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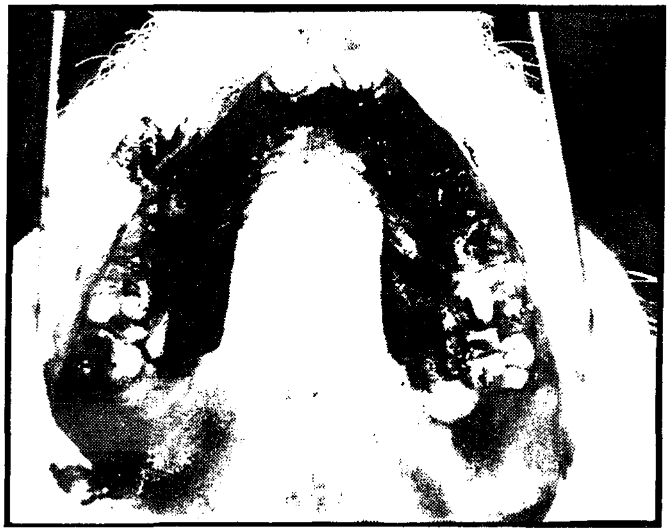
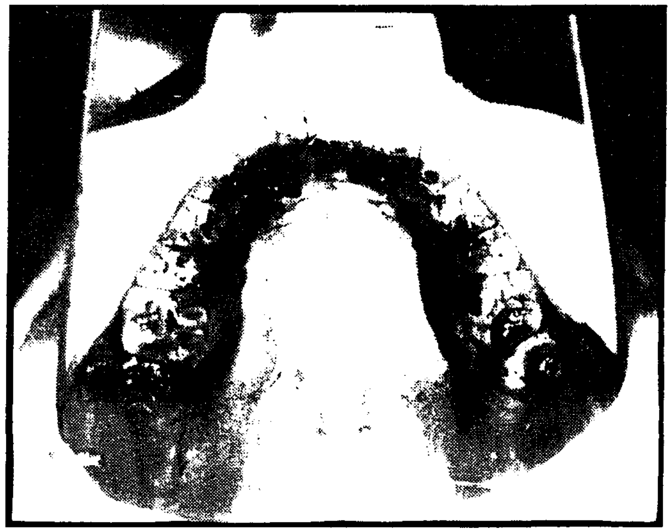
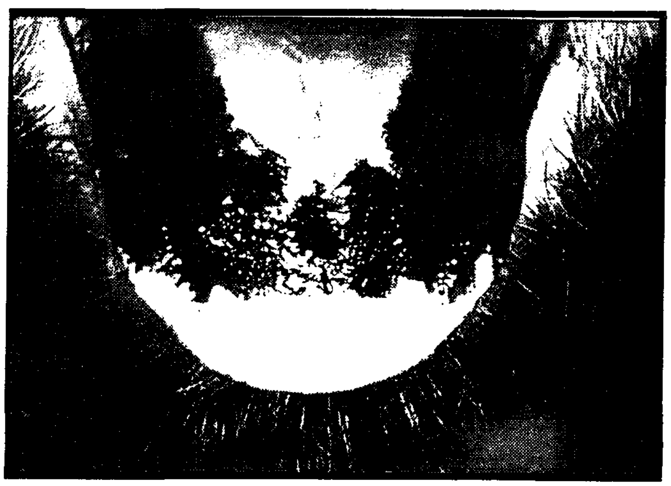
 

Articulatory and Acoustic Properties of Apical and Laminal Articulations

– **Sarah N. Dart**

The UCLA Phonetics Laboratory Group

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Articulatory and Acoustic Properties of Apical and Laminal Articulations

by

Sarah N. Dart

"Sa façon de dire les terminaisons en **i** faisait croire à quelque chant d'oiseau: le **ch** prononcé par elle était comme une caresse, et la manière dont elle attaquait les **t** accusait le despotisme du coeur."

Honoré de Balzac Le Lys dans la Vallée, p.48

Her way of pronouncing the endings in **i** was reminiscent of some bird song: the **sh** as she pronounced it was like a caress, and the manner in which she would attack the **t**'s underscored the despotism of her heart.

Acknowledgments

I would like to first express my gratitude to the 52 speakers who volunteered (often before knowing what exactly was in store for them) to have their mouths painted with charcoal and olive oil, without whom there would have been no data to analyze. I would like to particularly mention the people of Lille who were wonderfully helpful and willing to be "cobayes" (guinea pigs) for the seemingly bizarre experiment of a complete stranger and who have changed forever my image of that city

For patient encouragement, advice and inspiration throughout my long graduate career and for help with the many preliminary drafts of this dissertation, I would like to thank my advisor, Peter Ladefoged. I feel very fortunate to have been able to work with him over the years as part of the UCLA Phonetics Laboratory group. I have also received valuable comments on the dissertation and help at various phases of my graduate work from Patricia Keating and Ian Maddieson and have benefited greatly from their advice. Without the periodic feedback from these three members of the phonetics laboratory, each with their own special emphasis, this dissertation would have been much the poorer.

The 'O'odham study would not have been possible without the help of Molly Dufort, who, through her friendship with the 'O'odham people, smoothed the way for my experiment, and who took off time from her own work to drive me all around the Papago reservation in search of speakers.

I could not have completed my graduate work without the many hours of babysitting provided, free of charge, by my mother, Martha J. Dart. I am grateful for her determination to "see it through until the end", even in the face of the ever widening gap between her energy level and that of her grandchildren. I thank my father, S. Leonard Dart, for his quiet example and for periodic help with matters of acoustics.

Last, but far from least, I would like to thank René Coppieters for his help in France contacting the French speakers, for his daily patience and support while I was working on this dissertation and especially for graciously knowing when to stay out of it.

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Chapter 1. Introduction and method.

1.0 Introduction

Consonants have usually been described in terms of place of articulation in the vocal tract, that is, the location of the place of greatest constriction. Similar consonant segments which have comparable places of articulation on the roof of the mouth, can also differ in the shape taken by the lower articulator, especially the tongue. In particular, a distinction is often made between segments articulated with the tongue tip up (apical) and those with the tip down and the blade making contact on the upper surface (laminal). This distinction is reported as phonemic in some languages (e.g. Hupa, Bright 1978) and as a matter of individual variation in others, as in the articulation of /S/ in English (Wise 1957, Jones 1963). It has been hypothesized by some authors (Bright 1978) that these two articulatory strategies give audibly different acoustic effects, and by others that there is no acoustic difference at all (Wise 1957, Malmberg 1969). At the articulatory level itself there is considerable confusion as to the relevant parameter involved. For example, when comparing laminal dentals with apical alveolars, does the place of articulation feature imply the apical/laminal distinction, making the latter in fact redundant, or is it, on the contrary, the apical/laminal parameter which conditions the place of articulation? Should this difference in articulatory strategy, by itself, constitute a crucial part of a linguistic phonetic theory, or is it just a redundant speaker-specific or place of articulation-specific feature which does not need to be independently specified?

It has been suggested that some languages require a feature of apicality (or laminality) in order to condition some of the phonological rules. In Lardil, for example, Hale (1973) claims that no word may end in a non-apical consonant, which makes necessary a phonological rule that deletes non-apical final consonants. According to Beeler (1970), Chumash, of which the last speaker who had learned the language in childhood died in 1965, had an apicality harmony rule where all coronal affricates and fricatives in a word must agree in apicality, the coronals in the root word agreeing with the apicality of the suffix. There is unfortunately no detailed phonetic description of the actual articulation of the Chumash segments called apical and laminal, not even their place of articulation on the palate, so it is difficult to know exactly what is meant. It is probable, however, that a feature distinguishing apical from laminal is necessary to describe the phonological rules of at least these two languages, and certainly one would be needed in the description of the many languages which distinguish these sounds, such as most of the native languages of Australia.

The problem of apical and laminal articulations involves several different areas of phonetic research and theory. Firstly, it is important to know if such a distinction should be made in a phonetic or phonological feature system. If so, a meaningful choice of feature, tied to some direct phonetic reality, can only be made if the articulatory and acoustic parameters involved are known. It is also useful to take into account any possible connection which there might be between apicality and place or manner of articulation, as has been suggested in the literature. Is it true, for example, as Ladefoged and Maddieson (1986) claim, that "dental sibilants are always apical" (p.78) or that in contrasting apical and laminal stop consonants the laminal one will be more affricated (p.9)? If this were also the case for non-contrasting apical and laminal segments, such information on individual variation would be important for speech recognition systems as well as general phonetic knowledge. The present study attempts to clarify some of the conflicting claims in the literature and to describe the differences, both acoustic and articulatory, which exist between both contrastive and non-contrastive apical and laminal consonants. It has as its basis a cross-linguistic study of the articulatory and acoustic features of apical and laminal consonants involving both languages where apicality is distinctive and those where it is not. I will first review the treatment of this distinction in recent linguistic theory and summarize previous work in this area, then I will outline my method for investigating this phenomenon.

1.0.1 Apical and laminal in distinctive feature theory

In The Sound Pattern of English (1968), Chomsky and Halle proposed the feature [distributed], in part to distinguish dental from alveolar consonants, since they are both categorized as [+anterior] (in front of the palatoalveolar region) as well as [+coronal] (with the tongue blade raised from a neutral position). As they wished to use this feature to separate not only different coronal segments, but also to distinguish others such as labials from labiodentals, the feature is defined in terms of the length of the constriction (in the direction of the airflow) and not in terms of the place of articulation or the part of the tongue used. They noted, "...that the difference characterized by distributed versus nondistributed does not correspond precisely to the distinction between laminal and apical. The relevant distinction is not between articulations made with parts of the tongue other than the apex and those made with the apex, but rather between sounds made with long constrictions and those made with short constrictions." (pp. 313-14). The relevance of their feature for our purpose, then, is directly tied to whether or not laminal articulations really have, as they hypothesized, a longer constriction than apical articulations.

Linguists' ways of dealing with phonological descriptions of apical and laminal consonants have varied according to their understanding of the distinctions existing in natural languages. Ladefoged (1968) pointed out that at least in West African languages, pairs of contrasting dental and alveolar stops appeared to always differ in apicality, although which one was apical and which laminal could vary from language to language. On this basis, Chomsky and Halle (1968) felt that their feature [distributed] was enough to distinguish all contrasting dentals and alveolars. In a later book, however, Ladefoged (1971) pointed out that in Malayalam the dental and alveolar stops were reported to both be apical, and therefore would not be distinguished by the feature [distributed] of Chomsky and Halle, but would need a place of articulation feature such as Ladefoged proposed. In recent phonetic literature the dentals in Malayalam have been usually classed as laminal, and the alveolars as apical. This has been extended to be a general property of dentals vs. alveolars, as Stevens, Kaiser and Kawasaki (1986) state, "A dental or palatal consonant is laminal or [+distributed], whereas an alveolar or retroflex consonant is apical or [-distributed]." (p. 432). The schematic drawings they provide certainly don't illustrate the idea of a longer constriction for the dental and no mention is made of Ladefoged's (1968) conflicting claim that the dental stops in Temne are apical and the alveolars laminal. By their definition, apical versus laminal articulation would not be one of the "independently controllable aspects of the speech event" (Chomsky and Halle 1968, p.297), but rather would be an automatic correlate of the traditional "place of articulation" features, and as such, would not be one of the linguistically significant variables. It is evident that some clarification of these terms is long overdue. The feature [distributed] has been used to specify simultaneously the place of articulation on the palate, the length of the constriction and the part of the tongue used. These three parameters have been shown to vary independently (e.g. Ladefoged 1968) and thus should not be considered to form an invariant grouping. I would like to make it very clear that when I refer henceforward to the terms *apical* and *laminal*, this only applies to the part of the tongue used, and does not imply anything else unless precisely stated.

Along with the confusion in articulatory description, comes a similar lack of coherence in specifying the acoustic correlates of this feature. Although Chomsky and Halle (1968, p. 312) claim that, "The length of a constriction along the direction of the air flow has obvious acoustical consequences...", they give no indication as to what these consequences might be. Fant (1973) confesses his uncertainty, "The feature *distributed* which on the articulatory level is defined as a long versus short constriction in the direction of the airflow has not been analyzed very closely as to its acoustic correlates, and these are far from obvious." (p. 183). The only way to really tease out the acoustic difference between apical and laminal articulations is to find sounds in which the part of the tongue used is the primary, if not the only, articulatory difference, a goal which I have tried to realize in the present study.

1.0.2 Previous articulatory studies

Articulatorily, the question of apical versus laminal articulations is one that has not been much studied, despite the fact that there is no lack of phonetic techniques suitable for examining these differences. Different forms of palatography, a process in which the tongue is most often coated with a marking substance which rubs off on the palate during articulation of the segment being tested, a permanent record being obtained by photographing the marked palate, have been in use for over a hundred years (for a history of this technique see Abercrombie 1957). Most palatography studies, however, neglect the corresponding linguagraphic information (where the palate is coated and the contact area on the tongue is recorded) and the part of the tongue used is only assumed. It is no trivial task, however, to identify a segment as apical or laminal just by looking at the contact as seen on a palatogram. The two utterances in Figure 1.1, for example, are of two different native speakers of American English saying the word "pat". As can be seen, the area of contact (in black) on the palate is similar, but when compared with the corresponding linguagrams (area of contact also in black) it can be seen that very different parts of the tongue were used. The speaker labelled "apical" contacted the tip of the tongue for /t/, whereas for the speaker labelled "laminal" the contact was back from the tip on the blade of the tongue.

Ladefoged (1968) refers to contrasting apical and laminal consonants in various West African languages. He has palatograms illustrating these segments in Ewe and the part of the tongue used was verified visually at the time. Ladefoged specifies that /d/ in Ewe is apicolaminal (involving both the tip and blade of the tongue) dentialveolar and the contrasting /ḍ/ is apical alveolar. I know of no other study which uses linguagraphic evidence to directly address the question of apical and laminal articulations.

Another technique for observing tongue position during speech is that of x-ray cinematography or cinefluorography. In most of these studies, the relevant parts of the subject's tongue are marked with a radiopaque substance, to give a clearer outline of the contour of the tongue. The images on the film are then traced, frame by frame, and analyzed. The only specific study of this sort on the topic of apical and laminal articulations is that of Bladon and Nolan (1977), which reports tongue tip position in English alveolar stops and fricatives using lateral cinefluorography. They found that contrary to the previously given accounts in the literature, most of their 8 speakers had laminal s/z articulations and were fairly evenly split in terms of whether the stops t/d were apical or laminal. These findings suggest that earlier authors, who claimed that the English stops were apical, and were mixed in their predictions for the apicality of English fricatives, did not use a large enough sample upon which to base their generalizations. It is obviously crucial to any study of this sort to have as many speakers as practicable, in order to increase the possibility of making meaningful language-specific generalizations.

Borden and Gay (1978) obtained simultaneous x-ray and electromyographic data

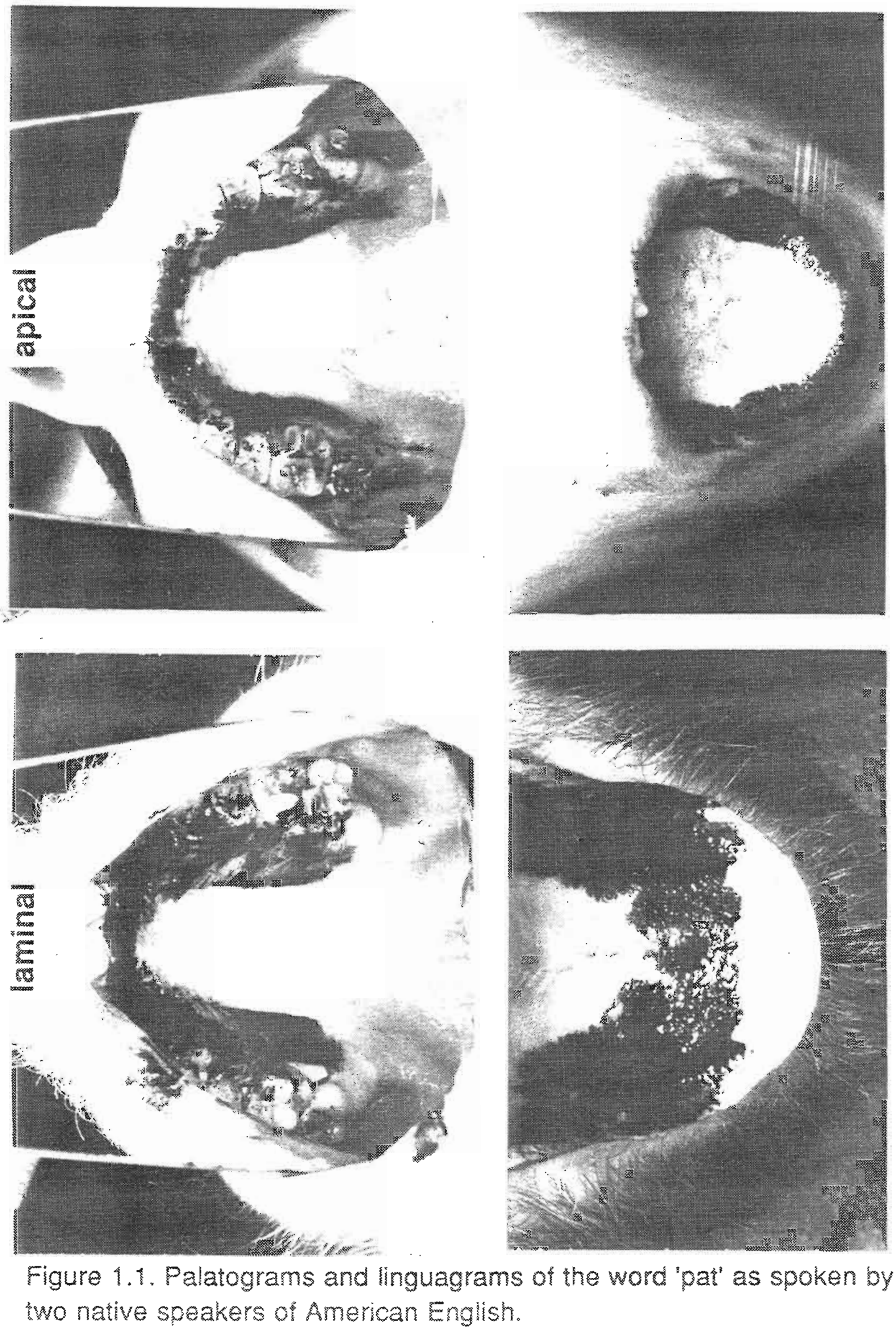


Figure 1.1. Palatograms and linguagrams of the word 'pat' as spoken by two native speakers of American English.

of an American English speaker with a laminal /s/ articulation. Electromyography, which measures the electrical activity in, in this case, the tongue muscles via hooked wire electrodes, showed that the lowered tongue tip is an active articulator during laminal /s/ production and not just passively kept "out of the way". The purpose of the study was to demonstrate a viable alternative to apical /s/ production in speech pathology therapy and was part of a larger study which would presumably contain similar data from speakers with apical /s/'s for comparison, but which, unfortunately, was never published.

Finally, there is an x-ray study of the laminalization (and consequent affrication) of /t/ and /d/ in Canadian French under the influence of a following high front vowel (Charbonneau and Jacques 1972). Since the vowel environment, which conditions the change, is necessarily different for the apical and laminal stops, it is difficult to compare the other physiological parameters (e.g. pharynx width) and know how much of their differences are due to the apical/laminal difference and how much to the tongue already taking the shape for the following vowel.

Other studies which have indirectly given data on apical and laminal articulation will be discussed under the appropriate headings in the next chapter.

1.0.3 Previous acoustic studies

At present, no precise acoustic correlates corresponding to the observed difference in articulatory gesture have yet been established and the question is still open to discussion. A number of predictions, often conflicting, have been made by various authors and these will be discussed in detail in Chapter 3.

1.1 Present study

The goal of the present study is to explore the question of what exactly is meant articulatorily by apical and laminal articulations (for example, whether length of constriction is a necessary feature of this difference and if there is a link with dental and alveolar articulations) and to examine the corresponding acoustic differences, if any exist. Another point to be determined is whether these differing articulatory strategies are consistent within a language or vary only according to speaker-specific idiosyncrasies. Most importantly for linguistic phonetic theory, I hope to show whether or not the terms apical and laminal are the appropriate ones to use in defining the feature [distributed] and whether or not there is really an acoustic difference between the two in cases which could not be attributed to other factors. If no acoustic difference is found, then perhaps we need to rethink the distribution of features and find out what it really is that distinguishes segments which have been reported to differ only in the part of the tongue used.

1.1.1 Data

The major data set used in the present study comes from utterances by native speakers of French and English. These languages were chosen because English is traditionally described as an 'apical' language and French often as a 'laminal' language. The following is a quotation from Passy, a 19th century French phonetician, discussing the articulation of /t/,/d/,/n/ and /l/.

"In French, at least in the Northern [i.e. standard] pronunciation, one most often presses the tip against the lower teeth and the upper blade against the upper teeth and the gums; it is the blade which closes the passage. In English, one presses the tip against the gums, which produces a sound very noticeably different." (Passy 1899, p.97)

Similarly, the language teaching literature is full of prescriptive and categorical remarks on pronunciation which leave very little room for individual variation, for example:

"When speaking French, on the other hand, the student must learn to *keep his tongue tip down behind his lower front teeth*, arching the back of the tongue at the same time." Gregg (1963) p.23 (italics in original)

In most of the phonetic literature, generalizations about the method of producing the coronal consonants in specific languages have been made with very little evidence shown. Table 1.1 gives the results of a survey of the literature taken of 19 sources reporting on French. Information on both the place of articulation and the part of the tongue used is included where available.

Table 1.1 Summary of sources specifying French articulation of coronal consonants. A=apical, L=laminal.

	/t/,/d/,/n/	/l/	/s/,/z/
Abercrombie (1967)	L dental		
Armstrong (1932)	A or L dental	A or L dentialv	A or L alveolar
Bascan (1933)	A dentialveolar	A alveolar	L alveolar
Gili y Gaya (1975)	A dental	A dent or alv	L dental
Gregg (1963)	L dental	L dental	L dental
Herman & Herman (1943)	L		
Jones (1969)	A or L dental		L alveolar
Kammans (1956)	dentialv	A alveolar	L dental
Kantner & West (1960)	A dental		
Landercy (1977)	A dentialveolar		L alveolar
Malmberg (1969)	A or L dental	A dental	A or L alveolar
Martinet (1955)			L alveolar
Nitze and Wilkins (1918)		A dental	
Nyrop (1914)	A dental	A dental	A dental
O'Connor (1967)	A dental		
Passy (1899)	L dentialveolar	L dentialveolar	L dentialveolar
Ripman (1929)	A dental		
Varney Pleasants (1960)	A dental	A dental	L dental
Wise (1957)	A dental	A dental	

The consensus seems to be that French /t̪,d̪,n̪/ are apical dental (9 sources) with a minority looking on these consonants as laminal (4 sources) and three sources offering the possibility of both variants. By apical is probably meant apicolaminal, since it is very difficult for someone with normal dentition to put the tip of the tongue on the teeth without the blade also touching the base of the teeth in front of the alveolar ridge. The sources specifying laminal articulation obviously meant with the tongue tip down, as the quotations given above from Passy (1899) and Gregg (1963) illustrate unambiguously. The French lateral was felt by most sources (8) to be apical, with 5 of these dental, one alveolar and one dental or alveolar. Two other sources stated that the French /l̪/ is laminal dental or dentialveolar and one source allowed for the possibility of either apical or laminal dentialveolar /l̪/. The reports of the /s̪,z̪/ articulations were evenly split between dental (6) and alveolar (6), with the majority (9) claiming a tip-down laminal tongue position. Only one source called these fricatives apical and two thought they could be either apical or laminal.

The following table gives the results of a similar survey of 23 sources for English articulation.

Table 1.2. Summary of sources specifying English articulation of coronal consonants. A=apical, L=laminal.

	/t/,/d/,/n/	**/l/**	**/s/,/z/**
Abercrombie (1967)	A or L alveolar		A or L alveolar
Agard & Di Pietro (1965)	A alveolar	A alveolar	A alveolar
Akin (1958)	A alveolar	A alveolar	L alveolar
Bronstein (1960)	A alveolar	A alveolar	A or L alveolar
Carrell and Tiffany (1960)	A alveolar	A alveolar	A or L (post)alv
Fairbanks (1940)	A alveolar	A alveolar	A or L alveolar
Gili y Gaya (1975)	A alveolar	A alveolar	L alveolar
Gimson (1962)	A alveolar	A alveolar	A or L alveolar
Grandgent (1892)	A alveolar	A alveolar	A or L alveolar
Gregg (1963)	A alveolar	A alveolar	A alveolar
Herman & Herman (1943)	A		
Jones (1963)	A alveolar	A alveolar	A or L alveolar
Kantner & West (1960)	A alveolar		A or L alveolar
Kenyon (1930)	A alveolar	A alveolar	A or L alveolar
Malmberg (1969)	A or L alveolar	A alveolar	A or L alveolar
Mosher (1929)	A alveolar	A postalveolar	A dentialveolar
Moulton (1962)	A alveolar		A or L alveolar
Nitze and Wilkins (1918)		A *alveolar*	
O'Connor (1967)	A alveolar	A alveolar	A alveolar
Passy (1899)	A alveolar	A alveolar	
Ripman (1929)	A alveolar	A alveolar	
Thomas (1947)	A alveolar	A alveolar	A or L alveolar
Wise (1957)	A alveolar	A dent or alv	A or L alveolar

According to this survey, English /t̺,d̺,n̺/ and /l̺/ are apical alveolar, with two sources offering the possibility of a laminal alveolar stop or nasal variant and two sources placing the lateral slightly farther forward or backward. Most of the sources stated that English /S/ and /Z/ could be either apical or laminal, although two of these felt that the apical was more common. Four sources stated that the English /S/ was apical and two that it was laminal. All but two felt that /S,Z/ were alveolar, one placed them slightly farther forward and one farther back. This information is summarized below in Table 1.3.

Table 1.3. Summary of the articulations for French and English consonants reported in the literature.

		English				**French**		
		Dental		**Alveolar**		**Dental**		**Alveolar**
/t,d,n/								
	A	**0**		**20**		**9**		**0**
	L	**0**		**0**		**4**		**0**
	A or L	**0**		**2**		**3**		**0**
/l/								
	A	0	1	**17**	1	**5**	1	**2**
			D or Alv		postalv		D-alv	
	L	0		0		2		0
	A or L	0		0		0	1	0
							D-alv	
/s,z/								
	A	0	1	3		1		0
			D-alv					
	L	0		2		**5**		**4**
	A or L	0		**12**	1	0		2
					alv/post-alv			

I will discuss in the next chapter how far these articulatory claims hold true in the light of palatographic and linguagraphic evidence.

