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ACOUSTIC COARTICULATORY PATTERNS OF VOICELESS FRICATIVES IN CVCV IN STANDARD CHINESE

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普通话清擦音协同发音的声学模式

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[详细提要] 本文以普通话的清擦音为材料，归纳出擦音的声学模型及其连读变化的规律。普通话的清擦音共有五个：/f/、/s/、/ʂ/、/ɕ/和/x/，本文把它们放在双音节中与三个元音搭配。这些辅元分配情况，见表1－3中的C1V1C2V2栏下的各音组，共计45组，其中C1都与C2相同，以节省例字。各双音节组都改写成汉字（不具意义），由两位发音人（北京籍）A和B按口语读出，全用阴平调，避免轻读，速度中等（每秒约3个音节）。各音录入磁带，用KEY 7800语图仪作出语图（图1－5）。

普通话清擦音的协同发音约分为三类：第一类，异体的协同发音：唇齿擦音/f/，由上齿和下唇的狭缝产生噪音，与元音的舌音属于不同的发音器官。在辅元结合中，受元音的唇形影响而有过渡段，/f/在元音/u/前或/e/前时，因唇部已预先圆唇化或展唇化，擦音有被同化现象。第二类，同体异位的协同发音：这类擦音是由舌的动作来发音的，与元音同用一舌，故称同体。它的特点是辅元之间一定有牵制关系，因而过渡音在这类音组中是有前后关连的。这一类擦音在普通话中有三个部位：1)齿龈音或舌尖前音/s/；2)后龈音或舌尖后音（又称卷舌音）/ʂ/；3)龈腭音或舌面前音/ɕ/。它们与元音相连时，发音部位（舌与龈或腭的收紧点或面）与舌位（舌高点）距离的远近以及其它条件，形成不同走势的过渡音。但它们与同位元音相拼时，如/sɿ/、/ʂʅ/、/ɕi/等，过渡音也会消失；第三类，同体同位的协同发音：后腭音或舌面后音/x/，它的收紧点与所拼元音的舌高点在同一位置，它随元音的移动而移动其收紧点或面。它的前腔基本上和后接元音的前腔相似，因此也具备与元音共振峰相似的强频集中带，只是声源不同。

表1是/f/与前半高元音/e/、后高元音/u/和央低元音/a/构成的音组。在普通话音系中，/f/不与前高元音/i/拼，而韵母较前较高的只有/ei/．在普通话语音中的/ei/是前响二合元音，/e/是主要的．现为列表方便，表中就只用/e/来代表这一音位．从C1和C2的下限频率可知，/u/前的/f/下限是偏低的，/e/前的/f/下限是偏高的，足证/f/是受到圆唇化或展唇化的影响的．在/a/的元音前，/f/下限频率的起讫点走势是平坦的。总的来说，/f/在V与C之间的协同发音，当V为/a/时是顺同化，为/u/或/e/时是逆同化。

表 2 是/s/、/ʂ/或/ɕ/与三个元音搭配的音组。在普通话中，/s//ʂ/不能与前元音/i/拼，它们能拼的最前的元音各为/ɿ/与/ʅ/。/ɕ/不能与后元音/u/拼，所能拼的圆唇化（被称为撮口化）元音为/y/。从表 2 中可见，这三个擦音频率下限在 C1 时都是先高后低，这是因为它们发出时，狭缝一开始先要偏紧而偏前，前腔就变短而致频率升高。随后狭缝即稍稍放松而后移，滑到这个擦音所需的正确部位再接上元音。这时前腔已稍延长而致擦音下限频率变低了。它们和同部位元音相拼时也有这种现象，这不属于协同发音性质，而是擦音始发时先紧后松的生理现象。试看它们在 C2 时，因为前已有个元音，后接 C2 时，狭缝由松变紧，就没有这种下限先高后低的现象。/ɕ/音和元音相拼，在一般语音学 的描写中总是有介音/i/或/y/的。在汉语音韵学中称为韵头。但事实上它的声学特征只是辅元间的过渡，本表中就只用/ɕ/和元音直接相拼。/s/、/ʂ/、/ɕ/三个擦音在 C2V2 中，C2 的规律与 C1 大致相同；不过它又受前面 V1 的影响。看表中这些擦音在 C2 的下限起点频率都低于 C1 的起点。因此除了前节所述原因外，C2 在两元音之间还都有协同发音作用．也就是说，这个 C2 下限也同元音共振峰相似，既有出渡，也有入渡。这点和普通话的清塞音不同．清塞音在双音节中，C2 往往不受 V1 的影响，这是因为汉字是一字一音节，音节中有协同发音，音节间如后面是塞音，由于阻断关系而不受前音的同化．这三个擦音则不然，因为他们在成阻时是狭缝的阻碍而不是关闭的阻塞，他的舌位是作连续的移动，而不是对抗的移动，故协同发音是跨音节的，在协同发音性质中称为"延伸"，而不是"阻断"．

表 3 是/x/与三个元音相拼。普通话的/x/不能与前高元音/i/拼，它所能拼最前的元音是/ə/，实际在北京话中是稍后的/ɤ/。许多文献说明这个擦音与后 接元音基本上是同部位的。它的前腔长短在形状上与所接元音的相似，因此噪音受前腔的调节也具备了和共振峰相似的一个或几个强频带。而不同于前两表的强频区和下限模型。它最低的强频带与后接元音的 F2 对应。它的高次强频带也各与元音的高次共振峰相对应。从表 3 可见，/x/在 C1 时不同音境的强频 带平稳而没有升降走势的过渡，主要是 V1 的同位擦音．他在 C2 时与前面的 V1 有时也有过渡出现（以上 3 表均只列发音人 A 的材料）．

表 4 列出两位发音人的擦音频谱模型。普通话中擦音模型在本实验中可分为 5 类。如表 4 下的图解。1 型是由高到低全面分布的噪音区。上限最高可到 10kHz 以上，因仪器所限，一般频谱多做到 8kHz 为止，本文附图(图 1－5)只显示到 6kHz。它的下限频率宽窄不等，因擦音部位而异。在这频率分布区内有时也出现一两个强频集中区，它与后接元音共振峰的"音轨"点相对应。这是前腔中极点的反映。2 型是一片噪音频谱下接一条强频带，是 1 型的变体，也偶在第 2 类擦音中出现，不过与 1 型不成比例。3 型是在高频部分有两条强频带，隔开一段频谱后，下面又有一条低的强频带与元音的 F2 对应。4 型是从高到低有 4 条强频带，各与元音的 F2 以上各次共振峰对应。5 型是只有一条低的噪音强频带，只与元音的 F2 对应。以上 3、4、5 型都在第 3 类擦音/x/中出现，而 5 型只出现在/u/元音之前。从/xu/的模型来看，发音人 A 的多为 5 型，B 的多为 3 型，说明 B 的/u/ F2 以上有较多的高次共振峰，而 A 的/u/ F2 以上就没有共振峰了．这 在/u/的频谱中是常见的现象。

表 5 是双音节中元音受到擦音影响而离位的数据。由于擦音在音节间的协同发音同时有顺同化和逆同化，元音离位程度就有不同。它是这样测算的，在 CVCV 中，元音共振峰 F2 的入渡段后的稳定段和单音节 CV 中元音稳定段的频差，改成百分比，前者大于后者为正，反之为负。百分比的大小代表元音离位的大小，也就代表音节间擦音协同发音影响的大小。(表 5 只列了 A 的材料)。

