

## TONAL COARTICULATION PATTERNS IN QUADRISYLLABIC WORDS AND PHRASES OF MANDARIN

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### 北京话四音节词和短语中声调协同发音模式

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[详细提要] 沈晓楠(1990)首先用确实证据说明,北京话跟越南话(Han & Kim, 1974)和彝(Abromson, 1979)一样,在声调产生中也存在协同发音。她的论文给出了北京话声调协同发音的一个特点:声调协同发音影响整个音节;声调协同发音是双向的,这种双向作用是对称的;它仅限于邻声调。然而,她所用的实验材料是无意义的三音节序列,并要求发音人用相同重音念这种序列的各个音节。但是在平常所说的词和短语中,各个音节有不同重音,对三音节词和短语来说,如身正常重音念,末音节最重,首音节次之,中间音节最弱(Yan & Lin, 1988)。这样,必然就提出一个问题,有意义的词和短语中的声调协同发音的表现是不是跟无意义音节序列的相同。本文的目的在于研究北京话有意义的词和短语中声调协同发音的特点,并力图找出其模式。

北京话有四个单念的声调:阴平(55),阳平(35),上声(214)和去声(51)。对四音节组来说,256个四声组合。对每个四声组合,选用两个四音节词或短语。所以,本实验用了512个四音节或短语。把这些词或短语放在“我说××××四字词”这样的引导句中。它们分别写在4×3(4厘米)的卡片上,并加以打乱。一位北京男人(语音学家)作发音人,用高质量录音机录其声音。

这些词或短语声音的F0曲线用音高显示器(Lin, 1965)提取。图1给出四音节词或短语的每种四声组合的F0曲线。

在每个音节的F0曲线上,不仅有调型段,而且还可能有弯头段和降尾段,如图2所示。弯头和降尾段是由于声带运动的惯性引起的,本地人听字音时听不出来这个弯头段和降尾段,而调型却携带着声调的区别特征信息。图3左边给出“浪漫主义”中“浪”跟“漫”和“主”跟“义”之间F0曲的过渡段(“4”),右边的“到处表现”F0曲线无这种过渡段。

用方差分析和t-检验对所有数据作统计分析,以确定协同发音的存在及其程度。

图4给出在前面声调或后面声调的协同发音作用下,每个声调的平均F0曲线。从图4可以看到,在声调的产生中,确实存在着协同发音作用,这是因为在环境中每个声调有不止一条F0曲线它们在起始部分或末了部分明显地分散开来。表1给出对调型段数据作二维方差分析得到的结果

从表1可以看到,第二,第三和第四音节中的阴平,阳平和上声的起点,第二音节的阴平终

第二和第四音节中的上声转折点,在 0.001 水平上受前面声调的作用是明显的,而后面声调对阴平,阳平和上声终点的作用是不明显的.在 0.001 水平上,后面声调对去声终点作用是明显的,而前面声调对其起点的作用是不明显的,这说明声调协同发音作用是单向的.

从表 1 还可以看到,在显著性水平为 0.001 时,顺向作用只影响调型段的起点,除第二音节阴平终点以外,这种作用不会扩展到其终点;逆向作用只影响调型段的终点,不会扩展到其起点.

图 5 给出对协同发音作用材料用单边  $t$ -检验,在  $p=0.05$  显著性水平上得到的结果.从图可以看到,第二,第三和第四音节中的阴平和阳平起点,和第二音节中的阴平终点,在上声和去声后面要比在阴平和阳平后面的低;第二,第三和第四音节中的上声起点和它的一些转折点,在阴平和阳平后面要比在去声后面的高;第一,第二和第三音节中的去声终点,在去声前面要比在阴平阳平和/或上声前面的高;第一音节中上声终点,在去声前面要比在阴平和阳平前面的高.虽然四声调型段的起点或终点受到了协同发音的作用,但各个声调的本身特点仍保持不变.

本实验还研究了跨过音节的声调协同发音作用.在显著性水平为 0.05 时,协同发音作用一般不跨过相邻声调,这在表 2,表 3,表 4 和表 5 中可以看到.本实验得到的北京话声调协同发音的结果归纳如下几点:

(1) 声调协同发音一般仅仅作用于两个相邻音节,也就是说,声调协同发音作用一般不跨过音节;

(2) 声调协同发音作用是单向的,也就是说,北京话四声不是受顺向协同发音作用,就是受逆向协同发音作用.而且顺向协同发音作用一般只影响其后面调型段的起点,逆向协同发音作用一般只影响前面调型段的终点.

(3) 声调协同发音表现在  $F_0$  高度的变化上,它不改变  $F_0$  的移动方向. $F_0$  高度的这种变动不影响各个声调本身的性质;

(4) 第二,第三和第四音节中的阴平,阳平和上声的起点受到顺向作用的程度可由前面声调的终点高度来预测;第一,第二和第三音节中的去声终点和第一音节中的上声终点受到逆向作用的程度可由后面声调的起点高度来预测.

本实验关于声调协同发音不跨过音节和声调协同发音不改变声调性质的结论,跟沈晓楠(1990)的结论是一致的.但是,本实验看到顺向作用不会扩展到声调终点,逆向作用不会扩展到声调起点以及声调协同发音作用是单向的.这两个实验所得结果所以不同的原因可能在于两个实验所用的材料不同,一个实验是用有意义的词和短语,另一个实验是用无意义的音节序列.

北京话词和短语中,不仅存在着变调,而且还有轻重音.对用正常重音念(即其中没有音节为轻声和强调重音)的词和短语来说,有如下的重音模式:(a) 四声的  $F_0$  范围从第一音节到最后音节逐渐下降,这个  $F_0$  范围也逐渐扩大,其下限比起上限下降得更快.(b) 最后音节的  $F_0$  拱度接近单念时的声调模式.(c) 最后音节的时长较长(Yan & Lin,1988).由于词和短语的  $F_0$  范围的上限一般是由阳平终点和去声起点确定,所以,由于声调协同发音受到扰动的是阳平起点而不是其终点,去声终点而不是其起点.由于词和短语的  $F_0$  范围下限由上声最低部分确定,所以,由于声调协同发音受到扰动的多是上声起点和终点.至于阴平,在本实验中其起点受到了扰动,但其终点也可能受到扰动.所以,声调协同发音要受到词和短语重音模式制约.声调协同发音还要受变调规则的制约.一个熟悉的例子是,在另一个上声之前的上声要先变成阳平,然后它再像固有阳平那样受到前面声调的协同发音作用.

有文章谈到，在三音节词或短语中，如果第一音节为阴平或阳平，第二音节为阳平，而第三音非轻声的任何声调，那么，当说话速度快时，第二音节的阳平要变成阴平，如果说话速度较慢，不变(Chao, 1968)。阴平和阳平后面的阳平变成阴平这个现象，是由于协同发音引起的，这时前平或阳平的高终点把其后面阳平的起点抬高了。有文章指出，阴平或阳平后面的阳平，当其后上声或阳平时，其 F0 曲线将进一步变成微降 Wu, 1988。这个现象是由于逆向协同发音引起，受后面上声和阳平的低或中起点的影响，使这个阴平终点受到扰动。这说明词和短语中的声调发音还跟说这个词的速度有关。关于这个问题，将在另一个实验作进一步研究。

## TRACT

Meaningful Quadrisyllabic words and phrases in Mandarin were used to study tonal coarticulation. This experiment found that in general the coarticulatory effects are unidirectional, and the carryover effect does not extend to the ending-point of tone-section and the anticipatory effect does not extend to the starting point of that. The extent of the carryover effect on the start-point of tone-1, 2 and tone-3 in each syllable can be predicted by the height of the ending-point of the preceding tone, and the extent of the anticipatory effect on the ending-point of tone-4 in each syllable can be predicted by the height of the starting point of the following tones. It is highly probable that tonal coarticulation is conditioned by both tone-sandhi and stress. Tonal coarticulation in word or phrase is related to the speed at which word or phrase is pronounced.

## INTRODUCTION

Shen(1990) was the first to provide corroborating evidence to the claim that as Vietnamese(Ham & Kin , 1978) and Thai(Abramson , 1978), tonal coarticulation presents in the production of Mandarin tones. The result of her study showed several characteristics of tonal coarticulation in Mandarin. Coarticulation affected the onset and offset values of a tone affected, but so were the overall tonal contour. Tonal coarticulation was bidirectional, but the bidirectional effects were symmetric; anticipatory effect and carryover effect were similar. And it was restricted to contiguous tones. However, the experimental materials used in her study were nonsense sequences of three syllable. The speakers were asked to stress each syllable in the nonsense sequences evenly. But in Meaningful words and phrases, each syllable bears different degree of stress, for example, in trisyllabic words and phrases with normal stress, the last syllable has the greatest stress (the most prominence), the first next and the second least(Yan & Lin , 1988). A question is raised inevitably; whether or not the manifestation of the tonal coarticulation in meaningful words and phrases is the same as that in the nonsense sequences. The aim of this paper is to study the characteristics of tonal coarticulation in actual words and phrases for Mandarin and try to find out its patterns.

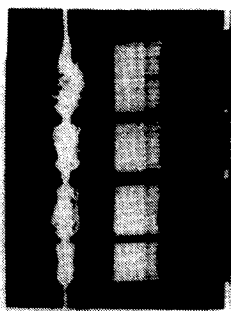
## MATERIAL AND METHOD

It is well known that there are four tones in citation form for Mandarin, namely: tone-1(11), tone-2(35), tone-3(214), and tone-4(51). There are 256 combinations of the four tones into four-syllable groups. In the following, "1" is the symbol of tone-1, "2" tone-2, "3" tone-3, "4" tone-4. So, the combinations are 1111, 1112, 1113, 1114; .....; .....; 2441, 2442, 2443, 2444; 3111, 3112, 3113, 3114; .....; .....; 4441, 4442, 4443, 4444. For each combination of the four tones, two quadrisyllabic words and phrases were selected. For combination of 1111, "跟踪追击" (go in pursuit) and "今天开张" (begin doing business today) were selected; for 1112, "八一宣言" (manifesto of the August 1) and "空中飞人" (flying trapeze); for 1113, "拥军优属" ((of civilians) support the army and give preferential treatment to families of revolution army men and martyrs); and for 1114, "吃穿戴" (eat, drink and dress) and "天刚刚亮" (day break just); .....; for 4441, "大事大非" (matters of principle) and "数目最多" (number at most); for 4442, "治病救人" (cure the sickness to save patient) and "自顾不暇" (be busy enough with one's own affairs); for 4443, "世界市场" (world market) and "渐渐变冷" (its getting colder and colder); for 4444, "上上下下" (all members) and "供地" (supply to any place). There were altogether 512 quadrisyllabic words and phrases used in this experiment. The test-words and phrases were embedded in the carrier sentence 我说××××四字词 (I say ×××× quadrisyllabic word). They were individually written on 4 (cm) × 3 (cm) cards using Chinese characters. They were presented in random order. They were uttered by one native male speaker (phonetician) and recorded by high-quality tape recorder.