Before making any claims about the necessity of apical/laminal as a phonetic feature, it is important to compare the acoustic and articulatory differences between apical and laminal articulations in a language where this is said to be a distinguishing feature, since speakers of French and English may presumably vary their articulation, using either the tongue apex or the blade without danger of trespassing on the domain of another segment. According to Bright (1978), Langdon (1976) and Langdon and Silver (1984), several native languages of the western United States distinguish apical and laminal stops, nasals, laterals and fricatives. I was able to test 8 speakers of

'O'odham (Papago), a language spoken in southern Arizona, which contrasts dental and alveolar stops (both said to be apical) and a laminal alveolar stop or affricate. Papago also has contrasting sibilants, sometimes described as laminal vs. apical and sometimes as alveolar vs. postalveolar. Even though, as seems usual in such languages, the distinction may be maximized by differences in place of articulation on the palate or by affrication of one segment in addition to the apical/laminal contrast, information about the acoustic effects of varying the part of the tongue used can still be gleaned.

Because of the frequent use of the Dravidian language Malayalam in the phonetic literature as an example of a language with a contrast involving the feature [distributed], three Malayalam speakers were also tested. Malayalam is said to contrast intervocalic geminate voiceless stops and nasals in six places of articulation: bilabial, dental, alveolar, retroflex, palatal and velar. In the present study I will discuss only the so-called dental, alveolar, retroflex and palatal stops and nasals.

1.1.2 Method

The method of investigation for studying apical and laminal articulations is outlined below. Palatograms and linguagrams were made of 20 American English speakers, 21 French speakers, 8 'O'odham speakers and 3 Malayalam speakers uttering phrases containing the relevant segments. Acoustic recordings were also made (on a Marantz PMD 340 cassette recorder with a Sennheiser MD 419 microphone) synchronous with the palatograms and linguagrams, in order to be certain that each given acoustic signal corresponded to an articulation with known articulatory characteristics.

The palatograms and linguagrams were taken by the direct method using, instead of the traditional dry spray mix of charcoal and chocolate powder, a liquid medium of one part charcoal to two parts olive oil which was painted on either the upper or lower articulator (palate or tongue) with a small brush. After utterance of the test word, the area where the medium wiped off on the opposing articulator was photographed with a Polaroid Land camera modified for dental use. This solution was easily rinsed away with a little water, or water and lemon juice, between each photograph. Several advantages of this method over the traditional dry spray method have been noted. In the first place the area of contact is much more clearly delineated, leaving fewer ambiguities for interpretation. It is also more pleasant for the speaker since the solution is painted directly on the relevant area during which time the speaker may breathe normally, thereby avoiding the inhalation of the powder and irritation of the nasal cavities which is often a problem with the dry method. There is also no problem with the secretion of excess saliva as has been reported when sweetened chocolate powder is introduced directly into the mouth. The major drawback with using a liquid medium is that although the solution transfers nicely onto the opposite articulator, it is not completely removed from the surface onto which it was originally painted. This necessitates using two different utterances, one for the palatogram (by painting the tongue and photographing the contact area on the palate) and one for the linguagram (by painting the palate and photographing the contact area on the tongue). Because of the possible misinterpretations which could arise from using separate articulations for the palatogram and linguagram, I was very particular in comparing the acoustic signal of the two different recordings. For all parts of the acoustic analysis, I first separated the recordings obtained from the linguagraphic tokens and palatographic tokens. If there were any differences in the acoustic measures obtained from these two sets of recordings, then only the recording accompanying the linguagraphic token was used for measures involving apicality and only that from the palatographic token was used in measures involving place of articulation.

In order to facilitate interpretation of the palatograms, an impression was made of each speaker's palate and cast in plaster to give a permanent record of the shape of the speaker's palate and dentition. This was especially important for measuring constriction length, since the relationship between the angle of the mirror and the slope of the palate changed the apparent length of the constriction in the photograph. This parameter, being crucial to the definition of the feature [distributed], was measured for all tokens. Measurements were made by mapping the place of constriction shown in the palatograms onto the casts of the palate and measuring the distance from front to back at the central area in line with the central incisors and following the curved surface of the palate. For fricatives the measurement was taken adjacent to the central channel. The palatograms were chosen for measurement since the linguagrams 1) had no corresponding life-size cast to compare them to and 2) did not represent the actual shape of the tongue during articulation and therefore the apparent length of the articulatory contact area could be expanded or contracted depending on the way the tongue was protruded for the photograph.

1.1.3 Speakers and words recorded

The French speakers were from various areas around Paris or farther north. They were all, however, highly educated people and were chosen for their lack of specific regional accent. Eleven of the speakers had lived all or part of their lives in Paris, seven were from the area around Lille, in the north, two were from Belgium and one was from Normandy. The phrases in the French data are given in Table 1.4 below, with the segment of interest given in bold type.

Table 1.4. French test utterances.

peu à **taper**	[pø a tape]	little to type
Papa m'é**p**ate	[papa mepat]	Papa astounds me
à ma **d**ame	[a ma dam]	to my lady
ma pomma**d**e	[ma pomad]	my pomade
ma **n**appe	[ma nap]	my tablecloth
poupée en pa**nn**e	[pupe ã pan]	out-of-order doll
ma **l**ame	[ma lam]	my blade
à mon ba**l**	[a mõ bal]	at my ball (dance)
bois à **s**abot	[bwa a sabo]	wood for wooden shoes
impa**ss**e	[ɛ̃pas]	impasse
à Ma**z**amet	[a mazame]	at Mazamet
à ma ba**s**e	[a ma baz]	at my base

All of the American English speakers grew up on the Pacific coast (California, Oregon or Washington states). The phrases used in the English data are given below.

Table 1.5. English test utterances.

a **t**ap	[ə tæp]	a **l**ap	[ə læp]
a pa**t**	[ə pæt]	a pa**l**	[ə pæl]
a **d**ab	[ə dæb]	a **s**ap	[ə sæp]
a pa**d**	[ə pæd]	a pa**ss**	[ə pæs]
a **n**ap	[ə næp]	a **z**ap	[ə zæp]
a pa**n**	[ə pæn]	Pa ha**s**	[pɑ hæz]

In each language, each segment is featured both at the beginning of a word and at the end of a word, surrounded by low, unrounded vowels. This vowel environment was thought to be the least biased for part of the tongue used. To test how big a part vowel environment played, one French speaker uttered additional phrases illustrating seven different vowel environments. The additional French phrases were: typer [tipe] 'to type (characterize)', battu [baty] 'beaten', me hâter [mø ate] 'to hurry (myself) up', pâteux [patø] 'mealy, doughy', bateau [bato], baton [batõ] 'stick', pas tout [pa tu] 'not all'.

The eight 'O'odham speakers were from various villages on the Papago Indian

Reservation near Tucson, Arizona. Slight dialect differences showed up in the dental-alveolar contrast, since the actual value given to the stop in any particular word may vary from one dialect to another (Jane Hill, personal communication). This was evident only in one speaker, who did not make a contrast between dental and alveolar stops in the test words, both of them being alveolar. The 'O'odham test words are given in Table 1.6.

Table 1.6. 'O'odham test words

a'ada	[ˈaʔad̪a]	a kind of ritual
aḍawi	[aˈdawi̥]	buffalo gourd
je'e	[ˈɟɨʔɨ]	mother
ha'asa	[ˈhaʔasa]	the end
haṣaba	[ˈhaṣaba]	but

Of the three Malayalam speakers, two were from the Malabar (northern) area of Kerala and one was from Trichur, in the central part of the state. The test words are given in the table below.

Table 1.7. Malayalam test words.

[poːt̪ːɨ]	buffalo	[ɛn̪ːɨ]	when
[potːa]	scab	[ɛnːe]	me (dat.)
[poṭːɨ]	dot on forehead	[ɛṇːa]	oil
[ocːa]	sound	[maɲːa]	yellow

The final /ɨ/'s were pronounced very close to [a] by one of the speakers and were depicted as such in one of the studies from which the word list was taken. For two of the speakers, however, the words in question were pronounced with the high central unrounded vowel, which unfortunately made the acoustic study a little less uniform. This difference in vowel quality did not coincide with the difference in geographical origin of the speakers.

The results of the articulatory and acoustic studies are presented in Chapters 2 and 3, respectively, in each case the languages without an apicality contrast (French and English) will be discussed first, followed by a discussion of the languages where the two methods of articulation have been said to be contrastive (Malayalam and 'O'odham).

Chapter 2. The articulation of apical and laminal sounds

2.0 Introduction

This chapter focusses on the articulatory aspects of consonants with apical and laminal tongue contact. In the first section a classification system is established for analyzing palatographic and linguagraphic data which, in the second section, is applied to the data in the present study. The presentation and analysis of the data is organized language by language, beginning with the two languages without an apicality contrast (French and English) and followed by the two languages (Malayalam and 'O'odham) where apicality has been said to play a contrastive role. Under each language heading will be discussed the various articulatory parameters found in the data: place of articulation, part of the tongue used, constriction length and, in the case of fricatives, width of the air channel. The acoustic implications of these parameters will be discussed in Chapter 3. The third section deals with various hypotheses that have been made in the literature to which the data in the present study give support or contradiction. Finally, as a preparation for the acoustic discussion which follows in the next chapter, section 4 presents articulatory data from other studies which bear on the physiological consequences associated with tongue tip up or down consonant production, notably tongue height and pharynx width as well as questions of timing and release characteristics.

2.1 Classification of the data

Determining apicality and place of articulation from physiological data is by no means a straightforward task, as many investigators have remarked (e.g. Bladon and Nolan 1977, Ladefoged and Maddieson 1986). One would like to make very strict definitions for terms such as 'alveolar' or 'apical', but the variety of data found, and especially the very different physical shape of the articulators in different speakers, make such definitions difficult to formulate. The following classification system is one that seems reasonable given the range of data obtained from the 52 different speakers in the study and allows for fairly precise categorization of the different articulations involved.

The linguagrams are divided into four different tongue contact patterns and the palatograms into six different places of articulation ranging from dental to post-alveolar. Figure 2.1 illustrates the four linguagraphic divisions. On the top left is a typical linguagram representing the designation *apical*. Only a very fine line of contact is visible and this on the very tip of the tongue. To the right of that is an example of the designation *upper apical,* where it is not the rim, but the upper surface of the apex which has made contact. This may be assumed to come from a different tongue position, the two being perhaps like those seen for two subjects in Bothorel, Simon, Wioland and Zerling (1986) in the production of [n] in the phrase 'Une pâte à choux'

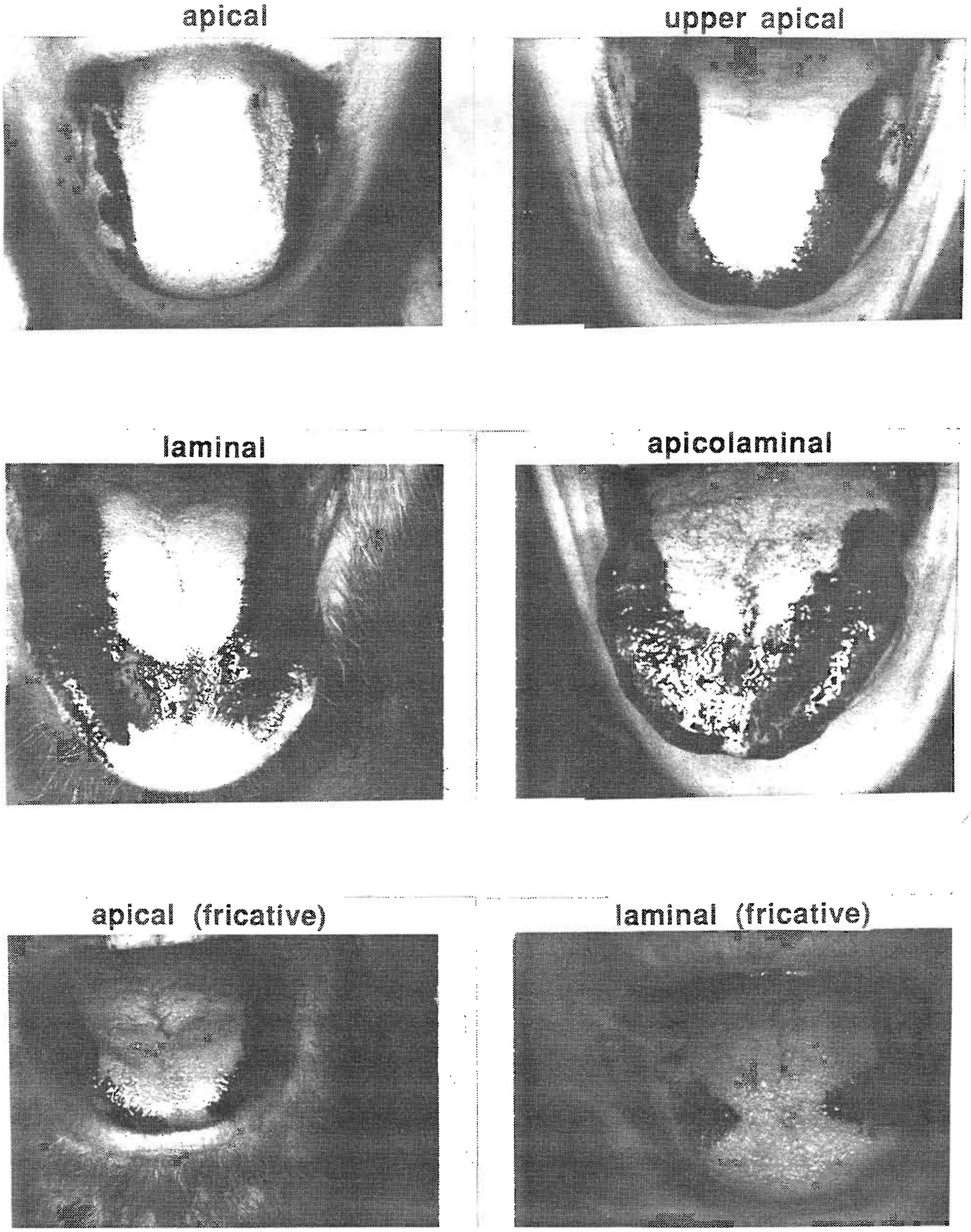


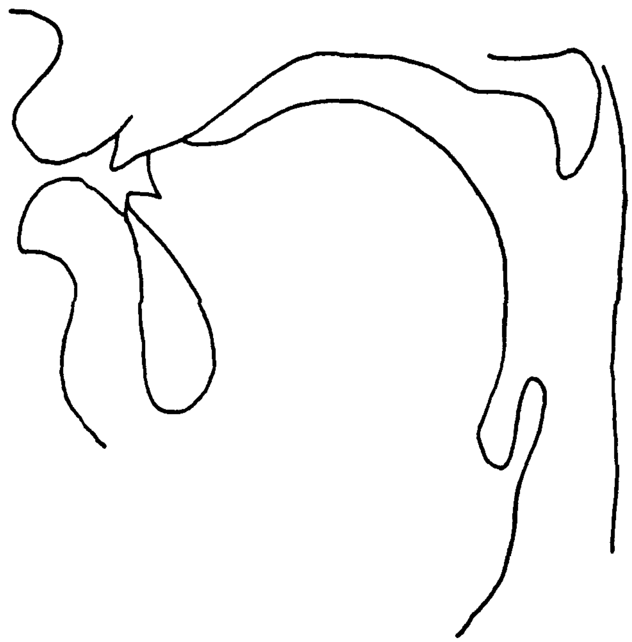
Figure 2.1. Examples of the linguagraphic classifications.

[yn pat a ʃu] 'puff pastry dough' (Figure 2.2). In the top one *(apical)* the tip would come up from a lower position of the overall tongue body (in this case in spite of its high position from the preceding high front vowel), and in the second instance *(upper apical)* the tongue body just behind the apex may be higher, causing the contact of only the upper surface of the tip, although the length of the contact in the direction of the airflow is similar.

The linguagram in the middle right of Figure 2.1 illustrates the *apicolaminal* designation. Both the apex and the blade make contact over a wide area. The fourth designation, *laminal*, is illustrated at the middle left, where only the blade makes contact, and the tip has obviously been kept entirely out of the way, perhaps down behind the lower incisors. These two ways of articulating may be illustrated by the x-ray tracings in Figure 2.3, the one at the top of the figure from Simon (1967), illustrating a /t/ articulation where both the apex and the blade make contact and the bottom a /t/ articulation from Rochette (1973) where the tongue tip is down and only the blade touches the palate. As shown at the bottom of Figure 2.1, fricatives were classified only as either *apical* or *laminal*, depending on whether the contact was made respectively with or without the tip of the tongue. The sections which follow will refer to these four designations as just defined.

Figure 2.4 illustrates the way the palatograms were sorted for place of articulation. The designations take into account only the most forward part of the contact area. Thus the label dental (1) was given to articulations where contact was made completely covering the back of the upper central incisors, regardless of how much else was touched (typically, dental consonants had continuous contact all the way back to the alveolar area). Coming back in the mouth, the next designation (2) includes those palatograms where contact reached about halfway down the length of the central incisors. Classification (3) refers to those articulations where contact was mainly just behind the teeth, but some contact was made also on the base of the teeth. The following classification (4) includes those consonants where the contact area comes up to, but does not touch, the base of the teeth. Designation (5) covers those articulations with a clearly visible space between the base of the teeth and the front area of contact, and the last group (6) has roughly double that space before the contact area begins. For some of the Malayalam and 'O'odham retroflex consonant tokens it was necessary to add a seventh class which was at a distance behind (6) comparable to that of (6) behind (5). The data are more accurately described by a classification system of this kind than by the traditional place names such as *dental* and *alveolar*, which have been used to mean different things by different people. When, later in the chapter, it seems useful to group the tokens into fewer categories, the 6 or 7 part continuum given serves to define exactly what is meant by the cover terms.

Apical



Upper apical

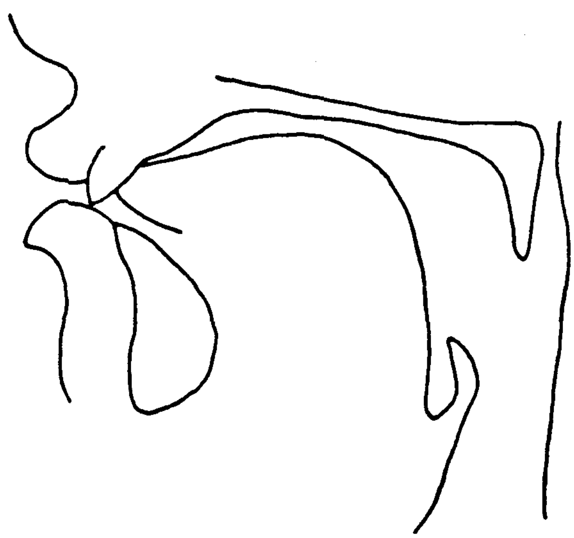
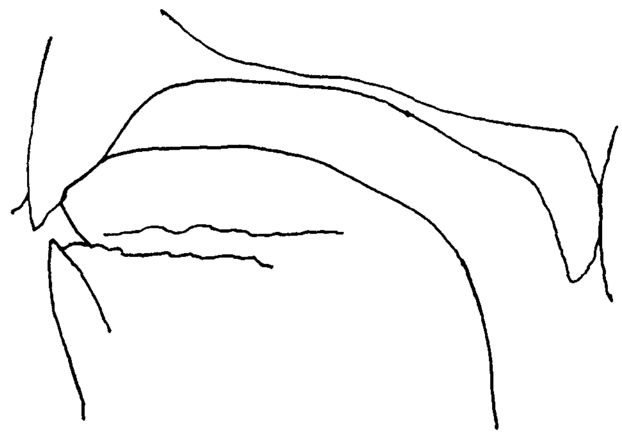


Figure 2.2. Tracings from x-rays of two different speakers during the /n/ closure in the phrase *Une pâte à choux* [yn pat a ʃu] 'puff pastry dough' (after Bothorel et al. 1986)

apicolaminal



laminal

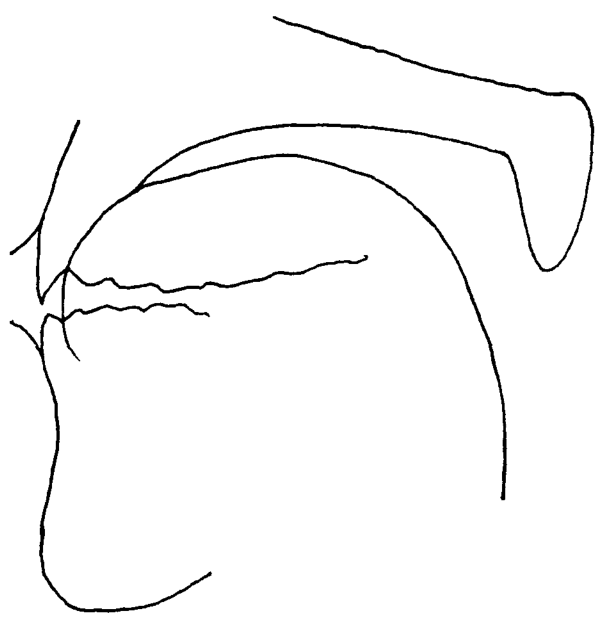


Figure 2.3. X-ray tracings depicting apicolaminal (top, after Simon 1967) and laminal (bottom, after Rochette 1973) articulations.

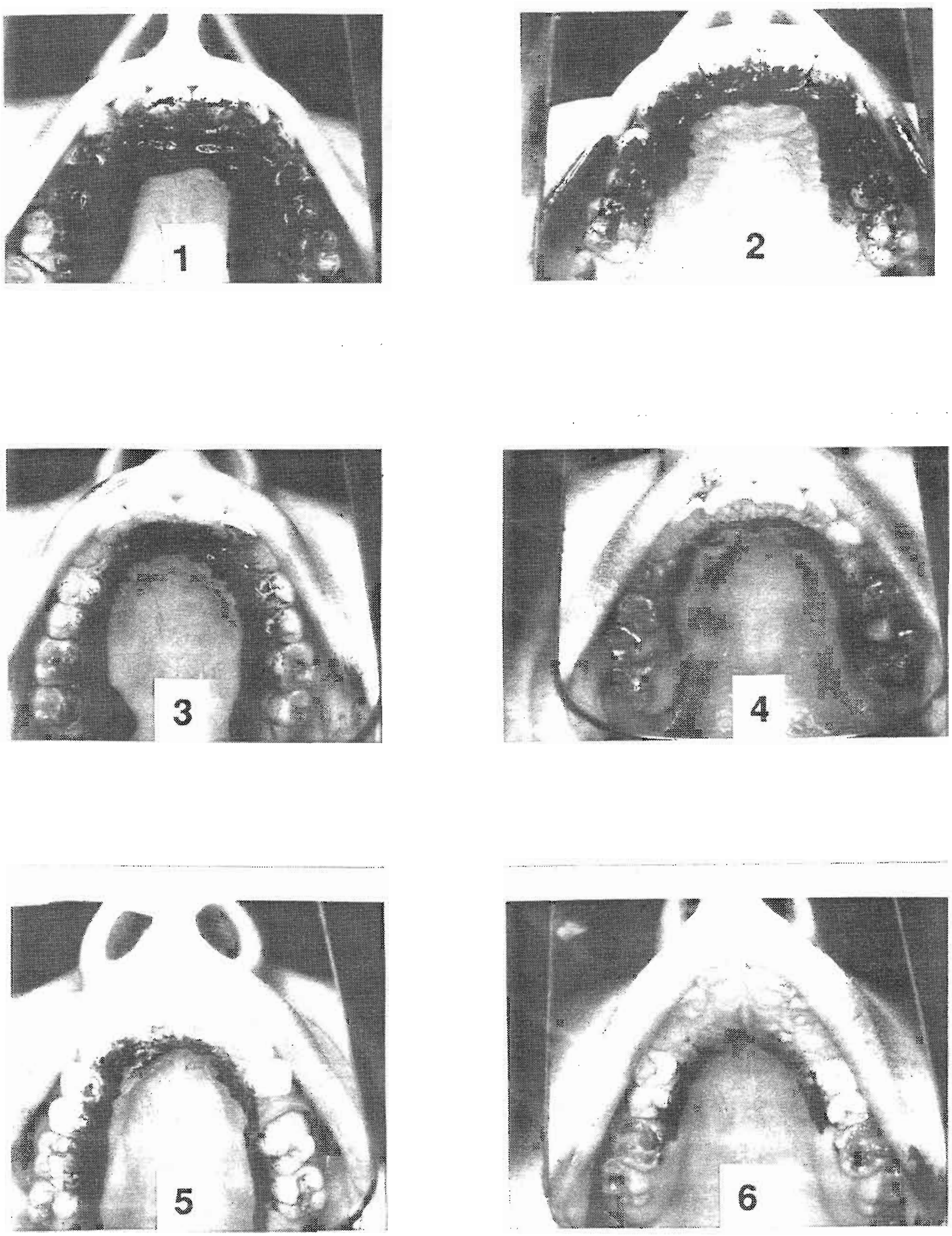


Figure 2.4. Examples of the palatographic classifications from dental (1) to postalveolar (6).

2.2. Results of the palatographic and linguagraphic study

2.2.1 French

Analysis of the linguagrams of 21 French speakers revealed the following percentages of the four linguagraphic classifications (Table 2.1). For each segment there are 42 different tokens, representing word-initial and word-final tokens from each of the 21 speakers, except the fricative columns which contain initial and final tokens from each of 19 speakers (38 tokens), since 2 speakers were thought to have slightly defective sibilant production and were therefore eliminated. Defective sibilant production (in this case a slight 'lisp', that is, a substantially wider than normal air channel) did not correlate with any measures of articulation discussed for other segments produced by those speakers. The initial and final tokens are considered together in the tables and figures which follow. Differences found between the two are discussed in section 2.3.5.

Table 2.1 Distribution of the four linguagraphic classifications for 21 French speakers for /t,d,n,l/ and 19 speakers for /s,z/ (percent of all tokens).

	t	d	n	l	s	z
%apical	2.38	11.90	16.67	85.72	31.60	31.60
%upper apical	19.05	21.43	9.52	9.52	----	----
%apicolaminal	47.62	42.86	40.48	2.38	----	----
%laminal	30.95	23.81	33.33	2.38	68.40	68.40

The highest percentage of French stops are apicolaminal, while close to a third are laminal, and upper apical and apical percentages vary quite a bit with the segment in question. Laterals are overwhelmingly apical (85.72%) and fricatives tend to be about 2/3 laminal and 1/3 apical.

Table 2.2 shows the distribution of the six palatographic classifications in the French data.

