An acoustic study of intersyllabic anticipatory coarticulation of three places of articulation of C2 in CVCV in Standard Chinese

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汉语普通话两音节 CVCV 间 C2 为三个发音部位的逆向协同发音声学研究

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[摘要] 关于协同发音的研究，在国外开展得较早，著名的是 Öhman 进行的研究，他对俄语，瑞典语，英语进行研究，得出声学过渡模式。其后又有大量这方面的研究。国内自八十年代开始对普通话进行这方面的研究，得出了一些定性的结论，但选材的范围一般较小。在此基础上，本实验在更大范围对这种现象进行研究。同时根据过去的研究，普通话中逆向协同发音主要发生在相邻音之间。但是否相隔的音也存在协同发音？本文对普通话中 C1V1C2V2 两音节结构中， C2 为三个发音部位：唇辅音，舌尖辅音，舌根辅音， V1 为 22 个元音韵母， V2 为三个极端位置的元音的音节间逆向协同发音现象进行研究。本文首先研究同一发音部位，不同发音方法的辅音对 V1 的影响有何差别；然后考察 C2 为三个不同发音部位的辅音：唇音，舌尖音和舌根音时，对 V1 的影响有何不同，同时考虑 V2 是否对 V1 有影响，目的是研究逆向协同发音影响的程度；并给出第一音节元音韵母受第二音节不同声母辅音影响的声学过渡模式；但只用过渡方向和过渡模式不能精确地体现辅音的发音部位，最后本文根据声学过渡寻求表示发音部位信息的规律。

实验材料是由一位中年男性北京发音人发的普通话两音节 C1V1C2V2 结构， V1 包括普通话 22 个元音韵母， C2 包括四个唇辅音，四个舌尖音，三个舌根音， V2 包括三个极端位置的元音。实验材料制作成宽带语图后，用数字化仪测量 V1 的过渡从起点到终点的前三个共振峰的频率值，然后对过渡段从时间上做规一化处理，当 C2 为唇音类四个辅音时，对 V1 过渡的起点和终点的频率值分别进行方差分析，考察它们之间是否有差异，对 C2 为舌尖类辅音和舌根类辅音做同样处理；然后归纳表现发音部位规律的声学特征并得出 V1 到 C2 过渡的声学模式；最后求出表示发音部位的音轨方程的斜率和截距。本实验的结果表明，同一发音部位，不同发音方法的辅音 C2 对 V1 的影响没有显著差异(显著性水平在 $P<0.01$)。逆向的协同发音影响在 CVCV 中，除 C2 对 V1 的直接影响外，我们还看到当 C2 为唇音时， V2 通过 C2 对 V1 产生影响，主要表现在过渡方向不同。最后根据声学过渡，给出表示三个发音部位的音轨方程。

Abstract

The aim of this experiment is to investigate the intersyllabic anticipulatory coarticulation in disyllabic strctures (i.e. C1V1C2V2) in Standard Chinese in which V1 represents 22 vocalic ends, C2 consists of consonants characterized by three places of articulation, and V2 represents three extreme articulatory postures on the vowel chart (i.e. /a/, /i/, /u/). Acoustic transition from V1 to C2 is studied. Firstly, we examine whether the acoustic manifestations of the transition from V1 to C2 are similar or not when C2 has the same place of articulation but differs in the manner of articulation. Secondly, we consider the possible types of anticipatory coarticulation.

Thirdly, the acoustic patterns of transition from V1 to C2 are formulated. Finally, the slopes and Intercepts of the locus equation are given to characterize different places of articulation of C2. One male speaker was asked to produce the speech materials. Wide-band sonagrams were made with Kay 5500 sonagraph.The first three formants in the transitory part from V1 to C2 were measured from the beginning to the end points. The results show that (a) there are no evident differences with C2 being the same place but different articulation manner, and (b) anticipatory coarticulation has two forms, one being from C2 to V1, the other being from V2 through C2 to V1.

