CHAPTER 4
Articulatory Investigation of
Coronal Consonants

1. INTRODUCTION
The goal of this chapter is to explore the articulatory parameters under
control in the production of coronal sounds, the sounds which participate
in consonant harmonies. In so doing, this chapter lays the foundation for
the cross-linguistic study of consonant harmony presented in the next
chapter. In order to understand consonant harmony, i.e. consonant-to-
consonant assimilations across a vowel in a CVC sequence, it is important
first to grasp the features which are involved in such assimilations. This
chapter will introduce two such features, corresponding to two gestural
parameters: the first feature captures the well-known distinction between
apical and laminal gestures, and the second is a new feature distinguishing
fricative gestures in terms of their cross-sectional channels. Each of these
features corresponds to an articulatory configuration which can propagate
through a vowel without significantly affecting the vowel’s acoustic
output. Observing this special property will lead us to an understanding of
consonant harmony as a case of assimilation, where the assimilating
features in a CVC propagate through the intervening vowel, in accordance
with the predictions of Articulatory Locality. The main contribution of this
chapter is a proposal for a new distinctive feature defined on the cross-
sectional (or transverse) dimension. The new feature is used as a basis of
phonological contrasts among coronal fricatives. By introducing the new
feature, I hope to provide a solution to a heretofore largely untackled
problem of phonetics, namely, the issue of speaker-to-speaker variation in
the phonetic realization of phonological contrasts.
Specifically, the phonetic reality of cross-speaker variation in the production of fricatives articulated with the tip-blade appears to be rather puzzling. It is known that 50% of Californian English speakers produce [s] as an apical sound and 50% as a laminal one. The same distribution applies to [ʃ]. Dart (1991) has also shown that the place of articulation of [s] in both English and French varies considerably from speaker to speaker, being articulated with a constriction that varies from as far forward as the dental zone to as far back as the post-alveolar zone. Apical or laminal, dental, alveolar or post-alveolar [s] always sounds like an [s] to the ears of English speakers.

Ladefoged & Maddieson (1986), in a cross-linguistic survey of coronal fricative articulations, write that “separating apical from laminal articulations does not seem to be as useful in the case of sibilants as it is when distinguishing among stop consonants or liquids” (p. 78), and that “we cannot distinguish different sibilant fricatives from one another by means of the places of articulations used for stops” (p. 93). However, the features currently in use for the phonological specification of fricatives, Anterior and Distributed, correspond to the parameters of place of articulation and apicality-laminality, exactly the parameters which simply prove ineffective in describing the data.

Phonological features may also be grounded in acoustic terms, and perhaps it is in the acoustic domain that we might be able to locate the parameter for a contrast between, say, [s] and [ʃ]. Even here, however, things look equally dim. Ladefoged & Maddieson (1986) write:

> The acoustic structure of fricatives seems to vary widely from individual to individual, but this really reflects only the unfortunate fact that we do not yet know what it is that we ought to be describing. We do not know how to sum up what is constant, and what is linguistically and perceptually most relevant in acoustic terms. As we do not yet have an adequate model for the acoustics of fricatives, we are in a position comparable to have to describe vowels without having the notion of formants, or at least peaks in the spectrum. (p. 59)

Building on Catford (1977), who notes a distinction in terms of the channel area of [θ] and [s], and by examining experimental evidence from
various languages, I argue for a new distinctive feature, called Tongue-Tip Constriction Area (TTCA), which serves as the basis for a phonological contrast in coronal fricatives. TTCA provides a three-way distinction among English [θ]-[ʃ]-[s], while other languages, like Chinese and Tohono O’odham, contrast only two values of this feature. The new feature is defined on the cross-sectional dimension, a dimension of articulatory control that has been largely neglected as a domain for phonological features. One of the strongest arguments for the new feature is its ability to account for the puzzling speaker-to-speaker variation observed in the data. I also argue that two competing proposals, specifically the feature Distributed of Chomsky & Halle (1968), and the feature Groove of Halle & Stevens (1979), are not able to provide the basis for the desired contrasts.

This chapter is organized as follows. Section 2 introduces the anatomical facts crucial to the following discussion. It presents the model of lingual and palatal topography that will be used throughout this and the next chapter for the classification of articulations. Sections 3 and 4 elaborate further on this model. Section 3 discusses the articulatory independence between the tip-blade articulator and the tongue dorsum articulator, while section 4 reviews mid-sagittal configurations of tip-blade articulations. Using experimental evidence which allows us to infer the cross-sectional shape of the tongue, section 5 develops the proposal for the new distinctive feature. The main body of evidence comes from three languages, English, Chinese, and Tohono O’odham. This section also argues that other proposals cannot provide the basis for the needed contrasts. The problem of variability in articulation is addressed at two levels: the level of speaker-to-speaker variability within a language, and the level of language-to-language variability. Section 6 recapitulates the main result of this chapter and closes the discussion by stressing the importance of the cross-sectional dimension of articulatory control for fricatives.

Before I begin, I define some basic terms used in this chapter. Articulations can be described by looking at the vocal organs from two different views, the mid-sagittal and the cross-sectional. A sagittal view of the vocal apparatus is the view of a slice of the head from front to back, as seen from the side. A mid-sagittal view, in particular, is the view of the apparatus when the slice is taken along the mid-line of the head. For
example, a mid-sagittal view of the tongue is a trace of the central line of the tongue, which divides its body into two longitudinal halves. Finally, a cross-sectional or transverse view is the side-to-side view of the vocal apparatus. In sections 2 through 4 of this chapter I describe various articulations from the traditional mid-sagittal view. In the remainder of the chapter I explore the behavior of the front part of the tongue from a cross-sectional view.

2. ARTICULATORY SUBDIVISIONS OF THE TONGUE AND PALATE

The various articulations discussed in this chapter are described with reference to the diagram of the supra-laryngeal vocal tract shown stretched-out in (1) below. The subdivisions in this diagram are essentially the ones proposed by Recasens (1990), with two minor additions. I have included the Dental place of articulation on the front part of the palate, and the Tip on the front edge of the tongue, both important in the ensuing discussions of anterior coronal articulations. In this section, I discuss the proposed palatal and lingual topography and relate it to other models of the vocal tract.

1. Stretched-out topography of the vocal tract

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<th>Dental</th>
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The palate is divided into five zones: the dental, the alveolar, the pre-palatal, the medio-palatal, and the post-palatal zones. The pre-palatal zone corresponds to the postalveolar zone of Ladefoged & Maddieson (1986), and overlaps with the postalveolar and prepalatal zones of Catford (1977). The medio-palatal zone corresponds to the palatal place of articulation, and the post-palatal zone to the velar place of articulation of Catford (1977) and Ladefoged & Maddieson (1986). Although the latter two
terms, palatal and velar, are standard in the phonological literature, I shall continue to use the terminology of Recasens because the prefixes pre-, medio-, and post- allow easier visualization of the various gestures of the sounds in languages with complex coronal consonants. The post-palatal zone or place of articulation is of course followed by the uvular, pharyngeal, laryngeal, and epiglottal places of articulation, which are not important for the purposes of this chapter.

The tongue is divided into five regions: the tip, the laminal, the pre-dorsal, the medio-dorsal, and post-dorsal regions. Starting with the tip, Catford (1977) distinguishes the forward edge of the tongue, called the “rim”, from the central point of this edge, called the “tip” or “apex”. The term “tip” has become standard, and I will use it here with the meaning ascribed to it by Keating (1991) and Ladefoged (1989), that is, referring to both the rim and the apex of the tongue. The reason for this choice is that it is impossible to make contact with the apex without also making contact with the area around it, and to my knowledge no language has been reported to distinguish between tip and rim articulations.

An articulation involving the tongue tip forming a constriction somewhere on the palate is called an apical articulation. Apical articulations can be formed at any point from the dental zone to the front portion of the pre-palatal zone. Many languages have apico-dental [t, d, n, l], where the tip makes full contact with the back of the upper teeth. An example of an apico-prepalatal sound is the British English approximant [ɹ], as in red, with the tip making contact behind the alveolar ridge.

Another standard term which does not have a direct representation in the diagram of (1) is the ‘blade’ of the tongue. The blade is the front part of the tongue starting from the tip and ending at the beginning of the dorsum. Many authors attempt to delimit the region of the tongue corresponding to the blade by giving estimates of its length. These attempts have come to represent one of the differences between two phonetic traditions. The tradition of the British school of phonetics defines the blade as the part of the tongue that includes the tip and runs 10-15 mm behind it. This use of the term is attributed in particular to the phonetician Henry Sweet, one of the leading figures of the British school tradition. This is also the definition of the term adopted by Catford (1977). The American speech science tradition, on the other hand, assumes a longer blade, running from a minimum of 1 cm to a maximum of 4 cm behind the
tip (Pike 1943). Keating & Lahiri (1993), for example, estimate that the blade has a length of 2-3 cm running behind the tip. They arrive at this measure by observing that some coronal sounds, which are assumed to be formed with the blade of the tongue, are articulated with a part of the tongue which lies 2-3 cm behind the tip. This operational definition of the blade is the one that I also adopt here. Thus in the diagram of (1), as Recasens (1990) points out, the blade covers an area that runs behind the tip, includes the laminal region and some part of the predorsal region as well.

Any articulation that is formed by raising the laminal region of the tongue to form a constriction at some place on the palate is called laminal. As with apical ones, laminal articulations can be executed at various places of articulation. A typical lamino-dental articulation involves laminal contact at the backs of the upper teeth, with the tip tucked behind the lower teeth. The tip can also be between the upper and lower teeth, as in one possible articulation of [θ], in which case the articulation can more accurately be characterized as interdental. Both these dental varieties are attested in the stops of many Australian languages, usually transcribed as [t, d]. The stops [t, d] of English are usually lamino-alveolars. The English fricative [s] is also typically characterized as lamino-alveolar, but as we will see later this is just one of the many possible articulations of this sound. A somewhat more retracted laminal sound is one of the possible articulations of the fricative [ʃ] and its corresponding affricate [tʃ], the initial sounds of Shaw and choose, respectively. In the production of [ʃ, tʃ], the laminal region of the tongue is raised to form a constriction that extends from the back of the alveolar zone to the front part of the pre-palatal zone. The pre-dorsum may also be involved but only because its raising is a consequence of the raising of the adjacent laminal region. During this articulation the exact position of the tongue tip can vary, being either in contact with the backs of the upper central incisors, or tucked behind the lower central incisors, the choice usually considered to be a matter of speaker preference.

