On the Three-Way Distinction of Lip Rounding in Ningbo Chinese

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Abstract. *This paper examines the three-way distinction of lip rounding among the three high front vowels in Ningbo Chinese. The articulatory data from 7 speakers show that the three high front vowels have similar lingual configurations but differ in lip gesture, namely spread for [ɪ], horizontal protrusion for [y], and vertical protrusion for [ʏ]. And the results are supported by the acoustic data from 20 speakers.*

1. Introduction

Lingual articulation plays a crucial role in determining the shape of vocal tract and consequently the acoustics of vowel sounds. Naturally, tongue height and backness are the two fundamental vowel features observed nearly in all of the world's languages. In addition to lingual articulation, lip gestures are also frequently used in human speech, helping configuring the shape of vocal tract, and thus lip rounding occurs as the third basic vowel feature. Although in the majority of the world's languages, there is a predictable relationship between the phonetic vowel backness and rounding dimensions, namely front vowels are usually unrounded and back vowels rounded (Lindau, 1978; Maddieson, 1980; Ladefoged & Maddieson 1990), quite a number of languages, e.g., French, German, Swedish, Chinese, etc., contrast in lip rounding. Ningbo Chinese is of particular typological interest in that there is a three-way distinction of lip rounding among the high front vowels.

As pointed out in Ladefoged and Maddieson (1990: 100), "there are no clear-cut cases of three contrastive types of rounding", and a controversial case may be found in Swedish. The Swedish vowel [ʉ] brings about a long history of debate about whether the vowel is a high front vowel as [i] or [y] with a different lip gesture (Sweet, 1877, 1879; Malmberg, 1956; Fant, 1973). Fant (1973) provided the x-ray data of [i y ʉ] and suggested that Swedish may have three degrees of lip rounding. Lindau (1978) and Ladefoged & Maddieson (1990: 101, 102, 120) proposed two lip rounding parameters for vowels, namely vertical lip compression as in the production of the Swedish [ʉ] and [u] and horizontal lip protrusion as in the production of the Swedish [y]. It should be noted here that in the production of the Swedish rounded vowels, the parameter of compression/protrusion is distinctive, while the other parameter, vertical/horizontal, is redundant. In this paper, based on the articulatory and acoustic data, it is proposed that

Ningbo Chinese has a distinctive use of vertical/horizontal—the two rounded high front vowels are both produced with lip protrusion but with different directions.

2. Methodology

Both the articulatory data and acoustic data presented here were extracted from a larger database containing the EMA and audio recordings for all the monophthongal vowels and diphthongs in Ningbo Chinese. As for the ten Ningbo monophthongal vowels [i y ʏ e ø ɛ a ɔ o u] that occur in (C)V syllables, meaningful monosyllabic words containing the target vowels alone were used as test words, except for [ø] that must co-occur with an alveolar consonant. Test words were placed in a carrier sentence and 5 repetitions were recorded. The present study mainly focuses on the three high front vowels [i y ʏ].

In the articulatory study, 7 speakers, 4 male and 3 female, were recorded using Carstens Electromagnetic Articulograph (EMA). The first two male speakers were recorded using a 5-sensor AG 100 system, so only the lower lip position was monitored; the rest speakers were recorded using a 12-channel AG200 system, and both upper lip and lower lip positions were monitored. In the acoustic study, 20 speakers, 10 male and 10 female, were recorded.

3. Results

3.1 Articulatory results

3.1.1 Lingual articulation

Before moving forward, the lingual articulation of the ten Ningbo normal-length vowels was reviewed briefly here (see Hu, 2006 for discussion in length). Figure 1 shows an example of lingual configuration for the ten Ningbo vowels from Male Speaker 1.

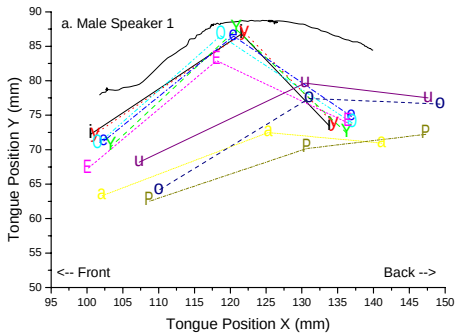


Figure 1. Lingual configurations for the ten Ningbo vowels from Male Speaker 1.

In the figure, the speaker faces left and the three IPA symbols connected by lines represent the mean tongue positions of the sampled tongue points for each vowel. And a tracing of the speaker's hard palate contour is also plotted in the figure for reference. It

should be highlighted here that the three high front vowels [i y ʏ] have a similar lingual configuration.

