ANN.Bull.RILP(1990)No.24, 7-17

AN ELECTROMYOGRAPHIC STUDY ON LARYNGEAL ADJUSTMENT IN PRODUCTION OF THE MANDARIN CHINESE LIGHT TONE

Seiji Niimi, Qun Yan, Satoshi Horiguchi* and Hajime Hirose

Introduction

It is well known that in polysyllabic words in Mandarin Chinese, some syllables can lose their proper tones and be pronounced in a neutral tone with a slight declination of pitch. This tonal feature has been described as a light (or neutral) tone. It has been reported that the light tone is seen in 4.6 % of Mandarin Chinese words[1].

There have been several investigations on the light tone mainly from an acoustic point of view[2]. They all agree in terms of the following points

1) The duration of the syllable with the light tone is shorter than that of the ordinary tone syllable.
2) Although the tonal pattern of the light tone depends on that of the previous syllable, the essential tonal pattern of the light tone is falling.
3) The acoustic power in the light tone is weaker than in the traditional four Chinese tones.

As far as the declination in pitch is concerned, a decrease in the subglottic pressure near the end of the phrase is one of the contributing physiological factors[3]. The acoustic characteristics of the light tone could be produced by the factor of the subglottic driving force, and it should not be necessary to control the larynx actively. In other words, the light tone could be produced without any active neural control for the larynx, but by the contribution of the decreasing subglottic pressure in an uttered phrase. On the other hand, since the pitch pattern of the light tone is, in a sense, unique, there should be active or unique neural commands for its production. These arguments turn on the question of whether there is particular neural command for production of the light tone.

In order to answer this question, the present electromyographic study was conducted.

Method

Two native speakers of Mandarin Chinese served as the subjects. Test words were bisyllable meaningful words whose first syllable was either tone 1,2,3 or 4 and where the second syllable was either the light tone or tone 4 (List 1). For the convenience of processing, all test words began with a voiceless

* Department of Neuro-otology, Tokyo Metropolitan Neurological Hospital

stop consonant /p/. These test words were embedded in the carrier sentence / zhe^4 shi^4 ... ... de^0 yi^4 si^1 /.
(这是 ○○的意思。 [tsəsɿ˥˩tə i sɿ])
which means that "this word means .....".

These test sentences were uttered by the subjects 14 times as naturally as possible. Since the main interest of this study concerned a tone pattern and the laryngeal adjustment for the tone, the cricothyroid muscle (CT) and the sternohyoid muscle (SH) were selected for investigation. The CT muscle is known as a pitch raiser, and the SH is supposed to be one of the contributing muscles for pitch lowering[4,5,6,7,8,9].

Electromyographic signals were recorded from these two muscles using hooked wire electrodes with acoustic signals. The EMG signals were rectified and integrated for a certain period of time (5 msec). These pre-processed signals were digitized with 12-bit accuracy and fed into a personal computer. The sampling rate for the acoustic signals was 5kHz and for the integrated EMG signals, 1kHz. The acoustic signals were also recorded on a DAT recorder for further acoustic analysis. The EMG data were aligned with a line-up point and were ensemble-averaged. For the present study, the moment of the release of /p/ in the test words was selected as the line-up and was defined by an inspection of the acoustic wave form. A sound spectrograph was used to extract the fundamental frequency (F0) of the speech sample. The averaged EMG and F0 patterns were aligned on the same time scale.

Results

In general, regardless of the tone type, the SH became active during the syllables with the lower F0, and the CT became active for the syllables with higher F0. Figure 1 shows one of these results. The top curve indicates the F0 pattern and the lower two curves represent the averaged EMG patterns. Since the tonal pattern of the light tone depends on that of the preceding syllable, it should be possible to show the different results for each combination of the tone types.