Continuing with the subdivisions of the tongue surface in (1), Recasens divides the dorsum into a pre-dorsal, a medio-dorsal, and a post-dorsal region. This is not the standard topography of the tongue. Putting aside Malmberg (1963), who has a distinction only between the tip and the dorsum, Catford (1977), Keating (1988), Browman & Goldstein (1989),
and Ladefoged (1971, 1989) all have the same three-way distinction among tip, lamina, and dorsum, without recognizing a distinct pre-dorsal region between the laminal and the medio-dorsal regions. Based on a survey of a large number of X-ray data, Recasens argues that the sounds which are usually called ‘alveopalatals’ are primarily formed by a part of the tongue lying between the typically laminal and the typically dorsal region, hence his addition of a distinct pre-dorsal region.

Examples of sounds which are formed with the pre-dorsum are [c, p, k]. The sound [c] is a voiceless stop corresponding to the ty in Hungarian orthography, [ŋ] is a voiced nasal corresponding to the orthographic gn in French and Italian, and [k] is a voiced palatal lateral approximant corresponding to the ll in Castilian Spanish, and the gl in Italian. These sounds are very similar in their articulatory configurations, which involves raising the pre-dorsum to create complete contact or approximation with a continuous area from the back of the alveolar zone and into the pre-palatal zone. The tongue tip may be tucked down against the lower teeth, and the laminal region lies halfway between the upper and the lower structures of the oral cavity. This class of sounds is the main motivation behind Recasens’ proposal for recognizing the distinction between the laminal and the pre-dorsal regions.

Two sounds which illustrate an articulation with the medio-dorsum, and thus the distinction between the pre-dorsal and the medio-dorsal regions, are the ‘palatal’ [y, ç]. The approximant [ç] is the first sound of English you, and the voiceless fricative [ç], also known as the ‘cedilla c’ in IPA, is the initial segment of Japanese hito, and the final sound of German ich. In producing these sounds, the regions of the tongue raised are mostly the medio-dorsum and the pre-dorsum, depending on how fronted the articulation is. For the approximant, the tongue dorsum is raised below the pre-palatal and the medio-palatal zones, assuming a heavily arched shape, characteristic of ‘palatal’ sounds. The fricative has a very similar shape, the only difference being the formation of a closer constriction between the dorsum and the palate, close enough so that turbulence can be produced.

The division of the tongue into separate regions just outlined finds support not only in observations of articulatory configurations of sounds in different languages. At another level of description, the study of dynamic tongue movements, Stone (1990) finds evidence for a strikingly
similar division of the tongue. The experimental procedure in Stone's study consists of an X-ray system which tracks the movements of five pellets, placed along the surface of the tongue as shown in the diagram in (2) below. The measures shown above the pellets TT (tongue tip), TB (tongue body) 1-3, and TD (tongue dorsum) are the distances of the positions of the pellets from the tongue tip. Spatial displacement, speed, as well as the inter-pellet distances are recorded during the production of various VCVC\textsubscript{0} utterances, where the consonants were [s] and [l], and the vowels [i], [a], and [o].

2. Functional segments of the tongue

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<td>Middle</td>
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The results support a division of the tongue into four functional sections that operate as semi-independent units. The first section roughly extends from TT to TB\textsubscript{1} and is called the Anterior section. The second extends from TB\textsubscript{1} to TB\textsubscript{2} and is called the Middle section. The third extends from TB\textsubscript{2} to TD (including TB\textsubscript{3}) and is called the Dorsal section. Finally, there is the Posterior section which runs behind the TD pellet.

Functional independence of these sections of the tongue is inferred from measurements of their movement behavior. One of the important findings of this study is that the tongue as a surface expands or compresses non-uniformly at different sections during production of various sounds. For example, the middle functional section, encompassing the area TB\textsubscript{1}-TB\textsubscript{2}, is kept relatively compressed. This compression facilitates expansion of the anterior and dorsal sections of the tongue, recorded in the measured inter-pellet distances. For example, in the production of [l] the dorsal segment is the most expanded segment of the tongue, while for [s] the anterior segment is the most expanded one. Expansion or compression at some section of the tongue has effects for the neighboring sections, because the tongue is a "muscular hydrostat," meaning that it consists entirely of muscles and has constant volume (Kier & Smith 1985). This is particularly evident for the posterior segment during the production of vowels. For example, in the vowel [a], the dorsal and middle segments
compress to push the posterior section into the pharynx.

There is a simple correspondence between the four functional subdivisions of the tongue revealed in Stone’s study, shown in (2), and the articulatory regions of the tongue in (1). The laminal region in (1) can be seen to correspond roughly to the Anterior section of (2), the pre-dorsal region to the Middle section, the medio-dorsal to the Dorsal, and the post-dorsal to the Posterior. A number of other consistencies between the two models in (1) and (2), support this mapping. In the articulatory configuration of [l] there is raising of the (medio- and post-) dorsum of the tongue, and hence expansion of the Dorsal section of the tongue as in fact observed in Stone’s study. Similarly, the articulatory configuration of [s] involves raising of the blade, which is consistent with the expansion of the Anterior section of the tongue for this sound as also observed by Stone. Moreover, the observation that the Middle section of the tongue was relatively compressed to facilitate expansion for the Anterior or the Dorsal sections is also consistent with the fact that none of the consonant or vowel phonemes used in Stone’s study involved active raising and thus expansion of the pre-dorsal region of the tongue, as for example in the ‘alveopalatal’ stops [c, p, ɟ] discussed earlier. These considerations suggest that it is not an accident that a similar four-way division of the tongue is reached by two entirely distinct experimental methods. Stone’s study is based on information about dynamic movements of the tongue from a single speaker of English, while Recasens’ inferences are based on a cross-linguistic study of static articulatory configurations.

3. SEMI-INDEPENDENCE BETWEEN THE TIP-BLADE AND THE DORSUM
The purpose of this section is to elaborate on the evidence for the functional semi-independence between the tip-blade and the dorsum articulators. This evidence will be important for understanding one crucial property of consonant harmony, namely, its limitation to consonants articulated with the tip-blade.

Before I proceed, I would like to make clear that henceforth I use the compound term ‘tip-blade’ to refer to the section of the tongue which includes the tip and the blade. The terms ‘apical’ and ‘laminal’ introduced in the previous section receive a formal definition in the next section, under this interpretation of the tip-blade combination as a single
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articulator.

The tongue is undoubtedly the most important articulator in the production of speech, and a great deal of effort has been devoted to the construction of articulatory models of its behavior. The standard approach to this enterprise is first to collect the data, which are either in the form of X-ray pictures of the tongue (static or dynamic), or trajectories of pellets attached at various points on the tongue's surface. After the data have been collected, an analysis, usually based on the statistical method of factor analysis, is performed to identify the parameters that best account for the variation in the data set. The underlying hypothesis is that the complex articulatory patterns of tongue movement are described by specifying the values of a small set of independent articulatory parameters.

One of the most telling sources of evidence for the independence of the tip-blade and the dorsum articulators stems from the unanimous conclusion from several models of the tongue that there are two independent parameters, one corresponding to the configuration of the tip-blade and the other to the configuration of the dorsum. To give a few examples, in Lindblom & Sundberg (1971), Lindblom, Pauli & Sundberg (1974), and Lindblom (1983), a parameter of ‘tongue blade’ is identified as controlling the position of the tip-blade in the vertical dimension (elevation vs. lowering), and in the horizontal dimension (protrusion vs. retraction). Mermelstein (1973) also includes a ‘tongue tip’ position parameter independent from the tongue jaw and tongue body position parameters. Coker (1968), as cited in Carré & Mrayati (1990), has a parameter of place and degree of ‘tongue tip’ constriction independent of the tongue body position parameter. Finally, Maeda (1979, 1990) also has a ‘tongue-tip position’ parameter independent from the tongue-dorsal position, and tongue-dorsal shape parameters. Apart from the terminological disagreements in the use of the terms ‘tip’ and ‘blade’, all these models recognize a distinction between the tip-blade and the tongue dorsum articulators.3

However, because the tip-blade and the dorsum are adjacent sections of a single organ there are constraints that limit their independence. For example, the tip-blade can assume an extreme articulatory configuration in the production of a retroflex sound by bending the whole articulator backward, so that the tip or the underside of the blade ends up somewhere below the pre-palatal zone. To allow for this bending to take place, the
tongue-dorsum must be depressed downward, an effect that accounts for the characteristic lowering of vowels by retroflex consonants (Catford 1977). Hence, extreme postures of the tip-blade place constraints on the posture of the tongue dorsum. I will argue in the following chapter that such biokinematic constraints play an active role in the phonology, accounting for blocking of the spreading of retroflexion in the consonant harmony of Sanskrit.

4. MID-SAGITTAL POSTURES OF THE TIP-BLADE

In this section I provide some refinements specific to the description of tip-blade articulatory configurations. Several investigators have observed that there are different ways by which a tip-blade constriction can be executed, subject to considerable variation sometimes even in the same language. Different sources choose different ways to describe the variation, but the recurrent distinction is the one between ‘apical’ articulations and ‘laminal’ articulations. It will be recalled that an articulation involving active raising of the tongue tip to form a constriction somewhere on the palate is called ‘apical’, while an articulation that is formed by the raising of the laminal region of the tongue to form a constriction at some place on the palate is called ‘laminal’. Building on a suggestion of Browman & Goldstein (1989), I assume that a tongue tip-blade gesture includes, in addition to its CL (constriction location) and CD (constriction degree) tract variables, another variable called ‘Tongue-Tip Constriction Orientation’ or TTCC, specifying the orientation on the sagittal plane of the tongue tip-blade with respect to the tongue body. I assume that TTCC is the controlled parameter distinguishing apical and laminal articulations. In (3) below, I show the mid-sagittal tracing of the tip-blade for an apical and a laminal gesture. For the apical gesture, the constriction between the tip-blade and the palate is formed with the raised tongue tip, while for the laminal gesture the constriction is formed with the raised tongue blade. Roughly speaking, a TTCC value of less than 180 degrees corresponds to an apical gesture, and a value of more than 180 degrees corresponds to a laminal gesture.³
3. Apical-laminal in terms of TTCO

Apical Laminal

Parallel to evidence from articulatory configurations for the apical-laminal distinction, there is also evidence from electromyography, the technique which records the electrical activity accompanying muscle contraction during speech production (see Gentil 1990, Smith 1971). Curling of the tip is caused by the two longitudinal (i.e. extending lengthwise) muscles of the tongue, the Superior Longitudinal (SL) and Inferior Longitudinal (IL), running along the upper- and under-side of the tongue’s surface respectively. Retracting of the IL causes downward curling of the tip, while retracting the SL causes upward curling of the tip (MacKay 1987, Sauerland & Mitchell 1975). Borden & Gay (1978) use electromyography to record the activity of the Genioglossus (GG), the SL, and IL muscles during the production of [s]. Their subject produced an ideal laminal [s] by forming a blade constriction at the alveolar zone, with the tip placed behind the lower incisors. In an utterance like pis, there is significant activity of the GG during the vowel, followed by significant activity in the IL during [s]. The significant activity of the IL indicates that tip lowering is an actively controlled part of [s] articulation, and not simply the passive concomitant of blade raising to form the constriction at the alveolar zone.

