THE ARTICULATORY AND ACOUSTIC STUDY OF FRICATIVE VOWELS IN SUZHOU CHINESE

Ling Feng

Department of Chinese, Translation and Linguistics, City University of Hong Kong
50006412@student.cityu.edu.hk

ABSTRACT

The present study investigates the acoustic and articulatory characteristics of a Fricative vowel in Suzhou Chinese. The acoustic results show that the fricative vowel has more noise and a lower F2 than its pure vowel counterpart. The articulatory results show that the constriction of fricative vowel locates at a more anterior position than the pure close vowel. The commonly accepted correlation between F1 and vowel height, and F2 and vowel backness does not apply to the fricative vowel in the present study.

Keywords: fricative vowel articulatory acoustic

1. INTRODUCTION

Vowels involving frication are found in many languages and distributed over wide geographical regions. In addition to some Sino-Tibetan languages and the Proto-Bantu, provided as examples by Ladefoged & Maddieson [7], fricative vowels have also been observed in Salish languages (Hoard [5]), Afroasiatic languages (Coleman [2]) and African languages as summarized by Connell [3]. As suggested by Ladefoged & Maddieson [7], frication can be treated as an added vowel feature, and a new term ‘fricative vowel’ was adopted for these vowels.

Fricative vowels have been found in many Chinese dialects, for example, Jin Chinese (Karlgren [6]), Wu Chinese (Chao [1]), and Xining Chinese (Zhang [11]) which is a member of Northwestern Mandarin. The distribution covers most areas of China. According to Zhu [12], the fricative vowels play important roles in the historical sound change of Chinese dialects.

In this paper, I investigate the articulatory and acoustic characteristics of a fricative vowel in Suzhou Chinese, a major Chinese dialect which is considered as a representative of the Wu Chinese dialect family.

There are totally 12 vowels in Suzhou Chinese, which are [i_z y_z u i y ø ɛ o æ ɑ ɿ ʮ].Two pairs of contrasts of the fricative vowel and the pure close vowel, i.e. [i_z i] and [y_z y], can be found in the vowel inventory. The only difference between the fricative vowels and their pure vowel counterpart was considered to be the absence and presence of frication (Wang [10]). The present study will concentrate on the study of the unrounded fricative vowel and its pure vowel counterpart.

2. METHDOLOGY

2.1. Test words

In order to minimize the effect of the fundamental frequency change and the initial consonant on the vowel quality, the test words associated with high level tone [44] with zero initial consonant were selected. The test words were:

[i_z^{44}] (coat) [i^{44}] (smoke).

2.2. Subjects

Ten male and ten female subjects provided the acoustic data. They were all native speakers of Suzhou, aged between 50 and 60 and with no history of speech or hearing disorder.

Four of the above subjects, two males and two females, took part in the palatogram and linguagram experiment.

Two subjects, one male and one female, took part in the Electromagnetic Articulograph (EMA) analysis.

2.3. Acoustic analysis

Subjects were recorded in a quiet room using a Shure SM-58 microphone and MD Recorder. The subjects were asked to read the word list at a normal rate of speech. Three repetitions for each subject were recorded.

A sampling rate of 10 kHz is enough for most acoustic analysis of vowel. However, a larger sampling rate was used in this study, since most fricative noise energy is higher than 5 kHz. The recording were digitized at 20 kHz with a 10 kHz low-pass filter setting with 16 bit precision in the

CSL 4400 speech analysis software (Kay Elemetrics).

All acoustic analyses were made using the professional phonetic software Praat.

The frequencies of the first three formants of the vowels and Harmonics-to-Noise Ratio (HNR) were measured.

All the LPC measurements were performed at the mid-points of the vowels. The default settings of Praat were used (The time step was auto selected. The maximum number of formant is 5. The ceiling of formant searching range is 5000Hz for male speakers and 5500 for female speakers. The window length is 25 millisecond, and Pre-emphasis from 50 Hz). For each analysis window, Praat applied a Gaussian-like window, and computes the LPC coefficients with the algorithm by Burg, as suggested in Praat user's manual. A wide spectrogram was also performed as reference.

To get HNR value, the option of "To Harmonicity (cc) with time step of 10 millisecond, minimum frequency of 75Hz, silence threshold of 100 millisecond and 4.5 period per window" was used first. Then a mean HNR value of the whole vowel was calculated.

2.4. Articulatory analysis

Articulatory analysis included palatogram, linguagram and EMA.

