either approximant or fricative. Although this distinction often correlates with voicing - approximants being voiced and fricatives being voiceless - it cannot be predicted from it, since voiced and voiceless fricative laterals contrast, as do voiced and voiceless approximant laterals. Hence degree of stricture - approximant or fricative - must be specified with respect to the lateral aperture. The location of this aperture, except perhaps for velar laterals, is at a different position on the upper surface of the vocal tract from that for the maximal constriction, which is traditionally recognized as the place of articulation for the lateral. The manner specification describing the lateral aperture thus does not apply to the action at the articulatory target region which defines the place of the lateral segment.

Moreover, as we noted above, it is not necessarily true that laterals are produced with a central contact, nor is it appropriate to limit the term lateral to approximants and fricatives. Hence, to describe phonetic detail, including important allophonic variation in some languages, the type of central stricture also needs to be specified. In a sense, then, we are arguing that laterals are segments with two articulations. One governs the location and type of stricture of the central articulation and the other governs the location and size of the lateral aperture. Admittedly, there are probably few instances where advantage is taken of the degrees of freedom implied by recognizing two articulations. Lateral fricatives (and the fricative phase of lateral affricates) will normally be produced with a central closure since this will facilitate narrowing of the lateral escape aperture. Most research indicates that lateral approximants also usually have a central closure. Nonetheless we need to be able to provide a description of (at least) lateral approximants with and without central closure and laterals with a central closure with and without a fricative escape. In considering the production of laterals, it is important to bear in mind that the place of articulation for a lateral and its degree of stricture result from two separate articulatory components.

7.1 Rhotics

This chapter describes the class of sounds that are sometimes labeled 'rhotics', or more informally, 'r-sounds'. Most of the traditional classes referred to in phonetic theory are defined by an articulatory or auditory property of the sounds, but the terms rhotic and r-sound are largely based on the fact that these sounds tend to be written with a particular character in orthographic systems derived from the Greco-Roman tradition, namely the letter Y or its Greek counterpart *rho*. The International Phonetic Alphabet provides a wide selection of symbols based on plain, rotated, turned or otherwise modified lower-case and capital versions of the letter 'r', including r, r, J, [, 4, R, B, J. Brief definitions of the sounds represented by these symbols are given in table 7.1.

The most prototypical members of the class of rhotics are trills made with the tip or blade of the tongue (IPA r). These central members of the class show phonological relationships to the heterogeneous set of taps, fricatives and approximants which form the remainder of the class. In addition to tongue tip and blade articulations, trills and other continuants made at the uvular place are also classed as rhotics. (As we noted in chapter 4, bilabial trills also occur but they are not part of the class of rhotics.) It is not therefore the manner of articulation that defines this group of sounds. Neither is there a particular place involved, as both Coronal and Dorsal articulations are included. Consequently an issue for phoneticians is whether the class membership is based only on synchronic and diachronic relationships between the members of the class, or whether there is indeed a phonetic similarity between all rhotics that has hitherto been missed. This similarity might be auditory or acoustic, rather than articulatory. The issue has been particularly discussed by Lindau (1985), and the following account will draw quite heavily on the data and ideas in that paper, as well as further materials collected by Inouye (1991a, b).

Phonologically, rhotics tend to behave in similar ways. In particular, rhotics often occupy privileged places in the syllable structure of different languages. They are not uncommonly the only consonants allowed as second members of clusters in the syllable onset, or as first members of clusters in coda position. More generally, we may say that in languages with consonant clusters, rhotics tend to occur close to the syllable nucleus (Lindau 1985). Frequently they share this privileged position with lateral approximants, and/or nasals. The affinity between rhotics and vowels is apparent in a number of other ways as well. Rhotics are quite likely to have syllabic variants, or to merge in various ways with contiguous vowels. Such processes, operating diachronically, are a particularly fertile source of phonetic differences between dialects of the same language. Hence the familar division of varieties of English into 'rhotic' and 'non-rhotic' types, depending on whether or not historic postvocalic /r/'s in prepausal and preconsonantal positions are retained in pronunciation. Somewhat parallel variations occur in other Germanic languages, including German, Danish, and Swedish. Further evidence of the rhotic-vowel affinity is the fact that vowels before *I*r/'s tend to lengthen, as in Swedish, and to be 'colored' in their quality by the following /r/. Acoustic modifications of vowels before /r/'s are known from French and Danish with their uvular r-sounds, as well as in Standard Swedish with its apical r-sound. Most important as evidence that they belong in a single class, at least from a phonological point of view, is the fact that rhotics of one type often alternate with other rhotics. In Farsi, /r/, which is a trill in initial position, has a tap allophone in intervocalic position and a voiceless trill variant in word-final position. In Fula, /r/ is realized as an approximant a before a consonant, as a trill elsewhere. In Palauan / r/ is generally a tap in intervocalic and postvocalic environments but an these types, paying particular attention to the possibilities that seem to occur contrastively. Following this discussion, we will return to the question of whether an auditory or acoustic property can be held to unify the various disparate members of the group.