1. Introduction

The aim of this experiment is to study anticipatory coarticulation in the context C1V1C2V2 in Standard Chinese. V1 represents 22 vocalic ends, C2 consists of consonants which characterized by three places of articulation and V2 consists of three vowels /a,i(ɤ),u/. The acoustic transition part from V1 to C2 is studied in spectroal and durational aspects.

Delattre etc.(1952) proposed that /b p m w/ might have the same second-formant locus corresponding to their common place of production. Ohala,M(1995) made an acoustic study about Hindi stops, showed the formant tracks for voiceless consonants are similar to those for the voiced consonants.But whether is it the same occasion in SC?This experiment will make a study for the differences among /p,p',m,f/, also among /t,t',n,l/ and among /k,k',x/ in SC.

Coarticulation usually has two kinds of type,one is anticipatory ,the other is carryover . There are different forms in many languages.Ohman(1965) first made a wide range study about coarticulation in Swedish, English and Russian in VCV context. The result showed there were coarticulation from V to C. "The initial vowel influences the medial stop-to-final vowel transition across the intervocalic consonant" .Also, from his figures, it can be seen that the final vowel influencing the medial stop to first vowel.Whether does the final vowel affects the first vowel through the medial consonants in Standard Chinese?

Wu & Sun (1988) have researched the intersyllabic coarticulation of Stops in SC.It is the first paper about stops coarticulation in Standard Chinese.According to their study, for intersyllabic coarticulation, anticipatory is stronger than carryover in SC. The coarticulation appeared between adjcent phonemes. They gave the acoustic patterns of formant transition. This experiment intents to look for the phenomena the effect of the end vowel across medial consonant to the first vowel in Standard Chinese and to study the intersyllabic anticaptory coarticulation in SC as C2 being three different places of articulation, labial, alveolar and velar consonants.

Furthermore, this experiment tries to work out a locus equation characteristic different places of articulation in the light of the formant transition .Sussman (1991) proposed the locus equation in English. Some papers(Bakran,J.etc.,Celdran,E.M.etc.,Ohala,M.) about locus equation made in the case of CV. The locus means the place of articulation of consonant according to the transition of vowel not only following the consonant but also preceding the consonant, the transitions of V-C and C-V often show the mirror phenomena. It is reasonable to get the locus equation with formants transition of V-C.

2. Materials and Methods

The materials were gotten from the database of phonetic lab.Institute of Linguistics, Chinese Academy Social Sciences. The disyllabic structure is C1V1C2V2. V1 including 22 /a,o,ɤ,i,u,y,ɿ,ʅ,ɚ,ai,ao,ei,ie,ia,ye,ou,ua,uo,iao, iou,uai,uei/ vowel final in SC,C2 including labial consonants /p,p',m,f/, alveolar consonants /t,t',n,l/ and velar consonants /k,k',x/. V2 consists of vowels /a,i(ɤ),u/. The number of all the materials is 22x11x3=726.

The subject was a male speaker whoOne male speaker produced all the speech materials. The recording was made in recording room of phonetic lab. with high level kenwood taperecorder. The recording materials were made into sonagrams with Kay 5500 Sonagraph.

With a measuring procedure (The measuring procedure is developed specifically for this experiment by Yan Jingzhu), the first fthree formants of the transition of V1 to C2 were measured from the beginning point to the end point of transition fromo V1 to C2 and the data were analysized.

3. Result and discussion

3.1. *the transition compare as C2 being different manner of articution*

The next work is to research if the transition of V1 is different as manner of articulation of C2 differs in each set. There are three sets according to the place of articulation of C2.One is as C2 is labial /p,p',m,f/,the second as C2 is /t,t',n,l/ and the last as C2 is /k,k',x/.

