SPECTRAL CHARACTERISTICS OF THE MALE AND FEMALE VOWELS IN YONGDING HAKKA CHINESE

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ABSTRACT

This paper presents the formant data on the three Yongding Hakka vowels [i a ɨ]. Results of a spectral analysis show (i) F_2 for the vowel [a] is larger for Yongding Hakka than other Chinese dialects, due probably to the 'nudging effect' of the mid centralization of the historical */u/; (ii) the Yongding Hakka /ɨ/ has the F-pattern of a schwa; and (iii) the F-pattern of the Yongding Hakka /ɨ/ is similar to that of the plain apical vowel [ɿ] in Beijing Mandarin, except for a larger F_1 for /ɨ/. Between the male and female F-values, (i) the scaling relation is non-uniform across vowels and formants; (ii) the female vowels exhibit larger between-category dispersion; (iii) the size of vowel space area in the F_1F_2 plane is larger for female than male vowels, suggesting larger between-vowel category dispersion for female vowels; and (iv) the gender differences are reduced to a minimum after normalization.

Keywords: Yongding Hakka vowels, spectral analysis, F-values, male and female vowels, vowel normalization

1. INTRODUCTION

Yongding, a member of the Hakka Chinese group, spoken in the southwest of Fujian Province in southeastern China has a vowel system of three vowel phonemes /i a ɨ/ ([7]), the smallest one among the Chinese dialects ([19]). It is assumed that the vowels have developed from the historical */i a u/ with */u/ undergoing diachronic processes of de-rounding and mid-centralization. The present study investigates the acoustic phonetic characteristics of the three Yongding Hakka vowels /i a ɨ/. It obtains measurements of the formant frequencies ($F_1F_2F_3F_4$) for the three Yongding Hakka vowels. It also determines (i) the scaling between female and male F-values across vowel categories and across vowel formants and (ii) the differences in between-category dispersion in the F_1F_2 plane between male and female Yongding Hakka vowels.

2. METHOD

2.1. Test materials

The test materials for the investigation consisted of a minimal set of three meaningful CV monosyllables [ki^{55}] 'machine', [ka^{55}] 'family', and [kɨ^{55}] 'aunt'. Each contained one of the three Yongding Hakka vowel phonemes (/i a ɨ/). All the test vowels were preceded by a velar stop consonant [k] and associated with a high level [55] tone.

2.2. Speakers

Digital audio recordings were made of 40 native speakers of Yongding Hakka, 20 male and 20 female. The speakers who were all college students in their early twenties did not have history of speech and hearing difficulties.

2.3. Recording and spectral analysis

The test material was digitally recorded in a quiet room. Speakers were instructed to read at a normal rate of speech a randomized list of five repetitions of each of the three test words in Chinese character. A total of 600 test tokens (3 test words *x* 5 repetitions *x* 20 speakers *x* 2 genders) were recorded of the speakers for spectral analysis.

Using KayPentax CSL4450 speech analysis software, pitch synchronized LPC analysis was performed at the acoustical vowel target or the vowel's temporal mid-point for measurements of the formant frequencies of Yongding Hakka vowels.

3. RESULTS AND DISCUSSION

Table 1 and Table 2 present the mean $F_1F_2F_3F_4$ values (in Hz) and standard deviations for the Yongding Hakka vowels [i a ɨ] from 20 male and 20 female speakers, respectively. For speakers of both genders, F_1 (500.92 Hz; male and 567.91 Hz; female) is large for the close central [ɨ], relative to the F_1 for the close front [i] (339.89 Hz; male and 405.46 Hz; female). The formant data show that the Yongding vowel in question is more appropriately described as a mid-central schwa rather than [ɨ]. And for speakers of both genders,

F_2 for the vowel [a] is significantly larger for Yongding Hakka than other Chinese dialects. For instance, the mean F_2 for [a] is 1311.99 Hz (n = 250; male) and 1713.24 Hz (n = 250; female) in Beijing Mandarin ([21]) and 1257.48 Hz (n = 250; male) and 1501.58 Hz (n = 250; female) in Cantonese ([20]), but 1529.33 Hz (n = 100; male) and 1859.46 Hz (n = 100; female) in Yongding Hakka. This may be due to the 'nudging effect' of the mid-centralization of the historical */u/ when turning into /ɨ/ (a schwa rather) in Yongding Hakka.