Following conventional notions of the membership of the class as being primarily those sounds that are written with some variant of the letter 'r', it is apparent that rhotics are quite common in the languages of the world. About 75 percent of all languages contain some form of an /r/ phoneme (Maddieson 1984a). These languages mostly have a single /r/, and it is most commonly some form of trill, but 18 percent of languages with /r/'s contrast two or three rhotics. Languages with multiple rhotics are especially common in the Australian language family.

7. 2 Trills

The primary characteristic of a trill is that it is the vibration of one speech organ against another, driven by the aerodynamic conditions. One of the soft moveable parts of the vocal tract is placed close enough to another surface, so that when a current of air of the right strength passes through the aperture created by this configuration, a repeating pattern of closing and opening of the flow channel occurs. This movement has been modeled by McGowan (1992). In its essentials this is very similar to the vibration of the vocal folds during voicing; in both cases there is no muscular action that controls each single vibration, but a sufficiently narrow aperture must be created and an adequate airflow through the aperture must occur. The aperture size and airflow must fall within critical limits for trilling to occur, and quite small deviations mean that it will fail. As a result, trills tend to vary with non-trilled pronunciations. So with trills, as with voicing, there is a potential conflict between an acoustic definition (more than one period of actual vibration) and an articulatory definition (positioning of the articulators in a configuration such that, given the right aerodynamic conditions, vibration would occur). In this chapter we will consider trills to be sounds made with an articulatory configuration

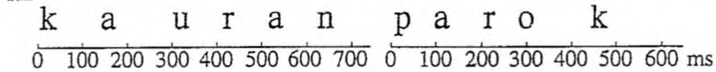

Figure 7.1 Spectrograms *of* apical trills in the Finnish word kauran 'oats (genitive)' and the Russian word porok [pa'rok] 'threshold'. Both speakers are female.

appropriate for vibration, regardless of whether vibration actually occurs. Although a vibratory pattern can be sustained for as long as a sufficient airflow is available, acoustic trills in linguistic use usually consist of two to five periods (geminate occurrences may be longer). We have noted that the first closure in a trill often has a slightly longer duration than following ones.

Trills are much more easily produced if the vibrating articulator has relatively small mass, hence the most common trills involve the tongue tip vibrating against a contact point in the dental/alveolar region, or the uvula vibrating against the back of the tongue. In fact by far the most common type of trill is one involving the tongue tip. We will discuss trills of this general type at some length, using them to illustrate some of the general characteristics of trills, before going on to talk of ones made at other places of articulation. Figure 7.1 shows spectrograms of voiced apical trills in Finnish and Russian. Apical trills typically consist of two to three periods of vibration - these examples both have two - but may contain only one or have more than three. Each period consists of a closed phase during which the articulators are in contact, succeeded by an open phase in which they are slightly apart. On the spectrograms the closed phases appear as light areas, as the formant energy is absent or weak. The open phase between these two closures, which is vowel-like in its acoustic structure, appears as a dark area with concentrations of energy in characteristic formant regions. The closed phases of these trills last on the order of 25 ms each. The open phases have roughly similar duration, so that each complete cycle occupies about 50 ms. There would thus be about 20 of these cycles in a second, and we can say that these particular trills have a frequency of vibration of about 20 Hz. In Lindau's study, the mean rate of vibration for apical trills produced by a total of 25 speakers of Edo, Degema, Ghotuo, Kalahari, Bumo, Spanish, and Standard Swedish was 25 Hz (range 18-33 Hz, s.d. 4.5).

a similar formant structure to that seen in the open phase. This is part of the consonant duration, as the tongue does not move away from the consonantal position until it ends. The end of the consonant is indicated by an abrupt upward transition of the third formant, as well as a significant upward shift in Fl. The approximant phases flanking this trill indicate that the tongue was not consistently held close enough to the upper surface of the mouth for trilling to be sustained. Approximant phases at the end of trills occurred on some occasions in all the languages with trills studied by Lindau (1985). By contrast, the initial trill in speaker B's pronunciation of rosso 'red' contains five very short closures, including an initial one before phonation begins, and there is no delay of the transition to the vowel following the last closure release. As a result the total acoustic duration of the initial consonants in these two words is very similar, although their detailed phonetic structure is quite different.

