Gender-related Frequency Characteristics in Children's Speech

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Abstract

This study investigates the two frequency characteristics, F_0 and F_1F_2, of the speech of Cantonese children, male and female, of nine age groups from 4 to 12. The F_0 data on the Cantonese tones [55 33 22] from children show that (*i*) the patterns of the age-related decrease in F_0 are similar between male and female children before age 12; (*ii*) at age 12, there is a large drop in F_0 in male children, but not female children; and (*iii*) a significant difference in F_0 between the two genders occurs only at age 12. The formant data on the five Cantonese vowels [i u ɛ ɔ a] show that the patterns of the overall drop in F_1F_2 as a function of age between male and female children are similar. The gender differences in F_1F_2 emerge at age 7 and increase significantly at age 12. Generally speaking, for Cantonese children, the gender-related difference lies mainly in F_1F_2 not F_0, similar to the frequency data from English children reported in previous studies, which suggests a possible universal pattern of frequency development in children's speech.

Keywords: developmental change, F_0 and F_1F_2, vowel and tone, male and female children, Cantonese.

1. Introduction

As reported in the two reviews of previous studies of children's speech ([1, 2]), investigators have a special interest in the developmental changes in frequency characteristics, F_0 and formant frequencies of the vowels, with reference to continuous physical growth during childhood. Speech data from English children presented in previous studies ([1, 2, 3, 4, 5, 6, 7, 8, 9, 10]) show that there is no apparent difference in F_0 between male and female children, but the gender of their voice can be identified ([4, 5, 6]). According to the two reviews ([1, 2]), the gender difference in vowel formants is said to appear earlier at the ages from 3 to 5. And, in the studies [4, 5, 6, 9, 10], the lower formant frequencies in male children than female children are thought to contribute to gender identity.

It is generally acknowledged that there is a scarcity of information on the frequency characteristics of Chinese children's speech. The present study (*i*) investigates the frequency characteristics, F_0 and F_1F_2, of the speech of Cantonese preadolescent children, male and female, from 4 to 12 years of age; (*ii*) examines the patterns of developmental change in F_0 and F_1F_2 as a function of age and gender in Cantonese children; and (*iii*) compares the developmental frequency data from Cantonese male and female children with those from English children of both genders to ascertain the cross-language similarities and differences in frequency characteristics of children's speech.

2. Method

2.1. Speakers

In this study, speech samples were collected from a total of 90 preadolescent Cantonese children in Hong Kong. A cross-sectional approach was employed, where the 90 children were divided into nine age groups, ranging from 4 to 12 years of age, with 5 males and 5 females in each of the nine age groups. The means and standard deviations of the ages of five children of the same gender in each of the nine age groups are given in Table 1. For male or female children, the age difference between any two consecutive age groups is at one-year interval plus/minus two months, i.e., 10 to 14 months. Between male and female children of the same age group, the difference is 1 to 2 months.

Table 1: Means and standard deviations (SD) of the ages of Cantonese male and female children.

Male children		**Female children**	
Mean (year; month)	**SD** (month)	**Mean** (year; month)	**SD** (month)
4; 6	1.87	**4**; 5	2.74
5; 8	2.49	**5**; 6	1.52
6; 6	1.41	**6**; 7	0.89
7; 6	2.49	**7**; 5	2.07
8; 8	2.17	**8**; 7	0.89
9; 5	2.59	**9**; 7	1.10
10; 5	0.89	**10**; 5	0.71
11; 4	0.89	**11**; 5	1.00
12; 4	1.34	**12**; 4	2.28

All the children were born in Hong Kong and grew up in Cantonese-speaking families. They did

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not have history of speech and hearing problems. All parents gave permission for their children to provide speech samples for the study.

2.2. Test materials

The test materials for eliciting speech samples consisted of two sets of meaningful Cantonese monosyllabic words. As presented in Table 2, Set I consists of the test words that contain one of the five basic Cantonese vowels [i u ɛ ɔ a] associated with the same Tone [22]. Set II consists of the test words that contain the same vowel [a] associated with each one of the three Cantonese level tones [55 33 22].

Table 2: Cantonese monosyllabic words used in this study.