Palatogram and linguagram analysis are usually used in consonant study to determine the location of contact between the tongue and the upper articulator. The two sides of the tongue contact the upper articulator for close vowels, because the diameter of the constriction is small. Therefore the palatogram and linguagram can be used in my study to determine the size and location of the constriction for the fricative vowel and the pure close vowel.

The Carstens Electromagnetic AG 100 system was used in this study to confirm the palatografic and linguagrafic results.

3. RESULTS

As shown in Table 1, the fricative vowel has higher F1, lower F2 and F3 than the pure close counterpart. All the differences between the formants are significant except the F1 of male speakers.

Table 1: The mean frequencies (in Hz) of the first three formants of [i_z] and [i] for male and female speakers.

	Vowel	*F1*		*F2*		*F3*	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Male	i_z	*278*	55	2058	150	3157	297
	i	*277*	35	2499	119	3573	288
Female	i_z	342	35	2247	187	3551	285
	i	311	23	3092	234	3944	283

Figure 1: Narrow band Spectrograms of [i_z] (left), [i] (right) from a female speaker

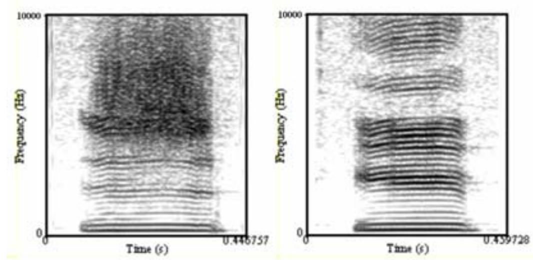
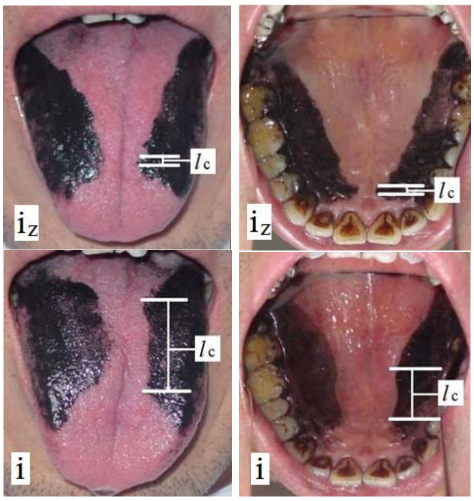


Table 2: A comparison of the mean HNR of the fricative vowel and the pure vowel

Vowels	*HNR (0-10k Hz)*	*P-value*
i_z	15.7	P<0.0001
i	26.2	

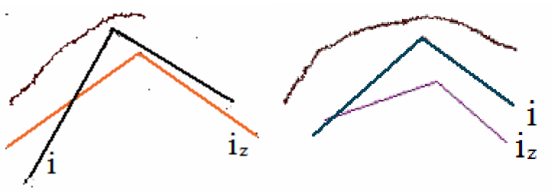
As predicted by the term, fricative vowels should have more noise than pure vowels. The spectrogram and HNR results are compatible with the prediction. The HNR for the fricative vowel is significantly lower than that for the pure vowel, which indicates that noise energy occupies larger ratio in the fricative vowel than that in the pure vowel. As shown in Figure 1, the noise concentrated in the high frequency range of the fricative vowel.

Figure 2: Palatograms and linguagrams of [i_z] and [i] of a male speaker.



The palatograms and linguagrams show that the constriction for the fricative vowel [i_z] locates at a more anterior position than that for the pure close vowel. The length of constriction (l_c) for the fricative vowel is much shorter than that for the pure close vowel (See Figure 2).

Figure 3: Lingual configurations of [iz] and [i] in EMA for the two subjects. The left is a female subject, and the right is a male subject. The highest curves are the contours of hard palates. The speakers are facing left.



As shown in Figure 3, the constriction of the pure close vowel [i] is no doubt near the hard palate. The constriction of fricative vowel [i_z] might be a bit difficult to determine. Comparing the distance from the point of tongue tip to the upper articulator and the distance from the mid point of the tongue to the hard palate, the former is shorter than the latter. It indicates the vowel constriction is more close to the tongue tip than the middle of the tongue. Therefore, EMA results are compatible with the palatogram and linguagram.

It is generally accepted that a lower F2 indicates a more posterior constriction. However, in our experiment, the fricative vowel [i_z] has a lower F2 but more anterior constriction compared with the pure vowel [i]. This problem will be discussed in next section.