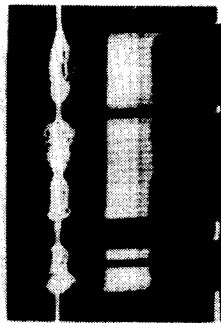
The F<sub>0</sub> curves were extracted from all these words and phrases by means of pitch indicator (Lin, 1964). Figure 1 gives the F<sub>0</sub> curves of 256 quadrisyllabic words or phrases, that have different combination of the tones, and their waves.

Besides the tone-section, an onset-curving section, or an offset-curving section appears probably on the F<sub>0</sub> curve in a syllable. Figure 2 gives the F<sub>0</sub> curves of the quadrisyllabic word "自顾不暇" and their sections. In Figure 2, part "2" is the tone-section, part "1" is the onset-curving section, and part "3" is the offset-curving section. The onset-curving section and the offset-curving section are caused by the inertia of the vocal-cord, but the tone-section carries the information about the distinctive feature of the four tones.

This experiment determined not only the F<sub>0</sub> values of the starting point, the ending-point, and the turning-point (if there is) of the tone-section in each syllable, but also the F<sub>0</sub> values of the start-point of the onset-curving section, and that of the ending-point of the offset-curving section. If the initial consonant in the second, third or fourth syllable is voiceless, the F<sub>0</sub> values of these points can be independently determined in Figure 1. But, if the initial in the second, third or fourth syllable is voiced or zero, a glide-section has to be spanned across the tone-sections of adjacent syllables. For example, Figure 3 shows the glide-section of F<sub>0</sub> between "浪" and "漫", and that between "主" and "义", this is because the initial of "漫" is a voiced consonant, and the initial of "义" is zero. In Figure 3, the glide-section is represented by part "4". In the experiment, the F<sub>0</sub> values of the ending-point in the tone-section of "浪" or "主" was determined to be equal, respectively, to that of the ending-point in the tone-section of "到" or "表", because both "浪" and "到" were all in the first syllable and had the same tone-4, and both "主" and "表" all were in the third syllable and had the same tone-3. And the F<sub>0</sub> value of the starting point in the tone-section of "漫" or "义" to



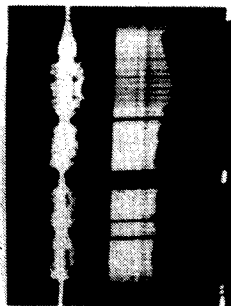
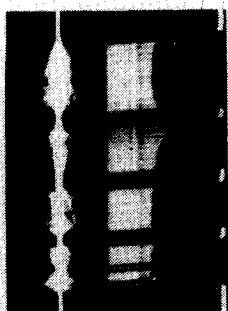
今天开张



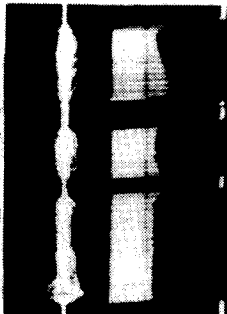
当清活工



中篇小说



空中飞人



丰衣足食



三纲五常

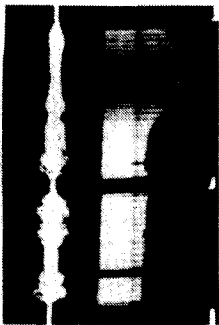


图 1.1 分清是非

青红皂白

千军万马

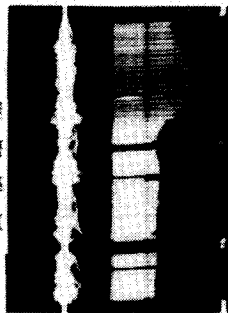
天天向上



参加婚礼



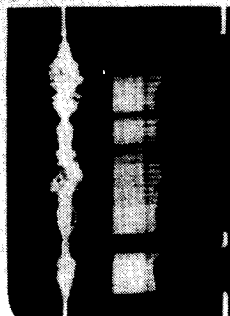
归根结底



三三两两



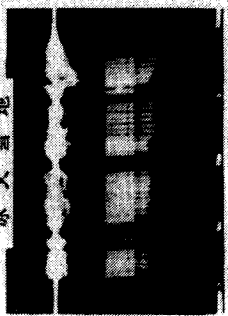
吃肥穿瘦



伊斯兰教



冰天雪地



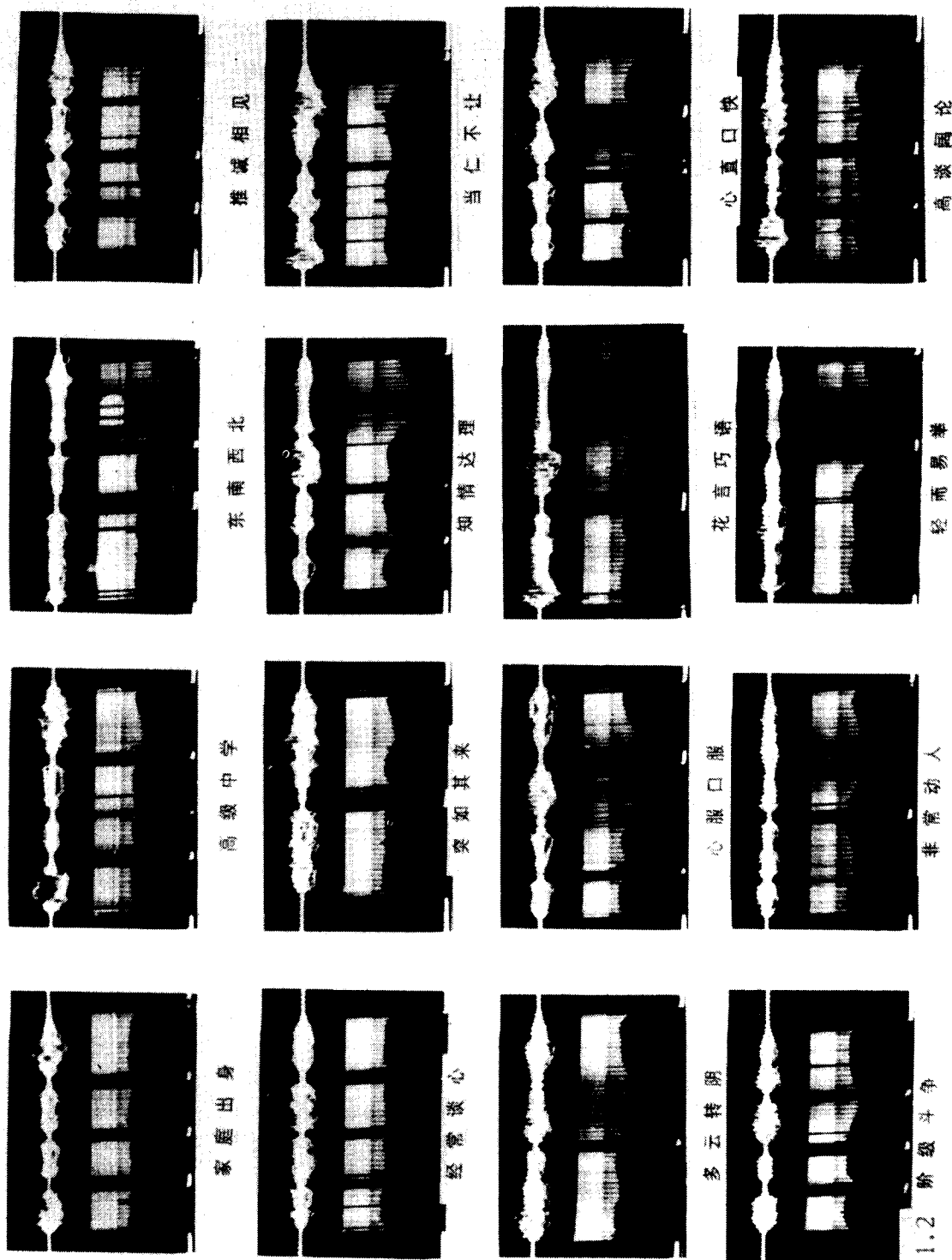
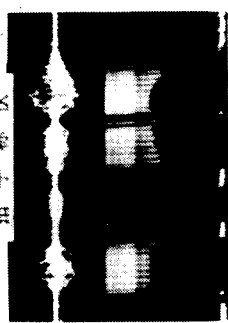


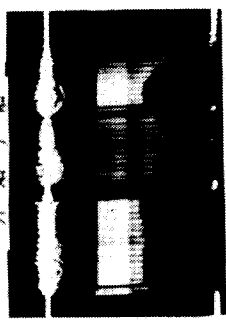
图 1.2 阶级斗争



拍手称快



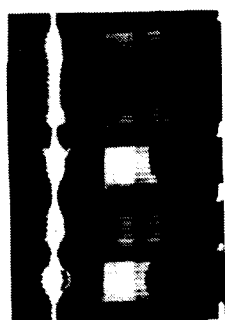
开始学话



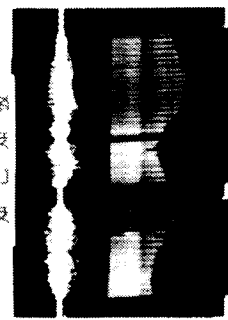
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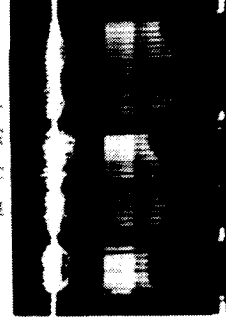
基本建设



