Tonal Effect on Vowel Articulation in a Tone Language

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Abstract

This study investigates the tonal effect on vowel articulation in the Ningbo Chinese, a tone language. Tongue, jaw, and lip articulators were monitored during the production of different types of high and low tones using EMA. Preliminary results suggest that there are articulatory differences between high and low short tones and high and low rising tones, namely a retraction of tongue is detected in the production of low short and rising tones. However, for the high and low tonal element in the falling tone within the same syllable, there is no articulatory difference observed.

1. Introduction

The tendency that high vowels are produced with a higher F0 than lower vowels is known as intrinsic pitch in the literature (Peterson & Barney, 1952; Lehiste, 1970; Fisher-Jorgensen, 1990; Whalen & Levitt, 1995). This robust phenomenon is detected in a large number of world's languages (Whalen & Levitt, 1995). In seeking the explanation of the intrinsic pitch phenomenon, investigators find that there is an interaction between the laryngeal and supralaryngeal articulators (e.g.: Ladefoged, 1964; Lehiste, 1970; Ohala, 1973; Ohala & Eukel, 1978; Rossi & Autesserre, 1981; Honda, 1983, 1995; Vilkman, et al., 1989; etc. and see Sapir, 1989; Honda 1995; Torng, 2000 for a review of theories). Therefore, different lingual configurations in producing vowels with different vowel heights may have effect on F0 control and consequently give rise to the phenomenon of intrinsic pitch on one hand; and different tone (F0) heights may also have effect on the lingual articulation on the other. And some researches show that in addition to the lingual articulators, jaw movements also contribute to this kind of tone-vowel interaction, especially when producing a low F0 (Zawwadzki & Gilbert, 1989; Honda, 1998). The tonal effect on vowel articulation is sometimes referred to as an inverse effect to intrinsic pitch. However, this kind of inverse effect may not be obvious in read utterances (Honda, 1998).

Though the majority of previous studies on the interaction of F0 control and supralaryngeal articulation are from non-tonal languages, there are a few studies that have investigated the tonal effect on vowel quality in some tone languages. Unlike in non-tone languages, where pitch can be freely varied, in a tone language, pitch is phonemically contrastive. That is, F0 variation is basically used to convey lexical meanings. What is interesting is that previous studies in tone languages have shown that by and large, F0 control may have influences on vowel articulation (e.g., Han, 1966, for Vietnamese; Zee, 1980, for Taiwanese Chinese; Torng, 2000, and Erickson et al., 2004, for Mandarin Chinese). However, it remains unclear how and to what extent tonal differences affect the supralaryngeal articulation. Zee's acoustic study shows that tonal effect on vowel quality is not systematic for different vowels and for different speakers. Torng's EMA study also reveals that not all speakers demonstrate a tonal influence on vowel articulation, and high tones are not necessarily produced with high tongue and/or jaw positions. Erickson et al.'s articulatory data indicate that there are significant effects of tone height on tongue positions, namely speakers tend to use a retracted tongue in producing low tones. However, only one vowel [a] and one pair of contrasting tones (high level vs. low dipping) were examined in their study.

This study examines tonal effects on vowel articulation in another tone language, the Ningbo Chinese. The main purpose of the experiment to be reported below is to investigate whether tone height also affects vowel articulation in Ningbo, and if yes, to explore how articulators change when a vowel is produced with different tones.

2. Methods

Two Ningbo vowels [a] and [i] were used for investigation. Vowel [a] was uttered with high and low short tones, high and low rising tones, and a falling tone; vowel [i] was uttered with high and low rising tones and a falling tone. These vowels are all meaningful monosyllabic words in Ningbo. All test words were written with Chinese characters in an A4 paper in a random order. Each word was read in isolation and five repetitions were recorded.