Table 2.2 Distribution of the four palatographic classifications for 21 French speakers for /t,d,n,l/ and 19 speakers for /s,z/ (percent of all tokens).

	t	d	n	l	s	z
1	**38.09**	**38.09**	**45.24**	4.76	23.68	18.42
2	26.19	14.29	14.29	0	15.79	**26.32**
3	16.67	26.19	21.43	7.14	**28.95**	23.68
4	14.29	16.67	9.52	11.9	13.16	15.79
5	4.76	4.76	9.52	**52.38**	18.42	15.79
6	0	0	0	23.81	0	0

Figure 2.5 combines the information in Tables 2.1 and 2.2 to give a general idea of the distribution of the data in terms of both place of articulation on the palate and part of the tongue used. As can be seen, the greater percentage of /t/, /d/ and /n/ tokens are dental whereas for /l/, the favored place of articulation is well back on the alveolar ridge. The fricatives tend to be articulated with closure contacting some part of the upper incisors. The actual position of the contact varied laterally according to each speaker's idiosyncratic method of forming the segments. Some speakers made the channel for the frication on the left, some on the right, and some straight down the middle where the two upper central incisors meet. These differences need not concern us here, as Catford (1977) says, "...most articulations are more or less symmetrical about this line [down the center of the tongue], and even if they are not, the assymetry is of little phonetic consequence." p.144.

A certain correlation between part of the tongue used and backness is evident in the French data. In general, the more apical the articulation, the farther back on the palate it is articulated. A Spearman's rho correlation gave the results listed in Table 2.3. Naturally, the significance of the correlation depends on the rank order given to the linguagraphic classifications. Three orders which seemed logical were tried, all with *apical* at one end of the scale.

A: 1) apical 2) laminal 3) upper apical 4) apicolaminal
B: 1) apical 2) upper apical 3) laminal 4) apicolaminal
C: 1) apical 2) upper apical 3) apicolaminal 4) laminal

The correlation was not significant in order C. This order may be described as following a progression of distance from the tip of the tongue from nearest to farthest, or it may be interpreted as a continuum in height of the body of the tongue behind the constriction, from lowest to highest, although this is for the most part only speculation. The orders which yielded significant correlations were the two which place apical at

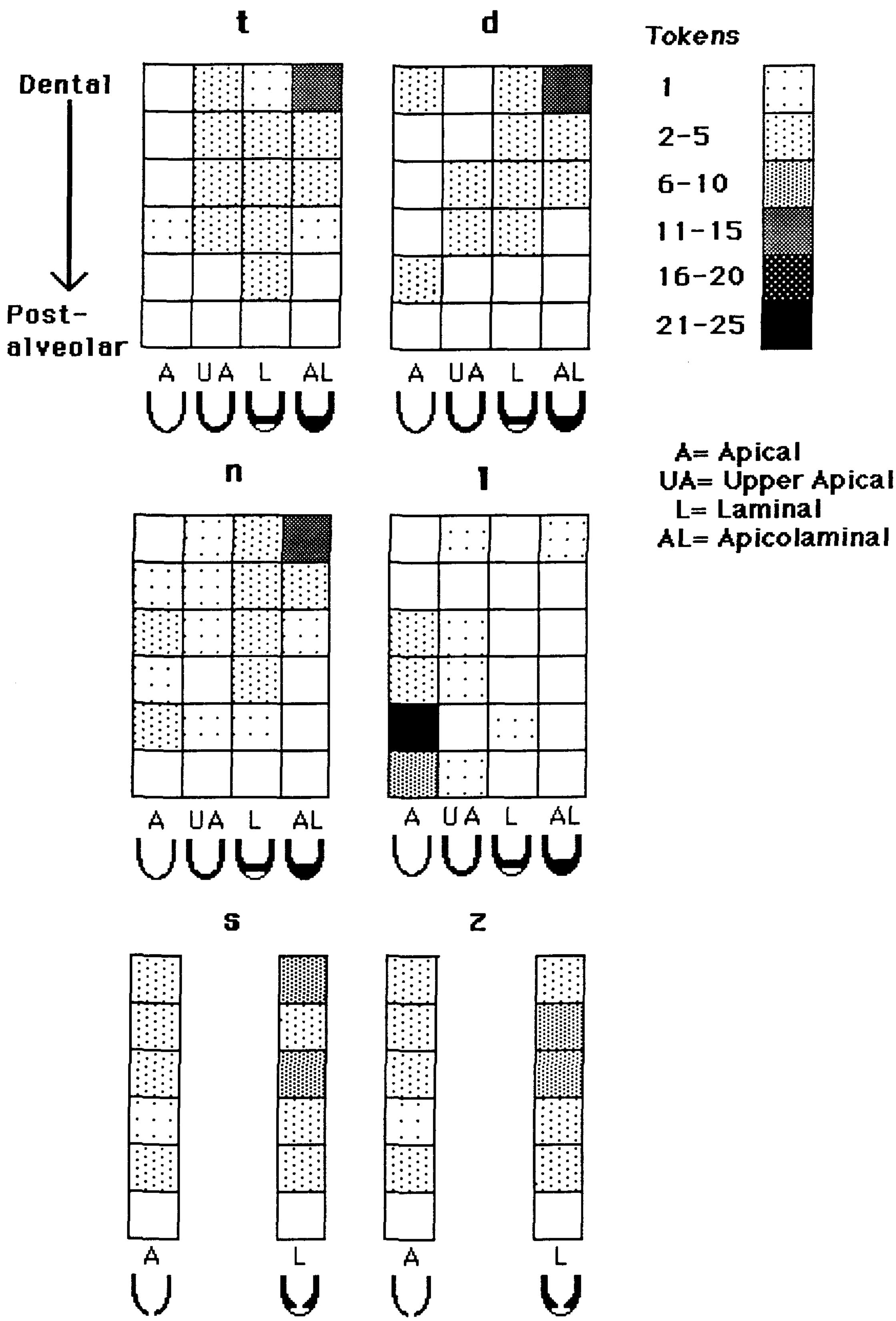


Figure 2.5. Summary of French data by linguagraphic and palatographic classification. Includes two tokens of each segment from each of 21 speakers for /t,d,n,l/ and 19 speakers for /s,z/.

one end and apicolaminal at the other, orders which we will see coincide with constriction length. Table 2.3 gives the results of the Spearman's rho correlation for both of the significant orders. There was no significant correlation between the apical-laminal dimension and place of articulation in French fricatives.

Table 2.3. Results of the Spearman's rho correlation (corrected for ties) for two different orders of linguagraphic classifications vs. place of articulation on the palate. Order A= 1)apical, 2)laminal, 3)upper apical, 4)apicolaminal Order B= 1)apical, 2)upper apical, 3)laminal, 4)apicolaminal.

	t		**d**		**n**		**l**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**
rho	.585	.52	.318	.401	.627	.637	.461	.444
p	.0001	.0006	.037	.0086	.0001	.0001	.002	.0036

Table 2.4 gives the constriction length means for each linguagraphic classification covering all 42 tokens from 21 speakers.

Table 2.4. Constriction length means for each linguagraphic classification in the French data (in mm).

	/t,d,n,l/		**/s,z/**	
	# of tokens	mean constriction length	# of tokens	mean constriction length
apical	49	5.69	**23**	6.43
upper apical	25	9.72		
laminal	37	9.39	**52**	7.63
apicolaminal	56	13.02		

It is clear from Table 2.4 that there are important constriction length differences between apical and apicolaminal articulations, with upper apical and laminal articulations falling together in between. This factor may be behind the significant correlation between linguagraphic classification and place of articulation, which might be better stated as a correlation between constriction length and place of articulation. Figure 2.6 illustrates this correlation graphically, the distribution of points indicating that for /t/, /d/, and /n/ longer constriction lengths tend to be farther forward in the mouth. This is less significant for fricatives, and not true at all for /l/, which has very little variation in constriction length in French, since it is articulated mainly apically.

One final measurement made from the palatograms in conjunction with the casts

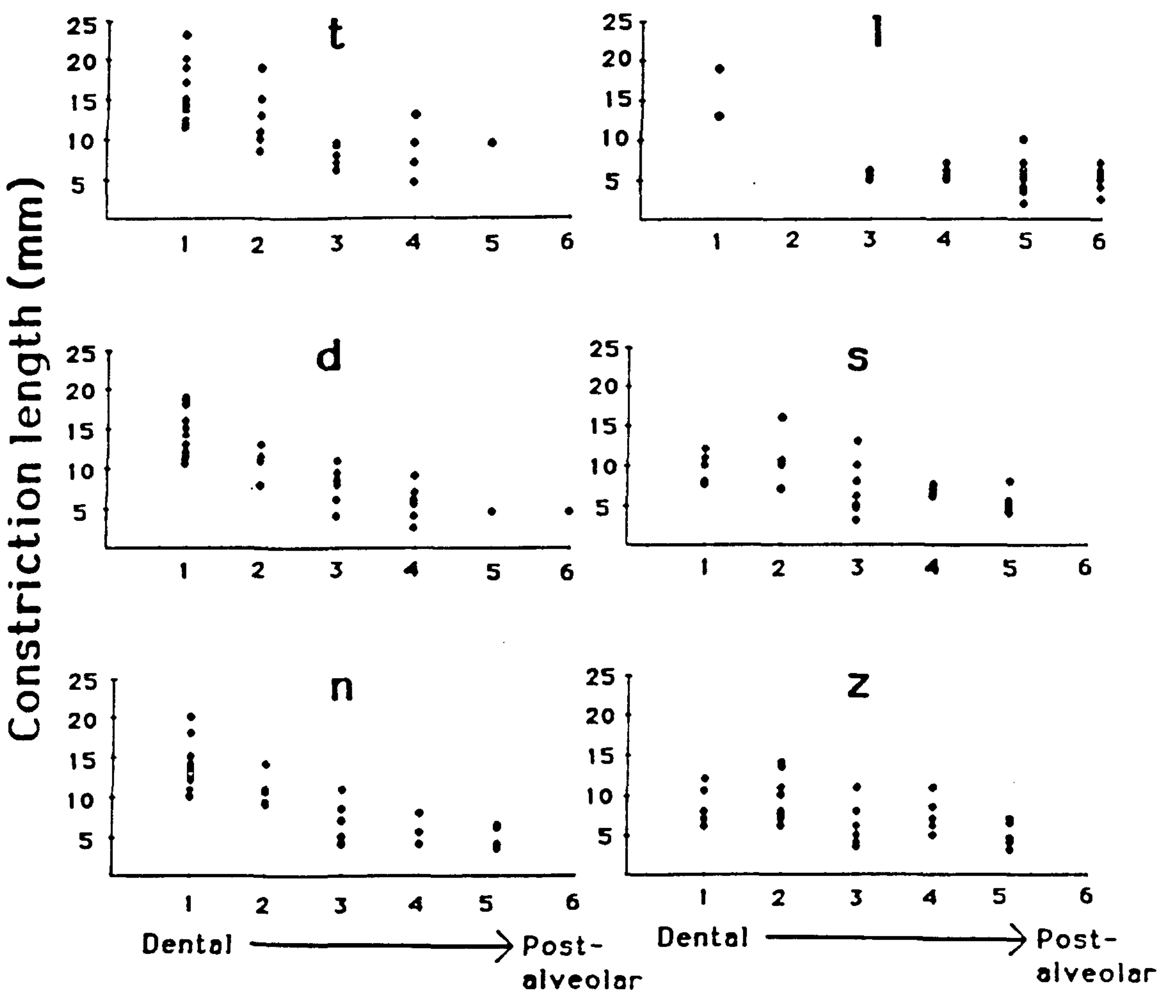


Figure 2.6. Graph of place of articulation (abscissa) against constriction length in mm (ordinate) for each segment in the French data.

of the palate, was the width of the channel in fricative production. Although the means of the channel widths in apical fricatives were greater than the means in laminal fricatives (10.59 mm vs. 7.94 mm for /s/ and 8.9 mm vs. 7.78 mm for /z/), individual variation was such that the difference was not shown to be significant in an analysis of variance. Channel width was not correlated with any other measure in the French data. Wolf, Fletcher, McCutcheon and Hasegawa (1976) found a tendency for channel width to diminish with increase in speaking rate within English speakers, but the present study was not constructed to test for this.

2.2.2 English

Analysis of the English articulatory data revealed both similarities and differences with the French data. Table 2.5 shows the percentages of the four linguagraphic classifications and can be compared with the corresponding French data in Table 2.1. For /d/, /n/, /s/ and /z/ there are 40 different tokens each, representing word-initial and word-final tokens from each of the 20 speakers. Only 39 tokens are represented in the /t/ column, since one speaker did not make oral closure in word-final /t/. Similarly, in the /l/ column only 38 tokens are represented, because 2 speakers had no tongue-palate contact in word-final /l/. As with the French data, the initial and final tokens are considered together in the English tables and figures. Differences found between initial and final segments are discussed in section 2.3.5.

Table 2.5 Distribution of the four linguagraphic classifications for 20 English speakers (percent of all tokens).

	t	**d**	**n**	**l**	**s**	**z**
%apical	**66.67**	**70.00**	**57.5**	**63.16**	42.50	42.50
%upper apical	2.56	17.50	32.50	5.26	----	----
%apicolaminal	10.26	2.50	5.00	28.95	----	----
%laminal	20.51	10.00	5.00	2.63	**57.50**	**57.50**

The highest percentage of English stops and laterals were apical, with the next most common manner of production being laminal for /t/, upper apical for /d/ and /n/, and apicolaminal for /l/. As in French, the largest percentage of fricatives were laminal, although the percentage of apicals was higher in English fricatives than in French. For the most part, speakers did not vary from one fricative token to another in terms of apicality, with the exception of one speaker who made a regular difference between initial and final fricatives. For this speaker initial fricatives were apical and articulated on the base of the teeth, with a long constriction length and a narrow channel width, whereas final fricatives were laminal and articulated in the postalveolar region, with a very narrow constriction length and a wide channel. This difference was highly audible and seemed simply to reflect the speech characteristics of this individual, or perhaps of his social circle.

In general, these findings tend to support those given in Bladon and Nolan's (1977) x-ray study of British English mentioned in the last chapter. Recall that the articulation of /t/ and /d/ in their study was split between apical and laminal and that /n/ and /l/ were articulated apically. Seven out of their 8 speakers had laminal fricatives. Since all these factors tend to vary among individuals, the actual distribution that one finds in a comparatively small sample is much affected by chance. In a preliminary version of the present investigation involving 22 English speakers (only seven of whom were also included in the final experiment which had stricter dialect controls), for example, a much higher proportion of the speakers (7, i.e.,32%) used a laminal /t/ articulation. Considering all 35 English speakers as a group, irrespective of dialect differences, 9 (26%) used a laminal articulation. In light of this, it may be that the higher percentage of laminals in French as compared to English is not significant, but the differences in percent apicals and percent apicolaminals are quite strong and appear to represent the major tongue contact difference between the two languages.

Table 2.6 gives the distribution of the six palatographic classifications in the English data.

Table 2.6 Distribution of the six palatographic classifications for 20 English speakers (percent of all tokens).

	t	**d**	**n**	**l**	**s**	**z**
1	7.69	2.5	5	**26.32**	12.5	12.5
2	17.95	12.5	7.5	23.68	17.5	5
3	**30.77**	**32.5**	25	23.68	**25**	45
4	17.95	**32.5**	27.5	10.53	22.5	12.5
5	20.51	15	**30**	13.16	20	**25**
6	5.13	5	5	2.63	2.5	0

Figure 2.7 corresponds to Figure 2.5 in the French data, showing the distribution in terms of both place of articulation on the palate and part of the tongue used. When comparing the two figures, a shift is evident towards apicality and an area farther back on the palate in the English data from the prototypical apicolaminal dental in French. This is true in general for /t/, /d/, and /n/. The French laterals, on the other hand, were overwhelmingly apical and postalveolar and it is the English laterals which tend to be farther forward (73.68% of the English laterals touched some part of the teeth in

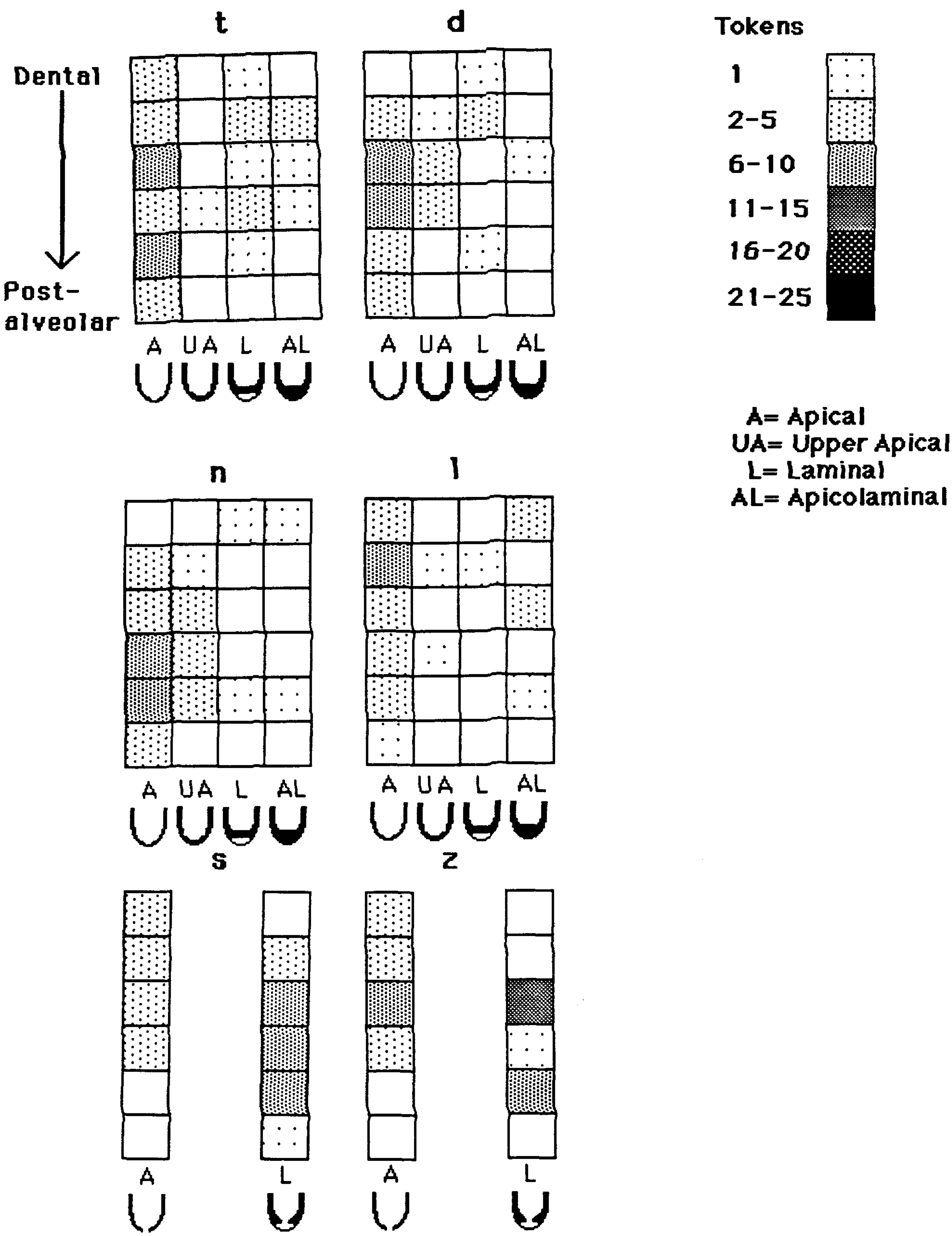


Figure 2.7. Summary of English data by linguagraphic and palatographic classification. Includes two tokens of each segment from each of 20 speakers.

contrast to only 11.9% in French). Laminal /S/ and /Z/ tend to be articulated farther back in English than in French, but there is no significant difference in the place of articulation of the apical fricatives.

The correlation between part of the tongue used and backness that was found in French was not found in the English data for the stops and laterals, perhaps because of the considerably smaller number of laminals and apicolaminals in English. Instead, a similar correlation was found in fricatives, only in the reverse direction. Whereas apical stops and laterals in French tended to be farther back, English apical fricatives tended to be farther forward. Table 2.7 below gives the results of the Spearman's rho correlation for the two fricatives in English. The explanation for this difference may lie in the fact, as stated by Catford (1977, p.157), that the acoustic and aerodynamic differences between apical and laminal /S/ are more evident if they are alveolar than if they are dental. A retracted apical fricative opens up a large sublingual resonance cavity, which is characteristic of [ʃ] production and would presumably cause the /S/ to trespass on the acoustic space of this contrasting segment, an effect naturally to be avoided.

Table 2.7. Results of the Spearman's rho correlation for the linguagraphic classifications apical and laminal vs. place of articulation on the palate for the English data.

	s	**z**
rho	3.242	3.758
p	.0012	.0002

The English data was also measured for constriction length, the results of which are given in Table 2.8 below.

Table 2.8. Constriction length means for each linguagraphic classification in the English data (in mm).

	/t,d,n,l/		**/s,z/**	
	# of tokens	mean constriction length	# of tokens	mean constriction length
apical	101	6.60	34	8.68
upper apical	23	6.52		
laminal	15	9.90	46	6.82
apicolaminal	18	10.30		

The results contained in Table 2.8 bear some notable differences from the corresponding results in French (Table 2.4). The most striking is that whereas in the French data the linguagraphic classifications tended to group in three categories by constriction length, in English they group into only two. In French, apical articulations had by far the shortest constriction length, apicolaminal articulations had the longest constriction length, and upper apical and laminal were together in the middle. In English, on the other hand, upper apical articulations tend to group with apicals, and laminals with apicolaminals to form only two categories in this measure.

There is one more thing that should be noted on the subject of constriction length. A number of puzzling cases were observed where the linguagram showed a very thin line of apical contact, yet the corresponding palatogram indicated a long, dental constriction, as exemplified on the top of Figure 2.8. This anomaly proved to be widespread, involving 8 English speakers and 5 French speakers, in fact all of the examples of apical dental (place of articulation classifications 1 or 2) articulation, although it was much less pronounced in fricatives. Table 2.9 shows the mean constriction length for apical dentals, which is substantially longer than the mean for all apicals together.

Table 2.9. Comparison of the mean constriction length (in mm) for apical dentals with the mean for all apicals. The number of tokens involved is in parentheses.

mean constriction length	**French** /t,d,n,l/	**French** /s,z/	**English** /t,d,n,l/	**English** /s,z/
all apical	5.69	6.43	6.6	8.68
apical dental only	13.1 (5)	8.2 (12)	9.87 (19)	9.96 (12)

Such a regular phenomenon could clearly not be attributed to a "mistake", i.e., a change of pronunciation between the linguagram and the palatogram. It was also odd that these speakers, none of whom had unusual dentition, were able to make apical dental consonants without the blade also contacting the area behind the teeth. The explanation turned out to be quite simple, although unexpected. These articulations were primarily sublaminal, with the underside of the blade against the back of the upper central incisors, which is why only a thin line of contact could be seen on the linguagram. When the experiment was redone on four of these speakers (3 English and 1 French), painting only the underside of the blade, the medium was likewise transferred onto the backs of the teeth (see the lower palatogram in Figure 2.8). Unfortunately, by the time this anomaly was discovered, not all of the speakers were still available, but it seems reasonable to suppose that the same results would come from a similar method of articulation. It appears, therefore, that we might add a fifth possibility, apicosublaminal, to the four designations for lingual contact, and that this possibility is used by some speakers.

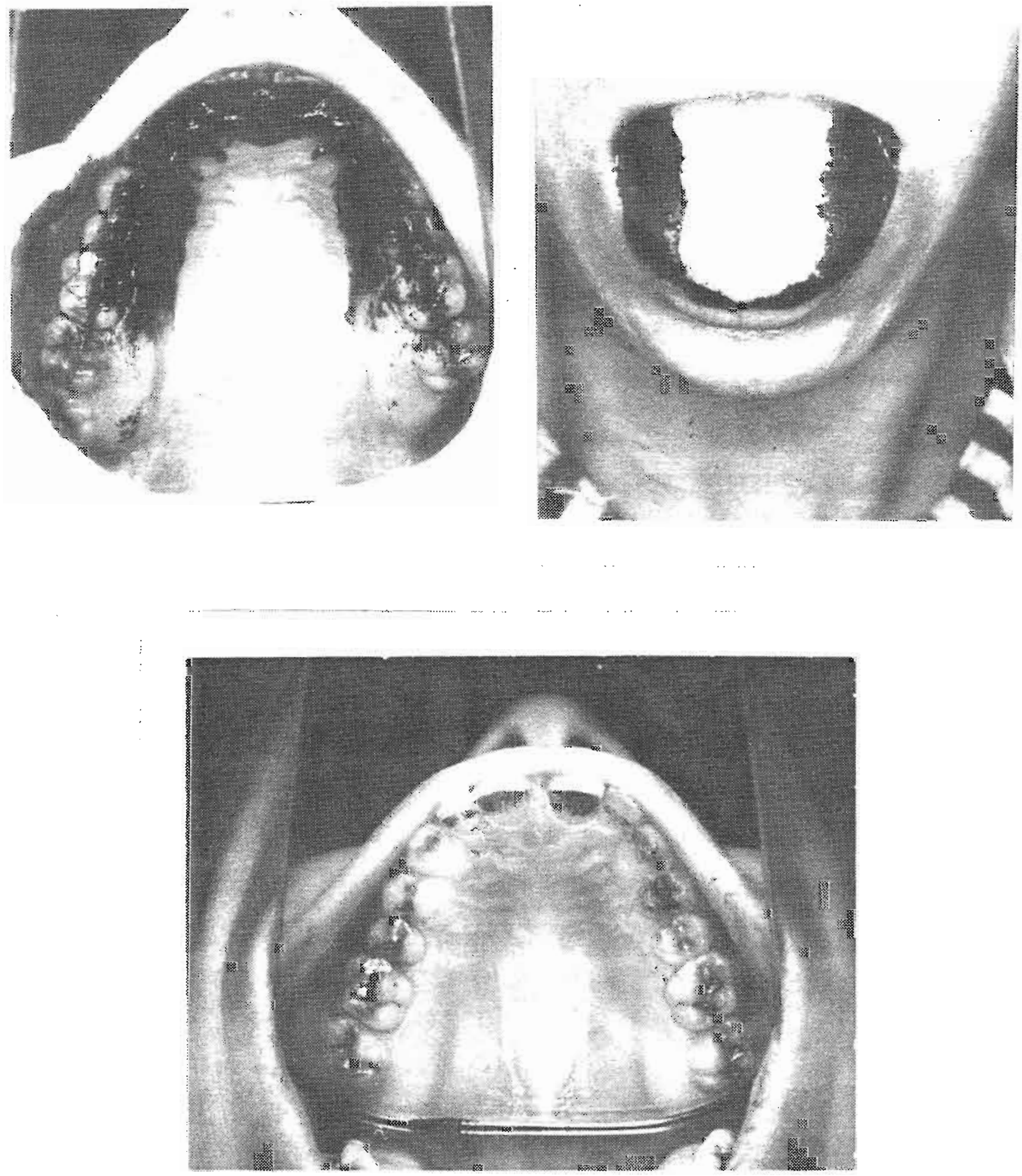


Figure 2.8. Palatogram and linguagram of an English speaker's articulation of the word "pat" (top) and a palatogram from the same speaker with only the underside of the tongue painted with the marking solution. An example of a sublaminal dental articulation.

