DEVELOPMENTAL CHANGE OF VOWEL PRODUCTION IN CANTONESE CHILDREN

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ABSTRACT

The paper investigates the developmental change in formant frequencies (F_1F_2) of the vowels [i u ɛ ɔ a] in Cantonese male and female children of the ages ranging from 4 to 12. Results show that (*i*) a decrease in formant frequencies and vowel loop area is a function of age and the change is a gradual process; (*ii*) the developmental change with age is non-uniform across vowel types and formants, with a larger decrease in F_1 for the mid and low vowels [ɛ ɔ a] than the high vowels [i u] and a smaller decrease in F_2 for the rounded back vowels [u ɔ] than the unrounded front equivalents [i ɛ] and the low vowel [a]; (*iii*) the difference in vowel formant frequencies between male and female children starts at 7 years of age and peaks at 12 years of age; and (*iv*) the difference in vowel loop area between male and female children as a function of age is not significant.

Keywords: Cantonese vowels, developmental change, vowel loop area, vowel formants, children

1. INTRODUCTION

There have been a number of studies of the developmental change in children's speech given an account in two reviews of the previous research on speech development [5 9]. Of particular interest is the developmental change of vowel production, which is related to the anatomical and physiological development in children. Previous studies of vowel production in children ([1 2 3 4 6 7 8 10]) show (*i*) larger formant values and greater spectral variability in children than adults; (*ii*) gradual decrease in formant frequencies variability and vowel space with increasing age; (*iii*) differentiation between male and female in formant patterns appears at three to five years of age; and (*iv*) from childhood to adulthood formant frequencies decrease at a faster rate and reach smaller values for male than female children.

The present paper investigates the developmental change of formant frequencies in male and female Cantonese children of four to twelve years of age.

2. METHOD

2.1. Subjects

Speech data were elicited from a total of 90 Cantonese-speaking children (5 children *x* 2 genders *x* 9 age groups) in Hong Kong. All the children were born in Hong Kong and grew up in a monolingual Cantonese-speaking family, and they did not have history of speech and hearing problems. Following the cross-sectional approach, children were divided into nine age groups, ranging from four to twelve years of age, with a one-year increment between any two successive age groups, and in each age group there were five males and five females.

2.2. Test material

The test words for eliciting speech data were meaningful Cantonese (C)V monosyllables, [ji^{22}] 'two', [fu^{22}] 'father', [sɛ^{22}] 'to shoot', [ɔ^{22}] 'hungry', and [ha^{22}] 'down'. These are commonly used in every-day speech. Each test syllable contains one of the five Cantonese vowels [i u ɛ ɔ a]. To rule out pitch effect on formant frequencies, all the test syllables were associated with a mid-level tone [22]. The test words were in Chinese characters when presented to the speakers. For the younger children who were not yet familiar with the Chinese characters, pictures illustrating the meaning of the words were shown alongside the test words.

2.2. Data collection and analysis

Digital audio recordings were performed in quiet rooms at the schools. Five repetitions of each test word were recorded of each speaker. Pitch synchronized LPC formant analysis was performed at the temporal mid-point of the steady-state portion of the formant trajectories for measurement of formant frequencies, using the CSL4500 (Computerized Speech Lab) speech analysis software.

3. RESULTS

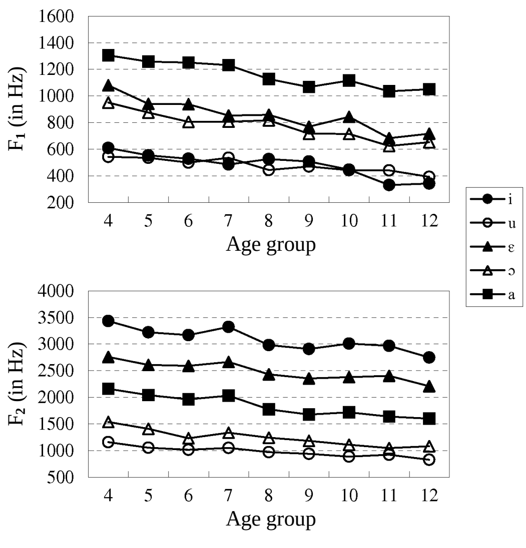
The formant frequencies (F_1F_2) for each of the five Cantonese vowels [i u ɛ ɔ a] to be presented are the average across five Cantonese children of each age and gender group. Also presented are (*i*) the areas of the vowel loops based on the positions of the vowels [i u ɛ ɔ a] in the F_1F_2 plane for each of the age and gender groups, and (*ii*) results of the cross-age and cross-gender group comparisons of the formants and vowel loop areas.