擦音是"延音"，与塞音的"暂音"在"区别特征"系统中是一对对立特征。延音在听辨中承担一定程度的区别功能。普通话擦音在重读时，噪音的时长都比较长，但长度因发音部位不同，并因

人、因环境而异。表 7 是两发音人的擦音在不同环境中的平均时长，总的看来，发音人 B 的擦音比 A 的约长 20%。各音中以/f/为最短，/x/次之，/s/、/ʂ/、/ɕ/较长。C1 比 C2 也各有长短不同，一般是/s/、/ʂ/、/ɕ/在 C1 都比在 C2 的长，而/f/和/x/则相反。

总之，协同发音的基本现象，就是两音连读时相互适应(有时是相互对抗)的结果. 它在两个不同的语音间服从生理惯性并照顾到表达信息的一种矛盾的统一. 各清擦音的发音方法相同，但部位各异. 擦音的协同发音现象是多种多样的，不能就以一种噪声来概括. 一般说来，/f/在音节中和音节间，受元音 唇形的同化作用，而不是舌位的同化. /s/、/ʂ/、/ɕ/ 在音节中和音节间都有协同发音现象，而且同化有顺有逆，元音的唇形、舌位对它都起作用. /x/主要在音节中有逆同化，而且同化得彻底，它没有过渡段，而是使辅音根本上随元音而定部位. 它在音节间有时被前音节的元音所同化，所以它的强频带基本上是平稳的. 清擦音在频谱中的噪音模型基本上有两种型式. 一是全区噪音的模型，以频率下限为其特征，这类型式有时也在噪音中出现强频集中区，有时下面有一条噪音横杠，称为强频带(1,2 型). 另一完全是噪音横杠模型，或强频带(3,4,5 型). 前者出现在/f/及/s/、/ʂ/、/ɕ/中，后者则只出现在/x/中.

ABSTRCT

Fricatives are produced with a constriction in the vocal tract narrow enough to produce turbulence. Their acoustic features are analyzed based upon the gestures of the front cavity. The present experiments are dealing with five voiceless fricatives /f/,/s/,/ʂ/,/ɕ/,/x/ in Standard Chinese(SC). They are arranged in CVCV contexts in which three peripheral vowels are combined with each fricative in C1 and C2, thus made 45 tokens, and spoken by two Pekinese of middle age. Spectrographs of all the tokens are made and their acoustic data are measured, i. e., frequencies and durations of the lower margins (LM) and/or that of the concentration bars of fricative noise in C1 and C2, frequencies of vowel formants up to F4, and both the onset and offset transitions in each formant in V1 and V2. In this paper, spectrograms of the whole tokens are shown, and seven tables of different data are given. According to the different articulatory gestures, the coarticulation effects of voiceless can be classified into three groups: (1) homorganic, (2) heterorganic and (3) contiguous. Coarticulationof /x/ belongs to the first group, /f/ the second and /s/, /ʂ/, /ɕ/ the third. In this paper, intra-syllabic and inter-syllabic coarticulations which occured anticipatory and/or carry-over are discussed.

INTRODUCTION

Since the nature of fricatives are not so simple as that of the stops, for they are featured by timing varied continuants instead of interruptors. The intrinsic feature of a fricative is rather better for perception than that of a stop, for the information elemants of the latter is most borne in its extrinsic feature, thus, to examine the acoustic features on the noise segments might be more reliable than that on the transition cues. "Fricatives are produced with a constriction somewhere in the vocal tract narrow enough to produce turbulence. The cxcitation is best modeled as a pressure source in front of the constriction ", as Zue has stated (Zue 1985)." In general, the transfer function of the vocal tract will have poles if one assumed that the constriction is small enough to permit decoupling of the cavities, In this case, the transfer function might be dominated only by poles, which are the natural frequencies of the front cavity," This is true when a fricative noise produced by a constriction in vocal tract at a distance from the mouth aperture is good enough to give an ideal front cavity by which the transfer function poles are well-formed in the noise spectrum. However, when the place of constriction is quite fronted, there will be no more poles of concentration area can be found in the spectrogram. There are five voiceless fricatives in SC, i. e. /f/, /s/, /ʂ/, /ɕ/ and /x/. The fricative /x/ is a best sample for the former case, and /f/ the latter case. Thus, the acoustic features of fricatives are mostly differed by the various lengths of the front cavities. Also, the voiceless fricatives are sustained and dynamic, their noise spectra give the overall acoustic features from begining to ending, which are modeled by the transfer functions of the articulatory gestures dynamically configureted and mostly determined by the position of constrictions. In the noise spectra, the lower margin is usually identified with the lower formants of succeeding vowel, especially the F2, of the adjacent vowels. Attention paid to these lower margins as well as to the noise patterns may be a brief way to obtain more understanding of the fricatives (Badin 1989, Soli 1980, Stevens 1987). As for the coarticulation effects of the fricatives in a sequence of speech, examination of the shifting of vowels' formants and comparing that in syllables with that in contexts may give more informations about the coarticulation of fricatives. Owing to the fricative features are strongly differed by their articulatory gestures, their coarticulations may be classified into three groups, as stated by Catford (Catford 1977), namely, homorganic, heterorganic and contiguous, in which the effects of coarticulations can be seen in the data rather different from each other.

EXPERIMANTAL DESCRIPTION

Our experiment for the coarticulation of SC fricatives is dealing with the contexts of double syllabic C1V1C2V2. The project is laid the reason that the feature of C1 followed by V1 gives an intrasyllabic coarticulation effect, while that of C2 interleft between V1 and V2 gives an intersyllabic one. Three peripheral vowels are distributed to each of the five fricatives, that would have made a total of 15×15= 225 combinations. For the sake of simplicity, the tokens are reduced to 45 with C1 and C2 being the same. However, the peripheral vowels /i/, /a/, /u/ are not all combined with the five fricatives respectively in SC phonology, some of them have to be substituted by their adjacent vowels as /ɿ/, /ʅ/, /e/ and /ɤ/ for /i/, and /y/ for /u/, according to phonological rules of SC. In fact, /e/ is an abbreviation of dephthong /ei/. These tokens are written in Chinese characters instead of alphabets, in order to give an impression of one character by one syllable, and can be spoken by the speakers naturally in a disyllabic combination for one token but meaninglessly. The readings are in normal speed and moderate stress, and all the characters are in first tone of SC avoiding the neutral tone.

All the spectrograms are measured and give the data of frequency in hertz and duration in micro-second. The data of the frequency are including the lower margin of noise spectrum with measurements at begining and ending; concentration noice bar; the formants of vowel with measurements at begining, middle and ending. The formant measurements also include both the onset and offset transitions of F1 to F4. The data of duration include two measurements at begining and ending of all the consonants and the vowels in the tokens. In addition, a list of the five fricatives in monosyllables CV combined with the vowels as C1V1 in the tokens

Table 1. The lower margins(LM) of frequency ranges of C1 and C2 and the formants F2 of V1 and V2 of SC fricative /f/.
表1. 普通话擦音/f/的下限频率及元音F2共振峰数据表.