Set I	Set II
[j**i**^{22}] 二 (*two*)	[p**a**^{55}] 爸 (*father*)
[f**u**^{22}] 父 (*tofu*)	[p^{h}**a**^{33}] 怕 (*fear*)
[s**ɛ**^{22}] 射 (*to shoot*)	[h**a**^{22}] 下 (*down*)
[**ɔ**^{22}] 餓 (*hungry*)	
[h**a**^{22}] 下 (*down*)	

All the test words are commonly used in everyday speech in Hong Kong and are familiar to school-age children. A randomized list consisting of five repetitions of each test word in Chinese character was presented to the children for elicitation of speech samples. Pictures illustrating the meaning of the words were placed alongside the words for younger children who were not yet familiar with all the Chinese characters.

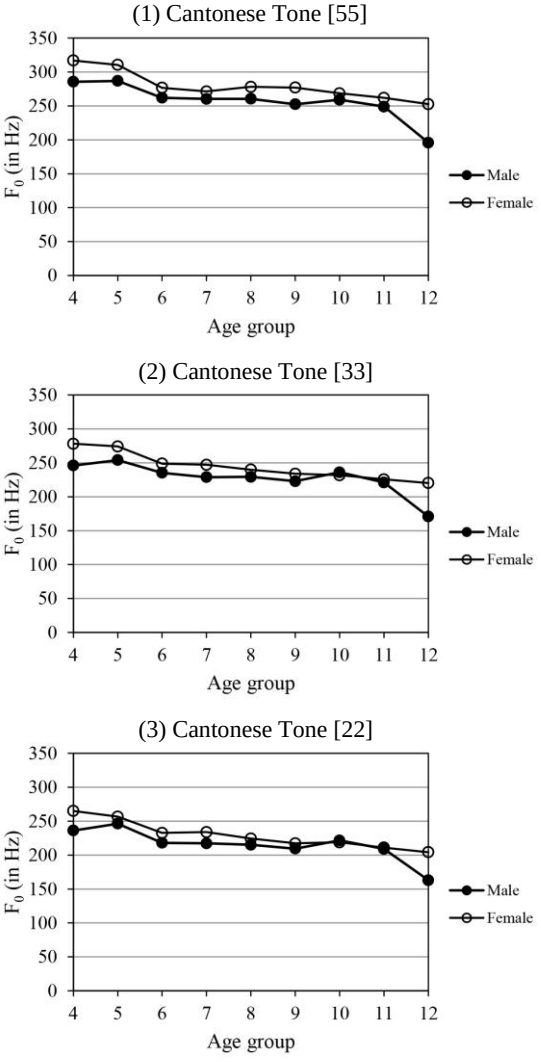
2.3. Data collection and analysis

The children took part in individual audio recording sessions performed in a quiet room at their school. The recorded speech samples were digitalized and down-sampled with the upper cut-off frequency at 6,000 Hz. An acoustical analysis was carried out, using the KayPENTAX CSL4500 speech analysis software. Pitch synchronized LPC formant analysis and F_0 analysis were performed at the temporal mid-point of the vowels and tones for measurements of (*i*) the formant frequencies (F_1F_2) of the five Cantonese vowels [i u ɛ ɔ a] and (*ii*) the F_0 values of the three Cantonese tones [55 33 22]. The mean F_0 value of each tone and the mean F_1 value and F_2 value of each vowel were obtained, by averaging across a total of 25 tokens (5 repetitions x 5 children) for five children of the same gender of each one of the nine age groups.

3. Results

3.1. F_0 for male and female children

Figure 1 shows the F_0 values of the Cantonese high level Tone [55] averaged across five male (represented by dark circles) or five female (represented by empty circles) children of each of the nine age groups from 4 to 12 years. As shown in the figure, there is a tendency for the F_0 to drop as age increases for both genders. For male children, the F_0 drops from 286 Hz at age 4 to 196 Hz at age 12. For female children, the F_0 drops from 317 Hz at age 4 to 253 Hz at age 12. At ages 4-11, the general patterns of the age-related F_0 decrease for male and female children are similar, with a slightly higher F_0 value for female than male children. At age 12, a large drop in F_0 is observed in male children, but not female children, which is taken to indicate the onset of the male adolescent voice change. Between male and female children of the same age, a significant gender difference in F_0 occurs at ages 4 (p <.01), 8 (p <.01), 9 (p <.01) and in particular at age 12 (p <.001).



