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An Acoustic Analysis of Cantonese Vowels and Tones Produced by Hearing-Impaired Speakers

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ABSTRACT

This study investigates the acoustic characteristics of Cantonese vowels and tones produced by speakers with hearing impairment, in order to determine the deficiency in their pronunciation. Speech samples of all the 11 vowels [i y ɛ œ a ɔ u ɪ ɵ ɐ ʊ] and 9 citation tones [55 33 22 21 25 23 5 3 2] in Cantonese were elicited from six hearing-impaired (HI) and two normal-hearing (NH) Cantonese speakers who were in their 20s. The six HI speakers included three males and three females with severe to profound hearing loss, who have received cochlear implants or are wearing a hearing aid. The formant frequencies (F_1F_2) of the vowels, fundamental frequency (F_0) of the tones, and durations of the vowels and tones were measured and compared between the two groups of speakers.

The main findings are presented as follows. (a) Duration. The HI speakers make sufficient duration contrast between the long and short types of vowels and tones in Cantonese as the NH speakers do, while vowel prolongation is observed in the speech of some HI speakers. (b) Formant frequencies. Compared to the NH speakers, some HI speakers tend to have a reduced size of vowel space, due to centralization of the peripheral vowels, in particular the backward shifting of the front vowels. However, no significant effect on the differentiation of vowels in the reduced vowel space is observed. (c) Fundamental frequency. The HI speakers show deficiency in tone production, with a major problem in the flattening of the F_0 contours of the contour tones, which leads to the merging with the level tones. Overall, the HI speakers are more successful in producing the vowels than the tones, which may suggest a difference in articulatory mechanism between tone production and vowel production.

Keywords: hearing impairment, pronunciation deficiency, Cantonese vowels and tones, F_0 and formant frequencies, duration

SECTION ONE: INTRODUCTION

This research project investigates the acoustic characteristics of Cantonese vowels and tones produced by hearing-impaired (HI) speakers. Due to limitation of auditory input, deficiencies are observable in the speech of HI speakers. There have been a number of studies on the language ability of HI speakers of different languages, such as English (Geffner, 1980; Osberger and McGarr, 1982), Croatian (Liker et al., 2004), Dutch (Verhoeven et al., 2016), Swedish (Löfqvist et al., 2010), Cantonese (Barry et al., 2000, 2002; Ciocca et al., 2002; Khouw and Ciocca, 2006; Lee et al., 2002, 2007), and Mandarin (Peng et al., 2004; Han et al., 2007; Tseng et al., 2011; Hung et al., 2017). It is reported that HI speakers have great difficulty in differentiation of tones, due to lack of or insufficient auditory input and feedback to the difference in fundamental frequency (F_0) among the tones. Similar problem for HI speakers is also in differentiation of vowels which relies on the auditory, rather than kinaesthetic, feedback to the movement and position of the tongue during the articulation. While most of HI people have received remedy through wearing hearing aids or undergoing cochlear implantation, their ability of speech perception is still not the same as the normal-hearing (NH) people, due to the intrinsic difference between the artificial hearing device and the human auditory system. It is, therefore, affecting the speech intelligibility of HI speakers.

1.1 Literature Review

1.1.1 Vowel

Osberger and McGarr (1982) is an earlier work on speech production of English HI speakers. The authors, based on the findings of their previous studies together with those reported in the similar studies carried out by other scholars, summarize the common vowel errors emerging in the speech of English HI speakers. The vowel errors are generalized in five types: (1) substitution, to replace a vowel with another vowel; (2) neutralization, to produce the different types of vowels as the same; (3) diphthongization, to produce vowels with dynamic or changing quality; (4) nasalization, to produce vowels with additional nasality; and (5) monophthongization, to produce the two vowel components of diphthongs as two single vowel units or to drop the last vowel component in the diphthongs.

By comparing the various types of English vowels produced by HI speakers with those by NH speakers, Osberger & McGarr (1982) reports that HI speakers tend to pronounce the front and high vowels less accurate than the back and low vowels, which results in a change in size of the vowel space in the speech of HI speakers.

The conclusion drawn by Osberger and McGarr (1982) about vowel production by English HI speakers is in agreement with the findings of the vowel studies on HI speakers of other languages, such as Mandarin (Hung et al., 2017), Croatian (Liker et al., 2004), Swedish (Löfqvist et al., 2010) and Dutch (Verhoeven et al., 2016). In the study of Hung et al. (2017), the authors examine the production of three corner vowels [i, u, a] by HI speakers with three different types of hearing loss, namely conductive, mixed and sensorineural hearing loss. It is found that the vowel space for all three types of hearing loss is compressed with smaller F_2 values for the two high vowels, [i, u], compared to the F_2 values of the vowels for NH

speakers. The authors also point out that there is a noticeable centralization for the high front vowel [i] in the vowel space (Hung et al., 2017).

Similar findings of vowel space reduction and vowel centralization are also observed in the speech of HI children of Dutch as reported in Verhoeven et al. (2016). According to the authors of the study, all the Dutch vowels produced by HI children are centralized towards a more schwa-like vowel, resulting in a large reduction in the size of their vowel space. A small vowel space is also found in the speech of Croatian HI children. It is reported in Liker et al. (2007) that the HI children with cochlear implant have a smaller and fronted vowel space due to the higher F_2 frequencies for the vowels in their speech as compared to the formant frequencies of the vowels produced by NH children.

Löfqvist et al. (2010) presents the data on vowel space reduction for Swedish HI adolescents. In their study, the reduction of vowel space for HI speakers is mainly due to the smaller F_1 values for the HI speakers' vowels than the NH ones, and there is no significant difference in F_2 between the HI and NH vowels.

By and large, a small or reduced vowel space is observable for all the HI speakers of different languages reported in the previous studies, although the size of reduction and the factors attributed to the reduction differ between the studies. To my knowledge, no publications on vowel production by HI speakers of Cantonese are hitherto available. The present research project intends to provide such information for a better understanding of the speech of HI speakers.

1.1.2 Tone

Based on the review of the studies on speech disorder given in Osberger and McGarr (1982), inaccuracy of F_0 is a major deficiency in the speech of HI speakers. Cantonese is a tone language which has nine citation tones, including the three long level tones [55 33 22], three long contour tones [21 25 23], and three short level tones [5 3 2]. According to Khouw and Ciocca (2006), not only the F_0 level, the direction and magnitude change in F_0 all contribute to the categorization and distinction between the different types of tones in Cantonese. There have been a number of studies of perception and/or production of Cantonese tones by HI speakers. The major ones are presented as follows.

Lee (2007), a PhD dissertation, investigates the production of Cantonese tones by 16 prelingually HI children. The results of the study show that among the six Cantonese long tones [55 33 22 21 25 23], the rate of accuracy in pronunciation is highest for the two high-pitched tones [55] and [25] and lowest for the two low-pitched tones [21] and [22], due to the deficiency in tone perception for the HI children. The findings of Lee's study are not in full agreement with the data on Cantonese tone production by HI adolescents in Khouw and Ciocca (2006). In the latter, the difficulty of HI speakers is mainly in producing the three Cantonese contour tones [25], [23] and [21], where the second half of the F_0 contours of the three tones are flattened in the speech of HI speakers compared to the tones produced by NH speakers.

Khouw and Ciocca (2006) also presents the data on perception of Cantonese tones by HI speakers. Their data are consistent with those of the Cantonese HI children with cochlear implant in Ciocca et al. (2002). In both the studies, the Cantonese high level tone [55] is least confused with the other tones for the HI speakers. The data however are not true for the

group of Cantonese HI children with cochlear implant in Lee et al. (2002), where the pair with the tones [55] and [25] is the least distinguishable one, as compared to the perceptual results of the other pairs of Cantonese tones investigated in the study. Barry et al. (2009) also presents the perceptual data on the identification of Cantonese tones by cochlear implant children. In their study, the tones [21] and [23] are worst to be discriminated, which is likely due to the gentle change in the F_0 contours of the two tones.

By and large, among the different Cantonese tones, the high-pitched level tone [55] is the least difficult one, but the contour tones [21 25 23] are the most difficult ones, in both perception and production for HI speakers. Yet, the previous studies have shed the light on the understanding of production and perception of Cantonese tones by HI children or adolescents. In view of the fact that speech development is on-going before adulthood, the present study intends to collect data from HI adult speakers to offer a fuller insight into the deficiency in tone production due to hearing loss.

1.2 Purpose of study

The present study intends to fill the research gap by investigating the acoustic characteristics of Cantonese vowels and tones produced by HI adult speakers. The data are used to answer the three research questions of this study as presented below.

1. Are the different types of vowels and tones in Cantonese produced distinctively in the speech of HI adult speakers, in terms of the formant frequencies, F_0, and duration of the vowels and tones?
2. Are the vowels and tones in Cantonese produced by HI speakers similar to those of NH speakers?
3. Are the deficiencies in Cantonese vowel and/or tone production, if any, for HI adult speakers in the present study similar to those for Cantonese HI children and adolescents reported in the previous studies?

SECTION TWO: METHODOLOGY

2.1 Participants

In this study, for comparison purposes, speech samples were elicited from six pre-lingually HI speakers, three male and three female, as well as one male and one female NH speakers who have no history of speech and hearing problems. All the eight speakers were young adults aged from 21 to 27 (mean = 23.25), who were born and grew up in Cantonese-speaking families in Hong Kong. More information about the age, gender, hearing ability, and history of hearing problems of the participants is presented in Table 1.

Participants	Age	Sex	Level of hearing loss	Diagnosis of hearing loss	Hearing device
M-HI-1	23	M	Profound	Birth	CI since age 5
M-HI-2	24	M	Profound	Age 3	CI since age 5
M-HI-3	21	M	Severe	Birth	HA since age 3
F-HI-1	27	F	Profound	Age 2	HA since age 2
F-HI-2	27	F	Profound	Birth	HA since age 1
F-HI-3	22	F	Profound	Birth	CI since age 3
M-NH	21	M	-	-	-
F-NH	21	F	-	-	-

Table 1. Information on the HI and NH speakers, male (M) and female (F), in this study.

2.2 Test Materials

The test materials used for investigation were Cantonese monosyllabic words. Table 2 presents the test words that contain the 11 Cantonese vowels, including seven long vowels [i y ɛ œ a ɔ u] and four short vowels [ɐ ɪ ɵ ʊ].

Long vowels	CV syllables	CVS syllables	Short vowels	CVS syllables
i	[si^{55}] 詩 (poem)	[sit^{3}] 薛 (a family name)	ɐ	[hɐp^{2}] 合 (to close)
y	[sy^{55}] 書 (book)	[hyt^{3}] 血 (blood)	ɪ	[sɪk^{2}] 食 (to eat)
ɛ	[sɛ^{55}] 些 (some)	[hɛk^{3}] 吃 (to eat)	ɵ	[sɵt^{2}] 術 (method)
œ	[hœ^{55}] 靴 (boot)	[sœk^{3}]削 (to cut)	ʊ	[fʊk^{2}] 服 (clothes)
a	[ha^{55}] 蝦 (shrimp)	[hak^{3}] 客 (customer)		
ɔ	[hɔ^{55}] 呵 (laughter)	[hɔt^{3}] 喝 (to drink)		
u	[fu^{55}] 夫 (husband)	[fut^{3}] 闊 (wide)		

Table 2. Test monosyllabic words containing the 11 Cantonese vowels used for investigation.

For the 7 long vowels, there are two sets of test monosyllabic words, with one set in CV structure and the other set in CVS structure closed with a syllable-final stop [-p], [-t], or [-k].

As for the four short vowels, there is only one set of test words of CVS syllables due to the Cantonese phonotactic constraints on the occurrence of the short vowels in syllables. In order to limit the contextual effect on the vowels, all the test CV monosyllabic words have a voiceless fricative [s], [h], or [f] in the syllable-initial position and are associated with the same long high level tone [55]. As for the test CVS monosyllabic words, they have a syllable-initial voiceless fricative [s], [h], or [f] and are associated with a non-high short level tone [3] or [2]. All the test monosyllabic words are meaningful and commonly used by Cantonese speakers in daily conversation.

Table 3 presents the test words used for elicitation of the nine citation tones in Cantonese, including six long ones [55 33 22 21 25 23] and three short ones [5 3 2]. As shown in the table, there are two types of test monosyllabic words, with one type in CV structure associated with the six long tones, and the other in CVS structure associated with the three short tones. This is because in Cantonese, the short tones, but not the long ones, can only be produced on checked syllables with a final stop [-p], [-t], or [-k]. The test CV monosyllables associated with the long tones include [si] and [fu]. The test CVS syllables associated with the three short tones are [pit]/[sit] and [put]/[fut] ending in the syllable-final stop [-t], while the initial consonant varies as a voiceless [p-], [s-], or [f-]. Similar to the six long tones, each of the three short tones is associated with the two high vowels [i] and [u] in the test CVS syllables.

Long tones	CV syllables		Short tones	CVS syllables	
	V = [i]	V = [u]		V = [i]	V = [u]
55	[si^{55}] 詩 (poem)	[fu^{55}] 夫 (husband)	5	[pit^{5}] 必 (necessary)	[put^{5}] 咄 (sound of toy car)
33	[si^{33}] 試 (to try)	[fu^{33}] 富 (rich)	3	[sit^{3}] 薛 (a family name)	[fut^{3}] 闊 (wide)
22	[si^{22}] 是 (to be)	[fu^{22}] 負 (negative)	2	[pit^{2}] 別 (other)	[put^{2}] 撥 (to set aside)
21	[si^{21}] 時 (time)	[fu^{21}] 符 (symbol)			
25	[si^{25}] 史 (history)	[fu^{25}] 苦 (bitter)			
23	[si^{23}] 市 (city)	[fu^{23}] 婦 (woman)			

Table 3. Test monosyllabic words associated with the 9 Cantonese citation tones used for investigation.

A comparison of Table 2 and Table 3 shows that there are four test words, [si^{55}] 詩, [fut^{3}] 闊, [sit^{3}] 薛 and [fu^{55}] 夫, repeated in the two tables. Thus, the total number of the test words used for the investigation is 32 (7 long vowels x 2 test words + 4 short vowels x 1 test word + 9 tones x 2 test words – 4 repeated words). The test words were presented in Chinese character on a randomized list. Six repetitions of the word list were recorded from each

speaker, making up of a total of 1,536 test tokens (32 test words x 6 repetitions x 8 speakers) for subsequent acoustic analysis.

2.3 Recording

The participants were invited to take part in an audio recording individually in the acoustic sound-proof booth in the Phonetics Lab of the Department of Linguistics and Translation at the City University of Hong Kong. Before recording, the participants were given time to get familiar with the test words presented on the reading list. During the recording, the participants were instructed to read aloud the test words one by one in a neutral voice and at a normal speed. The speech samples were recorded through a microphone connected to a high quality digital recorder, TASCAM HD-R1, and then saved as WAV format for acoustic analysis.

2.4 Data Analysis

The recorded speech samples from the participants were analysed acoustically using the free speech analysis software, Praat, available on the internet. For the test vowels, spectral analysis was performed to measure the frequencies of the first three formants (F_1, F_2 and F_3) at the mid-point of the steady-state portion of each vowel, making reference to the wideband spectrogram with the superimposed formant trajectories provided by the Praat program. The measured values of F_1 and F_2 for each vowel were then used to draw vowel ellipse on the F_1-F_2 plane using the Praat script. For each speaker, the mean values of F_1 and F_2 averaged across the different tokens of a given vowel in the same test syllable were calculated and used for determining the vowel space of the speaker.

As for the test tones, pitch synchronized analysis was performed for obtaining the fundamental frequency (F_0) contours of the tones. For each tone contour, F_0 was measured proportionally at seven temporal points, including the onset or 0%, 12.5%, 25%, 50%, 75%, and offset or 100% of the total duration of the contour. The F_0 values at the same temporal point were averaged across the different tokens of a given tone and used for drawing the mean F_0 contours of the whole set of Cantonese tones produced by each speaker.

For both the test vowels and tones, their durations were also measured and extracted. The mean duration of each vowel or tone averaged across the different tokens was calculated for the speakers. The data on the mean frequency and duration values for each speaker are presented in the ‘Results’ section. Based on the data, comparisons are made among the different types of vowels and tones within each HI speaker, between different HI speakers, and between HI and NH speakers.

SECTION THREE: RESULTS

3.1 Duration

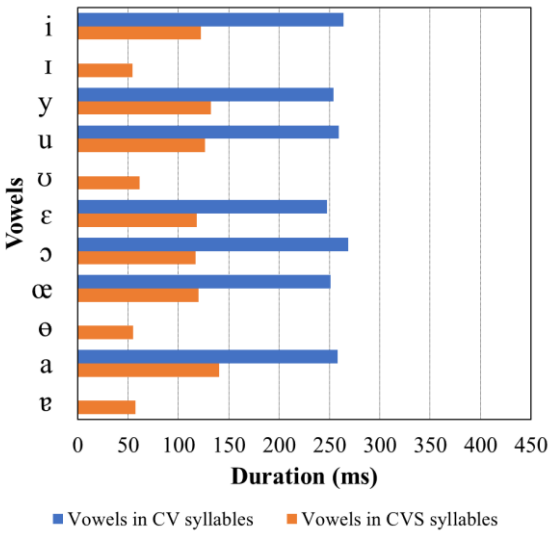
This section presents the temporal data on the mean durations of Cantonese vowels and tones across different tokens produced by each of the six HI and two NH speakers, male (M) and female (F). Comparisons are to be made between the individual speakers of each gender and between the HI and NH speakers.

3.1.1Vowel Duration

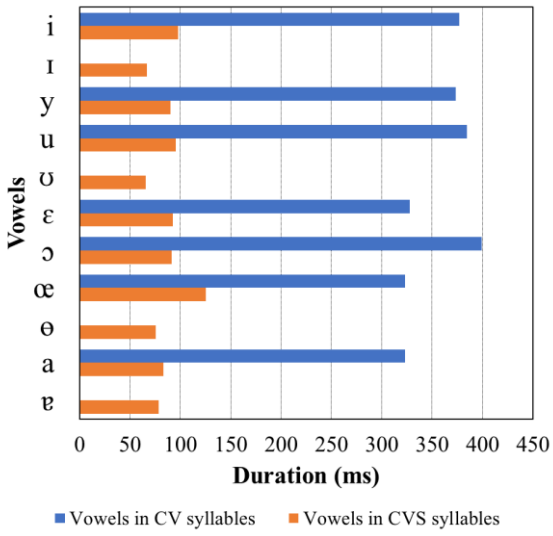
Figs. 1a to 1d are the bar charts showing the mean duration (in ms) of six tokens of each of the seven long vowels [i y ɛ œ a ɔ u] in CV syllables (blue bars) and all the eleven vowels [i y ɛ œ a ɔ u ɐ ɪ ɵ ʊ] in CVS syllables (orange bars) for the male NH speaker, M-MH (Fig. 1a), and the three male HI speakers, M-HI-1 (Fig. 1b), M-HI-2 (Fig. 1c), and M-HI-3 (Fig. 1d). For M-HI-2, the vowel [œ] in CVS syllables is not shown in the chart (Fig. 1c) due to mispronunciation. The four charts are on the same scale, with the durations of the vowels shown on the *x*-axis.

As shown in Fig. 1a for M-NH, there is a significant difference in duration between the seven long vowels [i y ɛ œ a ɔ u] and the four short vowels [ɐ ɪ ɵ ʊ] in CVS syllables. The duration difference between the two types of vowels is further increased when the long vowels occur in CV syllables. Based on visual inspection, the durations of the long vowels in CV syllables (LV-CV) are about two times of the long vowels in CVS syllables (LV-CVS), and the durations of the long vowels in CVS syllables are also about two times of the short vowels in CVS syllables (SV-CVS). The inspection is supported by the numerical data on the average durations of the three groups of vowels for M-NH presented in Table 4. As can be seen, the ratio of the mean duration of LV-CV to that of LV-CVS is 2.06:1 (257.5 ms/125.3 ms). Similar duration ratio of 2.19:1 is observed for LV-CVS to SV-CVS (125.3 ms/57.1 ms).

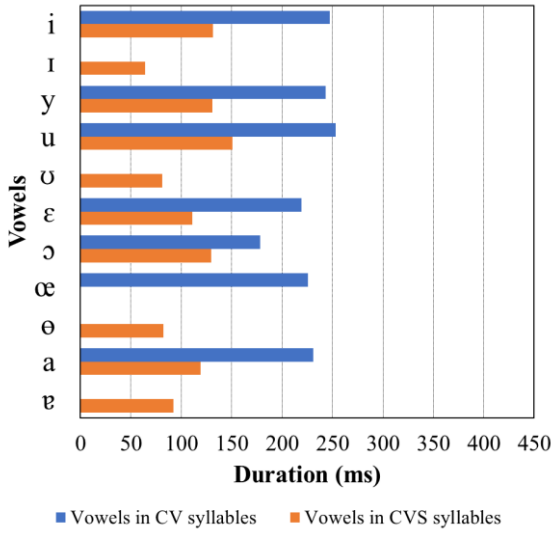
(1a) Male NH speaker (M-NH)



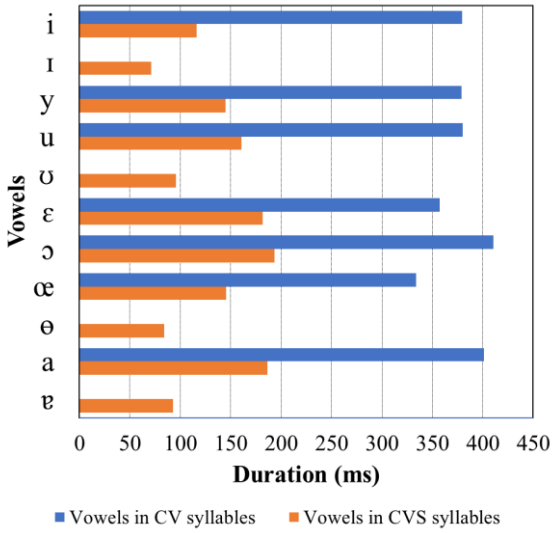
(1b) Male HI speaker 1 (M-HI-1)



(1c) Male HI speaker 2 (M-HI-2)



(1d) Male HI speaker 3 (M-HI-3)



Figs. 1a-1d. Mean durations (in ms) of the Cantonese vowels [i y ɛ œ a ɔ u] in CV syllables (blue bars) and [i y ɛ œ a ɔ u ɐ ɪ ɵ ʊ] in CVS syllables (orange bars) for four male (M) speakers, one NH and three HI.

Speakers	LV-CV	LV-CVS	SV-CVS	Ratio of LV-CV to LV-CVS	Ratio of LV-CVS to SV-CVS
M-NH	257.5	125.3	57.1	2.06 : 1	2.19 : 1
M-HI-1	358.4	95.4	71.7	3.76 : 1	1.33 : 1
M-HI-2	228.1	164.2	80.0	1.39 : 1	2.05 : 1
M-HI-3	377.4	161.2	85.9	2.34 : 1	1.88 : 1

Table 4. Mean durations (in ms) of the Cantonese long vowels in CV syllables (LV-CV) and CVS syllables (LV-CVS) and short vowels in CVS syllables (SV-CVS) for four male (M) speakers, one NH and three HI.

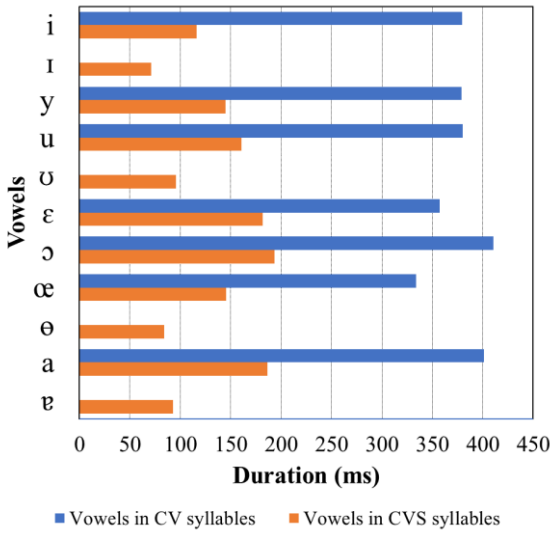
Similar temporal patterns of the Cantonese long and short vowels in CV and CVS syllables for M-NH are also observed in the speech of M-HI-3, although the duration values of the vowels are considerably larger for M-HI-3 (Fig. 1d) than M-NH (Fig. 1a). Based on the temporal data on the mean durations of the vowels for M-HI-3 presented in Table 4, the order of decreasing duration is LV-CV (377.4 ms) > LV-CVS (161.2 ms) > SV-CVS (85.9 ms), and the duration ratios are 2.34:1 for the first two groups of vowels and 1.88:1 for the last two groups of vowels.

As for the other two male HI speakers, M-HI-1 (Fig. 1b) and M-HI-2 (Fig. 1c), the duration is also longest for LV-CV, shortest for SV-CVS, with LV-CVS coming in between. However, for M-HI-1, the duration of LV-CV is extremely long (358.4 ms) and the difference in duration between LV-CVS (95.4 ms) and SV-CVS (71.7 ms) is much reduced, as compared to the vowel durations for M-NH. This results in a large duration ratio of LV-CV to LV-CVS (3.76:1) and a small duration ratio of LV-CVS to SV-CVS (1.33:1) for M-HI-1. The latter may indicate that the difference in duration between the long and short vowels in CVS syllables is not salient or perceptible in the speech of M-HI-1.