Although the apical-laminal distinction is used widely in the descriptions of various articulations, it is important to keep in mind that this does not always imply that languages employ the TTCO parameter as a basis for a contrast (or ‘distinction’, in Praguian terms). An example of a language with non-contrastive TTCO is English, which I illustrate here by reviewing the attempt of Bladon & Nolan (1977) to characterize the articulatory configurations of the consonants [t, d, n, l, s, z] by eight speakers of the variety of English known as Received Pronunciation (RP) English. The authors use a technique called ‘video-fluorography’ that collects X-ray motion pictures of the moving articulators by projecting X-
radiation onto a fluoroscopic screen, converting the radiation into light energy. Bladon & Nolan acknowledge that it is difficult to classify the various articulations into simply apical versus laminal. They instead adopt a system of classification which employs two indices. The first index corresponds to the height of the tip and the second to the height of the blade. The authors recognize three degrees of tip or blade height, labeled as 1, 2, 3, from lowest to highest. A height value of 3 for the tongue tip means that the tip is making contact at the upper surface of the vocal tract, the palate. A value of 1 means that the tip is tucked behind the lower incisors, and a value of 2 corresponds to intermediate degrees of tip height. Similarly, for the blade, a value of 3 means contact of the blade with the palate, while 2 and 1 correspond to progressively lower values of blade height.

By convention, Bladon and Nolan define ‘laminal’ articulations as those articulations where the second index is higher than the first. ‘Apical’ articulations are those where the first index is higher than the second. The 3-3 configuration, although not explicitly classified by Bladon & Nolan, would presumably be called ‘apico-laminal’. It is clear that Bladon & Nolan are dealing with a continuum of apicality-laminality values, which they arbitrarily choose to divide into two categories for reasons of descriptive expedience.

The authors report that seven out of eight speakers of RP English use a laminal, 1-3, articulation for the fricatives [s, z], while only one speaker produces an apical articulation, 3-2. On the other hand, the consonants [l, n] are clearly apical, being categorized as either 3-1 or 3-2. Finally, the stops [t, d] are apical for four of the speakers, and laminal for three of the speakers (no data are reported on the eighth speaker). Hence the apical-laminal parameter is not contrastive for English stops or fricatives.

There are languages where unlike English the apical-laminal distinction (or TTCO) does play a role in phonological contrasts. Ladefoged & Maddieson (1986) write that usually sounds which differ in terms of apicality-laminality also differ in their places of articulation. For example, a frequent contrast, attested in the West African languages Tiv and Ewe, and numerous Austrōaian languages, is that between laminal dental and apical alveolar stops (Ladefoged 1968, Dixon 1980). There are, however, cases where the contrast seems to be purely in terms of the apical-laminal distinction. Ladefoged & Maddieson cite Bulgarian as an
example of a language contrasting apical alveolar [t d n] and laminal alveolar [t d n]. Two other cases of pure apical-laminal contrasts are known to me. Dart (1991) finds that the ‘palatal’ [c] of one Malayalam speaker is in fact a laminal alveolar which contrasts with an apical alveolar [t]. The other case is found in Tohono O’odham where two speakers in Dart (1991) have a contrast between an apical alveolar [d] and a laminal alveolar [j].

Finally, there is another type of contrast for which I will assume that TTCO is the gestural parameter under control. Many Australian, Dravidian, and Indo-Aryan languages have sounds which are articulated by the tip-blade making contact at some part of the palate behind the alveolar zone. These sounds are usually called ‘retroflex’, and are transcribed by the IPA symbols [d t n l] or as [d t n l] in the American tradition. For example, in Sanskrit the retroflex stop [t] is articulated with the tip-blade “turned up and drawn back into the dome of the palate” (Whitney 1889). These sound contrast with the non-retroflex ‘dental’ stop [t] which is “formed at the teeth (or at the roots of the teeth)” (Whitney 1889). Following Browman & Goldstein (1989), I will assume that TTCO is the controlled parameter in the contrast between retroflex and non-retroflex sounds as well.

All the above cases of apical-laminal distinctions involve stops. For fricatives, the situation is usually somewhat different. When faced with the task of classifying fricative articulations, a look at data from different languages quickly reveals that the parameters of apicality-laminality and place of articulation are not of much assistance. The rest of this chapter develops a proposal for a new parameter of articulatory control in coronal fricatives.

5. PROPOSAL FOR A NEW DISTINCTIVE FEATURE

In this section, I propose that there is another dimension of articulatory control, so far largely neglected in the articulatory descriptions of sounds. In contrast to the predominance of descriptive parameters and features that refer to the mid-sagittal dimension, I argue for a new feature based on the cross-sectional dimension. This new feature will shed light on the puzzling variability of coronal fricative articulations I noted in the introduction to this chapter.

The proposal for the new feature is based on evidence from English,
Chinese, and Tohono O’odham, adduced in 5.1, 5.2, and 5.3 respectively. In 5.4, I provide tentative evidence from other languages as well. In 5.5, I summarize the evidence and define the proposed feature Tongue-Tip Constriction Area (TTCA). In 5.6, I show how the new feature makes sense of the puzzling variability observed when the fricatives are described in terms of the traditional parameters of apicality-laminality, place of articulation, and shape of the tongue. The next section, 5.7, deals with the variability of coronal fricatives across different languages. Section 5.8 evaluates the feature Distributed, arguing that this feature cannot provide a basis for a contrast and should be replaced by the proposed feature TTCA for the case of fricatives, and by the apicality-laminality distinction for the case of stops.

5.1 English
Dart (1991) has shown that in a sample of 20 speakers of American English the fricatives /s, z/ were 42.50% apical and 57.50% laminal (the same distribution in terms of apicality/laminality obtains for each of the fricatives). To better evaluate this result, I review Dart’s definitions of the descriptive parameters used to categorize the data. The first parameter is the part of the tongue involved in the constriction. When the constriction is formed with contact of the tongue tip only, the articulation is called apical. When contact is only with the tongue blade, the articulation is called laminal; when both the tip and the blade make contact, the articulation is called apicolaminal. The second parameter is the place of articulation. Dart recognizes six distinct places of articulation (categories 1-6 from front to back). The Dental place corresponds to categories 1 and 2, with 1 being a forward dental and 2 a somewhat more retracted dental articulation. The alveolar place corresponds to 3 and 4, and post-alveolar to 5 and 6, the first number again corresponding to the more forward and the second to the more retracted articulation. The following table reproduces the distribution of the data reported in Dart’s study, along the two dimensions just described.
4. Variability in place and apicality-laminality for [s, z]

<table>
<thead>
<tr>
<th>POA</th>
<th>Apic. [s]</th>
<th>Lam. [s]</th>
<th>Apic. [z]</th>
<th>Lam. [z]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>5</td>
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<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key to the table above

<table>
<thead>
<tr>
<th>Cell</th>
<th>Tokens</th>
<th>Cell</th>
<th>Tokens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-6</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td>2-5</td>
<td>11-15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This variability in the [s] data is consistent with results from previous studies (e.g. Bladon & Nolan 1977). A similar variation has also been reported for [ʃ], a sound which is usually described as a ‘laminal postalveolar’ (see, for example, Recasens 1990: pp. 289, 270). Ladefoged & Maddieson (1986) have found that in a set of sixteen speakers of Californian English, eight speakers produced [ʃ] as apical and eight as laminal. The apicality-laminality and the place of articulation parameters, then, are not very useful in describing the production characteristics of [s], [ʃ]. In particular, it is not at all obvious what kind of articulatory feature could provide a basis for the contrast between these two sounds.

It is widely recognized, however, that the shape of the tongue plays an important role in the articulation of fricative sounds (Pike 1943, Malmberg 1963, Ladefoged & Maddieson 1986). The main source of the acoustic energy of fricatives is the turbulence produced by the airstream...
going through a channel created by the approximation of the tongue to some area on the palate.\(^8\) The shape characteristics of this channel do seem to be different for different fricatives. For example, many writers describe [s] as having a characteristic groove running midsagittally along the length of the tongue. The sides of the tongue are elevated laterally and the airstream is directed into a channel that is formed between the palate and the tongue at the place of the main constriction. Other fricatives, like [θ], are described as being flat in contrast to the grooved shape of [s]. Despite the general feeling that shape is important, there is some confusion in the literature as to what the exact classification of [ʃ] would be in terms of such a parameter. For example, while MacKay (1987: p. 96) writes that [s], [z] are produced with the tongue slightly grooved as opposed to [θ], [ʃ] which are articulated with a flat tongue, Clark & Yallop (1990: p. 87) have [s], [ʃ] as grooved and [θ] as flat. Nevertheless, groove is a good candidate as an articulatory basis for fricative distinctions. In fact, a feature [groove] has been proposed by Halle & Stevens to distinguish between the ‘palato-alveolar’ fricative [ʃ], which would be [+grooved], from the ‘palatal’ fricative [ç] which would be [−grooved] (Halle & Stevens 1979: p. 347). In taking [ʃ] to be [+grooved], Halle & Stevens apparently follow Smalley (1989), who characterizes [s], [ʃ] as grooved and [θ] as flat (like Clark & Yallop 1990).

