A PERCEPTIAL STUDY ON THE DOMAIN OF TONES IN BEIJING MANDARIN ①

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北京话声调分布域的感知实验研究

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[**提要**] 声调分布域问题是要研究声调信息跟字音组成成分之间的关系。汉语语音学家根据自己对语音的直觉，在归并北京话的音位系统和制订拼音方案时，对这个问题提出了不同看法。有的认为声调属于整个音节，有的主张声调是附丽在韵母或主要元音上的。

关于北京话声调分布域，Howie(1974)主张，北京话声调的基本曲拱仅仅跟主要元音及其后接带音段有关。这个主张是他根据对标准形式声调的 F0 曲线作分析得出的。Shen 和 Lin (1991)在对声调协同发音作感知实验中看到，音节相连时，不仅作为第二音节起头的浊辅音和介音中 F0 要受到扰动，而且以主要元音起头的第二音节起始部分也受到了扰动。Kratochvil (1970) 和 Dow(1972)主张把鼻音韵尾排除在声调分布域之外；我们认为元音韵尾也跟声调音高无关，但对这些看法仍需用实验证实。

本文采用感知实验方法，研究单念字音"弯头段"和"降尾段"中 F0 与其声调音高的关系，从而确定北京话声调的分布域。

一位说北京话的男青年单说的"癌"，"矮"和"爱"；"羊"，"养"和"样"；"苗"，"秒"和"妙"及"前"，"浅"和"欠"等字音。用 Kay 7800 型语图仪里的切音装置，设置窗宽为 80ms 和 100ms，以 20ms 的步长，对每个字音从头到尾进行切割，为了确保各个字音的最后一个刺激时长一定为 80ms 或 100ms，最后窗口的右缘一定置于字音终点上。对每个字音都得到刺激时长分别为 80ms 和 100ms 的两个刺激系列。由 10 位受试者作辨认实验，其结果表明，当字音 F0 曲线有明显的"弯头"和"降尾"，这个字音声调的音高感知与浊辅音声母或介音，和鼻音韵尾或元音韵尾无关；甚至当字音 F0 曲线的"降尾"不明显，介音或元音韵尾对字音声调音高感知也无关。

总而言之，对北京话单说的字音来说，不仅可以把浊辅音声母和介音，而且也可以把鼻音韵尾以及元音韵尾排除在声调分布域之外，因而，北京话单说声调的基本曲拱只跟主要元音有关，即字音声调信息存在于主要元音之中；单说的字音 F0 曲线有"弯头段"，"调型段"和"降尾段"。"弯头段"和"降尾段"里的 F0 是人们无意产生，而调型段里 F0 曲拱是说话人有意产生的，因而，可以认为，F0 跟声调音高相联系的函数分布区域不是连续的，并不是只要有 F0 都能引起声调音高的感觉。

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ABSTRACT

A perceptual experiment was conducted in which stimuli sliced from 12 Mandarin syllables spoken in isolation were identified by 10 native speakers of Mandarin. The results of the experiment indicate that when the pre－onset or post－offset of a tone is extended to a great degree, the initial voiced consonant, the medial, the nasal coda, and the vocalic ending are not related to the tonal pitch; even when the post－offset is extended to a small degree, the nasal coda and the vocalic ending are neither related to the tonal pitch. Thus, with regard to the tonal domain of Mandarin monosyllables in isolation, not only the initial voiced consonant and the medial, but also the nasal coda and the vocalic ending are excluded from the domain of tones; in other words, the basic contour of Beijing Mandarin tones in isolation is strictly related to the syllabic vowel (and its adjacent transition).

Because the F0 in pre－ onset and post－ offset tones are not related to the tonal pitch, there is no exact match between F0 and tonal pitch.

Ⅰ. INTRODUCTION

As for the domain of tones in Mandarin, Howie (1974) claimed that the basic contours of Mandarin tones were coextensive only with the syllabic vowel and any voiced segment that may follow it. This claim was based on the analysis of the F0 curves in the citation tones. However, Shen and Lin (1991) in a perceptual study on tonal coarticulation found that in connected speech, any portion of foundamental frequency at intertonemic noset was perturbed－－－－－this included initial voiced consonants and vowels (syllabic vowel and non－syllabic vowel were alike) and concluded that Howie' claim was only applicable to tones in citation form.