Figure 2 shows the distribution of vowels in the Factor 1/Factor 2 space from the results of a two-factor PARAFAC modeling (see Harshman et al., 1977 and Hoole, 1999 for details of the application of PARAFAC modeling for vowel production; see Hu, 2006, for discussion on the Ningbo case). The model captures the mechanisms of lingual articulation in vowel production in Ningbo and explains about 90% of variance. It is clear from the figure that there is merely slight difference among the three high front vowels. It is, therefore, hypothesized that the phonological opposition among the three high front vowels mainly results from the differences in lip gesture.

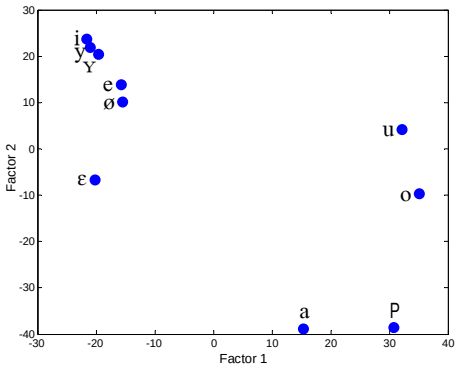


Figure 2. Vowel loadings in a two-factor solution of PARAFAC modeling for the ten Ningbo vowels: Factor 1 'retraction and back raising of the tongue' and Factor 2 'front raising of the tongue'.

3.1.2 Lip positions

An examination of the lip positional data shows that there is a clear distinction between the rounded and unrounded vowels in terms of the sampled lip positions. Compared with the unrounded vowels, rounded vowels are produced with a more raised and advanced lower lip position, suggesting the gesture of lip protrusion. Figure 3 shows an example of the mean lower lip positions with standard deviations as error bars for the ten Ningbo vowels from Male Speaker 3.

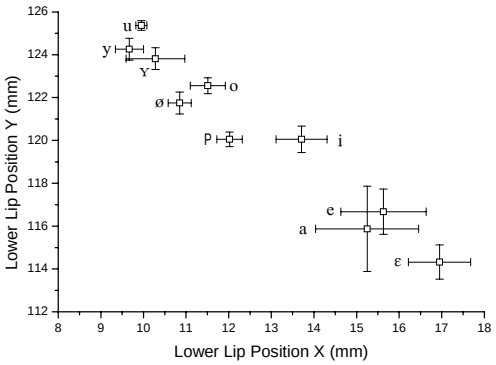
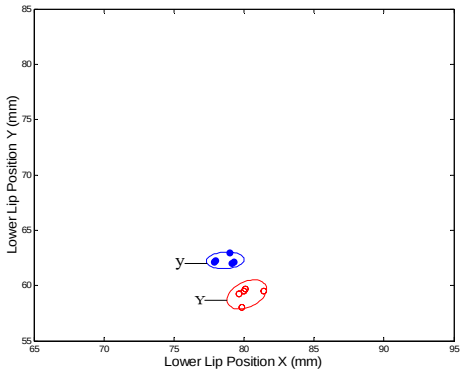
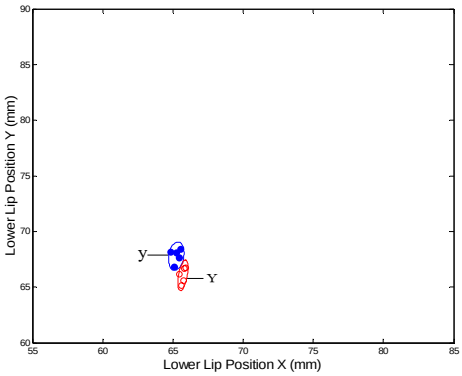


Figure 3. Lower Lip positions for the Ningbo vowels from Male Speaker 3.

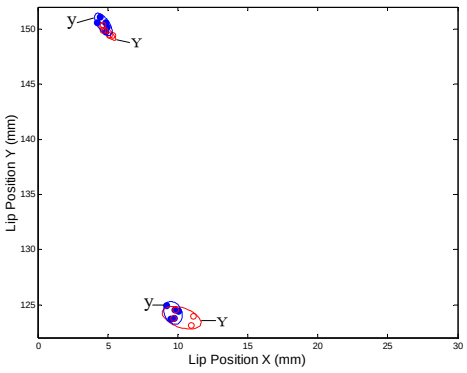
Due to the limit of space, the following discussion focuses on the two rounded high front vowels. Figures 4a-4g show scatter plots of lip positions, with a 2-sigma confidence ellipse superimposed on the data points, for the individual male and female speakers, respectively. All the speakers face left in the figures.