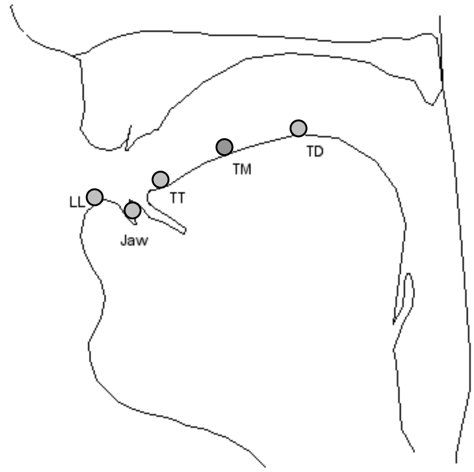

Figure 1: *Attachment of receiver coils on articulators.*

Articualtory and acoustic data were collected using the Carstens electromagnetic articulatograph (EMA) AG 100 system at the Phonetics Lab in City University of Hong Kong. One name native speaker at his early 20s provided the speech data. As illustrated in Figure 1, five receiver coils were attached at the midline on the lower lip (LL), the gum ridge at the lower teeth (Jaw), and the three points of the tongue, namely the tongue tip (TT), tongue mid (TM), and tongue dorsum (TD) respectively. The TT coil is placed less than 1 cm to the tongue tip, the TM coil is about 3 cm to the TT coil, and the TD coils is about 6 cm to the tongue tip.

The Carstens WinPact software package was used in processing and analyzing the EMA data. Before serious analysis, the raw articulatory data was down sampled from 500Hz to 250 Hz and smoothed, and was then rotated so that the new horizontal (x) axis was parallel to the subject's occlusal plane. Both articulatory and acoustic measurements of high and low short tones of vowel [a] and high and low rising tones of vowels [a] and [i] were made at the midpoint of vowel duration. And the articulation of the high short tone and high rising tone is compared to that of the low short tone and low rising tone respectively to see if there is any difference. For the falling tone, articulatory differences were examined within the syllable. And the point at 10% of vowel duration was selected as the measure point of high tone, and the point at 90% of duration as the measure point of low tone.

3. Results and discussion

Results of the mean F0 values (with the Standard Deviations in parentheses right after the means) on the measure points of different tones are shown in Table 1. As can be seen from the table, all the high tonal points have a greater F0 value than the corresponding low points. The difference between the high and low tonal elements in the falling tone is the greatest (about 100 Hz). The difference between a high and low short tone is as great as about 40 Hz. And the difference between high and low rising tones is the smallest (about 15-20 Hz).

Table 1: *Mean F0 (in Hz) of different tones*

Vowel	Tone	High	Low
[a]	short	174 (4)	130 (7)
	rising	137 (2)	122 (3)
	falling	176 (5)	73 (9)
[i]	rising	150 (4)	128 (6)
	falling	177 (5)	73 (10)

3.1. Short tones

As shown in Figure 2[1], mean positions of TM and TT in high short tone are similar to those in low short tone. The main differences between the high and low rising tone are the positions of TD and Jaw and LL.

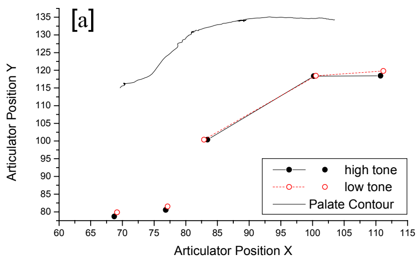

Figure 2: *Mean articulator positions (mm) of vowel [a] in High and Low short tones.*

Figure 3 shows the TD positions in the high and low short tones, with a 2-sigma confidence ellipse superimposed on the data points. From the figure we can see that the TD points in low short tone are comparatively higher (about 1.4 mm on average) and more posterior (about 0.5 mm on average) than those in high short tone. That is, the tongue dorsum is relatively more raised and retracted in producing the low short tone.

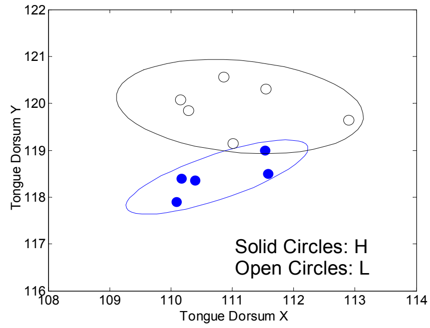

Figure 3: *TD positions (mm) of vowel [a] in High and Low short tones.*

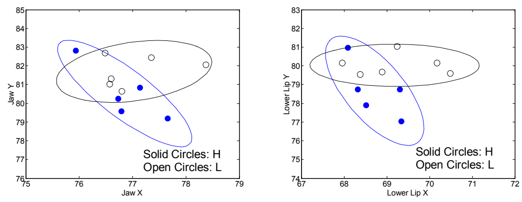

Figure 4: *Jaw (Left) and Lower Lip (right) positions (mm) of vowel [a] in High and Low short tones.*

Figure 4 shows Jaw and LL positions in the production of high and low short tones. It can be seen from the figure that the jaw and lower lip is also slightly more retracted in the production of low short tones vis-à-vis that of high short tones. And it is interesting to note that the ellipses of data points in the low short tone have a different orientation to those in the high short tone. In the production of high short tone, the major variance axis is distributed along the high-low dimension, whereas in the low short tone production, a horizontal distribution of the major variance is detected, which implies that the jaw and lower lip are more variable horizontally in the low tone production.