CVCV	LM of C1			F2 of V1			LM of C2			F2 of V2	
	Be	En		Be	Mi	En	Be	En		Be	En
fafa	1540	1540	F2	1230	1230	1230	1930	1930	F2	1160	1230
fafu	2080	1230		1230	1230	1230	1000	1000		770	770
fafe	1160	1160		1230	1310	1310	1000	2310		1460	2160
fufa	1000	1000	F2	850	770	770	1000	1460	F2	1080	1230
fufu	1000	1000		770	770	770	1000	1000		770	770
fufe	1000	1000		770	770	770	1080	1390		1460	2080
fefa	2000	1230	F2	1460	2080	2080	1770	2230	F2	1160	1230
fefu	1160	1390		1460	2080	2080	1000	1000		770	770
fefe	2000	1460		1460	2080	2080	2160	2160		1690	2080

Be: bigining, Mi: middle, En: ending

Table 3. The lowest noise bar (LNB) of C1 and C2 corresponding to formants F2 of V1 and V2 in C1V1C2V2 of fricative /x/ in SC.
表3. 普通话擦音/x/的最低强频带与相对应的元音F2共振峰数据表.

CVCV	LNB of C1		F2 of V1			LNB of C2		F2 of V2	
			Be	Mi	En			Be	En
xaxa	1000	F2	1230	1230	1230	1540	F2	1230	1230
xaxu	1540		1390	1230	1390	540		770	770
xaxɤ	1000		1310	1310	1310	1230		1160	1160
xuxa	600	F2	770	770	850	1160	F2	1230	1230
xuxu	690		770	770	770	620		770	770
xuxɤ	620		770	770	770	1000		1160	1160
xɤxa	1230	F2	1230	1230	1230	1230	F2	1230	1230
xɤxu	1230		1230	1230	1080	620		770	770
xɤxɤ	1160		1230	1230	1230	1160		1230	1230

Be: bigining, Mi: minddle, En: ending

Table 2. The lower margins (LM) of frequency ranges of C1 and C2 and the formants F2 of V1 and V2 in C1V1C2V2 Of the SC fricatives /s/, /ʂ/, and/ɕ/.

表2. 普通话擦音/s/,/ʂ/,/ɕ/ 的下限频率及元音F2共振峰数据表.

CVCV	LM of C1		F2 of V1				LM of C2		F2 of V2		
	Be	En		Be	Mi	En	Be	En		Be	En
sasa	4620	2310	F2	1390	1390	1160	1770	2310	F2	1230	1390
sasu	4640	2400		1390	1310	1230	2390	2310		1160	780
sasɿ	4080	2660		1390	1310	1310	2160	2310		1230	1230
susa	2700	1930	F2	1160	850	1080	2460	2460	F2	1310	1310
susu	3230	2230		1160	710	1000	2230	2620		1080	770
susɿ	3160	1160		1080	770	1080	1160	1160		1230	1230
sɿsa	4000	1850	F2	1310	1310	1310	2230	1620	F2	1310	1310
sɿsu	3310	1460		1310	1310	1310	1230	2000		1390	770
sɿsɿ	3470	1390		1310	1310	1310	1310	1310		1310	1310
ʂaʂa	2700	2000	F2	1540	1390	1390	2000	1540	F2	1310	1390
ʂaʂu	3000	1310		1620	1390	1540	1310	1310		1160	770
ʂaʂʅ	2700	1540		1460	1460	1460	1540	1540		1620	1620
ʂuʂa	2310	1160	F2	1000	770	850	1620	2160	F2	1460	1310
ʂuʂu	2310	1230		1080	850	1000	1230	1230		1080	850
ʂuʂʅ	2230	1160		1080	770	1230	1160	1540		1620	1620
ʂʅʂa	2460	1690	F2	1690	1690	1690	1690	1690	F2	1460	1390
ʂʅʂu	2540	1390		1770	1770	1770	1390	1160		1080	850
ʂʅʂʅ	1770	1460		1770	1770	1770	1460	1460		1690	1690
ɕaɕa	2350	2540	F2	1850	1460	1690	2000	2310	F2	1850	1460
ɕaɕy	3850	2620		1690	1540	1540	2080	2080		1930	1930
ɕaɕi	2850	2310		1850	1460	1690	2080	2080		2080	2080
ɕyɕa	2080	1770	F2	2000	2000	2080	1770	1930	F2	1930	1390
ɕyɕy	2080	1770		1930	1930	1930	1620	1620		1930	1930
ɕyɕi	1850	1770		1850	1850	2160	2000	2000		2080	2080
ɕiɕa	2390	2000	F2	2080	2080	2080	2230	2230	F2	1850	1390
ɕiɕy	2850	1930		2000	2000	2000	2080	1930		1930	1930
ɕiɕi	2230	1930		2080	2080	2160	1930	1930		2080	2080

Be: begining, Mi: middle, En: ending

are also spoken by the same speakers. Their spectrographs are also made and measured to compare with that of CVCV. All the measurements of the two speakers make an amount of 9600 data, After simplifying, only F2 are chosen for the representation for coarticulation effects of fricatives as listed in Table 1—3. As has been mentioned before, the data of F2 are sufficient to denote the distinction of coarticulation effects of fricatives(Soli 1980, Repp et al 1987).

The acoustic features of various fricatives are not as simple as the white noise with several concentration areas, actually they are the sequence of noise modeled by the transfer function of the front cavity and appeared in the spectrograph with quite different patterns according to variant gestures. In SC, the voiceless fricatives are represented by five general patterns determined by the following formants patterns as shown by diagrams in Table 4. Pattern 1 is a segment of random "filling" in spectrogram, with an upper threshold up to 8kHz or more, and the lower margin is varied as the following vowel. Pattern 2 is a varient of the pattern 1, with its lowest portion separated from the noise filling and become a concentration noise bar as broad as a formant of wide band spectrograph, This is a speaker-dependent feature that can be seen in Figrue 1—3. The pattern 1 deffers from pattern 2 for a pole of transfer function in the latter is more dominant than that of the former. In fricative /f/, there are only pattern 1 occurred, and in fricatives or sibilants /s/, /ʂ/, /ɕ/, pattern 1 and 2 are all occurred subject to the different utterances as well as the different speakers.

The fricatives of pattern 1 and 2 in SC assimilated by their adjacent vowels are shown by the difference in frequencies between the begining and the ending of the lower margins in certain fricatives, which denote that the modification of the front cavity varied immediately after the turbulence excited from the constriction. In a noise string of C1V1, the begining frequency denotes the gesture approaching to the starting point of the onset transition of a certain formant of the succeeded vowel. The envelop direction of the lower margin downward, or upward or curved , denotes a CV transition similar to that in a stop consonant. However, the transition of a stop is undertaken by the vowel only, while that of a fricative is undertaken partly by the noise and partly by the vowel, although the contour of the lower margin is usually not smoothly connected with the onset transition of the vowel(Wu 1989 b).

Pattern 3,4 and 5 are all of the apectra of fricative /x/. In pattern 3, there are three noise bars with a highest one at the top, a next one of half high identified to F5 of the succeeded vowel if any, and a lower one identified to F2. As in the pattern 4, there are four noise bars with a highest one at the top, and other three ones located corressponding to F2, F3 and F4 respectively. In pattern 5, there is one noise bar identified to F2 of vowel /u/ only. All of these three patterns are occurred only in /x/, and the number of noise bars are determined by how many formants of the succeeded vowels are shown in the spectrograms. Table 4 gives all the tokens grouped into five columns, with fricatives /s/,/ʂ/ and /ɕ/ in the left three columns belonged to the coarticulation group of the "contiguous", /f/ the "heterorganic" and /x/ the "homorganic". Pattern numbers in C1 and C2 are given in this table in which the occurence of different patterns refer to the different coarticulation groups as well as the cavities of the vowels.