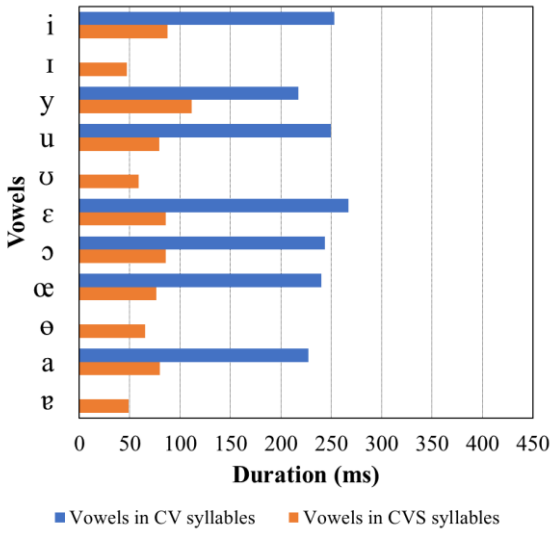
Compared to the temporal data for M-NH, M-HI-2 produces a longer duration for both the long vowels (164.2 ms) and short vowels (80.0 ms) in CVS syllables, but a shorter duration for the long vowels in CV syllables (228.1 ms). As a result, M-HI-2 has a small duration ratio of LV-CV to LV-CVS syllables (1.39:1), while the duration ratio of LV-CVS and SV-CVS (2.05:1) is similar to that for M-NS. The data indicate the duration difference between the long vowels in CV and CVS syllables is not salient in the speech of M-HI-2.

Figs. 2a to 2d show the durations (in ms) of the long vowels [i y ɛ œ a ɔ u] and short vowels [ɐ ɪ ɵ ʊ] in CV and CVS syllables for the four female speakers, the female NH speaker (Fig. 2a) and the three female HI speakers (Figs. 2b, 2c and 2d). Table 5 presents the mean durations of the three groups of vowels, LV-CV, LV-CVS, and SV-CVS, and the duration ratios of LV-CV to LV-CVS and LV-CVS to SV-CVS for the four female speakers.

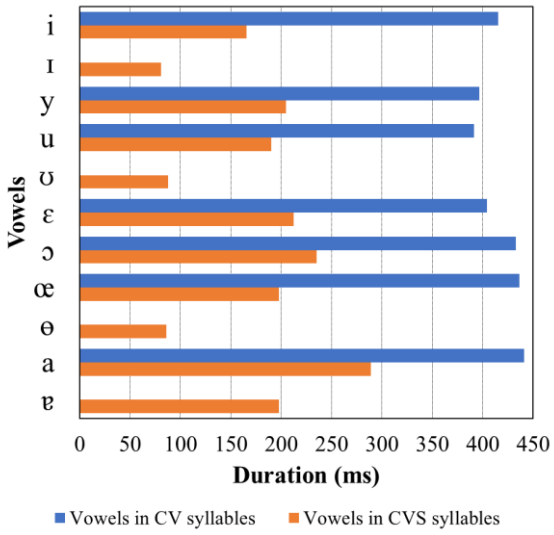
(2a) Female NH speaker (F-NH)



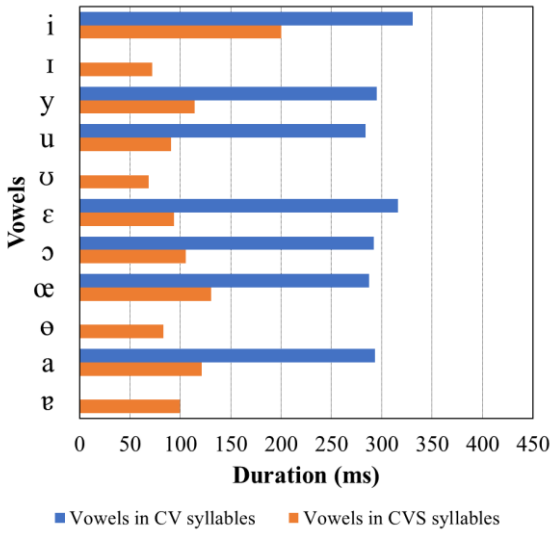
(2b) Female HI speaker 1 (F-HI-1)



(2c) Female HI speaker 2 (F-HI-2)



(2d) Female HI speaker 3 (F-HI-3)



Figs. 2a-2d. Mean durations (in ms) of the Cantonese vowels [i y ɛ œ a ɔ u] in CV syllables (blue bars) and [i y ɛ œ a ɔ u ɐ ɪ ɵ ʊ] in CVS syllables (orange bars) for four female (F) speakers, one NH and three HI.

As shown in Figs. 2a to 2d, there is a considerable difference in duration between the long vowels in the two syllable contexts, CV and CVS. This is true for all the four female speakers, NH and HI. As for the long and short vowels in CVS syllables, the duration tends to be longer for the long vowels than the short vowels for all the four female speakers, but the difference is relatively smaller for two HI speakers, F-HI-1 and F-HI-2, than the female NH speaker.

Speakers	LV-CV	LV-CVS	SV-CVS	Ratio of LV-CV to LV-CVS	Ratio of LV-CVS to SV-CVS
F-NH	239.9	154.1	80.4	1.56 : 1	1.92 : 1
F-HI-1	251.5	86.5	55.1	2.91 : 1	1.57 : 1
F-HI-2	417.0	213.5	113.1	1.95 : 1	1.89 : 1
F-HI-3	229.7	122.4	81.0	1.88 : 1	1.51 : 1

Table 5. Mean durations (in ms) of the Cantonese long vowels in CV syllables (LV-CV) and CVS syllables (LV-CVS) and short vowels in CVS syllables (SV-CVS) for four female (F) speakers, one NH and three HI.

A comparison of the temporal data on the average durations of the three groups of vowels, LV-CV, LV-CVS, and SV-CVS, for the two NH speakers, male (Table 4) and female (Table 5) shows that F-NH has a duration ratio of LV-CV to LV-CVS (1.56:1) slightly smaller than that of M-NH (2.06:1), while the duration ratios of LV-CVS to SV-CVS are similar between F-NH (1.92:1) and M-NH (2.19:1). As for the female HI speakers, the duration ratios of both LV-CV to LV-CVS (1.95:1) and LV-CVS to SV-CVS (1.89:1) for F-HI-2 are similar those for M-NH, but the duration values of L-CV (417 ms), LV-CVS (213.5 ms), and SV-CVS (113.1 ms) for F-HI-2 are noticeably larger than those of the three groups of vowels for the NH speakers, either M-NH (257.5 ms, 125.3 ms, and 57.1 ms) or F-NH (239.9 ms, 154.1 ms, 80.4 ms).

As for F-HI-1 and F-HI-3, their temporal data are similar to the data of at least one NH speaker, except for few cases. For LV-CV, the durations of both F-HI-1 (251.5 ms) and F-HI-3 (229.7 ms) are similar to the durations of the two NH speakers, M-NH (257.5 ms) and F-NH (239.9 ms). As for LV-CVS, the durations of F-HI-1 (86.5) and F-HI-3 (122.4 ms) are shorter than the duration of F-NH (154.1 ms), but the duration of F-HI-3 is similar to that of M-NH (125.3 ms). As for SV-CVS, the duration of F-HI-1 (55.1 ms) is similar to that of M-NH (57.1 ms), whereas the duration of F-HI-3 (81.0 ms) is similar to that of F-NH (80.4 ms). With respect to the duration ratios of the three groups of vowels, the ratio of LV-CV to LV-CVS for F-HI-1 (2.91:1) and F-HI-3 (1.88:1) are larger than that of F-NH (1.56:1), but the ratio of F-HI-3 is similar to that of M-NH (2.06:1). As for the duration ratio of LV-CVS to SV-CVS, the ratios of both F-HI-1 (1.57:1) and F-HI-3 (1.51:1) are smaller than those of M-NH (2.19:1) and F-NH (1.92:1).

Overall, in the speech of the male and female HI speakers in this study, the duration difference between the long vowels in the CV and CVS contexts is considered sufficient and presumably also salient in perception, as the duration ratio of LV-CV to LV-CVS is larger than the ratio of 1.56:1 for the female NH speaker. The exception is only for a single HI male

speaker, M-HI-2, where his duration ratio of LV-CV to LV-CVS is just 1.39:1. As for the duration difference between the long and short vowels in the CVS context, it is sufficient only for two male HI speakers (M-HI-2 and M-HI-3) and one female HI speaker (F-HI-2), who have a duration ratio of LV-CVS to SV-CVS (2.05:1, 1.88:1, 1.89:1) similar to the duration ratios of both the male (2.19:1) and female (1.92:1) NH speakers. As for the other three HI speakers, M-HI-1, F-HI-1, and F-HI-3, they have a duration ratio of LV-CVS to SV-CVS (1.33:1, 1.57:1, 1.51:1) smaller than the duration ratios of the two NH speakers, which indicates that the difference in duration between the long and short vowels in CVS syllables is not sufficiently salient in the speech of these three HI speakers.

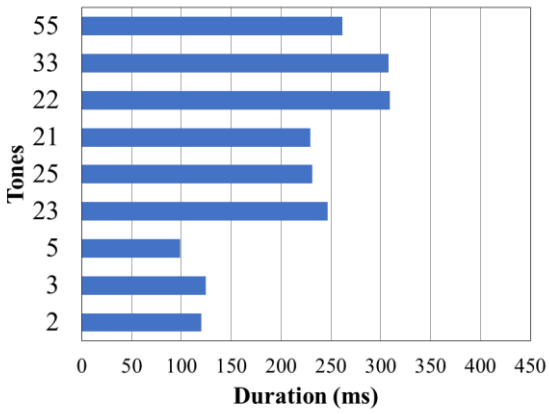
3.1.2 Tone Duration

In this section, the temporal data on the durations of the nine Cantonese citation tones, including the six long ones [55 33 22 21 25 23] and three short tones [5 3 2], produced by the NH and HI speakers are presented and compared. The data are the mean durations of 12 tokens of each tone associated with two vowels, [i] and [u], produced by a particular speaker. Figs. 3a to 3d and Figs. 4a to 4d are the bar charts presenting the durations (in ms) of the nine Cantonese citation tones for the four male speakers (on the left) and the four female speakers (on the right). The charts for all the speakers of the two genders are on the same scale, with the duration of the tones shown on the *x*-axis.

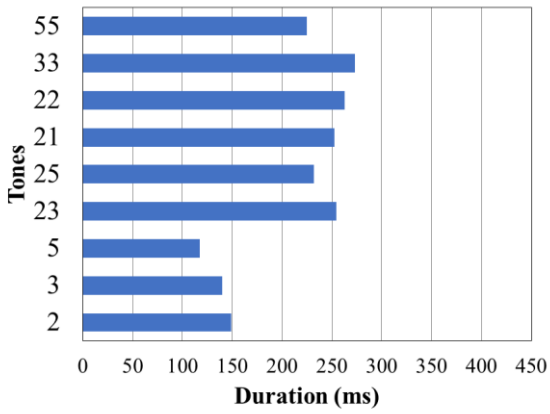
As shown in the charts, for all the speakers, NH and HI, of both genders, the durations of the six long tones [55 33 22 21 25 23] are significantly longer than the durations of the three short tones [5 3 2], while the difference between the two types of tones varies among the speakers. For the two NH speakers, male (Fig. 3a) and female (Fig. 4a), the durations of the six long tones are ranging from about 220 ms to 310 ms, whereas the three short tones are ranging from about 100 ms to 150 ms.

As for the male (Figs. 3b to 3d) and female (Figs. 4b to 4d) HI speakers, all of them produce the long tones with a duration over 200 ms, except for a single case, where the duration of the tone [21] of F-HI1 is slightly below 200 ms (Fig. 4b). For three HI speakers, M-HI-2 (Fig. 3c), F-HI-1 (Fig. 4b), and F-HI-3 (Fig. 4d), the durations of their long tones fall in the range of the NH speakers.

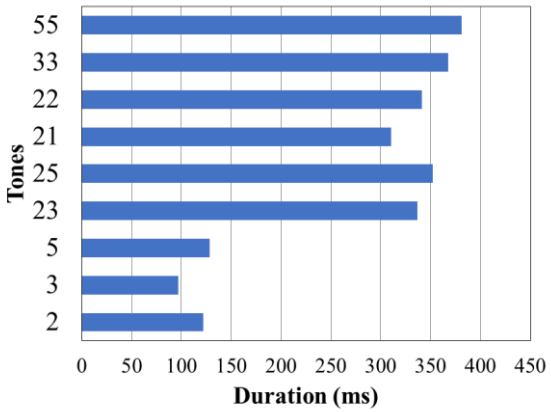
(3a) Male NH speaker (M-NH)



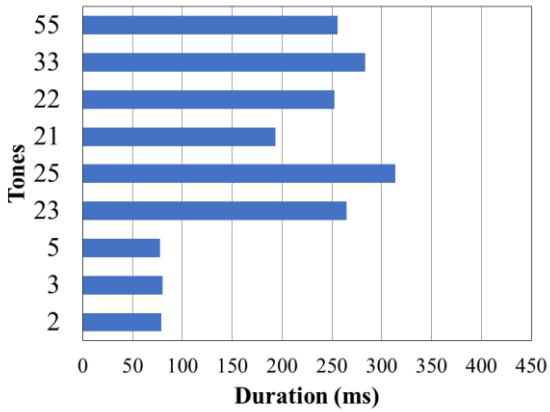
(4a) Female NH speaker (F-NH)



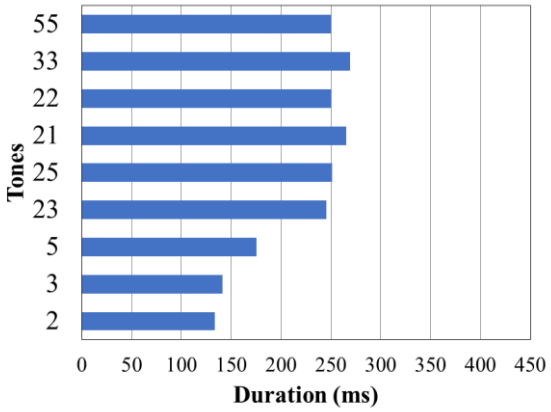
(3b) Male HI speaker 1 (M-HI-1)



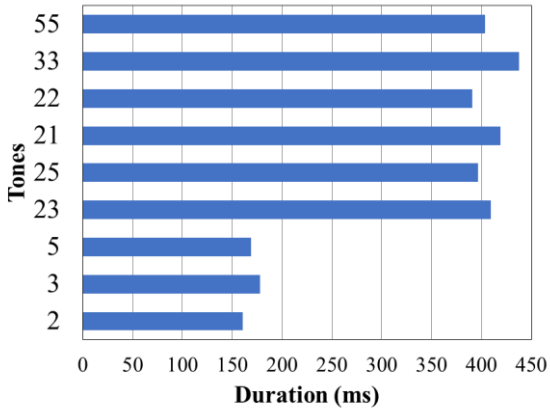
(4b) Female HI speaker 1 (F-HI-1)



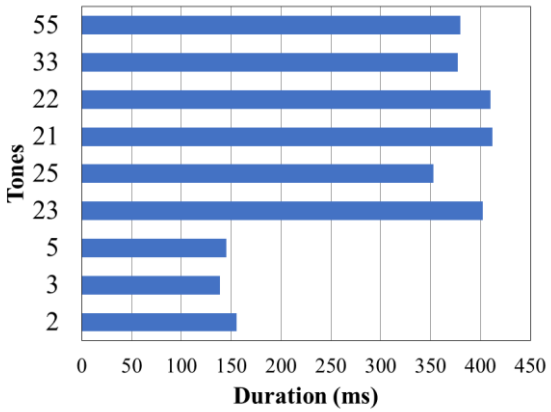
(3c) Male HI speaker 2 (M-HI-2)



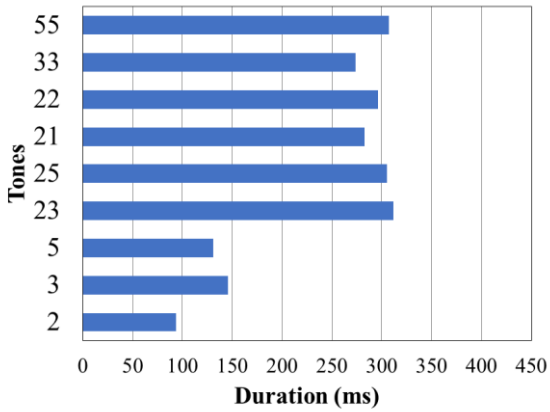
(4c) Female HI speaker 2 (F-HI-2)



(3d) Male HI speaker 3 (M-HI-3)



(4d) Female HI speaker 3 (F-HI-3)



Figs. 3a-3d and 4a-4d. Mean durations (in ms) of the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] for the NH and HI speakers, male (on the left) and female (on the right).

As for the other three HI speakers, M-HI-1 (Fig. 3b), M-HI-3 (Fig. 3d), and F-HI-2 (Fig. 4c), their long tones are significantly longer (ranging from about 300 ms to 430 ms) than the long tones of the two NH speakers. As for the three short tones, the durations of the HI speakers are in the range which is similar to the range of 100-150 ms for the two NH speakers. However, there are some exceptions, including (i) the three short tones for F-HI-1 and the short tone [2] for F-HI-3 with a duration below 100 ms and (ii) the three short tones

for F-HI-2, the short tone [5] for M-HI-2, and the short tone [2] for M-HI-3 with a duration over 150 ms.

Table 6 presents the average durations of all the six long tones (LT) and the three short tones (ST) for each of the NH and HI speakers, male and female. The temporal data also presented in the table are the ratio of the durations of LT to ST for each speaker. As can be seen, the durations of LT and ST are similar between the male (264.3 ms, 114.1 ms) and female (251.1 ms, 129.4 ms) NH speakers, while the duration ratio of LT to ST is slightly larger for the male NH speaker (2.32:1) than the female NH speaker (1.94:1). Comparing the temporal data of the HI speakers with those of the NH speakers, the duration ratio of LT to ST is slightly smaller for M-HI-2 (1.70:1) and slightly larger for M-HI-3 (2.66:1), F-HI-2 (2.42:1), and F-HI-3 (2.40:1). The smaller duration ratio of LT to ST for M-HI-2 is because the duration of ST of the HI speaker (149.9 ms) is longer than that of the NH speakers, both male (114.1 ms) and female (129.4 ms). As for the other three HI speakers, M-HI-3, F-HI-2, and F-HI-3, their durations of LT (388.9 ms, 409.6 ms, 296.1 ms) are longer than those for the male (264.3 ms) and female (251.1 ms) NH speakers, resulting in a larger duration ratio of LT to ST for the three HI speakers than the two NH speakers.

Male speakers	LT	ST	Ratio of LT to ST	Female speakers	LT	ST	Ratio of LT to ST
M-NH	264.3	114.1	2.32 : 1	F-NH	251.1	129.4	1.94 : 1
M-HI-1	348.1	115.5	3.01 : 1	F-HI-1	251.9	79.5	3.17 : 1
M-HI-2	255.2	149.9	1.70 : 1	F-HI-2	409.6	169.1	2.42 : 1
M-HI-3	388.9	146.3	2.66 : 1	F-HI-3	296.1	123.3	2.40 : 1

Table 6. Mean durations (in ms) of the Cantonese long tones (LT) and short tones (ST) for NH and HI speakers, male (M) and female (F).

As for M-HI-1 and F-HI-1, their duration ratios of LT to ST (3.01:1, 3.17:1) are considerably larger than those for the two NH speakers (2.32:1, 1.94:1). The larger ratio for the two HI speakers is because the duration of LT for M-HI-1 (348.1 ms) is much longer than those for M-NH (264.3 ms) and F-NH (251.1 ms), whereas the duration of ST for F-HI-1 (79.5 ms) is much shorter than those for M-NH (114.1 ms) and F-NH (129.4 ms).

Overall, the general temporal patterns of the durations of the long tones and short tones for the HI speakers are similar those for the NH speakers, while the duration ratio of LT to ST tends to be larger for the HI speakers (2.40:1 to 3.17:1) than the NH speakers (1.94:1 to 2.32:1) and there is an exception for a single HI speaker (M-HI-2) who has a slightly smaller duration ratio of LT to ST (1.70:1). The data suggest that the duration contrast between the long and short tones is sufficient in the speech of the HI speakers. In view of the fact that both the long tones and short tones in the study are associated with the long vowels [i] and [u] in the respective CV and CVS test syllables, the temporal data of the long and short tones are corresponding to the temporal data of the long vowels in CV and CVS syllable contexts. A comparison of the two sets of temporal data on vowel duration (Tables 4 and 5) and tone duration (Table 6) for the HI speakers shows that the results are in agreement with each other,

indicating that the HI speakers produce a sufficient duration contrast between the vowels or tones in the checked and non-checked syllable contexts.

3.2 Formant Frequencies for Vowels

This section compares the vowel formant data between the NH and HI speakers, with respect to the positions of the vowels on the F_1/F_2 plane and the size of vowel space.

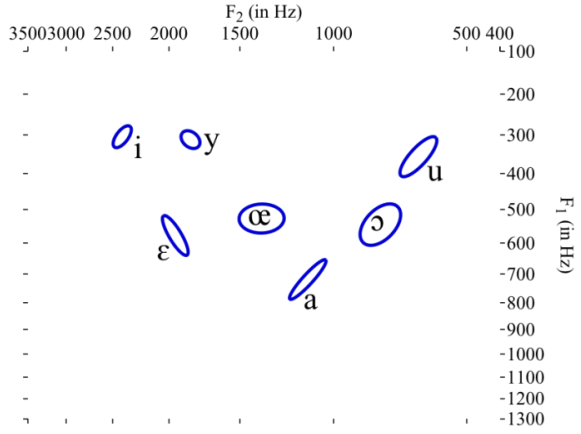
3.2.1 Vowel Ellipses

The vowel ellipses on the F_1/F_2 plane for the seven long vowels [i y ɛ œ a ɔ u] in CV and CVS syllables and the four short vowels [ɐ ɪ ɵ ʊ] in CVS syllables produced by the NH and HI speakers, male and female, are presented as follows. The vowel ellipses are drawn based on the F_1 and F_2 values of six tokens of each vowel from a particular speaker, except the ellipse for vowel [ɛ] in CVS syllables produced by M-HI-1 which is drawn based on five tokens due to one mispronunciation. The area and shape of a vowel ellipse is depending on the variations in F_1 and F_2 of a given vowel.

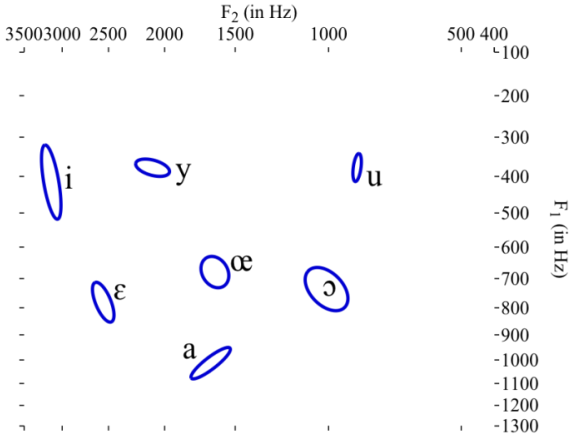
a. <u>Long vowels [i y ɛ œ a ɔ u] in CV syllables</u>

Figs. 5a to 5d show the vowel ellipses for the seven long vowels [i y ɛ œ a ɔ u] in CV syllable on the F_1/F_2 plane for the four male speakers, the male NH speaker (Fig. 5a) and the three male HI speakers, M-HI-1 (Fig. 5b), M-HI-2 (Fig. 5c), and M-HI-3 (Fig. 5d). The same set of vowel ellipses for each of the four female speakers are shown in Fig. 6a (F-NH), Fig. 6b (F-HI-1), Fig. 6c (F-HI-2), and Fig. 6d (F-HI-3). As presented in Fig. 5a for the male NH speaker, the vowel ellipses for all the seven long vowels [i y ɛ œ a ɔ u] in CV syllables occupy distinct positions on the F_1/F_2 plane without overlap. This is also true for the seven vowels in CV syllables produced by the female NH speaker (Fig. 6a).