3.1. Vowel formant frequencies

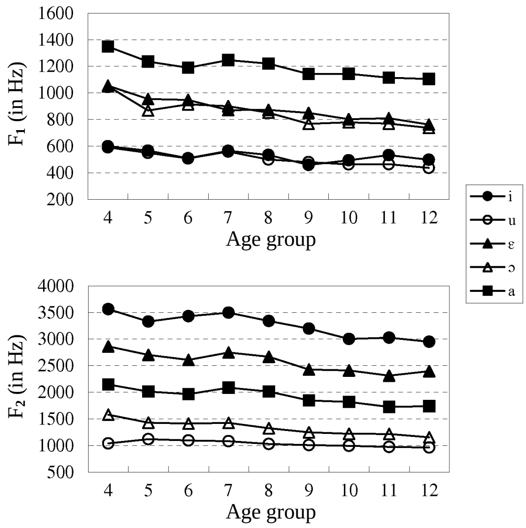
Fig. 1a shows the F_1 (upper chart) and F_2 (lower chart) values for the Cantonese vowels [i u ɛ ɔ a] plotted as a function of age for male children of the nine age groups from 4 to 12. The F_1 and F_2 values for female children are shown in Fig. 1b.

Figures 1a-1b: F_1 (upper chart) and F_2 (lower chart) values for the Cantonese vowels [i u ɛ ɔ a] for male and female children of the nine age groups from 4 to 12.

(1a) Male children



(1b) Female children



As can be seen in the figures, F_1 and F_2 for children of both genders decrease as age increases. The differences in F_1 and F_2 across the nine age groups is significant ($p < 0.001$) for each of the five vowels, yet between any two consecutive age groups of male or female children the difference in F_1 or F_2 is non-significant. This suggests that the decrease in formant frequency values with an increase in age is gradual.

Table 1 presents the F_1 and F_2 values for the Cantonese vowels [i u ɛ ɔ a] from male children (on the left) and female children (on the right) of the two age groups of 4 and 12. The data show that between the two age groups of male children, (*i*) the difference in F_1 is smaller for the high vowels [i u] (268 Hz; 149 Hz) than the mid and low vowels [ɛ ɔ a] (363 Hz; 298 Hz; 255 Hz), and (*ii*) the difference in F_2 is smaller for the rounded back vowels [u ɔ] (331 Hz; 455 Hz) than the unrounded front equivalents [i ɛ] (688 Hz; 550 Hz) and the low vowel [a] (560 Hz).

Table 1: F_1 and F_2 values (in Hz) and the differences (Diff.) in F_1 and F_2 between two age groups of 4 and 12 for the Cantonese vowels [i u ɛ ɔ a] from male and female children.

	Male children Age 4-Age 12 (Diff.)		Female children Age 4-Age 12 (Diff.)	
Vowels	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)

What has been said about male children is also true for female children (Table 1, right column). As presented in the table, between the two age groups of 4 and 12 of female children, (*i*) the difference in F_1 is smaller for the high vowels [i u] (101 Hz; 155 Hz) than the non-high vowels [ɛ ɔ a] (292 Hz; 313 Hz; 243 Hz), and (*ii*) the difference in F_2 is smaller for the rounded back vowels [u ɔ] (76 Hz; 355 Hz) than the unrounded front equivalents [i ɛ] (612 Hz; 465 Hz) and the low vowel [a] (406 Hz).