知己知彼



私有财产



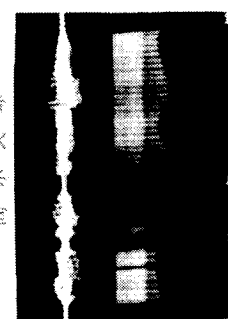
抽水马桶



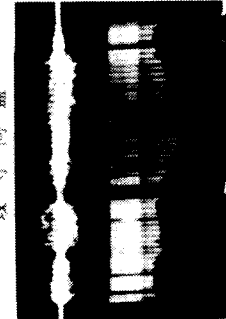
生老病死



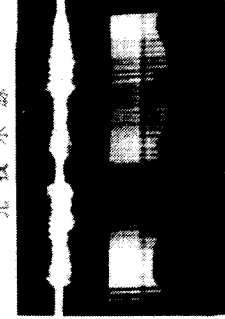
高尔夫球



攻守同盟



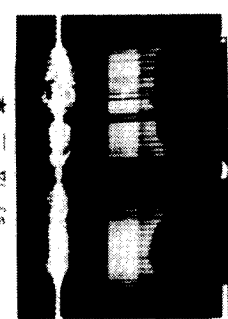
先找水源



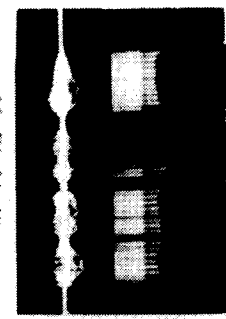
充耳不闻



约法三章



阴雨成灾



他很省心

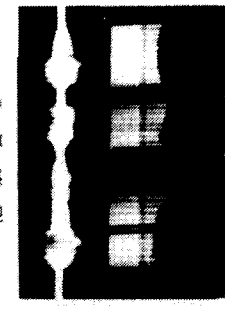


图 1.3 先礼后兵

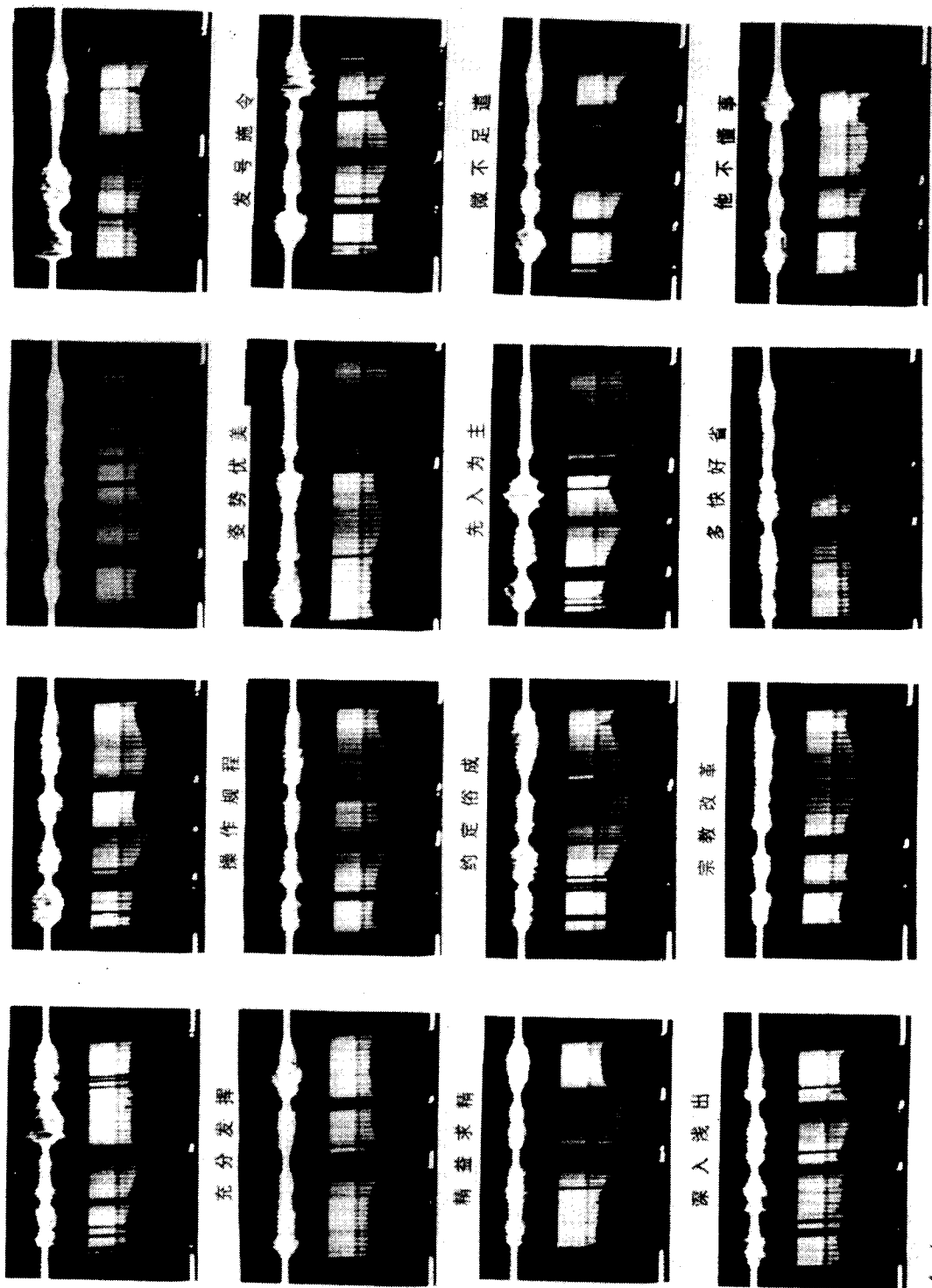
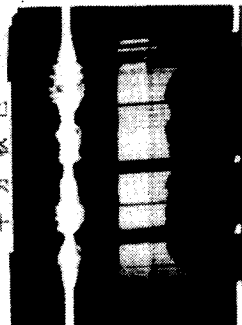


图 1.4 甘拜下风

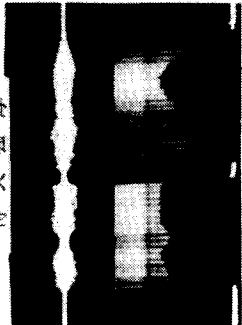




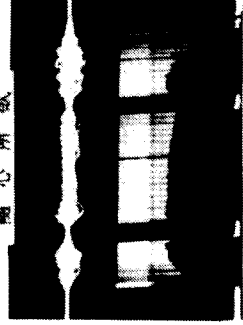
平分秋色



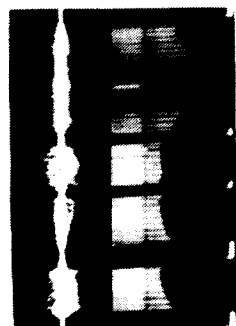
得天独厚



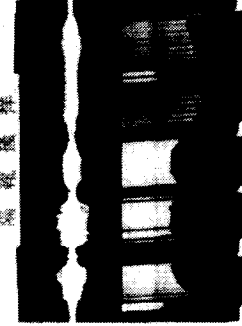
随心所欲



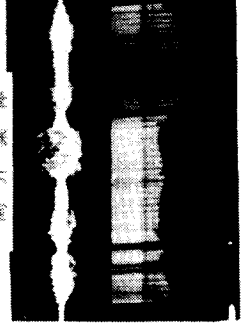
眉清目秀



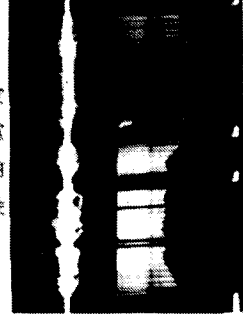
隔梁隔痒



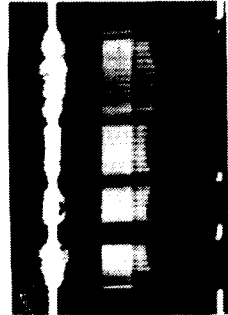
离开集体



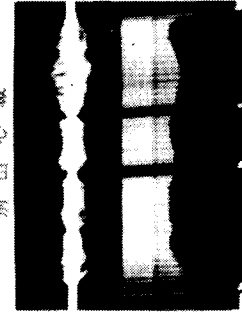
排山倒海



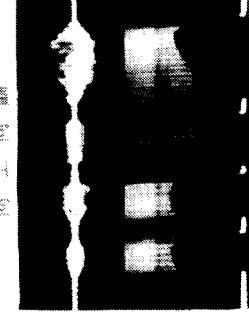
城乡市场



别出心裁



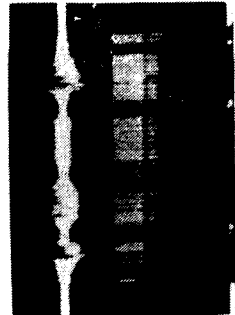
同工同酬



十七孔桥



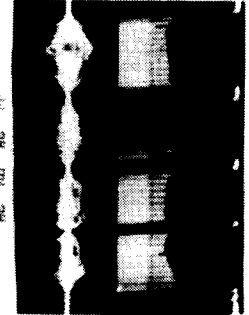
人身自由



国家机关



能屈能伸



长篇小说

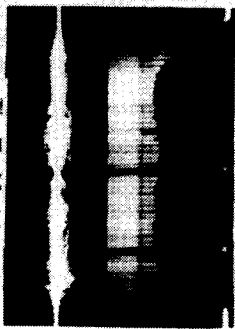


梅花盛开

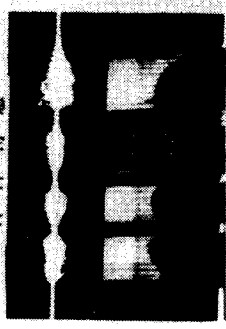
图 1.5



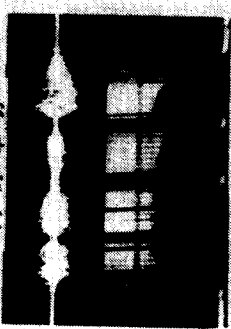
人民公社



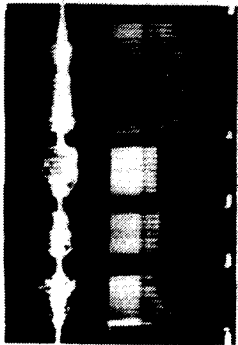
洋洋得意



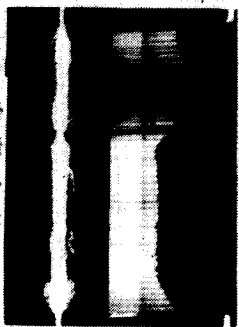
同时举办



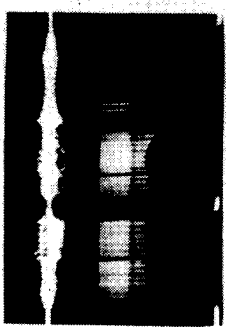
头头是道



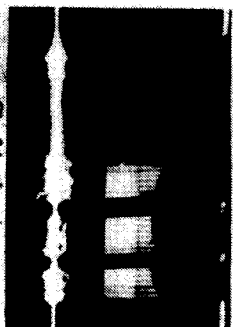
磨拳擦掌



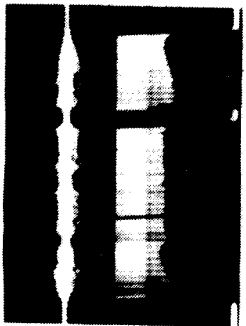
人民民主



十全九美



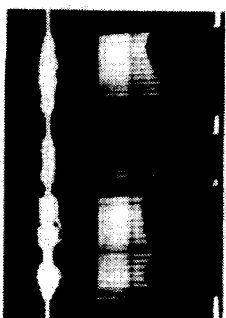
肥头大耳



民族英雄



活鱼食堂



执行主席



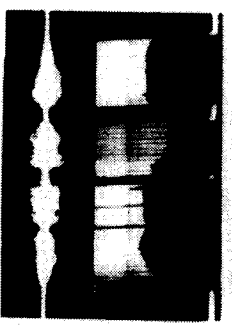
情投意合



捷足先登



同流合污



明哲保身

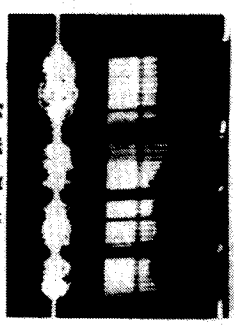
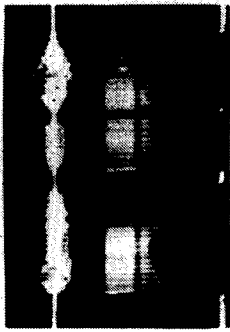
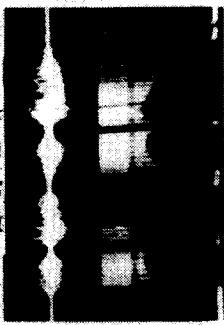