In contrast to proposals that consider shape to be important, Catford (1977) is unique in pointing out that with respect to the acoustics it is not the actual shape of the tongue that is the crucial characteristic of fricatives but the cross-sectional area of the channel between the tongue and the palate. In his own words:
Some writers (for example, Pike 1943) have used the terms *groove(d)* and *flat or slit* to characterize different transverse shapes of the articulatory channel. According to this terminology [θ] is flat and [s], for example, is grooved. However, it is probable that the crucial characteristic here is not the transverse shape of the channel, but its cross-sectional area. Thus [θ], irrespective of the *shape* of its channel, has a channel area that is three or four times that of [s], and this means that for a given volume-velocity the velocity of air-flow through the [s] channel is three or four times that of flow through the [θ] channel, and it is this velocity difference which is crucial. (p. 153)

Although Catford seems convinced of the significance of the [s]-[θ] distinction in terms of the cross-sectional area, he goes on to write that “it is just possible that, on the average, the channel area of [ʃ] is somewhat larger than that of [s], although there is not much evidence for this” (p. 154).

With this in mind, I will now proceed as follows. First, I confirm the irrelevancy of the actual shape of the channel parameter for the articulation of English [ʃ], eliminating the confusion about whether [ʃ] is flat or grooved. It can be either. Then, I provide evidence that the correct dimension of distinction among all three fricatives, [s]-[ʃ]-[θ], is indeed the cross-sectional area. This will serve as the basis of contrast between the English coronal fricatives, and for the coronal fricatives of other languages as well, as the following sections will argue.

Consider first the assumption of Halle & Stevens that [ʃ] is grooved. Ladefoged & Maddieson (1986: p. 67) show a transverse view of the shape of the tongue for [ʃ] which is in fact convex (i.e. arched). If the tongue were grooved, then the expected shape would be concave (i.e. depressed or sunken), not convex. However, the portion of the tongue whose cross-sectional shape is pictured in Ladefoged & Maddieson (1986) is just below what seems to be the postalveolar part of the palate, while the main constriction seems to be right at the alveolar ridge. Perhaps, then, a groove could exist in the part of the tongue under the alveolar place of articulation. The situation is clarified in Stone et al. (1992). Using ultrasound, Stone et al. were able to produce images of the tongue’s
surface by scanning the soft tissue with an ultra-high-frequency wave. This technique is particularly informative for the kind of information we are seeking here. The subject of this study produces [s] with a mid-sagittal groove along the entire length of the tongue. For [ʃ], however, only the posterior part of the tongue was grooved mid-sagitally, while the dorsal and anterior parts were oblique, creating a parasagittal air channel, directing the airstream more out of one side of the tongue than out of the other. Schematically, the different shapes of [s] and [ʃ] channels can be represented as in (5) below. The lines depict the cross-sectional outline of the surface of the anterior tongue, as seen from the frontal view. The anterior part of the tongue corresponds roughly the part under the alveolar place of articulation, that is the tip-blade of the tongue.

5. Anterior tongue shape

[s]  [ʃ]

Groove  No groove

It is thus clear that grooving is not a characteristic of this [ʃ]. However, when the cross-sectional channel areas of the two fricatives are compared, a consistent relation emerges. Stone et al. note that although [ʃ] did not have a groove anteriorly, its “air channel, created by a parasagittal depression, was quite deep (7.2 mm)” (p. 260), while [s] had a groove of 5.9 mm. Stone et al. do not report width measures, but it is clear from (5) above, which preserves the relative lengths from the ultrasound images of Stone et al., that the width for [ʃ] is greater than for [s]. The estimates I have computed from the ultrasound images are 20 mm for [s] and 35 mm for [ʃ]. Based on this information, we may compute an approximation to the channel area by making the simplifying assumption that the channel is a triangle. Two such triangles are shown in (5) above: the channel with the mid-sagittal groove corresponds to an isosceles triangle, and the parasagittal channel corresponds to a right triangle. In the actual shape of the channel, the two sides of the virtual triangle corresponding to the raised sides of the tongue will not be straight but curved, as will also be
the base of the channel corresponding to the usually convex surface of the palate. For current purposes, however, these simplifications suffice in providing us with rough estimates of the actual channel areas, given that what is important here is the area difference between different sounds and not the precise areas of the individual sounds. Specifically, the estimate for the cross-sectional channel area for [f] is 126 mm$^2$ ($= \frac{1}{2} \times 35 \text{ mm} \times 7.2 \text{ mm}$) which is considerably larger than that for [s], 59 mm$^2$ ($= \frac{1}{2} \times 20 \text{ mm} \times 5.9 \text{ mm}$).

In evaluating the generality of the evidence above, we must first consider the fact that the subject produces, perhaps somewhat unexpectedly, a parasagittal channel for [f]. Yet such individual ‘peculiarities’ in articulation seem to be the canon, as shown by Hamlet (1987) who finds that 37% of 357 subjects produce [s] with an asymmetrical channel, similar to the parasagittal channel for [f] produced by the subject of Stone et al. (1992). Second, the validity of the cross-sectional area difference between [f] and [s] finds additional support in Ladefoged (1957), who reports that in a palatographic survey of 164 speakers of English “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 in ship.”

These results imply that the tentative proposal of Halle & Stevens (1979) for a feature [+/-groove] cannot in fact be maintained. As I pointed out earlier, Halle & Stevens used the feature [groove] to distinguish between the ‘palato-alveolar’ [f] which would be [+grooved], and the ‘palatal’ fricative [ç] which would be [-grooved]. We now know that these two fricatives cannot be distinguished on the basis of this feature, because grooving is not a reliable characteristic of [f]. In the next section, I propose to distinguish them in terms of the different active articulators involved in these two sounds.

Next consider the fricative [θ]. Variation in terms of place of articulation and apicality-laminality can also be found here. According to Catford, one articulation of [θ] is as a ‘lamino-dental’, where the tip touches the back or the rim of the lower teeth and the lamina is in contact with the upper teeth (Catford 1977: p. 152). Another articulation of [θ] is as an ‘apico-dental’, where the emphasis is on the contact of the tip of the tongue with the upper teeth, irrespective of the fact that there is also some lamino-alveolar contact (p. 151, 154). Yet another articulation is as an
'apico-alveolar', where the contact of the tip is immediately behind the upper teeth on the flat part of the alveolar zone (p. 151). A similar ‘apical’ articulation is also noted by Ladefoged & Maddieson (1986) ‘with the tip of the tongue behind the upper front teeth’ (p. 62). Ladefoged & Maddieson (1986) also comment on the term ‘interdental’ which is typically used for [θ]. They report that 90% of 28 Californian English native speakers produce this sound with the tip protruded between the teeth. Ladefoged & Maddieson choose to call this latter articulation ‘laminal’, because the constriction is between the lamina and the upper teeth. In a study of 28 speakers of British English, Ladefoged & Maddieson find that only 10% of the speakers have this type of ‘interdental’ articulation. The other 90% have what has been referred to above as an ‘apico-dental’ articulation. To sum up, at least four different articulations of [θ] have been noted: [θ] can be produced with the tip protruded between the upper and lower incisors, with the tip behind and in contact with the upper incisors, with the tip behind the lower incisors, and with the tip behind the upper incisors but making no contact with the teeth ridge. No doubt, this sound also shares the same variability in terms of place of articulation and apicality-laminality as I have documented for [ʃ] and [s] above.

Concerning the channel characteristics of [θ], however, there is general agreement that [θ] has a wider channel than [s] or [ʃ]. As noted, Catford (1977: p. 153) estimates the channel area for [θ] to be three or four times that of [s] and also significantly greater than that of [ʃ]. Stone & Lundberg (1996) note that [θ] is grooved shallowly throughout, and with the surface of the tongue more laterally spread anteriorly than for any of the other sounds, implying significant differences in channel width. The electroglottographic results from the same study also clearly show a very wide channel for [θ], as compared to the channel of [ʃ] or [s]. (Data are reported from a subject different from that of Stone et al. 1992.)

In short, there is abundant evidence that the three English fricatives [θ], [ʃ], and [s] are distinguished by their cross-sectional area, according to the scale [θ] > [ʃ] > [s].

5.2 Chinese
Another language of interest is Chinese, which has two fricatives, an “s”-type fricative [s], and a “sh”-type fricative [ʃ]. Data are drawn from
Ladefoged & Wu (1984) who provide X-ray photographs and palatographic information from three speakers of Mandarin Chinese. For all three speakers, [s] is produced with the tip of the tongue raised to form a constriction at some point in the front palate. The characteristic groove of [s] is seen in all three speakers, although as Ladefoged & Wu point out, it is not as deep as that for the English [s]. Finally, the exact location of the channel is different for each speaker, being on the teeth for speaker A, behind the teeth for speaker B, and further back on the alveolar ridge for speaker C. Despite this difference, the cross-sectional areas of the [s] channels of the three speakers turn out to be very similar. Given the data in (6), providing channel width and depth information, I have computed the cross-sectional areas of the channels. It can be seen that the area measurements range from about 3.75 to 4.5 mm$^2$.

<table>
<thead>
<tr>
<th></th>
<th>Width</th>
<th>Depth</th>
<th>Channel area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speaker A</td>
<td>&lt; 3.75 mm</td>
<td>1 mm</td>
<td>&lt; 3.75 mm$^2$</td>
</tr>
<tr>
<td>Speaker B</td>
<td>4.5 mm</td>
<td>1 mm</td>
<td>4.5 mm$^2$</td>
</tr>
<tr>
<td>Speaker C</td>
<td>3.75 mm</td>
<td>&lt; 1 mm</td>
<td>&lt; 3.75 mm$^2$</td>
</tr>
</tbody>
</table>

Turning to the “sh”-type fricative [s], all three speakers produce this sound with the upper surface of the tip. The constriction location is more consistent than for [s], being around the center of the alveolar ridge for all three speakers. It is clear from the X-ray photographs in Ladefoged & Wu that this sound is different from a typical apical sound. In fact, different classifications of this sound have been given in different studies. For example, while Ladefoged & Wu write that it is formed “with the upper surface of the tip of the tongue” (p. 271) and avoid labelling it as either apical or laminal, Ladefoged & Maddison (1986: p. 71) call it laminal. Perhaps the most descriptively accurate characterization would be in terms of the “upper apical” category proposed in Dart’s study discussed below. But whatever the exact characterization of that sound may be in terms of the part of the tongue involved, it is clear that no useful distinction between [s] and [s] in Chinese can be drawn in terms of the apical vs. laminal parameter, exactly as was the case with English [s] and [ʃ].