Tables 1-2: Average $F_1F_2F_3F_4$ values (in Hz) and standard deviations (in parentheses) for the Yongding Hakka vowels [i a ɨ] for 20 male (n = 100) and 20 female (n = 100) speakers.

(1) Yongding Hakka male speakers

Vowel	F_1	F_2	F_3	F_4
i	339.89 (39.43)	2362.12 (153.45)	3269.60 (162.37)	3886.29 (161.46)
a	927.71 (77.35)	1529.33 (74.01)	2630.46 (191.78)	3856.57 (218.92)
ɨ	500.92 (49.33)	1323.36 (83.21)	2722.94 (125.20)	3674.93 (158.04)

(2) Yongding Hakka female speakers

Vowel	F_1	F_2	F_3	F_4
i	405.46 (82.52)	2860.07 (161.64)	3728.16 (199.74)	4576.84 (196.02)
a	1083.68 (54.12)	1859.46 (115.67)	3079.78 (204.52)	4433.00 (215.83)
ɨ	567.91 (44.33)	1473.21 (93.94)	3242.66 (172.98)	4355.04 (204.19)

Table 3: Average $F_1F_2F_3F_4$ values (in Hz) and standard deviations (in parentheses) for the plain apical vowel [ɿ] in Beijing Mandarin for 50 male (n = 250) and 50 female (n = 250) speakers (Zee and Lee [21]).

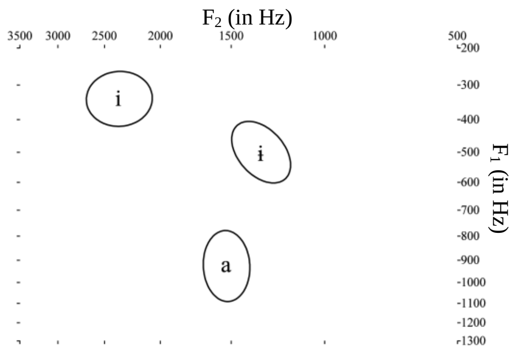
Vowel	F_1	F_2	F_3	F_4
[ɿ] (Male)	383.41 (36.19)	1311.54 (140.76)	2834.28 (161.23)	3813.18 (280.12)
[ɿ] (Female)	391.50 (42.05)	1695.20 (119.86)	3454.26 (211.61)	4619.50 (179.16)

The F-pattern of the Yongding Hakka vowel [ɨ] is similar to that of the plain apical vowel [ɿ] in Beijing Mandarin, except for a higher F_1 in /ɨ/. As presented in Table 3, the mean F_1 value for the Beijing Mandarin apical vowel [ɿ] is 383.41 Hz (n = 250) for male speakers and 391.50 Hz (n = 250) for female speakers, but 500.92 Hz (n = 100) and 567.91 Hz (n = 100) for the respective male and female Yongding [ɨ]. This may explain why in the speech of some Yongding speakers [ɨ] is pronounced as a plain apical vowel [ɿ]. This illustrates how in Yongding Hakka a historical */u/ evolves into an apical vowel [ɿ] through an intermediate stage of [ɨ].

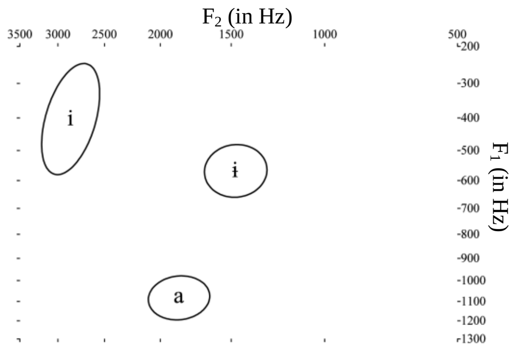
Figure 1 and Figure 2 show the ellipse plots of the three Yongding Hakka vowels [i a ɨ] in the F_1F_2 plane for 20 male and 20 female speakers, respectively. Each vowel ellipse encloses at least 95% of the tokens. The center positions of vowel symbols in the vowel ellipses were based on the mean F_1 and F_2 values presented in Table 1 (male speakers) and Table 2 (female speakers). The ellipses for female vowels (Figure 2) are located to the left and the lower part of the F_1F_2 plane relative to the corresponding vowel ellipses for male vowels (Figure 1). For both male and female speakers, the vowel ellipse for [ɨ] is positioned in the mid central, rather than close central, area of the acoustical vowel space.