Figures 1-3: F_0 of the Cantonese Tones [55 33 22] for male and female children at the ages of 4 to 12.

Similar F_0 developmental patterns to that in Tone [55] is observed in Tones [33] and [22] for male and female children. As shown in Figure 2 and Figure 3, in Tone [33] and Tone [22], there is an overall age-

related F_0 decrease across the nine age groups for children of both genders. At the ages from 4 to 12, (*i*) F_0 of Tone [33] drops from 246 Hz to 171 Hz for male children and from 278 Hz to 220 Hz for female children, and (*ii*) F_0 of Tone [22] drops from 236 Hz to 163 Hz for male children and 265 Hz to 204 Hz for female children. For both Tones [33] and [22], there is a large drop at age 12 in male children, but not female children. The F_0 values of Tones [33] and [22] tend to be slightly higher for female than male children of each age group, and a pronounced and significant gender difference in F_0 is observed only at age 12 (p <.001).

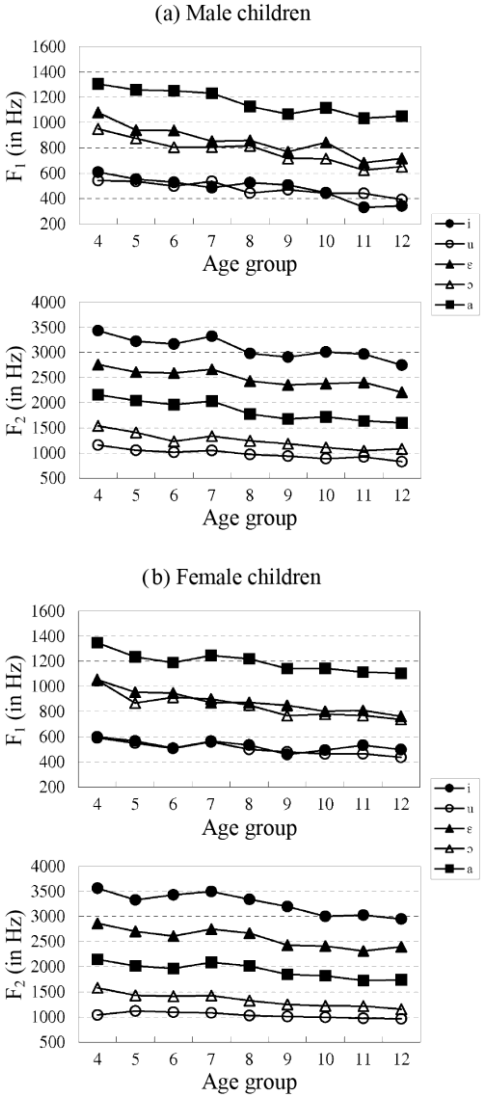
Table 3 presents the F/M (female to male) F_0 ratios with respect to Tones [55 33 22] for each of the nine age groups. In the table, the F_0 ratios which are marked with an asterisk are larger than 1.00 and at the same time are associated with a significant difference in F_0 between male and female children (p <.01). As presented in the table, the F/M F_0 ratio is larger than 1.00 in most cases, indicating that generally there is a higher F_0 for female than male children of the same age. For children below age 12, i.e., at ages 4-11, the F/M F_0 ratio ranges from 1.0 to 1.1 with respect to the three tones [55 33 22], indicating that the difference in F_0 between the two genders is minimal. At age 12, the F/M F_0 ratio increases to a range of 1.2 to 1.3 and the difference in F_0 between the two genders is significant (p <.01) for all the three tones. The data suggest the gender difference in Cantonese children's voice begins to emerge at the age of 12.

Table 3: F/M F_0 ratios for each of the nine age groups with respect to the Cantonese Tones [55 33 22] (*ratio > 1.00, with a significant (p <.01) difference in F_0 between the two genders).