Turning to cross-sectional area, however, the same relationship established between English [s] and [ʃ] obtains here between [s] and [s]. Although Ladefoged & Wu do not give all the necessary information for
the [s] channel measures, they do remark that “both the height and the width of the channel are greater than in [s]”. It follows that the area of the channel for [s] is consistently greater than for [s] for all three speakers.

It is interesting to note that although speaker C’s [s] has the smallest channel width of 5 mm, quite close to the 3.75 mm width of his [s], he also seems to have the greatest hollowing of the tongue with respect to the roof of the palate, as can be inferred from the X-ray photographs. Anticipating a later discussion of speaker variability in 5.6, note that since channel area is essentially the product of constriction width by groove depth, it is obviously possible to attain the distinction between the areas of [s] and [s] in an infinite number of ways, one of which is to keep the width relatively constant and increase the depth of the channel.

Chinese has another fricative, [ç], for which there are no available channel measures. For this fricative the tongue is at a much higher and more retracted position than for [s] or [s], hence Ladefoged & Wu’s characterization of this sound as a ‘palatalized postalveolar’. From the X-ray photographs provided in Ladefoged & Wu it appears that this sound is very similar to the ‘front palatal’ category of Recasens (1990). Two examples of front palatals, the approximant [y] and the voiceless fricative [ç], were discussed at the beginning of this chapter. These sounds are produced under the regime of another articulator, which includes the pre-dorsum and the medio-dorsum, as opposed to the tip-blade articulator employed for [s] and [s]. I assume that a different active articulator suffices to provide the needed distinction between Chinese [ç], on the one hand, and [s]-[s], one the other hand, the latter two fricatives being distinguished by the proposed feature based on the phonetic dimension of the cross-sectional area.

The last point takes us back to the proposal by Halle & Stevens (1979) discussed in the previous section. Halle & Stevens used the feature [groove] to distinguish between [ç] and [s]-[s], although apparently also aware of some differences in terms of the active articulator. As argued in the previous section, grooving is not a reliable characteristic of [s]-[s] (or [f]), and thus it cannot be employed as a phonological feature. The proposed new distinction in terms of the cross-sectional area of the channel is relevant to fricatives produced with the tip-blade articulator. Other distinctions between fricatives are to be drawn in terms of the active articulator.
5.3 Tohono O’odham

William Bright reports on his fieldwork on Karok in the mid 1950s: “I was having trouble with sibilants; in some words I consistently wrote an [s]; in others, I consistently wrote [ʃ]” (Bright 1978: p. 43), the latter meant to be the same “sh”-type of fricative as the English [ʃ]. The problem was certainly not Bright’s alone. Other linguists doing fieldwork in several aboriginal languages of California had gone through similar experiences, and Bright comments that the earlier literature on Californian languages, mainly that published in the U. C. Publications in American Archeology and Ethnology between 1900 and 1940, is particularly oblivious to this problem of categorization “seriously lacking in phonetic accuracy”. The following passage characteristically sketches some of the concerns relevant to the issues discussed in this section, and outlines the linguistic geography of the problem.

At first, many words were written inconsistently with [s] and [ʃ]; later, it was recognized that such words actually contained a sibilant which was somehow, articulatorily and acoustically, intermediate between [s] and [ʃ]. In some languages, it was furthermore recognized that a contrast existed between this ‘intermediate’ [ʃ] and some other sibilant; e.g., Kroeber (1911:11), discussing the general problem of sibilants in Californian languages, noted: “In the . . . Kato language . . . and in Karok, Luiseño, and Papago [the last-named being an Arizona language], two sounds analogous to English s and sh, but also not identical to them, exist.” (p. 43)

The next language with available phonetic data I discuss is in fact the last language just mentioned. Formerly known as Papago, this language is now called Tohono O’odham, an Uto-Aztecan (Tepiman) language of Arizona. The data on this language come from the linguagraphic and palatographic study of eight speakers in Dart (1991, 1993). O’odham has two coronal fricatives, an “s”-like [s], and another sound which is somewhat ‘intermediate’ between an “s” type and a “sh” type, labeled [ʃ].

In (7) below, I have reproduced Dart’s results, in the following format. For every speaker (1-8) there are four cells. In the [s] and [ʃ] columns, the top two cells indicate whether [s], [ʃ] are formed by an apical
Articulatory Investigation of Coronal Consonants

or a laminal constriction, and the bottom two cells give the corresponding places of articulation. The definitions of apical and laminal are the same as those given in the discussion of English in section 5.1.

7. Eight O’odham speakers’ characteristics of [s] and [s]

<table>
<thead>
<tr>
<th>Speaker</th>
<th>[s]</th>
<th>[s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>laminal</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>postalveolar</td>
</tr>
<tr>
<td>2</td>
<td>laminal</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>postalveolar</td>
</tr>
<tr>
<td>3</td>
<td>laminal</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>postalveolar</td>
</tr>
<tr>
<td>4</td>
<td>apical</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>dental</td>
<td>postalveolar</td>
</tr>
<tr>
<td>5</td>
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<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>postalveolar</td>
</tr>
<tr>
<td>6</td>
<td>laminal</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>postalveolar</td>
</tr>
<tr>
<td>7</td>
<td>laminal</td>
<td>apical</td>
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<tr>
<td></td>
<td>alveolar</td>
<td>alveolar</td>
</tr>
<tr>
<td>8</td>
<td>apical</td>
<td>apical</td>
</tr>
<tr>
<td></td>
<td>alveolar</td>
<td>alveolar</td>
</tr>
</tbody>
</table>

Reviewing the results in this table, five out of eight speakers produce [s] with a laminal constriction and three of them produce it with an apical constriction. On the other hand, six out of eight speakers produce [s] with
an apical constriction at the postalveolar zone, while speaker 7 forms the
apical constriction at the alveolar zone, as he does for [s], but with [s]
articulated slightly farther back. The last speaker made no distinction in
terms of Dart’s parameters, with both fricatives being apical alveolar, but
again [s] was formed at the front edge and [s] at the farthest back edge of
the alveolar region, the distance between the two points of articulation
being 5-6 mm.

What seems to be clear from this table is that [s] is consistently apical.
However, [s] is not consistently laminal or apical, and seems to be formed
somewhat further forward than [s]. Also, the place of articulation of [s] is
not consistently postalveolar (witness the data on speakers 7, 8). These
problems are by now familiar. We saw that variation in the place of
articulation was also found in the productions of [s] by three speakers of
Chinese, and in the productions of [s], [ʃ] by twenty speakers of American
English (Ladefoged & Wu 1984, Dart 1991). Variation in the apical-
laminal parameter was found in the productions of [s], [ʃ] by sixteen
speakers of Californian English, and in the productions of [s], [z] by
twenty speakers of American English and twenty-one speakers of French

I now turn to examine the cross-sectional area differences between
these two sibilants, which will turn out to be more meaningful. Dart
provides measurements of the channel width, given in the table below.
8. Channel width measurements (in mm) for [s], [s`
(from palatographs)

<table>
<thead>
<tr>
<th>Speaker</th>
<th>[s]</th>
<th>[s`]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
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<td>8.5</td>
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<tr>
<td>7</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Except for speakers 4 and 7 who have the same channel width, all speakers exhibit greater channel width for [s] than for [s]. It is crucial to point out that this channel width is measured from the palatograms, not from the linguagrams. Dart carefully observes an important difference between the palatograms and the linguagrams. Looking only at the linguagrams a “wider channel appeared to occur for all the speakers” (Dart 1993: p. 32, emphasis AG). However, when the palatograms are examined some speakers have quite comparable, indeed equal width spans. This situation is depicted schematically in (9) below. The widths of the palatograms are shown on the top, and are indicative of the widths of the cross-sectional channels of [s] and [s`], indeed relatively similar in span. This much of the palate, outlining the upper boundary of the channel, was not contacted by the tongue. In contrast, the linguagrams show a marked difference in span length, which comprises the parts of the tongue forming both the lower and the lateral parts of the channel.
Inferring channel depth

<table>
<thead>
<tr>
<th>Channel Width</th>
<th>s`</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width from palatogram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width from linguagram</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This difference between the palatograms and the linguagrams allows us to infer, as Dart does, that there is a much deeper channel in the tongue for the articulation of [s`] than for [s]. Given that the cross-sectional area is the product of channel width by channel depth, it follows that the area of [s`] is larger than that of [s]. Crucially this is true even for speakers 4 and 7 who have equal palatographic widths for [s`] and [s], because according to Dart all speakers had a substantially wider linguographic width, and thus deeper channel, for [s`] than for [s].

This suffices to establish once again that there is a consistent relation between the cross-sectional areas of the channels for [s`] and [s], with [s`] > [s]. Although the same contrast appears to be widespread in aboriginal Californian languages, the lack of available data unfortunately precludes an extension of this result to these other languages as well. The following section presents tentative evidence from other languages.