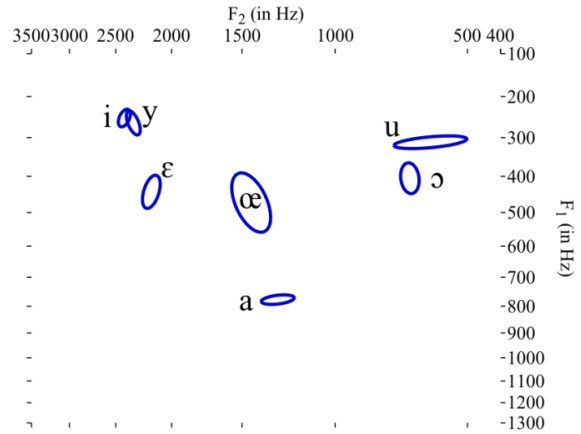
(5a) Male NH speaker (M-NH)



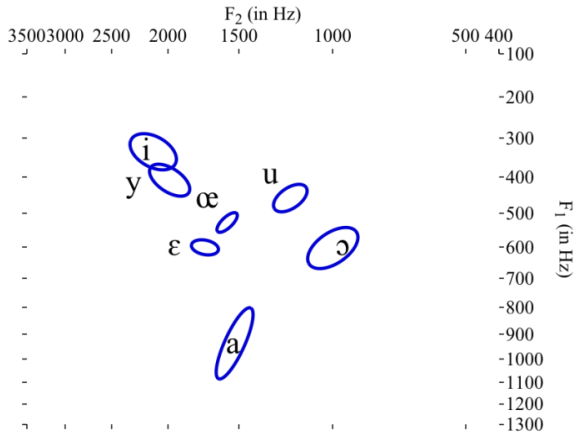
(6a) Female NH speaker (F-NH)



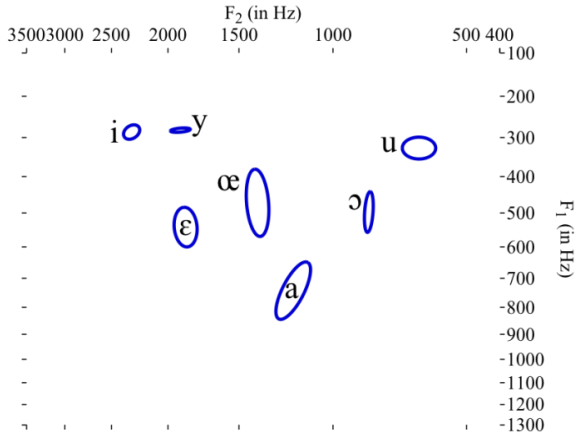
(5b) Male HI speaker 1 (M-HI-1)



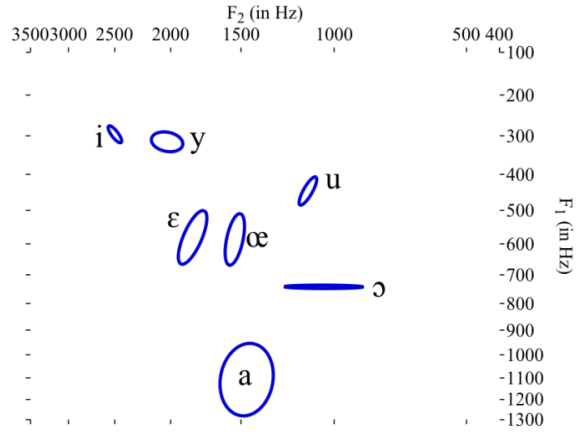
(6b) Female HI speaker 1 (F-HI-1)



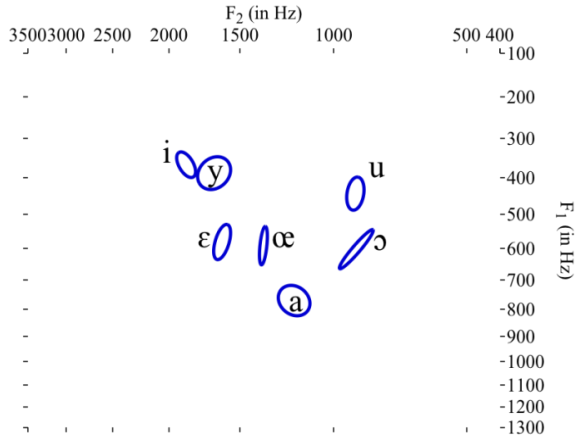
(5c) Male HI speaker 2 (M-HI-2)



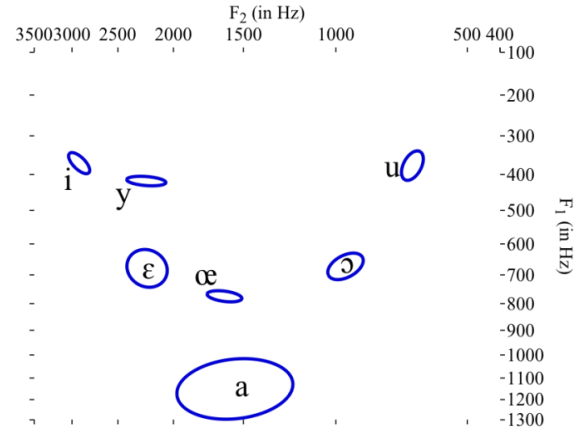
(6c) Female HI speaker 2 (F-HI-2)



(5d) Male HI speaker 3 (M-HI-3)



(6d) Female HI speaker 3 (F-HI-3)



Figs. 5a-5d and 6a-6d. Vowel ellipses for the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables on the F_1/F_2 plane for the NH and HI speakers, male (on the left) and female (on the right).

For both the male and female NH speakers, with respect to the position of vowel ellipses on the F_1/F_2 plane in the vertical dimension, the vowels [i y u] are positioned at the top, the vowels [ɛ œ ɔ] at the mid level, and the vowel [a] at the bottom. This is related to the increasing order of F_1 for [i y u] < [ɛ œ ɔ] < [a] for both M-NH and F-NH. In the horizontal

dimension, the unrounded front vowels [i] and [ɛ] are positioned to the left, due to their large F_2, and the rounded back vowels [u] and [ɔ] to the right due to their small F_2, with the rounded front vowels [y] and [œ] and the low vowel [a] close to the centre of the vowel space. It is assumed that the centralization of [y] and [œ] is due to their small F_2 resulting from the lip rounding effect, whereas the low [a] is intrinsically a centralized vowel in Cantonese.

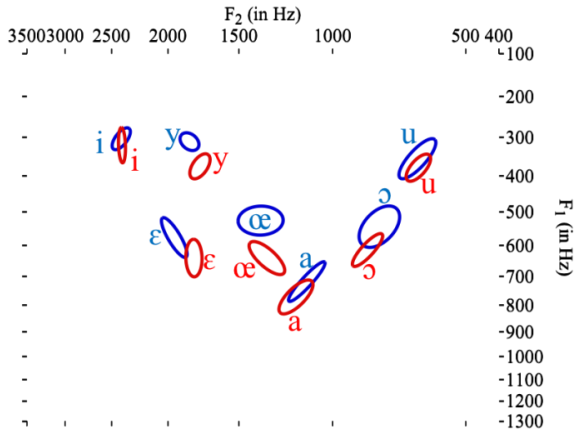
As for the six HI speakers, M-HI-2 (Fig 5c) and F-HI-3 (Fig. 6d) produce the seven long vowels [i y ɛ œ a ɔ u] in CV syllables distinctly on the F_1/F_2 plane without overlap, and the pattern of the relative positions of the seven vowels is similar to that for the two NH speakers (Fig. 5a and Fig. 6a). For F-HI-2 (Fig. 6c), the vowel ellipses for the seven long vowels do not overlap on the F_1/F_2 plane, but the four peripheral vowels [i ɛ ɔ u] are more centralized as compared to the positions of the vowels for the NH speakers. The centralization of the four peripheral vowels [i ɛ ɔ u] on the F_1/F_2 plane is also observed for M-HI-3 (Fig. 5d) and F-HI-1 (Fig. 6b), which results in the proximity of the vowel ellipses for [i] and [y] for each of the two HI speakers. As for the remaining HI speaker, M-HI-1 (Fig. 5b), the vowel ellipses for [i] and [y] are also very close to each other and overlap in a slight degree. However, this is not because of the centralization of [i], but the de-centralization of [y] resulting from an increase in F_2 (2333 Hz) for [y] of M-HI-1 as compared to the F_2 of [y] for the male NH speaker (1835 Hz).

In spite of the differences in centralization of the peripheral vowels [i ɛ ɔ u] and the vowel [y] between the HI and NH speakers, the general pattern of the relative positions of the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables on the F_1/F_2 plane for the HI speakers is similar to that of the NH speakers.

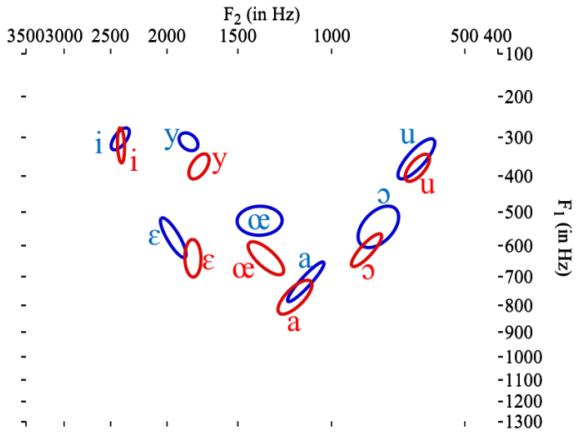
b. <u>Comparison of the long vowels in CV and CVS syllables</u>

Figs. 7a to 7d and Figs. 8a to 8d present the superimposed vowel ellipses for the seven long vowels [i y ɛ œ a ɔ u] in two syllable types, CV (in blue line) and CVS (in red line) syllables, on the F_1/F_2 plane for the NH and HI speakers, male and female, respectively. Note that the vowel [œ] in CVS syllables is not shown in Fig. 7c for the male HI speaker 2, due to mispronunciation of the vowel. Comparisons of the two sets of long vowels in CV and CVS syllables for each speaker and between speakers are made and presented as follows.

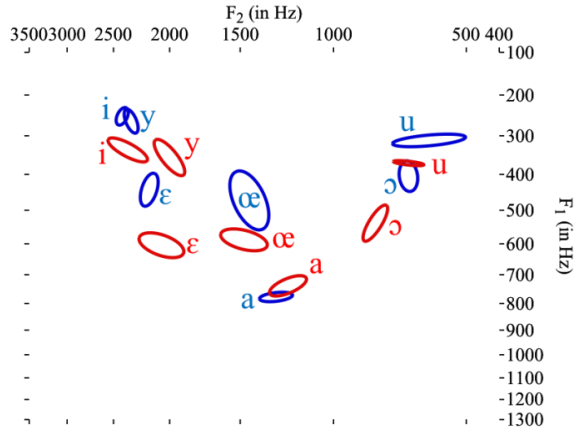
(7a) Male NH speaker (M-NH)



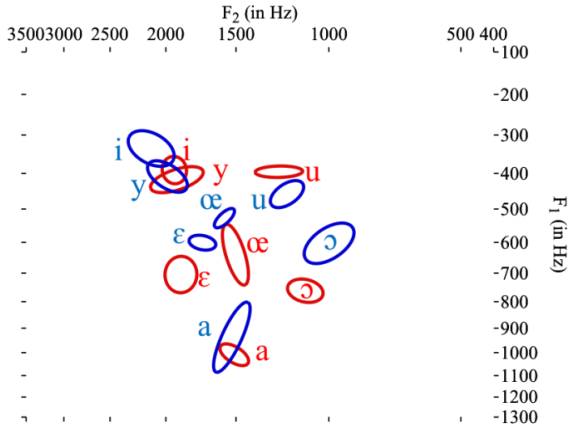
(8a) Female NH speaker (F-NH)



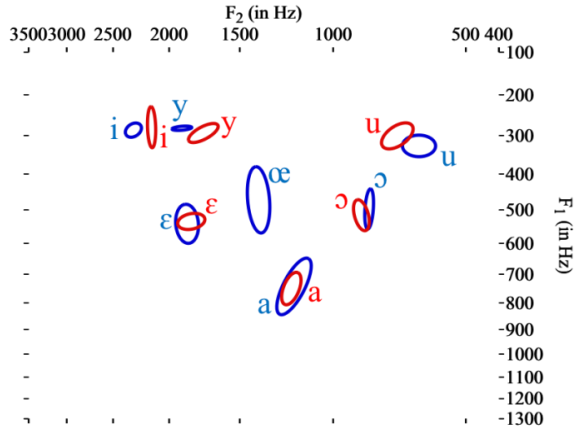
(7b) Male HI speaker 1 (M-HI-1)



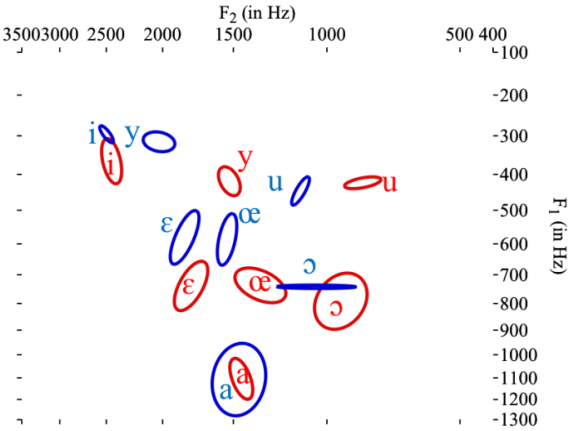
(8b) Female HI speaker 1 (F-HI-1)



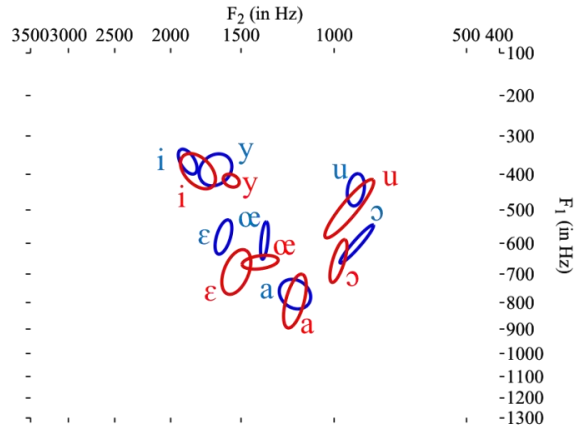
(7c) Male HI speaker 2 (M-HI-2)



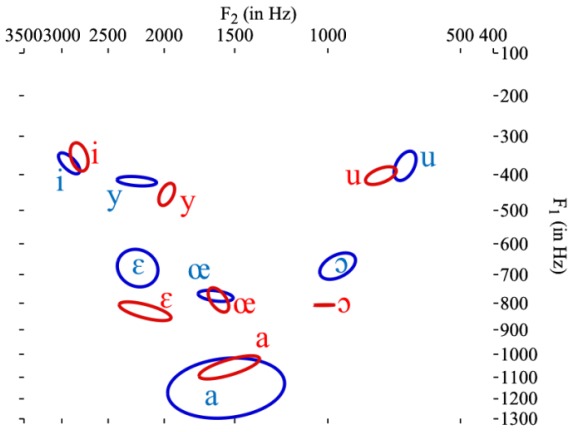
(8c) Female HI speaker 2 (F-HI-2)



(7d) Male HI speaker 3 (M-HI-3)



(8d) Female HI speaker 3 (F-HI-3)



Figs. 7a-7d and 8a-8d. Superimposed vowel ellipses for the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables (in blue line) and CVS syllables (in red line) on the F_1/F_2 plane for the NH and HI speakers, male (on the left) and female (on the right).

From the figures for the two NH speakers, M-NH (Fig. 7a) and F-NH (Fig. 8a), it can be seen that the relative positions of the seven vowels in the two syllable contexts on the F_1/F_2 plane are similar, while there is a general tendency that the positions of the vowels in CVS syllables are lower than those of the corresponding vowels in CV syllables. There are few cases, for instances, the high vowels [i] and [u] for M-NH and the vowels [i] and [ɛ] for F-

NH, without the lowering or downward shift in position on the F_1/F_2 plane when the vowels occur in CVS syllables.

As for the HI speakers, the general tendency of the downward shift in position for the long vowels in CVS syllables on the F_1/F_2 plane is observed, while exceptional cases are also found. Considering the male HI speakers, for M-HI-1 (Fig. 7b), the mid vowels [ɛ] and [ɔ] are more or less the same in CV and CVS syllables and the low vowel [a] in CVS syllables is slightly raised, whereas the other four vowels, [i y u œ], in CVS syllables are lowered on the F_1/F_2 plane. As for M-HI-2 (Fig. 7c), he produces the long vowels in CVS syllables similar to those in CV syllables in terms of the vertical position on the F_1/F_2 plane. This is more even so for the vowels [ɛ] and [a], where their positions are almost the same in the two syllable contexts on the F_1/F_2 plane. For M-HI-3 (Fig. 7d), all the seven long vowels [i y ɛ œ a ɔ u] are positioned lower on the F_1/F_2 plane in CVS syllables than in CV syllables, while the degree of downward shift is minimal for [a]. It should be noted that for M-HI-3, the centralization of the positions of the four peripheral vowels [i ɛ ɔ u] is observed in both CV and CVS syllables, by comparing with the formant patterns of the vowels in CV and CVS syllables for the male NH speaker.

As for the three female HI speakers, F-HI-1 (Fig. 8b) also produces the long vowels in CVS syllables with a lowered position on the F_1/F_2 plane as compared with the long vowels in CV syllables, except for [u] which has a higher position on the F_1/F_2 plane in CVS syllables than in CV syllables. For F-HI-2 (Fig. 8c), the downward shift in position on the F_1/F_2 plane for the long vowels in CVS syllables is except for [u] and [a]. Furthermore, both F-HI-1 and F-HI-2 are similar to M-HI-3 that the positions of the four peripheral vowels [i ɛ ɔ u] are centralized in CV and CVS syllables, as compared to the vowel formant patterns for the NH speakers. As for F-HI-3 (Fig. 8d), the general tendency that the long vowels in CVS syllables have a lowered position on the F_1/F_2 plane is not true for [i u œ] and [a]. The positions of the former three vowels [i u œ] in CVS syllables are similar to those in CV syllables, whereas the position of the vowel [a] in CVS syllables is raised as compared to the position of [a] in CV syllables.

In general, the HI speakers distinguish the seven long vowels in each of the two syllable contexts, CV and CVS, acoustically, although the centralization of the peripheral vowels [i ɛ ɔ u] is observed for three HI speakers, which results in the reduction of the vowel space for the three HI speakers. For both the NH and HI speakers, it is observed that the patterns of the relative positions of the seven vowels in the two syllable contexts are generally similar, except for the tendency that the positions of the vowels are lowered on the F_1/F_2 plane in CVS syllables than in CV syllables.

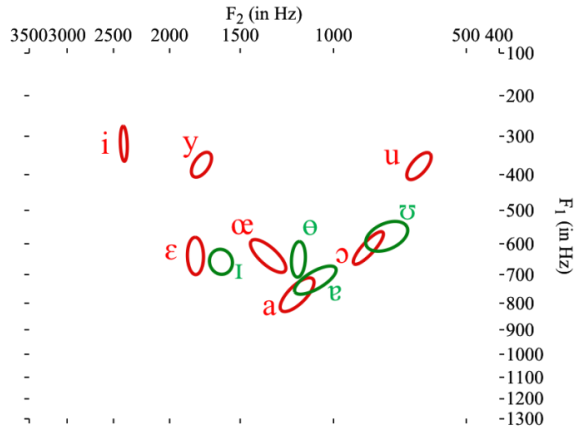
c. Comparison of the long vowels and short vowels in CVS syllables

Figs. 9a to 9d and Figs. 10a to 10d present the superimposed vowel ellipses for the seven long vowels [i y ɛ œ a ɔ u] (in red line) and the four short vowels [ɪ ɵ ʊ ɐ] (in green line) in CVS syllables on the F_1/F_2 plane for the NH and HI speakers, male and female. Comparisons of the two sets of vowels for each speaker and between speakers are presented below.

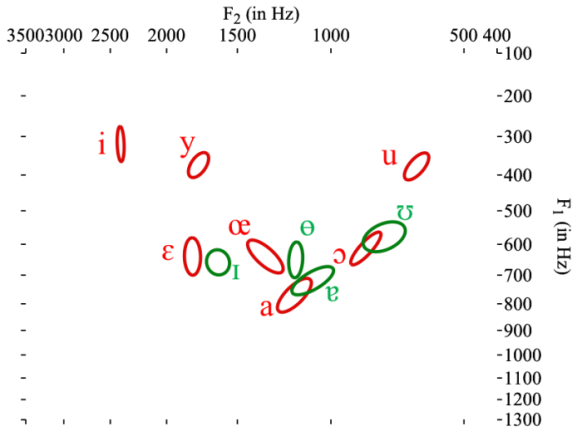
For the male (Fig. 9a) and female (Fig. 10a) NH speakers, the long vowels [i y ɛ œ a ɔ u] and short vowels [ɪ ɵ ʊ ɐ] in CVS syllables are positioned distinctly on the the F_1/F_2 plane, except for the partial overlaps between [ɔ] and [ʊ] and between [a] and [ɐ] for M-NH and the

proximity of the vowel ellipses of [ɛ] and [ɪ] for F-NH. Based on the vowel formant data of the two NH speakers, it can be characterized that the two short lax vowels [ɪ] and [ʊ] are centralized and much lowered than the tense counterparts [i] and [u], resulting in the proximity to the respective mid long vowels, the front [ɛ] and back [ɔ]. As for the short vowels [ɵ] and [ɐ], they are positioned closer to the centre of the vowel space than the long vowels [œ] and [a], respectively.

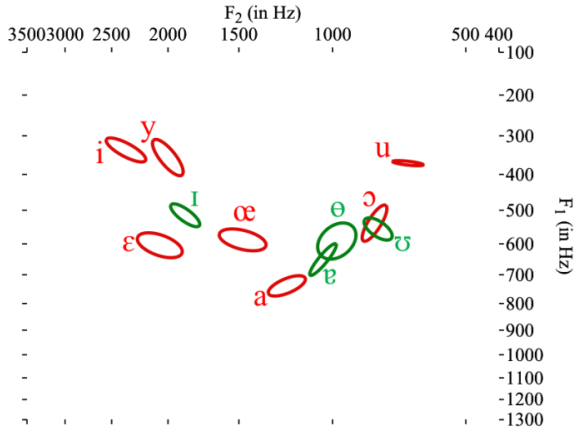
(9a) Male NH speaker (M-NH)



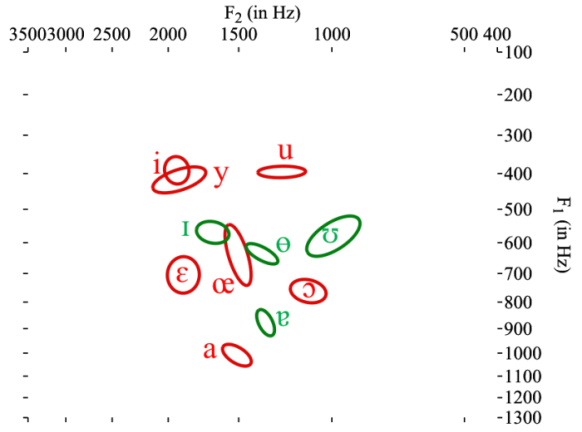
(10a) Female NH speaker (F-NH)



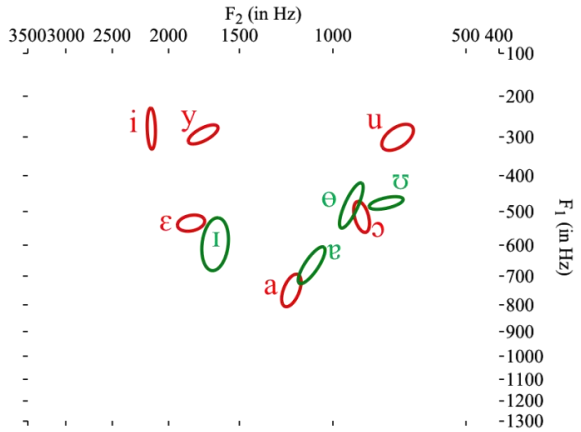
(9b) Male HI speaker 1 (M-HI-1)



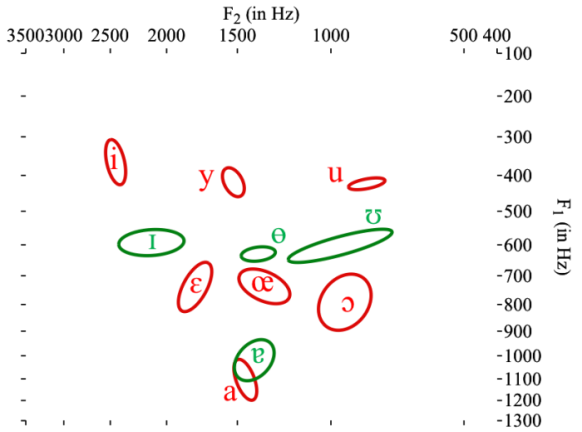
(10b) Female HI speaker 1 (F-HI-1)



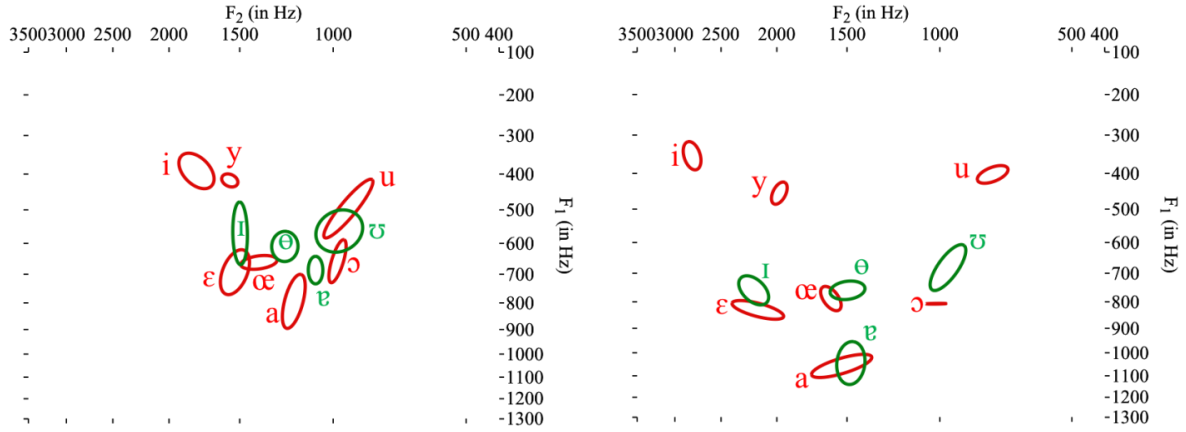
(9c) Male HI speaker 2 (M-HI-2)



(10c) Female HI speaker 2 (F-HI-2)



(9d) Male HI speaker 3 (M-HI-3) (10d) Female HI speaker 3 (F-HI-3)



Figs. 9a-9d and 10a-10d. Superimposed vowel ellipses for the Cantonese long vowels [i y ɛ œ a ɔ u] (in red line) and short vowels [ɪ ɵ ʊ ɐ] (in green line) in CVS syllables on the F_1/F_2 plane for the NH and HI speakers, male (on the left) and female (on the right).