Age group	F/M-[55]	F/M-[33]	F/M-[22]
4	1.11*	1.13*	1.12*
5	1.08	1.08	1.04
6	1.06	1.06*	1.07*
7	1.04	1.08*	1.08
8	1.07*	1.05	1.04
9	1.10*	1.05	1.04
10	1.04	0.98	0.99
11	1.05	1.02	1.01
12	1.29*	1.29*	1.25*

3.2. F_1F_2 for male and female children

Figure 4a and Figure 4b show the F_1F_2 values of each of the five Cantonese vowels [i u ɛ ɔ a] averaged across five children of the same gender for each of the nine age groups from 4 to 12 years. In the figures, the F_1 (upper panel) and F_2 (lower panel) values of the five vowels are represented by the lines connecting the symbols of different shapes. As can be seen, there is an overall gradual drop in the F_1F_2 values of each vowel as the age increases from 4 to 12 for both male (Figure 4a) and female (Figure 4b) children. For instance, from 4 to 12 years of age, the F_1 and F_2 values of the vowel [i] (lines connecting dark circles) drop from 610 Hz and 3,434 Hz to 342 Hz and 2,746 Hz for male children and from 599 Hz and 3,561 Hz to 498 Hz and 2,949 Hz for female children.



Figures 4a-b: F_1 and F_2 of the Cantonese vowels [i u ɛ ɔ a] for male and female children at the ages of 4 to 12.

Table 4 presents the F_1F_2 values of the five Cantonese vowels [i u ɛ ɔ a] for the youngest children at age 4 and the oldest children at age 12, male (left panel) and female (right panel). The differences in F_1F_2 of the five vowels between the two age groups of each gender are given in parentheses. As presented in the table, for both male and female children, the F_1F_2 values of any vowel are noticeably larger for age 4 than age 12. The differences in F_1F_2 between the two age groups are non-uniform across the vowel types. Between male children at ages 4 and 12, the difference in F_1 is

smaller for the high vowels [i] (268 Hz) and [u] (149 Hz) and low vowel [a] (255 Hz) than the mid vowels [ɛ] (363 Hz) and [ɔ] (298 Hz). The difference in F_2 is smaller for the rounded back vowels [u] (331 Hz) and [ɔ] (455 Hz) than the unrounded vowels [i] (688 Hz), [ɛ] (550 Hz) and [a] (560 Hz). Similarly, between female children at ages 4 and 12, the difference in F_1 is smaller for the high and low vowels [i] (101 Hz), [u] (155 Hz), and [a] (243 Hz) than the mid vowels [ɛ] (292 Hz) and [ɔ] (313 Hz). The difference in F_2 is smaller for the rounded back vowels [u] (76 Hz) and [ɔ] (355 Hz) than the unrounded vowels [i] (612 Hz), [ɛ] (465 Hz), and [a] (406 Hz). The data show similarities in the age-related vowel development between male and female children, though the vowel formant values tend to be slightly higher for female children than male children.

Table 4: F_1F_2 (in Hz) of the Cantonese vowels [i u ɛ ɔ a] for male and female children at age 4 and age 12 (differences in F_1F_2 between the two age groups in parentheses).

	Male: Age 4 & Age 12		Female: Age 4 & Age 12	
	F_1	**F_2**	**F_1**	**F_2**
i	610 & 342 (268)	3434 & 2746 (688)	599 & 498 (101)	3561 & 2949 (612)
u	542 & 393 (149)	1159 & 828 (331)	591 & 436 (155)	1040 & 964 (76)
ɛ	1080 & 717 (363)	2758 & 2208 (550)	1055 & 763 (292)	2861 & 2396 (465)
ɔ	950 & 652 (298)	1536 & 1081 (455)	1050 & 737 (313)	1510 & 1155 (355)
a	1305 & 1050 (255)	2158 & 1598 (560)	1348 & 1105 (243)	2144 & 1738 (406)

