question to answer, but it seemed that the constriction was usually between the edge of the tip of the tongue and the upper teeth.

A similar difference to that between British and American dialects has been observed between several Shandong dialects of Chinese by Sung (1986). Where the majority of dialects in this group have sibilants, Rongcheng and Qingdao have developed dental nonsibilant fricatives, and Jiaonan has taken the change still further and uses interdental fricatives. The speakers of this latter dialect are well known for the way in which they actually protrude the tongue between the teeth.

Both the American and British varieties of 0 and 3 are non-sibilant fricatives, with the turbulence being produced at the interdental or dental constriction. Non-sibilant fricatives of this kind can also be made further back, with the tongue near the front part of the alveolar ridge. The IP A does not provide a symbol specifically for non-sibilant alveolar fricatives. Following the principles used in the previous chapter, we will use 0 and 3 with the diacritic indicating a more retracted articulation. In Icelandic both 0 and 3 are definitely alveolar non-sibilant fricatives, the former being laminal, and the latter usually apical. Figure 5.5, based on data in Petursson (1971), shows the pronunciation of 0 as in 0aki3 'roof, and 3 as in vaSan 'whence'. In each case the constriction is in the alveolar region, and the teeth are fairly far apart so that it is clear that they do not form an obstruction.

A voiced alveolar fricative 3 sometimes occurs as an allophone of the alveolar stop d in formal Danish, in phrases such as lieda foyi3 *{lade foged)* 'barn keeper'. Jespersen (1897-9) describes this Danish sound as a laminal alveolar fricative, made with the tip of the tongue behind the *lower* front teeth. However, the constriction in present-day Danish 3 is often so weak that there is little audible friction, and the sound might be better classified as an approximant. Bauer, Dienhart, Hartvigson and Jakobsen (1980) note that "only in very distinct Danish - as from the stage of the Royal Theater - do we get a fricative."

It is possible to form a non-sibilant fricative using the teeth themselves as the only constriction. Passy (1899) describes a fricative in the Shapsug dialect of Adyghe which has "the lips fully open, the teeth clenched and the tongue flat, the air passing between the teeth; the sound is intermediate between J and f"

(Passy 1899: 110, our translation). This sound was noticed independently by Catford who comments that "the Adyghe bidental fricative is, in fact, a variant of x, occurring for the x in such words as xa 'six' and daxe 'pretty' in the Black Sea sub-dialect of Shapsug" (Catford, personal communication). A convention for transcribing bidental sounds with the dental diacritic both above and below a Coronal symbol has been proposed by Duckworth, Allen, Hardcastle and Ball (1990).

5.2 Sibilants

The more usual fricatives in the dental and alveolar regions are the sibilant fricatives s, z, s, z. In these fricatives the principal source of the sound is the turbulent airstream produced when the jet of air created by the dental or alveolar constriction strikes the teeth, which form an obstacle downstream from the constriction itself. We see, therefore, that at some points within the vocal tract it is possible to form two different constrictions, one that will produce a sibilant fricative, and one that will produce a non-sibilant fricative. Icelandic, in fact, has both a sibilant and a non-sibilant alveolar fricative. The right-hand part of figure 5.5 shows the Icelandic sibilant fricative s. Petursson (1971), describing the difference between what we have called the non-sibilant and sibilant voiceless alveolar fricatives says: "The first important difference is that 0 is articulated with the blade of the tongue, but for s the tip is raised. The place of articulation is more advanced for 0 than for s. The shape of the tongue is different for the two consonants; for 0 it is flat, for s it has a characteristic curve. The alveolar constriction is also different: for 0 it is large, for s it is a narrow channel." (Our symbols and translation.) An apical/laminal distinction is thus playing a role in this distinction, but it is not the only one. Note also that although both these fricatives have constrictions near the alveolar ridge, in the sibilant fricative the teeth are also close together.