3.1.1. *Labial set*

In this set, C2 has four consonants,unaspirated voiceless stop /p/, aspirated voiceless stop /p'/, fricative /f/, nasal /m/. The end point of F2 transition of V1 preceding C2 in this set are analysized with ANOVA. The result is showed in Table 1. There are not evident significant.

Table 1 The ANOVA of the end point of transition of V1 to C2 as C2 being labial consonants

source	SS	D.F	variance	F	P-value	critical-value
inter-group	62315.77	3	20771.92	0.112598	0.952511	4.023718
intra-group	15496093.8	84	184477.3			
sum	15558409.5	87				

3.1.2. *Alveolar set*

In this set, C2 are four consonants respectively,unaspirated voiceless stop /t/, aspirated voiceless stop /t'/, lateral /l/, nasal /n/. The same work was made in this set. The results are showed in Table 2. There are not evident significant among the four groups.

3.1.3. *Velar set*

In this set, C2 consists of three consonants,unaspirated voiceless stop /k/, aspirated voiceless stop /k'/, fricative /x/. The same work was made as before. The results are showed in Table 3. There are not evident significant.

Table 2 The ANOVA of the end point of transition of V1 to C2 as C2 being alveolar consonants

source	SS	D.F	variance	F	P-value	critcal-value
inter-group	21441.94	3	7147.314	0.032905	0.991928	2.713228
intra-group	18245455.7	84	217207.8			
sum	18266897.7	87				

Table 3 The ANOVA of the end point of transition of V1 to C2 as C2 being velar consonants

source	SS	D.F	variance	F	P-value	critical-value
inter-group	90496.39	2	45248.19	0.224995	0.799158	3.142808
intra-group	12669752.2	63	201107.1			
sum	12760248.6	65				

3.2. *the degree of anticipatory coarticulation*

Fig.1 represents an example about transition of V1 to C2.The first disyllabic group is "boda/pota/, modi/moti/", the transition of F2 is similar, the second is"poba/p'opa/, modi/moti/", the transition of F2 is not similar.The F2 of /a/ in "mobi"was influenced by /i/.But F1 varies similar in the example.F3 vaires little.So,according to the transition of F2,there are two forms in these materials.

Table 4 The two forms of V1 to C2 among three groups

	V1transition-labial	V1transition-alveolar	V1 transition-velar
C2 to V1	V1(22vocalic ends) as V2 (/a,u/), V1(front vowel)as V2(/i/)	V1(22vocalic ends)as V2(/a,u,i/)	V1(22vowels)as V2(/a,u,ɣ/)
V2 across C2 to V1	V1(back vowels)as V2(/i/)		

Table 4 gives two types of articipatory coarticulation. One is from C2 to V1, the other is V2 across C2 to V1. These materials were divided into three sets according to the commom place of articulation of C2. The first set as C2 being labial,the transition of V1 has two types. The second set as C2 beingalveolar consonants and the third set as C2 being velar consonants, the transition of V1 has the first type of C2 to V1.

3.3. *Acoustic pattern*

According to the formants data, the formant transitions of V1 to C2 were gotten. Three parts were gotten corresponding to the C2. The first part is C2 being labial consonants, the second part is C2 being alveolar consonants and the third part is C2 being velar consonants. There are 34 groups in Labial type. But there were 22 types inalveolar groups and there were also 22 groups in velar types. Next, they were described. Also, duration of transition and the rate of transition/V1 was made.

3.3.1. *Transition patterns*

3.3.1.1. *Labial type*

As C2 being /p,p',m,f/,V1 being 22 vowels and V2 being /a,i,u/,.the formant transition of V1 to C2 were divided 34 group.There are two forms of anticipatory coarticulation,one is C2 to V1,the other is V2 to C2 to V1.Fig.2 give all the 34 groups.C2 presents labial consonants /p,p',m,f/ in this part.