As for the HI speakers, the general patterns of the positions of the seven long vowels and four short vowels in CVS syllables on the F_1/F_2 plane are similar to those of the NH speakers. Basically, the two sets of vowels are positioned separately on the F_1/F_2 plane, except for the partial overlap between some vowels. For M-HI-1 (Fig. 9b), partial overlap is observed between the long vowel [ɔ] and short vowel [ʊ], which is also true in the speech of the male NH speaker (Fig. 9a). Partial overlap is also observed between the two short vowels [ɵ] and [ɐ] for M-HI-1, which is likely due to the backward shift in position for the vowel [ɵ] as compared to the vowel [ɵ] for the male NH speaker.

For M-HI-2 (Fig. 9c), a minimal degree of overlap is observed between the long vowel [ɔ] and short vowel [ɵ] and between the two low vowels [a] and [ɐ]. The overlap between [ɔ] and [ɵ] is also likely due to the backward shift in position for the vowel [ɵ] in the speech of M-HI-2, as compared to the vowel [ɵ] for the male NH speaker (Fig. 9a). As for the overlap between [a] and [ɐ], it is also observed in the speech of the male NH speaker.

For M-HI-3 (Fig. 9d), it can be seen that all the 11 vowels in CVS syllables are crowded toward to the centre of the vowel space on the F_1/F_2 plane, as compared to the vowel formant patterns for the male NH speaker (Fig. 9a). In spite of the centralization of the vowels in the vowel space for M-HI-3, partial overlap is observed only for the paired long vowel [ɛ] and short vowel [ɪ] and for the three back vowels in the group of [u ʊ ɔ]. In view of the fact that the overlap between [ɛ] and [ɪ] is minimal and the position of the short vowel [ʊ] is basically positioned in between the two long vowels [u] and [ɔ], it is considered that the HI speaker, M-HI-3, distinguishes all the 11 vowels in CVS syllables acoustically on the F_1/F_2 plane.

As for the female HI speakers, the centralization of the vowels in the vowel space is observed for F-HI-1 (Fig. 10b) and F-HI-2 (Fig. 10c), as compared to the formant patterns for the vowels produced by the female NH speaker (Fig. 10a). Similar to the case of M-HI-3, in spite of the centralization in the vowel space, partial overlap is observed only for few paired vowels, between the paired long vowel [œ] and short vowel [ɪ] for F-HI-1 and between the paired long vowel [a] and short vowel [ɐ] for F-HI-2. The overlap between [œ] and [ɪ] is minimal for F-HI-1 (Fig. 10b), whereas the overlap between [a] and [ɐ] for F-HI-2 (Fig. 10c)

is also found in the speech of the male NH speaker (Fig. 9a). Thus, these two female HI speakers are considered to have no difficulty in differentiating the 11 vowels in CVS syllables.

As for F-HI-3 (Fig. 10d), her formant patterns for the vowels produced in CVS syllables are similar to the vowel formant patterns for the two NH speakers (Fig. 9a and Fig. 10a). For F-HI-3, both the proximity of the positions of the paired long vowel [ɛ] and short vowel [ɪ] and partial overlap between the paired long vowel [a] and short vowel [ɐ] are observed, the same to the case of the male NH speaker (Fig. 9a). Overlap between the paired long vowel [œ] and short vowel [ɵ] is also observed for F-HI-3, but the degree of overlap is minimal.

Overall, the HI speakers produce distinct formant patterns for the Cantonese long and short vowels in both CV and CVS syllable contexts, similar to the vowel formant patterns for the NH speakers. A significant difference in vowel production between the HI and NH speakers is mainly in the centralization of the vowels, in particular the four peripheral vowels [i ɛ ɔ u], in the vowel space.

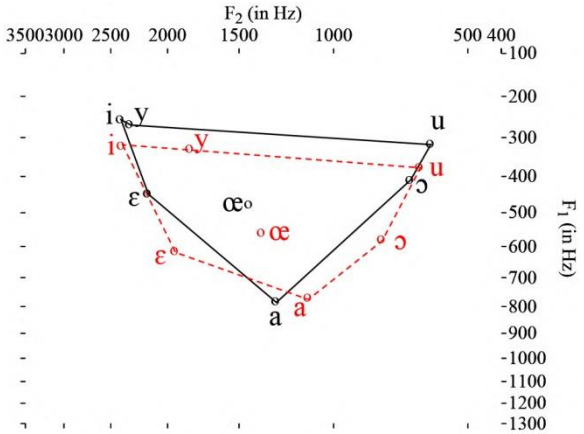
3.2.2 Vowel Space

In this section, comparison is made for the entire vowel spaces for the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables and all the eleven Cantonese vowels, including the seven long ones [i y ɛ œ a ɔ u] and the four short ones [ɪ ɵ ʊ ɐ], in CVS syllables produced by the HI and NH speakers. The vowel space for each group of vowels is drawn by connecting the mean F_1F_2 data points of the six peripheral vowels [i y ɛ a ɔ u] in the group on the F_1/F_2 plane for a particular speaker. The figures presented below show the superimposed vowel spaces for the NH speaker and each of one of the HI speakers of the same gender.

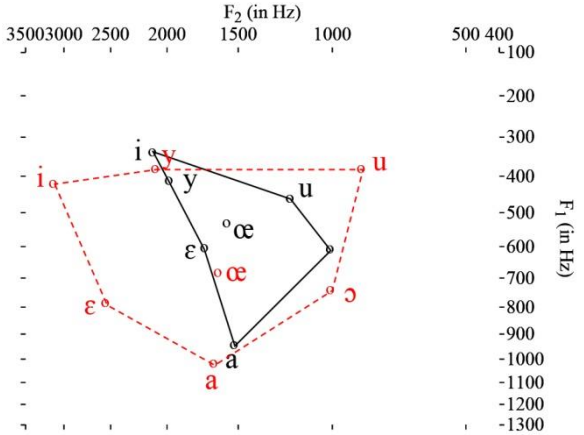
a. <u>Long vowels in CV syllables</u>

Figs. 11a to 11c show the superimposed vowel spaces for the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables on the F_1/F_2 plane between the male NH speaker (in red dashed line) and each of the three male HI speakers (in dark solid line). Figs. 12a to 12c show the superimposed vowel spaces for the female NH speaker and each of the three female HI speakers.

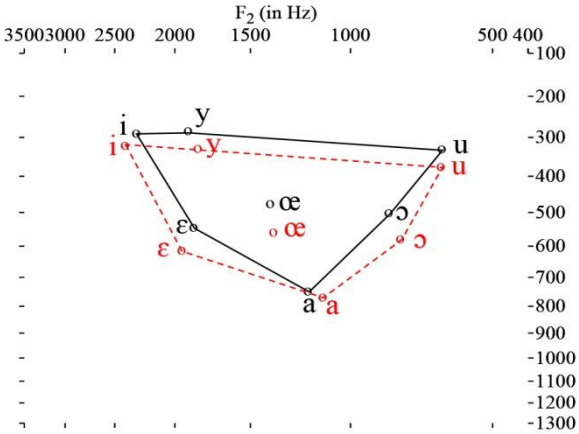
(11a) Male NH speaker and HI speaker 1



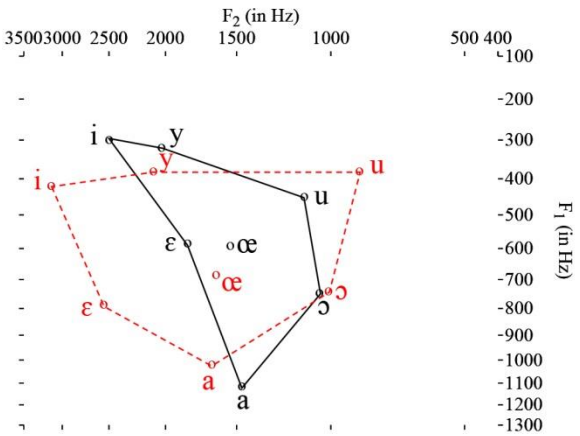
(12a) Female NH speaker and HI speaker 1



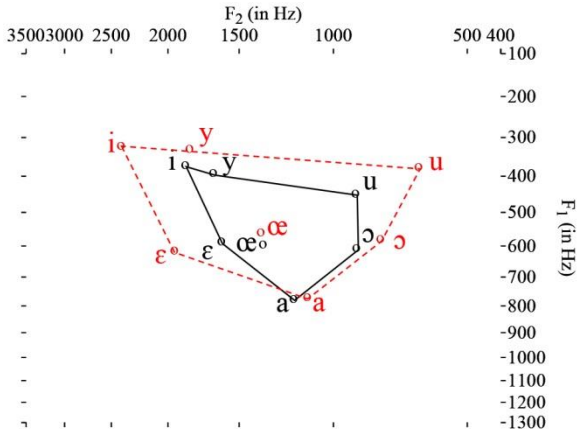
(11b) Male NH speaker and HI speaker 2



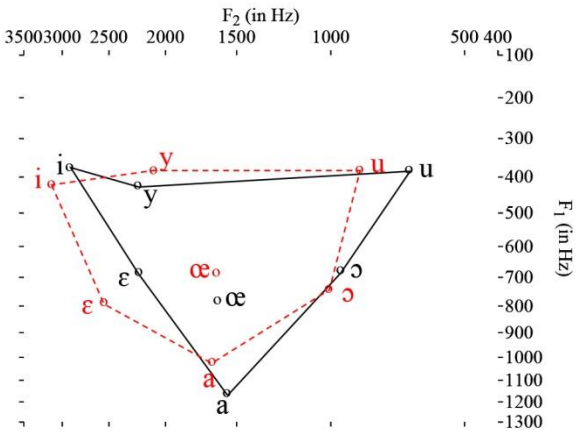
(12b) Female NH speaker and HI speaker 2



(11c) Male NH speaker and HI speaker 3



(12c) Female NH speaker and HI speaker 3



Figs. 11a-11c and 12a-12c. Superimposed vowel spaces for the Cantonese long vowels [i y ɛ œ a ɔ u] in CV syllables on the F_1/F_2 plane for the NH speaker (in red dashed line) and each of the HI speakers (in dark solid line) of the same gender, male (on the left) and female (on the right).

From the figures for the male speakers, it can be seen that the vowel spaces for two HI speakers, M-HI-1 and M-HI-2, are similar to the vowel space for the male NH speaker in size and in position on the F_1/F_2 plane. This is evidenced by the extensive overlap between the vowel spaces for the NH and each of the two HI speakers shown in Fig. 11a and Fig. 11b. As for the male HI speaker 3, M-HI-3, his vowel space is noticeably smaller than the vowel space for the male NH speaker (Fig. 11c). The reduction in size of the vowel space for M-HI-3 lies in the centralization of the peripheral vowels [i y ɛ ɔ u], resulting in the downward and inward shrinkage of the vowel space relative to the vowel space for the male NH speaker.

A reduction in size of the vowel space is also observed for two female HI speakers, F-HI-1 (Fig. 12a) and F-HI-2 (Fig. 12b), in comparison of the vowel space for the female NH speaker. For these two female HI speakers, the reduction in vowel space size is mainly due to the centralization of the peripheral vowels [i ɛ u], in particular the two front vowels [i] and [ɛ], resulting in the backward shrinkage of the vowel space relative to the vowel space for the female NH speaker. As for the female HI speaker 3, F-HI-3 (Fig. 12c), her vowel space is similar in size to the vowel space for the female NH speaker, while there is a slight backward shift in position for the vowel space of F-HI-3 than that of F-NH.

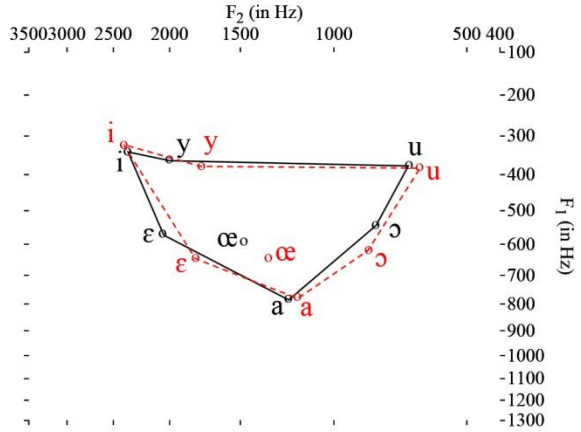
b. Long vowels in CVS syllables

Figs. 13a to 13c and Figs. 14a to 14c show the superimposed vowel spaces for the seven Cantonese long vowels [i y ɛ œ a ɔ u] in CVS syllables on the F_1/F_2 plane for the NH speaker (in red dashed line) and each one of the HI speakers (in dark solid line) of the same gender.

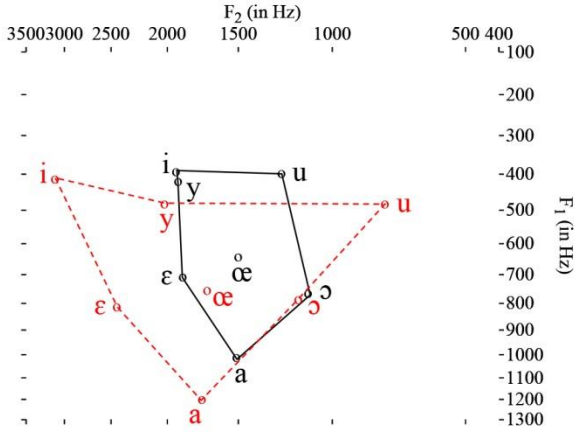
As can be seen in the figures for M-HI-1 (Fig. 13a) and M-HI-2 (Fig. 13b), their vowel spaces are generally similar to the vowel space for the male NH speaker in both size and position, though the vowel space is positioned more upward for M-HI-2, relative to the position of the vowel space for M-NH. As for M-HI-3 (Fig. 13c), the vowel space is noticeably reduced in size as compared with the vowel space for M-NH, due to the centralization of the peripheral front and back vowels, in particular the high vowels [i y u]. The reduction in vowel space size for M-HI-3 results in the downward and inward shrinkage of the vowel space, which is similar to the shrinkage pattern of the vowel space for the long vowels in CV syllables for M-HI-3 (Fig. 11c).

As for the female HI speakers, F-HI-1 (Fig. 14a) and F-HI-2 (Fig. 14b), the vowel space for the vowels in CVS syllables is smaller than the vowel space for the female NH speaker. For both the female HI speakers, the reduction in vowel space size for the vowels in CVS syllables is due to the centralization of the vowels [i ɛ u a], in particular the two front vowels, resulting in the backward and upward shrinkage of vowel space relative to the vowel space for the female NH speaker.

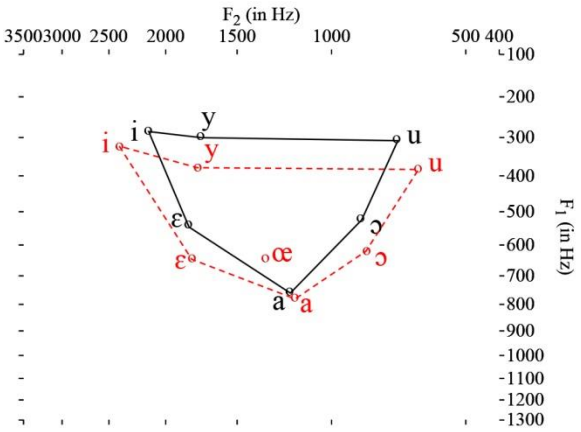
(13a) Male NH speaker and HI speaker 1



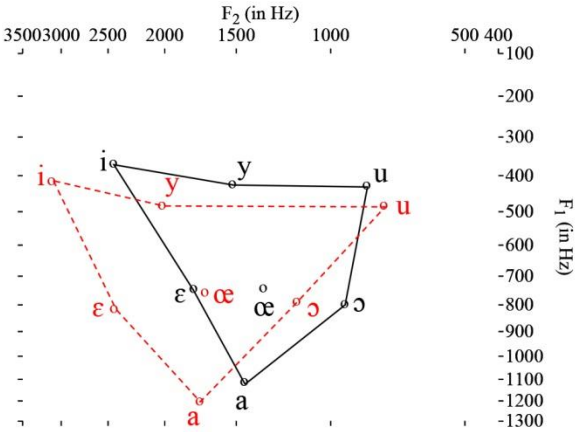
(14a) Female NH speaker and HI speaker 1



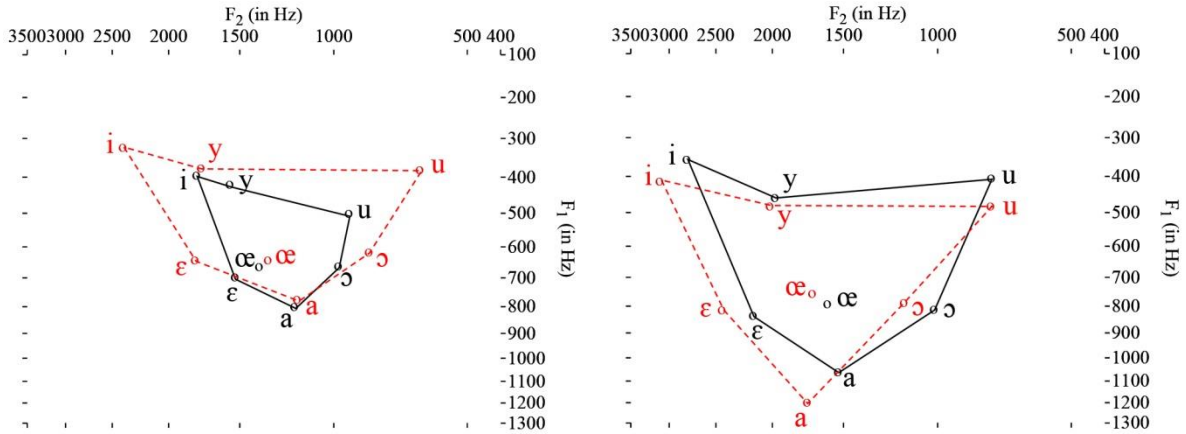
(13b) Male NH speaker and HI speaker 2



(14b) Female NH speaker and HI speaker 2



(13c) Male NH speaker and HI speaker 3 (14c) Female NH speaker and HI speaker 3



Figs. 13a-13c and 14a-14c. Superimposed vowel spaces for the Cantonese long vowels [i y ɛ œ a ɔ u] in CVS syllables on the F_1/F_2 plane for the NH speaker (in red dashed line) and each of the HI speakers (in dark solid line) of the same gender, male (on the left) and female (on the right).

As for the female HI speaker 3, F-HI-3 (Fig. 14c), the positions of the peripheral vowels [i ɛ a] are slightly centralized and the positions of [i] and [a] are raised, resulting in a small degree of backward and upward shift for the vowel space as compared to the vowel space for the female NH speaker. In spite of that there is no significant reduction in the size of the vowel space for F-HI-3 relative to the vowel space for F-NH.

In general, the vowel formant data show that there is a considerable reduction in the size of vowel space for three HI speakers, M-HI-3, F-HI-1, and F-HI-2, mainly due to the centralization of the peripheral vowels in the vowel space. There is a minor difference in pattern of the reduction in vowel space between the male and female HI speakers. For M-HI-3, the reduction in vowel space leads to the shrinkage of the vowel space toward to the centre and the downward part of the F_1/F_2 plane. As for F-HI-1 and F-HI-2, the reduction in vowel space results in the backward shrinkage of the vowel space, as compared with the vowel space for the female NH speaker.

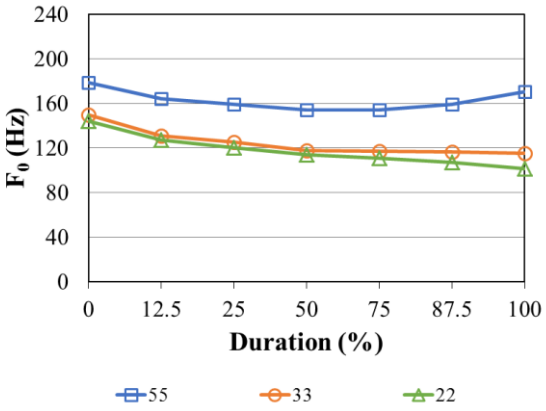
3.3 Fundamental Frequency (F_0) for Tones

This section is concerned with deficiency in tone production for the HI speakers, by comparing their fundamental frequency (F_0) values for the nine Cantonese citation tones, including the six long tones [55 33 22 21 25 23] and the three short tones [5 3 2], with those for the NH speakers. The nine Cantonese tones are divided into three groups for comparison, with the three level tones [55 33 22] in one group and the three contour tones [21 25 23] and the three short tones in the other two groups. The figures presented below show the mean F_0 contours of the three groups of Cantonese tones, based on the F_0 values for 12 tokens for each tone produced by a particular speaker. The F_0 contours of the tones are normalized in duration, represented with a series of seven time points evenly sampled at every 12.5% of a tone.

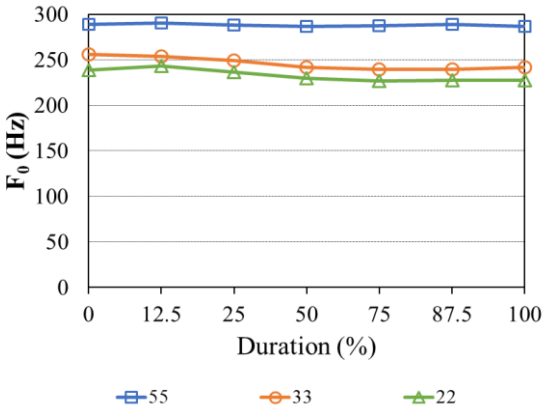
a. Level tones

Figs. 15a to 15d present the F_0 contours of the three Cantonese level tones [55 33 22] contours, based on the average F_0 values (*y-axis*) at the seven evenly spaced time points of each tone (*x-axis*) produced by one of the four male speakers in this study, the male NH speaker (Fig. 15a) and the three male HI speakers, M-HI-1 (Fig. 15b), M-HI-2 (Fig. 15c), and M-HI-3 (Fig. 15d). The average F_0 contours of the three long level tones presented in Figs. 16a to 16d are for the four female speakers, F-NH (Fig. 16a), F-HI-1 (Fig. 16b), F-HI-2 (Fig. 16c), and F-HI-3 (Fig. 16d). The figures for the speakers of each gender are on the same scale.