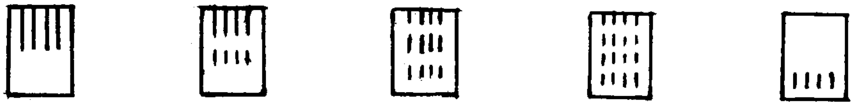
In C2V2, when a fricative of C2 is articulated between two vowels V1 and V2, the gesture of the front cavity has to be configureted firstly to accomodate to the gesture of the preceding vowel, then lastly to the gesture of the succeeding vowel as the C1V1 does. Thus the coarticulation of C2 effects both anticipatory and progressively. So the lower margin of C2 and that of C1 are rather different in the begining but similar in the ending if their succeeding vowels V1 and V2 being the same.

Table 4. The noise patterns of C1 and C2 in C1V1C2V2 in SC fricatives.
表4. 普通话擦音在双音节中的噪音模型.

C1V1C2V2	Pat. C1C2	C1V1C2V2	Pat. C1C2	C1V1C2V2	Pat. C1C2	C1V1C2V2	Pat. C1C2	C1V1C2V2	Pat. C1C2
/sasa/	1 1	/ʂaʂa/	1 1	/ɕaɕa/	2 2	/fafa/	1 1	/xaxa/	5 4
	1 1		1 1		2 2		1 1		4 4
/sasu/	1 2	/ʂaʂu/	1 2	/ɕaɕy/	1 1	/fafu/	1 1	/xaxu/	4 5
	1 1		1 2		2 2		1 1		3 3
/sasɿ/	1 1	/ʂaʂʅ/	1 1	/ɕaɕi/	1 1	/fafe/	1 1	/xaxɤ/	3 3
	1 1		1 2		2 2		1 1		3 3
/susa/	1 1	/ʂuʂa/	1 1	/ɕyɕa/	1 1	/fufa/	1 1	/xuxa/	5 5
	1 1		1 1		1 1		0 1		3 3
/susu/	1 2	/ʂuʂu/	1 2	/ɕyɕy/	1 1	/fufu/	1 1	/xuxu/	5 5
	1 1		1 2		1 1		1 1		3 3
/susɿ/	1 2	/ʂuʂʅ/	1 1	/ɕyɕi/	1 1	/fufe/	1 1	/xuxɤ/	5 3
	1 2		1 1		1 2		1 1		3 3
/sɿsa/	1 1	/ʂʅsa/	1 1	/ɕiɕa/	1 1	/fefa/	1 1	/xɤxa/	5 2
	1 1		1 1		2 2		1 1		3 3
/sɿsu/	1 2	/ʂʅsu/	1 1	/ɕiɕy/	1 1	/fefu/	1 1	/xɤxu/	3 3
	1 1		1 1		2 2		1 1		3 3
/sɿsɿ/	1 1	/ʂʅsʅ/	1 1	/ɕiɕi/	1 1	/fefe/	1 1	/xɤxɤ/	2 2
	1 1		1 1		2 2		1 1		3 3

Legends for the table:

Pattern 1 Pattern 2 Pattern 3 Pattern 4 Pattern 5



For each C1V1C2V2, pattern numbers in the upper row: speaker A,
Pattern numbers in the lower row: speaker B.

DISCUSSION

The fricatives are not only featured by their concentration areas and transitions as had been understood since the fifties of this century, but also, as mentioned before, they are bearing almost all the possibilities of coarticulation effects of the consonants intrasyllabic and interacting with their surrounding vowels. Their acoustic coarticulatory features and patterns can be briefly grouped into three categories as Table 1—3, which are discussed here.

In Table 1 (cf. Fig. 4), The data of LM of fricative noise are given. For the noise production, the /f/ is produced by a constriction between the upper teeth and the lower lip with a slit turbulence. Its gesture is not as regular as that of the sibilants in Table 2, which are produced with groove turbulence. In fricative /f/, there is a very shallow cavity which gives an effect of radiation rather than that of resonance. Its spectrum is random without any concentration area. The LM of fricative /f/ is depending upon the mouth shapes rather than the tongue positions of the vowels. In Table 1, it can be seen that in C1, the LM ending frequencies of /fu/ is lower than that of /fe/ because the lips of the former is rounded while the latter is spreaded. As in /fa/, the fricative noise is starting with its lips in natural state. In all the CVCV tokens, the LM freqencies of /fa/ are not in the same pattern because their lips are not always kept in the same gesture.

In Table 2 (cf. Fig. 1 — 3), there are three sibilant fricatives /s/,/ʂ/, and /ɕ/ each followed by three vowels, i. e. , /a, u,ɿ/ for /s/, /a, u,ʅ/ for /ʂ/ and /a, y, i/ for /ɕ/. The LM of the three fricatives in C1 are higher at the begining and lower at the ending, no matter what the succeeded vowels are. It is because that these sibilants are articulated with their tongue tips streching towards the alveolus or palate, and at the very begining of the articulations for these fricatives, the degree of their constrictions are not able to be adjusted so exactly and are ussually overshot, then the slits become more narrower and the front cavities more shorter, thus the LM frequencies become higher and decline to accommodate the following vowels.

The LM of the three fricatives in C2 are different from that in C1, for they are coarticulated with their preceded vowels also, so their begining frequencies are identified with the offset transitions of V1s instead of high initial frequencies.

As in Table 2, when the fricatives /s/ and /ʂ/ are followed by vowel /a/, the releasing of the constrictions with the tongue tips moving downwards, that give little effects of transitions in the noise area. The transitions of coarticulation are revealed in the vowel formants, both the offset in V1 and onset in V2. When they are followed by the vowel /u/, the lips rounded and protruded anticipatorily, and the tongue tips withdraw backwards. Both the movements cause the front cavity being lengthened, thus the LMs become lower. When they are followed by high front vowel /ɿ/ and /ʅ/ respectively, the tongue tips move a little to cause the constriction being loosened, by which the turbulence are just ceased but kept the tongue positions unchanged, then the vowels started. So there are no transitions can be seen both in noise and in voice areas. In general, as the dynamic gestures for coarticulation of these fricatives are configured by continuous tongue movements, the coarticulations are grouped as "contiguous".

The fricative /ɕ/ is different from the other two in table 2. The constriction is formed by the tongue blade against the front palate and is named as palatalized. Owing to the consonant is palatalized, any of its succeeded vowels must have a palatalized onset transition. According to the "final" system of SC, these transitions are symbolized as /i/ or /y/, and should be written between C and V in a syllable in "Pingyin" text. These transitions are called "medials" of the diphthong or triphthong in Chinese phonological works. The /ɕ/ with the transition /i/ preceding a vowel is articulated with a spreaded-lip gesture, while with a /y/ is with a protruded-lip gesture. The coarticulation effects of palatalized /ɕ/ are shown by LM clearly in the spectrograms, and their transitions are of both progressive and regressive.