It is also possible to produce sibilant fricatives with a dental constriction, in the same region as that used for the non-sibilant 0 sounds. Indeed, the sibilant

'deer' vs *jukinal* 'awl'.

English s usually has a constriction in the middle of what we refer to as the alveolar region (i.e. the forward part of the alveolar ridge). It can be formed either by the tip of the tongue, or by the blade with the tip behind the lower front teeth. Bladon and Nolan (1977) point out that there is considerable disagreement among authorities as to which is the most common articulation. In their own videofluorographic study of eight speakers of different forms of British English, they found that seven of these speakers had a laminal s. In her investigation of 20 American English speakers, Dart (1991) found that 52.5 percent of the tokens had laminal articulations and 42.5 percent had apical articulations. The differences in the part of the tongue used are probably due to individual anatomical characteristics. The amount of protuberance of the alveolar ridge, and the relation between the lower jaw and the upper teeth, affect the gesture that is required to produce the acoustic structure necessary for s. Indeed, McCutcheon, Hasegawa and Fletcher (1980) have shown that even the location of the rugae (the ridges on the roof of the mouth) have an effect on how an individual chooses to form the constriction for s. There are, of course, articulatory regularities that are constant. All speakers of English pronounce this sound with the upper and lower teeth close together, making it a strident fricative; and there is always a narrow groove in the tongue directing a jet of air towards the teeth. For many speakers the lower lip is also involved in directing the airstream towards the edge of the upper teeth. The constriction must be close to the teeth, but the precise channel location, and the apical-laminal distinction are not of particular importance in the characterization of the general, cross-speaker, properties of English s.

Perhaps the most remarkable but least remarked feature of the articulatory gesture for English s is the deep pit which may occur in the center of the tongue. The articulatory constriction forming the jet of air consists of a groove, 5-10 mm long, running in the posterior-anterior direction. Behind this groove there is often a wide pit, extending out to the sides of the tongue. Some English speakers produce s in a word such as *saw* with the center of the tongue depressed several millimeters below the level of the sides of the tongue, as can be seen in figure 5.6, which is based on x-ray and palatographic data reported by

positions of the side of the tongue as indicated by palatograms. The coronal section on the right gives a transverse view of the shape of the tongue at the point indicated by the arrow on the sagittal section on the left (based on data in Ladefoged 1957).

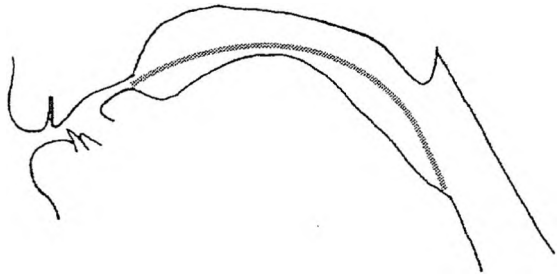

Figure 5.7 Tracings from an x-ray photograph of David Abercrombie, another speaker of British English (RP dialect), taken during the pronunciation of s as in *saw*. The grey line indicates the position of the sides of the tongue. The solid line shows the center of the tongue, as outlined by a radio opaque marker.

Ladefoged (1957). For this speaker (Peter Ladefoged) at a point about 20 mm behind the tip of the tongue the midline is 12 mm below the sides. This particular utterance may have had a slightly exaggerated articulation in that the x-ray picture was taken during a very slow pronunciation of the word *saw;* but it neither sounded nor felt in any way atypical.

The fact that there is a deep hollow in the center of the tongue is often hard to determine from x-ray pictures in which the midline of the tongue has not been explicitly marked. Bladon and Nolan (1977) do not comment on the possibility, perhaps because they chose to mark the sides rather than the center of the tongue, fearing that a strip down the center of the tongue might affect the pronunciation. We did not notice anything unusual in the speech of any of our subjects who were being photographed while they had a thin line of barium sulphate down the midline of the tongue. Figure 5.7 shows the gesture used by

other comments in the text, it is likely that the "characteristic curve" mentioned by Petursson (1971) in his description of Icelandic s quoted above is a hollowing of this kind. We do not know the proportion of all s sounds that involve a hollowing of the tongue just behind the constriction, but it is probably more common than has been previously reported.