Kratochvil (1970) and Dow (1972) proposed that the nasal coda could be excluded from the domain of tones. In a acoustic study (Lin, 1965), it was found that the F0 curve of a tone in isolated citation form exhibits not only a basic contour and a pre－onset, but also a post－offset, as illustrated in Fig. 1 bellow. This perceptual experiment wants to study whether the vocalic ending, nasal coda are irrelevant to the domain of tones in Beijing Mandarin.

Ⅱ. METHOD

2.1 stimuli

In this experiment, the syllables of "癌" [ai˥] (carcer), "矮" [ai˨˩] (short), "爱" [ai˥˩] (love); "羊" [iaŋ˧˥] (sheep), "养" [iaŋ˨˩] (keep), "样" [iaŋ˥˩] (shape); "苗" [miao˧˥] (seeding), "秒" [miao˨˩] (second), "妙" [miao˥˩] (excelcent); "前" [tɕʻian˧˥] (front), "浅" [tɕʻian˨˩] (shallow) and "欠" [tɕʻian˥˩] (owe) were used to examine the relevance of the syllabic vowel, medial, initial voiced consonant, vocalic ending, and nasel coda to the domain of tones.

80ms and 100ms segments were sliced from 12 syllables pronounced by a young male native speaker of Beijing Mandarin, through the "gating" equipment in Kay Digital Sona－Graph 7800; the window－length of 80ms or 100ms in step of 20ms was used to scan each syllable from its beginning to its ending. In order to ensure that the last stimulus of each syllable has the duralion of 80ms or 100ms, the righ edge of the window had to be placed on the ending－point of the syllable. The durations of 80ms and 100ms were selected, because these durations were above the 40－65ms duration threshold for the perception of contouricity in rising F0 (Greenberg and Zee, 1979) and the 40－80ms duration threshold for the perception of contouricity in falling F0 (Sun, 1994). The numbers of the stimuli made from each syllable were as follows:

"癌":12 tokens at 100ms, 13 tokens at 80ms;
"矮":18 tokens at 100ms, 19 tokens at 80ms;
"爱":13 tokens at 100ms, 14 tokens at 80ms;
"羊":18 tokens at 100ms, 19 tokens at 80ms;
"养":21 tokens at 100ms, 22 tokens at 80ms;
"样":10 tokens at 100ms, 11 tokens at 80ms;
"苗":20 tokens at 100ms, 21 tokens at 80ms;
"秒":23 tokens at 100ms, 24 tokens at 80ms;
"妙":16 tokens at 100ms, 17 tokens at 80ms;
"前":13 tokens at 100ms, 14 tokens at 80ms;
"浅":15 tokens at 100ms, 16 tokens at 80ms;
"欠": 9 tokens at 100ms, 10 tokens at 80ms;

Thus, there were two series of stimuli for each syllable, the duration of each stimulus in one series was 100ms, that in the other series was 80ms.

Each stimulus token was first recorded onto the master tape, and then A/D converted with a 20kHz sampling frequency and 16bit quantification; each stimulus was repeated 4 times. The slimuli of each series were randomized; after being D/A reconverted, they were recorded on a test tape. In the test tape, each stimulus was repeated 3 times with a 1－sec. interval to make a triad; each triad was indexed in serial number, the interval between successive triads was 5 seconds.

In this experiment, stimuli were not made from the syllable in tone－1, the reason was based on the Following consideration. The pre－onset and post－offset may occur probably on the F0 curve in tone－1, nevertheless, there are no obvious differences in pitch perception between the stimuli covering pre－onset and post－offset and that covering the basic tonal contour: tone－1 is level pitch, the stimuli ccovering the pre－onset and the post－offset is also perceived as a level pitch.

2.2 Subject

Ten monolingua Chinese listeners (five male, five female), all young native speakers of

Beijing Mandarin, voluntarily participated in this experiment. They were the staffs at the Institute of Linguistics (CASS) in Beijing; None of them was a phonetician. The participants had no speech and hearing impairments, and they were naive as to the purpose of the experiment. None of them had ever participated in this type of experiment before. The stimuli were presented to each listener over high quality earphone; the volume was adjusted to easy hearing by the listener him/herself. The listeners were provided with answer - sheets, and instructed to tell whether they heard a level pitch, a falling pitch, or a rising pitch, and instructed to chose the answer forcely when they felt uncertain about the pitch.