5.4 Other Languages

There is some indication that the above results can be extended to the distinction between the Polish ‘hard’ [s] and ‘soft’ [s`] fricatives (Wierzchowska 1965, Puppel et al. 1977). Puppel et al. describe [s`] and [z`] as follows: “The narrowing is made by the tip of the tongue and the blade of the tongue, and the alveolar ridge. The narrowing as compared with that of s and z is a bit more open” (as cited in Ladefoged & Maddieson 1986: p. 74). Similar evidence for a channel distinction between these fricatives can also be inferred from the discussion of Wierzchowska’s descriptions in the next section. However, at this point I do not have sufficient information to construct another instance of the argument for TTCA for these fricatives. I hasten to note that Polish has a three-way distinction among ‘hard’ [s, z], ‘soft’ [s`, z`], and [c, z] fricatives. The latter look very similar to the Chinese [ç], as also pointed out by Ladefoged & Maddieson (1986). I thus attribute the distinction between them, and both the ‘hard’ and ‘soft’ fricatives to the use of a separate active articulator. The ‘hard’ and ‘soft’ fricatives are primarily
formed with the tongue tip-blade, while the [ɛ, ژ] fricatives are primarily formed with the (pre-, medio-) dorsum, as is the case for Chinese.\footnote{12}

Another test for the proposed cross-sectional area distinction is provided by North-West Caucasian languages, like Adyghe and Kabardian, with rather complex coronal fricative inventories comparable only to those of the Athabaskan languages (to be discussed in the following chapter). Abkhaz, for example, affords a four-way distinction among [s], [ʂ], [ʂʰ], and [ɕ]. Ladefoged & Maddieson (1986: p. 77) show X-ray tracings of these sounds from the Bzyb dialect of Abkhaz, apparently drawn from unpublished work of Catford’s. From these X-rays, it appears that [ɕ] is similar to the sound symbolized this way for Chinese and Polish, that is a fricative under the regime of the dorsum articulator. This leaves us with a need to characterize the distinction between the three other fricatives. I will agree with Ladefoged & Maddieson here that [s], [ʂ] appear similar to the other sounds symbolized in this way, although it seems that the medio- and post-dorsum of the Abkhaz [ʂ] is a bit more raised than for the Polish [ʂ]. I do not know whether this indicates an active ‘palatalization’ gesture, but this is not unlikely given that North-West Caucasian languages typically make use of distinctive palatalization and labialization in their obstruents (Comrie 1981).

Catford describes Abkhaz [ɕ] as a sound ‘between [ʂ] and [ɬ]’ which resembles [ɬ] in that it has “a regular lamino-postalveolar channel, but with the point and rim of the tongue in contact with the rim of the lower teeth” (Catford 1977: p. 155). Unfortunately X-ray tracings by themselves are of no help when it comes to channel measures, which are needed to determine whether the cross-sectional area of the channel provides a distinction among [s], [ʂ], and [ɕ]. One thing that is clear, however, is that a three-way distinction in terms of the cross-sectional area is certainly a possibility. As I argued earlier, English implements such a three-way distinction among the sounds [θ], [ʃ], and [s]. In this regard, it is interesting that North-West Caucasian languages, as I infer from Comrie (1981: pp. 198 ff.), do not have [θ]-like fricatives in their inventories, suggesting that the same three-way distinction in the cross-sectional areas of English [s], [ʃ], and [θ] may be instantiated by the triad [ʂ], [ʂʰ], and [ɕ] of North-West Caucasian languages. This raises an interesting issue. Assuming that the distinctions among the fricatives in the Abkhaz triad [ʂ]-[ʂʰ]-[ɕ] are expressible in terms of the feature TTCA as in the English triad
[s]-[ʃ]-[θ], what determines the difference between Abkhaz and English? This is a question that relates to the more general problem of phoneme variation across different languages, an issue I turn to in 5.7.

Presently I know of no other languages with data that would be relevant to my proposal, so this completes the survey of the pertinent languages. The next section summarizes the evidence for the new distinctive feature and adduces further evidence in its support.

5.5 The Feature Tongue-Tip Constriction Area

The previous sections have examined data from different languages which include three cases of “s” fricatives, [s] of English, [s] of Chinese, and [s] of O’odham, and three cases of “sh” fricatives, [ʃ] of English, [ʃ] of Chinese, and [ʃ] of O’odham. I have noted that within each language there is often a puzzling cross-speaker variation in shape, place of articulation, and/or apicality-laminality for each individual sound. However, there is significant evidence to support the claim that in the examined languages the “sh”-like fricatives consistently have a greater cross-sectional area than the “s”-like fricatives. Moreover, in English the cross-sectional area of [θ] is also consistently greater than that of [ʃ].

I therefore propose a new feature, which I will call Tongue-Tip Constriction Area (TTCA), to express the contrasts among these fricatives. TTCA is defined on the phonetic scale of the cross-sectional area of the fricative channel. As with any phonetic scale, there is a continuum of cross-sectional area values. This continuum appears to be divided into three subzones, giving rise to a three-way categorical distinction among [wide], [mid], and [narrow] cross-sectional channels. Some languages, like English, employ the full triad of contrasts, with [θ] corresponding to the [wide] value of TTCA, [ʃ] to the [mid], and [s] to the [narrow], as shown in (10) below. Other languages, like Chinese and O’odham, employ only two values from this scale, presumably [wide] and [narrow], although there is not much evidence as to which pairs of values on the scale are being contrasted.

10. TTCA scale: [wide] > [mid] > [narrow]  
   θ    f    s

The new feature provides the needed phonological contrasts among
the fricatives of different languages. It also plays an important role in capturing natural classes in the phonological organization of languages, ultimately the role of any phonological feature. In the typological study of consonant harmony of the following chapter, I argue that assimilation in terms of the feature TTCA is one case of this phenomenon.

5.6 Speaker-to-Speaker Variation

TTCA enables us to come to terms with the puzzling cross-speaker variability noted in previous sections. We saw, for example, that in a study of 20 speakers of English it is found that the 'alveolar laminal' [s] and its voiced counterpart [z] are produced at a total of six distinct places of articulation, and 42.50% of the time as apical and 57.50% of the time as laminal. This variability in the data is the sort of thing for which phonology is typically considered not responsible, its accounting being relegated to 'low-level phonetic rules' which take the phonological output and map it onto the physical world. Irrespective of one's general position on the latter view, this is not an option for the case at hand. For, in the production of English [s], the variability manifests itself precisely in terms of the same parameters used in the phonological specification of [s]. This indicates that the problem lies in what we consider to be the parameters of [s]'s phonological specification.

The proposed solution to the variability problem is to elevate the search for invariance to a more abstract level. At that level, the roles of the descriptive parameters of shape of the articulator, place of articulation, and apicality-laminality are secondary in the sense that they are engaged in a synergistic way to effect the realization of the phonological contrast in terms of the TTCAs. Specifically, consider the variability in terms of each of the descriptive parameters. First, there is variability in terms of the actual shape of the channel. Some speakers of English, e.g. the subject studied in Stone et al. (1992), implement the [mid] value of TTCA for [ʃ] by a para-sagittal channel, instead of forming a symmetric hollowing of the tongue by raising both of its sides. By the definition of TTCA, the actual shape of the channel, para-sagittal or mid-sagittal, is irrelevant, as long as the channel area difference is attained faithfully. The second type of variability is in terms of place of articulation. For example, the three speakers of Chinese studied in Ladefoged & Wu (1984) had slightly different places of articulation for [s], and Dart’s 21 speakers of English
articulated [s] at up to six different places covering the entire area from the
dental to the back of the postalveolar zone. The third type of variability
is in terms of the apicality-laminality parameter. English speakers produce
apical and laminal versions of [s] and [ʃ] (Dart 1991, Ladefoged &
Maddieson 1986). O’odham [s] is produced as laminal by five speakers
and as apical by three speakers. The conclusion is inescapable that the
exact place of articulation and apicality-laminality of the fricative gestures
are not essential. What matters is the formation of a channel, the
definitional characteristic of fricatives, whose cross-sectional area must be
made significantly different for two contrastive fricatives for the same
speaker.

This is not to say that apicality-laminality and place of articulation can
vary freely. A salient statistical trend in the data is that “sh”-like fricatives
tend to be formed farther backward than “s”-like fricatives and with blade
of the tongue making contact at some point in the alveolar and/or post-
alveolar zones (Ladefoged 1957; see also the results reported in Dart
1991, reproduced here in the section on English). There seems to be a
simple interpretation of this tendency in terms of the TTCA feature. The
tongue’s width narrows towards its front end. The formation of a wider
and deeper channel requires a greater tongue width, because laterally the
tongue raises symmetrically or asymmetrically to form the sides of the
channel, hence the more retracted and usually laminal articulations of the
“sh”-type fricatives. However, these tendencies are merely statistical and
as such they cannot be elevated individually to the status of phonetic
properties implementing a phonological contrast. Their exceptions will be
the norm because individual oral morphology differences, in terms of
dentition, palate height and asymmetry, tongue length and width, are the
norm (see Best & Queen 1989, and the earlier discussion of Hamlet 1987).

In a more general context, both the variability problem and the
proposed solution are signature characteristics of sensorimotor systems of
skilled actions. The first goes under the name of ‘motor equivalence’.
Hughes & Abbs (1976) define this term as “the capacity of a motor system
to achieve the same end product with considerable variation in the
individual components that contribute to that output” (p. 199). Turvey
(1980) identifies the type of solution I proposed as another characteristic
property of skilled behavior, which he calls ‘indefiniteness of action
plans’. According to this property, plans for actions are indefinite in the
sense that “they are not ‘written’ in muscular predicates but in predicates of a more abstract kind” (p. 46). TTCA is such an abstract predicate or phonological primitive. Its implementation does not specify the exact values of shape, place, or apicality-laminality, but instead coordinates the aggregate of these attributes into achieving the realization of the phonological contrast in terms of the cross-sectional area of the fricative channel.14

5.7 Language-to-Language Variation
In this section, I consider another type of variation observed in the data, variation of a particular sound across different languages. Consider a particular fricative, for example, the wide fricative of English, [θ]. Other languages have wide fricatives which seem to be phonetically different from the [θ] of English. To the extent that such differences turn out to be systematic, an adequate phonetic theory ought to characterize them in some way. In what follows, I illustrate the cross-language variation of [f [θ]], but the situation is by no means limited to this sound only. Ladefoged & Maddieson (1986) report that 90% of Californian English speakers produce [θ] with the tip of the tongue inserted between the teeth, whereas 90% of British English speakers produce [θ] with the tip behind the upper front teeth. There is then a statistically significant difference between American and British English [θ]. However, no language is known to have a contrast on the basis of this distinction. Note also that there are various ways in which this distinction can be described. For example, the term ‘interdental’ is typically used for American English [θ], versus ‘dental’ for British English [θ], implying a distinction in terms of place of articulation. Alternatively, Ladefoged & Maddieson (1986) characterize the American English [θ] as ‘laminal’, and the British English [θ] as ‘apical’, emphasizing a distinction in terms of the part of the tongue involved.