The formant data presented in Figs. 1a-1b and Table 1 demonstrate similarities between the developmental vowel data from male and female children. For children of both genders, the decrease in the formant frequency values as a function of age is non-uniform across the vowel types and formants.

3.2. Acoustical vowel space

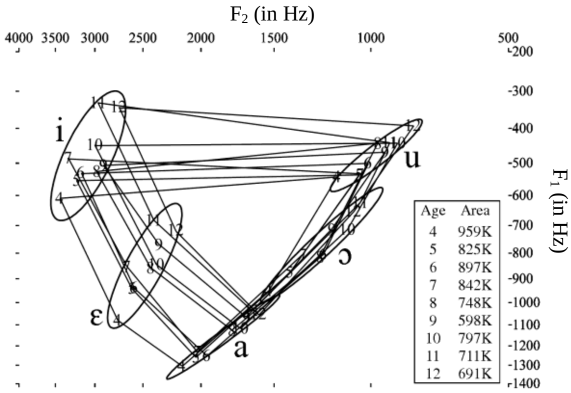
Fig. 2a shows the nine superimposed vowel loops which were drawn based on the positions of the Cantonese vowels [i u ε ɔ a] in the F_1F_2 plane on the Bark scale for the nine age groups of male children from 4 to 12. In the figure, the numbers represent the age groups, and their locations indicate the positions of the vowels which are determined by the mean F_1 and mean F_2. As can be seen, as the age increases, the positions of the vowel loops generally shift diagonally toward the origin of the F_1F_2 plane, an indication of decrease in F_1 and F_2 as the age increases. A larger decrease in F_1 and F_2 for [i ε] and [a] than [u ɔ] results in (*i*) a greater shift in [i ε a] than [u ɔ] and (*ii*) the reduction in the vowel loop area. The box in the lower right corner of Fig. 2a contains the data on the vowel loop areas (in Hz^2) for male children of the nine age groups. The areas were obtained by application of the formula that calculates the area of an irregular polygon ([9]). As shown in the figure, there is a general tendency for the vowel loop area to be negatively correlated with age. That is, the vowel loop area reduces as the age increases. However, there are two exceptions, where the vowel loop areas for the 6- and 10-year-old age groups (897K Hz^2; 797K Hz^2) are larger than the respective areas for the 5- and 9-year-old age groups (825K Hz^2; 598K Hz^2). Nonetheless, the general tendency stands.

Fig. 2b shows the nine superimposed vowel loops in the F_1F_2 plane for the nine age groups of female children from 4 to 12. Similar to male children (Fig. 2a), as the age increases the positions of the vowel loops for female children (Fig. 2b) shift diagonally towards the origin of the F_1F_2 plane, and there is also a general tendency for the areas of the vowel loops to reduce as age increases. Furthermore, the vowels [i ε a] undergo a large decrease in F_1F_2 than [u ɔ], resulting in a greater shift for [i ε a] than [u ɔ] and the reduction in the vowel loop area. And, as in the case of male children, despite a few exceptional cases, the general tendency remains for female children.

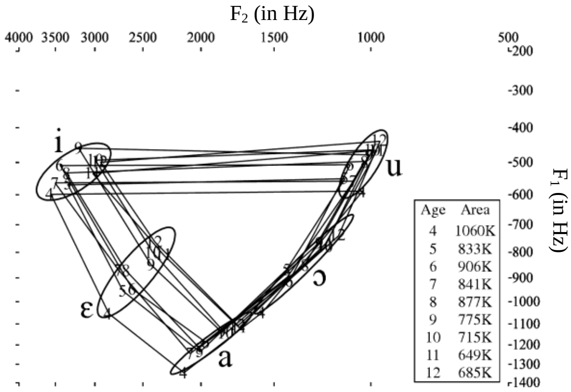
Thus, the patterns of the developmental change in the production of Cantonese vowels are similar for male and female children, despite the difference in the absolute values of F_1F_2 and the size of vowel loop area between the two genders. It should be added that for male and female children the difference in the vowel loop area across the nine age groups is significant ($p < 0.05$), but the difference between any two consecutive age groups is non-significant. This suggests that the change in the size of the vowel loop area is gradual for the nine age groups, male and female.