图 1.6 圆头再说



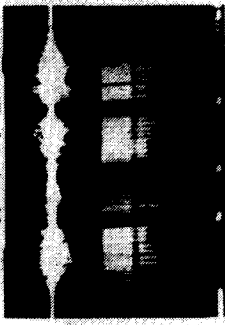
田野工作



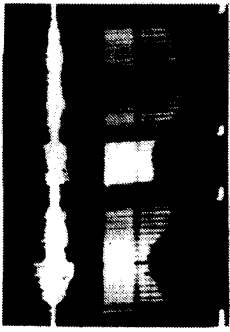
急转直下



没有武器



原始社会



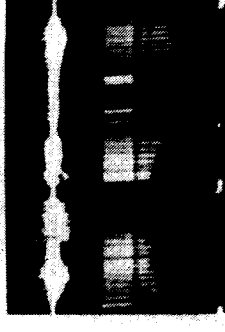
合理生产



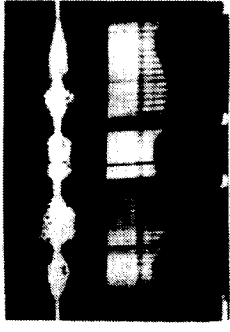
毛手毛脚



评选五好



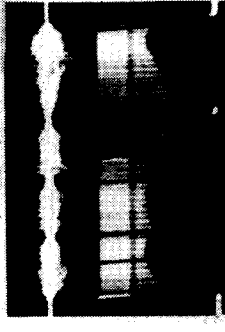
裁马粪纸



无法生存



十五年前



民主改革



无可奈何



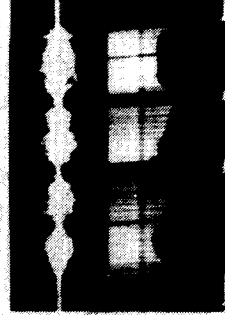
食品公司



集体农庄

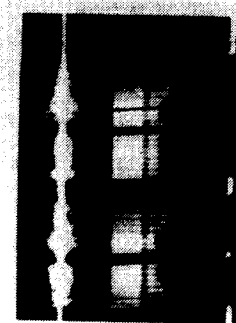


徒手操

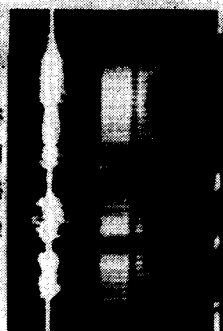


无轨电车

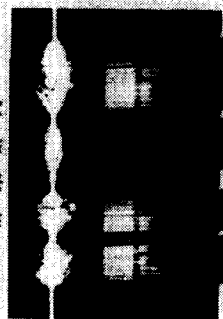
图 1.7. 无轨电车



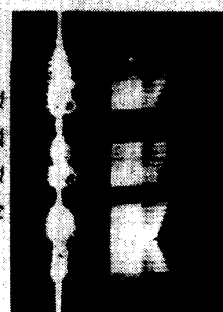
形象生动



群策群力



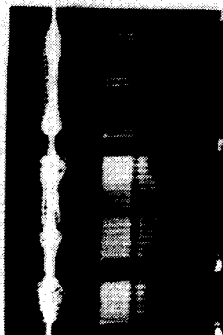
得过且过



量力政策



隔岸观火



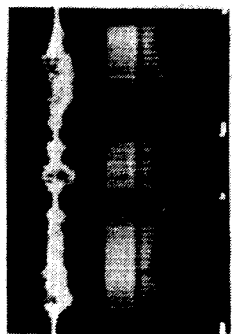
熟视无睹



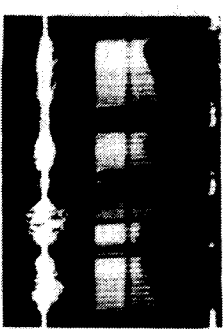
劳动保障



得寸进尺



来日方长



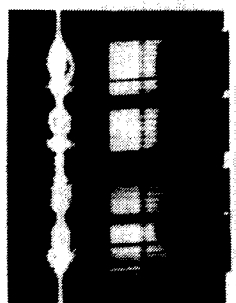
言过其实



文字改革



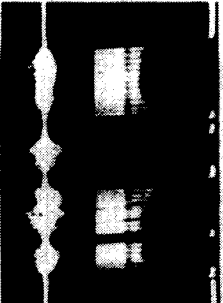
仁义道德



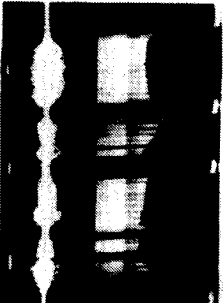
人地生疏



无牵无挂

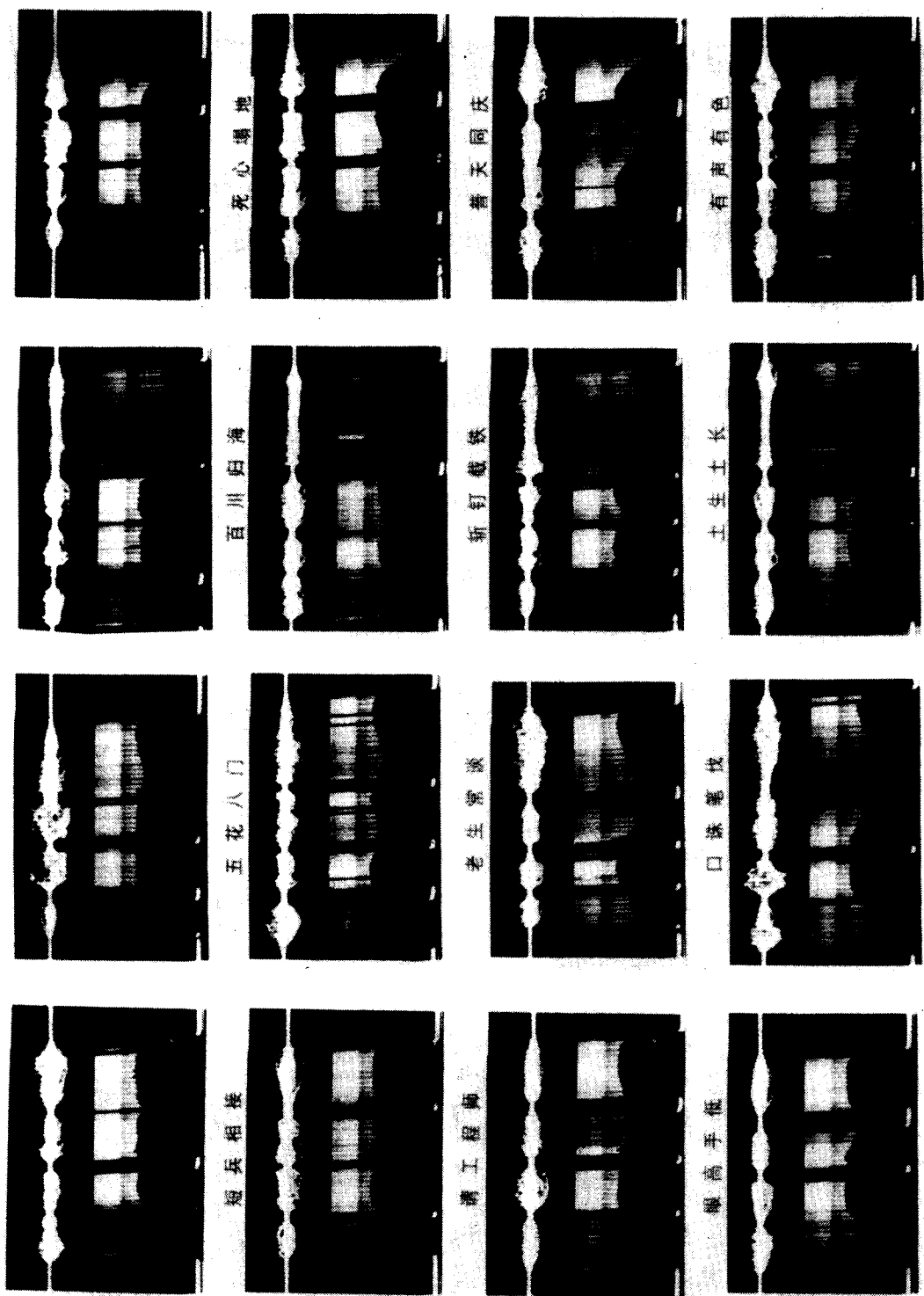


奇货可居



人定胜天

图 1.8

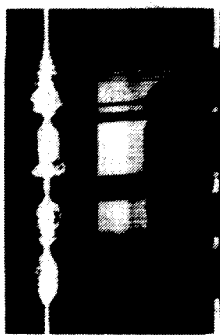


雪中送炭

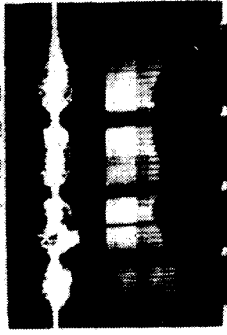
引经据典

广播电台

图 1.9 假公济私



举足轻重



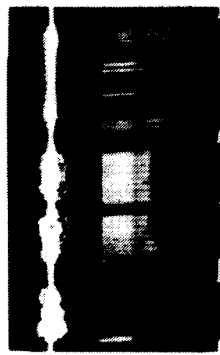
油然而生



走来走去



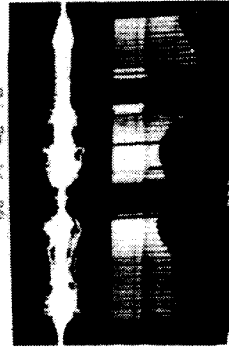
理直气壮



反求诸己



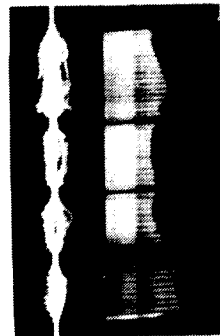
虎头蛇尾



忍无可忍



手无寸铁



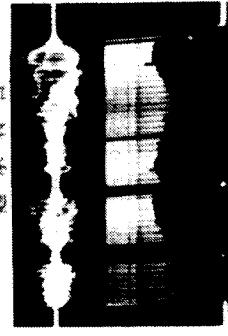
以毒攻毒