3.2. Rising tones

Figure 5 shows the mean articulator positions of high and low rising tones in vowels [a] and [i]. For the vowel [a], the mean TD position in low rising tone doesn't show a tendency of retraction as in low short tone, if judged from the position difference in the x-axis; rather, the mean TD position in high rising tone occupies a relatively back position. However, the TD position for the low tone is still higher (about 1 mm) than for the high tone. And this is also manifested from a closer examination of TD points and ellipse of vowel [a], as shown in Figure 6. Moreover, the sampled tongue contour for the low tone in Figure 5 is somewhat retracted in comparison to the high tone. And as shown in Figure 7 and 8, the TM position is slightly lower and the TT position is both lower

[1] In all figures in this paper, the speaker is facing to the left.

and more posterior in low rising tone. So, it is still tenable to summarize that there is tongue retraction in the production of low rising tone in vowel [a]. However, the raised TD position indicates that the retraction may not always be manifested in the horizontal tongue positional difference; rather it is very likely that the retraction is executed through the movement of the tongue dorsum towards the velum region.

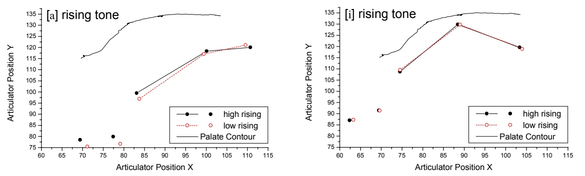

Figure 5: *Mean articulator positions (mm) of vowel [a](left) and [i] (right) in High and Low rising tones.*

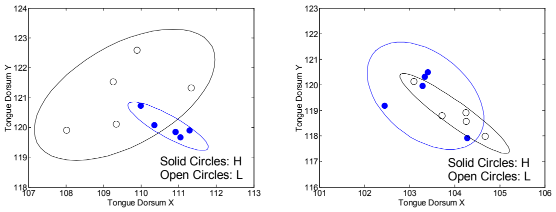

Figure 6: *TD positions (mm) of vowel [a](left) and [i] (right) in High and Low rising tones.*

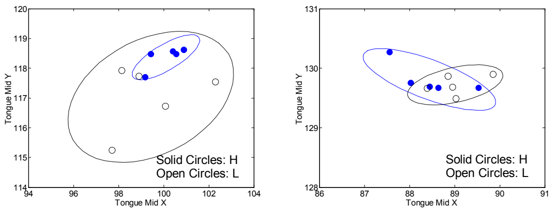

Figure 7: *TM positions (mm) of vowel [a](left) and [i] (right) in High and Low rising tones.*

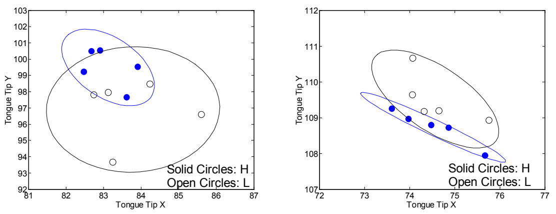

Figure 8: *TT positions (mm) of vowel [a](left) and [i] (right) in High and Low rising tones.*

Regarding the vowel [i], all TD, TM and TT data show a clearer picture of tongue retraction. However, it should be admitted that the effect is rather weak. As can be seen from Figure 5, the overall sampled tongue contour of [i] is different from that of [a], because for [i], TM is the principal articulator point. As shown in Figure 7, TM points of low rising tone occupy a slightly more posterior position than those of high rising tone. And the difference is about 0.6 mm on average. The TD points of low rising tone are also observed slightly retracted (about 0.7 mm on average), as shown in Figure 6. And the retraction is also manifested from the TT points. As can be seen from figure 8, TT points are comparatively higher (about 0.8 mm on average) in low rising tone than in high rising tone. It can serves as an evidence of retraction, because the raising of the tongue tip can be explained as a consequence of the retraction of the arched tongue.

Figure 9 shows Jaw and LL positions of vowel [a] in high and low rising tones. It is clear from the figure that the jaw and lower lip position in low rising tone is much lower and more posterior than in high rising tone. For the jaw, the difference is about 3.3 mm on average of height and about 1.7 mm on average of backness. This indicates that in the low rising tone production, the jaw is not only retracted but also lowered.