Figures 2a-2b: Vowel loops for the Cantonese vowels [i u ε ɔ a] in the F_1F_2 plane on the bark scale and their areas (in Hz^2) for male and female children of the nine age groups from 4 to 12.

(2a) Male children



(2b) Female children



3.3. Emergence of gender difference

To find out at what age a difference in the vowel formant values (F_1F_2) between male and female children begins to emerge, ratios of the F_1 and F_2 values for the vowels [i u ε ɔ a] for female children to the respective F_1 and F_2 values for the same vowels for male children are obtained. Table 2 presents the data on the ratios of female to male formant values (F_1F_2) for children of the same age group. In a large majority of cases, the ratios are larger than 1.00, indicating that F_1 and F_2 are in general larger for female children than male children. There is an increasing number of cases where the difference in F_1, F_2, or both between male and female children becomes significant ($p < 0.01$; marked with an asterisk '*') as the age increases. The differences in F_1 and in F_2 between the two genders become evident in children of 7 to 12 years of age, as in nearly all the cases, except two, the ratios are above 1.00, and the number of cases, in which the differences in formant values between the two genders are significant ($p < 0.01$), is larger for the 7 to 12 year old than the 4 to 6 year old. And, for only the children of 12 years of age, the differences in F_1 and in F_2 between the larger female values and smaller male values are significant ($p < 0.01$) for all the vowels. The data suggest that the difference between the two genders in vowel formant frequencies (F_1F_2) starts at 7 years of age and peaks at 12 years of age.

Table 2: Ratios of the F_1 and F_2 values for the Cantonese vowels [i u ɛ ɔ a] for female children (F) to those for male children (M) of the same age (* indicating the ratio > 1.00 and a significant difference ($p < 0.01$) between the two genders).

	F-[i]/M-[i]		F-[u]/M-[u]		F-[ɛ]/M-[ɛ]		F-[ɔ]/M-[ɔ]		F-[a]/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*	1.03	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*

As shown earlier in the paper, there is a general tendency for the areas of the vowel loops for the Cantonese vowels [i u ɛ ɔ a] in the F_1F_2 plane to be negatively correlated with age, that is, the vowel loop area reduces as the age increases (Figs. 2a-2b). To determine whether there is a difference between the genders in vowel loop area for children of any one of the age groups from 4 to 12, for each of the age groups the ratio of the vowel loop area for female children to that for male children is obtained.

Table 3: Vowel loop areas (in Hz^2) for male (M) and female (F) children and ratios of the female/male vowel loop areas.

Age	Male vowel loop area	Female vowel loop area	Ratio of F-area/M-area
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

The results in Table 3 show that there is a lack of patterning of the ratios between the male and female vowel loop areas as a function of age. For instance, the vowel loop area is larger for female than male children of the age groups of 4, 8, and 9 (with the respective ratios of 1.11, 1.17, and 1.30), but similar between female and male children of the age groups of 5, 6, 7, and 12 (with the respective ratios of 1.01, 1.01, 1.00, and 0.99) and smaller for female than male children of the age groups of 10 and 11 (with the respective ratios of 0.90 and 0.91). Thus, while there is a general tendency for the vowel loop area to be negatively correlated with age for male and female children, this is not true for the difference in the vowel loop area between male and female children as a function of age.

4. CONCLUDING REMARKS

The data on the developmental change of vowel production from Cantonese male and female pre-adolescent children presented in this study are similar to the findings of the previous studies of vowel production in English-speaking children ([2 5 6 7 9 10]), in that (*i*) the formant values and vowel loop area decrease as the age increases, and (*ii*) the changing in formant frequencies as a function of age is gradual and non-uniform across the different vowel types and formants. A difference is that in this study the difference in formant frequencies between Cantonese male and female children begins to emerge by at 7 years of age, rather than 3-5 for English-speaking children as reported in [7 9]. Thus, there are shared aspects and language specifics of the developmental change of vowel production between languages.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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