Fig.2a: The structure of V1C2V2 are: /a/-C2/(a,u)/, /a/-C2/i/, /o/-C2/(a,u)/, /o/-C2/i/, /ɤ/-C2/(a,u)/, /ɤ/-C2/i/, /i/-C2/(a,i( ),u)/, /u/-C2/(a,u)/sequences. F1 transition of V1 was the same in this group. F2 varied in two forms such as /a/, /o/, /ɤ/, falling as V2 were /a,u/, but rising as V2 was /i/. F3 of V1 transition fall all.

Fig.2b: The structure of V1C2V2 are /u/-C2/i/, /y/-C2/(a,i,u)/, /ɿ/-C2/(a,u)/, /ɿ/-C2/i/, /ʅ/-C2/(a,i,u)/, /ɚ/-C2/(a,i,u)/, /ai/-C2/(a,i,u)/, /ao/-C2/(a,u)/ sequences. F1 transition of V1 is flat all, F2 of V1 varies. F2 fall as V1 are /i/, /ɿ/, /ɚ/, /ai/, but rise as V2 are /u/, /ao/, F3 falls .

Fig.2c: The structure of V1C2V2 are /ao/-C2/i/, /ou/-C2/(a,u)/, /ou/-C2/i/, /ei/-C2/(a,i,u)/, /i ia/-C2/(a,u)/, /ia/-C2/i/, /ie/-C2/(a,i,u)/, /ua/-C2/(a,u)/. F1 transition of V1 fall as V1 are /ia/, /ua/, the others flat, F2 fall as V1 are /ia/, /ua/, /ie/, /ei/, /ou-C2-/(a,u)/, F2 rise as V1 are /ao/, /ou/-C2-/i/, F3 fall all.

Fig.2d: The structure of V1C2V2 are /ua/-C2/i/, /uo/-C2/(a,u)/, /uo/-C2/i/, /ye/-C2/(a,i,u)/, /iao/-C2/(a,u)/, /iao/-C2/i/, /iou/-C2/(a,u)/, /iou/-C2/i/. F1 fall as V1 is /ua/, the others are flat, F2 rise as V1C2V2 are /uo/-C2/(a,u)/, /iao/-C2/(a,u)/, /iou/-C2/(a,u)/, the others fall.

Fig.2e: The structures of V1C2V2 are /uai/-C2/(a,i,u)/,/uei/-C2/(a,i,u)/. F1,F3 varies consistently, F2 is affected only by C2.

It seems that F1 and F3 varies consistently in this part.F2 varies different as V2 varies.

3.3.1.2. *alveolar type*

Fig.3 gives all the transition patterns of V1 as C2 arealveolar consonants/t,t',n,l/. C2 presents the alveolar consonants in this part.

Fig.3a: The structures of V1C2V2 are /a/-C1/(a,i,u)/, /o/-C2/(a,i,u)/, /ɤ/-C2/(a,i,u)/, /i/-C2(a,i,u)/, /u/-C2/(a,i,u)/, /y/-C2(a,i,u)/, /ɿ/-C2(a,i,u)/, /ʅ/-C2(a,i,u)/. F1 transition of V1 falls as V1 are /a/, /o/,/ɤ/, the others flat. F2 rises as V1 are /a/, /o/, /ɤ/, /u/,the others fall or flat. F3 all fall.

Fig.3b: The structures of V1C2V2 are /ɚ/-C2/(a,i,u)/, /ai/-C2/(a,i,u)/, /ao/-C2/(a,i,u)/, /ou/-C2/(a,i,u)/, /ei/-C2/(a,i,u)/, /ia/-C2/(a,i,u)/, /ie/-C2/(a,i,u)/, /ua/-C2/(a,i,u)/. F1 transition of V1 fall as V1 are /ua/, /ia/, the others are flat. F2 rise except of V1 being /ai/, /ei/. F2 is slightly flat as V1 are /ai/, /ei/.F3 all fall .