It should be noted that most of the stimuli at 100ms or 80ms covering the pre - onset and the post - offset had been identified by three phoneticans as irrelevant to the tonal pitch, before the perceptual experiment was formerly conducted.

Ⅲ. RESULTS AND DISCUSSIONS

Fig. 2 shows the percentage of identicication averaged over 40 responses (4 occurances X ten subjects) for different kinds of pitch in stimuli made from "癌","矮" and "爱" (the syllables are composed of the descending diphthong with different tone). In the following figures, - - - -□- - - - denotes level pitch, - - - -●- - - - rising pitch, - - - -*- - - - falling pitch. Low panels illustrate the percentage of identification of the stimuli at 100ms; upper panels illustrate the percentage of the identification of the stimuli at 80ms. In the figures, for the stimuli at 100ms, the percentage of identification of the first stumalus was spotted at the point of 50ms away from the ordinate, that of the second stimulus at the point of 70ms away from the ordinate, … that of the last stimulus at the point of 50ms away from the ending point of the syllable; for the stimuli at 80ms, the percentage of identification of the first stimulus was spotted at the point of 40ms away from the ordinate, that of the second stimulus at the point of 60ms, … that of the last stimulus at the point of 50ms away from the ending point of the syllable. For the purpose of observing the temporal relationship between F0, F - pattern and the above stated identification function, the narrow - band and wide - band spectrograms, and the waveform and the amplitude curve of the syllable were superimposed in each of the following figures.

It can be seen in fig 2 that the F0 curves of "癌","矮" and "爱" exhibit a pre - onset, i. e., the F0 of the initial portions of the syllabic vowels are perturbed; the F0 curves also shows a post - offset, occurred at the vocalic ending. For the stimuli at 80ms or 100ms made from "癌", the stimuli covering the pre - onset and the post - offset were identified as level pitch well above 33% chance level, while the stimuli made from the transition from the syllabic vowel to the vocalic - ending were identified as rising pitch. In other words, the tonal rising pitch for "癌" was only relevant to those stimuli that were made from the (acoustical, the same below) transition from the syllablic vowel to the vocalic - ending. For the stimuli at 80ms or 100ms made from "矮", the two or three stimuli covering the pre - onset and the one or two stimuli covering the post - offset were level identified

as level pitch well above the chance level, while the stimuli made from the transition from the syllabic vowel to the vocalic－ending were identified as falling, level, and rising pitches respectively. In other words, the tonal falling－rising pitch for "矮" was only relevant to those stimuli made from the transition from the syllabic vowel to the vocalic ending. As for the stimuli at 80ms or 100ms made from "爱", the two or three stimuli covering the pre－onset were identified as level pitch; although the stimulus covering the post－offset was identified as falling pitch, the percentage of identification of the stimulus was lower than those preceding it, that is to say that the tonal falling pitch for "爱" was more relevant to those stimuli that were made from the transition from the syllabic vowel to the vocalic ending. In sum, for the syllables of "癌", "矮" and "爱", syllables of descending diphthong, the stimuli covering the initial portions of the syllabic vowel were identified as level pitch, and the stimuli covering the post－offset were identified either as level pitch or as the appropriate tonal pitch with less accuracy than those made from the transition from the syllabic vowel to the vocalic ending, while, the tonal pitch was relevant to the (acoustical) transition from the syllabic vowel to the vocalic－ending. Thus, the tonal pitch for "癌","矮" and "爱" was relevant only to the transition from the syllabic vowel to the vocalic ending.