The more posterior sibilant in English, symbolized J in the IPA tradition, has been variously described. Jones (1956), Abercrombie (1967), Ladefoged (1993), and Prator and Robinett (1985) call it a palato-alveolar fricative. Bronstein (1960) describes the tongue position in much the same way as Jones, but uses the term alveolo-palatal. Most of the authors note that the constriction in f is wider as well as being further back than in s. Both Jones and Bronstein say that most people make this sound with the tip of the tongue up, but that some speakers have the tip of the tongue down behind the lower front teeth. Borden and Harris (1980) somewhat eccentrically describe English J as palatal. Hockett (1958) describes it as a lamino-alveolar or lamino-domal surface spirant, involving "a close approximation of a whole area, from side to side and from back to front."

English J is similar to s in that for both sounds the teeth are close together, making them strident fricatives. There are several differences between them: the constriction is further back and wider for J; the part of the tongue immediately behind the constriction for f is raised (or domed), as opposed to being hollowed for s; and J has added lip rounding or protrusion. It should be noted that the secondary articulation of lip rounding is a feature of f in some languages, such as English and French, but it is not found in many other languages, such as Russian.

The articulation of J in 'Shaw' as produced by Peter Ladefoged is illustrated in figure 5.8. The constriction is in what we have called the post-alveolar region, that is, on the center of the alveolar protruberance. It is clearly further back than the alveolar s illustrated in figure 5.6, in which the constriction is on the flat part of the alveolar ridge, just behind the upper incisors. The front of the tongue is raised, with the center being above the level of the sides.

In a palatographic survey of 164 students at the University of Edinburgh,

positions of the side of the tongue as indicated by palatograms. The coronal section on the right gives a transverse view of the shape of the tongue at the point indicated by the arrows on the sagittal section on the left (based on data in Ladefoged 1957).

Ladefoged (1957) reported that "for every speaker the articulation of the voiceless fricative in *sip* involves the formation of a narrower channel (which is usually also further forward) than that in *ship.*" The wider channel in J results in the jet of air striking the teeth at a lower velocity in J than in s. In addition, all the speakers described in Ladefoged (1957) produced J with the sides of the tongue raised higher up towards the hard palate than for s, with, presumably, concomitant raising of the center of the tongue as shown for the speaker in figure 5.8. The degree of lip rounding was not recorded for these subjects, but, as we have noted, English / is typically somewhat rounded. The acoustic structure of sibilant fricatives will be considered later, but we may note here that both the lower velocity of the airstream, and the lengthening of the vocal tract by added lip rounding, will cause J to have a lower pitch than s.

Consideration of the articulatory characteristics that we have observed lead us to define J as a post-alveolar domed sibilant. By domed we mean to denote the raising of the front of the tongue that occurs, irrespective of whether an apical or laminal articulation is used. This doming is equivalent to a small amount of palatalization. We will regard the phrase palato-alveolar sibilant as an exactly equivalent specification, denoting a comparatively wide constriction in the post-alveolar region near the center of the alveolar protruberance, with concomitant raising of the front of the tongue. We will distinguish between palato-alveolar and alveolo-palatal sibilants, using the latter term as an alternative specification for the post-alveolar palatalized sibilants that we will describe in Standard Chinese. We will avoid Borden and Harris's use of the term palatal, reserving that for sounds made further back in the mouth.