Figure 2.9 illustrates the correlation also noted in French (Figure 2.6) between constriction length and place of articulation. This holds true for all segments in English even though the relation between the constriction length values and the linguagraphic classifications differs from one language to the other.

As in French, the channel width measure did not correlate with linguagraphic classification. It was, however, shown to be significantly correlated with constriction length in one factor, repeated measures analyses of variance (for /S/ p=.01 and for /Z/ .01>p>.005). In both cases the correlation was negative, indicating that the longer the constriction, the narrower the channel.

Although not significant for /Z/, channel width was highly significantly correlated with place of articulation for /S/ (p=.0001) as revealed by a one factor, repeated measures analysis of variance. The channel became wider as the place of articulation moved backward in the mouth.

2.2.3 Summary of French and English

In a review of the results of the French and English experiments, one can find both language-specific differences and inter-language similarities. The differences found between the data of French and that of English include the obvious fact that the major linguagraphic class employed in stop production is apical in English and apicolaminal in French. In both methods of articulation, however, the tip of the tongue is up behind or on the upper incisors, thus differing from the laminal articulation, which was the next most common linguagraphic classification in both languages. The difference in part of the tongue used could be associated with a difference in place of articulation, since for most speakers, it is hard to contact the backs of the upper central incisors without also contacting a portion of the alveolar ridge, thus making a long constriction. An exception to this is that mentioned above, where a lower tongue position makes a sublaminal dental articulation possible, also with a long constriction, but presumably with a different acoustic effect. The occurrence of this type of articulation in stop production was mainly found in English (19 tokens vs. 5 in French), which would go along with the general statement in "base of articulation" theories that the English tongue shape is concave and that of French convex (Honikman 1964), irrespective of the place of articulation on the palate.

Another related difference between the two languages is that in French the stops are generally articulated in a more forward position and the laterals farther back. The reverse is true in English. The correlation found in French stops and laterals, however, between place of articulation and part of the tongue used was found in English only in fricatives, and that in the reverse direction: apical fricatives were farther forward whereas French apical stops and laterals were articulated farther back in the mouth.

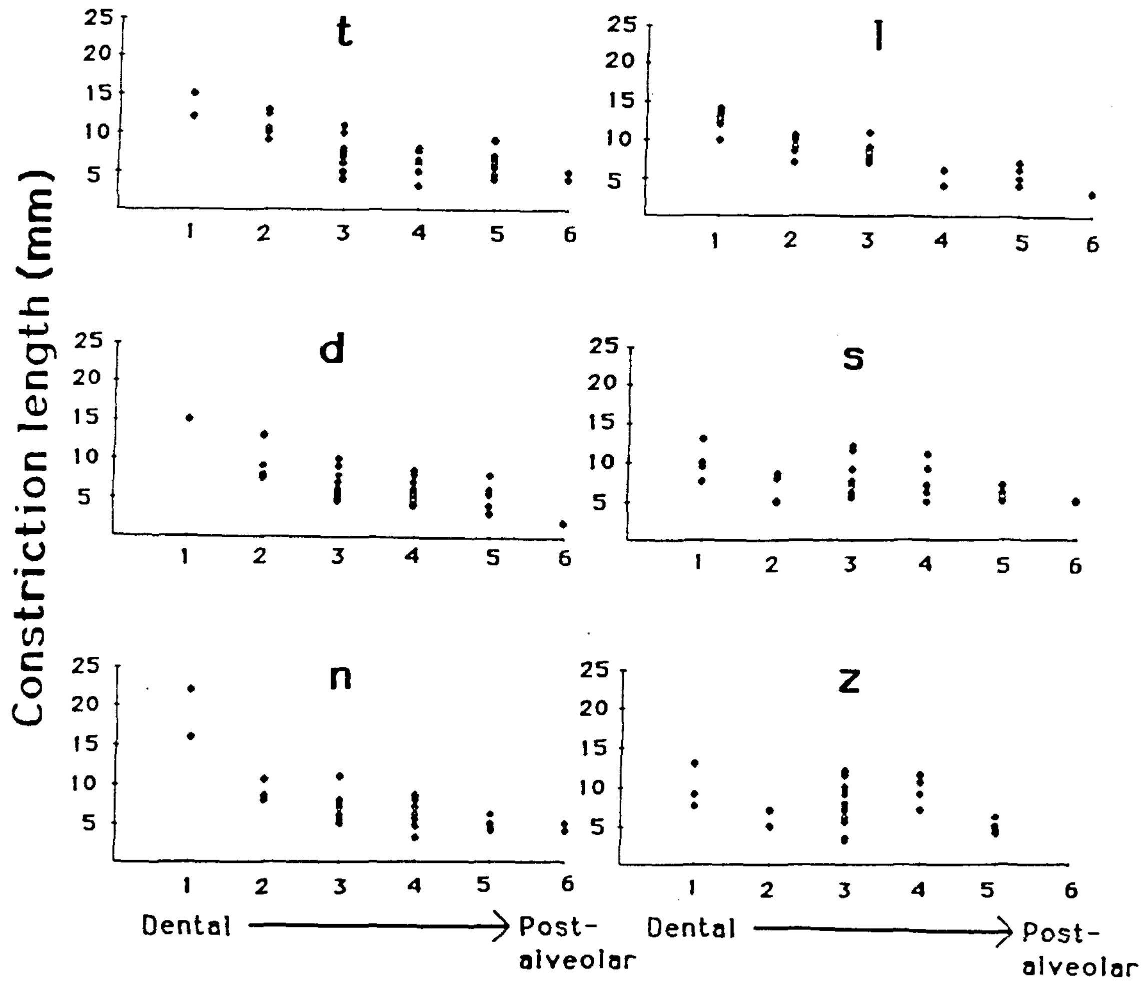


Figure 2.9. Graph of place of articulation (abscissa) against constriction length in mm (ordinate) for each segment in the English data.

The distribution of upper apical and laminal articulations in terms of constriction length also differed in the two languages. In French they paired together to form a class midway in length between apical and apicolaminal and in English upper apical paired with apical with a small constriction length and laminal paired with apicolaminal with a greater constriction length.

The last difference to be noted is the significance of the channel width measure in English /S/ in relation to place of articulation. This highly significant correlation was not duplicated for /Z/ or for either fricative in French. This fact, (assuming that channel width differences affect the acoustic signal) as well as the other similarities and differences just discussed, may prove important in interpreting the acoustic results which follow in the next chapter.

There are some similarities between the two languages which are interesting in that they occur despite the differences noted above. They might therefore have some bearing on the notion of a universal base of articulation. One such similarity is the strong tendency for /l/ to be apical. This tendency would seem to indicate that it is in some way easier to produce an apical lateral, although it is perfectly possible to produce an apicolaminal or laminal /l/. Perhaps it is easier to make the lateral escape channel when the body of the tongue is lower than the tip.

Another similarity found between the two languages is the distribution of fricative articulations. Both languages vary among individuals between apical and laminal fricative articulation and in both languages the laminal /S/ and /Z/ are more common. Again, this might indicate that laminal /S/ and /Z/ are in some way easier to produce, perhaps due to the precise aerodynamic control required in making sibilants. It seems that both languages exhibit some interference from general phonetic ease of articulation principles, which partially overcomes their language specific tendencies. Thus French, which has a tendency towards favoring apicolaminal articulations, does not maintain this tendency in the articulation of /l/, which may be easier to produce (or auditorily more salient) as an apical sound; and English, which tends to favor apical sounds, does not do so for the fricatives /S,Z/, which may be easier to produce as laminals.

In both languages the shortest constriction length was in apical segments and the longest constriction length was in apicolaminal segments. This is not surprising given the size of the parts of the tongue involved. What might not be so obvious is the inability to label laminal articulations in terms of constriction length, at least in relation to both upper apical and apicolaminal articulation. One might want to say, given the definition of the feature [distributed], that laminals have longer constrictions than apical segments, but when we consider the range found in the data (2-13.5 mm. for apicals (excluding the apicosublaminal dentals) and 4-19 mm. for laminals) it is obviously not that simple. This question will be taken up again in Section 2.3.1.

Another point relating to our understanding of the correlates of the feature [distributed] is that both languages show a significant correlation between place of articulation and constriction length, which would support the assumption of some investigators that alveolars have shorter constrictions than dentals, but would not prove the further claim that alveolars are apical and dentals are (apico)laminal (either one of those could be replaced by a laminal, still maintaining the difference in constriction length).

2.2.4 Malayalam

It is clear that the segments which contrast in a language should be acoustically different and therefore presumably articulated differently. Each speaker must make some sort of distinction, even if the manner of distinguishing the two segments differs from speaker to speaker. In this section the manners of distinguishing articulatorily the contrasting segments in both Malayalam and 'O'odham will be analyzed, speaker by speaker, but it will not be until the acoustic signal is analyzed in Chapter 3 that an underlying unity can be found which helps give a label to the contrasts in question. For place of articulation in these languages the cover terms *dental* (designations 1 and 2 of the classification system in Figure 2.4), *alveolar* (designations 3-5) and *postalveolar* (designations 6 and 7) will be used, except where there is a reason to be more specific.

The three Malayalam speakers had three different ways of producing the stop series usually referred to as *dental*, *alveolar*, *retroflex* and *palatal*, symbolized here as /t̪/, /t/, /ṭ/ and /c/ respectively. Each speaker's articulation is described in detail below and summarized in the tables which follow.

/t̪/-/t/

The part of the tongue used in the /t̪/-/t/ contrast in Malayalam has, as mentioned in the last chapter, been variously presented in the literature. Ladefoged (1971) called both of these segments apical, while later authors (e.g., Jongman, Blumstein and Lahiri 1985) have based research on the assumption that /t̪/ is laminal with a long constriction and /t/ is apical with a shorter constriction length. The following articulatory data, although drawn from only three speakers, can shed some light on this controversy.

Speaker 1, from Trichur, in central Kerala, produced the so-called dental-alveolar contrast in an extreme way, contrasting an interdental stop with laminal contact on the upper teeth and the tip out between the upper and lower central incisors, with an upper apical alveolar stop. The constriction length also differed from 19 mm for /t̪/ to 8 mm for /t/.

For Speaker 2, a native of the Malabar district (farther north than Speaker 1), the contrast was indeed between dental and alveolar stops as expected, but both of them were apicolaminal, articulated with both the tip and the blade of the tongue, thus making place of articulation the only observed distinctive articulatory parameter. The constriction lengths differed only slightly, from 15 mm for /t̪/ to 12 mm for /t/.

Speaker 3, also from the Malabar district, made both stops with an apicolaminal constriction like Speaker 2, but in her case they were both alveolar although the so-called 'dental' was slightly farther forward than the 'alveolar' (positions 3 and 4 respectively of the place of articulation categories). For this speaker another small articulatory difference between the two stops was a slightly longer constriction length for /t̪/ (14 mm vs. 11 mm for /t/), the same size constriction length difference (3 mm) as Speaker 2.

Table 2.10 summarizes some of the information given thus far for the three speakers' articulation of the /t̪/-/t/ contrast. Each speaker makes a difference between the two segments, but not the same difference as the others. Speaker 1 made a difference in all three parameters: place of articulation, part of the tongue used and constriction length. Speaker 2's distinction mainly involved place of articulation, and Speaker 3 made the contrast only with slight differences in constriction length and place of articulation. It is nevertheless true that for all three speakers /t̪/ is farther forward and has a longer constriction than /t/, however small these differences may be.

Table 2.10. Summary of the data for the Malayalam /t̪/-/t/ distinction for three speakers. The number in parenthesis indicates the place of articulation classification.

	Speaker 1	Speaker 2	Speaker 3
Place of articulation			
/t̪/	interdental	dental (1)	alveolar (3)
/t/	alveolar (4)	alveolar (3)	alveolar (4)
Part of tongue used			
/t̪/	(apico)laminal	apicolaminal	apicolaminal
/t/	upper apical	apicolaminal	apicolaminal
Constriction length			
/t̪/	19 mm	15 mm	14 mm
/t/	8 mm	12 mm	11 mm

/t/-/ṭ/

The /t/-/ṭ/ distinction ("alveolar" vs. "retroflex") was made by Speaker 1 with the expected place of articulation difference, that is, with /t/ being alveolar and /ṭ/ postalveolar. A contrast was also made, however, in the part of the tongue used, with the alveolar stop having an upper apical articulation and the postalveolar stop an apical and sublaminal contact. It was not possible to measure the constriction length on the postalveolar stop since the tongue brushed along the palate on release of the constriction and thus the area marked in the palatogram was much greater than that contacted during the actual stop occlusion. The constriction location in this case was estimated from the palatogram of the corresponding nasal, which was virtually identical to that of the voiceless stop, except that the tongue did not brush along the palate at release.

Speaker 2 also made an apical and sublaminal postalveolar stop for /ṭ/ which contrasts with her apicolaminal alveolar stop /t/. The constriction length was measureable for this speaker's /ṭ/ and it was found to be quite a bit shorter than for /t/ (4 mm vs. 12 mm).

For Speaker 3, both segments were alveolar, the difference being that /t/ was apicolaminal and /ṭ/ was apical. As with Speaker 2, the constriction length for /ṭ/ was shorter than that of /t/ (7 mm vs. 11 mm).

In the summary below it can be seen that Speaker 1 made the contrast by varying both place of articulation and part of the tongue used. Although constriction length was unmeasureable, in the corresponding nasals the constriction was slightly shorter for /ṇ/. Speaker 2 had a similar distinction with a measureable constriction length difference and Speaker 3 made the difference in the part of the tongue used and constriction length. All three speakers had a clear contrast in part of the tongue used (and therefore presumably overall tongue shape) and all had a more posterior articulation for /ṭ/, although this difference was very slight for Speaker 3.

Table 2.11. Summary of the data for the Malayalam /t/ - /ṭ/ distinction for three speakers.

	Speaker 1	Speaker 2	Speaker 3
Place of articulation			
/t/	alveolar (4)	alveolar (3)	alveolar (4)
/ṭ/	postalveolar (7)	postalveolar (6)	alveolar (5)
Part of tongue used			
/t/	upper apical	apicolaminal	apicolaminal
/ṭ/	apical & sub-lam	apical & sub-lam	apical
Constriction length			
/t/	8 mm	12 mm	11 mm
/ṭ/	?	4 mm	7 mm

/t/-/c/

The so-called 'palatal' stop or affricate in Malayalam was alveolar in all three speakers tested. Because of this there exists a contrast between a stop with tongue tip contact, /t/, and a stop in the same place of articulation with only the blade contacted, /c/, which is very interesting for determining the acoustic correlates of apical and laminal tongue positions.

For Speaker 1 the contrast is between an upper apical alveolar and a laminal alveolar stop. The two articulations had nearly the same constriction length, with /c/ slightly longer.

The contrast made by Speaker 2 in these two alveolar stops was that between apicolaminal and laminal stop articulations. Again there was very little difference in constriction length between the two, but for this speaker /t/ had the longer constriction.

Speaker 3 also made a contrast between apicolaminal and laminal alveolar stops, with a minimal difference in constriction length, again with the apicolaminal /t/ constriction slightly longer.

The articulatory contrast for these two segments appears to lie mainly in the part of the tongue used for all three speakers. All three speakers also articulated the laminal stop slightly farther back (see Table 2.12 below). It is interesting to note that for two of the speakers, the small constriction length difference goes in the opposite way than would be predicted by the literature, with the 'tip up' alveolar stop having the longer constriction.

It is clear that /c/ does not conform to the usual definitions of a palatal stop. In

Keating's (1988) in-depth investigation of the articulation of palatals, the chief requirement was a very long constriction and tongue involvement from the blade back to the front of the tongue, with a similar tongue shape to a high front vowel. In Malayam /c/ the front of the tongue does not appear to be involved and it is only the blade which rises to make contact.

Table 2.12. Summary of the data for the Malayalam /ʈ/-/c/ distinction for three speakers.

	Speaker 1	Speaker 2	Speaker 3
Place of articulation			
/ʈ/	alveolar (4)	alveolar (3)	alveolar (4)
/c/	alveolar (5)	alveolar (4)	alveolar (5)
Part of tongue used			
/ʈ/	upper apical	apicolaminal	apicolaminal
/c/	laminal	laminal	laminal
Constriction length			
/ʈ/	8 mm	12 mm	11 mm
/c/	10 mm	10 mm	9 mm

Nasals

Since the nasals were, for the most part, articulated in the same place and with the same part of the tongue as the corresponding stops, there is no need to discuss them in as much detail here. Table 2.13 shows the correspondence between the stop and nasal series, with the classification number for place of articulation included in parenthesis for clarification. The constriction length variations will be dealt with in detail in section 2.3.4, where theories of stop-nasal differences are discussed.

2.2.5 'O'odham

The articulatory data for the 'O'odham stop and fricative contrasts is given in Table 2.14 below and is discussed in the pages which follow.

/d̪/-/d/

There were four different realizations in the 'O'odham data for the contrast traditionally called "apical dental" vs. "apical alveolar, slightly retroflexed". Four of the seven speakers who made this contrast (one speaker did not have /d̪/ in the word tested) produced an apicolaminal dental stop for the segment I have symbolized /d̪/, one of them contrasting it with an apical postalveolar /d/ and three of them with an apical alveolar /d/. A fifth speaker also had an apicolaminal /d̪/, but it was alveolar rather than dental, and was contrasted with a laminal alveolar /d/. The last two speakers had a laminal dental /d̪/, contrasting with an upper apical alveolar /d/. Six of

Table 2.13. Comparison of the data for the Malayalam voiceless stop and nasal series.

	Speaker 1	Speaker 2	Speaker 3
Place of articulation			
/t̪/	interdental	dental (1)	alveolar (3)
/n̪/	dental (2)	dental (1)	dental (2)
/t/	alveolar (4)	alveolar (3)	alveolar (4)
/n/	alveolar (5)	alveolar (4)	alveolar (5)
/ṭ/	postalveolar (7)	postalveolar (6)	alveolar (5)
/ṇ/	postalveolar (7)	postalveolar (6)	alveolar (5)
/c/	alveolar (5)	alveolar (4)	alveolar (5)
/ɲ/	alveolar (5)	alveolar (4)	alveolar (5)
Part of tongue used			
/t̪/	(apico)laminal	apicolaminal	apicolaminal
/n̪/	apicolaminal	apicolaminal	apicolaminal
/t/	upper apical	apicolaminal	apicolaminal
/n/	upper apical	apicolaminal	apicolaminal
/ṭ/	apical & sub-lam	apical & sub-lam	apical
/ṇ/	apical & sub-lam	apical & sub-lam	apical
/c/	laminal	laminal	laminal
/ɲ/	laminal	laminal	laminal
Constriction length (mm)			
/t̪/	19	15	14
/n̪/	14	15.5	16
/t/	8	12	11
/n/	7.5	8	6
/ṭ/	?	4	7
/ṇ/	6	3	6
/c/	10	10	9
/ɲ/	16	10.5	13

Table 2.14. Raw articulatory data for the 'O'odham stop and fricative contrasts showing linguagraphic and palatographic classifications and constriction length measurements (in mm).

	/d̪/	/d/	/ɟ/	/s/	/ʂ/
Speaker 1					
Ling	--	apical	apicolaminal	laminal	apical
Pal	--	alveolar(4)	alveolar(5)	alveolar(4)	postalv(7)
Constrict.	--	7	7	7	2.5
Speaker 2					
Ling	laminal	upper apical	laminal	laminal	apical
Pal	dental(1)	alveolar(5)	alveolar(5)	alveolar(4)	postalv(6)
Constrict.	10	4	7	5	2
Speaker 3					
Ling	apicolaminal	apical	laminal	laminal	apical
Pal	dental(2)	postalv(6)	dental(1)	alveolar(4)	postalv(6)
Constrict.	12.5	6	16.5	7	3
Speaker 4					
Ling	apicolaminal	apical	laminal	apical	apical
Pal	dental(1)	alveolar(5)	alveolar(5)	dental(2)	postalv(6)
Constrict.	10	5	7	5	5
Speaker 5					
Ling	laminal	upper apical	laminal	apical	apical
Pal	dental(1)	alveolar(5)	alveolar(5)	alveolar(4)	postalv(6)
Constrict.	15	5.5	9.5	5.5	4.5
Speaker 6					
Ling	apicolaminal	apical	apicolaminal	laminal	apical
Pal	dental(1)	alveolar(4)	alveolar(3)	alveolar(4)	postalv(6)
Constrict.	18	6	12.5	2.5	1.5
Speaker 7					
Ling	apicolaminal	laminal	laminal	laminal	apical
Pal	alveolar(3)	alveolar(3)	postalv(6)	alveolar(4)	alveolar(5)
Constrict.	8.5	6.5	5	5	3
Speaker 8					
Ling	apicolaminal	apical	laminal	apical	apical
Pal	dental(1)	alveolar(3)	alveolar(3)	alveolar(3)	alveolar(5)
Constrict.	12.5	8	8	6	3

the seven speakers thus produced a dental stop for /d̪/, with four of these having the expected lingual articulation, if we consider apicolaminal to be 'apical', since in this place of articulation it is very hard to produce a stop which involves only the tip of the tongue, and the articulation consequently becomes either apicolaminal or apicosublaminal.

Six of the seven speakers used a more retracted place of articulation for /d/ than for /d̪/. It is difficult to know which place of articulation classifications would correspond to the label "slightly retroflexed" given in the literature to the alveolar stop. It may well refer more to the concave shape of the tongue behind the constriction than to the placement of the constriction itself. Assuming, however, that such a tongue position would necessitate retracting the place of articulation away from the upper central incisors, the articulations of four speakers in the data would presumably fall under the heading of "slightly retroflexed", three classified as the farthest back alveolar (5) and one as postalveolar (6). Only two speakers (Speakers 3 and 4) had the completely predicted articulation for both /d̪/ and /d/.

If we exclude Speaker 7, several generalizations can be made about this contrast. All of the six other speakers had an articulation involving the blade of the tongue for /d̪/ and no blade involvement for /d/; a dental articulation for /d̪/ and a postdental articulation for /d/; and the constriction length for all the speakers, no matter what their method of articulation, was significantly greater for /d̪/ (mean 12.36 mm) than for /d/ (mean 6 mm), as was also the case for Malayalam /n̪/-/n/ and to a lesser extent /t̪/-/t/.

/d/-/ɟ/

The segment referred to in the literature as a "laminal alveolar stop" was laminal alveolar for four of the speakers, and was laminal postalveolar for one more. One of the speakers had a laminal dental constriction, giving a total of 6 out of 8 speakers with a laminal articulation for this segment. The other two speakers made the closure with apicolaminal constrictions, both being alveolar. Apicolaminal and laminal /ɟ/ did not differ significantly in the articulatory measure of constriction length. There were, however, acoustic differences which will be discussed in the appropriate section of Chapter 3.

Six speakers had a /d/ - /ɟ/ distinction where the place of articulation on the palate was in the same broad category for the two segments and which centered around a difference in the part of the tongue used (4 apical or upper apical /d/ vs. laminal /ɟ/ and 2 apical /d/ vs apicolaminal /ɟ/). Some of these speakers made a moderate difference in constriction length (with the /ɟ/ constriction being somewhat longer) and others made no difference at all (means 5.9 mm for /d/ and 8.5 mm for / /ɟ/).

Of the remaining 2 speakers, one had only a difference in place of articulation (laminal alveolar (3) /d/ vs. laminal postalveolar (6) /ɟ/). There was very little constriction length difference between these two laminal articulations, with that of /d/ being slightly longer. The last speaker made a large difference in both place of articulation and part of the tongue used, contrasing an apical postalveolar /d/ with a laminal dental /ɟ/. This also resulted in a large constriction length difference (6 mm vs. 16.5 mm). With the exception of Speaker 7, all speakers distinguished these two consonants by a difference in the part of the tongue used (which was also the major distinction between Malayalam /t/ and /c/). For these 7 speakers /ɟ/ is a blade articulation and /d/ is articulated apically.

/s/-/ṣ/

The traditional description of the 'O'odham fricative contrast is "apical alveolar" /s/ vs. "apical domal retroflex" /ṣ/. In reality, for many (i.e. 5 of 8) of the speakers this is an apical-laminal contrast, with 5 out of the 8 speakers using a laminal alveolar /s/, and all of the speakers using an apical alveolar or postalveolar /ṣ/. For 4 of these speakers the distinction is maximized and involves both the part of the tongue used and the place of articulation on the palate (laminal alveolar vs. apical postalveolar). Two speakers have only a place of articulation difference, contrasting apical /s/ in place categories 2 and 4, with apical postalveolar /ṣ/ in category 6. One speaker made the contrast only by changing the part of the tongue used (laminal alveolar (4) vs. apical alveolar (5)) and the last speaker made no difference at all according to the broad categories described, with both fricatives being apical alveolar, but /s/ being at the farthest forward edge of alveolar (3) and /ṣ/ being at the farthest back edge of alveolar (5), a distance of 5-6 mm between the two. Table 2.15 schematizes this information, with the numbers indicating the different speakers.

Table 2.15. Palatographic and linguagraphic information on the /s/ - /ṣ/ contrast for each 'O'odham speaker.

	/s/	/ṣ/
apical dental	4	----
laminal dental	----	----
apical alveolar	5,8	7,8
laminal alveolar	1,2,3,6,7	----
apical postalveolar	----	1,2,3,4,5,6
laminal postalveolar	----	----

For the 5 speakers who had an apical-laminal distinction between the two fricatives, the constriction length of the laminal fricative was always greater (means 5.3 mm. for /S/, 2.4 mm. for /Ṣ/). For the 3 speakers who had apical fricatives for both phonemes, the constriction lengths were either about the same for both segments, or the constriction was slightly shorter for /Ṣ/. Two of the speakers made a large difference in channel width between the two fricatives, making a much wider channel in /Ṣ/. Judging only by the linguagrams, this wider channel appeared to occur in all the speakers, an observation which was not found to be true when measuring from the palatograms on the palate casts, where there was no large difference in channel width apparent (see Figure 2.10). This would seem to indicate that for most of the speakers there is a much deeper groove in the tongue for the articulation of /Ṣ/ than for /S/. The figures for channel width are given in Table 2.16

Table 2.16 Channel width measures in mm. between the contrasting fricatives /S/ and /Ṣ/ in 'O'odham.

		/S/	/Ṣ/
Speaker	1	7	15
	2	4.5	5
	3	8	10
	4	6.5	6.5
	5	3	13
	6	8.5	9
	7	8	8
	8	5	6

The only articulatory dimension which characterizes the /S/-/Ṣ/ distinction for all speakers is place of articulation, with /Ṣ/ articulated further back than /S/. In the one case where this difference was very small (Speaker 7), the speaker made an apical-laminal distinction as well.