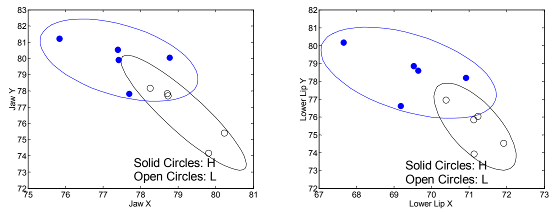

Figure 9: *Jaw (Left) and Lower Lip (right) positions (mm) of vowel [a] in High and Low rising tones.*

However, in the production of vowel [i], there is no jaw or lower lip lowering detected for the low rising tone, as shown in Figure 10. Actually, there is rarely jaw difference between the low and high rising tone. What of interest is that the LL position is relatively retracted (about 0.9 mm on average) in low rising tone. This implies that the Jaw and LL components are somehow controlled independently to the lingual component. And the jaw and lower lip may or may not perform in accord with the tongue.

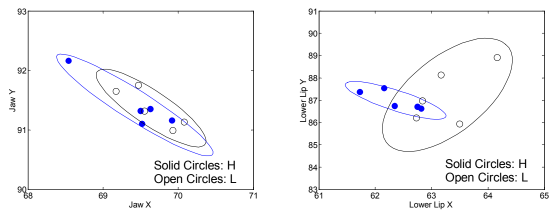

Figure 10: *Jaw (Left) and Lower Lip (right) positions (mm) of vowel [i] in High and Low rising tones.*

3.3. High and low tonal elements in falling tones

Figure 11 shows the mean articulator positions of high and low tonal elements in the falling tone for vowels [a] and [i]. From the figure we can see that for both vowels [a] and [i], data exhibits no noticeable difference of the tongue position between the high and low tonal elements in the falling tone. And for the vowel [i], the Jaw and LL positions for the high tonal element are nearly identical to those for the low tonal element in the falling tone. Regarding the vowel [a], the Jaw and LL data even contradicts with that in short and rising tones. The data points and ellipse of Jaw and LL for the vowel [a] are shown in Figure 12. As can be seen from the figure, both jaw and lower lip for the low tonal element occupy a relatively higher and anterior position. However, due to the absence of other evidence, this kind of difference is considered as arbitrary in the present study. And therefore, there is no significant articulatory difference observed for the high and low tonal element in the falling tone.

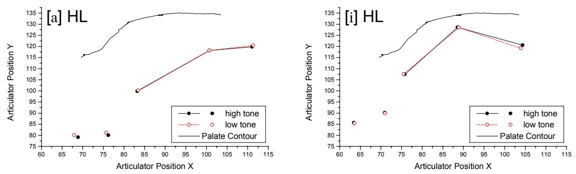

Figure 11: *Mean articulator positions (mm) of vowel [a] (left) and [i] (right) in the falling tone.*

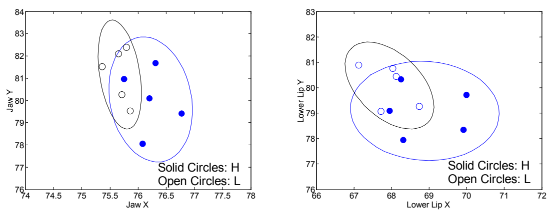

Figure 12: *Jaw (Left) and Lower Lip (right) positions (mm) of vowel [a] for the High and Low tonal elements in the falling tone.*

4. Conclusion

So far, this paper has presented some preliminary results of the tonal effect on vowel articulation in the Ningbo Chinese, a tone language. Data suggests that there are articulatory differences between high and low short tones and high and low rising tones. And in the production of low tones, basically a retraction of tongue is observed, whereas the jaw may behave in accord with the tongue movement or maintain its independence. The results are in favor of the viewpoint that there is physiological connection between the larynx and supralaryngeal articulators. But for the high and low tonal element in the falling tone within the same syllable, there is no articulatory difference detected.

Results are basically consistent with Erickson et al.'s study (2004). However, retraction of tongue during low tone production may not be simply correlated with the horizontal tongue dorsum differences. Rather, it can be manifested by other tongue points and should refer to the shape of tongue. And there may be differences between different vowels. And the jaw lowering or retraction in the low tone production may be optional. However, due to the limited size of the collected data at this stage, the presented preliminary results in this study is required to be tested in further investigations.

5. References

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