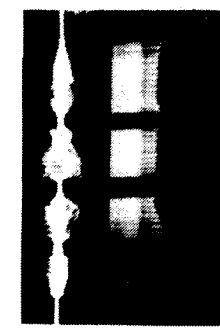
以讹传讹



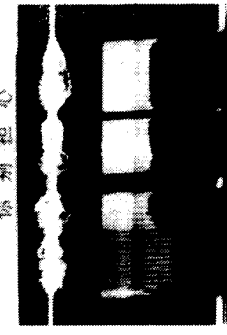
起承转合



百折不挠



你别担心



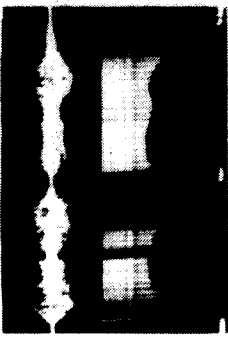
感觉神经



比学赶帮



正形外利



短小精悍



五体投地



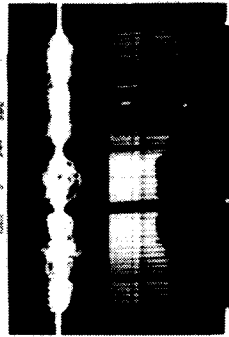
草草了事



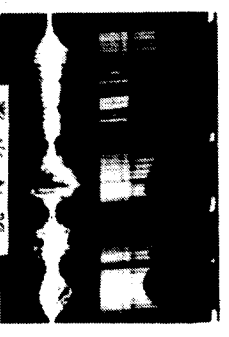
指示思想



胆小如鼠



洗冷水澡



打日清浩



勇往直前



好久以前



有口皆碑



水涨船高



甲乙丙丁

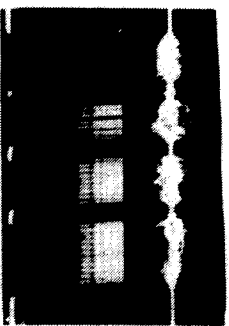


首脑会议

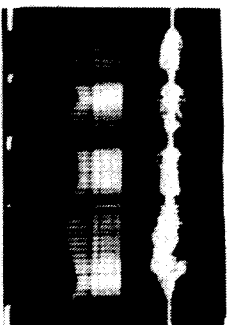
指手画脚

挥手告别

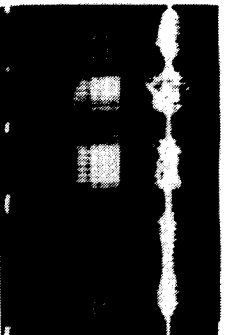
图 1.11 老解放区



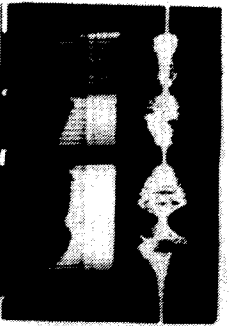
海阔天空



注重心长



雨后春笋



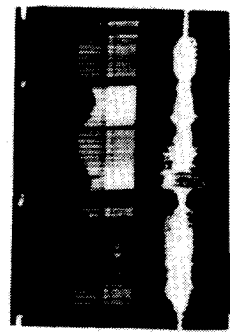
等价交换



百炼成钢



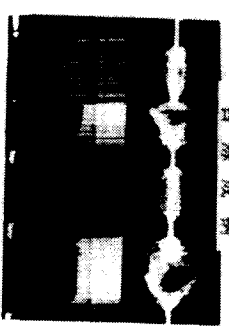
喜气洋洋



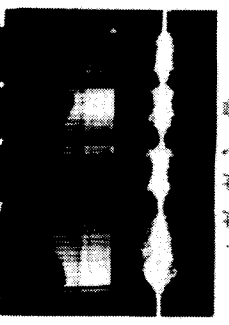
体育行法



体力劳动



统购统销



土地改革



有立体感



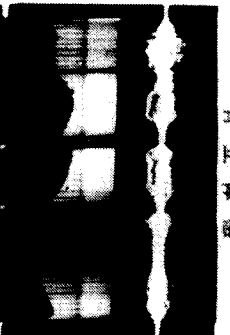
宇宙火箭



图 1.12 水泄不通



我去看牙

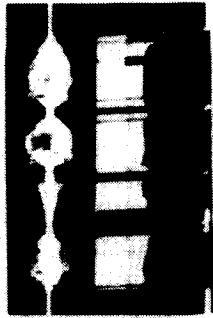


有目共睹



简化汉字





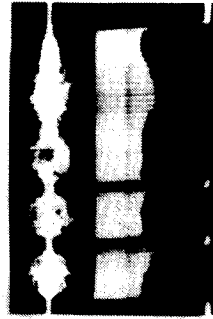
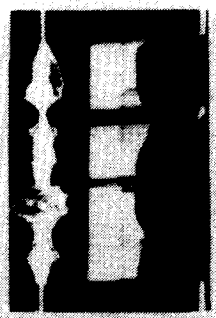
乱七八糟



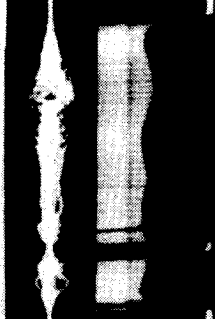
道听途说



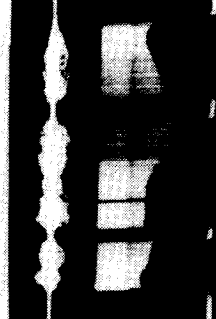
这人很高



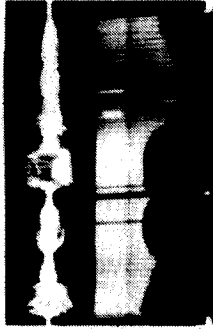
借刀杀人



目中无人



正三角形



半斤八两



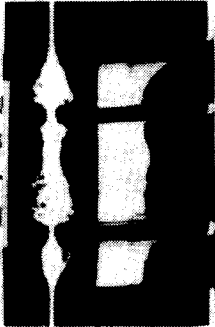
厚今薄古



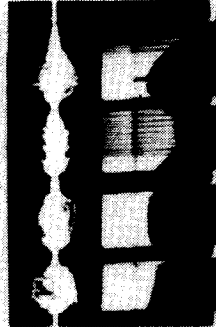
现金管理



上呼下道



至高无上



大街小巷

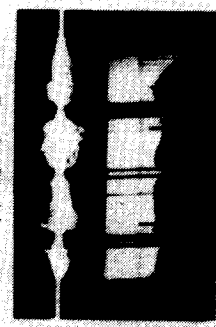
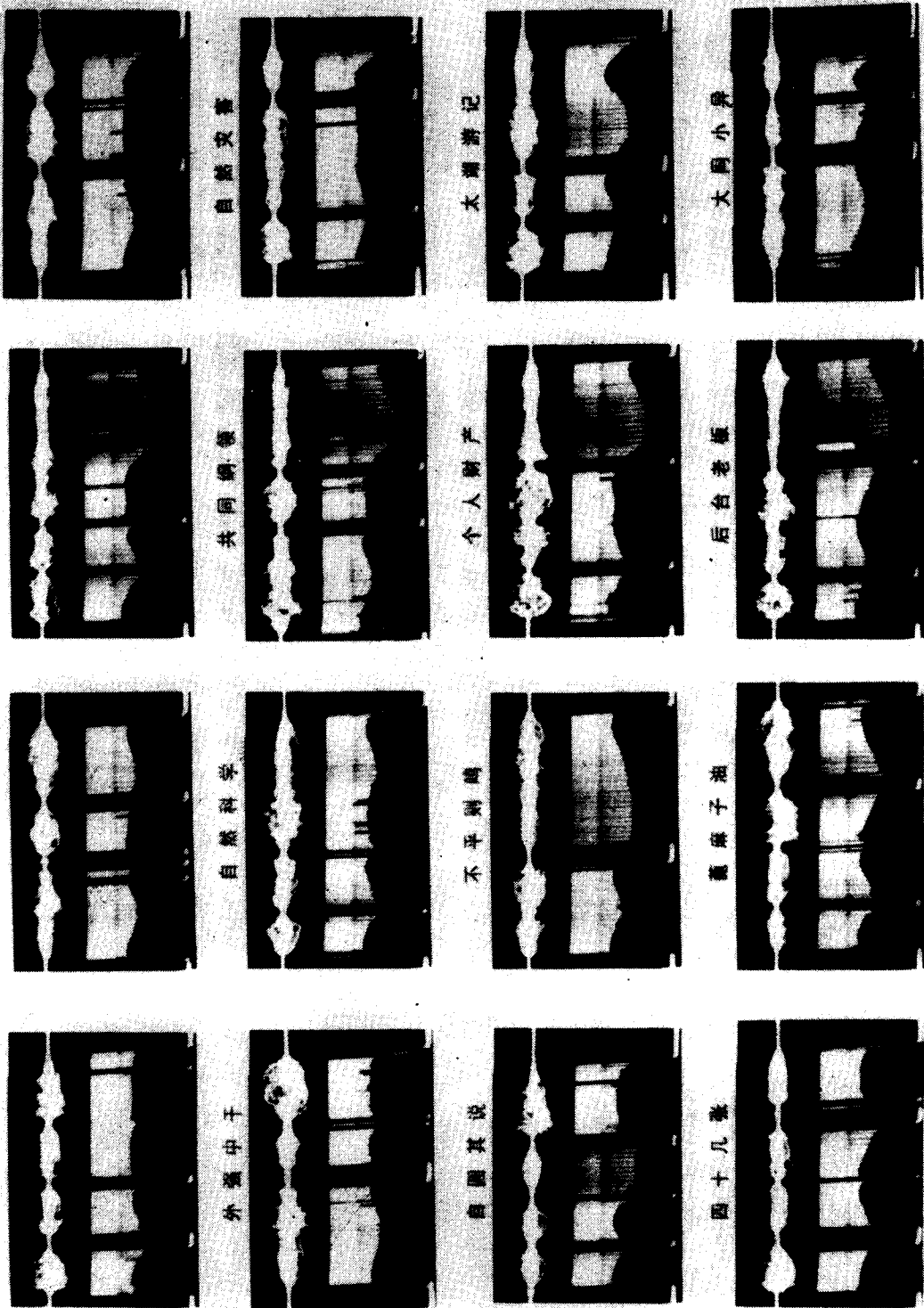