2.2.6 Summary of Malayalam and 'O'odham

The data in this section tend to support the notion that languages which contrast two segments which are usually categorized as having a minimal articulatory difference, such as dental vs. alveolar or apical vs. laminal, will augment the contrast with additional features to improve the perceptual salience. In Malayalam and 'O'odham the dental vs. alveolar contrasts were accompanied by a difference in constriction length (even if the place of articulation did not require it) and in the case of the 'O'odham contrasting apical and laminal fricatives, an extreme place of articulation is given to the apical fricative, causing other changes to take place in the rest of the tongue body. Catford (1977 p.157) claims that in apical postalveolar fricatives the tongue is often concave just behind the constriction and then domed upwards toward

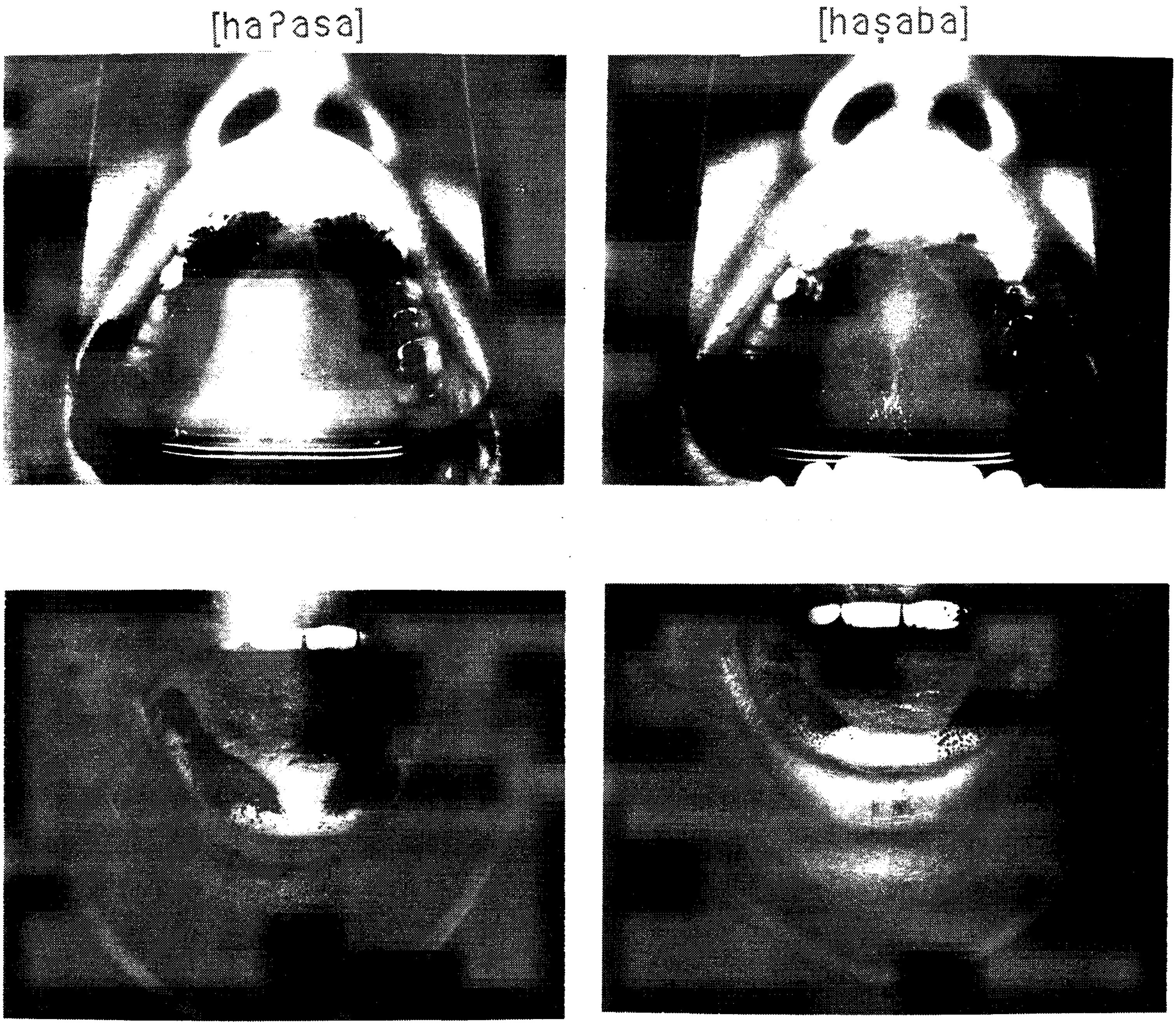


Figure 2.10. Palatograms and linguagrams of an 'O'odham speaker's utterance of haʔasa and haṣaba, illustrating a smaller difference between the channel widths shown on the palatograms (in the upper photographs) than channels marked on the flattened and projected tongue (linguagrams in lower photographs) would indicate, suggesting a deeper groove in the tongue during ṣ articulation.

the velum, giving a characteristic 'dark' or 'velarized' quality to the fricative, thus making it sound very different from the contrasting /s/. Such a tongue shape is perhaps evidenced in the present study by the deeper groove indicated by the linguagrams, although Catford was referring to the shape of the tongue relative to the sagittal plane and not to a transverse concavity.

2.3 Comparison of the results of the articulatory study with hypotheses in the literature.

2.3.1 The feature [distributed]

The answer to the question of whether laminal constrictions are longer in the direction of the airflow than apical constrictions is crucial to the definition of the feature [distributed] in the Chomsky and Halle (1968) framework. In the last chapter, Figure 1.1 showed palatograms and linguagrams from two speakers, one with an apical /t/ articulation and one with a laminal one. It was seen that the constriction length was not different for these two tokens. This kind of short constriction was quite common in the laminal articulations, another example being given in the top half of Figure 2.11. It is, of course, also possible, as shown in the bottom half of the figure, to have tokens illustrating a long constriction for a laminal articulation. The crucial difference here lies in the oral morphology of the speakers involved. For an alveolar stop, the form of the alveolar ridge itself obviously dictates the constriction length to a certain extent. Notice that the speaker with the short constriction has a very pronounced alveolar ridge. This makes it not only easy, but practically imperative, to produce a short alveolar constriction regardless of which part of the tongue is used. The speaker illustrated in the lower half of the figure has a smooth palate shape, making it nearly impossible to form a laminal stop without rather extensive contact on the passive articulator. In these cases the literal definition of [distributed] as a difference in constriction length, is tied in not with the apical/laminal parameter of specific segments, but with the anatomy of each individual speaker. In light of the above evidence, constriction length, although it may be used in some languages to distinguish contrasting segments, should not be regarded as a necessary result of the part of the tongue used in the articulation.

A related question, necessary because it has been used so often as an example in the literature, is the articulatory status of the Malayalam contrasting 'dental' and 'alveolar' stops. The relevant data was presented in Table 2.10. Perhaps the most striking detail that emerges from the table is that the much discussed difference in apicality is non-existent. The speaker who comes closest to making the predicted difference protruded his tongue during /t̪/ articulation thereby making an interdental stop instead of the expected stop against the back of the upper central incisors. The other two speakers produced both of these sounds with apicolaminal constrictions.

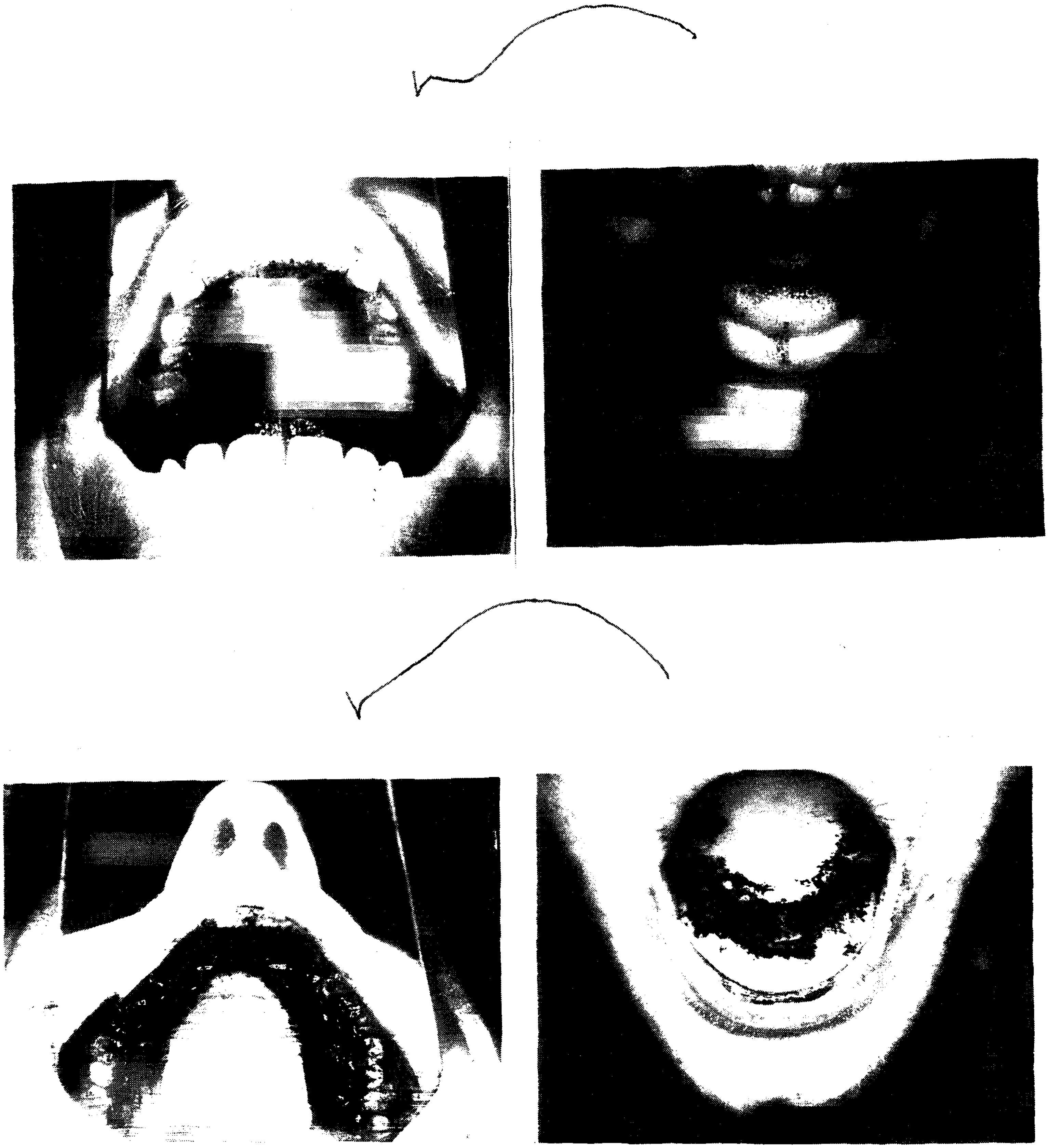


Figure 2.11. Palatograms, linguagrams and tracings of the palate shape from two different speakers producing laminal articulations with very different constriction lengths, illustrating the effect of alveolar ridge prominence on constriction length.

Although the difference is very small for Speaker 3, all the speakers do articulate /t/ farther back than /t̪/, however, and they all likewise have a longer constriction for the more anterior member of the pair, even if for two of the speakers this difference is very slight. For these three Malayalam speakers, the contrast can be said to involve place of articulation and constriction length, but not apicality. The feature [distributed] as it was originally described, referring to the length of the constriction in the direction of the airflow, is one possible way to distinguish these two stops articulatorily, although we shall see in the next chapter that this has little to do with the major acoustic differences found.

2.3.2 Place of articulation vs. tongue position

In Chapter 1 a survey of the literature regarding the articulation of French and English consonants was presented. It is interesting to look back at those descriptions and see how far they coincide with the results of the palatographic and linguagraphic study. Recall that the general consensus of the 19 sources for French was that /t/, /d/ and /n/ are apical or laminal dental, /l/ is apical dental and /s/ and /z/ are either dental or alveolar laminal articulations. Table 2.17 reformulates the data given in Figure 2.5. The six classifications have been reduced to three places of articulation in the same way as done previously in this chapter: classifications 1 and 2 are grouped under the *dental* heading, 3, 4, and 5 are called *alveolar* and 6 falls into the *postalveolar* category. Upper apical articulations are listed under the heading *apical* for this table, and the numbers represent numbers of tokens. /t/, /d/ and /n/ are combined in one group as they usually were in the sources referred to above.

Table 2.17. Summary of linguagraphic and palatographic data of both word-initial and word-final tokens from 21 French speakers. Data is presented as numbers of tokens.

		dental	**alveolar**	**postalveolar**
/t,d,n/	**apical**	11	23	0
	apicolaminal	47	8	0
	laminal	16	21	0
/l/	**apical**	1	29	10
	apicolaminal	1	0	0
	laminal	0	1	0
/s,z/	**apical**	12	12	0
	laminal	20	32	0

It can be seen in the table that the /t̪,d̪,n̪/ articulation of the majority of the speakers would be included under the general category of apical or laminal dental, assuming always that, because of the difficulty for most speakers in producing a purely apical dental, apicolaminal dental articulations are included among what previous authors would call 'apical'. This still leaves 52 tokens or 41% of the data unaccounted for, that is all those tokens which are not dental. Clearly, a number of French speakers articulate farther back than was previously supposed.

The point of view of the sources on fricative articulation was a bit more open to variation, with both dental and alveolar articulations mentioned (although only one source allowed for both possibilities). Most sources, however, stated quite firmly that French /s/ and /z/ were laminal. It is clear from the table that, although the majority of tokens were laminal, still 24 or 31.5% were not accounted for by the descriptions.

The most striking error in the descriptions was that for place of articulation in French laterals. There is such a strong feeling that the French "base of articulation" is dental, that authors appear to simply assume that /l/ has the same place of articulation as /t/, /d/ and /n/ (after all, they are nearly always put in the same column of the consonant chart in any given language). This is assumed, even though all the physiological data available, going at least as far back as Haden (1938), indicate an alveolar or postalveolar articulation for French /l/ (see also Simon 1967 and Rochette 1973). It is surprising that this information has not reached even other phoneticians, as the following quotation from Malmberg (1969) illustrates.

"Le caractère dental du /l/ français est aussi à retenir. La position alvéolaire de la pointe de la langue ne convient pas en français." p.108

"The dental character of French /l/ is also to be kept in mind. The alveolar position of the tongue tip is not suitable in French."

That this is not the case is evident from Table 2.17. The majority of tokens (30) were alveolar /l/'s and 22 of these were classification 5, the farthest back point in the alveolar category. A further 10 tokens were postalveolar /l/ articulations, leaving only 2 tokens of dental /l/ in the corpus of 42 utterances.

It might be argued that, since the articulation of laterals is known to vary considerably according to environment (Bladon and Carbonaro 1978, Hardcastle and Barry 1985, and Straka 1968), the data in the present study, all in the environment of a low central vowel, may not be representative of French /l/ in other, or even most, contexts. For this it is instructive to look at the x-ray tracings provided by Haden (1938), Simon (1967), Rochette (1973) and Bothorel et al (1986) which show /l/ in a number of different vowel and consonant contexts. In both Haden (1938) and Simon

(1967) /l/ is always alveolar or postalveolar, no matter what the vowel environment (tokens include environments of [a,i] (Haden) and [a,e,ɛ,ɛ̃,y,ɥ,ɔ] (Simon)). In Bothorel et al, two of the four speakers have a dental /l/ when it is followed by a high front vowel. Rochette (1973) investigated different consonant environments and found that /l/ was either alveolar or retroflex except when adjacent to another alveodental consonant (/t,d,n/), where it became also alveodental. It appears from these studies that French /l/ is alveolar except in specific dentalizing contexts.

The descriptions of the English articulations, while correctly describing the general trend, are also too narrow to reflect the diversity of individual variation. Apical alveolar constrictions were reported by nearly all 23 sources for English /t,d,n/ and /l/. The fricatives /s/ and /z/ were likewise felt to be strictly alveolar, but most of the sources recognized both apical and laminal variants.

Table 2.18. Summary of linguagraphic and palatographic data of both word-initial and word-final tokens from 20 English speakers. Data is presented as numbers of tokens.

		dental	alveolar	postalveolar
/t,d,n/	apical	10	81	7
	apicolaminal	3	4	0
	laminal	8	6	0
/l/	apical	13	12	1
	apicolaminal	5	6	0
	laminal	1	0	0
/s,z/	apical	16	18	0
	laminal	2	43	1

Table 2.18 reformulates the information in Figure 2.7 in the same way as the previous table for French. It can be seen that 81 tokens, or 68% of the data for /t,d,n/ are, indeed, apical alveolar as predicted. Of the remaining 38 tokens (there were only 119 tokens in all because one speaker made no contact in final /t/) 17 are also apical, but either dental or postalveolar, and 10 are also alveolar, but use a different part of the tongue. A total of 21 tokens (or 17.6% of the data) are dental and an equal number are laminal or apicolaminal.

The fricatives /s/ and /z/ were indeed divided between apical and laminal, but with the laminal predominating with slightly over half (57.5%) of the tokens. Again, most of the tokens were alveolar (75%).

As it turns out, the English laterals are far more likely to be dental than their French counterparts, again going against the neat organization of the consonant charts, which usually put /t,d,n,l,s,z/ in the same column. Exactly half of the /l/ tokens were dental in the English data (as compared to 4.8% of French tokens), in spite of the general acceptance in the literature that such English segments should be alveolar, just as the French are assumed to be dental. Even the apical articulation of the lateral, which was nearly universal for the French speakers (95%) was less strong in English (68%), the "apical" language par excellence. It seems, then, that /l/ need not necessarily share the articulatory characteristics of the other coronal consonants in any given language.

2.3.3 Coarticulation

Many investigators have noted that place of articulation may vary with vowel environment. Hardcastle (1984, p.23), for example, showed in an electropalatographic study that the contact for English /l/ before [i] extended farther back than before [æ] or [ɔ]. A similar extended contact area is evident in the electropalatographic data of Recasens (1984) for Catalan /n/, but the increased contact in the environment of a high front vowel extends forward from an alveolar position rather than backward in the mouth. In Italian /t/, at least for one speaker (Farnetani 1987), this kind of coarticulatory extension of constriction length does not appear to occur. In the present study, palatograms and linguagrams were made of one French speaker uttering /t/ in the environment preceding the following vowels: [i,e,y,ø,u,o,õ,a]. Figure 2.12 shows the palatograms from this speaker's 'hâter' [ate] (upper) and 'battu' [baty] (lower) production. It can be seen that the constriction extended farther back before the [y] vowel than before [e]. Figure 2.13 presents the linguagraphic results. It is clear that, at least with this speaker, a change in vowel environment does not affect the part of the tongue used for /t/ articulation, except in the environment before the high front rounded vowel [y] which causes more blade contact than the other vowel environments. Although the contact area does not extend further back from the tip for [i], there is a broader area of contact on the sides of the tongue, as is evident in the linguagram of [tipe]. Recall that in Canadian French (Charbonneau and Jacques 1972) /t/ and /d/ get laminalized and affricated before both /i/ and /y/. The x-ray tracings in Figure 2.14 illustrate this change: at the left /t/ before [u] in the phrase 'Tout cela lui plaît' [tu səla lɥi plɛ] and at the right, /t/ before [y] in the phrase 'Tu viens le matin' [t̻y vjɛ̃ lə matɛ̃] "You come in the morning" (transcription with subscript square in accordance with the new IPA convention for laminal articulations). It is clear that this is a natural coarticulatory phenomenon simply carried a bit farther in this dialect. Other non-Canadian French speakers I have consulted, have remarked a comparable lingual gesture in their own /t/ and /d/ production before high front vowels. As Marchal (1980, p.95) points out, the real question is not why Canadians affricate /t/ and /d/ before high front vowels, but how the other French speakers avoid doing so.

[ate]

[baty]

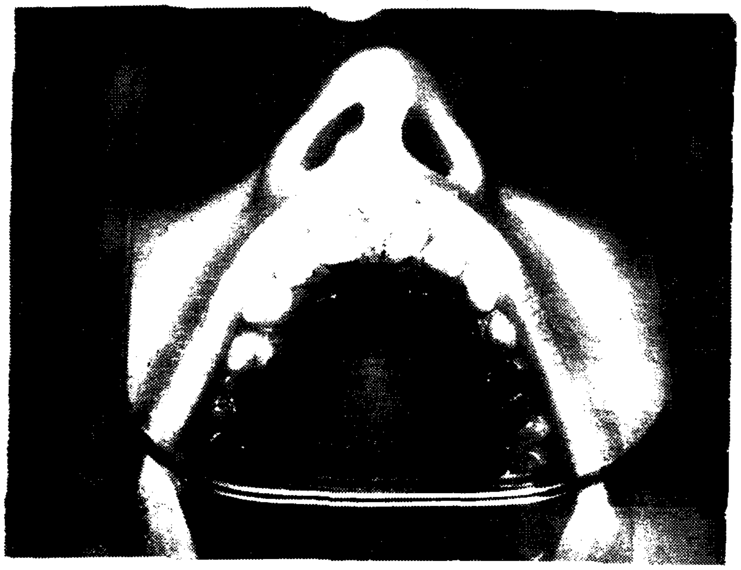


Figure 2.12. Palatograms of the words 'hâter' [ate] and 'battu' [baty] *showing coarticulation of the stop to the following vowel.*

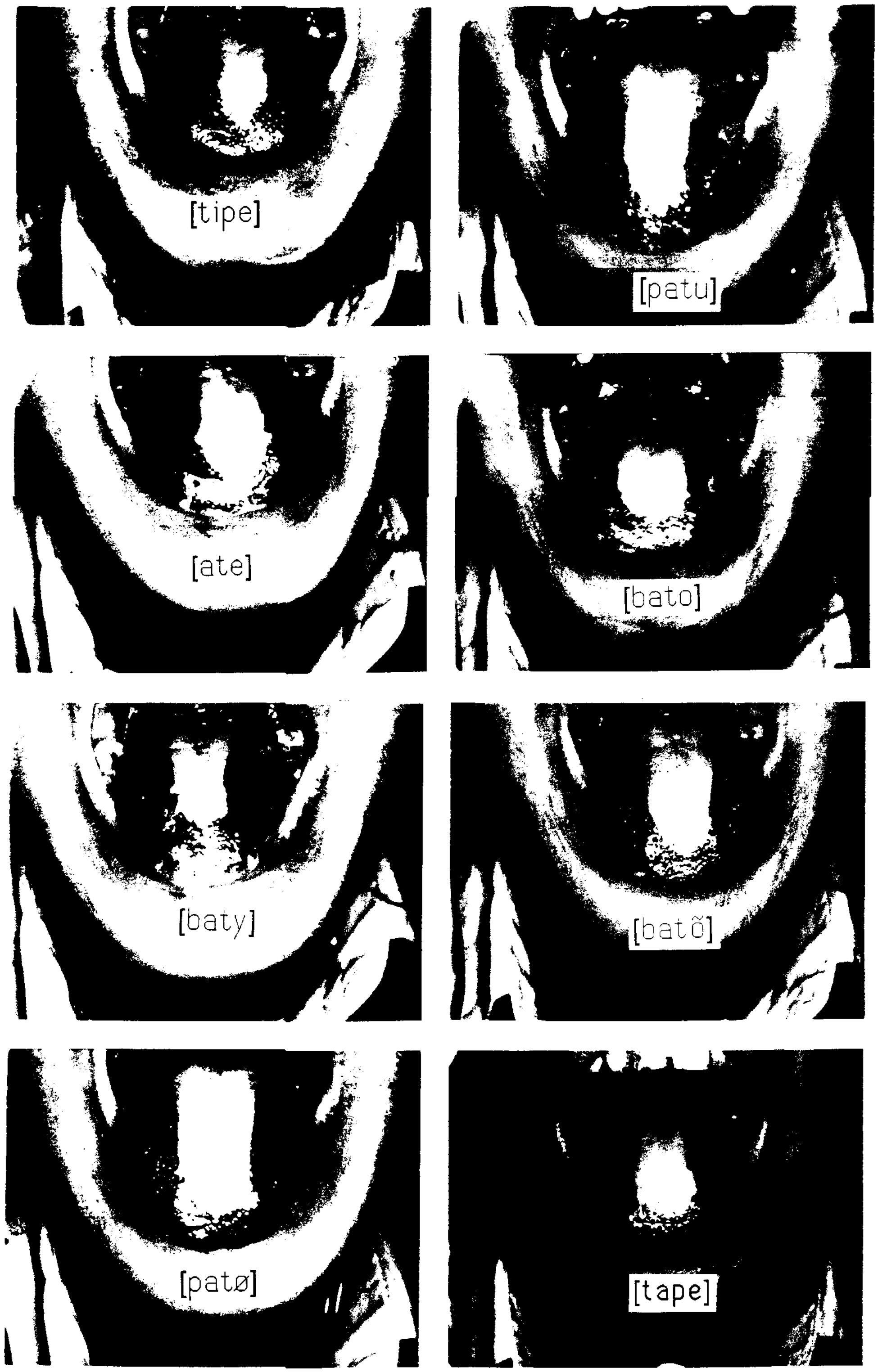


Figure 2.13. Linguagrams from one French speaker uttering phrases with /t/ followed by a variety of vowels.

Figure 2.14. X-ray tracings (after Charbonneau and Jacques 1972) of Canadian French apical (or apicolaminal) /t/ before a high back vowel (left) and laminal /t/ before a high front vowel (right).

2.3.4 Nasals

The acoustic cues that we look for in nasals are somewhat different from those in stop consonants. On the one hand, the nasals themselves are audible during the closure phase, unlike the stops, but on the other hand, there is no release burst or difference in VOT to assist with identification. Because of this, Ladefoged and Maddieson suggest that the articulatory gestures, and therefore the formant transitions for contrastive nasals may be more extreme, since there is very little else to go by (Ladefoged and Maddieson 1986 p.8). The data from the Malayalam speakers in the present study give support for Ladefoged and Maddieson's prediction that articulatory gestures will be more extreme in nasals than in stops. Referring back to Table 2.13 (p.40) it can be seen that only Speaker 3 made a difference in place of articulation which changed broad categories, advancing her /n̪/ slightly on to the upper central incisors, making it classification 2, which I am calling dental, instead of classification 3 in the alveolar category. In addition to this, the articulation of the dental and alveolar nasals was further separated by retracting the alveolar nasal slightly, amounting also to a change of one classification number, although staying within the same broad category. This retraction of the alveolar was also effected by the other two speakers, whose dentals were already quite far forward, making the difference between /n̪/ and /n/ greater than that between /t̪/ and /t/. For Speaker 1, who made an interdental /t̪/, the articulation of /n̪/ was actually retracted a bit to produce an apicolaminal dental, the opposite pattern from that observed in other speakers (reported in Ladefoged and Maddieson 1986 p.8) who had interdental nasals and dental stops. No change of place in reference to the stop consonants was observed in any of the other nasal segments in Malayalam.