In Table 3 (cf. Fig. 5), the fricative /x/ is succeeded by each of the three vowels /a/, /u/, and /ɣ/, in which /ɣ/ is a considerably front vowel that can be constructed in the /x/ V syllable in SC phoneme instead of a high-front /i/. The fricative /x/ is a V-dependent one whose constriction is always identified closely with tongue dorsum of the suceeded vowel, and the front cavities of both the former and the latter are similar in gestures. So there is no LM in the noise area but the formant-like concentration noise bars, which are closely connected with their corresponding formants appeared one or more in a spectrograph without transitions interleaving (Table 4 pattern 3—5). As in C2 of the tokens C1V1C2V2, the noise bars of /x/ are usually coarticulated with the succeeded formants of V2 and seldom assimilated by the preceded formants of V1. The carry-over coarticulation is only effected intra-syllabically in CV which is a case of homorganic coarticulation that is different from the other fricatives. In SC, /x/ is phonetically a velar fricative which is grouped in same place of articulation but different in manner simillar to the velar stops /k/ and /kʰ/. It may be moved somewhat forwards or backwards according to the dorsum position of the following vowel. The /x/ in SC is different from the pharyngeal /h/ in English.

In Table 5, the data of coarticulation effected on vowels in di-syllabic CVCV are given. The frequencies of three formants in C1 and C2 are measured. Their values are compared with the formants of the tokens of monosyllabic CV. Their difference are shown in percentage value, in which the + value means that the formant frequency in CVCV is higher than that in CV, While the — means it is lower. For example: the /su/ in C1V1, in which the value of F2 in V1 is +10%, which means that the /u/ influenced by /s/ becomes fronted, while the /su/ in C2V2, its F2 in V2 is also +10%, and the F1 is +18%, it means that this /u/ is fronted and also dawnward, and the formant of high-back vowel at the ending of a di-syllable is underspecified. While the /su/ in C1V1, the F3 in V1 is —34%. The decreasing of F3 means that the /u/ is more rounded by both reasons that /ʂ/ is retroflex and the F3 downwards, and as the /ʂu/ in C2V2, the F3 of V2 is —41%, it means that /u/ is more dawnwards with the lips more rounded.

When a fricative articulated without any preceding segment in a linguistic sequence, the constriction usually becomes narrower at the begining, then loosened afterwards to a certain extent to produce a perceptable friction as described before. according to the aero-dynamic aspect, the narrower constriction results an increasing of supra-glottic air presure, which gives to the fricative noise an exitative effect. It is presented by acoustic effects in different ways according to the coarticulation grouping. As in the Table 1—5, it can be found that in Table 1 and 3, the starting frequencies of /s/, /ʂ/ and /ɕ/ are higher than the ending ones. It can be explained as: when the starting constrictions are loosened, the lower lip for /f/ and the tongue dorsum for /x/ are lowered vertically with the lengths of cavities unchanged; while the tongue tipe for /s/, /ʂ/ and /ɕ/ are withdrawn horizontly with the cavities prolonged, thus the starting frequencies of the former are stable, and that of the latter are raised.

Here are two averaged data of the LM frequencies of some of the sibilants and of the duration of all the five fricatives (Table 6 and 7). In Table 6, the difference of frequencies between C1 and C2 is larger in /s/ and smaller in /ʂ/ and /ɕ/. That means the coarticulation effects in /s/ is greater than that in /ʂ/ and /ɕ/. In Table 7, the duration of the fricatives of speaker B are roughly 20% longer than that of A. It perhaps means that the coarticulation in duration is more speaker-dependent.

CONCLUSION

An investigation of fricatives articulatorily as well as acoustically might be one of the most interesting topics that many phoneticians and acousticians were dealing with. Although fricatives are rather complex and "far from being completely understood both in production and perception" as many phoneticians claimed. In short, the fricatives in production and perception can be closely related to their gestures grouped above.

Most of the literatures were published, that were on the fricatives of English and other popular languages but very few on Chinese. Moreover, the early studies on fricatives were mostly paid attention to the phenomena of acoustic features and transitions of monosyllales rather then multi-syllables (Fant 1960, 1973, Stevens 1960, Strevens 1960, Shoup 1976, Kagaya 1979, Soli 1981, Ladefoged and wu 1983, Wu 1988, 1989,

Table 5. The coarticulation effects on formants of V1 and V2 in C1V1C2V2 compared with the formants of V in CV in SC fricatives.

表 5. 普通话擦音在双音节中协同发音对元音的影响；元音离位程度的百分比.

Formants of V1 in C1V1C2V2				Formants of V2 in C1V1C2V2				Formants of V in CV				% of V1/V			% of V2/V		
C1V1	F1	F2	F3	C2V2	F1	F2	F3	CV	F1	F2	F3	F1	F2	F3	F1	F2	F3
/sa--/	770	1390	2540	/--sa/	770	1390	2540	/sa/	770	1390	2310	0	0	+10	0	0	+10
/ʂa--/	770	1390	2460	/--ʂa/	770	1390	2310	/ʂa/	770	1390	2390	0	0	+3	0	0	-3
/ɕa--/	770	1460	2540	/--ɕa/	770	1460	2540	/ɕa/	770	1390	2160	0	+5	+17	0	+5	+17
/fa--/	770	1230	2160	/--fa/	770	1230	2160	/fa/	770	1230	2160	0	0	-6	0	0	-6
/xa--/	770	1230	2230	/--xa/	770	1230	2310	/xa/	770	1230	2230	0	-3	-3	0	-3	0
/su--/	390	770	2390	/--su/	390	770	2460	/su/	390	770	3470	0	0	-34	0	0	-41
/ʂu--/	390	850	2310	/--ʂu/	460	850	2310	/ʂu/	390	770	2310	0	+10	0	+18	+10	0
/ɕy--/	390	1930	2460	/--ɕy/	390	1930	2460	/ɕy/	390	1930	2310	0	0	+6	0	0	+6
/fu--/	390	770	2230	/--fu/	390	770	2230	/fu/	390	770	--	0	0	0	0	0	0
/xu--/	390	770	2310	/--xu/	390	770	2310	/xu/	390	770	--	0	0	0	0	0	0
/sɿ--/	460	1310	2390	/--sɿ/	460	1310	2390	/sɿ/	540	1390	2390	-15	-6	0	-15	-6	0
/ʂʅ--/	460	1770	2390	/--ʂʅ/	460	1690	2310	/ʂʅ/	390	1690	2310	+18	+5	+3	+18	0	0
/ɕi--/	390	2080	2900	/--ɕi/	390	2080	2900	/ɕi/	390	2160	3000	0	-4	-5	0	-4	-5
/fe--/	460	2080	2780	/--fe/	460	2080	2840	/fe/	390	2080	3000	+18	0	-7	+18	0	-3
/xɤ--/	540	1230	2310	/--xɤ/	540	1230	2310	/xɤ/	540	1230	2390	0	0	-3	0	0	-3

etc,).

The articulation of voiceless fricatives /f,s,ʂ,ɕ,x/ in SC are different in place of articulation by gestures, and more or less differ in their articulation manner of whether it is a sibilant or not, or whether it is excited by the turbulence of a slit or of a groove. Their coarticulations can be classified into three groups according to their articulators, i.e., /f/, the heteroganic; /x/, the homorganic and /s/, /ʂ/ and /ɕ/, the contiguous. The coarticulations of these fricatives are also different in context distributions, which are controled by the relations intra-syllabic and/or inter-syllabic. For the effects of coarticulation, some of them are C-dependent, some V-dependent and some speaker-dependent. (Recasens 1989). Rules of coarticulation are not so easy to be established, for there are so many functions have to be touched on. Moreover, the variants between different speeches by a speaker, or between different speakers, give many difficulties to the phoneticians and technicians. As the relation between the gestures and the transfer functions are not one-to-one, so the data from articulatory measurements and that from acoustic experiments are not to be applied ideally yet. However, thoroughful studies of the acoustic features of coarticulation closely controlled by the knowledge of their articulatory interrelations may be of value.