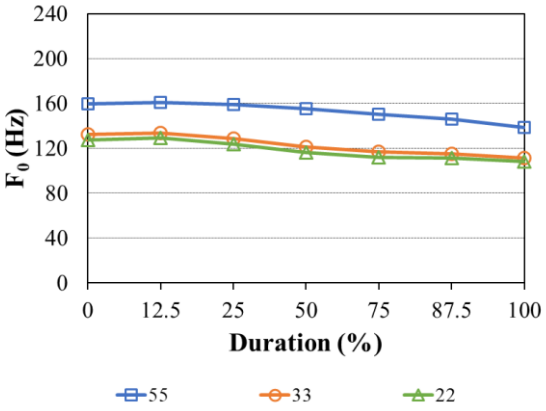
(15a) Male NH speaker (M-NH)



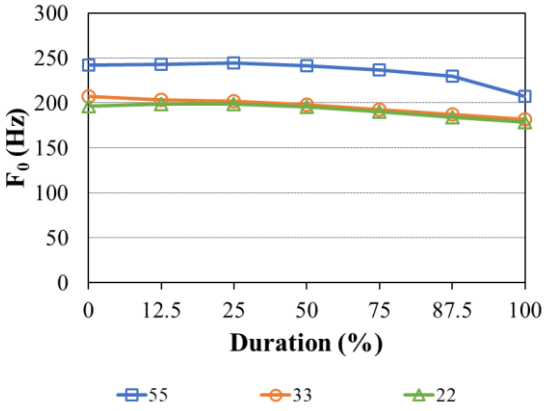
(16a) Female NH speaker (F-NH)



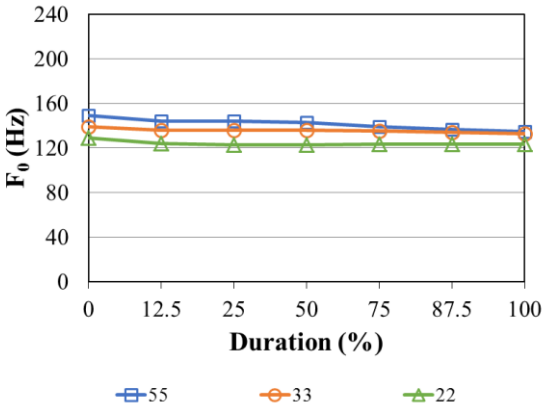
(15b) Male HI speaker 1 (M-HI-1)



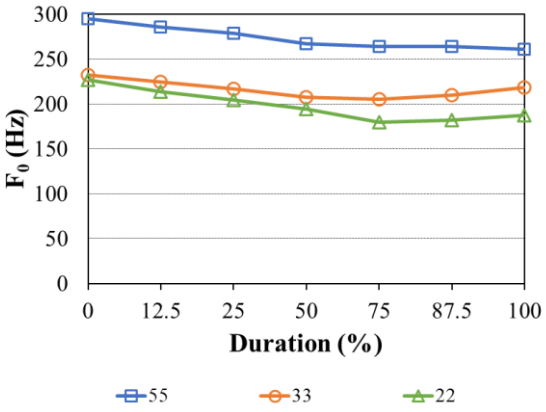
(16b) Female HI speaker 1 (F-HI-1)



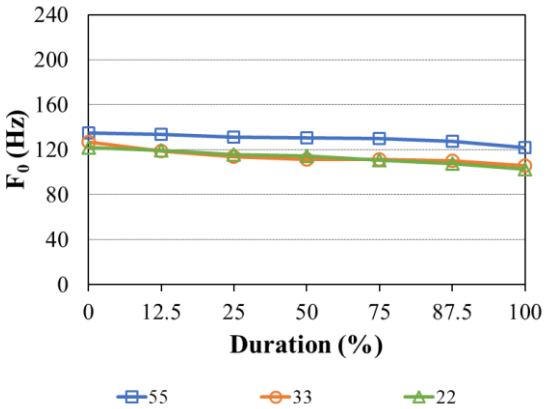
(15c) Male HI speaker 2 (M-HI-2)



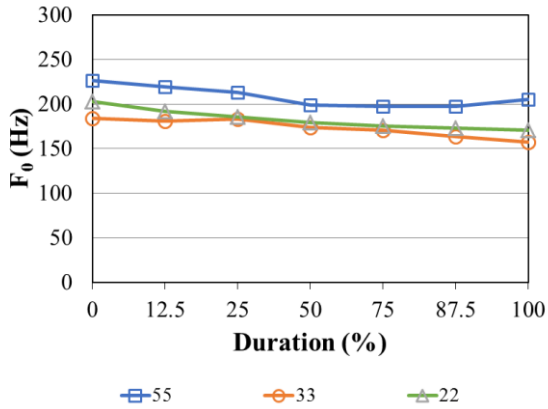
(16c) Female HI speaker 2 (F-HI-2)



(15d) Male HI speaker 3 (M-HI-3)



(16d) Female HI speaker 3 (F-HI-3)



Figs. 15a-15d and Figs. 16a-16d. F_0 contours of the three Cantonese long level tones [55 33 22] for the NH and HI speakers, male (on the left) and female (on the right).

As shown in the figures for the two NH speakers, M-NH (Fig. 15a) and F-NH (Fig. 16a), the F_0 contour of the tone [55] (in blue line) is basically level, while the male one tilts slightly upward toward the two ends. The F_0 contours of the other two tones, [33] (in orange line) and [22] (in grey line), slightly fall toward the end for both the male and female NH speakers, while the degree of falling is minimal for F-NH. A comparison of the F_0 contours of the three tones for each of the two NH speakers shows that the F_0 value average across the seven time points is largest for [55] (male: 163 Hz; female: 288 Hz), followed by [33] (male: 125 Hz; female: 246 Hz) and then [22] (male: 118 Hz; female: 233 Hz), where the difference in F_0 is much larger between [55] and [33] (male: 38 Hz; female: 42 Hz) than between [33] and [22] (male: 7 Hz; female: 13 Hz).

As for the HI speakers (Figs. 15b-15d and Figs. 16b-16d), the F_0 contours of the tones [55 33 22] are basically level, with a slight fall toward the end. This is true for all the six HI speakers, while the degree of falling of the F_0 contours of the three tones is slightly larger for F-HI-2 (Fig. 16c) than the other HI speakers. Furthermore, for all the HI speakers, the tone [55] is produced the largest F_0 value than the tones [33] and [22]. However, the difference in F_0 between the tone [55] and the other two tones are not significant for all the six HI speakers. Regarding the F_0 averaging across the seven time points, the difference between the tones [55] and [33] is sufficiently large for M-HI-1 (30 Hz), F-HI-1 (39 Hz), and F-HI-2 (58 Hz), similar to the difference between the two tones for the two NH speakers, M-NH (38 Hz) and F-NH (42 Hz). The difference in F_0 between the tones [33] and [22] for these three HI speakers, M-HI-1 (5 Hz), F-HI-1 (4 Hz), and F-HI-2 (18 Hz), is also similar to that for M-NH (7 Hz) and F-NH (13 Hz). Such patterns of difference in F_0 for the tones [55 33 22] however are not observed the other three HI speakers, M-HI-2 (Fig. 15c), M-HI-3 (Fig. 15d), and F-HI-3 (Fig. 16d).

For M-HI-2, the difference in F_0 is minimal and smaller between the tones [55] and [33] (5 Hz) than between the tones [33] and [22] (12 Hz). For M-HI-3, while the difference in F_0 is larger between [55] and [33] (16 Hz) than between [33] and [22] (1 Hz), the differences between the paired tones in the two cases are not sufficiently large as the cases for the NH

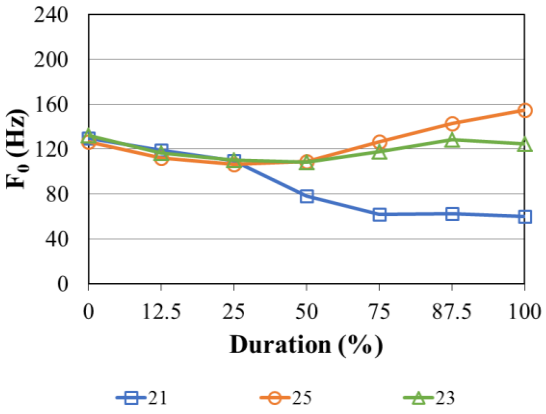
speakers. The data indicate that both M-HI-2 and M-HI-3 do not differentiate the three Cantonese long level tones [55 33 22].

As for F-HI-3, while the difference in F_0 between the tones [55] and [33] (34 Hz) is sufficiently large, it is not the case between the tones [33] and [22], where the F_0 of [33] (174 Hz) is smaller than the F_0 of [22] (183 Hz). The F_0 data of this HI speaker indicate that the speaker wrongly pronounces the tones [33] and [22].

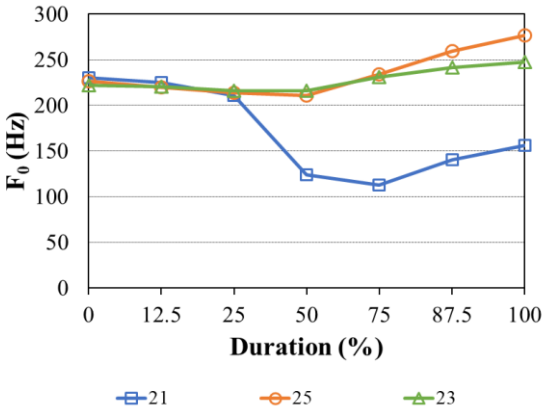
b. Contour tones

Figs. 17a to 17d show the F_0 contours of the three Cantonese contour tones [21 25 23] for the eight speakers, two NH speakers and six HI speakers, male (on the left) and female (on the right). As shown in Fig. 17a for the male NH speaker, the F_0 contours of all the three contour tones overlap extensively at the beginning, where the F_0 values at the onset or 0% of the contours of the tones [21] (129 Hz), [25] (126 Hz), and [23] (132 Hz) are similar. The difference among the three tones lies mainly in the second half of the F_0 contour. Basically, the F_0 contour of [21] is falling toward to the lower end of the pitch range of the speaker, whereas the F_0 contours of [25] and [23] are rising, with a higher offset for [25] than [23]. Thus, it can be characterized that [21] is low falling tone, whereas [25] is a high rising tone and [23] a mid rising tone.

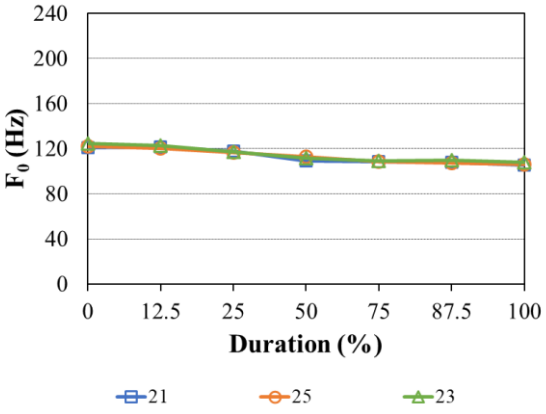
(17a) Male NH speaker (M-NH)



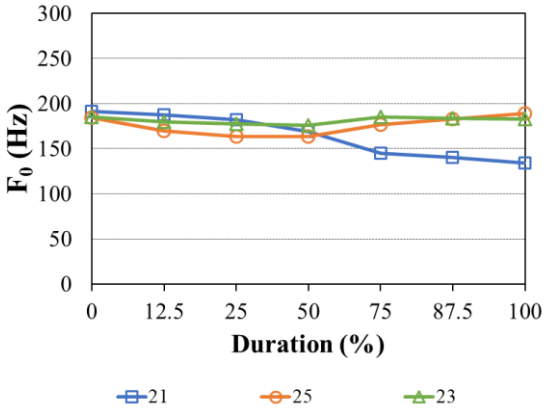
(18a) Female NH speaker (F-NH)

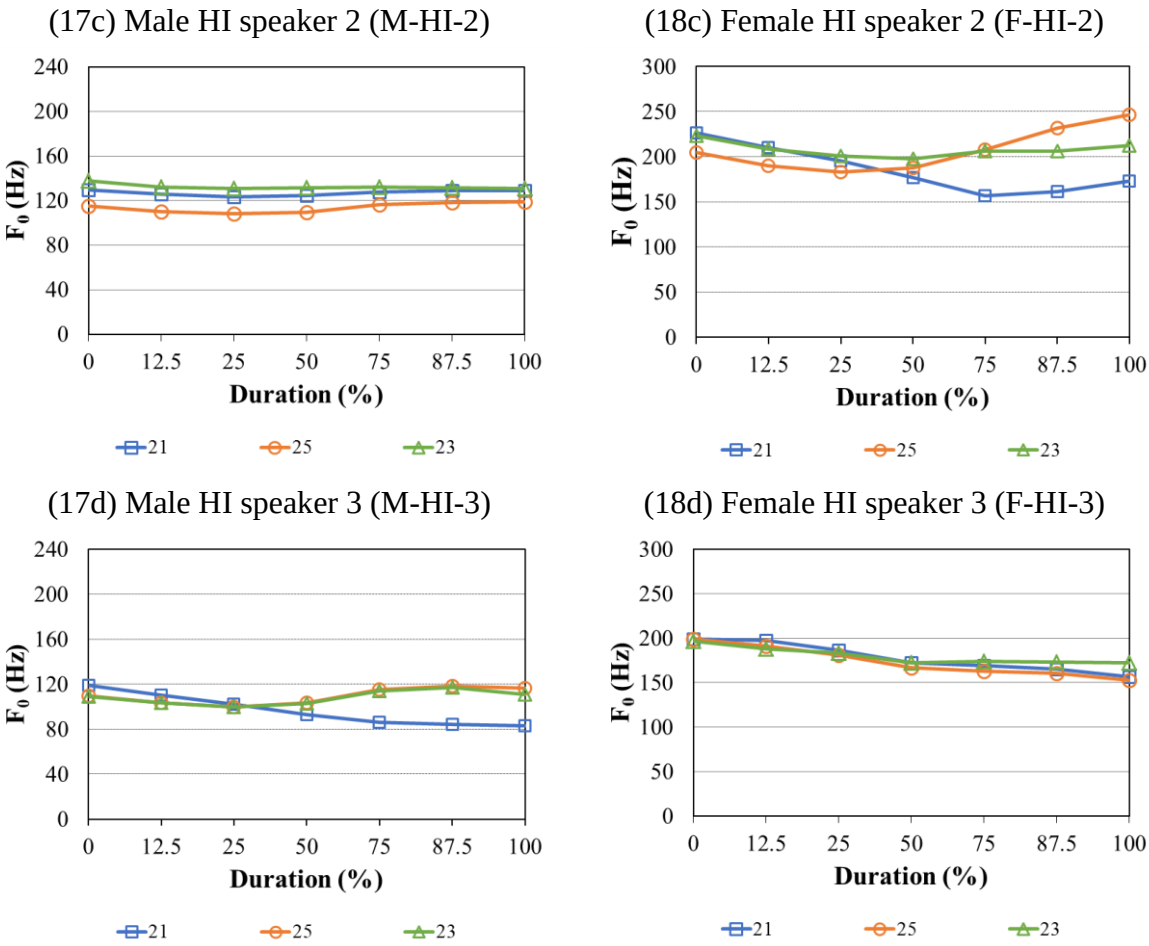


(17b) Male HI speaker 1 (M-HI-1)



(18b) Female HI speaker 1 (F-HI-1)





Figs. 17a-17d and Figs. 18a-18d. F_0 contours of the three Cantonese contour tones [21 25 23] for the NH and HI speakers, male (on the left) and female (on the right).

For the female NH speaker (Fig. 18a), the F_0 contours of the three contour tones are also generally low falling for [21], high rising for [25], and mid rising for [23], though the F_0 contour of [21] tilts slightly upward toward the end. The F_0 contours of the three tones also overlap at the beginning, with a minimal difference in F_0 at the onset points of [21] (230 Hz), [25] (227 Hz), and [23] (222 Hz).

As for the HI speakers, the F_0 contours of the tones [21 25 23] are flattened in the speech of two M-HI speakers, M-HI-1 (Fig. 17b) and M-HI-2 (Fig. 17c), similar to their F_0 contours of the three long level tones [55 33 22] (Figs. 15b and 15c). For M-HI-1, the flattened F_0 contours of the tones [21 25 23] overlap extensively, with a minimal difference in the average F_0 value across the seven time points of [21] (113 Hz), [25] (113 Hz), and [23] (115 Hz). As for M-HI-2, the F_0 contours of the three tones are close to each other in terms of the F_0 level, With respect to the average F_0 across the seven time points of each tone, the F_0 is slightly lower for [25] (114 Hz) than [21] (127 Hz) and [23] (132 Hz). The F_0 data indicate that the two HI speakers, M-HI-1 and M-HI-2, wrongly pronounce the three Cantonese contour tones [21 25 23] and fail in differentiating the three tones.

For the female HI speaker, F-HI-3, the tones [21 25 23] are also pronounced with a similar F_0 contour in her speech. As shown in Fig. 18d, the F_0 contours of the three tones are slightly falling. The drop in F_0 from the onset (0%) to the offset (100%) is 199 Hz to 156 Hz

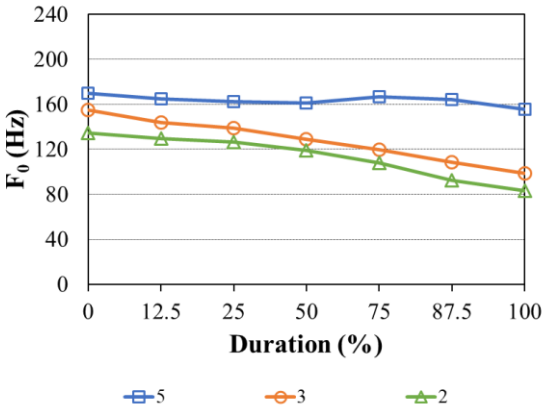
for [21], 199 Hz to 152 Hz for [25], and 196 Hz to 173 Hz for [23]. In view of the fact that the degree of falling of the F_0 contour of [21] for this female HI speaker (43 Hz) is significantly smaller than that for the female NH speaker (74 Hz) and both the F_0 contours of [25] and [23] are falling and similar to each other, it can be considered that the female HI speaker, F-HI-3, fails in pronouncing the Cantonese contour tones [21] and in particular [25] and [23].

As for the other three HI speakers, M-HI-3 (Fig. 17d), F-HI-1 (Fig. 18b), and F-HI-2 (Fig. 18c), the F_0 contour of the tone [21] is basically falling, while the degree of falling for all M-HI-3 (36 Hz), F-HI-1 (57 Hz), and F-HI-2 (53 Hz) is smaller than that for the male NH speaker (69 Hz) and the female NH speaker (74 Hz). As for the tone [25], the F_0 contour is rising only in the speech of F-HI-2, with a sufficient degree of rising (41 Hz) similar to that of the female NH speaker (50 Hz). The degree of rising is minimal for the tone [25] produced by the other two HI speakers, M-HI-3 (7 Hz) and F-HI-1 (5 Hz). As for the tone [23], the F_0 contour is flattened, with a minimal change in F_0 from the onset to the offset point for M-HI-3 (from 109 Hz to 111 Hz), F-HI-1 (from 186 Hz to 183 Hz), and F-HI-2 (from 223 Hz to 212 Hz). The F_0 data suggest that all the three HI speakers fail in pronouncing the tone [23], and M-HI-3 and F-HI-1 also fail in pronouncing the tone [25]. Both M-HI-3 and F-HI-1 pronounce the tones [25] and [23] with a similar flattened F_0 contour, as evidenced by the similar minimal change in F_0 at the onset and offset between the two tones for M-HI-3 ([25]: from 109 Hz to 116 Hz; [23] from 109 Hz to 111 Hz) and F-HI-1 ([25]: from 184 Hz to 189 Hz; [23]: from 186 Hz to 183 Hz).

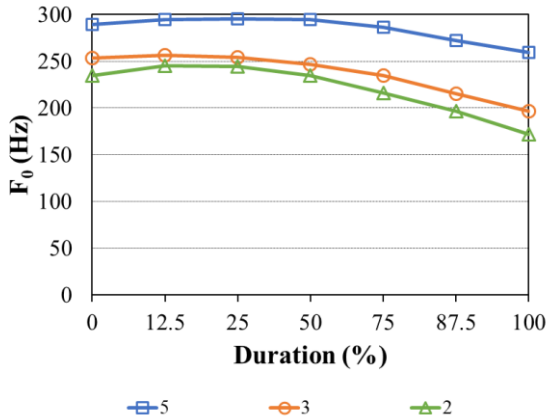
c. Short tones

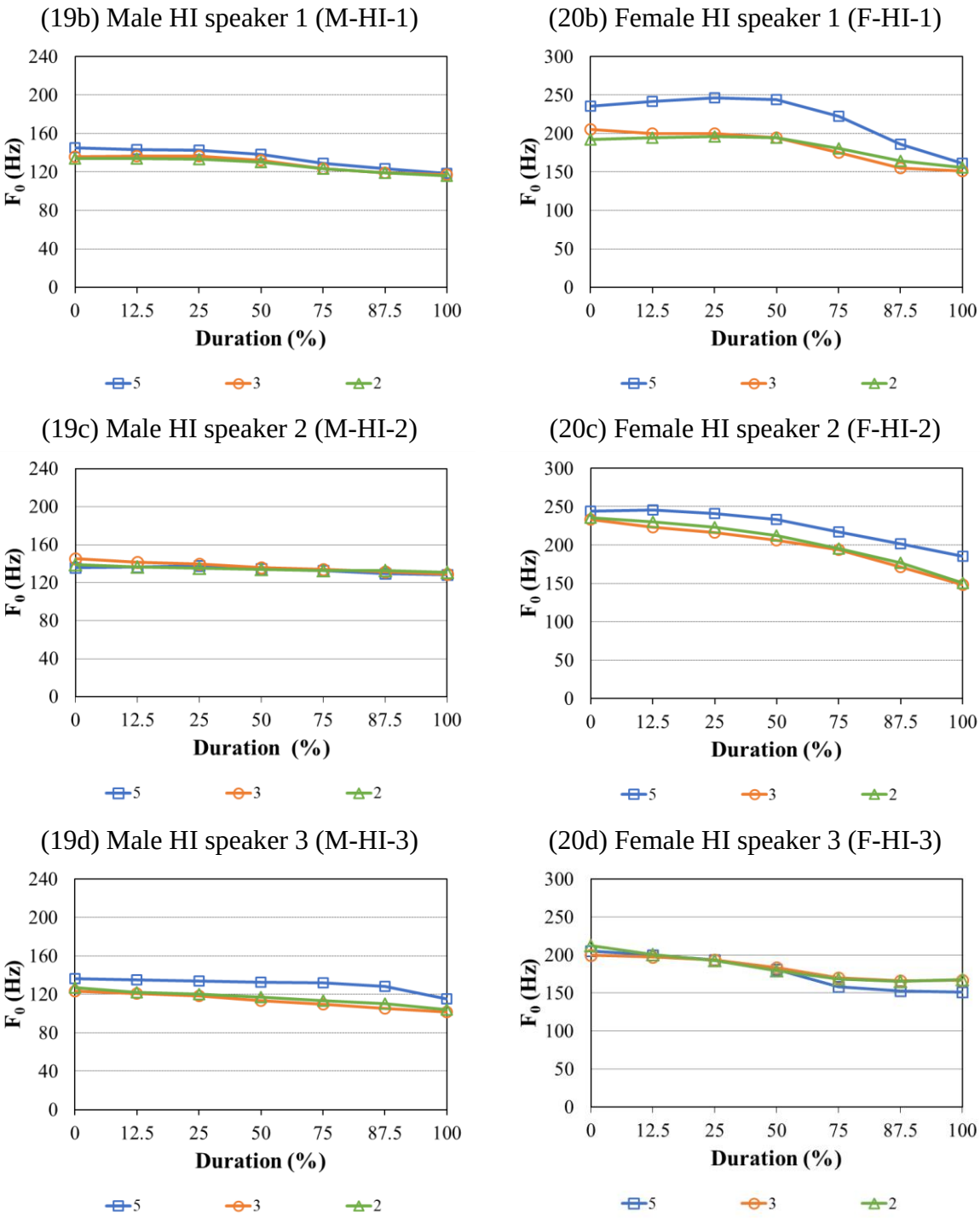
Figs. 19a-19d and Figs. 20a-20d show the F_0 contours of the three Cantonese short tones [5 3 2] for the two NH speakers and six HI speakers, male and female. For the two NH speakers (Fig. 19a and Fig. 20a), it can be seen that the F_0 contours of the three short tones are falling toward to the end, while the degree of falling is minimal for the tone [5] for M-NH. For M-NH, the difference in F_0 between the onset and the offset is smaller for the tone [5] (13 Hz) than for the tone [3] (56 Hz) and the tone [2] (51 Hz). Similarly, for F-NH, the difference in F_0 between the two end points of the tone is also smaller for the tone [5] (29 Hz) than for the tones [3] (57 Hz) and [2] (62 Hz).

(19a) Male NH speaker (M-NH)



(20a) Female NH speaker (F-NH)





Figs. 19a-19d and Figs. 20a-20d. F_0 contours of the three Cantonese short tones [5 3 2] for the NH and HI speakers, male (on the left) and female (on the right).

A comparison of the three short tones for each NH speaker shows that the F_0 contour is highest for the tone [5], followed by the tone [3] and then the tone [2], and the difference in F_0 is much larger between the tones [5] and [3] than between the tones [3] and [2]. Averaging the F_0 values for all the seven time points of each tone, the difference between the tones [5] and [3] is 35 Hz for M-NH and 48 Hz for F-NH, whereas the difference between the tones [3] and [2] is 15 Hz for M-NH and 17 Hz for F-NH.

As for the HI speakers (Figs. 19b-19d and Figs. 20b-20d), the F_0 contours of the three short tones [5 3 2] are also generally falling, although the degree of falling is smaller for the male HI speakers than the female HI speakers. The drop in F_0 from the onset to the offset for the three short tones is ranging from 8 Hz to 27 Hz for M-HI-1 (19-27 Hz), M-HI-2 (8-16 Hz), and M-HI-3 (21-23 Hz), but ranging from 33 to 85 Hz for F-HI-1 (36-74 Hz), F-HI-2 (59-85 Hz), and F-HI-3 (33-54 Hz).

For the three male HI speakers, the difference in F_0 among the three short tones is also small. With respect to the average F_0 across the seven time points of each tone, the differences in F_0 between the tones [5] and [3] and between the tones [3] and [2] are ranging from 2-5 Hz for the three male HI-speakers, except for the F_0 difference between [5] and [3] for M-HI-3 (17 Hz). As for the female HI speakers, there is a significant difference in F_0 between the paired tones [5] and [3] for F-HI-1 (37 Hz) and F-HI-2 (25 Hz), while the difference is minimal for F-HI-3 (6 Hz). As for the difference in F_0 between the paired tones [3] and [2], it is minimal for all F-HI-1 (1 Hz), F-HI-2 (4 Hz), and F-HI-3 (1 Hz).