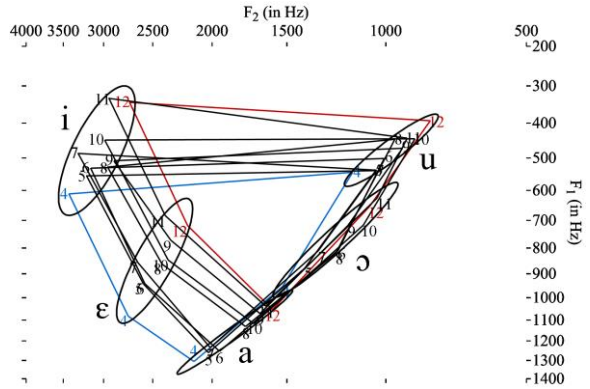
Table 5 shows the gender difference in children's vowel formant frequencies by presenting the F/M F_1 ratios and F/M F_2 ratios with respect to the five Cantonese vowels [i u ɛ ɔ a] for children of the same age group. In the table, the F/M F_1 ratios and F/M F_2 ratios marked with an asterisk are larger than 1.00 and at the same time the differences in F_1 or in F_2 between the two genders are significant (p <.01). The data in the table show that in a large majority of cases for the nine age groups, the F/M F_1 ratios and F/M F_2 ratios are larger than 1.00. This indicates that the F_1 and F_2 values are in general larger for female children than male children.

The gender differences in F_1 and F_2 are more apparent in older children at ages 7 to 12, as compared to younger children at ages 4 to 6, for older children there are more cases where the F/M F_1 ratios and F/M F_2 ratios are above 1.00 and at the same time the differences in F_1 and in F_2 between the two genders are significant (p <.01). At age 12, in all the cases, the F/M F_1 ratios and F/M F_2 ratios are larger than 1.00 and also the gender differences in F_1 and in F_2 are significant for all the five vowels. The data suggest that the difference in vowel formant frequencies between the two genders of Cantonese children commences at age 7 and increases significantly when reaching age 12.

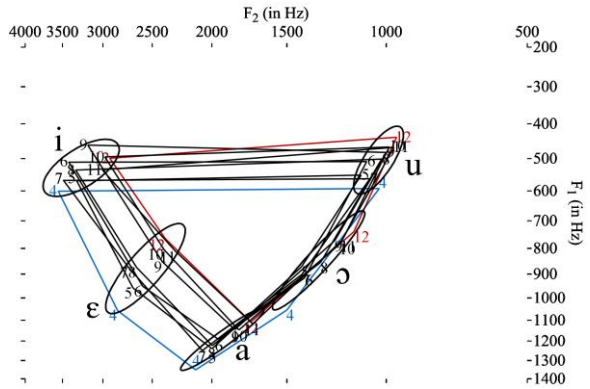
Table 5: F/M F_1 ratios and F/M F_2 ratios with respect to the Cantonese vowels [i u ɛ ɔ a] for each of the nine age groups (*ratio > 1.00, with a significant (p <.01) difference in F_1 or F_2 between the two genders).

	F/M-[i]		F/M-[u]		F/M-[ɛ]		F/M-[ɔ]		F/M-[a]	
Age	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
4	0.98	1.04*	1.09*	0.90	0.98	1.04	1.11*	0.98	1.03	0.99
5	1.02	1.03	1.03	1.07	1.02	1.04*	0.99	1.01	0.98	0.99
6	0.96	1.08*	1.02	1.08	1.01	1.01	1.14*	1.15*	0.95	1.00
7	1.16*	1.05*	1.04	1.03	1.02	1.03	1.11*	1.07	1.01	1.03
8	1.02	1.12*	1.13*	1.06	1.02	1.10*	1.04	1.06	1.08*	1.14*
9	0.90	1.10*	1.02	1.07	1.10*	1.03	1.07	1.05	1.07*	1.10*
10	1.10	1.00	1.05	1.12*	0.95	1.01	1.09*	1.10*	1.03	1.06*
11	1.61*	1.02	1.05*	1.06	1.19*	0.96	1.23*	1.16*	1.08*	1.05*
12	1.46*	1.07*	1.11*	1.16*	1.06*	1.08*	1.13*	1.07*	1.05*	1.09*

(a) Male children



(b) Female children



Figures 5a-b: Superimposed vowel loops for the Cantonese vowels [i u ɛ ɔ a] in the F_1F_2 plane for male and female children of the nine age groups from 4 to 12.