Table 6. Average data of lower margin frequencies of /s/,/ʂ/ and /ɕ/ with three vowels respectively in C1V1 and C2V2.
表6. 擦音/s/,/ʂ/,/ɕ/ 下限频率，C1与C2的平均数据.

		sa--	sɿ--	su--	ʂa--	ʂʅ--	ʂu--	ɕa--	ɕi--	ɕy--
C1	Be	4450	3590	3030	1800	2260	2280	3000	2490	2000
	En	2460	2170	1170	1620	1510	1180	2490	1950	1700
		--sa	--sɿ	--su	--ʂa	--ʂʅ	--ʂu	--ɕa	--ɕi	--ɕy
C2	Be	2150	1540	1630	1770	1620	1230	2000	2000	1930
	En	1920	1590	2310	1450	1510	1230	2160	2000	2080

Table 7. The average duration data(ms) of fricative noise in C1 and C2 of C1V1C2V2 in SC, spoken by speakers A and B.
表7. 普通话擦音在CVCV双音节中的平均时长.

	Speaker A					Speaker B				
	/s/	/ʂ/	/ɕ/	/f/	/x/	/s/	/ʂ/	/ɕ/	/f/	/x/
C1	160	180	190	110	140	200	210	190	140	120
C2	140	170	160	150	170	200	200	180	150	140

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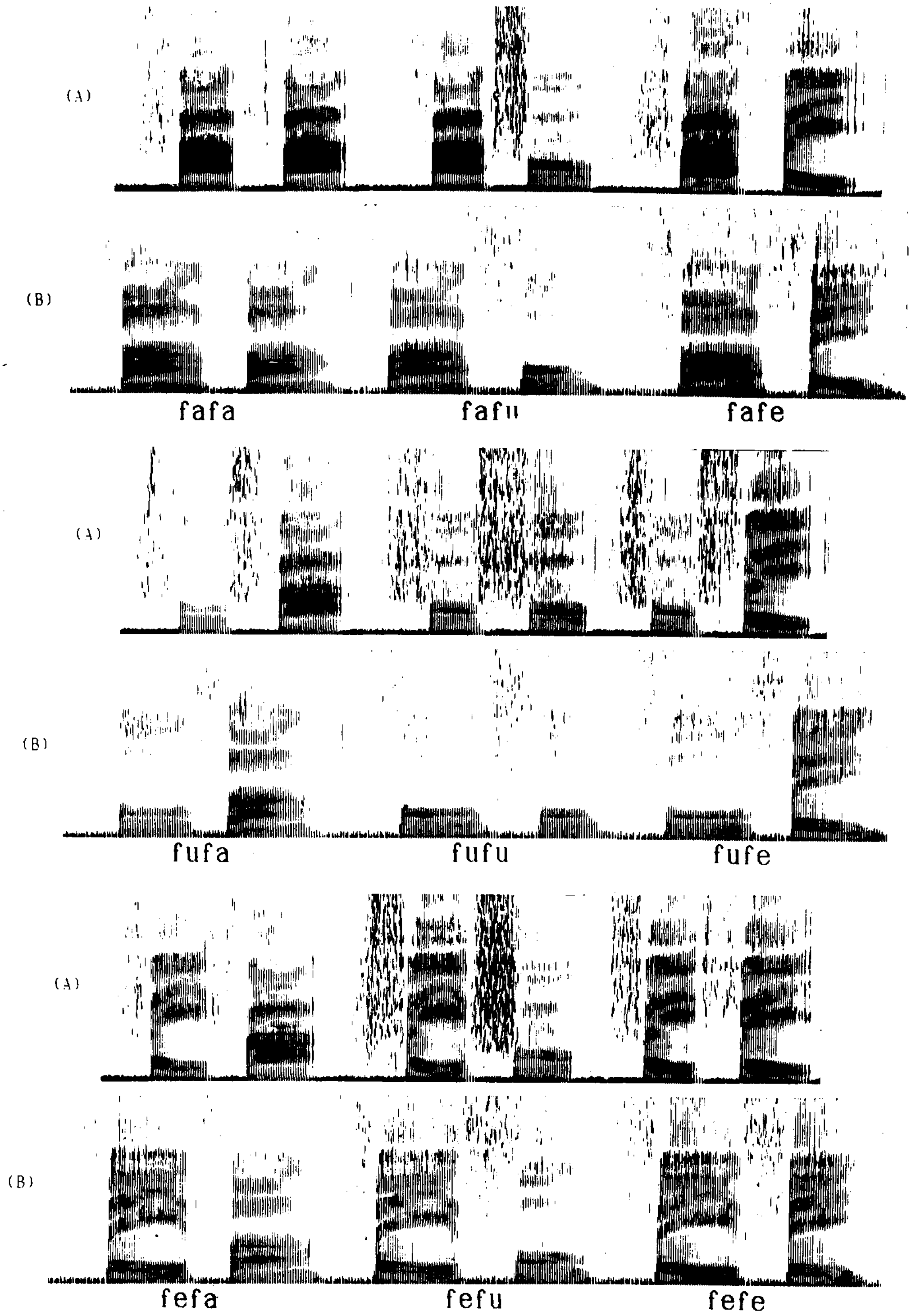

Fig. 1. Spectrograms of SC fricatives /f/ in CVCV spoken by speakers A and B.
图1. 普通话清擦音/f/在辅元辅元中的语图(发音人 A,B).