图 1.13 一窝蜜蜂

力争上游

大刀阔斧

负担过重

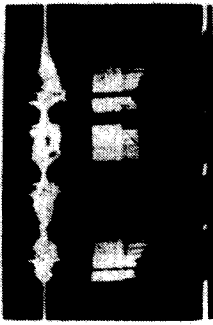


一年四季

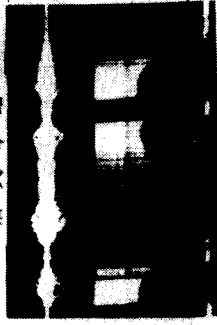
破铜烂铁

志同道合

图 1.14 大行政区



旧火车站



不可一世



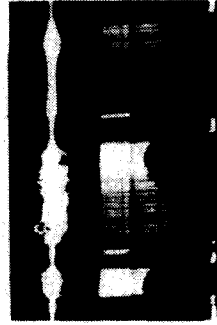
坐冷板凳



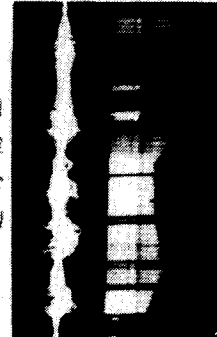
自我介绍



副总经理



适可而止



看展览馆



立体电影



色彩鲜明



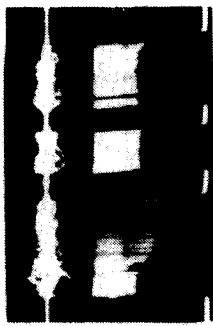
大海茫茫



趁火打劫



寸草不留



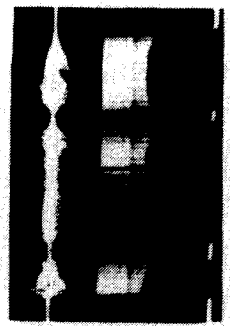
各有千秋



妙手回春

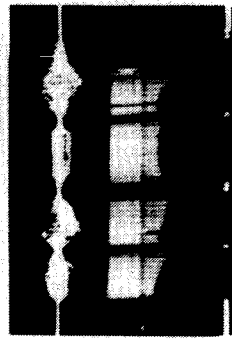


自讨苦吃



自作孽者

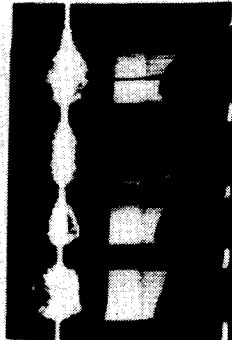
图 1.15



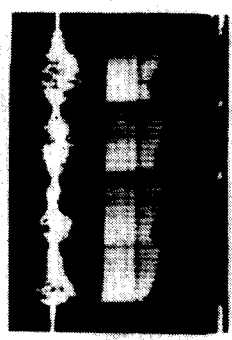
地下工作



念念不忘



到处表现



上上下下



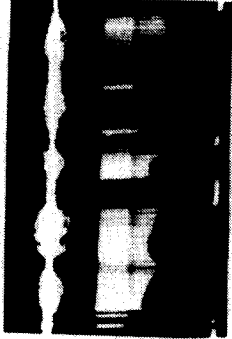
固定资本



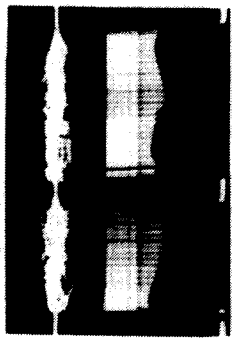
自备游艇



气候转暖



世界市场



富裕中农



越过墙头



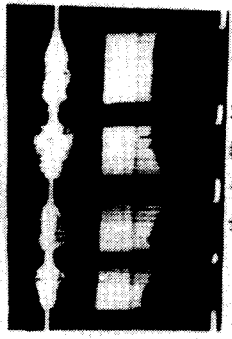
蟹钱海棠



治病救人



半夜三更



技术革新



目瞪口呆



图 1.16 大事大非

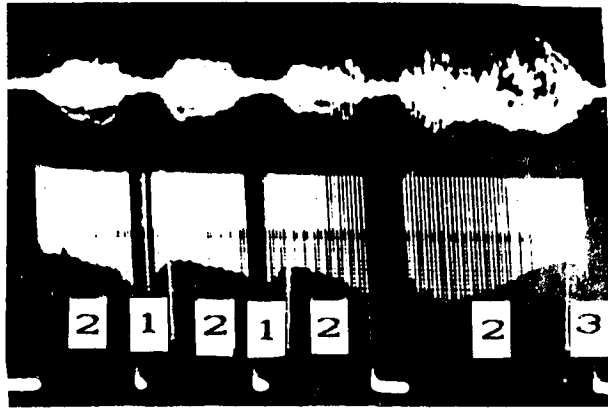


Figure 2 The tone-section ("2") on F0 curve of each syllable in "自顾不暇", and the onset-curving section ("1") and the offset-curving section ("3") (lower part). And the speech waves (upper part).

图 2 "自顾不暇"各音节里的调型段("2")及弯头段("1")和降尾段("3")(下部),和它们的波形(上部)

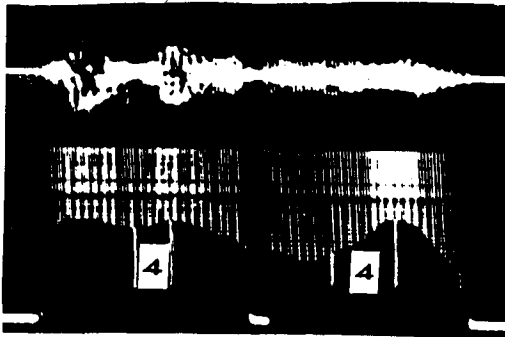


Figure 3 The glide-section ("4") on the F0 curve in "浪漫主义" (left), no glide-section on the F0 curve in "到处表现" (right)

图 3 "浪漫主义"中"浪"跟"漫"和"主"跟"义"之间的 F0 过渡段("4")(左边),而在"到处表现"中无这种过渡段

qual , respectively , to that of the start-point in the tone-section of "处" or "现" , because both "漫" and "处" all were in the second syllable and had the same tone-4 , and both "义" and "现" were all in the fourth syllable and had the same tone-4 . When a glide-section of F0 was spanned across the tone-sections in the adjacent syllables , the measurment of F0 value of the ending-point in the tone-section of the former syllable and that of the starting point in the tone-section of the latter one had to be done on the basis of the rules that had been used in the example above.

Tow-dimension analysis of variance was performed to examine that whether or not the preceding and following tones had exerted coarticulatory effects on a given tone . When the effects were significant at a given level , one-tailed t-test was done to estimate the extent with which the preceding or following tone had exerted carryover or anticipatory effect on the given tone. In addition , one-dimension analysis of variance was used to observe that whether or not the coarticulatory effect had extended beyond adjacent tones.

### 3. RESULTS

Figure 4 shows the mean F0 values at the overall shape of each tone under the coarticulatory effect of the preceding tones or the following tones. In order to illustrate clearly the variation in F0 height , the range for the ordinate is not constant across tones . The time is normalized . It can be seen from Figure 4 that coarticulation indeed present in the production of the tones , because each tone may have more than one F0 curves in context, which are dispersed clearly at their beginning or ending, and that the extent with which the starting point in the onset-curving section , or the ending-point in the offset-curving section is coarticulated by the preceding or following tones is nearly same to the extent with which the starting point , or the ending-point in the tone-section is done by the context . It is more important that the tone-section carries the information about the distinguish feature of the four tones , and the onset-curving section and offset-curving section can not be perceived by native speaker . The perceptual experiment indicated that the difference limen for frequency ( $\Delta F$ ) for the onset-curving section is 64 Hz when its duration ( $\Delta T$ ) is 50 ms , and  $\Delta F$  for the offset-curving section is 59 Hz when  $\Delta T$  is 50 ms , and the relation between  $\Delta F$  and  $\Delta T$  is suppletionive (Yang, 1989). So, Table 1 shows the result of two-dimension analysis of variance only on the tone-section .

It may be seen from Table 1 that the effects of the preceding tones on the starting point of tone-1, tone-2, and tone-3 in the second , third and fourth syllable , and on the ending-point of tone-1 in the second one , and on the turning point of tone-3 in the second and fourth one are significant at 0. 001 level , but the effects of the following tones on the ending pointp of tone-1 , tone-2 and tone-3 are not significant at 0. 001 level. And the effects of the following tones on the ending-point of tone-4 are significant , but that of the preceding tones on the start—point of tone-4 are not significant at 0. 001 level. It must be mentioned here that after sandhi , the tone-3 before another tone-3 firstly becomes a mid rising tone or a mid fall—rising tone, then this kind of the mid rising tone or the mid falling—rising tone is affected like the inherent tone-2 by the preceding tones . This indicates that the tonal coarticulatory effects are unidirectional.

It can be also seen from Table 1 that the effects of the preceding tones on the start—points of tone-1 , tone-2 , and tone-3 in the second , third and fotrth syllable , and on the turning—point of tone-3 in the second