Icelandic and Karok illustrate yet two more cases of wide fricatives. In Icelandic, [θ] is articulated with the tongue near the front part of the alveolar ridge (Pétursson 1971). Ladefoged & Maddieson (1986) characterize this retracted variety of [θ] as ‘alveolar’, as opposed to the ‘dental’ or ‘interdental’ varieties of [θ] found in English. Karok has an “s” type fricative, which according to Bright is “a very far-forward apico-dental sound” (Bright 1978: p. 43). Ladefoged & Maddieson (1986), who
use the symbol [s] for this sound, point out that [s] is an example of a sibilant produced in the same place of articulation as for [θ] non-sibilant sounds. Bright also notes a tendency of young speakers of Karok to pronounce [s] as [θ]. This may be the result of a number of factors. For example, underdeveloped dentition in younger speakers could result in a ‘dental’ [s] sounding as a lisped [θ], or perhaps the distinction between [s] and [θ] requires a degree of precision in the control of the articulators not yet developed by these young speakers. In any case, the [s] of Karok, contrasting with the two other fricatives of the language, [s] and [s], seems to correspond to the [θ] of English.

Obviously American English [θ], British English [θ], Icelandic [θ], and Karok [s] are different sounds. In some well-defined sense, however, they all are the same ‘type’ of sound, because in the phonological inventory of each particular language each of these fricatives corresponds to the [wide] value of TTCA. In other words, there is an equivalence class of [wide] fricatives which includes all these sounds (and perhaps others which happen consistently to differ from them). Languages seem to ‘select’ one such sound from the equivalence class of [wide] fricatives. Sounds from the same equivalence class differ along certain phonetic dimensions. Hence the conclusion is inescapable that there are language-particular properties, which must be part of the phonetic specification of a fricative sound. For example, the fricative [θ] must be specified to be ‘dental’ for British English, but ‘alveolar’ for Icelandic.  

Instances of the same situation for different sounds can be drawn at will from the literature. Disner (1983) finds several systematic differences in the vowels of various Germanic languages. Norwegian [ø] is less rounded than German [ø], Danish [ø] is more closed than Swedish [ø], Swedish [i] is more closed than English [i], Dutch [ɛ] is more open than German [ɛ] etc. Linker (1982) finds that [u] is produced by Cantonese and English speakers with less lower lip protrusion than that used by speakers of Finnish, French, and Swedish. There are then some phonetic parameters, e.g. ‘lower lip protrusion’, which do not independently serve as a basis for a contrast in any language, but are subject to language-particular specification.

Returning to the case of fricatives, we do not know yet exactly what parameters express the phonetic differences among the sounds in the equivalence class of [wide] fricatives. What has been done so far is a
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documentation of the different sounds that occur in some of the languages of the world, and a description of their differences along the lines sketched above (Ladefoged & Maddieson 1986). It is also clear that if we are to identify a parameter in terms of which sounds of the same equivalence class may differ, then we ought to ask why the phonetic differences which the parameter expresses are not contrastive in any particular language (Fromkin 1979, Ladefoged 1971). These are long-standing questions which phonetic theory has not yet addressed adequately, and which go beyond the goals of this chapter.

5.8 The Feature Distributed

The proposed feature TTCA is reminiscent of the feature Distributed of Chomsky & Halle (1968). In this section, I discuss the similarities and crucial differences between these two features. I argue that only TTCA and not Distributed withstands a rigorous cross-linguistic test in providing a consistent basis for a contrast. Previous objections to Distributed are also reviewed.

Chomsky & Halle define [distributed] as a feature implementing the phonetic dimension of “the length of the constriction along the direction of airflow” (p. 312). Distributed are those sounds whose constriction extends for a considerable distance along the direction of airflow. In nondistributed sounds the constriction extends only for a short distance. Chomsky & Halle make it clear that the feature is intended to capture further refinements of the [+anterior]/[−anterior] place distinction. Hence, as Keating (1991, 1988a) points out, although Distributed is not a place feature itself, it is typically used as such. For example, dental and alveolar correspond to a front and back subdivision of the [+anterior] place of articulation, as do retroflex and palato-alveolar for the [−anterior] places of articulation. Chomsky & Halle propose that in languages with either of these contrastive subdivisions “in most cases the subsidiary differences in point of articulation are also accompanied by characteristic differences in the length of the zone of contact”, and later “in effect claiming that subsidiary differences in points of articulation are in all cases describable with the help of low-level phonetic rules” (p. 312).

Some similarities and differences between TTCA and Distributed can be noted. First, both proposals treat the differences in place of articulation as secondary. Second, both features are implemented in the spatial
dimension, but whereas Distributed is measured on the midsagittal plane as length of a constriction, which is *a priori* relevant to both stops and fricatives, TTCA is measured on the cross-sectional dimension as the area of the channel, a characteristic only of fricative sounds. Hence, TTCA is irrelevant to stops by definition, while Distributed is meant to be relevant to both stops and fricatives alike (but see the discussion below). Second, Distributed is defined on the mid-sagittal dimension as length of the constriction in the direction of airflow, while TTCA is defined in the cross-sectional dimension, considering the relevant measures to be both the depth of the channel and the width of the constriction. The cross-sectional dimension of speech production has been largely neglected in descriptions of articulatory movements, and even more so as a possible basis for a feature. This seems to be a reflex of the technical difficulties associated with collecting cross-sectional images of the tongue, and thus carries no theoretical weight in deciding between TTCA and Distributed. It would be distinctly unwise to let mainstream technology obstacles dictate the choice for feature dimensionality, especially when it is becoming increasingly clear that the third spatial dimension is rich in structure and variation and is a promising area of research for phonetics (see Stone et al. 1992 and references therein), and according to the proposals of this and the following chapter, for phonology as well.

Now I turn to the substantial differences between Distributed and TTCA, and ultimately to the reasons for abandoning the former feature. Chomsky & Halle point out that the \([-\text{distributed}]/[+\text{distributed}]\) contrast does not correspond exactly to the apicality-laminality distinction, although they imply that this distinction is subsumed by Distributed, with laminal articulations having longer constrictions \([+\text{distributed}]\) than apical articulations \([-\text{distributed}]\). This issue is relevant to some previous attempts to evaluate the plausibility of the feature Distributed. In particular, the following critiques of Distributed attempt to evaluate the correlation between apicality-laminality and length of constriction. Keating (1991) points out the paucity of data on which the proposal for Distributed was based, and briefly reports on her own work, which leads her to conclude that “though laminal constrictions are longer than the shortest apical constrictions, apicals can also be long”, and that “there appears to be little support for this phonetic definition of Distributed” (p. 43). To the extent that I can draw inferences from Keating’s brief
discussion of this point, I do not believe that cross-speaker comparisons, on which Keating’s conclusions seem to be based, are particularly relevant. It may very well be the case that speaker A’s laminal constriction is shorter than speaker B’s apical constriction, and indeed expected given individuals’ variability in oral morphology. What seems to me relevant is whether each individual speaker consistently implements a contrast by means of a longer vs. shorter constriction for two contrastive sounds.

In a similar regard, some of Dart’s objections to Distributed should also be qualified appropriately. For example, Dart (1991: p. 46) discusses the case of two English speakers, one with an apical and the other with a laminal articulation of [t], but with indistinguishable constriction lengths. Again, cross-speaker comparisons seem irrelevant to the reality of Distributed, or any other feature for that matter. These ‘correlation tests’ between apical-laminal and length of constriction are also confounded by the necessarily subjective nature of individuals’ classifications of apical-laminal articulations. As is the norm with phonetic descriptions, there are no a priori categorical distinctions. Different observers divide the continuum of apicality-laminality in different ways. Bladon & Nolan (1977), for example, recognize three degrees of tip and blade height. Dart (1991), in addition to the apical-laminal distinction, recognizes an intermediate category of apicolaminals where both the tip and the blade are contacted. Ladefoged & Maddieson (1986) use yet another system of classification, considering an articulation to be apical when the tip of the tongue is above the plane running between the upper and lower incisors (p. 68). Another complexity factor associated with the correlation tests is that both stops and fricatives are used (at least by Dart) to draw conclusions about Distributed. These are two classes of sounds with entirely different aerodynamic properties, and it seems that an investigation of the plausibility of Distributed must take this into account. Ladefoged & Maddieson (1986), although not directly preoccupied with the correlation test of Keating and Dart, imply a similar concern when they write that “separating apical from laminal articulations does not seem to be as useful in the case of sibilants as it is when distinguishing among stop consonants or liquids” (p. 78). In short, I find that the above criticisms of Distributed based on the correlation test between apicality-laminality and length of constriction do not settle the issue of the reality of Distributed, mainly because of the complexities associated with the methodological details of
Refocusing on the comparison between Distributed and TTCA, I propose a different approach to the issue. Distributed will be evaluated in two separate cases. The first case corresponds to the first claim made by Chomsky & Halle that Distributed subsumes the apicality-laminality parameter. In testing this claim, I have the same intention as Keating and Dart above, but I employ a different method, which simply consists of finding cases where Distributed defined in terms of constriction length fails to give within-speaker contrasts. Such cases can indeed be found thanks to Dart’s detailed articulatory data. For example, speaker 8 (7) of O’odham contrasts an apical /d/ with a laminal (apicollaminal) /j/ stop, which are both articulated at the alveolar place and have equal constriction lengths of 8 mm (7 mm). If it was true that the apicality-laminality parameter is subsumed by Distributed, then the laminal /j/ should have a longer constriction than the apical /d/. Since this is not the case, it follows that Distributed does not subsume apicality-laminality. Rather, it seems that the apicality-laminality parameter, implemented in terms of TTO, should be maintained for these stop contrasts. Dart seems to be making a similar suggestion by viewing the place of articulation together with the apicality-laminality parameters as good descriptive classifiers for a wide body of data, but as pointed out earlier, she arrives at this view by a different methodology, which I think cannot correctly lead to this conclusion. Similarly, Keating (1991), in the context of her discussion referred to above, also concludes that her findings “support limiting the feature Distributed (by this or some other name) to the apical-laminal distinction.” (Keating 1991: p. 43).