Fig.3 shows the percentage of identification for different kinds of pitch in the stimuli made from "羊","养" and "样". "羊" "养" and "样" are composed of medial, syllabic vowel and nasal coda. It can be seen in Fig.3 that the F0 curves all exhibit a pre－onset, occurred at the transition from medial to syllabic vowel, and the F0 curve that of "羊" shows a post－offset extended to a great degree, while that of "养" shows a post－offset extented to a small degree, occurred at the nasal coda. And it can be seen that for the stimuli at 80ms or 100ms made from "羊", the five or six stimuli covering the pre－onset and the two or three stimuli covering the post－offset were identified as level pitch, while the stimuli made from the syllabic vowel and its adjacent transition were identified as rising pitch. In other words, the tonal rising pitch for the syllable of "羊" was only relevant to those stimuli that were made from the syllabic vowel and its adjacent transition. As for the stimuli at 80ms or 100ms made from "养", the stimuli covering the pre－onset were identified as level pitch; the stimuli following them were identified as falling, level and rising pitches respectively; the stimulus covering the post－offset was also identified as rising pitch, but the percentage of identification of the pitch in the last stimulus is lower than those that precede it. In other words, the tonal falling－tising pitch for "养" was more relevant to those stimuli that were made from the syllabic vowel and its adjacent transition. As for the stimuli at 80ms or 100ms made from "样", the two or three stimuli covering the pre－onset were identified as level pitch, the stimuli following them were identified as falling pitch, but the last stimulus covering the post－offset was perceived with less accuracy than those made from the syllabic vowel and its adjacent transition. In other words, the tonal falling pitch for "样" was more relevant to those stimuli that were made from the syllabic

vowel and its adjacent transition. In sum, for the syllables of "羊","养" and "样", the stimuli covering the pre－onset were identified as level pitch, while the one or two stimuli covering the post－offset were identified either as level pitch or as the appropriate tonal pitch with less accuracy than those stimuli precede them. Thus, the tonal pitch for "样", "养" and "样" was relevant to the syllabic vowel and its adjacent transition.

Fig.4 shows the percentage of identification for different kinds of pitch in the stimuli made from "苗","秒" and "妙". "苗","秒" and "妙" are composed of initial nasal consonant, medial, syllabic vowel and vocalic ending. It can be seen in Fig.4 that the F0 curves all exhibit the pre－onset, occurred at the initial nasal consonant, and the post－offset, occurred at the vocalic－ending and its adjacent transition. For the stimuli at 80ms or 100ms made from "苗", the stimuli covering the pre－onset and the two or three stimuli covering the post－offset were identified as level pitch, while the stimuli made from the syllabic vowel and its adjacent transition were identified as syllabic vowel and its adjacent transition were identified as rising pitch. In other words, the tonal rising pitch for the syllable of "苗" was relevant only to those stimuli that were made from the syllabic vowel and its adjacent transition. As for the stimuli at 80ms or 100ms made from "秒", the stimuli covering the pre－onset and the two or three stimuli covering the post－offset were identified as level pitch, while the stimuli made from the syllabic vowel and its adjacent transition were identified as falling, level or rising pitches respectively. In other words, the tonal falling－rising pitch for the syllable of "秒" was relevant only to those stimuli that were made from the syllabic vowel and its adjacent transition. As for the stimuli at 80ms or 100ms made from "妙", the six or seven stimuli covering the pre－onset were identified as level pitch; although the stimulus covering the post－offset was identified as falling pitch, the percentage of identification was lower than those stimuli made from the syllabic vowel and its adjacent transition. In other words, the tonal falling pitch for "妙" was more relevant to those stimuli made from the syllabic vowel and its adjacent fransition. In sum, for the syllables of "苗","秒" and "妙", the stimuli covering the pre－onset were identified as level pitch, the stimuli covering the post－offset were identified either as level pitch or with less accuracy to the tonal pitch than those stimuli preceding it. Thus, the tonal pitch for "苗", "秒" and "妙" were relevant to the syllabic vowel and its adjacent transition.