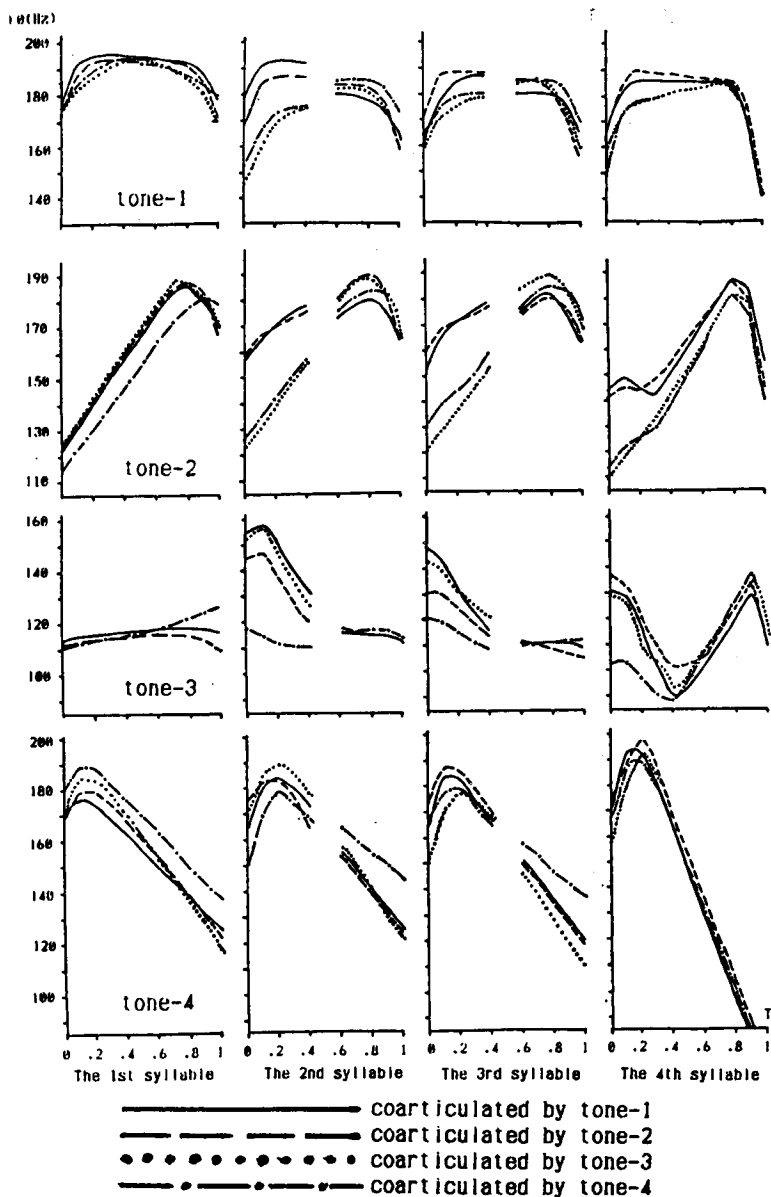
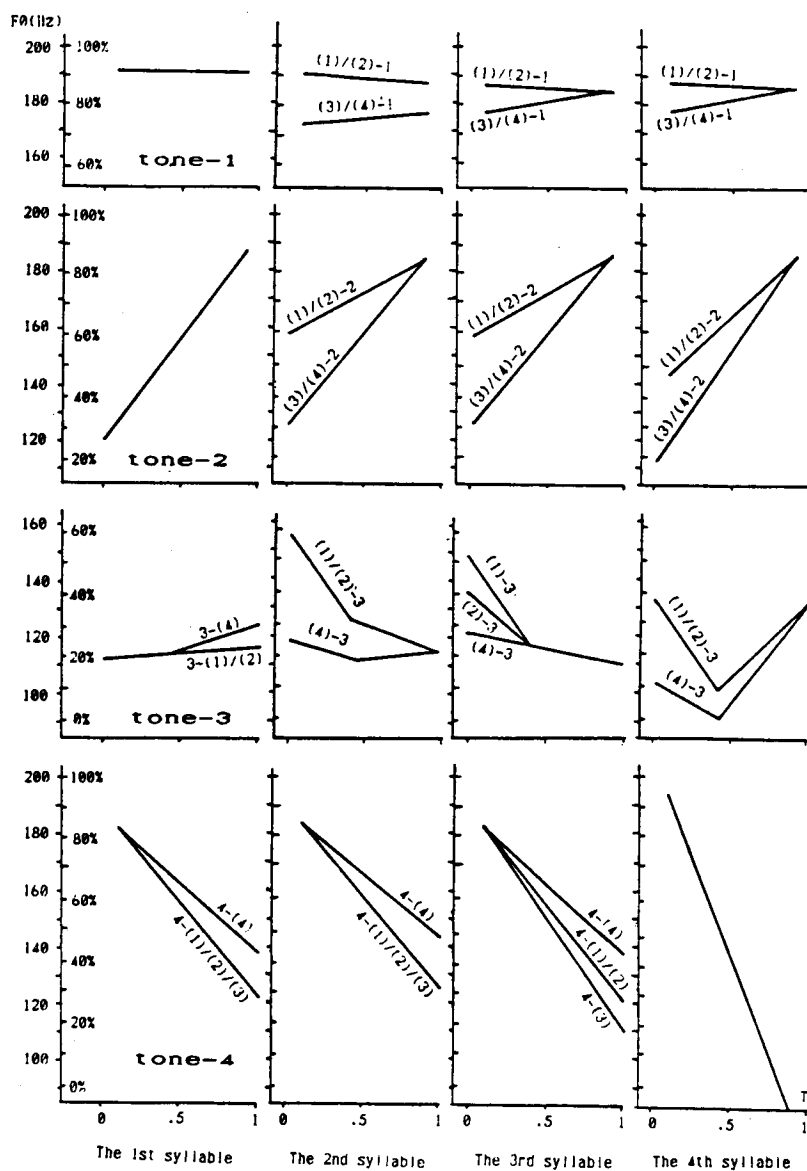


Fig.4 Mean values of F0 for the four tones . The former half of the F0 contour in the 2nd, or 3rd syllable , or the whole F0 contour in the fourth syllable shows the carryover effect from preceding tones. The whole F0 contour in the 1st syllable , or the latter half of the F0 contour in the 2nd , or 3rd syllable shows the anticipatory effect from following tones.

图 4. 四声 F0 的平均值. 第二及第三音节的前半部 F0 曲线和第四音节的 F0 曲线表明各受前面四声的顺向作用; 第一音节的 F0 曲线及第二和第三音节的后半部 F0 曲线表明各受后面声调的逆向作用



1: tone-1 2: tone-2 3: tone-3 4: tone-4  
 (1)/(2): tone-1 or tone-2  
 (m)-n: n is affected with a carryover coarticulation of the preceding m; n-(m): n is affected with an anticipatory coarticulation of the following m

Fig.5 Coarticulatory patterns on the tone-section for adjacent syllables

图 5 相邻声调的调型段协同发音模式



Table 1. Results of two-dimension analysis of variance on the significance of the coarticulatory effect that the tone-section is affected by the adjacent tones  
 表 1. 各音节调型段受到的相邻音节四声的协同发音作用, 二维方差分析的显著性结果

		the 1st syllable	the 2nd syllable	the 3rd syllable	the 4th syllable	
tone-1	start-point		F(3,71)=21.573 p<0.001	F(3,83)=6.683 p<0.001	F(3,85)=9.169 p<0.001	carryover
		F(3,57)=1.563 p>0.001	F(3,71)=1.465 p>0.001	F(3,83)=0.715 p>0.001		anticipatory
	ending-point		F(3,62)=11.781 p<0.001	F(3,83)=2.400 p>0.001	F(3,85)=0.040 p>0.001	carryover
		F(3,57)=1.241 p>0.001	F(3,62)=4.652 p>0.001	F(3,83)=1.498 p>0.001		anticipatory
tone-2	start-point		F(3,49)=44.093 p<0.001	F(3,44)=29.638 p<0.001	F(3,57)=36.855 p<0.001	carryover
		F(3,59)=2.752 p>0.001	F(3,49)=2.738 p>0.001	F(3,44)=1.272 p>0.001		anticipatory
	ending-point		F(3,49)=4.243 p>0.001	F(3,44)=1.405 p>0.001	F(3,57)=1.514 p>0.001	carryover
		F(3,59)=0.738 p>0.001	F(3,49)=2.468 p>0.001	F(3,44)=1.698 p>0.001		anticipatory
tone-3	start-point		F(3,43)=17.785 p<0.001	F(3,53)=11.527 p<0.001	F(3,56)=19.897 p<0.001	carryover
		F(2,48)=0.799 p>0.001	F(2,43)=1.976 p>0.001	F(2,53)=0.030 p>0.001		anticipatory
	turning-point		F(3,37)=8.751 p<0.001	F(3,53)=4.001 p>0.001	F(3,56)=7.450 p<0.001	carryover
		F(2,48)=0.962 p>0.001	F(2,37)=0.369 p>0.001	F(2,53)=1.340 p>0.001		anticipatory
	ending-point		F(3,37)=4.479 p>0.001	F(3,47)=1.547 p>0.001	F(3,56)=2.250 p>0.001	carryover
		F(2,48)=12.295 p<0.001	F(2,37)=0.966 p>0.001	F(2,47)=2.825 p>0.001		anticipatory
tone-4	start-point		F(3,44)=2.891 p>0.001	F(3,57)=1.464 p>0.001	F(3,67)=0.784 p>0.001	carryover
		F(3,51)=2.646 p>0.001	F(3,44)=2.131 p>0.001	F(3,57)=0.604 p>0.001		anticipatory
	ending-point		F(3,44)=1.302 p>0.001	F(3,57)=2.684 p>0.001	F(3,67)=2.199 p>0.001	carryover
		F(3,51)=7.225 p<0.001	F(3,44)=16.174 p<0.001	F(3,57)=27.154 p<0.001		anticipatory

Table 2. Result about the analysis of variance on the significance of the cross-tone carryover effect that the start-point of the tone-section in the third syllable is affected by the four tones in the first syllable  
 表 2. 第三音节调型段起点受到第一音节四声的顺向协同发音作用, 方差分析的显著性结果

		condition			
		the 2nd syllable as tone-1	the 2nd syllable as tone-2	the 2nd syllable as tone-3	the 2nd syllable as tone-4
The 3rd syllable	tone-1	F(3,23)=6.022 p<0.05	F(3,14)=1.102 p>0.05	F(3,20)=2.099 p>0.05	F(3,16)=1.602 p>0.05
	tone-2	F(3,11)=1.435 p>0.05	F(3,6)=1.083 p>0.05	F(3,9)=1.168 p>0.05	F(3,6)=3.218 p>0.05
	tone-3	F(3,10)=0.808 p>0.05	F(3,8)=0.406 p>0.05	F(2,6)=2.729 p>0.05	F(3,8)=0.570 p>0.05
	tone-4	F(3,16)=3.742 p<0.05	F(3,13)=3.409 p<0.05	F(3,8)=5.645 p<0.05	F(3,14)=0.143 p>0.05

Table 3. Results about the analysis of variance on the significance of the cross-tone carryover effect that the start-point of the tone-section in the fourth syllable is affected by the four tones in the second syllable  
 表 3. 第四音节调型段起点受到第二音节四声的顺向协同发音作用, 方差分析的显著性结果

		condition			
		the 3rdsyllable as tone-1	the 3rd syllable as tone-2	the 3rd syllable as tone-3	the 3rd syllable as tone-4
The 4th syllable	tone-1	F(3,23)=1.291 p>0.05	F(3,12)=1.554 p>0.05	F(3,19)=1.352 p>0.05	F(3,19)=1.762 p>0.05
	tone-2	F(3,15)=1.598 p>0.05	F(3,11)=0.865 p>0.05	F(3,13)=1.343 p>0.05	F(3,6)=0.293 p>0.05
	tone-3	F(3,15)=1.275 p>0.05	F(3,9)=1.611 p>0.05		F(3,11)=0.279 p>0.05
	tone-4	F(3,21)=2.599 p>0.05	F(3,7)=0.516 p>0.05	F(3,15)=0.862 p>0.05	F(3,12)=0.318 p>0.05

