overline{T}x$ (Hz)	$\overline{T}y$ (Hz)	$\overline{T}x/\overline{T}y$	Closest MI	Closest MI ref. value	No. of semitones
H:M	245.2154	218.3493	1.123042	M2	1.125	2.008939
H:L	245.2154	172.9993	1.417436	TT	1.40625	6.039400
M:L	218.3493	172.9993	1.262140	M3	1.25	4.030460

Table 2 shows all possible combinations of ratios for the Cantonese English tones, H, M and L, of speaker F2. The first

column ($\overline{T}x{:}\overline{T}y$) is filled with the ratio to which each row of data corresponds. The second and third columns ($\overline{T}x$ and $\overline{T}y$) are the mean F0 of the ten interval points on the tonal contour for each tone in Hz. The column $\overline{T}x/\overline{T}y$ shows the ratios in numbers. The ratios are then matched with the closest MI in the next column, followed by the actual ratio values for each MI. The last column shows the number of semitones calculated by the equation provided in Section 2.3. Let us take H:M as an example. The mean F0 of H and M are 245.2154 Hz and 218.3493Hz respectively. Their ratio is 1.123042 (= $\frac{245.2154\ \text{Hz}}{218.3493\ \text{Hz}}$),closest to a major second,having a ratio of 9:8, i.e. 1.125, and around two semitones. Figure4 shows the results using a similar method for each subject as in Section 2.2.
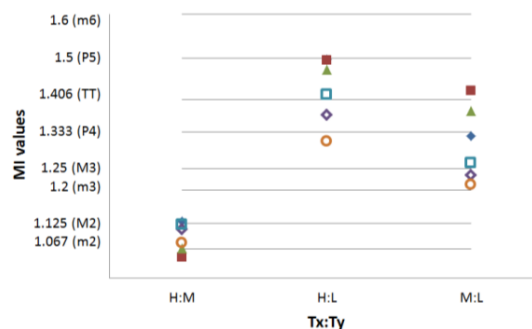

Figure 4: *Cantonese English MIs of all subjects.*

4.2.1. Distance between linguistic tones and tone space

The distance between two tones in a tone pair is reflected by the values of the MIs. The MIs of all subjects fall within the range of minor second to perfect fifth. A minor second is the shortest distance that two musical tones could have on a keyboard, with the distance of one semitone. A perfect fifth is the distance from C to G (cf. keyboard in Figure 1), with seven semitones in between. H:M is the tonal pair with the smallest MI (from minor to major second) whereas H:L is the pair with the biggest MI (from perfect fourth to fifth). M:L came within a minor third to a tritone.

Speaker F3 has a relatively narrow MI range – all tones are spaced within a perfect fourth, with five semitones between the highest and lowest tones. On the contrary, the male speakers have the widest range – their tones are spaced within a perfect fifth, with seven semitones between H and L. In other words, the tonal space of male speakers is wider than for the female speakers, especially for speaker F3. The tonal space of speakers F1 and F2 is wider than speaker F3 but still narrower than for the male speakers.

A wider tonal space allows a wider range of MIs. This can be checked by the number of semitones between the highest and lowest MIs of the subjects. Speaker F3 uses MIs ranging from a minor second to a perfect fourth, within four semitones, while speakers M2 and M3 use MIs from a minor second to a perfect fifth, within six semitones. Close to speakers M2 and M3 is speaker M1, who uses MIs from a major second to a perfect fifth, in five semitones. The MIs of female speakers all range within four semitones with different starting and ending MIs: speakers F1 and F2 range from major second to tritone, while speaker F3 ranges from minor second to perfect fourth.

4.2.2. Spatial relationship among linguistic tones

The spatial relationship among different tones in a tone inventory is reflected through comparison between the MIs of

different tone pairs in a tone inventory. By comparing the MIs of different tone pairs, whether M is closer to H or L in Cantonese English can be figured out. In Figure 4, H:L has the highest MI. Since there are only three tones, H and L ought to be at opposite ends with M somewhere in between. Interestingly, instead of being in the middle of H and L, M is closer to H than L. This relationship among the tones in Cantonese English is so neat that it holds across the MI profiles of all six speakers. This unanimity displayed by the subjects suggests that the M is not randomly assigned to anywhere between H and L in Cantonese English, and hence has a stable position in the tonal space of Cantonese English.

4.2.3. Flexibility of linguistic tones

The flexibility of linguistic tones is reflected by the range of MIs, i.e. the extent to which the MIs of different speakers cluster for different tone pairs. The more unanimous MIs (minor or major second) for H:M confirm that the interval between these tones corresponds to minimally one semitone while the more flexible MIs (perfect fourth, tritone or perfect fifth) for H:L indicates that a wider range of MIs are allowed.