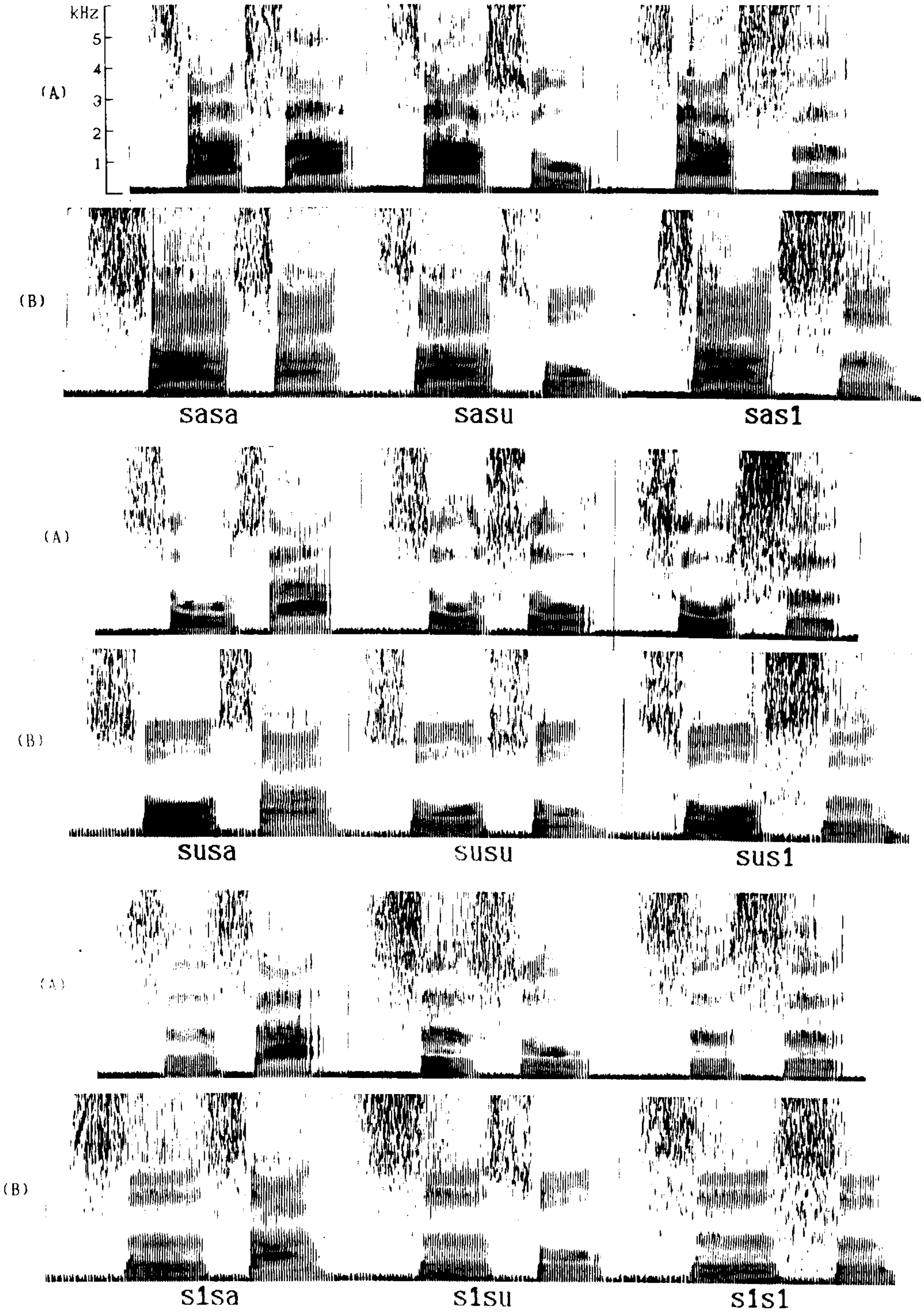

Fig. 2. Spectrograms of SC fricatives /s/ in CVCV spoken by speakers A and B.
图2. 普通话清擦音/s/在辅元辅元中的语图(发音人 A,B).

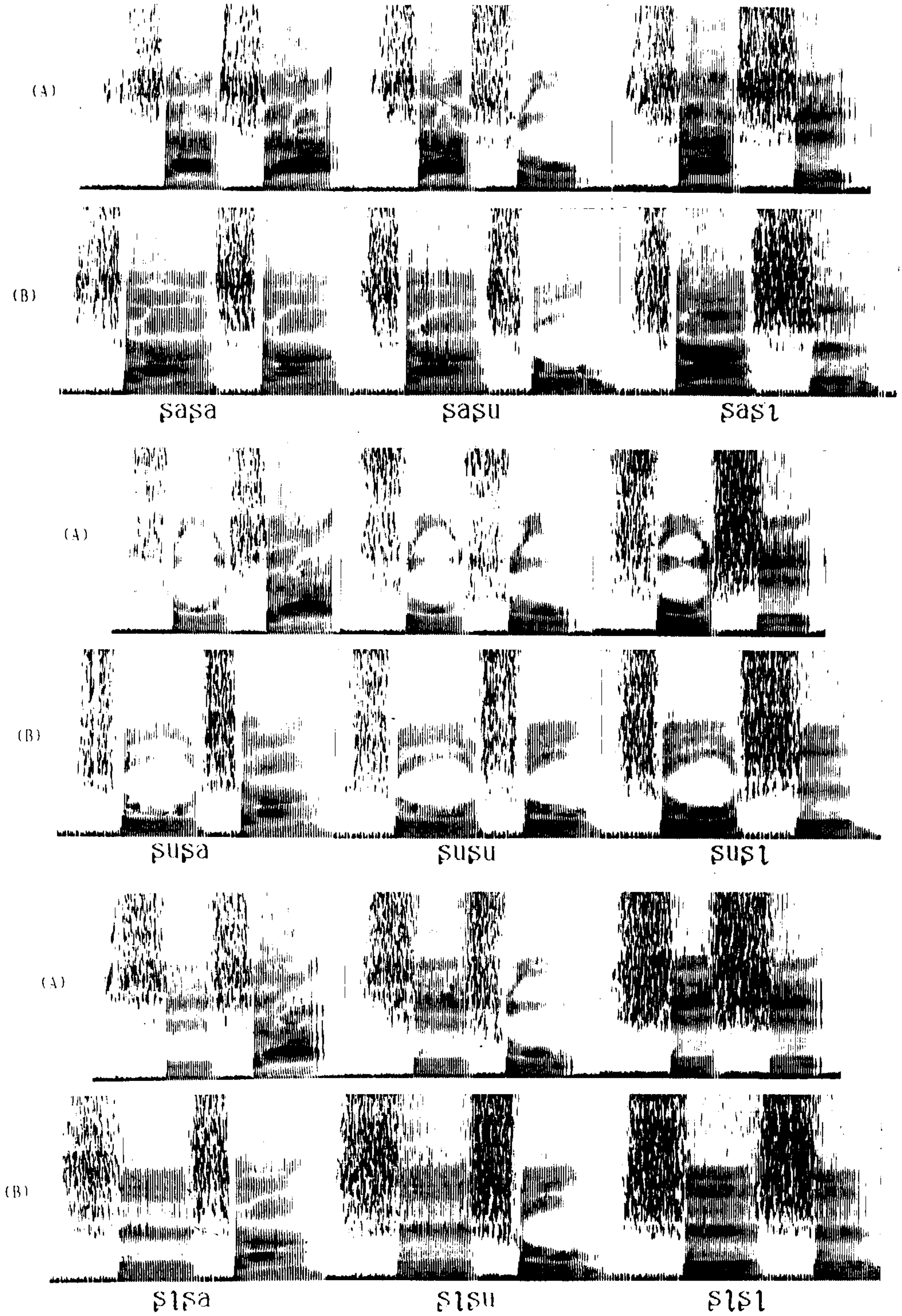

Fig. 3. Spectrograms of SC fricatives /ʂ/ in CVCV spoken by speakers A and B.
图3. 普通话清擦音/ʂ/在辅元辅元中的语图(发音人 A,B).