1)tone 1 + tone 4 (Figure 1)
Tone 1 is flat, and high, and tone 4 falls from high to low. As indicated in Figure 1, F0 leaps up from the end of the first syllable to the beginning of the second syllable, resulting in a prominence of the falling tone of the second syllable. The CT activity keeps it at a higher activity level from the first part of the utterance, and ceases its activity at the end of the first syllable. On the other hand, SH is suppressed during the first syllable and starts rising when the F0 comes down to a certain level. These EMG patterns are compatible with the F0 pattern of the utterance.

2)Tone 1 + light tone (Figure 2)

As noted before, the F0 pattern of the light tone is falling, but its duration is short. The F0 pattern shown in Figure 2 reflects the acoustic characteristics of the light tone. Since this tone is dependent on the preceding tone, there is little leap between the end of the first syllable and the beginning of the second syllable, and the duration is short. CT keeps its activity through the whole utterance with a slight suppression for the light tone syllable and the carrier sentence. SH shows a markedly increased activity at the end of the first syllable, where F0 starts to fall, and keeps its higher activity level until the end of the second syllable. Then, only slight activity is seen for SH through the carrier sentence.

3)Tone 2 + tone 4 (Figure 3)

Since the tone pattern of the first syllable (tone 2) is ascending, CT becomes active for the rising F0. In order to realize the falling tone for the second syllable (tone 4), it is necessary to keep F0 at a high level at the beginning of the second syllable. For that, CT continues its activity all through the second syllable. During the period of the high F0 level, SH is suppressed and becomes active near the end of the utterance, where F0 becomes lower.

4)Tone 2 + light tone (Figure 4)

When the second syllable is the light tone, the timing of the onset of the SH activity against the syllable boundary is different from that of the previous case (tone 2 + tone 4). The SH activity begins with the end of the first syllable. This earlier firing of the SH is probably caused by the shorter duration of the light tone syllable and the lower starting position of the fall in F0.

5)tone 3 + tone 4 (Figure 5)

It is well known that when a syllable with the tone 3 (falling and rising) is followed by another tone type, the tone pattern changes to flat and low. This tone pattern is called the "half-third tone"[10]. The F0 curve in Figure 5 shows the "half-third tone". In this case, in order to make the fall in the F0 of the second syllable clear, the F0 level of the second syllable becomes higher than that of the first syllable. The activity patterns of the CT and SH explain this F0 contour.

6)Tone 3 + light tone (Figure 6)

As shown in the figure, when the following syllable is the light tone, tone 3 keeps its original tone pattern (falling and rising) probably because the light tone is dependent on the preceding syllable and has no effect on the previous syllable. The F0 of the second syllable stays at a relatively low level, so that SH is not suppressed and is active for the declination of F0.

7)Tone 4 + tone 4 (Figure 7)

As far as the second syllable is concerned, the CT activity (bottom trace) increases just before the onset of the second syllable and is suppressed abruptly for the declination in the

pitch for the tone 4. On the other hand, SH starts its activity at the end of the second syllable, which corresponds to the termination of the utterance.

7)tone 4+light tone (Figure 8)

When the second syllable was replaced by the light tone syllable, CT became less active than in the previous case, which was a combination of tone 4 + tone 4. As a result, the suppression of the CT activity at the end of the second syllable, which was obvious in the previous case, is not clearly seen. Since the second syllable is the light tone, it is not necessary to raise F0 to the initiation of the second syllable. SH shows continuous activity for the F0 declination through the first syllable and the second syllable. The activity level is higher for this case than in the previous one (tone 4 + tone 4). Since there is no upward shift of the F0, SH is not suppressed for the initiation of the second syllable. This is the main difference between the case of tone 4 + tone 4 and the case of tone 4 + light tone.

8) tone 4+Null (Tone 4 + null)

In order to clarify the physiological characteristics of the production of the light tone, the case without a second syllable was investigated. In this case, we could only see the laryngeal adjustment for the tone 4 syllable, that is, suppression of the CT and activation of the SH for the declination of pitch of the syllable with tone 4. It is obvious that since this syllable is not followed by any syllable, these two muscles show the activity pattern only for the carrier sentence.