4.3. Comparing the new tones with canonical tones

Given the above tonal analysis of Cantonese English in terms of MIs, the next question is how the tone system of Cantonese English is similar to or different from that of its substrate language Cantonese. If the MIs of tones in Cantonese English can be related to Cantonese, not only does it show that MIs link speech tones and musical tones together, but it also serves as a link between the phonological tones in canonical tonal languages like Cantonese, and languages like Cantonese English where the tonal elements are probably substrate influence from one's tonal native language. With a similar methodology and the same subjects, this section compares the MIs of the new tones in Cantonese English and the canonical tones Cantonese.

The six phonemic tones in Cantonese are T1 [55], T2 [25], T3 [33], T4 [21], T5 [23] and T6 [22], according to [29]. Among the seven possible combinations of tone pairs in Cantonese and the three possible tone pairs in Cantonese English, the following tone pairs are selected for comparison: T1:T6, T1:T4 and T6:T4 in Cantonese, and H:M, H:L and M:L in Cantonese English respectively.

4.3.1. Distance between linguistic tones and tone space

The MIs for the tone pair whose tones are most distant from each other in Cantonese English (H:L) and Cantonese (T1:T4) are very close. They are the same for speakers M2, M3 and F1in both languages. The MI of speaker M1 is greater in Cantonese English by two semitones, while for speakers F2 and F3, their MI is smaller in Cantonese English by one semitone. H:L in Cantonese English and T1:T4 in Cantonese have the largest MI across speakers, ranging from perfect fourth to fifth. This suggests that the total pitch range used is much the same for Cantonese English and Cantonese.

For the other two tone pairs in both languages under comparison, while the smallest MI in Cantonese English and Cantonese are H:M and T6:T4 respectively, H:M is also the one with the smallest MI in the tone system of Cantonese English but T6:T4 is not in that of Cantonese. This could be due to the fact that the tonal space of Cantonese is more crowded than that of Cantonese English so that there can be even more fine-grained categorisation of tones.

4.3.2. Spatial relationship among linguistic tones

M is closer to H than L in Cantonese English, but T6 is closer to T4 rather than T1 in Cantonese across subjects. This may be due to having no perfect equivalent for Cantonese English M in Cantonese. The M in Cantonese English is slightly higher than T6 but not as high as T3 in Cantonese. Also, the unanimity displayed for the assignment of M suggests that the M in Cantonese English, like T6 in Cantonese, has a stable position in the tonal space, and hence in the tone inventory of Cantonese English.

4.3.3. Flexibility of linguistic tones

Unlike Cantonese, where the tone pair whose tones are most distant from each other, i.e. T1:T4, is also the most flexible tone pair in terms of MIs (perfect fourth, tritone and perfect fifth), the tone pair whose tones are second distant from each other, i.e. M:L is the most flexible tone pair (minor and major third, perfect fourth and tritone) in Cantonese English. The MIs of H:L are also quite flexible (perfect fourth, tritone and perfect fifth) but not as M:L, suggesting that a choice between transiting from H to L or from M to L should be available in tone-melody mapping.

The tone pair whose pitches are closest to each other in Cantonese English, i.e. H:M, is also the least flexible tone pair in terms of MIs (minor and major second), similar to T6:T4 (major third and perfect fourth) among the three tone pairs under comparison in Cantonese. That said, if all seven tone pairs are taken into account, the least flexible tone pair is T3:T6 (minor and major second), which is also the tone pair whose pitches are closest to each other.

5. Conclusions and implications

This paper has examined the correspondence between the new tones and MIs, and how the musical analogues relate to those for Cantonese. It has been demonstrated that the pitch levels of tones in Cantonese English correspond to the MIs in terms of the distance between/among tones and the flexibility of tonal intervals, given the converging ranges of MIs for different speakers, and similar MIs of different tone pairs for different speakers. It has also been shown that the MIs of tones in Cantonese English are related to those for Cantonese to some extent, with corresponding tone pairs in Cantonese English and Cantonese.

By demonstrating that such a musical treatment of linguistic tone is viable, it has been shown that MIs serve as a means to understand the tonal system of non-tonal languages whose speakers' native language is tonal, with characteristics of tones invisible in other existing approaches but visible through the MI glass. It has also extended the link between the use of pitch in speech and music. It seems promising to apply the proposed method to more new varieties of languages with a larger sample. Considering the convergence of tonal characteristics in Cantonese English, also in comparison with Cantonese, this paper supports the view that Cantonese English is an emerging tone language.

6. Acknowledgments

7. References

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