4. DISCUSSION

4.1. The explanation for F2

The F2 of the fricative vowel is lower than that of the pure close vowel [i] in Suzhou Chinese. Normally, a lower F2 means a more back position of the tongue. Connell [3] reported a similar result that the fricative vowel in Mambila has a lower F2 than the pure close vowel counterpart which he suggested to be indicative of a somewhat retracted quality. However, the articulatory results in the present study indicate that the fricative vowel [i_z] does not retract but advance, compared with [i].

Since there are clear formants in fricative vowel, I will explain the formant difference based on the tube model for vowel production. In the tube model for unrounded close vowel, the vocal tract is treated as a tube closed at one end and separated by a narrow constriction into two parts. Then the part behind the constriction is similar to a tube with two ends closed, and the other part with one end closed. The vowel formants come from the natural resonances of the two tubes.

The first formant normally is the Helmohotz resonance of the back tube, which will be discussed in more detail in next section.

The higher two formants are the lowest natural resonances of the front and back cavity. The lower one is F2 and the higher one F3. For most cases, F2 is the lowest resonance of the front tube. If the constriction is at a more posterior position, or, in other words, if the vowel is more back, the front cavity will be longer, and as a result, F2 will be lower. With the constriction moving forward, F2 increase and F3 decrease. When the two resonances frequencies are very close to each other, a relatively steady part of the formants can be found, which is the quantal position for [i] (Stevens [9]).

If the constriction is located at a position more anterior to the quantal position for the pure vowel [i], the correspondence between the two formants and the two tubes switch. In this case, F2 is the first resonance of the back tube instead of the resonance of front tube. F2 decreases with the constriction moving even forward.

Therefore, the lower F2 of fricative vowel does not indicate retraction but advancement of vowel constriction.

Although no articulatory data is available for the fricative vowel in Mambila, it might also have a advancement instead of retraction of constriction, since the formant pattern is quite similar to the fricative vowel in Suzhou Chinese.

4.2. The explanation for F1

As predicted by the tube model, F1 should be lower with the constriction advancing. This prediction is not compatible with my result.

For the [i] type sounds in the tube models, a constriction separates the front tube from the back tube, and the back cavity becomes a Helmholtz resonator. The natural resonance of the Helmholtz resonator is the first formant of the vowel. The formula for the resonance of a Helmholtz resonator is as follows:

$$(1)\quad f = \frac{c}{2\pi}\sqrt{\frac{A_c}{A_b l_b l_c}}.$$

where c denotes the speed of sound, A_c and A_b denote the cross-sectional areas of the constriction and the back cavity, l_b and l_c denote the lengths of the back cavity and the constriction. c and π are constants. As suggested by the formula, the value of F1 is negatively related to A_b, l_b and l_c, and positively related to A_c.

The tube model is an idealized model. The only variable is l_b with other parameters keeping constant. Therefore, F1 lowers with the constriction advancing, i.e. l_b is increasing. However, the real relation among all the parameters is quite complicated and many parameters change together.

As shown in Figure 2, A_b might be still treated as a constant, but A_c l_b l_c of [i_z] and [i] are quite different. A_c and l_c decreased while l_b increased. The final result depends on the degree of change of all the parameters. The parameter which changes greater than other parameters has more effect on the result. As shown in Figure 2, l_c, which is negatively related to F1, decreased and might be the parameter changes greatest. Therefore, the result is the F1 of [i_z] being higher than that of [i]. However, different speakers might have different pattern. That is why the F1 difference for male speakers is not statistically significant.

Ladefoged and Lindau [8] found a similar result as the results in this study. In their experiment, the subject was instructed to form an gesture for [i], and then raise the tongue blade gradually. The result showed that F1 increased and F2 decreased with the tongue blade raising.

The articulatory-acoustic relation is very complicated. In this paper, I provide one possible explanation. Further studies are still needed to explain the formant pattern.

5. CONCLUSIONS

There is more noise in the fricative vowel than the pure close vowel.

The formant pattern of fricative vowel can be well explained by the articulatory gesture. The correspondence between F1 and the vowel height and that between F2 and vowel backness for common vowels do not apply to the fricative vowels in Suzhou. The low F2 of fricative vowel is not due to the retraction of constriction but the advancing of constriction. The increase of F1 might be due to the decrease of the length of constriction instead of lowering of the tongue.

6. REFERENCES

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