Discussion

Although the physiological mechanism of pitch lowering is still under discussion, there are probably two major factors. One is the subglottic driving force and the other is the laryngeal adjustment. The declination of the fundamental frequency seen in an uttered phrase is essentially caused by the decreasing subglottic pressure. For this declination, laryngeal adjustment is rather stable. However, there have been many investigations concerning the laryngeal pitch control mechanism during speech or singing. These works agree that the cricothyroid muscle is the primary contributor to the F0 rise and that the strap muscles contribute to pitch lowering or at least that the strap muscles become active during low pitch phonation. Since the present study did not aim to clarify the pitch lowering mechanism, but to determine whether there is any neural command to the larynx for the production of the Chinese light tone , we chose the EMG activities from the cricothyroid muscle and the sternohyoid muscle as an indication of the neural command for the larynx to control F0.

Some previous studies on Chinese tones have reported that the acoustic characteristics of the light tone are (1) a declination in the pitch; (2) a short duration of the syllable; and (3)

small acoustic power. These acoustic properties could be realized either by the natural decrease in the subglottic pressure or by the active control of the larynx. In this experiment, the test words were selected to compare tone 4 with the light tone, because both of these show a declination of F0. Our assumption was that if there is any laryngeal contribution for the light tone, there should be unique EMG patterns for the production of the light tone.

In all of the EMG patterns examined in this experiment, SH became active and CT was suppressed during the low F0 period. However, the timing of activation of the SH and suppression of the CT was different for different combinations of tone type. Since the duration of the light tone is shorter than tone 4, the perturbations in these activities started earlier in the light tone than in tone 4. In all cases, the starting levels of the F0 declination for the light tone was lower than for tone 4. This acoustic evidence is reflected in the higher activity level of the SH. The two physiological points seen in the production of the light tone, i.e.,

(1) the earlier perturbation of the EMG activity
(2) the higher activity level of the SH,

indicate that there are some participation of the larynx for the production of the light tone.

Comparing the case of tone 4 + light tone (Figure 8) and the case of tone 4 without a following syllable (Figure 9), the F0 patterns are similar to each other, except for the longer duration in the former case. It seems that this elongation of the utterance is caused by the addition of a syllable with the light tone to the latter case. However, the amplitude of the SH activity is greater for the light tone case along with the elongation of active period. This observed alternation of the EMG of the SH also suggests that the production of the light tone requires some particular neural commands.

Conclusion

From the present EMG experiment, it was suggested that the larynx adjusts actively for the production of the light tone. Since the present study does not contain any data on aerodynamic parameters, we can only conclude that at least the larynx contributes to the production of the light tone. Further aerodynamic study is recommended.

Acknowledgement

This work was supported in part by a Grant-in-Aid for Scientific Research (No.01440071) from the Japanese Ministry of Education, Science and Culture.

References

1) Wu, Z.J. & M.S. Lin: An Outline of Experimental Phonetics (in Chinese).Higher Education Press. 230-239,1989
2) Li, W.M.: A Discussion of Light Tone & Stress in Standard Chinese(in Chinese). Zhongguo Yuwen, No.1, 35-40,1981
3) Collier, R: Physiological correlates of intonation patterns. J.Acoust.Soc.Am., 58,249-255, 1975
4) Atkinson,J.E.: Correlation analysis of the physiological factors controlling fundamental voice frequency. J. Acoust. Soc. Am. 63, 211-222, 1979
5) Erickson, D., Liberman, M. and Niimi,S.: The geniohyoid and the role of the strap muscles. Haskins Labs. SR-49, 103-110, 1977
6) Faaborg-Anderson, K. and Sonninen, A.:Function of the extrinsic laryngeal muscles at different pitches. Acta Otolaryngol. 51, 89-93, 1960
7) Kunitake, H.:Function of the extrinsic laryngeal muscles - An electromyographic study (in Japanese). Jpn. J. Otolaryngol. 74, 1156-1201, 1971
8) Ohala,J. and Hirose, H.:The function of the sternohyoidhyoid muscle in speech. Ann. Bull. RILP, No.4, 41-44, 1970
9) Simada,Z. and Hirose, H.:The function of the laryngeal muscles in respect to the word accent distinction. Ann.Bull.RILP, No.4, 27-40, 1970
10) Wang, William S-Y.,& Li, K-P.:Tone 3 in Pekinses. Journal of Speech and Hearing Research,10,629-636,1967