Fig.5 shows the percentage of identification for different kinds of pitch in the stimuli made from "前","浅" and "欠". Notice that the tonal contours of "前" and "浅" have the same concave shape. Because the turning point of the F0 contour in "前" is very near to the beginning of the F0 contour, and the degree of the initial fall is small, the percept of the tone in "前" has a rising pitch (Shen and Lin, 1993). "前","浅" and "欠" are composed of aspirated affricative, medial, syllabic vowel and nasal coda. It can be seen in fig.5 that the F0 curves all exhibit no pre－offset, and the F0 curves of "前" and "浅" shows a post－offset occurred at the nasal coda. It can be seen that for "前", the three or four stimuli covering the small inital F0 fall and the stimuli covering the post－offset were identi-

fied as level pitch, while the stimuli made from the syllabic vowel and its adjacent fransition were identified as rising pitch. In other words, the tonal rising pitch for "前" was relevant only to those stimuli that were made from the syllabic vowel and its adjacent transition. The stimuli at 80ms or 100ms made from "浅" were identified as falling, level and rising pitches respectively, while the stimulus covering the post－offset was identified either level pitch or as less accuracy to the tonal pitch than those preceding it. In other words, the tonal falling －rising pitch in "浅" was more relevant to those stimuli made from medial, syllabic vowel and its adjacent transition. As for the stimuli at 80ms or 100ms from "欠", the first stimuli and the last stimulus were identified as falling pitch with less accuracy than those that were made from the syllabic vowel and its adjacent transition. In other words, the tonal falling pitch in "欠" was relevant to those stimuli made from the syllabic vowel and its adjacent transition. In sum, the tonal rising pitch in "前" was relevant only to the syllabic vowel and its adjacent transition, the tonal falling－rising pitch in "浅" was more relevant to the medial, syllabic vowel and its adjacent transition, the tonal falling pitch in "欠" was more relevant to the syllabic vowel and its adjacent transition.

Some questions arise for these results:

1. Why were stimuli at 80ms or 100ms covering the pre－onset perceived as level pitch?
2. Why were stimuli covering the post－offset were perceived as level pitch, or with less accuracy to the tonal pitch than those made from the syllabic vowel?

There seems to be the following reasons:

(1)The duration of the pre－onset of "苗" was 80ms in which F0 rise was 9 Hz. Since the amplitude of the signal in the pre－onset is very small, the stimulus at 80ms was perceived as level pitch. When the pre－onset was connected by a signal with duration of 20ms, in which F0 rise was only 1 Hz, to make the first stimulus at 100ms, however, the stimulus was still as well perceived as level pitch.

(2)The pre－onset of "样" was extended to the greatest degree in the syllables used in this study: the duration was 70ms and the F0 rise was 46 Hz. Since the amplitude of the signal in the first most part of the pre－onset was very small, subjects were uncertain about whether the pitch was level or rising. When the pre－onset was connected by a signal with durations of 10ms or 30ms, to make the first stimulus at 80ms or 100ms, in which the shape of F0 was convex, it was easily perceived as level pitch.

(3)The post－offset in "秒" was 47ms with the F0 fall of 36Hz. The stimulus at 100ms covering the post－offset was composed of the F0 fall and a F0 rise preceding the F0 fall; the duration of the F0 rise was 53ms with a rise of 17Hz. Since in the stimulus, the degree of the F0 fall was much greater than that of F0 rise, and the durations of both were nearly equal, most of the stimulus tokens were perceived as level pitch, even though the amplitude of the signal in the last part (about 20ms) in the stimulus is small.

(4)The post－offset in "浅" was 38ms with a F0 fall of 28Hz. The stimulus at 100ms covering the post－offset was composed of this F0 fall and a F0 rise of 26 Hz at 62ms. Since

the duration of the F0 rise was greater than that of the F0 fall, the degrees of the F0 rise and the F0 fall were nearly equal, the percentage of identification as rising pitch was 56%. However, the percentage of identification was much lower than those stimuli made from the syllabic vowel.

In gengral, because in the stimulus covering the pre-onset, both the degree of the F0 rise and the amplitude of its signal are small, or, the F0 shape in the stimulus is convex, but the amplitude of the signal is small, most of these stimuli in the series are, therefore, perceived as level pitch. The F0 shape in the stimulus covering the post-offset is convex, and the amplitude of the signal is small. If the degree of the F0 fall in the convex is greater than that of the F0 rise, most of the stimuli are perceived as level pitch; if both the degrees of the F0 fall and F0 rise are nearly same, most of the stimuli were perceived as level pitch with less accuracy.

Return now to explain why are the nasal coda and the vocalic ending as well as the initial voiced consonant and the medial irrelevant to the tonal pitch.