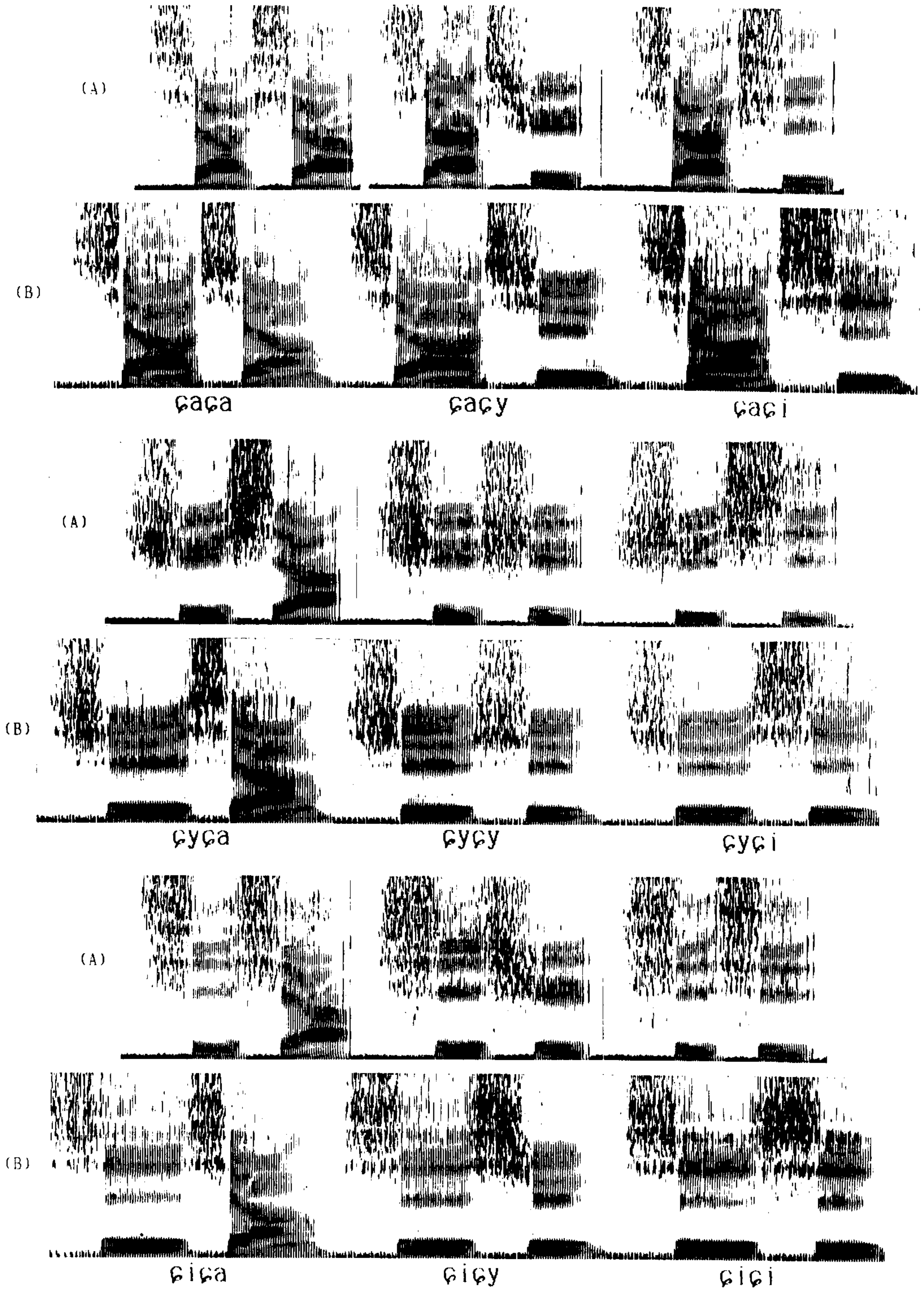

Fig. 4. Spectrograms of SC fricatives /ɕ/ in CVCV spoken by speakers A and B.
图4. 普通话清擦音/ɕ/在辅元辅元中的语图(发音入 A,B).

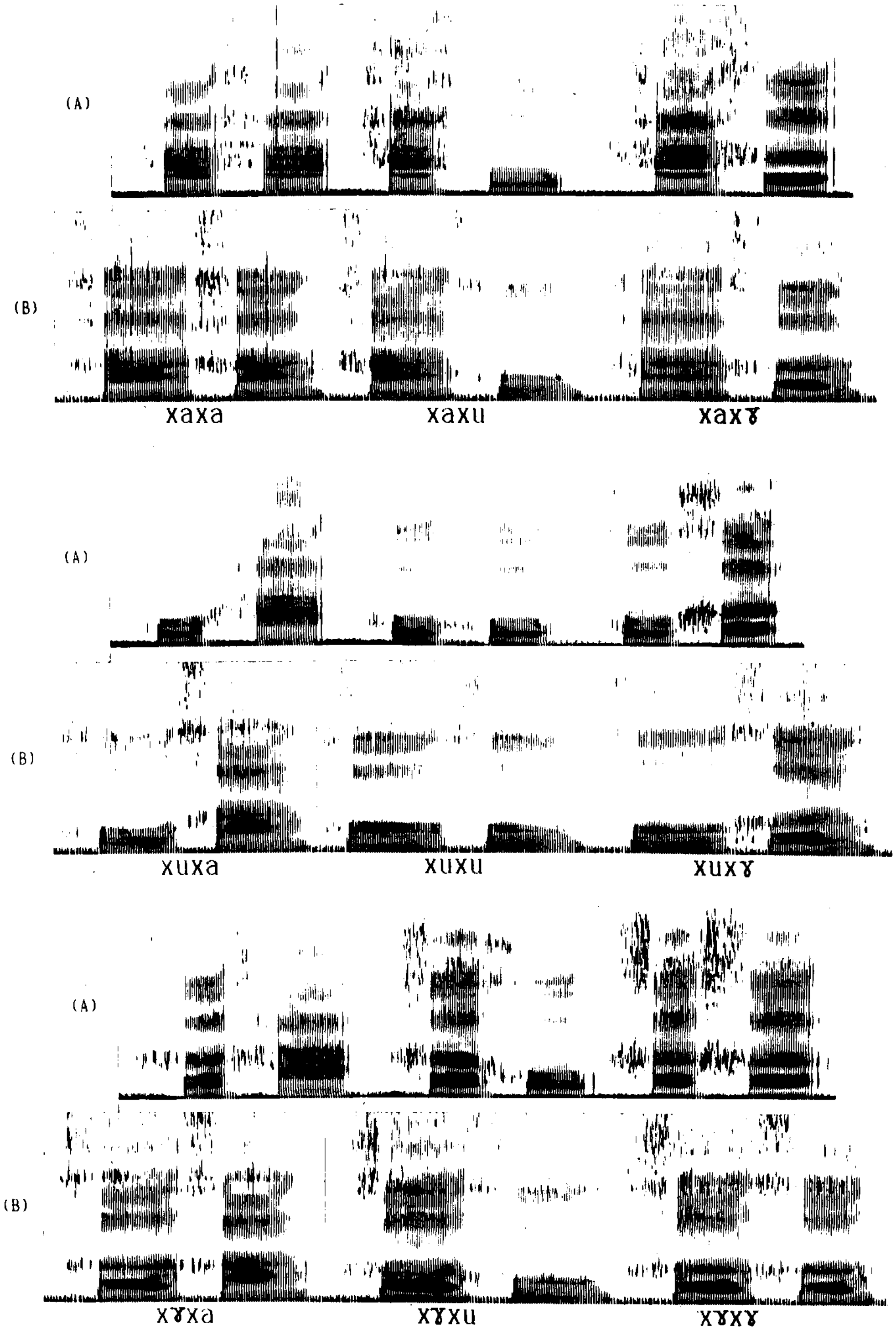

Fig. 5. Spectrograms of SC fricatives /x/ in CVCV spoken by speakers A and B.
图5. 普通话清擦音/x/在辅元辅元中的语图(发音人 A,B).