List 1

1+4	批字	[p'i z1]	3+4	苧字	[pi z1]
1+light tone	坯子	[p'i z1]	3+light tone	鼻子	[pi z1]
2+4	癖字	[p'i z1]	4+4	碧字	[pi z1]
2+light tone	庇子	[p'i z1]	4+light tone	鼙子	[pi z1]
			4+null	壁	[pi]

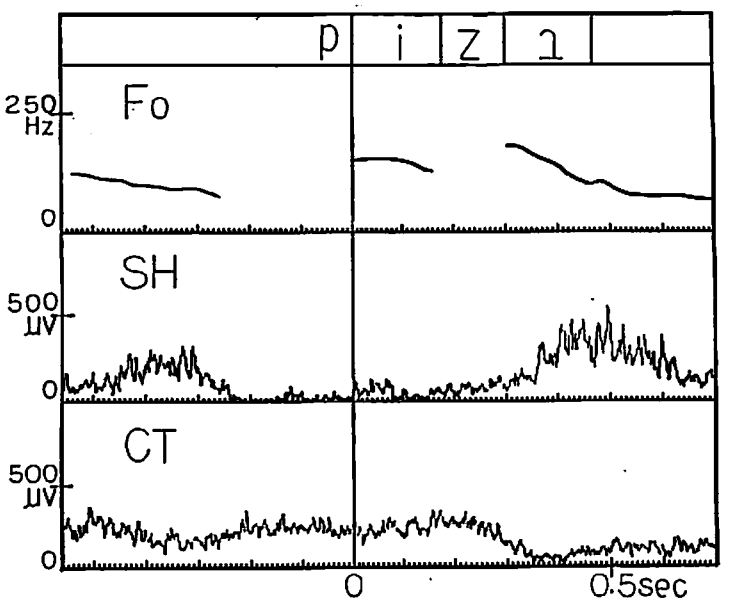

Figure 1
F0 contour and EMG patterns for Tone 1 + tone 4.
F0 coutour, EMG pattern of SH and CT are shown at top and bottom respectively. A vertical line indicates the line-up point for the averaging (the moment of the release of /p/ in the test sentence).
The test sentence is / zhe^4 shi^4 pi^1 zi^4 de^0 yi^4 si^1 /.