In general, the difference in F_0 among the three short tones is minimal in the speech of the three male HI speakers, except for the difference between the paired tones [5] and [3] for M-HI-3. The difference in F_0 between [5] and [3] is also minimal for F-HI-3, but it is significant for F-HI-1 and F-HI-2. As for the difference in F_0 between the paired tones [3] and [2], it is non-significant for all the six HI speakers, male and female. It should also be noted that the order of decreasing F_0 is not [5] > [3] > [2] for M-HI-2, M-HI-3, F-HI-2, and F-HI-3, as in the speech of the NH speakers. Thus, the F_0 data indicate that the three short tones, especially the tones [3] and [2], are not differentiated in the speech of the HI speakers.

Overall, the HI speakers have difficulties in (i) the production of Cantonese tones, in particular the contour tones [21 25 23], where the tones are flattened in their speech, and (ii) the differentiation between the level tones [33] and [22] and the short tones [3] and [2]. Due to the tendency of flattening of the contour tones, merging of the level and contour tones, in particular the non-high tones [33 22] and [21 25 23], is observed in the speech of the HI speakers. Merging is also observed for the three short tones, especially the non-high tones [3] and [2], produced by the HI speakers, which is similar to the merging pattern of the three long level tones. In the speech of HI speakers, the duration difference between the long and short tones are maintained as presented in Section 3.1.2, no merging between [55 33 22] and [5 3 2] produced by the HI speakers, in spite of their similarities in F_0 value and shape.

SECTION FOUR: DISCUSSION

In the previous section, the data on the durations and frequencies of the Cantonese vowels and tones produced by the six HI speakers have been presented and compared with those of the NH speakers. In this section, the findings of the production of vowels and tones for the HI speakers of Cantonese are compared and discussed with those of the HI speakers reported in previous studies.

4.1 Vowel Duration

As cited in Osberger and McGarr (1982), the temporal data reported in Calvert (1961) and Osberger and Levit (1979) show a significant lengthening of vowel duration in the speech of HI speakers of English. As for the HI speakers of Cantonese in the present study, vowel prolongation is observed for two male (M-HI-1 and M-HI-3) and one female (F-HI-2) HI speakers, but not apparent in the speech of the other three HI speakers. Furthermore, for M-HI-3 and F-HI-2, in spite of the lengthening of vowel duration in their speech, the relative difference in duration between the Cantonese long and short vowels and between the Cantonese long vowels in CV and CVS syllable contexts produced by them is similar to the temporal pattern of Cantonese vowels produced by the NH speakers. For M-HI-1, he also produces sufficient duration difference between the long vowels in CV and CVS syllables, while the difference in duration between the long and short vowels is slightly less sufficient as compared to the temporal data of the NH speakers. In general, the HI speakers of Cantonese in the present study have no problem in differentiating the temporal patterns of Cantonese vowels of different types and in different syllable contexts, despite of vowel prolongation in their speech.

4.2 Vowel Space

According to Hung, Lee and Tsai (2017), a greater vowel space area indicates a clearer speech, and vowel space area is commonly taken as an indication of the similarities or differences in vowel production between HI and NH speakers. In many previous studies Löfqvist et al., 2010; Verhoeven, 2015; Hung et al., 2017), it is reported that HI speakers have a significantly reduced vowel space as compared with NH speakers. Such phenomenon is also observed in the speech of three HI speakers, M-HI-3, F-HI-1, and F-HI-2, in the present study. The reduction in vowel space is true for the Cantonese vowels in both CV and CVS syllable contexts and in particular in the speech of M-HI-3 and F-HI-1. For these two HI speakers, the reduction in vowel space is mainly due to the centralization of the peripheral vowels [i ɛ u ɔ], resulting in the shrinkage of vowel space toward to the center. For F-HI-1, the degree of centralization is more pronounced for the two peripheral front vowels [i] and [ɛ], leading to the backward shrinkage of vowel space. Similar pattern of backward shrinkage of vowel space is also observed for another female HI speaker, F-HI-2, due to the large degree of centralization of the two peripheral front vowels [i] and [ɛ], though the degree of reduction in vowel space is smaller than that for F-HI-1. For all the three HI speakers with vowel space reduction resulting from vowel centralization, it is in relation to a large increase in F_1 for the high vowels [i] and [u] and in F_2 for the back vowel [u] and a large decrease in F_2 for the

front vowels [i] and [ɛ]. Similar pattern of centralization for the vowel [i] is also reported in the previous studies of HI speakers of Mandarin (Hung et al., 2017), Dutch (Verhoeven, 2015), and Croatian (Liker et al., 2007), and Swedish (Löfqvist et al., 2010). However, in the three former studies, the centralization of vowel [i] is mainly due to a decrease in F_2, whereas the centralization of [i] in the latter one is resulted from an increase in F_1.

In the present study, vowel space reduction is not apparent in the speech of three other HI speakers, M-HI-1, M-HI-2, and F-HI-3. For these three HI speakers, the vowel spaces are similar to those of the NH speakers in size, while the HI ones tend to positioned slightly upward relative to the NH ones, due to a decrease in F_1 for the three corner vowels [i u a]. In view of the small sample size of the present study, more data from HI speakers are needed for a better understanding of vowel space reduction in the speech of HI speakers.

It should be added that all the HI speakers in the present study produce distinct formant patterns for the various types of Cantonese vowels, long and short, in different syllable contexts, and the vowel formant patterns for the HI speakers are in general similar to those for the NH speakers. The data indicate that the HI speakers also have no problem in differentiating the spectral patterns of Cantonese vowels, despite of vowel space reduction in their speech.

4.3 Tones

Different from vowel production, most of the HI speakers in the present study have a difficulty in tone production. A major problem is the flattening of the F_0 contours of the three Cantonese contour tones [21 25 23]. For three HI speakers (M-HI-1, M-HI-2, and F-HI3), the F_0 contours of all the three contour tones become flattened, and the flattening is also observed for the F_0 contours of the tones [25] and [23] for the other two HI speakers (M-HI-3 and F-HI-1. The finding coincides with the ‘monotonous’ intonation of the speech of deaf people reported in the previous studies (Haycock, 1933; Rawling, 1935) cited in Osberger and McGarr (1982). In some more recent studies of the production of Cantonese tones by HI children (Lee, 2007) and adolescents (Khouw & Ciocca, 2006), similar results of failure to produce the contour tones are also found. The findings of all the studies show the limited capability of HI speakers in tone production and lack of progressive improvement with the increase of age.

Thus, in general, HI speakers are less capable of differentiating tones rather than vowels. This may be related to the fact that tone production relies solely on hearing and auditory input, as the laryngeal activities during tone production are invisible and impossible, or at least difficulty, to be mastered. By contrast, vowel production can be aided by some visual information on lip movement and varying size of the mouth opening, and the movement of the tongue in the mouth is easier than the control of the vocal cords in the larynx.

SECTION FIVE: CONCLUSION

This study has presented and compared the acoustic data on the frequencies and durations of all the Cantonese vowels and tones produced by eight young adult speakers, six HI and two NH, male and female. The temporal data show that the HI speakers basically produce sufficient duration contrast between the long and short types of vowels and tones, in spite of the tendency of vowel prolongation in their speech. For vowel production, a reduced or smaller vowel space is found in the speech of some HI speakers, due to the centralization of the peripheral vowels. Nonetheless, no significant effect on the differentiation of vowels in the reduced vowel space is observed. By contrast, the HI speakers show deficiency in tone production. A major problem is the flattening of the F_0 contours of the contour tones, which leads to the merging with the level tones. A lower capability to differentiate tones than vowels by HI speakers indicates a difference in articulatory mechanism between tone production and vowel production. On the whole, the data obtained in the present study are similar to those of the HI speakers of other languages and of the younger HI speakers reported in the previous studies.

To conclude, the present study is the first to provide empirical data on the acoustic characteristics of Cantonese vowels and tones produced by HI adult speakers. While the sample size of HI speakers in the present study is not much large, the data have shed more light on the deficiency in speech production due to hearing impairment. Further study on the perception of Cantonese vowels and tones by HI adult speakers may be carried out to gain insights into the capability relationship between production and perception of HI speakers.

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APPENDIX I: VOWEL DURATION

(1) Seven Long Vowels in CV Syllables

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
i	273	310	272	330	215	229	439	243
	244	327	258	371	248	271	411	333
	268	414	241	378	223	237	428	395
	280	393	205	399	229	272	357	340
	252	368	276	396	238	249	467	343
	268	451	231	402	210	260	394	328
Average	264	377	247	379	227	253	416	330
y	253	309	258	377	213	238	443	257
	253	322	268	372	278	241	302	276
	267	289	218	355	253	200	437	294
	276	450	219	387	241	195	388	280
	228	402	239	362	239	216	381	323
	246	468	258	422	285	215	430	340
Average	254	374	243	379	251	217	397	295
u	295	399	271	352	212	278	402	247
	264	380	278	410	233	243	362	171
	265	293	227	393	230	241	375	326
	227	459	263	348	243	204	391	298
	247	404	262	388	225	254	388	355
	256	374	217	391	193	248	433	305
Average	259	385	253	380	223	245	392	284
ɛ	240	327	253	298	218	271	389	258
	239	339	227	408	290	264	380	339
	256	331	190	353	229	269	410	305
	255	285	210	353	238	257	406	316
	228	327	218	365	220	268	423	327
	268	358	215	367	219	276	417	350
Average	247	328	219	357	236	267	404	316
œ	236	156	281	312	243	254	692	261
	228	411	242	335	242	247	385	329
	242	301	177	371	229	221	366	300
	261	358	246	341	264	244	355	257
	262	355	222	318	236	226	372	271
	278	357	186	328	233	250	448	307
Average	251	323	226	334	241	240	436	287
ɔ	265	437	157	355	246	284	367	302
	283	388	102	403	237	246	429	352
	264	389	160	446	244	240	415	316
	318	442	205	428	253	227	424	118
	231	410	251	409	259	219	468	294
	250	329	193	421	247	245	495	371
Average	269	399	178	410	248	244	433	292

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
a	250	333	236	358	251	258	432	286
	255	311	262	437	233	232	450	266
	270	310	208	431	245	240	434	273
	279	330	234	394	254	203	439	292
	256	309	233	408	252	219	413	303
	239	345	211	380	286	212	480	339
Average	258	323	231	401	253	227	441	293

Table 1. Durations (in ms) of the seven Cantonese long vowels [i y u ɛ œ ɔ a] in CV syllables for the two NH and six HI speakers, male (M) and female (F).

(2) Seven Long Vowels in CVS Syllables

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
i	137	115	94	101	123	99	143	176
	113	93	124	101	134	84	195	125
	133	120	133	121	171	84	164	202
	132	72	181	92	136	86	155	191
	121	97	131	137	150	79	164	267
	100	90	125	144	133	92	171	243
Average	123	98	131	116	141	87	165	201
y	110	66	136	120	164	107	170	77
	166	101	141	170	154	112	210	109
	160	105	143	156	184	131	218	93
	132	79	131	139	149	97	217	131
	106	92	139	153	179	113	191	130
	120	98	97	131	176	108	223	146
Average	133	90	131	145	168	111	205	114
u	131	71	164	133	125	81	178	82
	114	72	104	162	141	87	194	55
	155	88	145	151	153	83	218	92
	129	121	164	151	135	86	186	95
	129	99	160	155	151	78	170	103
	101	122	167	211	126	60	193	119
Average	126	95	151	161	139	79	190	91
ɛ	139	*	117	135	143	114	192	53
	138	98	130	175	138	83	211	113
	113	103	120	197	156	75	225	72
	115	73	119	217	139	81	214	53
	113	90	90	220	155	77	214	115
	92	101	91	146	165	86	215	154
Average	118	93	111	182	149	86	212	94

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
œ	112	120	*	123	151	76	182	109
	117	114	*	149	150	91	216	142
	127	109	*	162	176	64	199	125
	179	126	*	161	171	77	180	147
	103	131	*	160	161	81	208	99
	83	151	*	118	164	69	201	162
Average	120	125	*	145	162	76	198	131
ɔ	116	90	110	165	136	92	190	103
	149	78	141	212	140	93	281	95
	150	76	153	183	175	88	225	129
	95	86	112	226	166	90	256	113
	100	103	137	179	191	77	213	101
	94	114	123	196	188	76	246	93
Average	117	91	129	193	166	86	235	106
a	165	71	126	188	128	71	357	148
	166	71	114	181	140	93	287	119
	134	94	125	177	155	68	279	117
	133	77	97	200	160	69	255	100
	118	97	127	202	170	81	286	118
	126	91	126	172	169	97	272	125
Average	140	83	119	187	154	80	289	121

Table 2. Durations (in ms) of the seven Cantonese long vowels [I y u ɛ œ ɔ a] in CVS syllables for the two NH and six HI speakers, male (M) and female (F) (* indicates wrong pronunciation).

(3) Four Short Vowels in CVS Syllables

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
ɪ	46	52	88	67	74	33	92	80
	53	44	57	73	77	57	64	84
	51	62	59	82	77	50	74	62
	53	78	75	74	88	42	99	74
	62	96	53	69	81	52	94	69
	63	68	54	61	80	48	62	64
Average	55	67	64	71	79	47	81	72
ʊ	67	57	84	95	71	70	90	42
	84	54	55	103	67	70	106	76
	51	78	85	79	95	56	98	40
	51	81	86	122	92	55	86	84
	59	63	92	79	74	58	64	103
	59	62	84	96	93	44	84	67
Average	62	66	81	96	82	59	88	69

Vowels	M-NH	M-HI-1	M-HI-2	M-HI-3	F-NH	F-HI-1	F-HI-2	F-HI-3
ɵ	49	66	105	72	94	62	76	94
	64	73	63	111	72	69	86	78
	45	76	82	72	96	76	103	76
	53	73	83	92	104	59	67	76
	62	80	92	76	96	63	92	77
	56	85	69	81	90	64	93	98
Average	55	76	82	84	92	65	86	83
ɐ	40	62	86	102	63	43	183	112
	60	91	95	96	56	50	194	100
	65	66	82	95	74	49	190	58
	56	95	111	102	75	42	189	101
	75	67	91	80	67	44	221	96
	47	90	87	82	74	67	208	132
Average	57	78	92	93	68	49	198	100

Table 3. Durations (in ms) of the four Cantonese short vowels [ɪ ʊ ɵ ɐ] in CVS syllables for the two NH and six HI speakers, male (M) and female (F).

APPENDIX II: TONE DURATION

(1a) Nine Citation Tones Produced on [i] and [u] by Four Male Speakers

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Tones	**i**	**u**	**i**	**u**	**i**	**u**	**i**	**u**
55	273	295	310	399	272	271	330	352
	244	264	327	380	258	278	371	410
	268	265	414	293	241	227	378	393
	280	227	393	459	205	263	399	348
	252	247	368	404	276	262	396	388
	268	256	451	374	231	217	402	391
Average	264	259	377	385	247	253	379	380
33	312	280	504	372	270	290	340	347
	345	310	387	313	276	274	358	418
	315	305	386	347	267	259	353	416
	319	329	433	327	283	293	360	415
	302	305	350	293	276	264	359	427
	296	280	376	323	255	223	394	338
Average	315	301	406	329	271	267	361	394
22	299	307	419	320	289	277	383	425
	261	311	501	330	244	187	380	421
	283	336	326	235	248	260	387	388
	277	354	381	249	285	258	422	425
	298	364	390	338	233	248	391	433
	314	301	348	256	241	238	417	452
Average	289	329	394	288	257	245	397	424
21	210	224	193	189	311	298	347	489
	289	244	368	379	299	255	388	403
	138	240	264	348	262	241	384	470
	260	267	357	384	261	215	423	502
	229	243	300	373	303	239	384	425
	193	216	348	218	277	220	349	376
Average	220	239	305	315	285	245	379	444
25	200	217	331	236	346	239	340	328
	221	232	433	267	231	266	361	369
	222	255	345	317	210	203	385	388
	222	238	504	273	275	228	356	367
	241	254	522	255	250	277	303	342
	242	230	436	311	245	246	338	353
Average	225	238	428	277	260	243	347	358
23	242	271	426	335	259	213	319	397
	214	269	293	323	277	233	383	469
	216	254	296	316	262	212	421	441
	268	287	286	351	254	228	360	516
	241	234	365	386	268	248	344	392
	234	230	393	270	259	230	350	433
Average	236	257	343	330	263	227	363	441

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Tones	**i**	**u**	**i**	**u**	**i**	**u**	**i**	**u**
5	89	94	100	140	138	131	94	133
	115	102	96	115	164	135	103	157
	102	105	150	112	149	239	109	170
	97	107	140	151	127	260	108	211
	102	87	122	121	135	256	131	167
	91	95	124	169	145	222	147	210
Average	99	98	122	135	143	207	115	175
3	137	131	115	71	94	164	101	133
	113	114	93	72	124	104	101	162
	133	155	120	88	133	145	121	151
	132	129	72	121	181	164	92	151
	121	129	97	99	131	160	137	155
	100	101	89	122	125	167	144	211
Average	123	126	98	95	131	151	116	161
2	152	133	125	93	148	127	125	107
	111	122	132	102	170	96	138	154
	140	116	112	132	149	116	191	148
	127	120	111	120	125	124	179	197
	122	98	111	172	148	143	171	142
	106	94	99	151	131	127	164	149
Average	126	114	115	128	145	122	161	150

Table 1a. Durations (in ms) of the nine Cantonese citation tones [55 33 22 25 23 21 5 3 2] produced on the vowels [i] and [u] by the male NH speaker and three male HI speakers.

(1b) Nine Citation Tones Produced on [i] and [u] by Four Female Speakers

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Tones	**i**	**u**	**i**	**u**	**i**	**u**	**i**	**u**
55	243	247	229	278	278	229	439	402
	333	171	271	243	243	271	411	362
	395	326	237	241	241	237	428	375
	340	298	272	204	204	272	357	391
	343	355	249	254	254	249	467	388
	328	305	260	248	248	260	394	433
Average	330	284	253	245	245	253	416	392
33	274	280	263	310	310	263	528	520
	296	326	277	301	301	277	465	446
	251	93	280	273	273	280	420	457
	294	314	216	243	243	216	434	391
	392	207	289	275	275	289	380	429
	296	260	260	261	261	260	382	399
Average	301	247	264	277	277	264	435	440

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Tones	**i**	**u**	**i**	**u**	**i**	**u**	**i**	**u**
22	306	297	259	235	235	259	360	417
	281	280	279	223	223	279	329	429
	143	310	247	246	246	247	338	432
	209	403	244	229	229	244	340	414
	294	308	234	233	233	234	349	386
	362	360	253	251	251	253	391	509
Average	266	326	253	236	236	253	351	431
21	298	224	192	269	269	192	445	458
	266	130	243	249	249	243	368	441
	310	276	212	233	233	212	331	392
	240	372	100	180	180	100	378	434
	358	272	162	132	132	162	433	460
	337	312	139	170	170	139	464	422
Average	302	264	175	206	206	175	403	434
25	272	255	290	341	341	290	402	497
	299	348	319	302	302	319	364	447
	314	371	308	339	339	308	372	412
	154	320	258	266	266	258	332	376
	313	362	248	315	315	248	373	413
	346	310	287	342	342	287	388	383
Average	283	328	285	317	317	285	372	421
23	287	273	262	312	312	262	411	480
	330	345	234	213	213	234	373	494
	290	324	257	231	231	257	366	416
	267	289	254	197	197	254	290	426
	281	315	273	281	281	273	367	489
	342	399	286	275	275	286	335	468
Average	299	324	261	252	252	261	357	462
5	127	124	59	86	86	59	183	134
	151	164	82	86	86	82	174	167
	103	87	68	87	87	68	207	146
	138	53	62	94	94	62	181	147
	164	145	55	85	85	55	186	168
	124	192	73	84	84	73	188	145
Average	134	127	66	87	87	66	187	151
3	176	82	99	81	81	99	143	178
	125	55	84	87	87	84	195	194
	202	92	84	83	83	84	164	218
	191	95	86	86	86	86	155	186
	267	103	79	78	78	79	164	170
	243	119	92	60	60	92	171	193
Average	201	91	87	79	79	87	165	190

Tones	F-NH		F-HI-1		F-HI-2		F-HI-3	
	i	**u**	**i**	**u**	**i**	**u**	**i**	**u**
2	63	93	78	79	79	78	179	90
	135	107	74	67	67	74	197	106
	91	82	78	62	62	78	187	98
	37	128	93	100	100	93	150	86
	134	54	78	73	73	78	151	64
	105	91	72	87	87	72	194	84
Average	94	93	79	78	78	79	176	88

Table 1b. Durations (in ms) of the nine Cantonese citation tones [55 33 22 25 23 21 5 3 2] produced on the vowels [i] and [u] by the female NH speaker and three female HI speakers.

APPENDIX III: VOWEL FORMANT FREQUENCIES (F_1F_2)

(1a) Seven Long Vowels in CV Syllables for Four Male Speakers

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
i	283	2376	261	2442	283	2355	348	1853
	305	2398	261	2442	283	2267	370	1897
	305	2376	261	2420	305	2333	370	1831
	305	2464	239	2430	283	2267	370	1875
	305	2376	239	2398	283	2333	348	1918
	326	2464	249	2368	283	2311	392	1831
Average	305	2409	252	2417	287	2311	366	1868
y	305	1831	283	2333	283	1897	370	1744
	326	1809	249	2368	283	1853	392	1678
	326	1831	261	2333	283	1918	370	1613
	305	1875	280	2305	283	1918	414	1635
	305	1875	261	2289	283	1962	414	1722
	305	1788	249	2368	276	1875	370	1613
Average	312	1835	264	2333	282	1904	388	1668
u	370	654	305	501	348	675	436	872
	326	654	326	654	326	675	436	915
	370	675	305	632	326	610	414	915
	328	632	311	646	326	675	457	915
	348	632	311	654	326	632	436	893
	392	719	312	654	305	675	479	915
Average	356	661	312	624	326	657	443	904
ɛ	523	2049	479	2224	566	1853	566	1569
	566	1940	436	2136	501	1918	566	1635
	588	1897	457	2158	566	1875	588	1635
	588	1940	431	2124	523	1788	545	1591
	588	1940	436	2202	566	1875	610	1613
	610	1940	414	2180	523	1875	610	1635
Average	577	1951	442	2171	541	1864	581	1613
œ	501	1286	467	1496	501	1373	545	1351
	523	1395	405	1433	436	1373	588	1351
	566	1330	498	1433	479	1439	588	1351
	523	1460	529	1340	545	1351	610	1351
	523	1330	467	1464	414	1373	588	1373
	523	1417	467	1496	457	1417	632	1373
Average	527	1370	472	1444	472	1388	592	1358
ɔ	545	806	374	697	501	850	566	850
	501	763	405	675	501	850	610	893
	523	763	407	716	545	850	632	937
	588	784	396	709	479	828	632	937
	566	850	436	697	501	850	610	915
	544	850	414	675	457	850	566	872
Average	545	803	405	695	497	846	603	901

a	675	1090	779	1277	685	1184	784	1199
	741	1155	784	1242	806	1242	784	1199
	741	1155	779	1308	763	1242	763	1221
	697	1068	771	1272	784	1199	741	1242
	697	1090	763	1264	697	1155	806	1155
	763	1177	784	1373	719	1133	741	1133
Average	719	1123	777	1289	742	1193	770	1192

Table 1a. Formant frequencies, F_1 and F_2 (in Hz), of the seven Cantonese long vowels [i y u ɛ œ ɔ a] in CV syllables for the male NH speaker and three male HI speakers.

(1b) Seven Long Vowels in CV Syllables for Four Female Speakers

	F-NH		**F-HI-1**		**F-HI-2**		**F-HI-3**	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
i	414	3096	326	2115	306	2464	370	2921
	493	3052	370	2158	283	2551	348	2965
	370	3227	305	2271	305	2464	392	2834
	392	3118	329	2166	283	2507	370	2856
	457	3161	326	2029	299	2519	370	2987
	369	3140	356	2003	302	2493	370	2943
Average	416	3132	335	2124	296	2500	370	2918
y	370	2180	392	2006	305	2112	414	2289
	392	2115	392	2071	305	1959	414	2267
	392	2006	424	2063	326	2006	426	2111
	370	2049	385	1999	302	2055	414	2311
	370	2071	430	1925	326	1962	414	2136
	370	2180	430	1867	327	2086	426	2289
Average	377	2100	409	1989	315	2030	418	2234
u	370	872	457	1133	429	1102	375	707
	392	872	457	1221	457	1152	378	684
	348	872	424	1179	429	1102	375	707
	367	872	468	1220	472	1133	409	685
	392	893	456	1229	427	1116	348	654
	392	872	481	1255	458	1147	375	681
Average	377	876	457	1206	445	1125	377	686
ɛ	741	2573	610	1657	610	1744	707	2111
	741	2638	588	1700	523	1788	697	2311
	828	2551	606	1751	566	1766	654	2136
	806	2485	607	1693	566	1862	632	2311
	784	2507	585	1771	552	1836	675	2202
	784	2573	610	1771	621	1898	707	2289
Average	781	2555	601	1724	573	1816	679	2227

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
œ	654	1613	523	1569	566	1526	763	1677
	675	1657	545	1569	614	1504	763	1635
	719	1591	502	1517	566	1526	784	1613
	697	1678	524	1582	632	1569	772	1548
	675	1569	533	1616	528	1523	777	1697
	654	1678	533	1590	615	1585	784	1569
Average	679	1631	527	1574	587	1539	774	1623
ɔ	770	1046	610	937	777	1114	707	1013
	763	981	632	1024	528	866	654	930
	770	959	606	1074	593	1022	681	963
	719	959	552	969	741	1264	654	930
	685	1046	585	945	709	991	654	992
	708	1068	636	1049	646	1053	681	911
Average	736	1010	604	1000	666	1052	672	957
a	1071	1530	1024	1613	1071	1530	1166	1422
	1126	1381	981	1526	1308	1569	1114	1727
	1268	1543	866	1517	1268	1830	1141	1396
	1084	1397	941	1554	1084	1397	1267	1819
	1084	1397	842	1435	1084	1397	1053	1635
	1024	1548	971	1513	1024	1548	1166	1371
Average	1110	1466	938	1526	1140	1545	1151	1562

Table 1b. Formant frequencies, F_1 and F_2 (in Hz), of the seven Cantonese long vowels [i y u ɛ œ ɔ a] in CV syllables for the female NH speaker and three female HI speakers.