More generalized in the data are constriction length differences between corresponding stops and nasals. Notice that both Speakers 2 and 3 made larger constriction length differences between /n̪/ and /n/ than between /t̪/ and /t/. Since, as we have seen, the so-called 'palatal' stops and nasals are actually alveolar in Malayalam and are distinguished from the alveolar stop series by a laminal articulation, a change in place of articulation is not appropriate for making the nasal contrast more salient. The contrast was rather reinforced by larger constriction length differences between /n/ and /ɲ/ for two of the speakers when compared to their articulation of the /t/-/c/ contrast. For the third speaker (Speaker 2), although the actual difference in constriction length was not greater for the nasals, it was made in the other direction (as was the case as well with Speaker 3), i.e., with /ɲ/ having a slightly longer constriction than /n/, whereas in the stop distinction, the /t/ constriction was longer for this speaker than that of /c/. Ladefoged and Maddieson's (1986) claim that articulations in contrasting nasals will be more extreme than in contrasting stops then holds true for both place of articulation and constriction length in Malayalam.

Looking back at the non-contrastive nasals in French, we are now in a position to comment on a statement made by Mohanan and Mohanan (1984) in support of a phonological analysis which treats Malayalam /t/ as underlyingly dental and /n/ as underlyingly alveolar (which Bernard Tranel kindly brought to my attention) that "In most languages (for example, all the other Indian languages that we know of, as well as languages like French and Italian), the coronal nasal is alveolar and the coronal stop is dental even on the surface." (p.585 fn.22) To begin with, it is clear from the distribution in Figure 2.5 (p.23) that, at least in French, this is not the case. If we take the top two rows to belong to the category *dental*, and rows 3-5 to be *alveolar*, then out of the 42 tokens for each segment (21 speakers' word-initial and word-final consonants), there were 27 dental and 15 alveolar /t/s; 22 dental and 20 alveolar /d/s; and 25 dental and 17 alveolar /n/s. It is clear that /n/ has no more of a tendency to be alveolar in French than do /t/ and /d/.

Taking each speaker individually, for 14 of the 17 alveolar /n/ tokens (representing 10 different speakers), the corresponding /t/ for that speaker was also alveolar. Only 3 tokens (representing 2 speakers) had a corresponding dental /t/. The numbers are thus overwhelmingly against Mohanan and Mohanan's claim which, although it may be true for some speakers, does not hold up when the articulation of a large number of speakers is examined.

2.3.5 Sibilants

The literature contains a number of generalizations about sibilant production which relate directly to the data obtained in the present study. To begin with, Ladefoged and Maddieson (1986, p.57) state that sibilants have a greater constancy of shape in varying environments than do /t̪,d̪,n/. This was said to be the case for varying vowel environments, to which the present study has nothing to add. But such constancy could be judged in the present data from changes in place of articulation, apicality and constriction length from word-initial to word-final consonant tokens. Table 2.19 gives the number of speakers whose articulation changed from initial to final tokens in these three variables. A change was recorded in place of articulation whenever the initial and final tokens differed by one or more classification numbers, whether or not this change resulted in a change of broad category. Any change in apicality classification was noted, although it must be remembered that since there are 4 apicality categories for /t,d,n,l/ and only two for /s,z/, these results are not strictly comparable. More than 2 mm of difference in constriction length was counted as a change.

Table 2.19. Numbers of speakers with changes in articulation for French and English speakers between word-initial and word-final tokens.

	place of articulation		**apicality**		**constriction length**	
	English	French	English	French	English	French
/t/	9	6	1	2	10	9
/d/	11	11	4	3	11	10
/n/	9	11	7	8	7	10
/l/	14	10	4	4	11	6
/s/	3	11	1	2	2	5
/z/	5	12	1	0	2	7

English /s/ and /z/ seem to vary much less in place of articulation from word-initial to word-final tokens than do /t,d,n/ and /l/. This is not the case for French, however, where sibilants vary as much as do the other segments. Apicality, on the other hand, remains constant in sibilants for most speakers in both languages. In fact, this measure does not vary much for any of the segments, but more speakers have a difference in /d/, /n/ and /l/ than do for /t/, /s/ and /z/. This may be due in part, however, to the fact that there are more categories for variance in the non-fricatives. The final measure, constriction length, varies for around half of the speakers in /t,d,n/ and /l/ and there does appear to be less variation in fricatives, especially in English. French /l/ also has less variation than both English /l/ and French /t,d,n/. The data in Table 2.19 seem to support the claim of a greater constancy of shape in sibilants, particularly in English.

Another claim that Ladefoged and Maddieson (1986, p.78) make is that dental sibilants are always apical. This is clearly not true in the data from the present study, where 50 examples of dental sibilants occur, of which 28 are apical and 22 laminal.

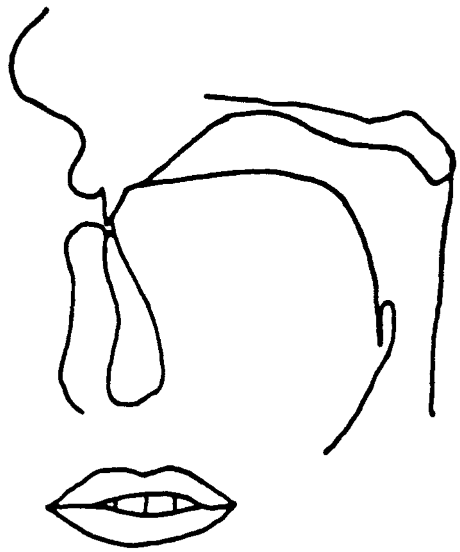
2.4 Additional articulatory evidence from other studies

There are a number of possible articulatory consequences of the apical and laminal articulations, besides the obvious difference in tongue tip placement. Some of these are necessary results from the placement of the tongue tip, others may usually, but not inevitably, follow from these gestures. X-ray studies can shed light on the articulatory differences between apical and laminal consonants, provided the tracings are carefully and precisely made and the dentition of the speaker is such that one can see the tongue tip clearly enough to determine whether it is up or down (not always a trivial task since x-rays pick up bones and teeth and particularly dental fillings, much more readily than they do the contours of the soft tissues of the tongue). One publication which has been of great use is Bothorel et al. (1986) where tracings from cine-x-rays of four French speakers are given for the sounds of French in several different contexts and over time. Opportunely, one and perhaps two of the four speakers appear to produce their stops laminally and the other two clearly apically or apicolaminally. Figure 2.15 gives examples taken from Bothorel et al. (1986). On the top is a tracing of a speaker with a laminal /t/ articulation and on the bottom a speaker with an apical or apicolaminal /t/ articulation. Both of these are taken from the /t/ closure in the phrase 'Une pâte à choux' [yn pat a ʃu] 'puff pastry dough'. It can be seen that in the lower tracing the tongue tip is up, leaving an empty sublingual resonance cavity underneath. In the upper tracing, this cavity is completely filled by the tongue. Also to be noted is the difference in pharyngeal width between the two speakers. The laminal articulation, because it uses a more posterior part of the tongue to make a closure in the same place in the front of the palate, necessarily draws the body and root of the tongue forward, resulting in a wider pharynx.

Also visible from the tracings in figure 2.15 is the more closed jaw position in the laminal articulation. This may be because the jaw is helping the tongue make the closure by passively bringing it up to meet the alveolar ridge or the upper incisors. This is clear, in fact, when one studies the full series of tracings from 6 frames comprising the [ata] portion of the utterance. The mandible rises up to the [t] closure, then descends for the following [a], and as a consequence, no sublingual cavity is created (Figure 2.16). For the other subject (with the apicolaminal occlusion) the mandible maintains a steady position, the tongue tip is mobile enough to raise itself up without any help from the mandible and the sublingual cavity is maintained. This observed difference in jaw movement, however, may be independent of the tongue position. In Ladefoged, DeClerk, Lindau and Papçun (1972) 5 English speakers were divided on whether the tongue height variation in vowels was or was not assisted by jaw movement.

Rochette (1973) provides x-ray tracings and tables of articulatory measurements taken from the tracings of segments in many different consonant environments as spoken by two speakers of Parisian French. Of the segments of interest here, there are a total of 50 examples of /t,d,n,l,s,z/ from one speaker and 19 examples of /t,n,l,s,z/ from the other. Upon examination of the measurement data, a negative correlation is evident between pharynx width and the distance from the upper surface of the tongue to a mid-point on the hard palate, as shown in Table 2.20.

Laminal



Apical

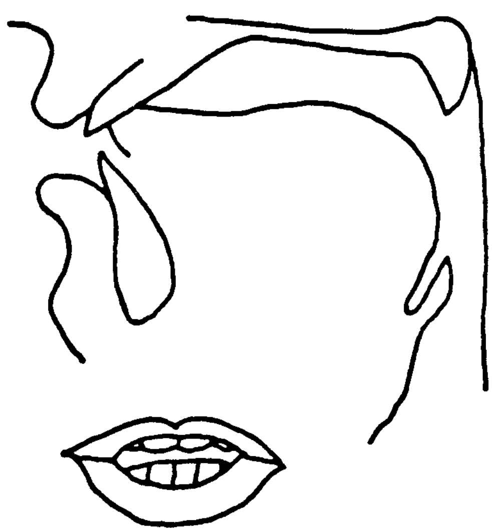


Figure 2.15. Tracings of x-rays and labiograms from two French speakers, taken from the middle of the /t/ closure in *Une pâte à choux* [yn pat a ʃu] 'puff pastry dough' (after Bothorel et al. 1986).

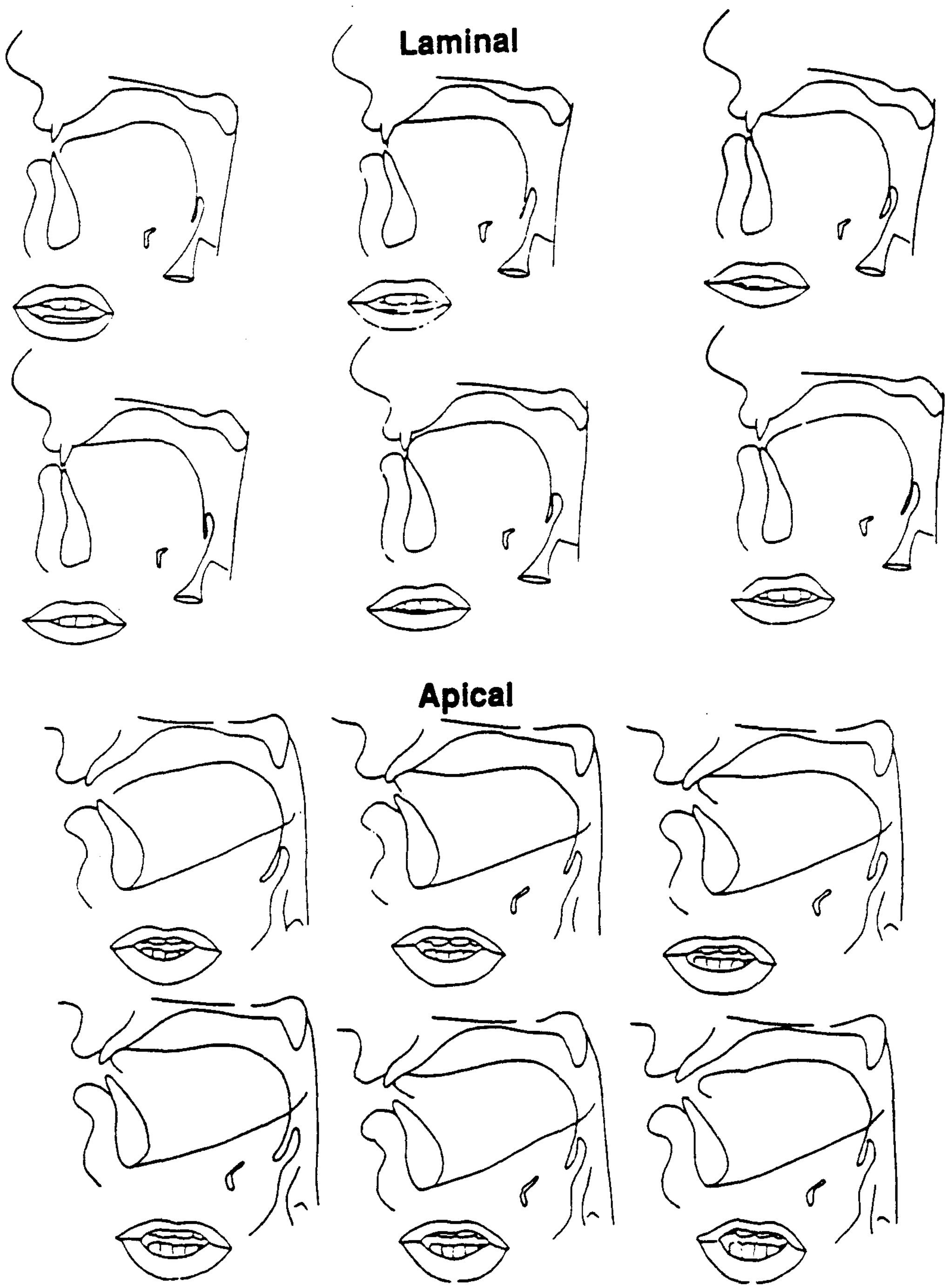


Figure 2.16. Six consecutive frames from the /ata/ portion of the utterance *Une pâte à choux* [yn pat a ʃu] 'puff pastry dough' for two speakers (after Bothorel et al. 1986).

Table 2.20. Results of a correlation between pharynx width and distance from the upper surface of the tongue to a mid-point on the hard palate during articulation of French coronal consonants by two speakers. Measurements were taken from Rochette (1973).

count	covariance	correlation	r-squared
69	-8.198	-.605	.366

This means that the wider the pharynx, the higher the tongue body, or, translated in terms relevant to this study, that laminal articulations might be likely to have a higher tongue body as well as a wider pharynx. Ladefoged and Maddieson (1986, p. 103) also suggest that, "...wide pharynx and raised tongue front usually accompanies the laminal articulations...", although they caution that this is not invariably so. This is also visible in the tracings given in Figure 2.15 (although somewhat obscured by the fact that the speaker with the laminal articulation also has a much higher palatal arch) and will be important in the discussion of the acoustic correlates in the next chapter.

Other differences between the two ways of articulating involve the timing of the gestures. Because the tongue tip is smaller than the blade area, it is also more mobile and can move more swiftly. As a consequence, the release gesture of an apical stop should be quicker than that of a laminal stop. In theory, this should not be difficult to prove by examination of sequential x-ray frames, but only if the frame rate is very high, and it rarely is so. I have found no conclusive evidence by this method. That there is a difference in release speed seems possible, however, from the increased turbulence visible in the acoustic records, as will be discussed in the next chapter. On the other hand, it is possible that greater turbulence at release could be caused by the release of a physically longer constriction rather than a slower release gesture.

Also of interest for an acoustic comparison is the direction of the release gesture, particularly in interpreting the acoustics of the apicolaminal release. It seems likely that the burst spectrum of an apicolaminal occlusion released back to front would resemble an apical release, in that the last part released would be the tip of the tongue. If, on the other hand, an apicolaminal occlusion is released front to back, the burst spectrum should resemble more the release of a laminal consonant, since the blade would be the last, and therefore the audible part of the release. This kind of information is rather difficult to glean from x-ray data, but is clearly visible in a data printout from a computer analysed electropalatograph. In reviewing electropalatographic studies with published closure and release sequences in both English and French, such as Hardcastle (1984), Hardcastle and Barry (1985), Barry (ms.) and Marchal, Courville and Belanger (1980), several interesting patterns were noticed, although the data must be regarded as inconclusive from our point of view, since the information concerns palate contact only, and it is impossible to be sure of the part of the tongue used. In data on English, alveolar releases in a neutral environment were always back to front (as were French /t̪/ and /d̪/ releases). Such segments may be tentatively supposed to be apically articulated, as the majority (but not all) of English speakers produce them this way. /t,d,n,l/ all followed this pattern of back to front release before non-high front vowels and before other alveolars or velars. Before[i] and [ɩ] and before [ʃ], however, the release was from front to back, presumably from the palatalizing environment. Velars also released from front to back. Pushing this admittedly inconclusive evidence a bit further, if an analogy can be drawn between palatalized consonants and vowels and a laminal articulation, then it might be assumed that laminal articulations are released from front to back and apical articulations from back to front (at least in a low vowel environment such as in the present study). This agrees with the introspective examinations of the author and several other linguists questioned, but of course cannot be supposed to be proven.

Niemeyer (1987), in examining x-rays of "alveolar" (i.e. versions of /t/, /d/, /n/, /l/) segments in 14 languages in the literature, found that segments with a wide area of contact had level or falling tongue shapes ('falling' in his terminology meaning sloping down from front to back as seen in the sagittal section), segments with a medium area of contact had an arching tongue shape, and segments with a small area of contact had a concave tongue shape. It is not too difficult to visualize these three divisions of tongue shapes as illustrating, respectively, apicolaminal, laminal (or upper apical?) and apical articulations as described in the present study.

From the above evidence, laminal articulations may be assumed to have a higher tongue body, a wider pharynx and possibly a more closed jaw position than apical articulations. In addition, the laminal stops may be released from front to back and the apicals from back to front. Also important is the possibility that apical consonants have a sublingual resonance cavity while laminals do not. All these factors will be considered when discussing the acoustic results in the next chapter.

Chapter 3. Acoustic consequences of articulatory differences

3.0 Expected acoustic effects

Before looking into the results of the acoustic analysis, it is instructive to outline what acoustic effects one would expect to find from the articulatory differences discussed in the previous chapter. We have characterized apical consonants as having a lower tongue body and narrower pharynx than corresponding laminal consonants, as well as having perhaps an extra cavity under the raised tongue tip. The area of contact and length of constriction in the direction of the airflow for apicals may be smaller, on the average, but counterexamples are also easy to find. For laminal consonants, one inevitable consequence of using a less mobile part of the tongue for articulation (i.e. the blade instead of the apex) may be a slower release gesture which, in the extreme case, may cause affrication in stops. If laminal articulations do, indeed, employ more jaw movement to compensate for a less mobile tongue mass as we have suggested, that also would have its acoustic consequences. The sections which follow take these physiological components one at a time, outlining their probable acoustic effects.

3.0.1 Position of tongue body

It is recognized by nearly all researchers, whether working with theoretical or real data, that a higher tongue body with a constriction in the front of the mouth leads to an increase in the frequency of the second formant (e.g. Stevens et al 1986, Recasens 1984, Santerre 1972). But, as was previously mentioned, there has been some dispute whether it is the apical or the laminal articulation which has the higher tongue body. Stevens et al (1986 p.434) theorized that apicality led to a more fronted tongue body position and therefore a higher F2, but physical evidence from x-ray data seems to show that it is rather the laminal articulations which have the more forward and higher tongue body positions (see Bothorel et al 1986, Recasens 1984 and Santerre 1972). Recasens (1984) noted that [n̻] in Catalan, while differing from [n] only in using the blade instead of the apex of the tongue (both are alveolar) is distinguished by a markedly higher F2. Similarly, Santerre (1972), working on Canadian French, was able to follow articulatory changes in synchronized spectrograms and noted that when the x-ray shows the blade of the tongue approaching the alveolar ridge, F2 rises in the spectrogram and F1 descends. When, instead, the tongue tip rises towards the alveolar ridge, F2 descends in the spectrogram and F1 rises. We will then take it as probable that laminal articulations should have a higher F2 (and possibly a lower F1) than corresponding apical articulations.

3.0.2 Pharynx width

X-ray evidence has shown that articulation of laminal consonants will involve a wider pharynx than that of apical consonants. According to Lindau (1978) and

Santerre (1972) increase in pharynx width results in a lowering of F1. From this we would expect to see a lower F1 at the release of a laminal consonant.

3.0.3 Extension of front cavity

When the tongue tip is raised an extra resonance cavity may be created in front between the floor of the mouth and the underside of the tongue (Perkell, Boyce and Stevens 1979). This has the same acoustic effect as lip rounding, since both involve lengthening the cavity in front of the constriction and result in a lowering of the higher formants. Another consequence of the creation of this small cavity is the bringing together of F3 and F4 caused by the proximity of the lowest resonance of the sublingual cavity to the third natural frequency of the back cavity, resulting in a prominent spectral peak near the location of F3 (Stevens 1989). Under this interpretation, we would expect to find a lowered F3 and F4 (and perhaps F2 as well) and a convergence of F3 and F4, in both the apical and apicolaminal articulations which have the tongue tip raised, and an absence of these effects in the laminal articulations, since the cavity in question would be at least partially filled by the tongue tip. Presumably, however, a laminal articulation which was slightly retracted, such as a postalveolar or retracted alveolar, would also have a front cavity and the accompanying resonances. It is also possible that in the articulations we are concerned with here, being alveolar and dental, the front cavity is too small, and therefore has a resonance too high to couple with one of the back cavity resonances and we would see no convergence of F3 and F4 (Stevens 1989).

3.0.4 Speed of release gesture

The apex, being small and narrow, is capable of much faster movement than the larger parts of the tongue body. We would expect to see in the burst of an apical stop consonant the evidence of a cleaner and more abrupt release than in the corresponding laminal consonant. This factor would presumably separate the apical consonants from both the apicolaminal and the laminal consonants, since the apicolaminal articulation involves both the apex and the blade and represents the longest constriction of the three types of articulation discussed. Such a difference in burst quality has been reported between the Malayalam apicolaminal dentals and apical alveolars (Jongman, Blumstein and Lahiri 1985). Ladefoged and Maddieson (1986) also mention the affricated quality of (apico)laminal articulations as well as the possibility of a double burst, presumably due to a Bernoulli effect occurring in the long constriction, since a long constriction, at least in velar consonants, has been claimed to be a factor in the characteristic double bursts (Keating, Westbury and Stevens 1980).

3.0.5 Jaw movement

According to Lindblom and Sundberg (1971) increasing jaw opening results in an increase in F1 in all tongue positions and an increase in F3 particularly when the tongue is in a forward, 'palatal' position. F2 is not much affected by jaw movement except a possible lowering with jaw opening when the tongue is in a backed [ɑ] position. We have suggested that there is more jaw movement in laminal stops to help make the closure since the blade of the tongue is not as mobile as the tip. This results in a more closed jaw position during the stop and a larger jaw movement coming out of the stop into the following vowel. We would expect to see, then, a steeper rise in F1 and F3 and a higher F2 after a laminal release.

3.0.6 Constriction area

Fant (1960 p.81) states that "An increase of the constriction area has the effect of increasing F1, providing the constriction is located in the front half of the model." In the present study we can estimate relative constriction area from the constriction length measure and we would expect to find a higher F1 in segments such as apicolaminals, which were found to have clearly longer constrictions.

3.0.7 Summary

If we sum up the effects just discussed, we arrive at the following acoustic profiles for apical and laminal consonants. A laminal stop would have a longer and perhaps more fricative-like burst, followed by a rise in F1 with a lower starting point than in an apical consonant and a fall in F2 as the high front tongue position gives way to the following vowel. F3 should climb out of both consonant types, in the apical because of the lowered F3 related to a raised tongue tip during the closure and in the laminal because of the greater increase in jaw opening at release. In addition, we would expect to find a convergence of F3 and F4 at the release of apical and apicolaminal consonants because of the spectral prominence in the vicinity of F3 caused by the cavity under the raised tongue tip. In the next section I will review the acoustic data gathered in the present study, comparing these results with those expected for the different articulations discussed.

3.1 Acoustic analyses

Method

In this section the acoustic data from the present study will be given by segment type. Several different methods of investigation were used and will be described below.

For the acoustic analysis, the palatographic classifications were simplified into *dental, alveolar* and *postalveolar*. Those tokens classified as 1 or 2 in the classification index given in Chapter 2 were called *dental;* those classified as 3-5 were called *alveolar;* and those classified as 6 or 7 were called *postalveolar.* These groups were analyzed one by one as they intersected with the linguagraphic classifications *apical, apicolaminal* and *laminal.* There were no speakers who used exclusively *upper apical* articulation, and in that sense, it is different from the other three classifications. It was found that some of the *upper apical* articulations had the acoustic characteristics of *apical* consonants and some were more closely aligned to the *apicolaminal* consonants. This was usually related to the type of articulation used by each speaker in the other segments. Judging that the acoustic differences found were related to the shape of the tongue behind the constriction, each *upper apical* utterance was placed under the category that its formant frequencies most exemplified for that speaker. Another approach would have been to group the *upper apical* articulations entirely with one of the other classifications for all speakers, but this did not seem advisable, given that these tokens tended to vary by speaker. Of the 48 tokens of this type (25 in French, 23 in English), 27 occurred with speakers who otherwise articulated apically, 16 with speakers who otherwise articulated apicolaminally and 5 tokens occurred with speakers who otherwise articulated laminally. These were divided fairly evenly between the two languages.

For all segments, closure duration was measured from spectrograms of the test utterances. For voiceless stops, in addition to the closure duration, the voice onset time was also measured. Voice onset time (VOT) was taken to be the time from the beginning of the consonant release burst to the point at which at least the first two formants had acquired their periodic voicing (as opposed to aspiration noise). For the Malayalam /t/-/c/ and 'O'odham /d/-/ɟ/ distinctions, the length of time from stop release to resumption of the periodic voicing of the following vowel (which might be termed the period of frication for some speakers who affricated the second segment) was also measured.

In determining the duration of fricatives, only the time of actual visible frication was measured; the silent intervals often found on spectrograms either just preceding or just following fricatives were not included in the measurement. The duration measurements for nasals and laterals were straightforward, being for the most part obvious because of the abrupt formant shifts. It was observed that for many of the speakers a slower speech rate tended to slow down some segments more than others, but no attempt was made to normalize the duration measurements for speech rate differences, because the variations were apparently unsystematic.

Formant frequencies were measured from wide band spectrograms for all tokens, both immediately before and after the consonant closure. Since women usually have smaller vocal tracts and therefore higher frequency formant values than men, an attempt was made to normalize across sex differences. Instead of using the measured formant transition values for comparison, the difference was calculated between the transition values and the average steady-state vowel formant value for each speaker ([a] for the French speakers, [æ] for the English speakers). These steady-state measurements were taken from the environments least likely to be influenced by neighboring consonants, as in the word-initial [a] of "à ma dame" [a ma dam] for French and the [æ] immediately following [h] in English "Pa has" [pa hæz]. The resulting numbers were therefore negative if the transition value was lower than the steady-state value and positive if the transition value was higher. The tokens were further separated into preconsonantal and postconsonantal groups, since there was often a difference between transitions going in and coming out of the consonants in question. The preconsonantal group was drawn from the word-final consonant tokens and the postconsonantal group from the word-initial tokens.

Laterals were considered separately, since their effect on formant frequencies was expected to be very different from the other consonants. Instead of measuring transitions, which were often difficult to pinpoint, measurements were made of the formant structure of the laterals themselves, to test various hypotheses in the literature.

Direct comparison between the formant frequency data of the French speakers and that of the English speakers was possible for F1, F3 and F4, due to the similarity in formant values of the adjacent vowel in the two languages. Table 3.1 gives the mean steady-state formant values of the low vowel for male and female speakers in both languages. It can be seen that with the exception of the second formant value, the two vowels have nearly identical formant frequencies.

Table 3.1. Mean vowel formant values in the French and English data.