English J is also like s in that both sounds can be made with the tip of the tongue up or down. In a survey of 16 speakers of Californian English we found that 8 of them raised the tip of the tongue above the plane between the upper

We will now consider Standard Chinese (Mandarin), which has a number of sibilant fricatives made in the alveolar and post-alveolar regions. Relevant examples are given in table 5.3, together with words illustrating the other fricatives of the language. We have given standard IPA transcriptions, with the initial consonants each followed by just the vowel a. From a phonetic point of view there is nothing other than a normal transition between the initial consonant and the following vowel in all these cases. But the usual Chinese Pinyin orthographic forms have *ia* where we have a in the palatalized post-alveolar (alveolo-palatal) column. This reflects one possible interpretation of the phonological status of the alveolo-palatal sounds, that is, that they are the result of assimilation of alveolar sibilants to a following high front vowel.

Figures 5.9 and 5.10 show data for alveolar s, post-alveolar (retroflex) 5, and palatalized post-alveolar (alveolo-palatal) c as produced by three speakers of Standard Chinese (based on Ladefoged and Wu 1984). The first point to note is that for all three sounds for all three speakers the upper and lower teeth are fairly close together, so that these three sounds are all clearly sibilant fricatives. In each of the sounds the tongue forms a differently shaped channel for the air; but the main source of acoustic energy is always the turbulence that arises when this air passes between the nearly clenched teeth.

Table 5.3 Words illustrating contrasts among Standard Chinese fricatives and affricates. All the words shown have high level tone (Tone 1)

LABIODENTAL	ALVEOLAR	FLAT POST-ALVEOLAR (RETROFLEX)	PALATAUZED POST-ALVEOLAR **(ALVEOLO-PALATAL)**	VELAR
fa 'to issue'	sa 'let out'	$a 'sand'	ca 'blind'	xa 'sound of laughter'
	tsa 'take food with tongue'	t$a 'to pierce'	tea 'to add'	
	ts^{h}a 'to wipe'	t$^{h}a 'to stick in'	tc^{h}a 'to dig fingernail into'	

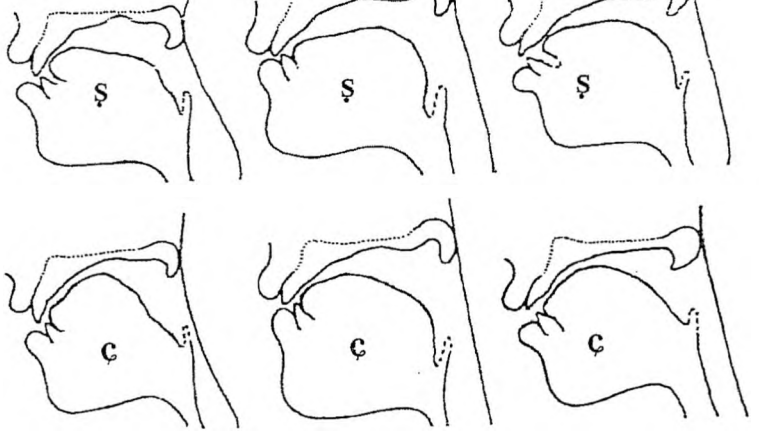

Figure 5.9 Tracings from x-rays of three speakers producing Standard Chinese sibilant fricatives, based on Ladefoged and Wu (1984).

As the top row of figure 5.9 shows, all three speakers produced s with the tip of the tongue; in all three cases there is a hollowing of the tongue such that the tongue is concave with respect to the roof of the mouth, although the hollow does not appear to be as deep as that for the English speakers reported above. The palatograms in figure 5.10 show that speakers B and C make this sound with a narrow slit, with a width of 4.5 mm for speaker B and 3.75 mm for speaker C. Speaker A made this sound with the narrowest channel on the teeth, so palatographic data is not available for this measurement. The height of the slit is about 1 mm for speakers A and B, and even less for speaker C. These measurements of the width and height of the constriction are similar to those for English s reported by Subtelny and Mestre (1964) and Subtelny and Oya (1972).