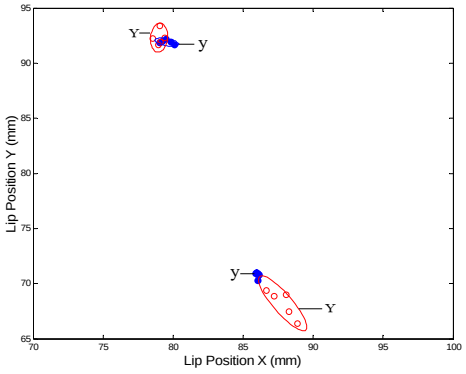
a. Male Speaker 1



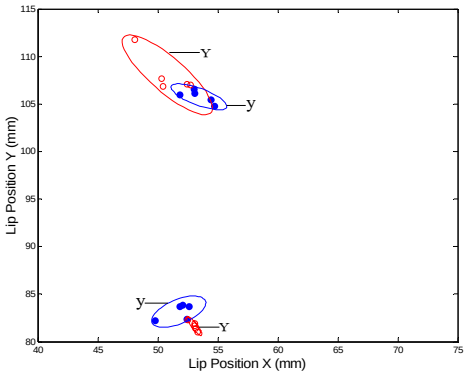
b. Male Speaker 2



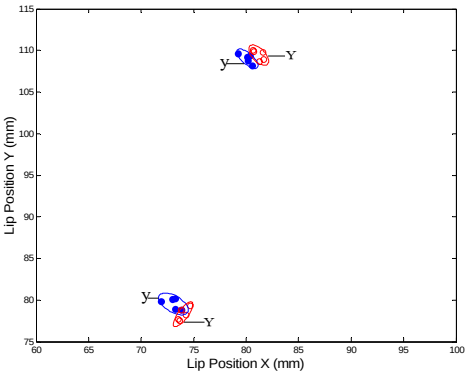
c. Male Speaker 3



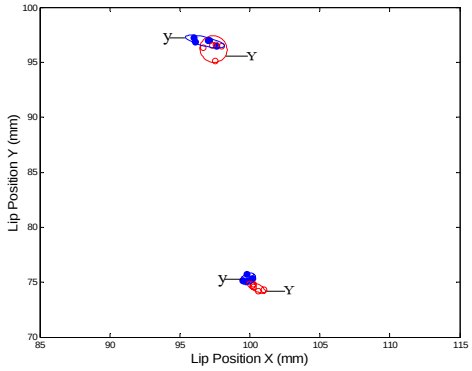
d. Male Speaker 4



e. Female Speaker 1



f. Female Speaker 2



g. Female Speaker 3

Figure 4. Lip ellipses for the rounded high front vowels.

As can be seen in the figures, the lower lip ellipse for [ʏ] has a relatively lower and less advanced distribution than that for [y] in all the speakers, though there is only a minute difference of several millimeters between [y] and [ʏ] and the ellipses do overlap, especially in Male Speaker 3 and Female Speaker 2. With regard to the upper lip ellipse, [ʏ] is distributed in a comparatively higher position than is [y] in Male Speaker 4 and Female Speaker 1. In the other speakers, a retracted upper lip position for [ʏ] is generally detected. These facts suggest that the upper lip is either more open or less advanced in the production of [ʏ].

It is plausible, then, to sum up from the data that there is a difference in lip gesture between the two rounded front high vowels [y ʏ]. In comparison with [y], [ʏ] is generally produced with a more open and less advanced lip gesture. The lip position data are consistent with the author's visual inspection. It is therefore proposed that [y] and [ʏ] have distinctive lip gestures from each other. As illustrated schematically in Figure 5, in the production of [y], lips are protruded horizontally, i.e., along the speaker's bite plane, while in the production of [ʏ], lips are protruded vertically, i.e., approximately being orthogonal to the speaker's occlusal plane.

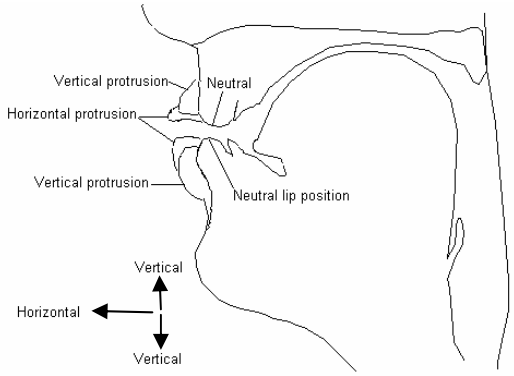


Figure 5. Schematic diagram of the lip gestures for the two rounded high front vowels [y ʏ] in Ningbo: horizontal protrusion [y] and vertical protrusion [ʏ].