In Italian, single and geminate forms of most consonants contrast in intervocalic position (a contrast between stops was illustrated in chapter 2). The single/geminate opposition also applies to trills. The second and third rows of figure 7.2 illustrate these single and geminate intervocalic trills in the minimal pair karo 'expensive' and karro 'wagon, cart'. In karo, speaker A has a very short trill consisting of only one contact and no other components, speaker B shows one clear contact followed by a less complete occlusion with frication. The gemmate trills in karro show multiple contacts followed by one or more periods in which the articulatory closure is not completed but the articulator is still oscillating sufficiently to produce a diminution of the amplitude. For speaker A the trill consists of three closures, a partial occlusion during which formant structure remains visible, and an extended approximant articulation, indicated by the low amplitude and the low frequency of the third formant. The end of the consonant can be recognized by the point at which the third formant begins to rise. Its total duration is about 200 ms. (The end of the final vowel is strongly laryngealized, giving a visual impression of another trill in the spectrogram.) For speaker B the trill ends as a fricative. There are also noticeable differences in the formant transitions, which are particularly apparent in the single trills. Speaker B has a greater increase in F2, and a lowering of F3, suggesting a more retracted position of the tongue.

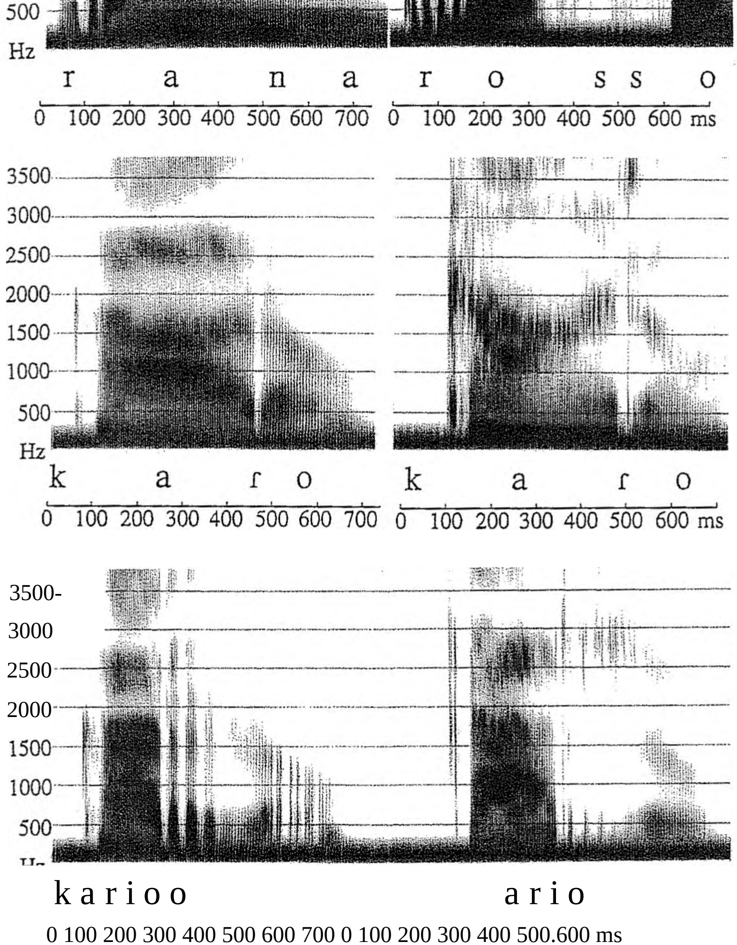

Figure 7.2 Initial, medial single and medial geminate alveolar trills from two speakers of Standard Italian. See text for discussion.

sometimes be seen more easily in examination of a waveform. Figure 7.3 shows a spectrogram of the Finnish word koiran 'dog (genitive)'. An expanded waveform of the portion containing the trill is also shown at eight times the time scale of the spectrogram. This particular trill contains two contacts of the tongue, indicated by the arrows linking the waveform and spectrogram. During the first, but not the second, the vocal fold vibration dies away. This absence of voicing cannot be due to active changes in the laryngeal setting. Voicing occurs during the open phase between the closures, and it is not possible to alternate voluntary movements with sufficient rapidity. Hayes (1984) suggests that, in Russian, r's that are adjacent to voiceless obstruents regularly show this devoicing in closures, with voiced open intervals. Although only a small amount of data is shown, this result might suggest that a slightly more open glottis throughout the trill is associated with the occurrence of voiceless closures. The devoicing in such cases is presumably aerodynamically driven, in that the rapid variations in oral pressure associated with a trill may result in moments in which the transglottal pressure drop is insufficient to sustain vocal fold vibrations. However, since the closures are of such short duration it is necessary to assume that the vocal tract walls are held in a stiff position so that there is very little compliance.