Fig.3c: The strctures of V1C2V2 are /uo/-C2/(a,i,u)/, /ye/-C2/(a,i,u)/, / iao/-C2/(a,i,u)/, /iou/-C2/(a,i,u)/, /uai/-C2(a,i,u)/, /uei/-C2/(a,i,u)/. F1 transition of V1 varies little, F2 rise as V1 are /uo/, /ye/, / iao/, /iou/. But F2 fall or flat as V1 are /uai/, /uei/. F3 all fall.

So, if the final vowel is /i/ or /y/, F2 fall or flat, the others rise consistently. If the final vowel is/a/, F1 fall, the others flat. F3 show a consistent tendency.

3.3.1.3. *velar type*

Fig.4 give the acoustic transition pattern of V1 as C2 are velar consonants /k,k',x/. C2 presents velar consonants in this part.

Fig.4a: The structures of V1C2V2 are /a/-C2/(a,i,u)/, /o/-C2/(a,i,u)/, / ɤ /-C2/(a,i,u)/, /i/-C2/(a,i,u)/, /u/-C2(a,i,u)/, /y/-C2/(a,i,u)/, /ʅ/-C2/(a,i,u)/, /ɿ/-C2/(a,i,u)/. F1 transition of V1 flat except of /a/. F1 transition of /a/ fall evidently. F2 rise as V1 are /a/,/o/,/ ɤ /,/u/, but they are lower than that in the second part Fig.4a. F2 fall as V1 are /i/, /ʅ/, /ɿ/. F3 fall mostly.

Fig.4b: The structures of V1 transition are / ɚ/-C2/(a,i,u)/, /ai/-C2/(a,i,u)/, /ao/-C2/(a,i,u), /ou/-C2/(a,i,u)/, /ei/-C2(a,i,u)/, / ia/-C2(a,i,u)/, /ie/-C2/(a,i,u)/, / ua/-C2(a,i,u)/. F1 transition of V1 fall as V1 are / ia/, / ua/, the others flat. F2 rise as V1 are /ia/, /ua/, /ao/, /ou/, / ɚ /, /ie/. F2 fall as V1 are /ai/, /ei/. F3 fall mostly except of / ɚ /.

Fig.4c: The structures of V1 transition are /uo/-C2/(a,i,u)/, /ye/-C2(a,i,u)/, /iao/-C2/(a,i,u)/, /iou/-C2/(a,i,u)/, /uai/-C2/(a,i,u)/, /uei/-C2/(a,i,u)/. F1 of V1 transition flat except of /a/. F2 rise as V1 are /uo/, /ye/, / iao/, /iou/, but the others fall sligntly. F3 fall mostly except of /i/, / yɛ /.

The transition tendency of V1 in this part is similar to that in the second part, but there are different degrees between the two parts.

3.3.2. *Transition duration*

The data about the transition duration of the three parts are given in table 5. They are the durations of V1(V1t), transition(TT) and the rate of V1T/TT.

Table 5 The duration of transition(TT) and the first vocalic end(V1T) and the rate of TT/V1T

	V1T	TT	TT/V1T(%)
(C2) labial	229(av)20.9(sd)	46(av)5.8(sd)	17
(C2) alveolar	266.7(av)34(sd)	54(av)11(sd)	13
(C2) velar	268(av)42(sd)	58(av)11(sd)	16.7

The result showed there are no evidently difference among the three parts.

C2 being alveolar consonants, the rate of TT/V1T is small than the other two. It showed the characteristic of articulation ofalveolar consonants. The trajectory of moving of the second part is little than the other two parts, because the articulation organ of V1 to C2 is similar, all with tongue.

But the others are not.

Furthermore, whether may it done with the acoustic pattern to show the place of C2? It will useful for speech processing.This experiment tries to work for this with locus equation.