3.2 Acoustic results

Figure 6 shows the distribution of the ten Ningbo vowels in the perceptually scaled acoustic F1/F2 vowel planes. It can be observed from the figure that [i y ʏ] have a similar F1 value, which indicates a similar vowel height. Meanwhile, vowel ellipses for [y] and [ʏ] overlap extensively with each other. The main difference between [y] and [ʏ] is in F2. As shown in the figure, the ellipse for [ʏ] distributes somewhat to the left of that for [y]. That is, [ʏ] has a smaller F2 than [y].

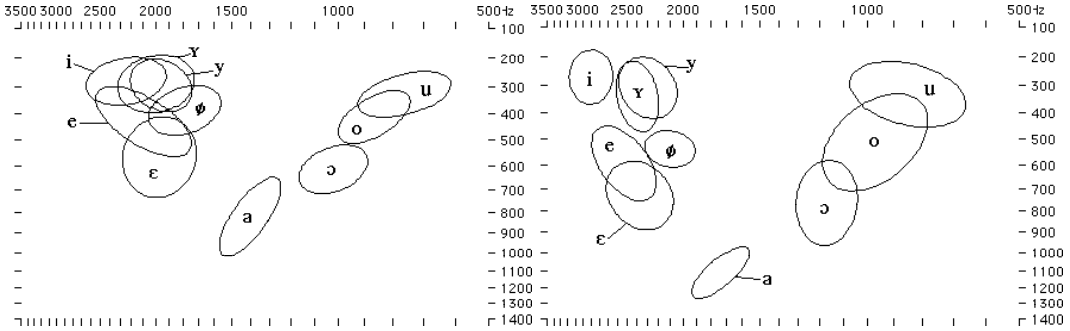


Figure 6. Vowel ellipses for the Ningbo vowels: pooled data from 10 male speakers (left) and 10 female speakers (right).

The F2 difference between [y] and [ʏ] could not be attributed to the difference in lingual articulation, since the two vowels are produced with a similar lingual configuration. However, the acoustic difference in F2 between the two rounded high front vowels can be explained by the lip positional data presented in 3.1.2. Horizontal protrusion as in [y] results in a relatively longer articulatory tube of vocal tract and a comparatively smaller lip opening than vertical protrusion as in [ʏ]. According to the acoustic theory of lip rounding (Stevens & House, 1955; Fant, 1960), F2 decreases when (1) lips are protruded horizontally and consequently the total articulatory cavity is lengthened, or (2) the size of lip orifice decreases. As far as the Ningbo case is concerned, both horizontal and vertical protrusions lengthen the articulatory tube and thus decrease the F2 vis-à-vis their unrounded counterpart [i], but the F2 lowering effect is not so pronounced in vertical protrusion ([ʏ]) as in horizontal protrusion ([y]) due to a relatively smaller effect on the lengthening of the articulatory tube and a relatively larger size of lip orifice. The results of a paired t-test show that the F2 difference between [y] and [ʏ] is significant ($p < .001$ for the pooled female data and $p < .05$ for the pooled male data).

4. Conclusion and discussion

The present paper examined the three-way distinction of lip rounding among the three high front vowels in Ningbo Chinese. The articulatory data from 7 speakers have shown that the three high front vowels have a similar lingual configuration while different lip gestures. A close examination of the lip position data reveals that [i] is produced with a spread lip gesture, [y] with a rounding gesture of horizontal protrusion, and [ʏ] with a rounding gesture of vertical protrusion. And the articulatory results are supported by the acoustic data, as both [y] and [ʏ] have a smaller F2 value than [i], while the F2 value

for [ʏ] is slightly larger than that for [y]. In other words, acoustically, the vertical lip protrusion results in a relatively smaller effect on formant lowering vis-à-vis the horizontal lip protrusion.

Lindau (1978) and Ladefoged & Maddieson (1990) both distinguish lip compression from lip protrusion. The motivation for proposing lip compression is to account for the 'inrounded' high front vowel [ʉ̟] in Swedish, which is produced with a compressed lip gesture, as if it is rounded in an inward manner. As pointed out by Ladefoged & Maddieson (1990), the major difference between an outward rounding and an inward rounding is that the former is a lip gesture of horizontal protrusion, i.e., the lips are protruded forwardly along the direction parallel to the speaker's occlusal plane, while the latter is a lip gesture of vertical compression, i.e., the lips are compressed inwardly along the direction vertical to the speaker's occlusal plane. Based on the Ningbo data presented in this paper, the rounding feature (Ladefoged & Maddieson, 1990) may be revised as follows:

The lip features for vowels

[-rounded]	[+rounded]		
[+Spread]	[+horizontal protrusion]	[+vertical protrusion]	[+(vertical) compression]
[i]	[y]	Ningbo [ʏ]	Swedish [ʉ̟]

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