The position of the point of greatest constriction is slightly different for each speaker. For speaker A it is on the teeth, for speaker B slightly behind the teeth, and for speaker C still further back, so that it is on the front part of the alveolar

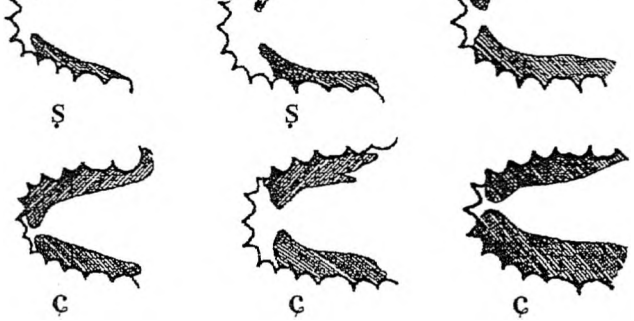

Figure 5.10 Palatograms of the same words illustrated in Figure 5.9, based on Ladefoged and Wu (1984).

ridge. Given these data, it seems that this sound does not have a very exact place of articulation (in the sense of the precise location of the constriction in relation to the anatomical features of the roof of the mouth). This again agrees with the data for English s as described above. In Chinese, as in English, s must have a constriction located close to the teeth; and this constriction must form a narrow channel directing air towards the teeth at a high velocity. But the speaker's individual dentition and mouth shape will determine where the constriction is in relation to the alveolar ridge. For each of the speakers in figure 5.9 the constriction is at a similar distance from whatever narrowing provides the obstacle - the gap between the lower and upper teeth for speakers A and C, but probably the gap between the lower lip and the upper teeth for speaker B.

The Standard Chinese so-called retroflex s is shown in the middle rows of figures 5.9 and 5.10. This gesture is plainly very different from that in the retroflex stops discussed in chapter 2. It does not involve the tip of the tongue being curled up and backwards into the palatal region, as in the Dravidian sub-apical retroflex stops, nor does it have the apical post-alveolar shape that occurs in the Hindi retroflex stops shown in figure 2.11. In our Standard Chinese data, all three speakers produce the constriction for this sound with the

sibilant. A further point to note about this gesture is that no part of the tongue is touching the lower teeth, as occurs in the articulation of s. Instead the tongue is drawn slightly back, so that there is a sublingual cavity. Perkell, Boyce and Stevens (1979) have shown that a cavity of this type has a significant acoustic effect, producing a comparatively low frequency spectral peak. Additional x-ray data in other publications (Zhou and Wu 1963, Ohnesorg and Svarny 1955) all show substantially the same gesture, confirming the notion that Standard Chinese 5 is a (laminal) flat post-alveolar sibilant. The traditional description of this sound as a retroflex is inappropriate as a description of its articulation.

The third sibilant in Standard Chinese, c, is usually termed an alveolo-palatal sound. The tongue has a very different position in this sound from that in any of the other sounds we have been considering, as may be seen from the data in the bottom rows of figures 5.9 and 5.10. There are some similarities to English f, but both the blade and the body of the tongue are higher in the mouth, forming for each speaker a comparatively long, flat, constriction. The extent of this constriction may be estimated from the palatograms in figure 5.10. For all three speakers there was contact between the sides of the tongue and the palate high in the mouth all the way back to the molar teeth. It is possible that some of the turbulence may be formed along the wall of this long constriction, as suggested by Shadle (1985) for palatal and velar fricatives. But it is also apparent that these speakers raise the lower jaw so that the upper and lower teeth are close together, making the Standard Chinese <; a strident fricative.

For none of the speakers is the constriction for c in exactly the same place as in either of the other two Chinese sibilants. From a comparison between the palatograms and the x-ray tracings it is apparent that the narrowest channel occurs near the front part of the alveolar ridge for speakers A and C, and notably farther back for speaker B. The palatograms show that it is consistently farther back than in s but not quite as far back as in s. The difference between 5 and c is small, so that it might be possible to consider both of them as having constrictions in the post-alveolar region, as in English J-. However, all phoneticians who are familiar with both English and Chinese invariably note that English J is not the same as Chinese c, the major difference being in the degree of raising of the front of the tongue. We referred to J' as a domed