3.4. *Locus equation for three place of articulation of C2*

How to find the invariant from the acoustic manifestation. It is always a problem. "Locus" proposed by Delattre etc. was an abstract concept.It was a supposed point.But Lindblom(1963) made a function to describe the place of consonant.It is convenvient for speech processing. Sussman (1991) made an experiment to give the locus equation of English. The locus equation is y=kx+b, x is the stability end point frequency of F2. y is the beginning point frequency of F2 transition and k is the slope and b is the intercept. Certainly it is in CV environment.It may be similar to that in VC environment.

This experiment would give the locus equation from V to C. So, the x is the stability part point of F2, y is the end point of F2 transition. There were different slopes and intercepts among Labial, dental and velar.

Table 6 The slopes and the intercepts of the transition of V1 to C2

	slope	intercept
labial	0.87,0.79	27,204
alveolar	0.61	605
velar	0.97	206

3.4.1. *C2 as labial consonants*

There are two types corresponds to V2,one is the first type as V2 is /a,u/,the other is the second type as V2 is /i/. It seems the slope is different.Intercept is small.It meaned that the transition of F2 varied little than that in alveolar consonants.

3.4.2. *C2 as alveolar consonants*

The transition of F2 varied evidently in this type.It showed the alveolar of consonants affected the preceding vowel .

3.4.3. *C2 as velar consonants*

The slope of it is the most but the intercept is not the largest among the three groups. It showed the little variance of transition.

4. Conclusions

Different places of articulation of consonants affecting formant transition stronger than that of manner of articulation. There are two types in anticipatory coarticulation strategy. One is C2 affects V1 directly,the other is V2 affects V1 indirectly across C2. Our findings do not conform with WU(1988), perhaps due to the different material.The phenomena which V1 may affect V2 only occurs in the context as C2 being labial consonants.

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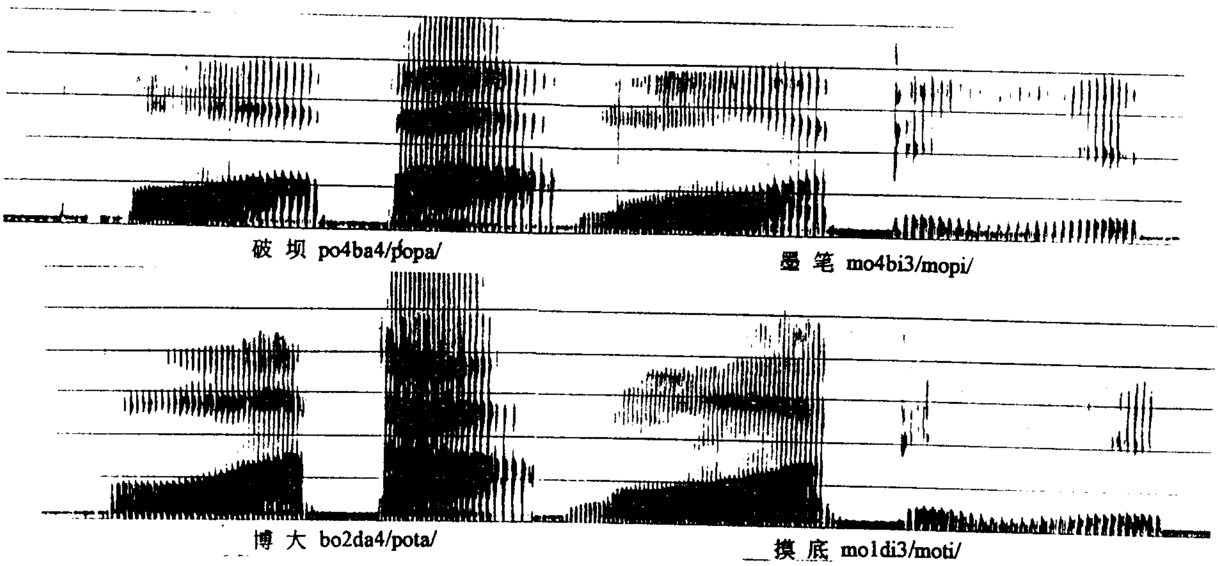