Although apical trills all use the same active articulator, they vary across speakers and languages in the location of the contact on the upper surface, and in some languages different places of articulation are contrastive for apical trills. An x-ray tracing of the apical trill of Peninsular (Iberian) Spanish in Quilis and Fernandez (1964) shows a contact just above the gum line of the upper teeth, which could be labeled postdental. In Russian, Skalozub (1963) shows a post-alveolar trill as typical for r, but a dental contact for the palatalized trill rL This difference is illustrated by the palatograms in figure 7.4 from one of the speakers she studied. Variations in the shape of the tongue behind the forward contact are also apparent in this figure, which shows much greater lateral contact for the palatalized trill. Skalozub reports that the post-alveolar trill had typically 3-4 contacts, whereas r^j often has only one. The raising of the blade and front of the tongue that is required for the palatalization may make it more difficult to maintain the aerodynamic conditions for trilling. Variation in

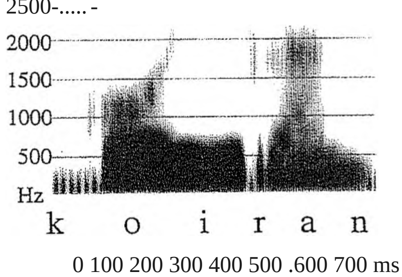

Figure 7.3 Spectrogram of the Finnish word koiran 'dog (genitive)' spoken by a female speaker from Helsinki, with expanded waveform of the apical trill showing devoicing of the first closure interval.

place of contact can also be inferred from acoustic records. Lower spectral peaks are likely to indicate more retracted articulations. Lindau noted a difference of this type between the Chicano Spanish of Los Angeles and other forms of Spanish from Argentina, Colombia, and Mexico. These display a much higher third spectral peak than the Chicano Spanish, indicating a more dental place of articulation. Lindau suggests that the low third spectral peak in Chicano Spanish may be due to influence from English.

Some Dravidian languages have more than one tongue tip trill. In careful speech (perhaps influenced by the orthography) some speakers of Malayalam contrast kan 'soot' and kari 'curry' by making the first of these words with a more advanced alveolar trill, and the second with a more retracted alveolar trill, which is almost a retroflex sound. Ladefoged, Cochran and Disner (1977) provide spectrograms of these two trills, showing that the more forward trill has a higher locus for the second formant (at approximately 1750 Hz in comparison with 1250 Hz). The more retracted trill has a lower third formant, as is commonly found in apical post-alveolar sounds. Other speakers of Malayalam use an alveolar tap in the first word and an alveolar trill in the second (Velayudhan 1971, Kumari 1972, Yamuna 1986). We will discuss this variety of Malayalam in section 7.6 below. It is perhaps worth noting that both these rhotics are phonologically related to stops in Malayalam.

Figure 7.4 Palatograms of r and *ri* in pa'ra 'time' and pa r^Ja 'soar, hover (past part.)' spoken by a female speaker of Russian (after Skalozub 1963).

Table 7.2 Words illustrating contrasting apical trills in Toda

	Fronted alveolar		Alveolar	Retroflex	
Plain	kar	'border'	kar 'juice, sap'	kac	'pen for calves'
	e:r	'to plough'	e: r 'male buffalo'	me:f	'to drive buffalo'
Palatauzed	pari	'to gallop'	kar^J 'to laugh'	$P°C^j$	'funeral rice'

Another Dravidian language, Toda, is the only language we know of that has rhotics at three places of articulation which are all trilled. All three contrast in postvocalic positions (Spajic, Ladefoged and Bhaskararao 1994). Words illustrating these three segments are given in table 7.2.

The words in the first row of table 7.2 are illustrated by the spectrograms on the left of figure 7.5 and by the palatograms and linguograms in figures 7.6-7.8. We have recordings of 12 speakers of Toda, together with palatographic and linguographic records of three of them producing these rhotic sounds. Two of the three speakers clearly produce the word meaning 'pen for calves' in the third column with an apical or even sub-apical retroflex articulation, as illustrated in figure 7.8. This column in the table has been labeled accordingly. The word for 'juice' in the second column is produced with an apical contact on the front part of the alveolar ridge at the base of the teeth. This column is therefore labeled 'alveolar'. In the standard work on Toda phonology (Emeneau 1984), the trill in the first column is described as post-dental. Our palatograms may show a slightly more forward contact, hence the label 'fronted alveolar' for this column, but there is very little visible difference in the articulatory position of the trills in the first and second columns, as shown in figures 7.6 and 7.7. However, the acoustic records indicate that this trill has a different shape of the tongue behind the contact area.

The spectrograms of the Toda trills on the left of figure 7.5 throw more light