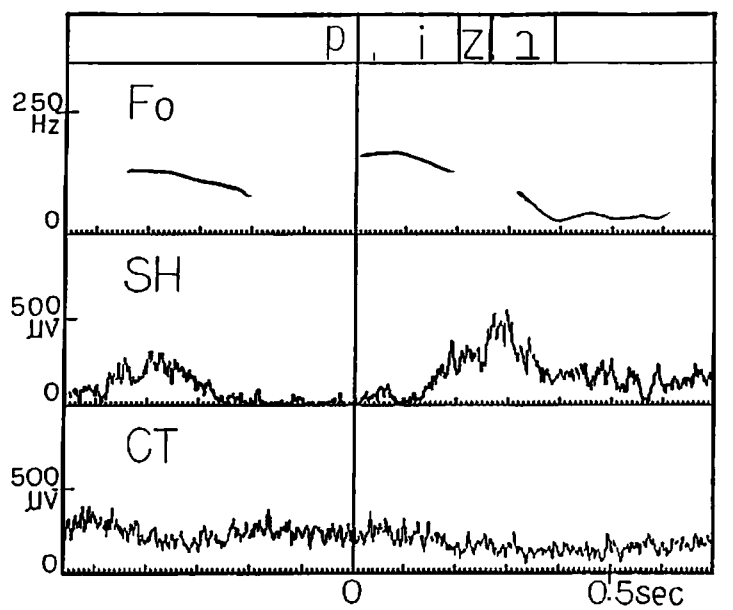

Figure 2
Tone 1 + light tone
Test sentence is / zhe^4 shi^4 pi^1 zi^0 de^0 yi^4 si^1 /.

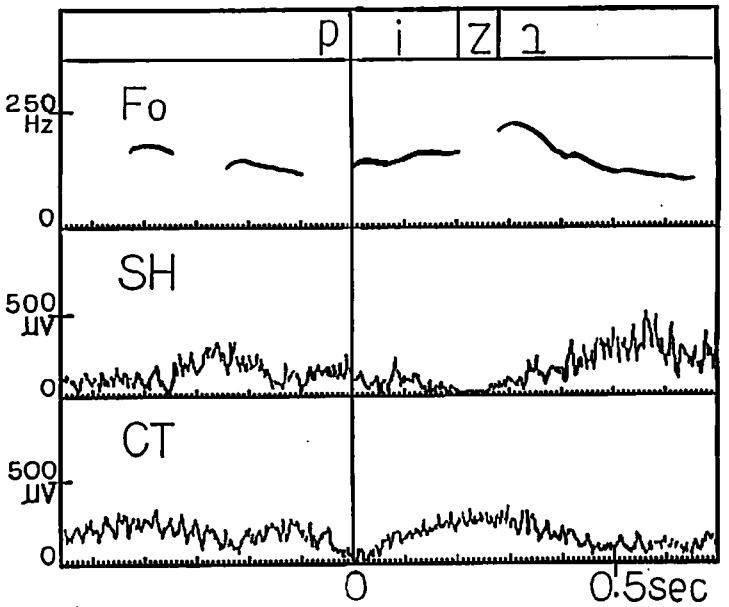

Figure 3
Tone 2 + tone 4
Test sentence is / zhe^4 shi^4 bi^2 zi^4 de^0 yi^4 si^1 /.
这 是 鼻 字 的 意 思。

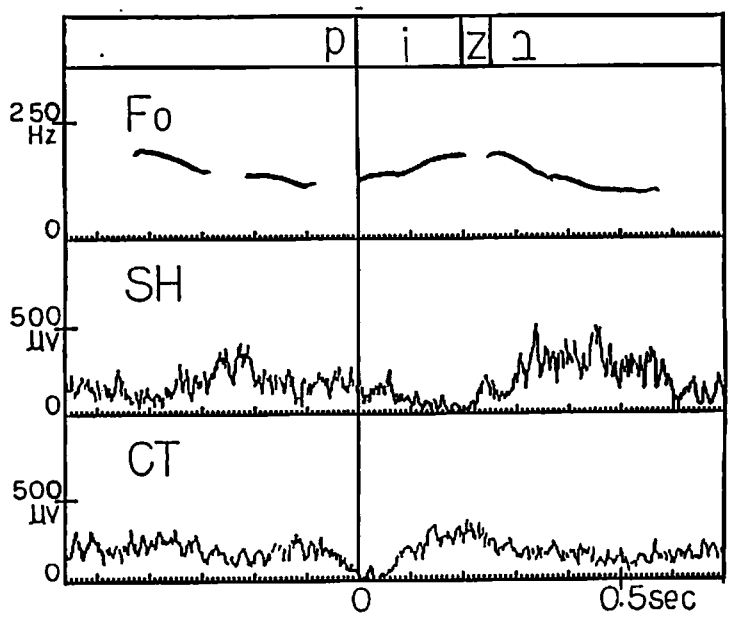

Figure 4
Tone 2 + light tone
Test sentence is / zhe^4 shi^4 bi^2 zi^0 de^0 yi^4 si^1 /.
这 是 鼻 子 的 意 思。