图 1 "破坝,墨笔,博大,摸底"的宽带语图./o/后接不同的 C2 时过渡方向不同

Fig.1 The wideband sonagrams of "/poba/,/mopi/,/pota/,/moti/".The transition direction of /o/ is different

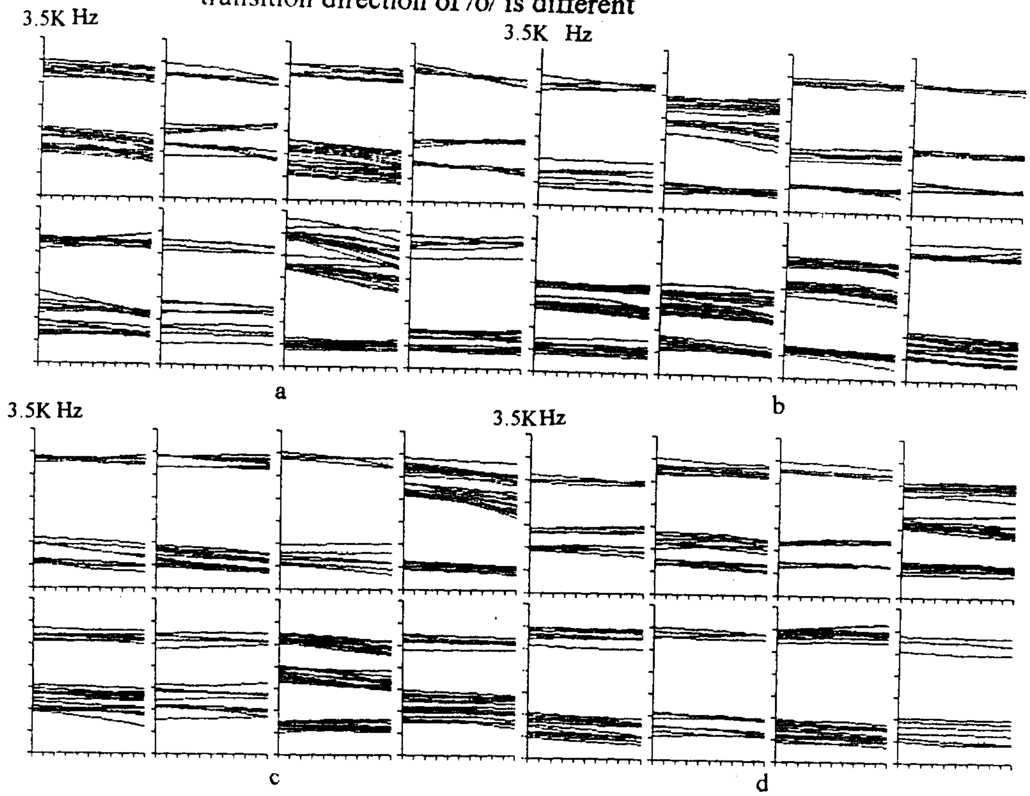

图 2 C2 为唇辅音时,V1 到 C2 的前三个共振峰过渡模式

Fig.2 The transition patterns of the first formants of V1 to C2as C2 being labial consonants