Figure 5a and Figure 5b present the superimposed vowel loops drawn by connecting the points representing the positions of the five Cantonese vowels [i u ɛ ɔ a] in the F_1F_2 plane for male and female children of the nine age groups from 4 to 12. In the figures, the numbers represent both the age groups and the positions of the five

vowels in F_1F_2 plane. The positions are based on the mean F_1 and mean F_2 values averaged across five children of the same gender of each of the nine age groups. The nine superimposed vowel loops represent separately the nine male (Figure 5a) or female (Figure 5b) age groups. As can be seen, for both male and female children, the vowel loop for age 4 is positioned in the most downward and leftward area in the F_1F_2 plane, due to the large F_1F_2 values, and the vowel loop for age 12 is positioned in the most upward and rightward area in the F_1F_2 plane, due to the small F_1F_2 values. The positions of the vowel loops generally shift toward the origin of the F_1F_2 plane located at the top right corner of the acoustical vowel space, as the age increases from 4 to 12 for both genders. This indicates similar age-related development in acoustical vowel space for male and female children.

The age-related reduction in F_1F_2 results in the shrinking of the overall vowel loop area for children of both genders. Table 6 presents the vowel loop areas (in Hz^2) for children of the nine age groups, male and female, obtained by applying the formula that calculates the area of an irregular polygon ([2]). The F/M vowel loop area ratios for each of the nine age groups are presented in the rightmost column of the table.

Table 6: Areas (in Hz^2) of the vowel loop for the Cantonese vowels [i u ɛ ɔ a] in the F_1F_2 plane for male and female children of the nine age groups from 4 to 12; F/M vowel loop area ratios for each age group.

Age group	Male vowel loop area	Female vowel loop area	F/M vowel loop area ratio
4	959K	1060K	1.11
5	825K	833K	1.01
6	897K	906K	1.01
7	842K	841K	1.00
8	748K	877K	1.17
9	598K	775K	1.30
10	797K	715K	0.90
11	711K	649K	0.91
12	691K	685K	0.99

As can be seen in Table 6, there is a tendency for the vowel loop areas for children of both genders to reduce progressively as age increases. The vowel loop area is largest at age 4 and smallest at ages 11-12. The age-related reduction in the overall vowel loop area is significant across the nine age groups for both male (p <.05) and female (p <.01) children. However, there is no significant difference in vowel loop area between any two consecutive age groups of the same gender. The data reveal that the developmental change of the acoustical vowel space is progressive for children of both genders.

Between the two genders, there is no significant difference in vowel loop area. The data presented in the rightmost column of Table 6 show that the F/M vowel loop area ratios for any one of the nine age groups are near 1.00, which indicates that the sizes of vowel loop area are similar between male and female children of the same age group and also across the nine age groups. The gender difference in children's speech is thus not reflected in the size of acoustical vowel loop area.

4. Discussion

The patterns of the age-related and gender-related developmental changes of F_0 and F_1F_2 for Cantonese children presented above are generally similar to those for English children reported in the previous cross-sectional studies of children's speech development ([3, 7, 8, 10]). To demonstrate the cross-language similarities and differences in frequency development of preadolescent speech, the F_0 and F_1F_2 data from Cantonese male and female children in the present study are compared with the comparable frequency data from English children of both genders as reported in [8]. As the youngest English children who provided the speech samples for [8] were five years old, the frequency data for comparison between Cantonese (the present study) and English ([8]) are those from children of the age groups of 5 to 12.

Table 7: F_0 values of the Cantonese vowel [a] (the present study) and the English vowel [ɑ] (reported in [8]) for male and female children of the age groups of 5 to 12; F/M F_0 ratios with respect to [a]/[ɑ] for each age group of the two languages.

Age group	Cantonese children			English children		
	Male	Female	F/M	Male	Female	F/M
5	287	311	1.08	263	277	1.05
6	262	277	1.06	263	258	0.98
7	260	271	1.04	264	278	1.05
8	260	278	1.07	248	268	1.08
9	253	277	1.10	253	267	1.06
10	259	269	1.04	251	257	1.02
11	249	262	1.05	243	246	1.01
12	196	253	1.29	225	230	1.02

Table 7 presents the F_0 values of the Cantonese vowel [a] associated with Tone [55] for male and female children in present study and the F_0 of the English vowel [ɑ] from children of both genders reported in [8] for the eight age groups from 5 to 12 years. Also presented in the table are the F/M F_0 ratios with respect to the Cantonese vowel [a] and English vowel [ɑ] for male and female children of each of the eight age groups. As can be seen, the patterns of the age-related developmental changes of F_0 are similar between Cantonese and English children of both genders. For children of both languages, male or female, there is an overall drop in F_0 as age increases. Two noticeable differences

between Cantonese and English are in male children. One difference is the large F_0 drop from age 5 and age 6 in Cantonese male children, but not in English male children. The other difference between the two languages is an abrupt F_0 drop between age 11 and age 12 in Cantonese male children, an indication of the onset of adolescent voice change, but the drop in F_0 between age 11 and age 12 is less pronounced in English male children.