Figures 1-2: Ellipse plots in the F_1F_2 plane for the Yongding Hakka vowels [i a ɨ] from 20 male and 20 female speakers.

(1) Yongding Hakka male speakers



(2) Yongding Hakka female speakers



Female vowels are known to have higher formant frequencies than male vowels ([2, 5, 8, 9, 11, 12, 13, 16, 17, 18, 19, 20, 21). Fant [4, 6] attributes this to (i) a longer vocal tract and (ii) a greater ratio of pharynx length to the overall vocal tract length for males than females. As reported in Fant [4, 6], the scaling relation between female and male F-values is non-uniform across different vowels and different formants. Applying Fant's K-factor formula ([4]),

(1) $K_n = (F_n, \text{female}/F_n, \text{male} – 1)\ x\ 100\%$

where K = K-factor, F = formant, and $_n$ = number, the percentages of the mean $F_1F_2F_3F_4$ values between the two genders for each Yongding Hakka vowel were calculated. The results are presented in Table 4. The values of both the female/male K_1- and K_2-factors are smaller for [ɨ] (13.37% and 11.32%) than [i] (19.29% and 21.08%) and [a] (16.81% and 21.59%). The female/male scale in F_1 (K_1-factor) is larger for [i] than [a], but the female/male scale in F_2 (K_2-factor) is similar for the two vowels. As for the values of the female/male K_3- and K_4-factors, they are larger for [ɨ] (19.09% and 18.51%) than [i] (14.02% and 17.77%) and [a] (17.08% and 14.95%). Between [i] and [a], the female/male K_3-factor is larger for [a], but the female/male K_4-factor is larger for [i]. Thus, the non-uniform scaling relation between female and male formant values across different vowel categories and across different formant frequencies for European languages reported in Fant [4, 6] are also observable in Yongding Hakka. It appears that there is no systematic patterning of the variations of the female/male scaling across the vowels within a language and between languages.

Table 4: Female/male K-factors (in %) for the mean $F_1F_2F_3F_4$ values ($K_1K_2K_3K_4$) of the Yongding Hakka vowels [i a ɨ].

Vowels	K_1	K_2	K_3	K_4
i	19.29	21.08	14.02	17.77
a	16.81	21.59	17.08	14.95
ɨ	13.37	11.32	19.09	18.51

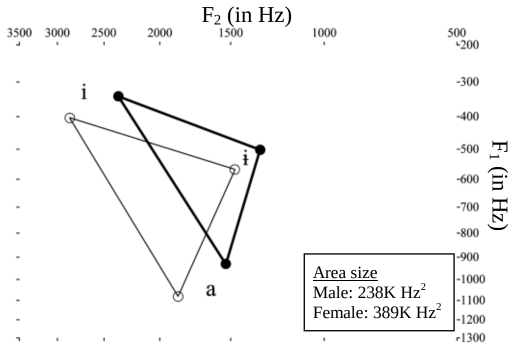
Table 5: Area sizes (in Hz^2) of the vowel ellipses for **the** Yongding Hakka vowels [i a ɨ] for 20 male and 20 female speakers.

Vowels	Male	Female
i	76K	149K
a	72K	78K
ɨ	47K	52K

Between the male and female speakers of Yongding Hakka, there is a difference in the size of the vowel ellipses, which is determined by the intra- and inter-variation of the vowel formant frequencies of each gender group. As presented in Table 5, the area size of the vowel ellipse for the vowel [i] is larger for female than male speakers, while the vowel ellipses for the other two vowels, [a] and [ɨ], are similar in area size between the two genders. The data suggest that there is no gender-related factor in the variability of vowels or the within-category variance in the vowels.

Figure 3 shows the vowel loop of the three Yongding Hakka vowels [i a ɨ] in the F_1F_2 plane for 20 male speakers (in solid dot and thick line) superimposed with that for 20 female speakers (in empty dot and thin line). The vowel loops were drawn by connecting the dots which represent the mean F_1 and mean F_2 values of the vowels [i a ɨ] of the same gender (*See* Table 1 and Table 2).