(2a) Seven Long Vowels in CVS Syllables for Four Male Speakers

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
i	305	2376	311	2431	239	2158	370	1766
	348	2398	349	2311	261	2136	370	1788
	305	2398	348	2224	305	2158	392	1853
	305	2420	333	2430	283	2115	436	1700
	305	2420	326	2464	283	2158	392	1875
	348	2398	348	2333	305	2136	392	1766
Average	319	2402	336	2366	279	2144	392	1791
y	370	1700	311	2119	305	1744	414	1548
	392	1788	370	2027	305	1766	414	1569
	370	1788	370	1984	283	1678	436	1548
	348	1744	365	1961	283	1766	414	1591
	370	1744	370	1962	305	1809	414	1591
	392	1788	348	1962	283	1678	414	1526
Average	374	1759	356	2003	294	1740	418	1562

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
u	392	654	370	719	305	741	475	893
	392	675	370	719	283	719	566	1002
	392	675	374	685	326	741	457	893
	348	632	365	716	283	697	523	1002
	370	632	374	654	305	784	501	915
	370	675	370	675	305	719	457	893
Average	377	657	371	695	301	734	497	933
ɛ	632	1853	632	1994	545	1897	654	1504
	588	1788	588	2027	523	1809	654	1504
	675	1809	584	2180	545	1831	719	1613
	654	1788	610	2158	523	1875	719	1482
	632	1809	610	1984	545	1788	675	1526
	654	1766	*	*	523	1766	741	1548
Average	639	1802	605	2069	534	1828	694	1530
œ	610	1417	558	1558	*	*	654	1308
	654	1308	592	1402	*	*	654	1373
	632	1330	588	1417	*	*	654	1395
	610	1330	592	1433	*	*	675	1351
	675	1264	610	1482	*	*	654	1417
	654	1351	588	1569	*	*	675	1460
Average	639	1333	588	1477	*	*	661	1384
ɔ	610	850	566	828	501	872	610	959
	610	828	545	828	523	850	697	981
	566	806	529	810	545	872	654	981
	632	850	521	834	523	872	697	1002
	632	872	566	850	523	893	654	1002
	632	893	498	779	479	893	632	959
Average	614	850	538	822	516	875	657	981
a	763	1133	748	1215	784	1242	828	1199
	719	1133	763	1286	741	1199	763	1177
	763	1199	741	1177	719	1177	763	1177
	784	1199	716	1184	727	1221	741	1199
	784	1155	741	1286	741	1177	872	1242
	806	1242	719	1199	784	1199	806	1155
Average	770	1177	738	1225	749	1203	796	1192

Table 2a. Formant frequencies, F_1 and F_2 (in Hz), of the seven Cantonese long vowels [i y u ɛ œ ɔ a] in CVS syllables for the male NH speaker and three male HI speakers (* indicates wrong pronunciation).

(2b) Seven Long Vowels in CVS Syllables for Four Female Speakers

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
i	392	3161	414	1984	366	2442	348	2856
	440	3138	370	1940	392	2420	326	2834
	436	3096	372	1959	326	2507	348	2834
	436	3052	385	1916	378	2376	348	2725
	392	3140	404	1951	333	2462	378	2770
	370	3096	404	1848	396	2493	370	2812
Average	411	3114	392	1933	365	2450	353	2805
y	479	2006	392	1722	436	1526	440	1942
	479	2071	414	1962	436	1482	457	1962
	501	2027	424	1985	414	1482	457	2006
	436	2027	440	1943	436	1548	479	1984
	479	2027	430	1900	396	1554	457	2027
	501	1984	404	1977	396	1554	436	1962
Average	479	2024	417	1915	419	1524	454	1981
u	479	981	392	1199	417	898	414	784
	479	981	392	1177	414	828	392	741
	501	893	398	1205	427	835	414	806
	479	719	385	1331	421	833	392	741
	479	741	404	1307	414	828	392	806
	479	719	404	1281	427	941	414	784
Average	483	839	396	1250	420	861	403	777
ɛ	777	2376	719	1831	806	1744	818	2245
	869	2464	741	1875	741	1809	850	2049
	850	2420	736	1907	675	1744	806	2267
	856	2485	673	1804	784	1766	850	2115
	746	2442	688	1977	784	1898	828	2027
	763	2485	673	1900	709	1742	828	2267
Average	810	2445	705	1882	750	1784	830	2162
œ	784	1678	697	1482	763	1286	763	1635
	784	1700	675	1504	614	1351	784	1657
	763	1744	643	1491	746	1451	808	1574
	697	1657	582	1582	719	1373	808	1574
	741	1766	662	1461	771	1241	763	1591
	741	1678	582	1500	727	1335	806	1591
Average	752	1704	640	1503	723	1340	789	1604
ɔ	806	1199	763	1068	806	888	808	1022
	806	1068	763	1155	741	915	808	1053
	763	1177	736	1074	850	1002	806	992
	784	1155	774	1102	850	915	808	1022
	784	1199	739	1178	681	937	808	992
	763	1177	791	1100	771	1022	806	1024
Average	784	1163	761	1113	783	947	807	1018

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
a	1177	1722	1046	1439	1046	1482	1083	1513
	1177	1766	981	1504	1074	1460	1046	1504
	1155	1700	996	1569	1175	1396	1083	1727
	1199	1722	997	1526	1133	1482	1034	1460
	1199	1788	1010	1487	1116	1460	1024	1460
	1264	1744	1023	1539	1084	1422	1068	1548
Average	1195	1740	1009	1511	1105	1450	1056	1535

Table 2b. Formant frequencies, F_1 and F_2 (in Hz), of the seven Cantonese long vowels [i y u ɛ œ ɔ a] in CVS syllables for the male NH speaker and three male HI speakers.

(3a) Four Short Vowels in CVS Syllables for Four Male Speakers

	M-NH		M-HI-1		M-HI-2		M-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
ɪ	654	1613	498	1963	673	1697	588	1504
	636	1613	529	1839	613	1637	566	1482
	654	1678	501	1897	583	1697	588	1460
	654	1569	529	1839	583	1607	479	1504
	697	1613	498	1860	583	1607	610	1504
	654	1657	529	1807	553	1697	588	1526
Average	658	1624	514	1868	598	1657	570	1497
ʊ	545	741	566	828	457	741	545	872
	588	719	523	850	479	806	545	1002
	566	784	561	779	479	806	523	1002
	566	806	552	803	479	763	610	981
	610	828	566	806	479	741	588	1002
	588	784	561	779	479	806	566	981
Average	577	777	555	807	475	777	563	973
ɵ	697	1155	623	1028	523	937	588	1177
	654	1177	592	935	457	893	610	1264
	610	1155	561	935	501	959	610	1242
	654	1177	561	1028	501	915	588	1264
	632	1155	592	966	436	893	610	1264
	654	1199	623	997	479	915	654	1221
Average	650	1170	592	981	483	919	610	1239
ɐ	719	1046	632	1046	697	1111	697	1090
	675	1024	654	1046	632	1068	675	1068
	741	1155	675	1068	697	1155	654	1090
	719	1133	685	1084	632	1090	719	1068
	719	1068	623	997	654	1068	675	1068
	741	1090	632	1024	675	1111	697	1111
Average	719	1086	650	1044	664	1101	686	1083

Table 3a. Formant frequencies, F_1 and F_2 (in Hz), of the four Cantonese short vowels [ɪ ʊ ɵ ɐ] in CVS syllables for the male NH speaker and three male HI speakers.

(3b) Four Short Vowels in CVS Syllables for Four Female Speakers

	F-NH		F-HI-1		F-HI-2		F-HI-3	
Vowels	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
ɪ	697	2115	551	1635	614	2295	741	2267
	784	2267	588	1678	562	2136	763	2245
	806	2267	580	1673	615	1961	763	2180
	806	2224	551	1775	601	2274	741	2115
	828	2006	582	1642	584	1992	741	2245
	719	2180	559	1616	584	2117	808	2126
Average	773	2177	568	1670	593	2129	760	2196
ʊ	654	1046	566	893	614	1068	675	937
	632	1068	588	1024	523	784	654	930
	632	1046	554	970	636	1111	624	930
	632	1111	552	979	584	959	719	959
	588	959	636	1049	615	928	697	1002
	654	1068	585	1049	610	915	719	1024
Average	632	1050	580	994	597	961	681	964
ɵ	719	1460	632	1373	636	1330	784	1526
	719	1395	632	1373	614	1330	741	1417
	675	1439	632	1309	632	1330	762	1482
	719	1417	643	1331	627	1395	762	1526
	741	1417	612	1438	646	1429	762	1460
	697	1439	662	1332	621	1429	741	1569
Average	712	1428	635	1359	629	1374	759	1497
ɐ	872	1330	850	1330	1024	1469	1022	1482
	872	1395	862	1330	981	1395	1024	1482
	893	1330	915	1308	990	1363	1090	1548
	937	1351	888	1347	1090	1460	992	1439
	893	1330	857	1384	1053	1335	1024	1482
	959	1330	894	1332	941	1366	1114	1421
Average	904	1344	878	1339	1013	1398	1044	1476

Table 3b. Formant frequencies, F_1 and F_2 (in Hz), of the four Cantonese short vowels [ɪ ʊ ɵ ɐ] in CVS syllables for the female NH speaker and three female HI speakers.

APPENDIX IV: FUNDAMENTAL FREQUENCY (F_0) FOR TONES

(1a) Nine Citation Tones on [i] and [u] Produced by Male NH Speaker (M-NH)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	178	159	156	152	147	153	177
		188	165	155	151	149	153	162
		170	160	154	149	146	150	161
		171	162	157	145	143	145	167
		185	168	162	161	158	167	168
		193	180	172	170	173	179	175
	Average	181	166	159	155	153	158	168
	u	175	162	156	152	152	156	170
		187	176	174	161	165	169	186
		189	169	163	158	163	169	176
		171	161	160	156	153	158	169
		174	159	155	150	153	157	153
		164	150	146	144	151	157	182
	Average	177	163	159	154	156	161	173
33	i	157	130	124	117	121	128	136
		154	129	123	119	114	113	107
		158	142	138	121	124	125	121
		146	129	126	119	119	115	133
		155	124	117	113	111	105	90
		125	112	109	106	107	98	88
	Average	149	128	123	116	116	114	112
	u	154	138	126	120	120	121	123
		144	131	124	115	113	115	112
		162	133	126	117	115	115	113
		153	134	129	123	124	123	123
		150	139	134	125	122	121	113
		142	130	127	121	118	116	125
	Average	151	134	128	120	119	119	118
22	i	148	126	116	112	107	106	107
		142	123	120	116	113	109	100
		147	128	122	116	116	113	110
		147	126	119	110	108	107	106
		142	122	117	113	110	103	95
		140	125	122	116	114	109	111
	Average	144	125	119	114	111	108	105
	u	150	135	124	114	113	110	106
		130	119	114	111	105	90	65
		152	136	123	117	115	113	106
		147	127	119	113	108	109	102
		138	122	115	110	107	106	102
		145	136	129	121	116	110	107
	Average	144	129	121	114	110	106	98

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	132	118	109	71	59	60	61
		121	112	98	68	59	59	62
		119	116	107	90	66	62	63
		125	114	110	77	59	67	57
		133	118	109	66	62	64	66
		114	108	102	70	57	58	55
	Average	124	114	106	74	60	62	61
	u	133	121	104	51	53	55	56
		135	115	107	72	51	52	54
		130	122	119	102	61	58	60
		143	135	123	105	93	79	59
		139	125	116	80	53	61	60
		130	122	113	86	72	71	66
	Average	135	123	114	83	64	63	59
25	i	122	107	103	102	119	135	172
		125	111	105	110	121	136	156
		123	118	112	109	126	142	169
		122	104	101	108	125	131	128
		121	106	101	112	130	147	163
		130	110	105	111	123	142	155
	Average	124	109	105	109	124	139	157
	u	119	108	102	101	125	144	138
		128	115	110	108	126	145	143
		141	117	109	117	137	158	179
		131	115	110	113	127	138	158
		132	119	110	108	130	147	150
		122	114	111	112	129	147	143
	Average	129	115	109	110	129	147	152
23	i	132	114	108	106	116	131	135
		141	118	110	110	125	143	156
		123	116	112	108	119	127	120
		133	116	113	112	122	133	140
		135	120	115	115	123	135	115
		126	114	107	106	113	126	124
	Average	132	116	111	109	120	133	132
	u	137	121	108	106	117	124	125
		140	122	116	110	120	131	131
		140	118	111	113	123	133	118
		121	111	103	101	110	115	116
		139	118	111	108	116	126	105
		116	109	105	104	111	116	111
	Average	132	116	109	107	116	124	118

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	168	167	166	166	171	179	172
		179	170	165	164	174	162	152
		159	157	155	155	160	157	153
		159	156	153	150	155	158	157
		187	168	164	164	172	171	162
		171	168	168	170	170	163	162
	Average	171	165	162	161	167	165	160
	u	180	177	172	166	173	165	154
		167	162	159	157	157	156	142
		176	172	171	169	172	172	158
		161	159	157	156	165	165	155
		158	158	158	159	165	165	157
		167	162	159	158	162	156	144
	Average	168	165	163	161	166	163	152
3	i	176	155	148	137	134	124	101
		158	140	134	126	117	105	86
		151	141	138	132	122	110	94
		159	143	138	130	123	109	104
		153	145	141	134	123	102	94
		155	144	138	125	105	88	81
	Average	159	145	140	131	120	106	93
	u	154	145	137	127	125	124	124
		154	145	137	124	111	96	86
		155	147	140	130	120	113	99
		150	143	139	127	115	105	105
		154	138	136	124	116	109	93
		139	138	137	133	124	117	117
	Average	151	143	138	128	119	111	104
2	i	145	137	129	119	117	100	101
		143	142	139	118	102	85	72
		132	128	125	113	97	76	65
		142	133	130	125	109	93	82
		126	122	121	115	96	78	67
		133	126	124	119	106	86	76
	Average	137	131	128	118	104	86	77
	u	142	138	129	120	116	106	89
		138	130	126	120	110	102	102
		123	120	118	115	109	98	87
		128	125	126	122	109	101	95
		127	124	123	121	108	85	71
		133	129	127	121	112	98	88
	Average	132	128	125	120	111	99	89

Table 1a. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the male NH speaker (M-NH).

(1b) Nine Citation Tones on [i] and [u] Produced by Male HI Speaker 1 (M-HI-1)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	159	151	146	144	166	177	161
		153	152	148	143	140	136	134
		151	148	146	146	143	144	143
		155	159	157	151	146	139	135
		153	145	139	134	127	119	118
		150	151	147	140	135	127	122
	Average	154	151	147	143	143	140	136
	u	168	171	172	174	162	156	138
		168	183	180	162	143	136	131
		162	163	165	163	158	152	147
		163	164	164	170	161	158	148
		167	175	170	164	154	147	139
		168	168	170	170	165	157	148
	Average	166	171	170	167	157	151	142
33	i	116	120	116	103	110	111	111
		128	122	120	113	107	109	109
		124	131	125	118	112	112	110
		125	126	121	117	115	113	110
		135	135	129	122	115	112	111
		143	139	133	122	120	117	110
	Average	128	129	124	116	113	112	110
	u	147	146	139	126	119	116	119
		123	133	131	127	120	114	104
		133	136	130	123	119	117	112
		139	137	129	125	120	116	113
		134	135	133	127	121	119	112
		142	140	137	129	126	120	117
	Average	136	138	133	126	121	117	113
22	i	127	131	127	121	114	115	111
		120	131	132	118	109	115	105
		127	128	124	119	116	115	114
		124	129	127	124	122	118	114
		134	128	122	116	113	113	110
		133	132	122	113	105	106	102
	Average	128	130	126	118	113	114	109
	u	125	121	113	113	107	105	107
		132	133	126	119	107	110	108
		127	123	118	112	113	109	108
		113	121	118	106	110	111	109
		136	139	129	120	113	109	107
		132	132	126	114	111	108	104
	Average	128	128	122	114	110	109	107

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	106	108	102	94	99	95	89
		111	115	106	104	113	115	107
		116	118	114	108	108	106	106
		123	118	120	114	119	117	108
		117	120	115	105	98	106	105
		126	127	122	110	112	105	105
	Average	117	118	113	106	108	107	103
	u	114	117	117	111	107	104	103
		125	123	117	111	108	109	111
		119	123	119	109	106	106	107
		124	128	121	118	117	118	113
		132	132	131	116	110	105	106
		137	128	125	111	106	105	103
	Average	125	125	122	112	109	108	107
25	i	119	117	113	109	104	101	99
		128	130	134	125	111	108	109
		119	118	109	106	101	100	99
		130	116	116	114	115	120	122
		125	120	115	108	99	102	101
		128	125	123	116	113	112	109
	Average	125	121	118	113	107	107	106
	u	110	106	102	103	103	102	98
		119	117	120	126	122	114	105
		127	127	118	114	107	104	102
		133	132	125	112	112	109	109
		124	118	116	117	109	106	109
		107	116	109	109	106	109	108
	Average	120	119	115	113	110	107	105
23	i	113	110	105	104	113	120	107
		124	118	117	110	109	115	101
		122	126	120	109	105	103	102
		130	125	123	117	116	113	113
		131	127	120	114	108	109	116
		128	123	117	113	108	107	105
	Average	125	122	117	111	110	111	107
	u	118	117	110	110	112	118	120
		131	130	123	114	107	107	104
		118	119	117	113	112	113	112
		125	129	123	113	112	110	110
		134	128	120	114	103	105	104
		123	118	114	105	103	99	99
	Average	125	124	118	111	108	109	108

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	168	161	164	153	140	133	129
		163	160	159	163	155	145	136
		138	139	138	132	119	110	98
		132	130	127	122	116	112	107
		146	139	136	133	126	122	118
		133	132	129	123	111	107	105
	Average	147	143	142	137	128	122	116
	u	134	135	135	132	125	118	111
		156	157	157	150	140	137	132
		139	142	143	138	128	122	121
		146	140	141	137	126	117	116
		149	150	148	142	136	132	127
		136	136	135	132	126	123	120
	Average	143	143	143	138	130	125	121
3	i	125	126	126	123	114	115	116
		124	123	121	121	117	115	114
		123	130	133	127	119	116	117
		143	143	143	144	138	132	128
		144	142	141	135	128	122	111
		143	141	141	138	127	123	122
	Average	134	134	134	131	124	121	118
	u	143	142	139	129	119	117	117
		144	147	148	144	132	125	121
		125	131	135	131	114	112	111
		134	132	134	127	116	112	113
		140	137	135	133	128	124	120
		140	141	138	134	123	116	114
	Average	138	138	138	133	122	118	116
2	i	128	120	123	125	117	112	107
		138	138	135	128	124	122	119
		119	126	130	129	123	118	119
		152	144	135	128	114	107	106
		137	134	132	128	121	112	103
		130	137	134	135	128	127	127
	Average	134	133	132	129	121	116	114
	u	122	128	132	134	129	125	121
		143	141	142	137	133	133	129
		132	135	135	129	123	122	123
		133	131	129	127	122	120	118
		141	137	136	129	122	118	110
		132	133	133	131	121	114	111
	Average	134	134	134	131	125	122	119

Table 1b. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the male HI speaker 1 (M-HI-1).

(1c) Nine Citation Tones on [i] and [u] Produced by Male HI Speaker 2 (M-HI-2)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	151	157	155	147	143	136	133
		150	137	137	142	138	138	140
		162	158	163	154	147	143	141
		147	142	139	137	134	131	130
		151	144	145	144	135	135	133
		154	149	147	141	137	133	131
	Average	152	148	148	144	139	136	135
	u	140	134	136	138	137	136	136
		150	139	142	140	132	127	131
		144	141	139	141	143	141	138
		144	139	139	138	135	132	127
		153	148	147	152	150	146	143
		146	138	137	138	140	138	136
	Average	146	140	140	141	139	137	135
33	i	121	114	116	124	128	129	128
		110	105	103	111	122	122	123
		142	131	132	136	138	136	135
		134	129	131	127	126	124	125
		124	121	117	108	109	107	112
		131	133	135	137	133	130	127
	Average	127	122	122	124	126	125	125
	u	160	159	154	146	142	140	139
		151	150	149	146	145	143	140
		132	134	141	150	155	154	150
		146	141	139	133	127	126	123
		155	153	153	153	150	149	146
		168	161	162	160	153	149	144
	Average	152	150	150	148	145	144	140
22	i	124	118	117	120	122	124	126
		117	111	111	114	118	120	119
		113	113	118	127	135	134	132
		136	129	124	123	120	118	115
		131	122	120	114	110	108	107
		135	137	137	135	130	124	125
	Average	126	122	121	122	123	122	121
	u	152	142	140	125	111	112	111
		103	99	98	98	102	108	116
		151	145	143	143	140	141	137
		108	103	102	108	122	125	128
		143	137	134	137	139	138	135
		136	131	130	130	132	127	130
	Average	132	126	124	124	124	125	126

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	114	113	112	117	125	128	128
		107	103	101	108	119	120	124
		129	124	121	119	124	123	123
		137	129	127	131	133	131	127
		112	108	105	105	111	115	116
		116	113	110	112	121	123	124
	Average	119	115	113	115	122	123	124
	u	138	138	134	134	133	132	132
		100	95	94	95	108	120	123
		162	157	153	155	152	150	146
		128	122	117	113	113	115	116
		157	152	151	151	150	149	149
		157	156	155	152	145	141	139
	Average	140	137	134	133	134	135	134
25	i	125	117	116	123	133	133	132
		105	100	99	104	118	122	123
		112	109	107	108	110	110	116
		102	98	100	116	131	139	140
		121	111	110	106	105	104	105
		123	116	111	111	116	117	121
	Average	115	108	107	111	119	121	123
	u	112	109	103	100	117	118	116
		108	101	96	95	105	113	115
		107	104	105	101	102	104	107
		114	112	115	119	124	122	118
		122	117	114	116	116	114	115
		130	126	123	119	121	123	122
	Average	116	111	109	108	114	116	116
23	i	121	121	121	114	123	125	126
		121	106	105	110	119	119	118
		120	112	113	117	124	126	127
		116	109	110	111	121	120	121
		127	122	119	114	111	110	109
		115	110	106	111	113	119	121
	Average	120	113	112	113	118	120	120
	u	162	153	151	151	149	146	144
		150	146	143	142	139	137	137
		166	162	165	164	158	153	153
		152	149	146	146	142	140	139
		152	150	150	150	148	147	143
		149	146	146	144	142	138	135
	Average	155	151	150	149	146	144	142

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	152	156	159	148	141	133	124
		133	125	123	124	127	125	123
		122	127	128	128	130	127	125
		140	140	139	133	131	133	133
		123	122	121	117	117	118	119
		133	130	128	123	119	118	116
	Average	134	133	133	129	127	126	123
	u	139	139	141	142	134	129	119
		147	148	146	141	135	130	133
		104	124	154	150	149	144	145
		148	143	139	135	139	134	136
		158	150	148	144	141	137	134
		134	132	130	129	131	130	130
	Average	138	139	143	140	138	134	133
3	i	130	120	117	115	119	119	117
		137	128	126	123	124	124	124
		143	142	140	135	132	130	121
		143	134	134	128	121	118	118
		143	141	136	131	130	117	102
		133	130	128	128	129	127	132
	Average	138	132	130	127	126	123	119
	u	164	161	158	152	147	143	142
		143	146	142	142	144	145	136
		153	155	156	153	150	146	142
		143	138	137	137	133	130	127
		148	148	146	141	137	137	137
		162	155	153	149	142	143	148
	Average	152	150	149	146	142	140	139
2	i	126	123	122	122	123	122	117
		122	116	114	122	122	119	119
		132	131	131	127	123	125	133
		136	128	127	127	127	127	118
		137	129	129	132	130	124	114
		136	128	128	130	137	132	123
	Average	132	126	125	127	127	125	121
	u	153	154	154	149	147	144	141
		139	139	139	134	132	133	133
		151	144	142	139	134	135	140
		134	137	137	136	135	135	137
		156	157	156	150	138	144	144
		147	150	148	145	147	155	156
	Average	147	147	146	142	139	141	142

Table 1c. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the male HI speaker 2 (M-HI-2).