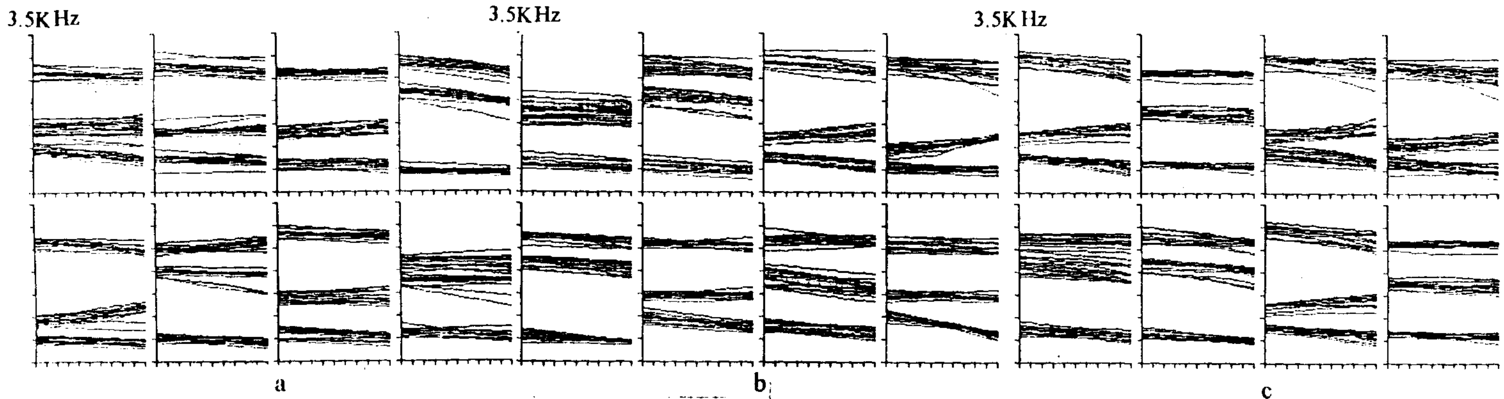

图 3　C2 为舌尖音时,V1 到 C2 的前三个共振峰过渡模式
Fig.3　The transition patterns of the first formants of V1 to C2 as C2 being alveolardental consonants

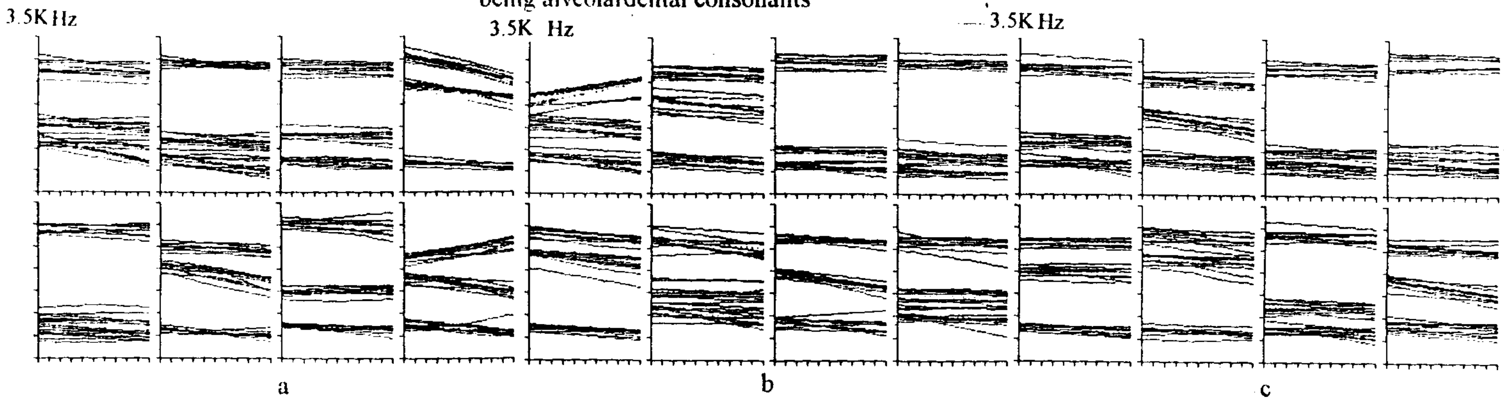

图 4　C2 为舌根音时,V1 到 C2 的前三个共振峰过渡模式
Fig.4　The transition patterns of the first formants of V1 to C2 as C2 being velar consonants