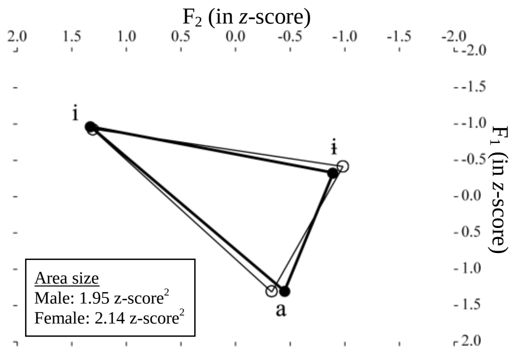
Figure 3: Superimposed vowel loops of the Yongding Hakka vowels [i a ɨ] in the F_1F_2 plane for 20 male (in solid dot and thick line) and 20 female (in empty dot and thin line) speakers.



As can be seen, there is a difference in the area size of the vowel loop between the two genders. The data presented in the box in the bottom right-hand corner of Figure 3 are the area sizes of the vowel loop or vowel space (in Hz^2) for the two genders, which are obtainable by application of Heron's formula that calculates the area of an irregular polygon ([9, 14, 15]). The vowel space area is larger for females (389K Hz^2) than males (238K Hz^2), which seems to support the assumption that female vowels exhibit greater between-category dispersion in the F_1F_2 acoustical plane than male vowels ([4, 6]). Since the difference in vowel space area between the two genders may be attributable to the larger F-values for female vowels than male vowels, vowel normalization was performed, using Lobanov's ([10]) vowel-extrinsic normalization procedure which has been accepted as the best way of transformation for minimizing the effect from the gender-related differences in anatomy and/or physiology on the F-values ([1]). Figure 4 shows the vowel loop of the three Yongding Hakka vowels [i a ɨ] in the normalized F_1F_2 plane (in *z*-score) for 20 male speakers (in solid dot and thick line) superimposed with that for 20 female speakers (in empty dot and thin line).

A comparison of Figure 3 and Figure 4 shows that after normalization (Figure 4), the differences in position and in area size of the vowel loops between the two genders diminish, in comparison to the differences before normalization (Figure 3). In the normalized F_1F_2 plane (in *z*-score), the positions of the three Yongding Hakka vowels [i a ɨ] for male speakers (in solid dot) and those for female speakers (in empty dot) are close to each other in proximity. The normalized vowel loops of the vowels [i a ɨ] for the two genders also overlap extensively. The vowel space areas based on the normalized *z*-score values for the two genders presented in the box in the bottom left-hand corner of Figure 4 show that female vowel loop (2.14 *z*-score^2) is just minimally larger than male one (1.95 *z*-score^2). Thus, by eliminating the gender-related anatomical/physiological factor in the F-values after normalization, the magnitudes of dispersion of male and female vowels in the F_1F_2 plane become similar. It follows that the observation that female vowels exhibit greater between-category dispersion in the F_1F_2 acoustical plane than male vowels in Yongding Hakka before normalization is resulted from the effect of the gender-related anatomical/physiological differences on the formant values.

Figure 4: Superimposed vowel loops of the Yongding Hakka vowels [i a ɨ] in the normalized F_1F_2 plane (in *z*-score) for 20 male (in solid dot and thick line) and 20 female (in empty dot and thin line) speakers.



4. SUMMARY

This paper resents the formant data on the three Yongding Hakka vowels [i a ɨ]. Results of a spectral analysis show (i) F_2 for the vowel [a] is larger for Yongding Hakka than other Chinese dialects, due probably to the 'nudging effect' of the mid centralization of the historical */u/; (ii) the Yongding Hakka /ɨ/ has the F-pattern of a schwa; and (iii) the F-pattern of the Yongding Hakka /ɨ/ is similar to that of the plain apical vowel [ɿ] in Beijing Mandarin, except for a larger F_1 for /ɨ/. Between the male and female F-values, (i) the scaling relation is non-uniform across vowels and formants; (ii) the female vowels exhibit larger between-category dispersion; (iii) the size of vowel space area in the F_1F_2 plane is larger for female than male speakers, suggesting larger between-vowel category dispersion for female vowels; and (iv) the gender differences are reduced to a minimum after normalization.

5. ACKNOWLEDGEMENTS

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