For both Cantonese and English children, the F_0 value is in general larger for female than male children of the same age group. As presented in Table 7, the F/M F_0 ratios are larger than 1.00 for Cantonese children of all the eight age groups and English children of almost all the age groups. For both languages, the gender differences in F_0 for any age groups are minimal, with the F/M F_0 ratio nearing 1.00 or 1.10. A single exception is the F/M F_0 ratio of 1.29 for Cantonese children of age 12, which is taken to be the onset of pitch distinction between male and female children. This gender difference in F_0 is not observed in English children of the same age, which suggests that the pitch distinction between male and female English children occurs after age 12.

Table 8: F/M F_1 ratios and F/M F_2 ratios with respect to the English vowels [i u ɛ ɔ ɑ] for children of each of the eight age groups from 5 to 12 (based on [8]).

	F/M-[i]		F/M-[u]		F/M-[ɛ]		F/M-[ɔ]		F/M-[ɑ]	
Age	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**	**F_1**	**F_2**
5	1.00	0.98	1.05	1.13	1.07	1.03	1.10	1.09	1.05	1.05
6	1.05	0.96	1.12	1.08	0.93	1.06	1.04	1.10	1.11	1.14
7	1.10	1.01	1.13	1.08	1.08	1.01	1.05	1.05	1.08	1.07
8	1.03	0.99	0.93	0.98	1.09	1.02	1.14	1.08	1.14	1.09
9	1.19	1.03	1.07	1.10	1.03	1.03	1.07	1.07	1.05	1.05
10	1.11	1.00	1.03	1.05	1.13	1.02	1.10	1.09	1.07	1.07
11	1.17	1.03	1.00	1.04	1.07	1.05	1.07	1.12	1.09	1.08
12	1.23	1.05	1.07	1.05	1.00	1.08	1.06	1.12	1.05	1.13

The F/M F_1 ratios and F/M F_2 ratios with respect to the five English vowels [i u ɛ ɔ ɑ] for children of each of the eight age groups from 5 to 12 (based on [8]) are presented in Table 8. They are compared with the F/M F_1 ratios and F/M F_2 ratios with respect to the five Cantonese vowels [i u ɛ ɔ a] for male and female children presented earlier in Table 5. Results show that the patterns of the gender differences in F_1F_2 for children of both languages are similar. For both languages, (*i*) the F_1 and F_2 values are larger for female vowels than male vowels, as in both languages the F/M F_1 ratios and F/M F_2 ratios in a large majority of cases are larger than 1.00, and (*ii*) the gender differences in F_1F_2 are more apparent for the older age groups, such as the ages of 9-12, as for both languages the F/M F_1 ratios and F/M F_2 ratios are large than 1.00 for all the five basic vowels except for a few cases.

For both Cantonese and English children, the gender-related differences lie mainly in formant frequencies (F_1F_2), not in F_0. The close similarities between the frequency data from Cantonese children and those from English children point to a possible universal development pattern of frequency characteristics of vowel production in male and female children.

5. Conclusion

The present study shows that (*i*) cross-age comparisons of the F_0 and formant data on the vowel sounds from Cantonese male and female preadolescent children generate useful information for deriving patterns of developmental changes of frequency characteristics of children's speech and (*ii*) cross-language comparisons of the F_0 and formant data may lead to possible universal developmental patterns. Future research will explore the roles of F_0 and formants as perceptual cues for distinguishing male and female voices of Cantonese children across age groups and compare with the findings of gender identification of the voices of English male and female children reported in the studies, such as [4, 5, 6, 9, 10].

6. Acknowledgement

Support by a SRG grant (#7002390) from the City University of Hong Kong for this research is gratefully acknowledged.

7. References

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