	French [a]		English [æ]	
	male	female	male	female
F1	685	815	720	805
F2	1385	1560	1645	1990
F3	2480	2790	2470	2780
F4	3740	4010	3680	4050

FFT power spectra were made of the release transients of the stop consonants, excluding, if possible, all of the frication noise, as shown in Figure 3.1. The spectra were made on a Kay DSP Sonagraph using a sampling rate of 20,480 samples/sec, and a bandwidth of 300 Hz. Cursors were placed on either side of the release transient and the average spectrum of the entire area covered was calculated. The same system was used to obtain power spectra of the middle sections of the fricative consonants, the size of the area covered varying according to the length of the fricative. In this case, care was taken not to include the outer edges of the fricative which might carry transitional information influenced by the surrounding vowels.

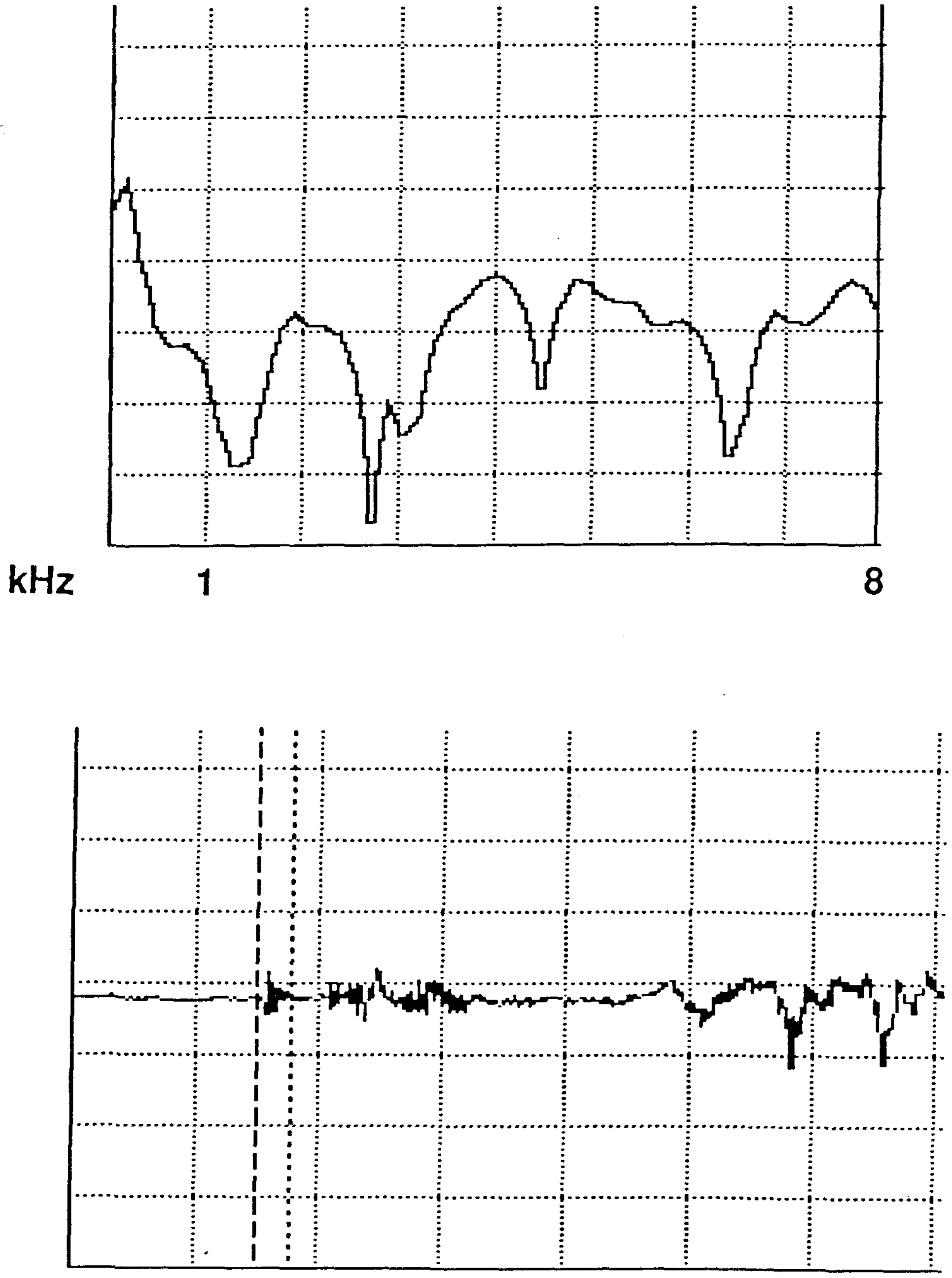


Figure 3.1. Sample window placement over burst transient for spectral analysis.

Figure 3.2 illustrates the method of marking the fricative portion to be analyzed.

Results

In the first section below, each segment type in French and English will be discussed separately beginning with fricatives and going from there to stops and nasals and finally laterals. Within the topics of fricatives on the one hand, and stops and nasals on the other, the results will be first discussed in terms of place of articulation differences and then in terms of apicality differences. Following the sections discussing the French and English data is a section on languages with contrastive segments, where the Malayalam and 'O'odham data will be presented.

3.2 Results: Non-contrastive segments: French and English

3.2.1 Fricatives: Place of articulation

Three places of articulation are represented in the French and English fricative data: dental, alveolar and postalveolar. The cutoff between alveolar and postalveolar was put between place categories 4 and 5 for fricatives, because that is where the acoustic change appeared to take place for most speakers. In the following sections, the acoustic differences between the three place categories will be discussed for both apical and laminal fricatives.

Stricture duration

One factor, repeated measures analyses of variance showed that significant differences in stricture duration (in each case $p \leq .0001$) exist between the initial and final, and between the voiced and voiceless fricatives in the data. This is mainly due to the French, since English has much less difference in these variables. Tables 3.2 and 3.3 give the means, standard deviations and token counts for each category in each place of articulation for the two languages.

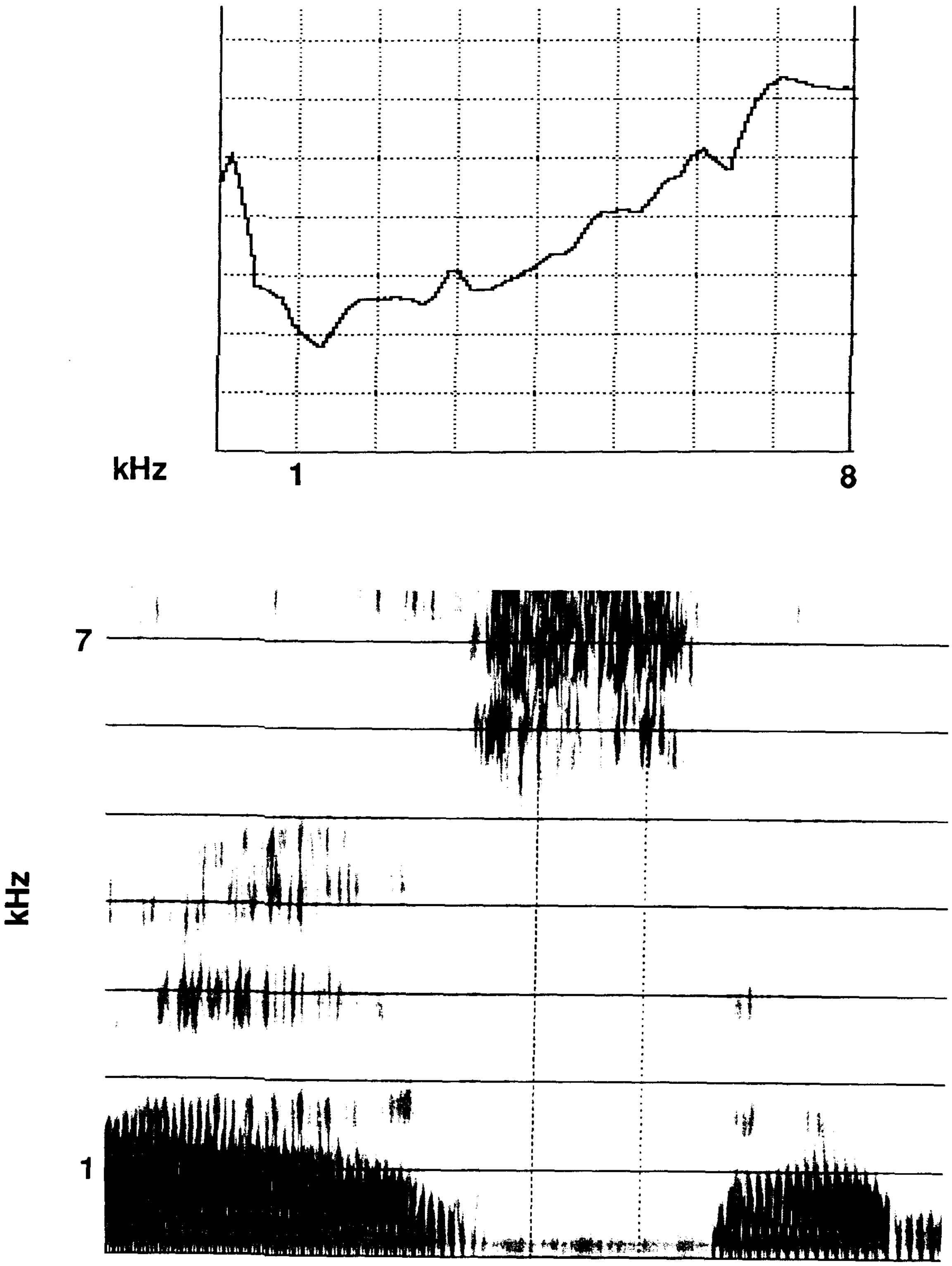


Figure 3.2. Sample window placement for spectral analysis in fricatives.

Table 3.2. Stricture duration (in msec) for fricatives in different places of articulation in French.

	#S	S#	#Z	Z#
Dental				
mean	125	235	90	125
s.d.	26	40	9	9
count	9	6	8	9
Alveolar				
mean	125	220	100	130
s.d.	32	50	26	42
count	6	9	7	7
Postalveolar				
mean	105	210	75	100
s.d.	4	35	16	20
count	4	4	4	3

Table 3.3. Stricture duration (in msec) for fricatives in different places of articulation in English.

	#S	S#	#Z	Z#
Dental				
mean	185	215	145	160
s.d.	28	52	28	42
count	5	5	4	4
Alveolar				
mean	155	180	130	130
s.d.	40	47	29	21
count	11	10	12	10
Postalveolar				
mean	175	180	140	130
s.d.	41	33	24	24
count	4	5	4	6

In French, the tendency is for postalveolar fricatives to have the shortest durations and in English, postalveolars and alveolars are about the same length with dentals somewhat longer. These tendencies were not, however, statistically significant.

Formant transitions

F1

Consistent place of articulation differences in F1 values were observed only in apical fricative articulations, but the direction of these differences varied according to language. Table 3.4 gives the mean difference in Hertz between transition F1 values both before and after the consonant and the value of F1 during the steady state vowel for each speaker in each language.

Table 3.4. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F1 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value.

French

	-S	S-	-Z	Z-
Apical				
dental	-90 (3)	-215 (3)	-275 (3)	-300 (3)
alveolar	-175 (1)	-250 (2)	-600 (1)	-365 (2)
postalveolar	+50 (1)	-150 (1)	-250 (2)	-250 (1)
Laminal				
dental	-325 (3)	-255 (6)	-330 (6)	-400 (5)
alveolar	-270 (8)	-250 (4)	-390 (6)	-365 (5)
postalveolar	-215 (3)	-325 (2)	-425 (1)	-400 (3)

English

	-S	S-	-Z	Z-
Apical				
dental	+25 (4)	-290 (4)	-395 (4)	-370 (4)
alveolar	+70 (4)	-200 (5)	-320 (4)	-255 (5)
postalveolar	-----	-----	-----	-----
Laminal				
dental	0 (1)	-300 (1)	-----	-----
alveolar	+35 (6)	-195 (6)	-370 (6)	-360 (7)
postalveolar	+30 (5)	-225 (4)	-350 (6)	-315 (4)

Since F1 values varied significantly between voiced and voiceless fricatives, these are given separately. In the French data, the apical alveolar fricatives had the lowest F1 values, the dentals somewhat higher and the postalveolars the highest F1. The F1 values in the case of these fricatives are assumed to be due mainly to differences in pharynx width, and not to jaw opening or constriction area. It is crucial for all obstacle fricatives, irrespective of their place of articulation or apicality that the upper and lower incisors be approximated, and constriction length was found to vary only minimally in fricatives. These results would indicate that the apical postalveolars have the narrowest pharynx, meaning that the root of the tongue was retracted along with the tip. *The relation between the F1 of dental and alveolar apical fricatives does not follow* the tongue tip placement and indicates that the body of the tongue behind the constriction and therefore the tongue root may have a different shape in the two articulations, with the apical alveolar fricatives having the wider pharynx. In English, however, the reverse is true, with alveolars having consistently higher F1 values than dentals, giving a straightforward relationship between the postion of the tongue tip and that of the tongue root.

Another language-specific difference to note in the F1 values is the fact that in nearly every case the French F1 value is lower than that of the English, suggesting that a wider pharynx is typical of French /s/ and /z/ production. Language differences will be summarized and discussed in section 3.5.7.

F2

Table 3.5 gives the mean differences between transition F2 values and those of the steady-state vowel.

Table 3.5. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F2 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Apical				
dental	+155 (6) 3	+105 (6) 3	-245 (8) 4	-165 (8) 4
alveolar	+340 (2) 1	+120 (4) 3	-240 (8) 4	-125 (10) 5
postalveolar	+100 (3) 2	+140 (3) 2	--------	--------
Laminal				
dental	+115 (9) 6	+55 (11) 6	-200 (1) 1	-50 (1) 1
alveolar	+100 (14) 10	+110 (9) 6	-220 (12) 7	-60 (13) 8
postalveolar	+140 (4) 3	+10 (5) 3	-160 (11) 6	-100 (8) 5

Recall that F2 values were quite different in the French and English vowels, so inter-language comparisons are difficult. Within each language the relation between F2 and place of articulation varies, with F2 tending to be higher in French alveolars than dentals, and very little F2 difference in English between these two places of articulation. If the F2 value is associated with the height of the tongue behind the constriction, it would appear that French alveolar fricatives have a higher tongue position than dentals, perhaps contributing to the wider pharynx hypothesized above, since if the body of the tongue is pulled upwards towards the hard palate, it would naturally pull away from the pharyngeal wall, unless a specific effort was made to keep it there, as in the case of pharyngealized sounds.

F3 and F4

Table 3.6. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F3 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Apical				
dental	+145 (6) 3	+155 (6) 3	+65 (8) 4	+70 (8) 4
alveolar	+165 (2) 1	+5 (4) 3	+90 (8) 4	+35 (10) 5
postalveolar	+230 (3) 2	+175 (3) 2	--------	--------
Laminal				
dental	+125 (9) 6	+115 (11) 6	+100 (1) 1	-100 (1) 1
alveolar	+35 (14) 10	+75 (9) 6	+100 (12) 7	+55 (13) 8
postalveolar	-70 (4) 3	-30 (5) 3	+125 (11) 6	+90 (8) 5

Table 3.7. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F4 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Apical				
dental	+380 (5) 3	+350 (5) 3	+115 (6) 3	+190 (6) 4
alveolar	+475 (2) 1	+200 (4) 3	+185 (5) 3	+165 (6) 4
postalveolar	+430 (3) 2	+150 (3) 2	--------	--------
Laminal				
dental	+485 (9) 6	+460 (11) 6	+150 (1) 1	+250 (1) 1
alveolar	+315 (14) 10	+415 (8) 6	+120 (10) 6	+95 (10) 6
postalveolar	+220 (4) 3	+30 (5) 3	+145 (9) 5	+200 (6) 4

As can be seen in Tables 3.6 and 3.7, the pattern is nearly the same for F3 and F4 in both languages: dental fricatives have higher transition values for these formants than alveolars, except for apical preconsonantal transitions, where the values are reversed. In the two cases where the English data deviates from this pattern (F3 for laminals) the dental fricatives are represented by only one token each. The higher values for dentals are easily explained by the fact that dentals, being farther forward, would normally have smaller (if any) sublingual cavities than alveolars. It is odd that this relationship is so consistently reversed during the approach to an apical constriction, especially because the apical dentals, if they are indeed sublaminal as hypothesized earlier, should fill up even more of the cavity.

Spectra

Representative spectra from initial /S/ in the three places of articulation are given in Figures 3.3-3.6 for French and English. In both languages, the spectrum of the apical alveolar fricative starts to rise at a slightly lower frequency than the apical dental fricative spectrum. For French apical postalveolars, the rise in amplitude occurs at a still lower frequency and there is less of an amplitude difference between the low and high frequency spectrum. Individual variation will be discussed in the next section.

In laminals, the dental-alveolar difference is more striking and more consistent from one speaker to another. The laminal alveolar spectrum in both languages is very flat and has no high frequency peak, such as that found in the laminal dentals. The spectra of laminal postalveolars in French are very like those of the alveolars, except that they have more energy in the 7-8000 Hz region. In English, the laminal postalveolars also have more energy in the high frequencies than the alveolars, but this rise in amplitude begins much lower, between 3000 and 4000 Hz. This is perhaps due to the comparatively wider channel for frication found in the English postalveolars.

3.2.2 Fricatives: Apical vs. laminal

Stricture duration

Tables 3.8 and 3.9 give the means, standard deviations and token counts for stricture duration in all apical and laminal fricative tokens in the French and English data.

Table 3.8. Means, standard deviations and token counts for stricture duration in apical and laminal fricatives in French.

	#S	S#	#Z	Z#
Apical				
mean	110	210	80	120
s.d.	21	35	13	19
count	7	5	6	6
Laminal				
mean	130	220	95	125
s.d.	25	44	21	32
count	12	14	13	13

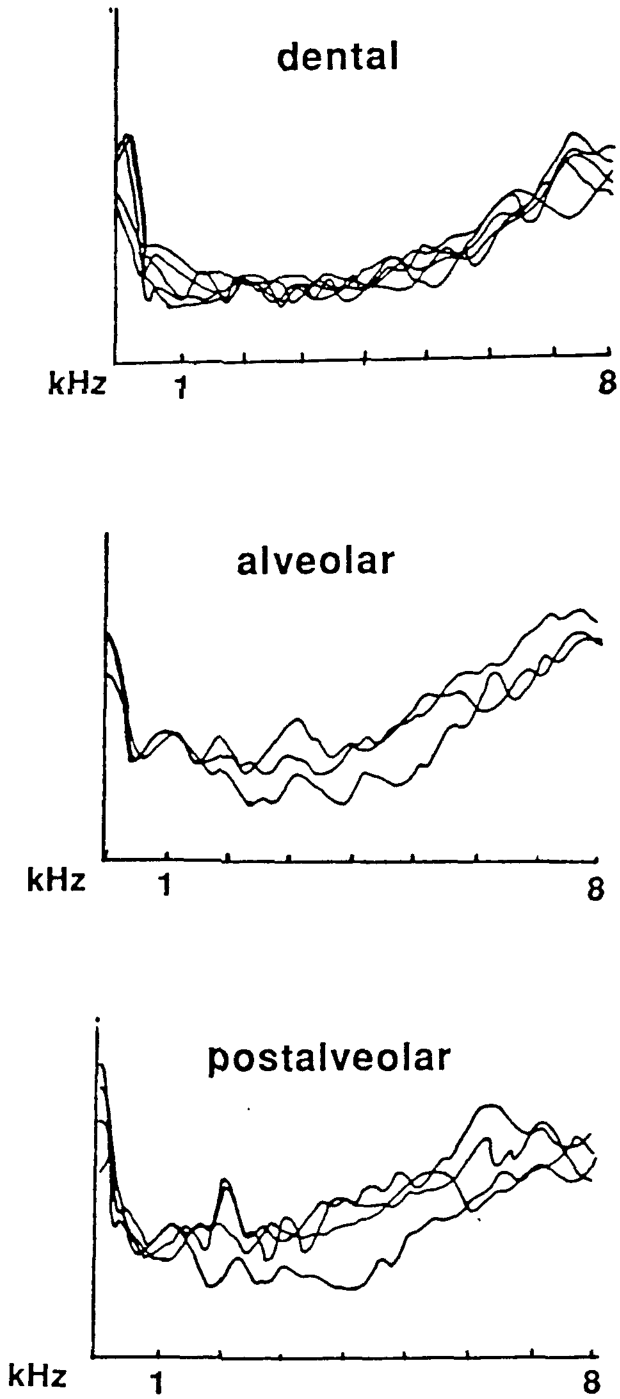


Figure 3.3. Spectra of apical /s/ in three places of articulation in French.

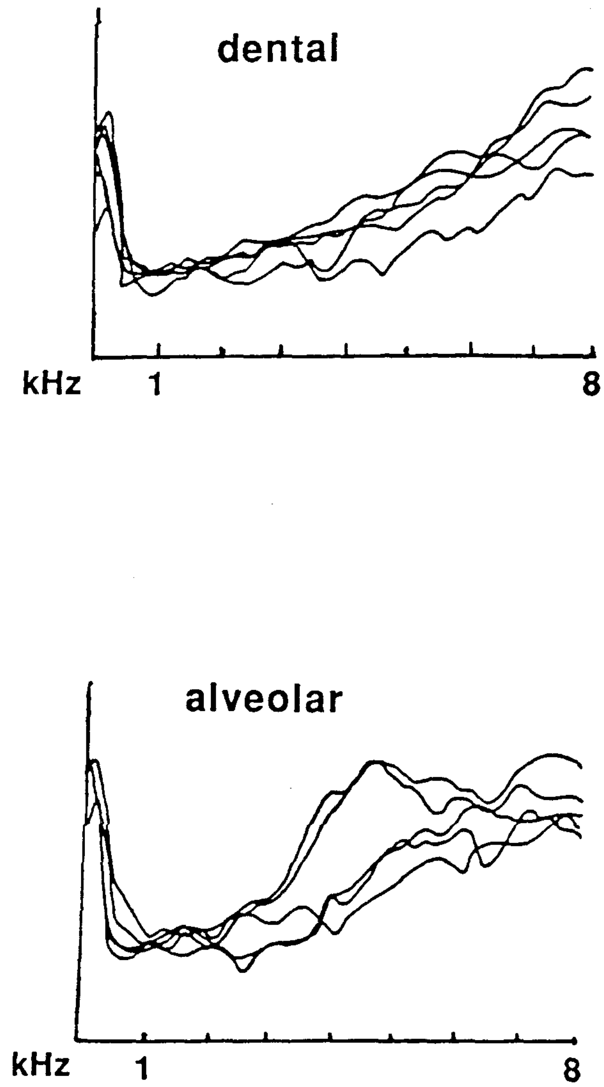


Figure 3.4. Spectra of apical /s/ in two places of articulation in English.

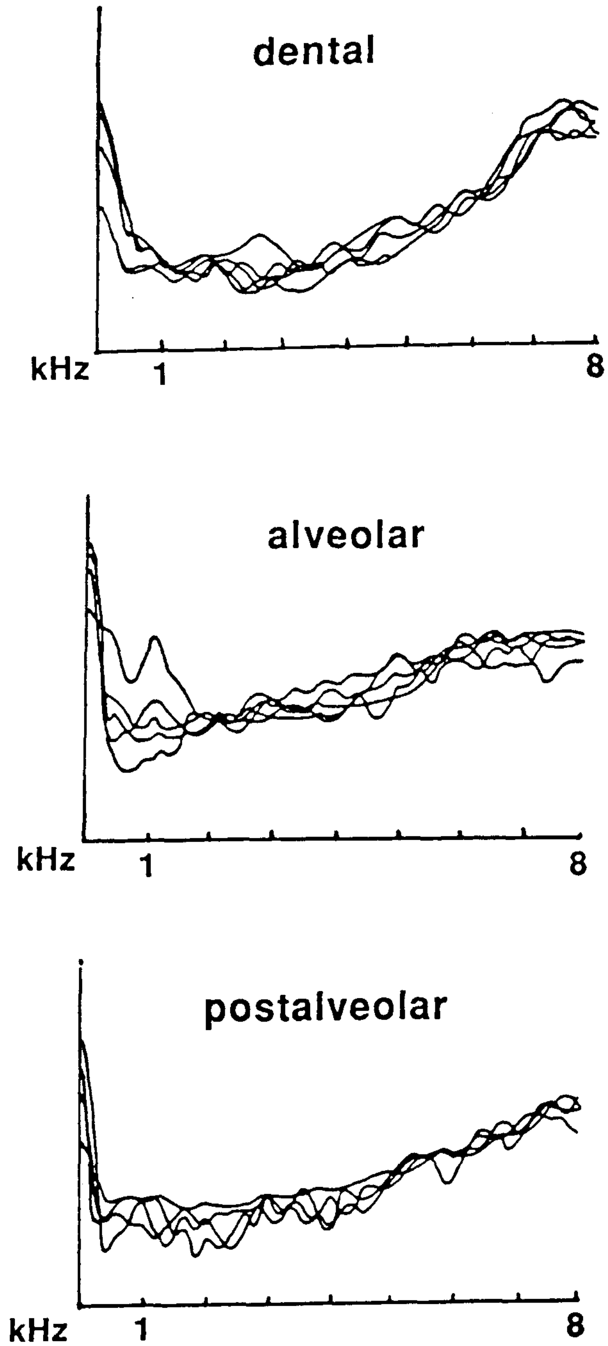


Figure 3.5. Spectra of laminal /s/ in three places of articulation in French.