I now turn to the second case in the evaluation of Distributed. As pointed out earlier, Chomsky & Halle believe that Distributed does not only subsume the distinction of apicality-laminality, but also that it correctly captures another type of contrast, which the apicality-laminality distinction fails to describe. Chomsky & Halle’s discussion centers around the following passage from Wierczowska (1965), describing the articulatory differences between the “hard” and the “soft” fricatives of Polish.
The contact made by the tongue with the roof of the mouth in articulating [the “soft” dentals-NC/MH] \(\acute{c}\ \grave{z}\) as well as \(\acute{s}\ \grave{z}\) is considerably wider than the contact made in the hard \(c\varsigma\)\(\varsigma\). The closure in the forward portion of the region of contact includes in the case of \(\acute{c}\ \grave{z}\) the teeth ridge and extends to the forward part of the hard palate...

The groove in \(\grave{s}\ \grave{z}\) is longer than in the hard consonants \(c\varsigma\)\(\varsigma\) extending not only across the teeth ridge but also across the forward part of the hard palate...

[The groove] is formed by a part of the tongue that is farther back than that used in the case of the hard consonants.

Chomsky & Halle’s view is that what provides the distinction between the “hard” and “soft” fricatives is not the apicality-laminality parameter, but rather the length of the constriction in the direction of airflow. The place of articulation differences between the two classes of sounds are considered subsidiary (similarly to my proposal). However, that view arbitrarily focuses on the portion of Wierzchowska’s description I underlined, interpreting the rest as incidental or derivable by some sort of low-level phonetic rules, as assumed for the place differences also. Note that other portions of Wierzchowska’s description are consistent with the distinction being in terms of the TTCA feature; witness the phrase “considerably wider” referring to channel width, in conjunction with no mention of apparent differences in groove depth between hard and soft consonants, providing some evidence for a distinction in terms of TTCA and no evidence against it. Also, note that the comment about the length of the groove is irrelevant to the evaluation of TTCA. Finally, the phrase “a part of the tongue that is farther back” is reminiscent of the correlation between [wide] TTCA fricatives and blade constrictions discussed in 5.6.

(The discussion of Polish fricatives in 5.4 also provides some tentative support for TTCA from another source.)

The above conclusions are, however, speculative, and to avoid problems of overinterpretation, I turn to a case where actual measurements are available, again thanks to Dart’s experimental data. The relevant case is found in O’odham, whose [s]-[\(\varsigma\)] contrast provides a situation entirely parallel to the Polish case discussed by Chomsky & Halle based on Wierzchowska’s data. For the O’odham fricatives, the apical-laminal
distinction is irrelevant, because [s] is variously produced as apical (by 3 speakers) or laminal (by 5 speakers), while [s] is consistently apical for all 8 speakers. The place of articulation does differ, with [s] articulated at the dental or front alveolar zone, and [s] articulated at the alveolar or postalveolar zone, but I assume, like Chomsky & Halle, that this difference is subsidiary.

Having set up the conditions for the comparison between TTC A and Distributed which are as similar to the Polish case as possible, I now proceed to examine actual measurements. The crucial case is that of speaker 4. (The rest of the speakers’ contrasts can be captured by either Distributed or TTCA.) Constriction length along the direction of airflow is 5 mm for both [s] and [s]. Constriction width is 6.5 mm. Both constriction length (Distributed) and constriction width fail to give a distinction. This much is enough to confirm the failure of Distributed to provide the basis for the contrast, but not so for TTCA. Constriction width is only partly involved in the proposed basis of the contrast, namely, the cross-sectional area of the channel, whose other dimension is the channel depth. Crucially, according to Dart all speakers have deeper channels for [s] than for [s], and hence speaker 4 implements the distinction between the two fricatives in terms of TTCA. The conclusion is that whereas Distributed fails to give a consistent distinction, TTCA succeeds, because the additional dimension of channel depth is also relevant to the implementation of TTCA.

Summarizing the results of this section, I have made two points. First, I have shown that there are cases where Distributed fails to provide a basis for a contrast in the case of coronal stops. These cases falsify one aspect of Chomsky & Halle’s proposal, namely, that the feature Distributed subsumes the apicality-laminality parameter. I have proposed that in the case of stops the feature Distributed should be replaced by the apicality-laminality parameter. Second, for coronal fricatives only TTCA and not Distributed provides a basis for a contrast. For coronal fricatives, then, TTCA must replace Distributed.

6. SUMMARY AND CONCLUSION

Traditionally, articulatory observations in speech are based on a sagittal view of the vocal apparatus. The surface of the tongue, however, is adjustable in both the sagittal and the cross-sectional plane. There seem to
be no *a priori* reasons why articulatory descriptions should be based exclusively on the sagittal plane. This is particularly true for one class of sounds, the fricatives, articulated with the front part of the tongue, where articulatory control in the cross-sectional dimension is unanimously thought to be crucially involved: most researchers describe a groove-shaped tongue as an important characteristic of [s]. Indeed, the signature characteristic of fricatives is the creation of a channel which funnels the air out of the vocal tract. Obviously the characteristics of this channel can be observed and quantified only by taking a cross-sectional view of the vocal tract.

In this chapter, I have explored the behavior of the front part of the tongue in a cross-sectional view. While some traditional beliefs about the importance of the actual shape of the tongue were found to be factually incorrect, I have identified a phonetic scale of articulatory control, namely, the cross-sectional area of the channel, based on an original proposal of Catford (1977). On this scale, I have defined a new feature, TTCA, with three contrastive values [wide], [mid], and [narrow], which provides the needed phonological contrasts among fricatives across different languages. An important virtue of TTCA is its ability to account for the widespread cross-speaker variation observed in terms of the descriptive parameters of place of articulation, apicality-laminality, and shape of the tongue. A further result of this chapter is a demonstration of the inadequacy of competing proposals, such as the feature Distributed of Chomsky & Halle (1968) and the feature Groove of Halle & Stevens (1979), which are subsumed by the new TTCA feature.

With the two basic gestural parameters, TTCA and TTCO, for coronal sounds now at hand, we are prepared to begin the study of consonant harmony in the next chapter. As we will see, there are two species of consonant harmonies: TTCA harmony and TTCO harmony, where the assimilating parameters, TTCA and TTCO respectively, propagate through intervening vowels in accordance with Articulatory Locality.
NOTES

1. A concise version of this chapter has appeared after the completion of the dissertation as Gafos (1997). See also Ni Chiosáin & Padgett (1997) and Wiltshire & Goldstein (to appear) for work that builds on this chapter.

2. This term is introduced in Ladefoged (1968) and refined in Catford (1977). See the discussion in section 4.5 of the next chapter. Other terms are ‘frictionless continuant’ used by older publications of the International Phonetic Association, and ‘glide’ or ‘semi-vowel’, the latter two being common in the modern phonological literature.

3. In another well-known model, that of Harshman, Ladefoged & Goldstein (1977), there is no parameter controlling the position of the tongue tip. The reason is that this model describes the mid-sagittal shapes of the tongue during vowel production, and takes the precise position of the tip to have very little effect on the quality of the produced sound.

4. As with other articulatory parameters, I follow Browman & Goldstein (1989) in assuming that in the languages where TTOC is contrastive the categorical distinctions between the [apical] and the [laminal] range of values of the TTOC parameter are derived from quantal articulatory-acoustic relations (Stevens 1972, 1989).

5. In describing obstruent sounds with this system one of the two indices must have the value 3, because either the tip or the blade must make contact with the upper surface of the vocal tract. There are then five possible configurations which are produced by this system: 3-1, 3-2, 3-3, 2-3, and 1-3.

6. In the following chapter, I return to Bladon & Nolan’s findings to discuss the very interesting long-distance coarticulatory effects between alveolar consonants over a vowel that are reported in their study.

7. Each speaker produced a word-initial and word-final version of each fricative (as in a sap, a pass), resulting in 40 tokens for each fricative. Except for one speaker who made a consistent distinction between an apical word-initial articulation and a laminal word-final articulation,
speakers did not vary their productions of the fricatives in terms of apicality/laminality in the two different environments.

8. In labio-dental fricatives, of course, the lower articulator is not the tongue but the lower lip. Here, I am strictly concerned with lingual fricatives and in particular those articulated with a constriction of the tip-blade.

9. Ladefoged & Maddieson (1986) also describe a retracted version of this latter articulation which they characterize as being ‘farther back, with the tongue near the front part of the alveolar ridge’ (p. 63). They illustrate this articulation with Icelandic [θ] and [ð]. The [θ], which as shown in the X-ray makes contact with the lamina at the alveolar zone and the tip at the lower incisors, they call ‘laminal-alveolar’. The [ð] is instead an ‘apico-alveolar’, where the tip of the tongue seems to be in contact with the alveolar ridge. Ladefoged & Maddieson cite Pétursson (1971) as their source of data, whose study appears to be based on a single speaker of Icelandic. Given the ubiquitous cross-speaker variation shown in Dart (1991) and the other multi-speaker studies discussed later, there is not much one can infer about Icelandic in particular. One can still register, however, another possible articulation of [θ] and [ð] in our already rich repertoire of different articulations.


11. A palatogram or a linguagram is taken by painting a subject’s palate or tongue with a dark liquid, and having the subject utter a test word, containing only one consonant which requires contact of the tongue with the palate. Immediately after the word is produced the subject sticks his/her tongue out, and a photograph is taken of either the area of the palate that has come in contact with the painted part of the tongue, producing a palatogram, or the part of the tongue that has come in contact with the painted palate, producing a linguagram. See Ladefoged (1968:p. xv), Dart (1991: p. 11) for precise descriptions of these methods of investigation, and Abercrombie (1957) for the history of this over a hundred-year-old technique.
12. Note that the traditional description of the Polish fricatives, ‘hard’ [s, z] vs. ‘soft’ [ʂ, ʐ], implies a contrast, albeit impressionistic, between [s, z] and [ʂ, ʐ], exclusive of the third class of [ɕ, z], and thus supports my claim that the three classes of sounds should not be contrasted on the basis of a single phonetic scale.

13. See the arguments in Ladefoged (1988) that distinctive features can be multivalent. Fant (1973: p. 175) also points out that distinctive features need not be binary.

14. See Abb s (1986) for a discussion of the teleological basis of these properties of sensorimotor systems.

15. I use quotes to emphasize the point made earlier that it is not clear what the right parameters are which describe the differences between the [θ]'s of different languages. The terms ‘dental’, ‘interdental’ are then to be interpreted as cover features for the underlying set of desired parameters.

16. A notable exception is the proposal in Browman & Goldstein (1989: p. 228) for tongue body shape features based on Ladefoged’s descriptions of laterals.