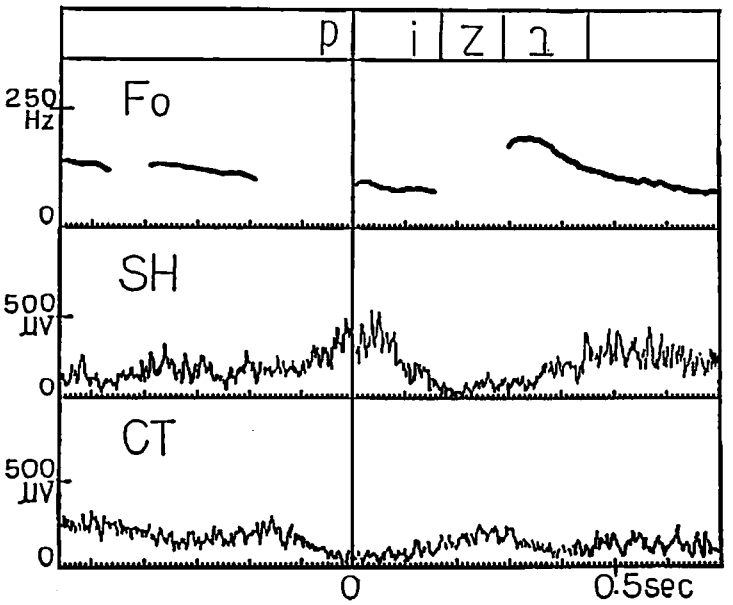

Figure 5
Tone 3 + tone 4
Test sentence is / zhe^{4} shi^{4} pi^{3} zi^{4} de^{0} yi^{4} si^{1} /.
这 是 癖 字 的 意 思。

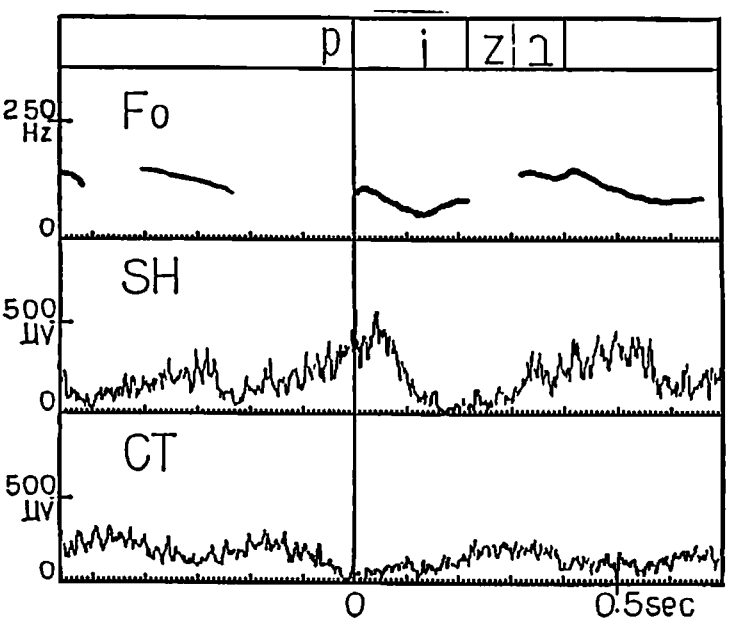

Figure 6
Tone 3 + light tone
Test sentence is / zhe^{4} shi^{4} pi^{3} zi^{0} de^{0} yi^{4} si^{1} /.
这 是 痞 子 的 意 思。