(1d) Nine Citation Tones on [i] and [u] Produced by Male HI Speaker 3 (M-HI-3)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	129	125	122	121	120	117	110
		138	134	129	126	125	121	117
		132	135	130	128	130	129	123
		136	134	132	131	129	127	123
		137	149	150	149	147	144	136
		133	134	131	133	132	129	124
	Average	134	135	132	131	130	128	122
	u	136	122	119	119	119	117	114
		125	124	123	122	120	120	115
		130	130	127	128	131	125	116
		140	137	135	137	134	131	126
		144	146	142	143	141	139	134
		136	134	132	132	128	127	123
	Average	135	132	130	130	129	127	121
33	i	123	115	110	105	99	99	99
		127	117	114	112	108	105	104
		132	122	116	110	110	107	103
		136	128	122	117	117	115	107
		125	117	110	109	119	121	113
		125	120	117	111	120	123	115
	Average	128	120	115	111	112	112	107
	u	118	111	105	103	102	99	94
		121	115	107	103	102	101	95
		139	125	115	114	113	110	107
		124	119	116	117	115	111	108
		129	118	118	118	116	115	112
		125	118	116	115	114	113	109
	Average	126	117	113	112	110	108	104
22	i	121	116	110	107	103	100	96
		122	119	114	113	110	111	105
		122	124	120	116	113	111	109
		122	119	117	114	101	91	95
		112	112	111	108	105	101	101
		123	121	118	118	116	115	108
	Average	120	118	115	113	108	105	102
	u	116	110	106	103	102	100	92
		123	119	114	114	114	111	105
		121	119	117	113	111	109	104
		119	123	117	116	111	101	91
		138	130	127	126	126	125	118
		122	121	118	118	117	114	110
	Average	123	120	116	115	113	110	103

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	116	110	101	88	82	80	80
		119	110	96	86	79	80	74
		117	108	104	92	82	79	81
		115	109	102	96	88	84	86
		136	121	110	97	89	86	87
		125	114	106	97	92	91	91
	Average	121	112	103	93	85	83	83
	u	105	98	93	87	80	78	73
		108	106	99	90	84	80	80
		124	114	103	90	87	84	84
		127	114	108	100	91	92	91
		114	109	103	95	88	87	86
		123	110	102	97	91	89	87
	Average	117	109	101	93	87	85	83
25	i	100	96	93	96	106	110	109
		102	99	96	98	110	111	106
		108	102	99	103	114	117	102
		114	107	104	108	118	121	126
		116	114	111	115	128	131	125
		106	104	103	110	121	126	123
	Average	108	103	101	105	116	119	115
	u	101	98	94	96	107	110	112
		105	98	94	95	107	108	107
		115	104	98	102	112	113	112
		116	105	101	105	122	127	125
		111	108	105	109	122	126	131
		119	105	100	102	113	118	118
	Average	111	103	99	102	114	117	117
23	i	109	103	97	99	108	113	113
		107	99	95	98	107	112	108
		112	112	106	104	117	119	107
		112	107	104	108	119	121	111
		110	106	105	107	120	120	114
		108	109	107	112	123	125	115
	Average	110	106	102	105	116	118	111
	u	99	96	92	97	110	112	107
		106	98	95	99	110	112	105
		107	101	97	101	115	120	119
		106	101	99	100	106	112	106
		112	105	102	107	117	121	112
		123	104	98	104	112	114	110
	Average	109	101	97	101	112	115	110

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	142	134	131	128	126	122	107
		130	132	128	125	127	123	119
		129	130	132	131	128	125	118
		132	129	130	130	131	128	110
		137	136	137	138	139	136	129
		128	122	122	125	126	120	107
	Average	133	130	130	130	130	126	115
	u	129	129	130	128	127	123	116
		139	140	136	134	134	131	118
		135	136	132	128	129	126	108
		148	147	143	141	144	139	126
		146	146	146	145	142	134	114
		140	136	137	136	132	129	108
	Average	140	139	137	136	135	130	115
3	i	120	117	114	109	107	98	98
		124	125	123	119	115	114	112
		127	126	124	118	112	103	87
		131	131	128	123	120	117	117
		128	128	125	117	113	100	95
		127	126	124	119	114	110	102
	Average	126	125	123	118	113	107	102
	u	121	111	108	105	101	92	90
		110	109	109	103	100	98	96
		122	120	120	112	108	107	108
		116	114	111	105	103	104	104
		121	119	119	116	112	113	110
		128	121	116	112	110	107	99
	Average	120	116	114	109	106	104	101
2	i	131	119	116	112	109	105	104
		119	122	120	117	113	112	106
		118	121	120	116	112	106	102
		146	129	128	124	118	117	112
		141	129	126	122	120	119	114
		115	119	118	117	116	114	104
	Average	128	123	121	118	115	112	107
	u	121	118	114	109	106	106	106
		127	122	118	118	113	104	96
		124	123	122	121	116	115	108
		122	116	113	113	111	108	95
		130	128	125	123	113	112	105
		126	123	118	113	111	108	98
	Average	125	121	119	116	112	109	101

Table 1d. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the male HI speaker 3 (M-HI-3).

(2a) Nine Citation Tones on [i] and [u] Produced by Female NH Speaker

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	283	273	271	268	269	273	269
		276	290	269	276	283	274	269
		289	294	293	296	300	302	288
		291	290	287	286	288	291	294
		286	289	285	284	284	289	292
		295	298	292	287	289	291	292
	Average	287	289	283	283	285	287	284
	u	300	285	291	286	280	277	278
		287	283	290	287	288	292	288
		284	293	293	294	291	291	291
		287	292	292	292	296	301	287
		284	296	297	293	290	291	294
		301	300	294	292	292	293	295
	Average	290	292	293	291	290	291	289
33	i	273	245	242	236	234	231	226
		240	246	238	233	236	230	248
		251	255	250	241	240	241	236
		248	262	259	257	253	252	255
		255	259	254	245	243	242	243
		264	265	262	257	252	250	254
	Average	255	255	251	245	243	241	244
	u	259	248	247	234	232	230	225
		261	248	241	232	227	232	231
		249	251	248	245	242	242	244
		261	259	252	247	246	247	250
		251	248	241	232	230	234	241
		260	260	252	244	241	242	250
	Average	257	252	247	239	236	238	240
22	i	248	233	227	223	216	216	222
		224	241	233	227	231	227	223
		239	235	230	220	219	224	228
		251	255	251	249	249	250	255
		243	239	233	230	226	227	227
		248	246	239	234	230	235	236
	Average	242	241	235	230	229	230	232
	u	252	245	236	222	215	223	223
		227	243	235	224	221	216	213
		240	244	237	232	227	228	227
		235	243	243	236	232	232	227
		227	246	239	230	223	223	222
		232	244	238	230	227	226	230
	Average	235	244	238	229	224	225	224

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	216	218	202	95	55	56	58
		233	223	203	107	66	69	73
		229	225	207	148	152	154	156
		233	222	206	100	109	189	214
		237	224	209	95	99	203	205
		240	219	206	119	126	200	202
	Average	231	222	205	111	101	145	151
	u	253	237	231	96	55	86	90
		228	218	208	72	66	87	192
		224	232	221	101	73	95	110
		220	221	211	171	176	178	180
		227	233	219	191	177	171	191
		226	225	209	192	196	198	199
	Average	230	228	216	137	124	136	160
25	i	214	218	212	216	241	268	273
		233	216	226	207	243	274	269
		214	206	196	194	236	263	283
		219	220	210	209	243	277	300
		221	213	208	207	216	226	243
		212	210	204	199	222	249	289
	Average	219	214	209	205	233	259	276
	u	245	216	210	211	240	271	279
		237	230	221	220	247	276	302
		234	224	213	212	235	264	294
		231	232	224	216	234	264	289
		227	225	213	213	222	238	246
		234	227	224	224	232	246	257
	Average	235	226	218	216	235	260	278
23	i	214	198	194	200	223	247	269
		232	238	234	232	247	246	242
		203	212	203	199	218	233	238
		240	218	211	211	227	245	252
		218	225	217	218	231	239	253
		239	229	221	219	229	237	247
	Average	224	220	213	213	229	241	250
	u	231	220	210	210	231	238	239
		225	213	214	213	227	235	236
		216	224	222	221	236	245	247
		219	224	218	219	233	241	250
		212	224	226	225	240	249	252
		220	216	220	222	234	245	249
	Average	220	220	218	218	233	242	245

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	258	274	272	273	258	221	173
		267	279	281	283	267	229	210
		303	301	301	294	288	270	273
		300	303	306	304	303	288	262
		305	305	302	300	286	281	283
		302	299	301	300	295	291	283
	Average	289	294	294	292	283	263	247
	u	272	284	287	287	279	263	240
		292	293	295	295	280	263	247
		296	305	310	311	311	297	292
		284	289	292	287	270	257	253
		296	299	299	297	297	297	297
		298	302	303	305	306	304	303
	Average	290	295	298	297	290	280	272
3	i	246	246	241	232	208	175	118
		246	255	253	243	223	189	120
		250	257	258	253	243	221	200
		257	254	253	246	237	216	213
		255	254	248	243	226	212	210
		264	264	259	254	254	253	246
	Average	253	255	252	245	232	211	185
	u	253	253	250	237	221	183	172
		262	250	250	243	207	179	167
		258	263	258	252	246	230	243
		246	260	256	251	250	245	229
		251	265	262	252	246	240	219
		255	258	259	254	253	245	223
	Average	254	258	256	248	237	220	209
2	i	229	250	241	227	197	179	119
		213	241	242	223	187	172	125
		254	249	241	227	213	195	114
		238	248	242	231	219	203	169
		238	245	243	237	227	210	197
		249	252	247	238	228	202	188
	Average	237	247	243	231	212	193	152
	u	213	229	246	237	212	184	170
		240	244	246	238	218	186	166
		228	242	244	238	220	214	214
		242	250	247	239	227	213	206
		231	247	244	237	216	202	202
		239	247	247	243	228	201	192
	Average	232	243	246	239	220	200	192

Table 2a. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the female NH speaker (F-NH).

(2b) Nine Citation Tones on [i] and [u] Produced by Female HI Speaker 1 (F-HI-1)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	231	241	240	233	229	221	232
		219	230	230	230	233	220	218
		264	248	251	251	247	239	242
		249	233	240	238	229	229	231
		250	248	248	245	245	242	240
		265	256	256	250	244	246	225
	Average	246	243	244	241	238	233	231
	u	226	249	247	241	235	226	217
		213	238	240	241	235	229	161
		242	230	232	231	227	211	186
		263	244	249	247	241	235	166
		246	251	253	248	244	233	160
		233	245	245	239	233	221	211
	Average	237	243	244	241	236	226	184
33	i	209	208	207	204	198	193	179
		211	211	207	203	193	191	183
		214	210	210	205	198	194	225
		201	210	208	204	196	189	146
		219	222	219	216	208	205	214
		211	209	209	202	194	185	191
	Average	211	212	210	206	198	193	190
	u	206	192	191	190	187	179	177
		215	198	196	195	188	185	184
		199	195	195	188	184	172	160
		185	196	193	190	186	183	165
		218	194	190	187	185	181	171
		204	196	195	190	191	186	186
	Average	205	195	193	190	187	181	174
22	i	205	209	207	203	195	185	175
		201	191	192	188	184	177	159
		207	209	211	207	203	202	207
		207	200	199	198	195	188	193
		191	193	193	189	182	169	158
		204	206	205	199	190	189	201
	Average	202	201	201	198	192	185	182
	u	183	191	189	181	171	163	157
		186	203	200	199	192	187	193
		181	200	201	202	200	196	172
		212	205	206	203	200	188	154
		193	183	183	178	182	178	155
		186	197	200	195	193	187	217
	Average	190	197	197	193	190	183	175

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	187	179	173	143	54	64	100
		193	194	179	140	100	127	84
		205	192	184	162	140	139	163
		182	172	171	178	166	158	171
		188	180	178	168	153	151	121
		197	190	182	166	143	137	149
	Average	192	185	178	159	126	129	131
	u	182	205	206	197	187	173	163
		196	198	194	193	186	162	109
		184	181	177	162	138	104	132
		191	186	185	175	157	162	145
		217	186	173	172	162	166	149
		173	184	180	169	153	136	124
	Average	191	190	186	178	164	151	137
25	i	193	171	166	168	179	186	172
		178	163	159	161	173	175	196
		190	155	147	142	154	159	186
		191	177	174	177	189	193	194
		199	189	183	180	197	192	168
		187	180	168	166	187	192	217
	Average	190	172	166	166	180	183	189
	u	160	163	163	167	179	191	217
		201	175	158	163	174	185	184
		191	166	156	155	170	175	176
		187	166	160	154	159	166	183
		178	167	161	165	180	193	210
		154	166	167	165	177	187	168
	Average	179	167	161	161	173	183	190
23	i	180	169	170	173	182	182	192
		175	168	171	165	178	184	148
		183	165	163	162	183	188	199
		192	172	167	168	186	189	200
		194	167	164	166	182	188	179
		173	179	175	180	203	183	191
	Average	183	170	168	169	186	186	185
	u	198	209	206	196	188	165	192
		184	191	191	185	180	177	171
		191	201	196	189	188	186	169
		188	196	198	189	174	164	127
		196	174	166	170	197	215	231
		172	168	165	165	182	186	195
	Average	188	190	187	183	185	182	181

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	253	248	252	246	226	195	188
		224	233	242	243	218	216	246
		237	247	250	247	237	208	198
		224	236	240	235	214	174	143
		281	280	276	261	241	211	210
		235	238	241	248	236	214	190
	Average	242	247	250	247	229	203	196
	u	236	252	259	256	226	167	122
		212	218	222	221	191	137	101
		237	252	261	253	223	167	122
		229	219	218	227	214	180	145
		229	231	240	242	217	175	147
		227	248	254	246	227	190	121
	Average	228	237	242	241	216	169	126
3	i	198	197	197	186	182	178	152
		197	194	193	183	120	99	100
		211	211	213	201	175	151	182
		224	202	198	194	171	135	127
		213	206	203	198	181	155	133
		187	210	213	205	191	169	139
	Average	205	203	203	194	170	148	139
	u	197	198	201	200	196	191	178
		198	188	191	188	148	106	163
		210	192	192	200	182	158	158
		213	198	203	200	197	188	190
		206	196	197	192	184	180	174
		212	203	197	186	169	149	117
	Average	206	196	197	194	179	162	164
2	i	209	196	202	203	183	183	235
		175	181	190	188	158	126	125
		183	195	200	195	182	181	201
		193	192	192	193	185	157	123
		180	196	196	192	177	186	183
		194	204	205	201	195	176	158
	Average	189	194	198	195	180	168	171
	u	204	205	203	201	188	156	123
		190	190	190	190	168	150	143
		192	194	197	196	187	140	98
		176	182	188	184	175	173	155
		210	201	196	194	189	185	181
		196	197	198	193	180	156	141
	Average	195	195	195	193	181	160	140

Table 2b. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the female HI speaker 1 (F-HI-1).

(2c) Nine Citation Tones on [i] and [u] Produced by Female HI Speaker 2 (F-HI-2)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	303	292	284	270	260	247	250
		282	273	266	257	251	249	220
		299	282	279	264	260	266	296
		305	286	281	272	272	276	275
		314	293	285	267	274	275	246
		303	281	277	256	263	260	240
	Average	301	284	279	264	264	262	254
	u	299	290	281	273	273	275	271
		271	272	270	267	259	255	245
		292	287	281	269	263	261	272
		295	289	277	265	259	262	272
		289	303	292	281	271	281	275
		286	282	275	260	257	266	266
	Average	289	287	279	269	264	267	267
33	i	248	217	211	198	196	201	207
		245	217	212	199	199	204	225
		213	225	221	211	204	206	217
		224	226	216	207	209	213	220
		236	233	225	216	208	207	214
		235	229	223	216	208	209	216
	Average	234	224	218	208	204	207	216
	u	228	229	217	204	215	231	201
		237	226	210	203	199	201	213
		230	226	218	208	211	219	223
		238	231	223	210	206	208	235
		231	223	217	213	209	216	229
		224	213	204	201	197	205	218
	Average	231	225	215	207	206	213	220
22	i	218	216	211	197	194	195	195
		238	210	202	191	101	100	100
		246	227	218	203	188	189	199
		222	218	213	200	190	188	197
		245	224	208	196	193	189	176
		237	222	213	199	190	188	205
	Average	235	219	211	198	176	175	179
	u	230	221	209	193	184	198	193
		202	202	189	184	177	179	205
		227	213	206	203	202	202	199
		226	210	201	196	195	195	203
		209	199	187	183	161	162	183
		221	205	197	188	183	193	194
	Average	219	208	198	191	184	188	196

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	248	205	180	162	159	153	156
		200	193	180	161	84	124	167
		260	227	217	201	187	178	160
		232	220	208	181	169	168	197
		219	215	199	169	94	132	137
		231	214	202	182	189	195	199
	Average	232	212	198	176	147	159	169
	u	222	203	189	174	171	170	190
		232	220	209	181	163	166	182
		222	210	198	191	183	184	201
		210	203	188	182	172	167	178
		218	206	194	168	152	152	167
		222	201	185	169	155	144	146
	Average	221	207	194	178	166	164	177
25	i	217	193	189	193	217	247	284
		208	193	188	190	208	200	216
		207	191	184	189	213	221	256
		203	194	185	186	198	213	226
		197	197	194	194	206	207	207
		205	198	192	195	209	229	228
	Average	206	194	189	191	209	219	236
	u	212	189	181	180	219	266	275
		199	184	171	185	221	241	241
		201	187	174	186	206	242	253
		203	194	184	185	196	241	261
		198	182	178	184	205	240	250
		204	178	175	181	194	236	259
	Average	203	186	177	184	207	244	257
23	i	242	210	198	199	226	141	120
		206	182	181	184	206	219	201
		210	195	192	193	207	222	246
		204	203	195	189	196	200	209
		195	188	183	188	200	209	199
		219	200	190	187	206	209	218
	Average	213	196	190	190	207	200	199
	u	242	227	221	211	212	230	240
		228	222	211	199	201	209	230
		237	231	221	216	218	226	238
		241	226	213	210	213	214	214
		217	207	196	191	184	179	207
		234	215	208	206	206	219	227
	Average	233	221	212	206	206	213	226

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	305	297	292	284	266	251	176
		278	275	271	267	259	247	243
		133	134	132	124	117	119	129
		259	257	252	248	241	233	219
		261	256	252	243	239	243	246
		261	269	261	260	251	143	119
	Average	249	248	243	237	229	206	189
	u	243	230	226	223	223	263	284
		223	239	231	212	201	182	131
		247	244	235	217	175	176	177
		235	250	249	243	236	228	218
		241	250	252	249	172	109	66
		244	246	241	235	227	224	216
	Average	239	243	239	230	206	197	182
3	i	257	252	248	234	219	221	125
		120	117	112	106	149	116	158
		257	243	235	222	209	229	229
		250	243	235	228	221	199	194
		270	250	245	241	227	203	149
		268	253	247	236	219	169	161
	Average	237	226	221	211	207	189	170
	u	243	229	216	205	194	172	99
		240	225	217	206	202	190	210
		226	220	212	202	180	100	80
		223	217	210	200	187	189	190
		229	220	217	207	178	145	108
		214	206	199	189	140	125	77
	Average	229	220	212	202	180	154	127
2	i	249	235	228	218	204	178	131
		209	215	210	206	210	194	239
		240	235	228	216	202	176	142
		231	241	235	223	210	199	148
		223	223	227	218	211	195	192
		236	228	223	215	204	194	147
	Average	231	230	225	216	207	189	166
	u	257	245	234	222	208	194	113
		231	220	212	200	188	176	199
		237	233	229	216	186	179	180
		237	231	221	205	181	181	182
		233	225	216	206	156	123	64
		243	228	219	206	182	136	66
	Average	240	230	222	209	184	165	134

Table 2c. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the female HI speaker 2 (F-HI-2).

(2d) Nine Citation Tones on [i] and [u] Produced by Female HI Speaker 3 (F-HI-3)

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
55	i	253	256	250	244	242	248	252
		244	245	235	226	227	225	235
		270	257	245	237	235	238	238
		224	228	224	217	222	221	243
		248	249	243	233	230	230	234
		245	245	246	244	244	240	257
	Average	247	246	241	233	233	234	243
	u	240	228	222	210	184	181	179
		192	192	197	108	115	116	117
		214	189	181	174	173	169	187
		200	197	172	160	157	159	175
		186	166	163	163	167	169	172
		204	183	178	174	175	173	173
	Average	206	193	185	165	162	161	167
33	i	225	205	194	191	192	186	159
		197	184	181	191	183	175	158
		201	195	175	158	155	148	153
		205	190	184	174	174	166	144
		183	193	191	191	183	178	180
		103	103	200	189	183	177	156
	Average	186	178	188	182	178	172	158
	u	174	179	175	168	167	154	162
		196	190	183	163	162	161	165
		178	185	188	164	153	156	155
		193	168	167	166	165	155	145
		179	197	182	156	175	153	150
		179	186	179	174	160	160	167
	Average	183	184	179	165	164	156	157
22	i	180	193	190	189	187	180	156
		210	200	189	182	167	160	140
		216	190	178	141	141	142	144
		232	234	225	241	222	230	217
		206	189	186	188	186	185	190
		204	202	194	186	179	166	174
	Average	208	201	194	188	180	177	170
	u	198	186	178	177	176	173	167
		179	170	165	157	155	153	161
		174	156	159	158	158	156	156
		218	170	175	175	178	179	192
		227	230	205	177	172	171	170
		194	180	178	181	182	177	186
	Average	198	182	177	171	170	168	172

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
21	i	216	207	190	182	186	182	137
		192	181	173	154	151	141	125
		214	205	192	190	189	180	146
		213	196	183	166	140	142	145
		196	188	184	177	174	165	152
		214	187	193	187	179	181	142
	Average	208	194	186	176	170	165	141
	u	193	197	193	191	188	179	185
		197	218	209	179	181	182	183
		183	229	181	158	154	146	146
		180	179	155	147	154	154	173
		174	174	165	159	159	154	161
		218	209	224	178	176	174	182
	Average	191	201	188	169	169	165	172
25	i	207	193	174	172	172	161	127
		189	185	182	161	158	159	142
		207	182	183	181	150	150	143
		196	196	179	144	146	147	148
		182	184	178	168	162	150	157
		195	194	179	150	144	142	119
	Average	196	189	179	163	155	151	139
	u	189	183	178	172	175	184	184
		190	193	189	183	187	182	188
		231	212	178	171	170	167	150
		205	187	175	165	163	161	152
		194	189	174	159	161	156	151
		199	194	203	174	172	170	167
	Average	201	193	183	171	171	170	165
23	i	206	195	178	156	151	147	141
		185	178	168	151	157	169	168
		205	191	174	155	151	146	152
		209	172	177	187	194	178	166
		166	181	181	165	172	175	183
		211	200	198	178	178	186	151
	Average	197	186	179	165	167	167	160
	u	173	181	182	176	179	182	186
		217	215	199	162	163	158	154
		181	170	170	169	170	170	181
		188	176	176	177	173	170	167
		227	217	213	212	213	209	213
		187	180	181	183	184	183	208
	Average	196	190	187	180	180	179	185

Tones	Vowels	0%	12.5%	25%	50%	75%	87.5%	100%
5	i	228	212	197	178	144	138	139
		206	189	177	161	116	84	67
		197	199	185	150	71	58	61
		182	179	166	163	150	151	152
		214	219	214	197	148	147	151
		190	193	189	153	142	143	145
	Average	203	198	188	167	128	120	119
	u	196	197	191	183	179	182	189
		190	186	185	181	173	163	147
		205	201	221	221	198	198	199
		235	234	228	215	214	214	214
		197	190	181	179	177	176	162
		219	194	187	186	187	177	187
	Average	207	200	199	194	188	185	183
3	i	216	212	208	187	150	138	138
		184	183	181	175	152	140	132
		207	202	196	169	153	145	181
		180	182	185	175	158	162	153
		168	188	188	186	174	163	134
		195	200	189	164	158	151	162
	Average	192	195	191	176	157	150	150
	u	202	198	196	192	205	205	206
		188	188	183	180	175	175	176
		227	222	217	203	182	177	177
		192	183	178	177	178	190	197
		205	195	194	201	169	165	166
		231	219	206	193	187	184	182
	Average	208	201	196	191	183	183	184
2	i	215	208	199	177	142	141	141
		201	191	183	179	167	155	155
		218	205	183	151	152	152	153
		200	190	171	152	153	153	153
		215	186	179	178	152	152	152
		196	188	182	177	167	167	168
	Average	207	195	183	169	155	153	154
	u	194	190	188	186	176	168	177
		198	188	182	165	166	167	167
		217	203	203	207	207	207	207
		186	186	184	176	170	177	192
		266	252	235	191	173	152	150
		245	219	218	217	194	194	195
	Average	218	206	202	190	181	177	181

Table 2d. Fundamental frequency (F_0) values (in Hz) at seven time points for the nine Cantonese citation tones [55 33 22 21 25 23 5 3 2] produced on the vowels [i] and [u] by the female HI speaker 3 (F-HI-3).