Table 4. Results about the analysis of variance on the significance of the cross-tone anticipatory effect that the ending-point of the tone-section in the first syllable is affected by the four tones in the third syllable  
 表 4. 第一音节调型段终点受到第三音节四声的逆向协同发音作用, 方差分析的显著性结果

		condition			
		the 2nd syllable as tone-1	the 2nd syllable as tone-2	the 2nd syllable as tone-3	the 2nd syllable as tone-4
The 1st syllable	tone-1	F(3,12)=0.435 p>0.05	F(3,13)=2.003 p>0.05	F(2,9)=6.785 p<0.05	F(3,12)=2.164 p>0.05
	tone-2	F(3,19)=1.472 p>0.05	F(3,11)=0.071 p>0.05	F(2,8)=0.208 p>0.05	F(3,11)=1.360 p>0.05
	tone-3	F(3,19)=2.236 p>0.05	F(3,10)=0.911 p>0.05	F(2,10)=0.028 p>0.05	F(3,10)=0.226 p>0.05
	tone-4	F(3,12)=1.195 p>0.05	F(3,7)=2.816 p>0.05	F(2,10)=0.939 p>0.05	F(3,11)=0.384 p>0.05

Table 5. Results about the analysis of variance on the significance of the cross-tone anticipatory effect that the ending-point of the tone-section in the second syllable is affected by the four tones in the fourth syllable  
 表 5. 第二音节调型段终点受到第四音节四声的逆向协同发音作用, 方差分析的显著性结果

		condition			
		the 3rd syllable as tone-1	the 3rd syllable as tone-2	the 3rd syllable as tone-3	the 3rd syllable as tone-4
The 2nd syllable	tone-1	F(3,13)=1.751 p>0.05	F(3,10)=1.496 p>0.05	F(2,9)=0.254 p>0.05	F(3,12)=1.126 p>0.05
	tone-2	F(3,20)=0.262 p>0.05	F(3,8)=0.523 p>0.05	F(2,16)=0.407 p>0.05	F(3,10)=0.669 p>0.05
	tone-3	F(3,18)=0.875 p>0.05	F(3,15)=2.865 p>0.05	F(2,7)=4.315 p>0.05	F(3,11)=0.708 p>0.05
	tone-4	F(3,23)=0.725 p>0.05	F(3,6)=0.423 p>0.05	F(2,13)=0.444 p>0.05	F(3,15)=1.762 p>0.05

and fourth syllable are significant , but that on their ending—points are not significant at 0. 001 level , except for that the effect of the preceding tones on the ending—point of tone-1 in the second syllable is significant . And the effects of the following tones on the ending—points of tone-4 are significant , but that on the start—points of tone-4 are not significant at 0. 001 level . This indicated that the carryover effects affect only the start—point, but do not extend to the ending—point of tone-section and the anticipatory effects affect only the ending—point, but do not extend to the start—point of tone-section.

Figure 5 shows the results of one—tailed t—test on the coarticulatory effects at the significant level  $p=0.05$  . It can be seen from Figure 5 that the start—point of tone-1 and tone-2 in the second , third and fourth syllable, and the ending—point of tone-1 in the second one when following tone-3 and tone-4 is lower than that when following tone-1 and tone-2. The start—point and some turning—point of tone-3 in the second , third and fourth syllable when following tone-1 and tone-2 is higher than that when following tone-4; the ending—point of tone-4 in the first, second and third syllable when preceding tone-4 is higher than that when preceding tone-1, tone-2 and/or tone-3; the ending—point of tone-3 in the first syllable when preceding tone-4 is higher than that when preceding tone-1 and tone-2 . start—point of tone-1 is lowered in average of 13 Hz by the low ending—point of the preceding tone-3 and tone-4 ; start—point of tone-2 is lowered in average of 32 Hz by the low ending—point of the preceding tone-3 and tone-4; ending—point of tone-4 is raised in average of 20 Hz by the high start—point of the following tone-4 ; start—point of tone-3 is raised in average of 27 Hz by the high start—point of the preceding tone-1 , 23 Hz by that of the preceding tone-2 ; the ending—point of tone-3 is raised in average of 9 Hz by the high start—point of the following tone-4.

The start—point in the tone-section of tone-2 is coarticulated by the preceding tones , but its ending—point is not done by the following tones, therefore, the phonetic feature of tone-2 — —mid rising— — is maintained. For tone-4 , only its ending—point is coarticulated by the following tones, but its start—point is not done by the preceding tones , its phonetic feature — —high falling— — is preserved . Dispite the fact that the start—point , or the ending—point of tone-3 is coarticulated by the preceding tones, or by the following tones , its phonetic feature — — low — — is kept . It can be seen from Figure 5 that for tone-1 , two kinds of F0 contours have appeared by the coarticulatory effect, one is slight falling , the other is slight rising . The maximum of the rise for tone-1 is only 8 Hz , that is much more smaller than the minimum (27 Hz) of the rise for tone-2 ; the maximum of the fall for tone-1 is only 3Hz , that is much more smaller than the minimum(40 Hz) of the fall for tone-4 . It is much more important that even though the F0 contour has slight falling or slight rising , it is perceived as tone-1 by the native speaker . Although the start—point , or ending—point in the tone-section of the four tones is affected by the coarticulatory effect , each tonal identity is maintained .

This experiment observed the cross—tone coarticulatory effect. Table 2 shows that the carryover effects of the four tones in the first syllable on the start—point of each tone in the third syllable under the second syllable respectively as tone-1 , tone-2 , tone-3 or tone-4 are not significant at 0. 05 level , except for that on the start—point of tone-1 in the third syllable under the second syllable as tone-1 , and that on the start—point of tone-4 in the third syllable under the second syllable as tone-1 , tone-2 or tone-3 , which are significant at 0. 05 level . Table 3 shows that the carryover effect of the four tones in the second syllable on the start—point of each tone in the fourth syllable under the third syllable as tone-1 , tone-2 , tone-3 , or tone-4 are all not sig-

nificant at 0.05 level. Table 4 shows that the anticipatory effects of the four tones in the third syllable on the ending—point of each tone in the first syllable under the second one as any given tone are not significant, except for that on the ending—point of tone-1 in the first syllable under the second syllable as tone-3, which is significant at 0.05 level. Table 5 shows that the anticipatory effects of the four tones in the fourth syllable on the ending—point of each tone in the second syllable under the third syllable as any given tone are not significant at 0.05 level. It may be obtained from above—mentioned result that when the significant level is 0.05, coarticulatory effects in general do not extend beyond adjacent tones.

As it has been demonstrated above that tonal coarticulation does not extend beyond adjacent syllables, tonal coarticulatory effect is unidirectional and tonal coarticulation affects either start—point or ending—point of tone-section, therefore, the extent with which the start—point of the tone-section in tone-1, tone-2 and tone-3 is affected by the carryover effect can be predicted by the height of the ending—point in the preceding tones, and the extent with which the ending—point of the tone-section in tone-4 is affected by the anticipatory effect can be predicted by the height of the start—point in the following tone. This experiment preliminarily found out the tonal coarticulatory pattern in the quadrisyllabic words and phrases of Mandarin.

#### 4. CONCLUSION AND DISCUSSION

The results of this experiment on tonal coarticulation in Mandarin are summarized as follows:

(1) Tonal coarticulation only exerts on two adjacent tones, that is, coarticulatory effect does not extend across tones.

(2) Tonal coarticulatory effects are unidirectional, that is, Mandarin tones are affected by either the carryover coarticulatory effect or by the anticipatory coarticulatory effect. The carryover coarticulation affects only the start—point of tone-section, and the anticipatory coarticulation does only the ending—point of that.

(3) Tonal coarticulation is manifested in terms of changes in F0 height, but not in F0 direction. Changes in F0 height do not affect the tonal identities.

(4) The extent of the carryover effect on the start—point of tone-1, tone-2 and tone-3 in the second, third or fourth syllable can be predicted by the height of the ending—point of the preceding four tones, and the extent of the anticipatory effect on the ending—point of tone-4 in the first, second or third syllable, and that of tone-3 in the first syllable can be predicted by the height of the start—point of the following tones.

The conclusions of this study concerning that coarticulatory effect does not extend across tones and tonal coarticulation does not affect the identity of tones are in agreement with what has been found in the paper (Shen, 1990). But this experiment found that carryover effect does not extend to the ending—point, and anticipatory effect does not to the start—point, and the coarticulatory effects are unidirectional. The reason why the different results were obtained in the two experiments is perhaps that the experimental materials in our study are distinct from those of Shen's; one is meaningful words and phrases, the other is nonsense sequences.

In Mandarin, words and phrases possess not only tone-sandhi, but stress. Words and phrases with normal stress (i. e., none is in the neutral—tone or the contrasting stress) have their stress pattern as follows: (a) the F0 range for the four tones falls and widens gradually from the first syllable to the last, and its lower limit

does more fast than the upper one , (b) the F0 contour of the last syllable approximates its tone pattern in isolation , (c) the duration of the last syllable is longer (Yan and Lin , 1988) . Because the upper limit of the F0 range in word and phrase is caused in general by the ending—point of tone-2 and the start—point of tone-4 , the start—point of tone-2 , or the ending—point of tone-4 rather than the ending—point of tone-2 , or the start—point of tone-4 is perturbed by tonal coarticulation . Because the lower limit of the F0 range in word is caused in general by the lowest part in tone-3 , the start—point and sometime the ending—point of tne—3 is perturbed by the tonal coarticulation . As for tone-1 , this experiment showed that its start—point had been coarticulated, but its ending—point is probably perturbed . It is highly probable that tonal coarticulation is conditioned by stress in word and phrases. It has been pointed out that tonal coarticulation is also conditioned by tone-sandhi . A familiar example is that tone-3 before another tone-3 must firstly become a mid rising tone or a mid falling—rising tone because tone sandhi , and then it is coarticulated like the inherent tone-2 by the preceding tones .

It has been stated that if in a trisyllabic word or phrase , the first syllable is in the tone-1 or tone-2 , the second in the tone-2, and the third in any except the neutral tone, then tone-2 in the second syllable changes into tone-1 for speech at conversational speed ,but does not change at a more deliberate speed(Chao,1968). The phenomenon that tone-2 after tone-1 or tone-2 is changed into tone-1 is caused by carryover coarticulation in which the start—point of tone-2 is raised by the high ending—point of the preceding tone-1 or tone-2 . It has been found that the F0 curve of tone-2 after tone-1 or tone-2 would proceed to become(slight) fall when preceding tone-3 or tone-2 (Wu,1985). This phonemenon is caused by the anticipatory coarticulation in which the ending—point of tone-1 is affected by low or mid start—point of the following tone-3 or tone-2. This indicated that tonal coarticulation in word or phrase may be related to the speed at which word or phrase is pronounced . Further investigation on this point will be done in another experiment .

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