For the syllables in tone-2, the stimulus at 100ms was consisted of the pre-onset, in which F0 was slight rising, and of the initial part on the basic tonal contour, in which F0 was also slight rising. Since the stimulus was perceived as level pitch, the pre-onset are not related to the tonal pitch. As for the syllables in tone-3 and tone-4, the stimulus at 100ms or 80ms, which were perceived as level pitch, were composed of the pre-onset, in which F0 was rising, and of the initial part on the basic tonal contour, in which F0 was falling. Since the direction of F0 movement in the pre-onset is opposite to that in the initial part on the basic tonal contour regardless of the extent of the pre-onset, the F0 in the pre-onset are not related to the tonal pitch.

The last stimulus at 100ms or 80ms, which was perceived as level pitch, or with less accuracy to the tonal pitch, was composed of the post-offset, in which F0 was falling, and of the final part on the basic tonal contour, in which F0 was rising. Since the direction of F0 movement in the post-offset is opposite to that in the final part on the basic tonal contour regardless of the extent of the post-offset, the F0 in the offset-setion are not related to the tonal pitch.

Since the F0 in the pre-onset are not related to the tonal pitch, the medial and initial voiced consonant occurring the pre-onset are not related to the tonal pitch. Since again the F0 in the post-offset are not related to the tonal pitch, the nasnal coda and vocalic ending occurring the post-offset are not related to the tonal pitch.

This perceptual experiment as well as Howie's (1974) acoustic annalysis demostrated that as far as the syllable in isolated citation form is concenced, the initial voiced consonant and medial can be excluded from the domain of tones; furthermore, this paper suggested that the nasal coda and the vocalic ending can be excluded from the domain of tones as well. In summary, from the evidence of the acoustic analysis, the F0 curve of a tone of Beijing Mandarin in isolated citation form is divided into three parts, i.e., the pre-onset, the

basic contour, and the post－offset. From this perceptual experiment, not only the initial voiced consonant and the medial, but also the nasal coda and the vocalic ending can be excluded from the domain of tones. For the syllable of monophthong, the initial and final portion of F0 curve can be perturbed. Thus, the basic tonal contour in isolated citation tone in Beijing Mandarin is merely related to the syllabic vowel (and its adjacent transition); namely, the information of tones is carried by the syllabic vowel. Thus, there is no exact match between F0 and tonal pitch.

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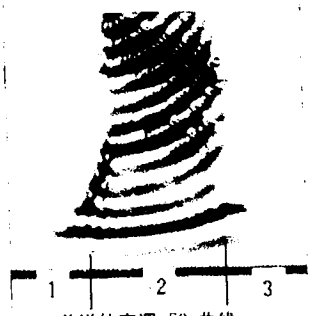