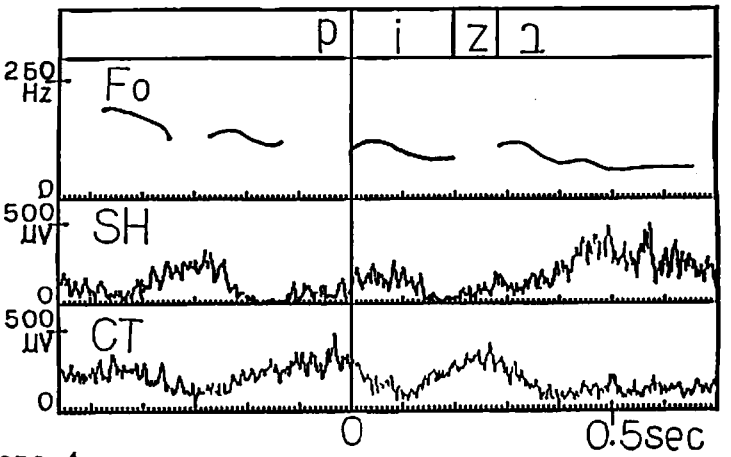

Figure 7
Tone 4 + tone 4
Test sentence is / zhe^4 shi^4 bi^4 zi^4 de^0 yi^4 si^1 /.
这 是 碧 字 的 意 思。

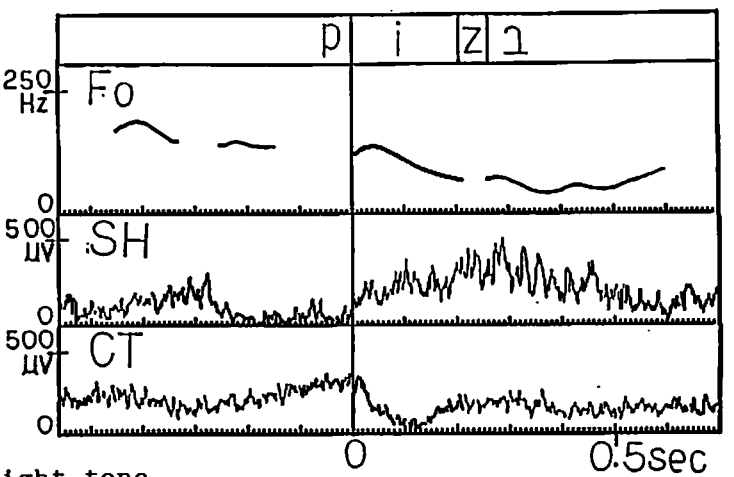

Figure 8
Tone 4 + light tone
Test sentence is / zhe^4 shi^4 bi^4 zi^0 de^0 yi^4 si^1 /.
这 是 笔 子 的 意 思。

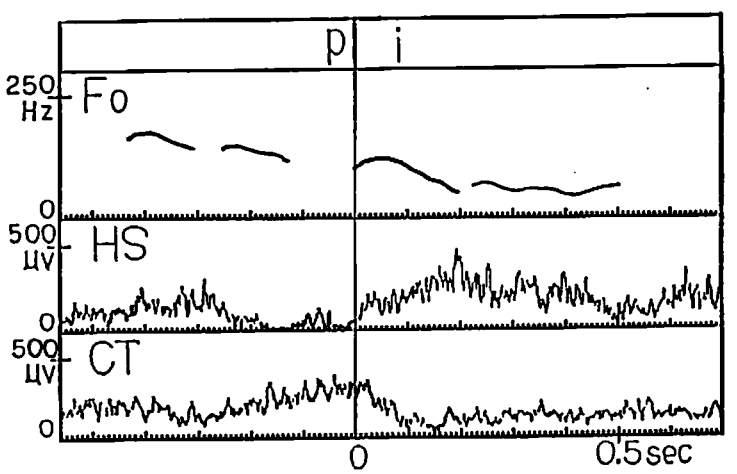

Figure 9
Tone 4 without a following syllable

Test sentence is / zhe^4 shi^4 bi^4 de^0 yi^4 si^1 /.
这 是 壁 的 意 思。