图 1　单说的声调 F0 曲线
Fig. 1　The F0 curve of a tone in isolated citation form

1: 弯头段;　2: 调型段;　3: 降尾段
1: Pre-onset;　2: basic contour;　3: post offset

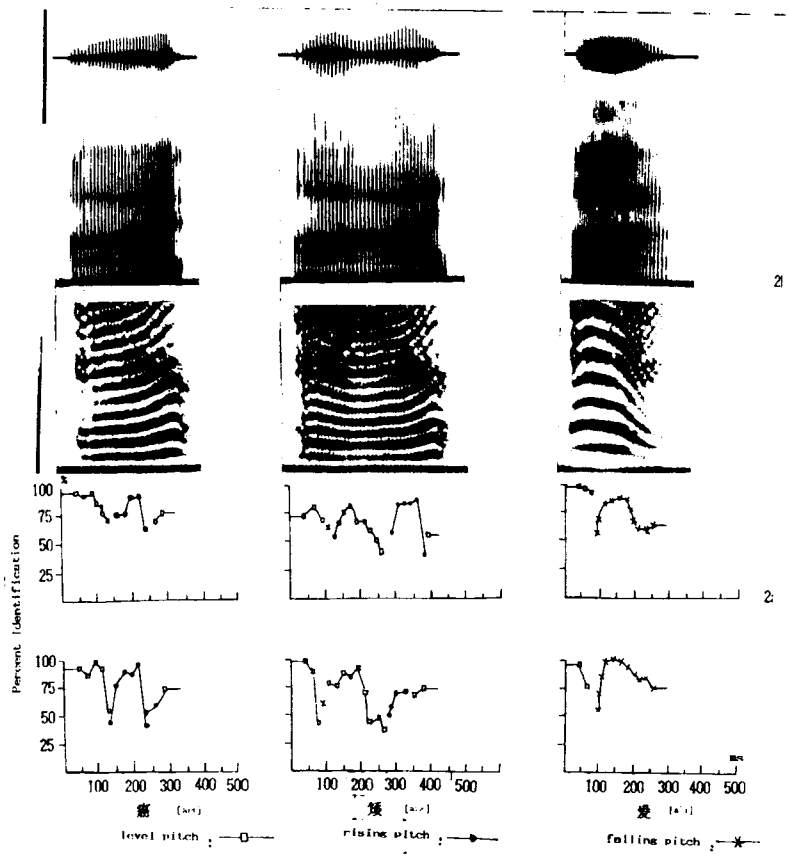

图 2　从"癌"、"矮"和"爱"字音切割来的刺激，10 位听音人作不同音高判断而得到的平均辨认百分数

Fig.2 The percent identification of the different kinds of pitch in the stimuli,that were sliced from the syllables of "癌","矮" and "爱".Judged by ten listeners

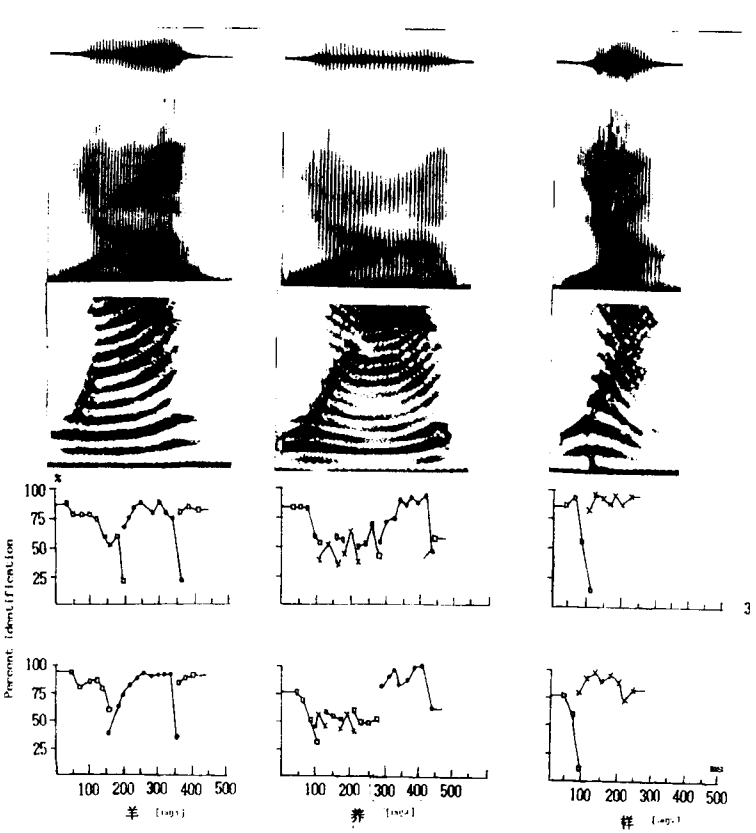

图 3　从"羊"、"养"和"样"字音切割来的刺激，10 位听音人作不同音高判断而得到的平均辨认百分数

Fig.3 The percent identification of the different kinds of pitch in the stimuli,that were sliced from the syllables of "羊","养" and "样", judged by ten listeners

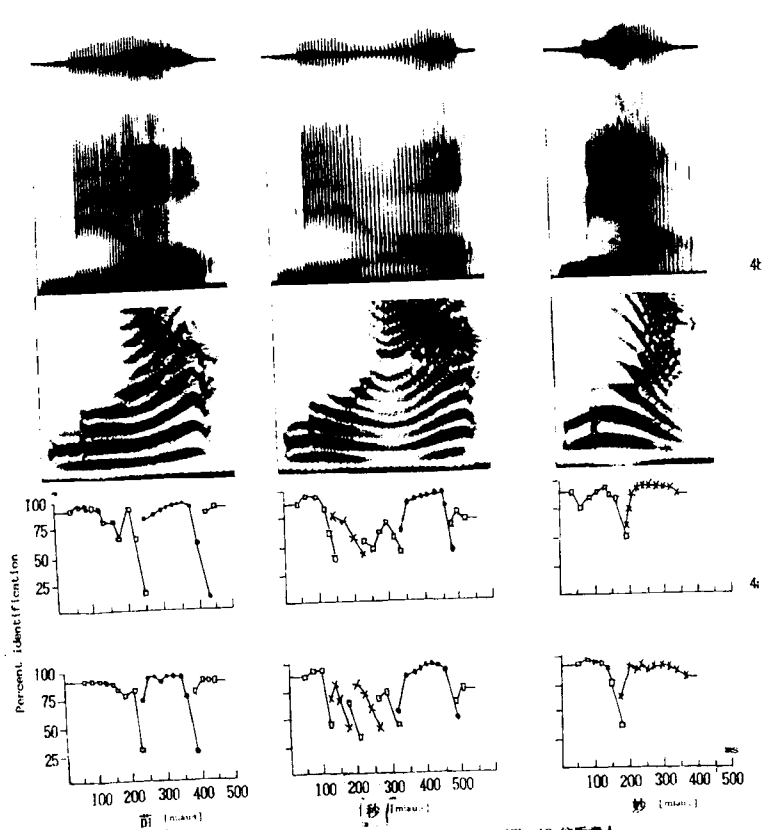

图 4　从"前"、"秒"和"妙"字音切割得到的刺激，10 位听音人作不同音高判断而得到的平均辨认百分数

Fig.4　The percent identification of the different kinds of pitch in the stimuli,that were sliced from the syllables of "前","秒" and "妙", judged by ten listeners

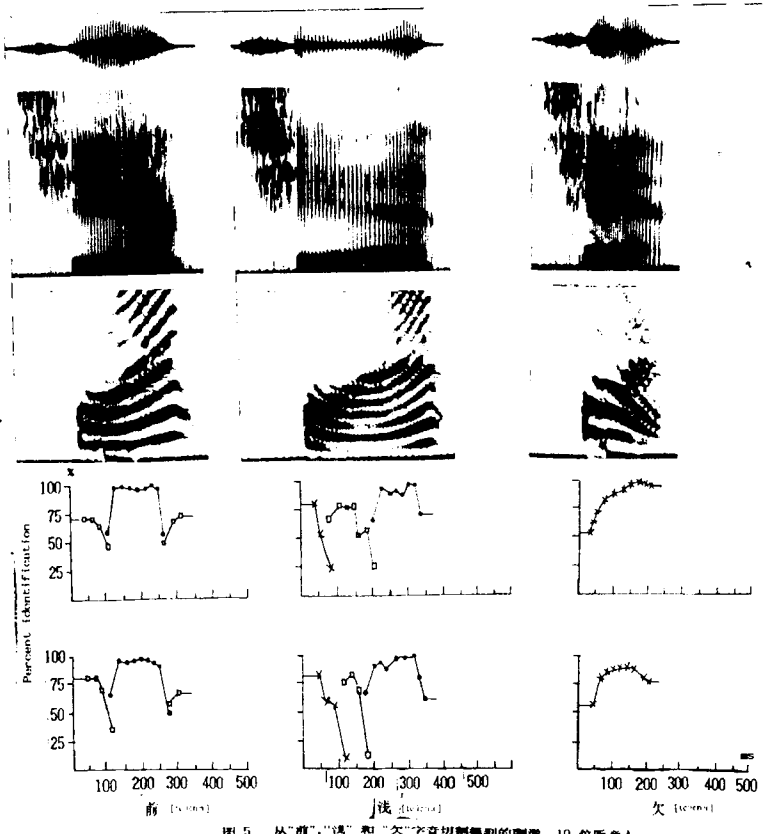

图 5　从"前"、"浅"和"欠"字音切割得到的刺激，10 位听音人作不同音高判断而得到的平均辨认百分数

Fig.5　The percent identification of the different kinds of pitch in the stimuli,that were sliced from the syllables of "前","浅" and "欠",judged by ten listeners