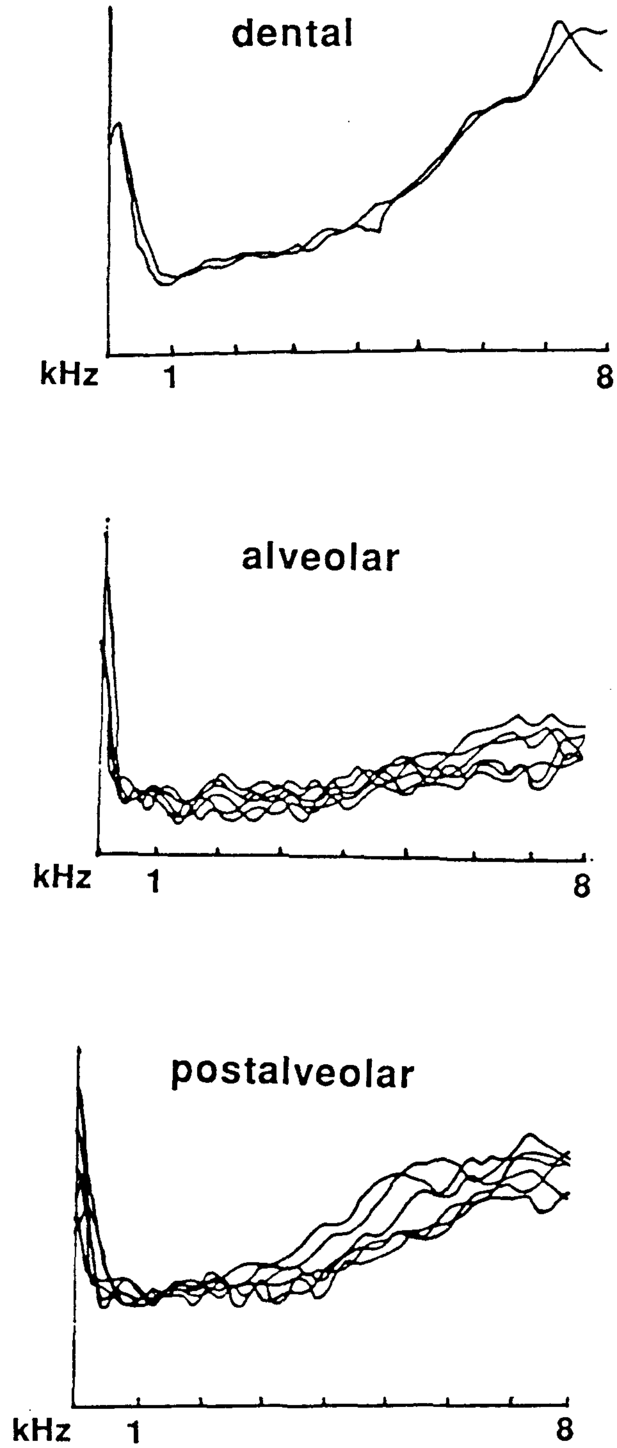


Figure 3.6. Spectra of laminal /s/ in three places of articulation in English.

Table 3.9. Means, standard deviations and token counts for stricture duration in apical and laminal fricatives in English.

	#S	S#	#Z	Z#
Apical				
mean	165	185	130	140
s.d.	44	55	32	37
count	9	8	9	8
Laminal				
mean	170	190	140	135
s.d.	35	40	24	23
count	11	12	11	12

It is clear from the tables that laminal fricatives tend to be slightly longer on the average than apical fricatives, although this difference was not large enough to be statistically significant.

Formant transitions

F1

Comparing the first formant values in apical and laminal fricative transitions (Table 3.10), there is a definite tendency for laminals in both languages to have lower values than apicals in the same place of articulation. This is particularly true in preconsonantal transitions, the one exception being before French alveolar /Z/, where the apical value is taken from only one token and is unusually low. The lower laminal F1 values support the notion that the pharynx is wider during laminal articulations. This difference, however regular, is far smaller in English than in French and perhaps should not be considered a real difference at all for that language.

Table 3.10. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F1 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value.

French	-S	S-	-Z	Z-
Dental				
apical	-90 (3)	-215 (3)	-275 (3)	-300 (3)
laminal	-325 (3)	-255 (6)	-330 (6)	-400 (5)
Alveolar				
apical	-175 (1)	-250 (2)	-600 (1)	-365 (2)
laminal	-270 (8)	-250(4)	-390 (6)	-365 (5)
Postalveolar				
apical	+50 (1)	-150 (1)	-250 (2)	-250 (1)
laminal	-215 (3)	-325 (2)	-425(1)	-400 (3)

English	-S	S-	-Z	Z-
Dental				
apical	+25 (4)	-290 (4)	-395 (4)	-370 (4)
laminal	0 (1)	-300 (1)	-----	-----
Alveolar				
apical	+70 (4)	-200 (5)	-320 (4)	-255 (5)
laminal	+35 (6)	-195 (6)	-370 (6)	-360 (7)
Postalveolar				
apical	-----	-----	-----	-----
laminal	+30 (5)	-225 (4)	-350 (6)	-315 (4)

F2

The mean differences in F2 given in Table 3.11 show that, in French, apicals nearly always have higher F2 values than laminals although the difference is not always very great. The opposite result is found in English, where it is the laminals which have the higher F2 values. These inter-language differences will be discussed in detail in section 3.5.7.

Table 3.11. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F2 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Dental				
apical	+155 (6) 3	+105 (6) 3	-245 (8) 4	-165 (8) 4
laminal	+115 (9) 6	+55 (11) 6	-200 (1) 1	-50 (1) 1
Alveolar				
apical	+340 (2) 1	+120 (4) 3	-240 (8) 4	-125 (10) 5
laminal	+100 (14) 10	+110 (9) 6	-220 (12) 7	-60 (13) 8
Postalveolar				
apical	+100 (3) 2	+140 (3) 2	--------	--------
laminal	+140 (4) 3	+10 (5) 3	-160 (11) 6	-100 (8) 5

F3 and F4

An increase in the cavity in front of the constriction should cause a lowering of F3 and F4, and it seems reasonable to suppose that at any given place of articulation, an apical tongue contact would create a larger sublingual cavity than a laminal contact, since the part of the tongue in front of the constriction in a laminal (the tip) would inevitably fill some of the space in the front of the mouth, thereby reducing the cavity size. The F3 values reflect this in the French data, but not in the English fricative transitions. The F4 values in Table 3.13, however, are more consistent and it can be seen that a higher F4 in laminals only occurs in the dental sibilants in the present study. As the constriction moves back in the mouth, it is most often the apicals which have the higher F4 values and therefore presumably the smaller front cavities than the laminals. The tip of the tongue, although making no palate contact during the laminal articulation, must therefore be raised in the front of the mouth, as suggested by Keating (1990), rather than placed down behind the lower incisors. In the case of dentals, however, if the blade of the tongue is touching the upper incisors there is nowhere for the tip to go but down, thereby decreasing the sublingual cavity. This pattern was more evident in French than in English, where the difference in F4 value between apicals and laminals was much smaller.

Table 3.12. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F3 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Dental				
apical	+145 (6) 3	+155 (6) 3	+65 (8) 4	+70 (8) 4
laminal	+125 (9) 6	+115 (11) 6	+100 (1) 1	-100 (1) 1
Alveolar				
apical	+165 (2) 1	+5 (4) 3	+90 (8) 4	+35 (10) 5
laminal	+35 (14) 10	+75 (9) 6	+100 (12) 7	+55 (13) 8
Postalveolar				
apical	+230 (3) 2	+175 (3) 2	--------	--------
laminal	-70 (4) 3	-30 (5) 3	+125 (11) 6	+90 (8) 5

Table 3.13. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F4 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-S, -Z	S-, Z-	-S, -Z	S-, Z-
Dental				
apical	+380 (5) 3	+350 (5) 3	+115 (6) 3	+190 (6) 4
laminal	+485 (9) 6	+460 (11) 6	+150 (1) 1	+250 (1) 1
Alveolar				
apical	+475 (2) 1	+200 (4) 3	+185 (5) 3	+165 (6) 4
laminal	+315 (14) 10	+415 (8) 6	+120 (10) 6	+95 (10) 6
Postalveolar				
apical	+430 (3) 2	+150 (3) 2	--------	--------
laminal	+220 (4) 3	+30 (5) 3	+145 (9) 5	+200 (6) 4

It will also be observed that, with the exception of postconsonantal postalveolar tokens, the F4 values of all fricative articulations in French were quite a bit higher than the corresponding English values. Since the steady-state vowel formant values were not different in the two languages, the F4 values would suggest that the sublingual cavity in French is always smaller than that in English.

Spectra

Figures 3.7-3.9 give representative spectra of apical and laminal fricatives in each place of articulation for both languages. In the dental fricatives the spectrum of the laminal articulation has a steeper slope and rises higher in the high frequencies. In the alveolars, it is the apicals which have the greater amount of high frequency energy, the laminals having an essentially flat spectrum. This may be what Bright (1978) meant when he referred to apical fricatives as having a "whistling" quality (also mentioned by Catford 1977). The French apical postalveolars are not consistently different from the laminal postalveolars, which may be partly due to the relatively large amount of individual variation in apical alveolars and postalveolars. Some of the variation in the fricative spectrum in this area of the mouth may stem from the precise slope of the individual's palate and the presence or absence of a prominent alveolar ridge, which could have an effect on the frequency of the fricative noise.

There is one example in the data of a single speaker with two very different fricative articulations, as mentioned in the last chapter. This (English) speaker had word-initial apical alveolar /s/ in "sap" and word-final laminal postalveolar /s/ in "pass". Spectra from the two tokens of each utterance are given in Figure 3.10, with the solid lines representing the laminal postalveolar articulation and the dotted lines the apical alveolar articulation. The chief difference appears to be more energy in the higher frequencies of the apical /s/, which was also the general case for apical vs. laminal alveolars. The presence of a high amplitude peak around 5000 Hz. in the laminal postalveolar distinguishes it from the flat spectrum of the laminal alveolars, and, as we will see, is more like that found in the postalveolar /ṣ/ in 'O'odham, than any of the French or English tokens. This fricative, indeed, had auditorily more of a 'hushing' quality than the same speaker's apical fricative, although still being clearly an /s/. This is probably due to the wide channel through which the air passed (18 mm as opposed to a 3.5 mm channel in this speaker's apical alveolar /s/), thereby lowering the velocity of the turbulent airflow and the frequency of the spectrum. Fletcher and Newman (1991) report that sibilants with wider channels are more often heard as /ʃ/ than /s/.

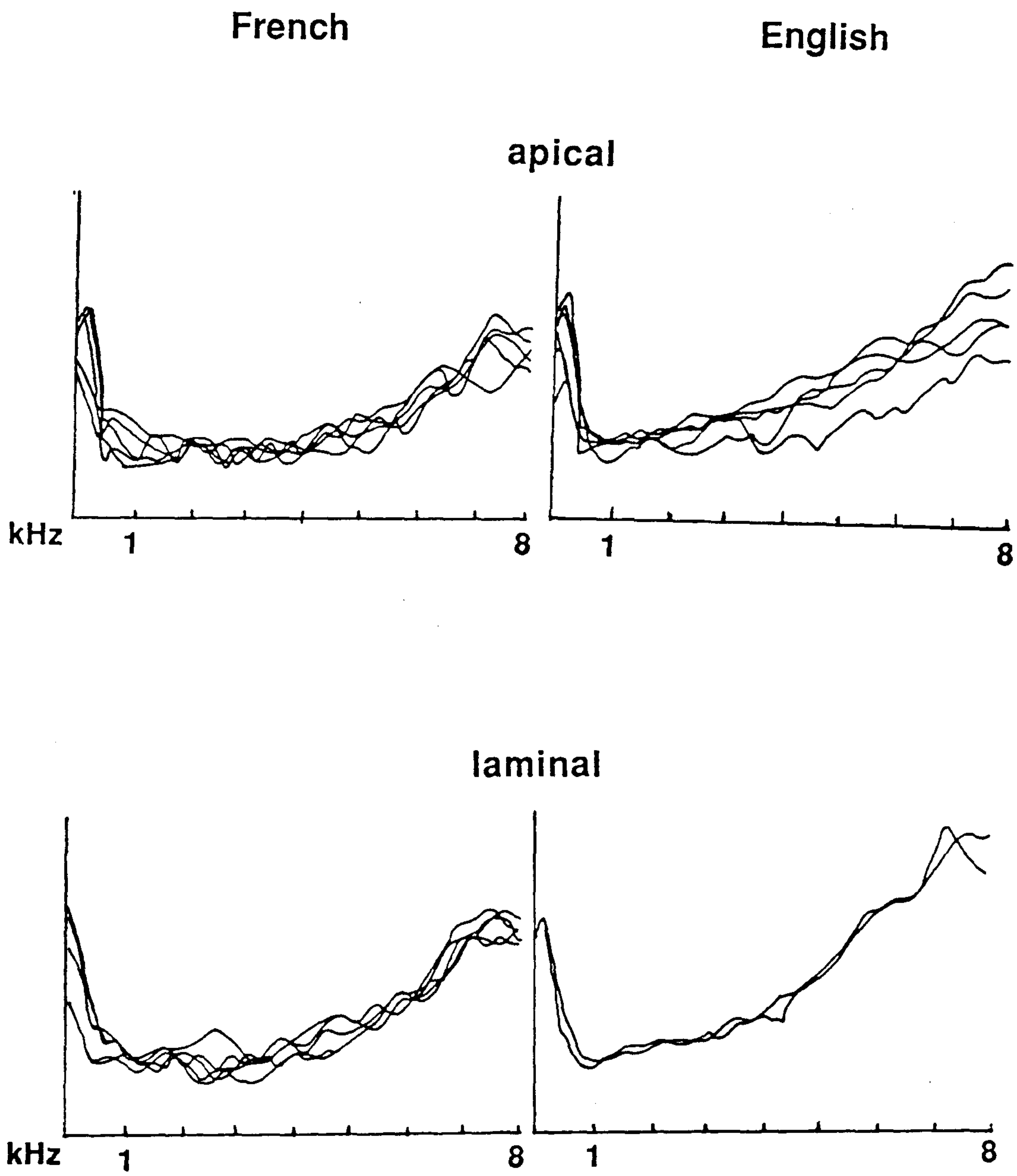


Figure 3.7. Spectra of apical and laminal dental fricatives in French and English.

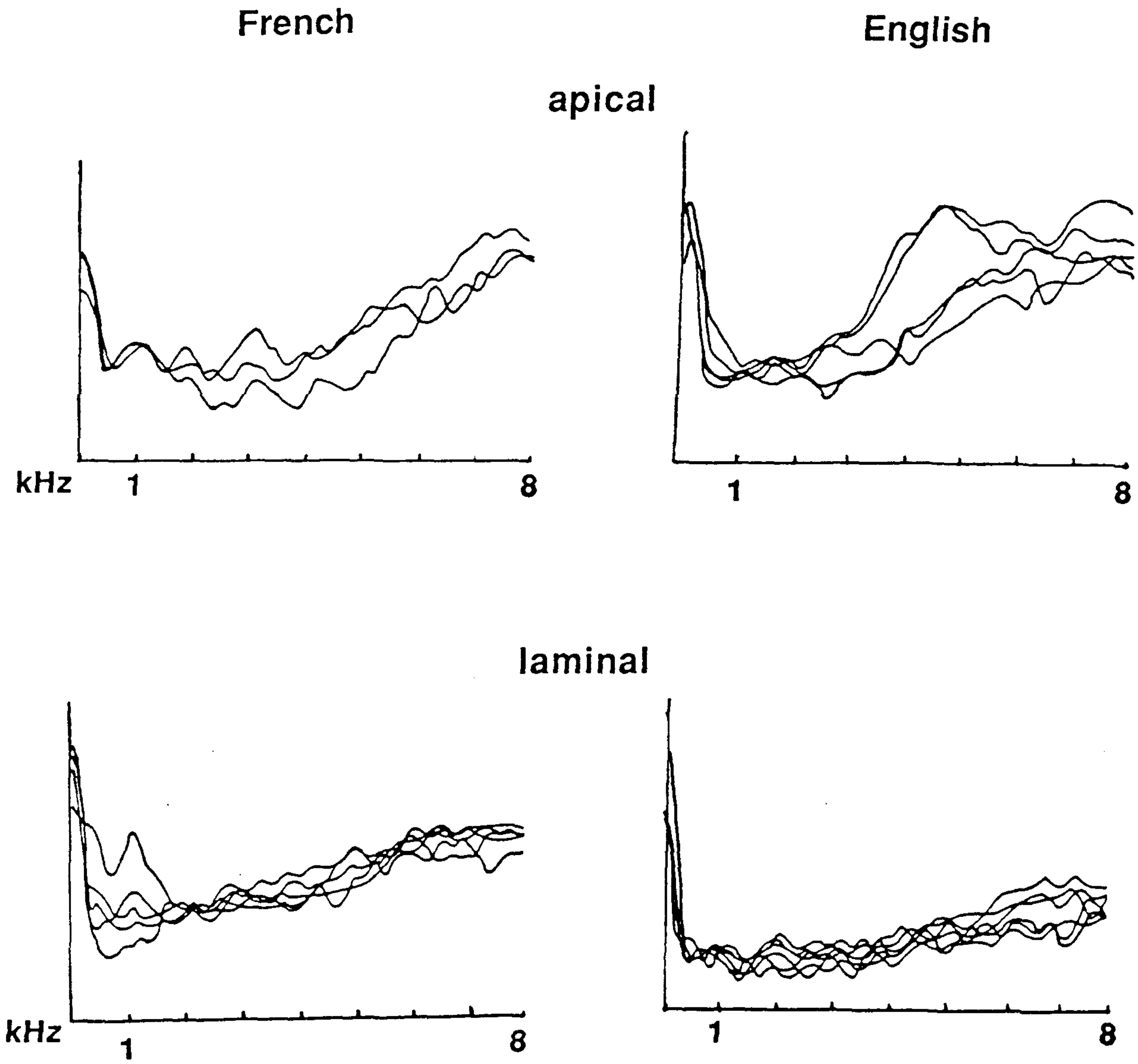


Figure 3.8. Spectra of apical and laminal alveolar fricatives in French and English.

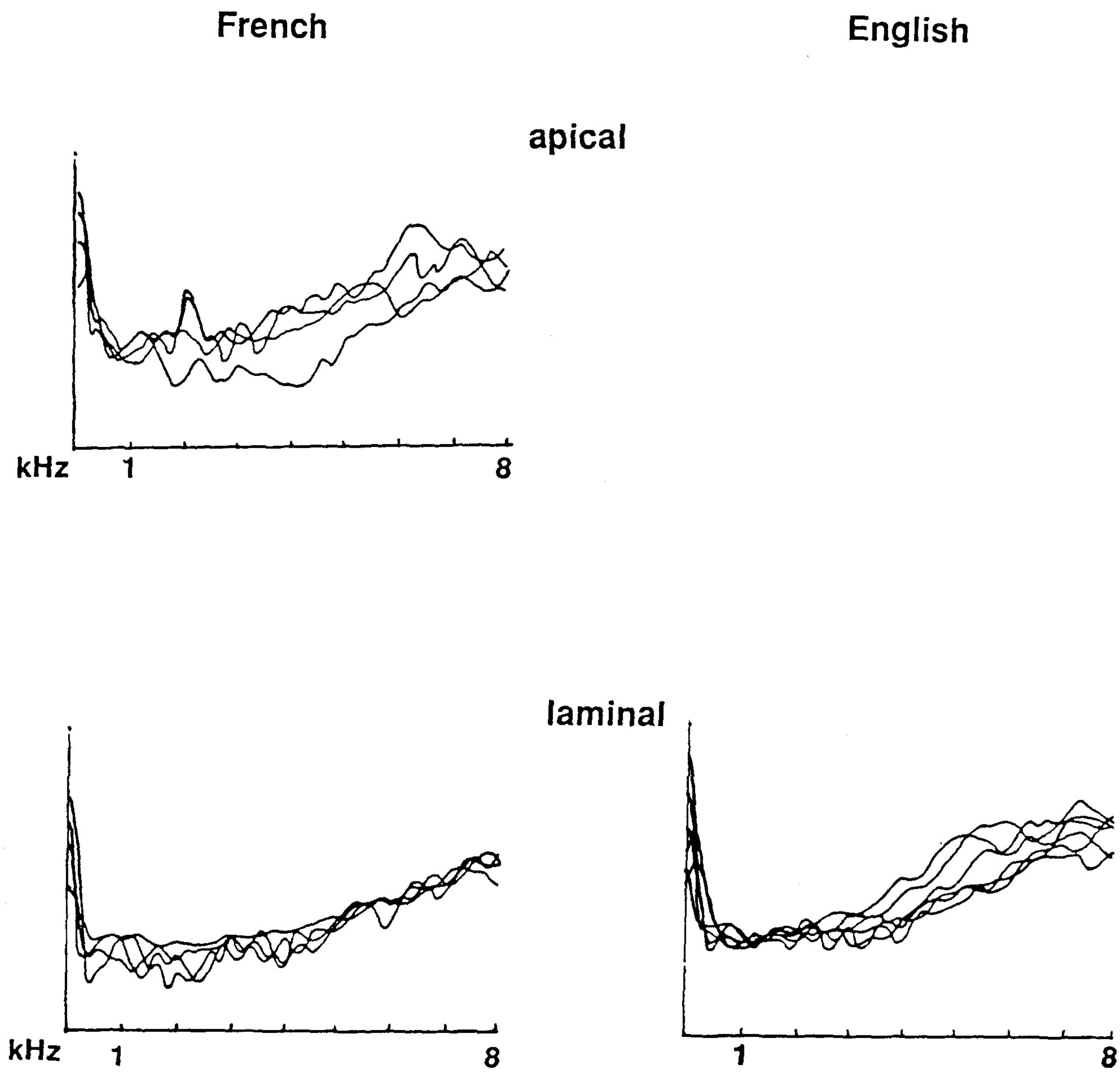


Figure 3.9. Spectra of apical and laminal postalveolar fricatives in French and English.

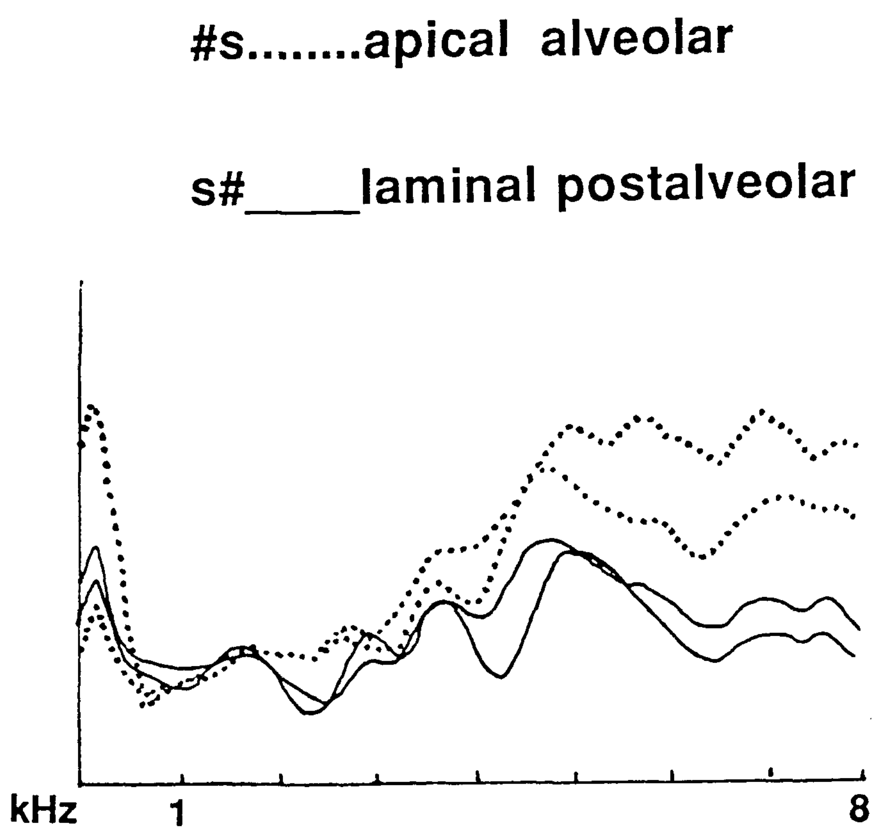


Figure 3.10. Spectra of one speaker's word-initial apical alveolar /s/ and word- final laminal postalveolar /s/ in English.

3.2.3 Stops and nasals: Place of articulation

The acoustic data for the stops and nasals is presented in the same order as that in the preceding section for fricatives.

Closure duration

There were no consistent differences between the closure duration of dental, alveolar or postalveolar /t,d,n/ in the French and English data.

Voice onset time

Table 3.14 gives the VOT means, standard deviations and token counts for initial /t/ in two places of articulation.

Table 3.14. Voice onset time (in msec) for dental and alveolar word-initial /t/.

	French	English
<u>dental</u>		
mean	19	84
s.d.	7.63	13.36
count	15	6
<u>alveolar</u>		
mean	19	68
s.d.	4.13	17.52
count	6	13

In English, dentals have a tendency towards longer voice onset times than alveolars. A one factor, repeated measures analysis of variance comparing VOT values for dental vs alveolar in English gives a significance level of $.05 < p \leq .10$. There was no difference in French dental and alveolar voice onset times.

Formant transitions

F1

Table 3.15 gives the mean differences in F1 for /t/, /d/ and /n/ in French and English. No consistent pattern of F1 variation due to place of articulation is evident, except perhaps in the case of apicolaminals in both languages. With the exception (in both French and English) of postconsonantal /t/ transitions, the apicolaminal alveolars always have a higher F1 than the apicolaminal dentals. This could mean either that during the dental occlusion the pharynx was wider or the jaw more closed than for the corresponding alveolar. Recall that this same tendency was noted in English apical fricatives, although the contrary was true in French.

Table 3.15. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F1 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value.

French

	-t	t-	-d	d-	-n	n-
Apical						
dental	-275 (1)	-515 (2)	-365 (1)	-340 (2)	-250 (1)	-250 (1)
alveolar	-365 (2)	-475 (2)	-475 (3)	-565 (3)	-225 (3)	-215 (4)
postalveolar	-----	-----	-----	-----	-----	-----
Apicolaminal						
dental	-285 (8)	-205 (10)	-375 (7)	-380 (8)	-240 (7)	-205 (8)
alveolar	-215 (3)	-225 (1)	-300 (5)	-315 (3)	-200 (1)	-150 (1)
postalveolar	-----	-----	-----	-----	-----	-----
Laminal						
dental	-170 (3)	-235 (3)	-440 (2)	-415 (2)	-165 (2)	-225 (4)
alveolar	-280 (4)	-240 (3)	-320 (3)	-325 (3)	-165 (6)	-225 (2)
postalveolar	-----	-----	-----	-----	-----	-----

English

	-t	t-	-d	d-	-n	n-
Apical						
dental	-40 (2)	-25 (2)	-250 (1)	-450 (1)	-200 (1)	-75 (1)
alveolar	-55 (10)	-135 (10)	-265 (14)	-340 (12)	-140 (14)	185 (11)
postalveolar	-50 (1)	-75 (1)	-200 (1)	-375 (1)	-----	-215 (2)
Apicolaminal						
dental	-125 (1)	-25 (1)	-350 (1)	-----	0 (1)	-175 (1)
alveolar	-100 (1)	-250 (2)	-250 (2)	-365 (3)	-115 (3)	-150 (4)
postalveolar	-----	-----	-----	-----	-----	-----
Laminal						
dental	+50 (1)	-35 (3)	-----	-350 (3)	-----	-150 (1)
alveolar	-10 (3)	-100 (1)	-200 (1)	-----	-50 (1)	-----
postalveolar	-----	-----	-----	-----	-----	-----

F2

In both languages F2 was found to be most often higher in transitions to and from dental stops and nasals than in alveolar transitions (see Table 3.16). The only exceptions to this (French preconsonantal apicals and English postconsonantal apicals and preconsonantal laminals) were cases where one of the categories was represented by only one or two speakers. The higher F2 indicates that dental stops and nasals have a higher tongue position behind the constriction than alveolars, as was true also for English /S/ and /Z/, but not for French fricatives.

Table 3.16. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F2 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Apical				
dental	+120 (3) 1	+285 (5) 3	-50 (4) 2	+30 (4) 2
alveolar	+185 (8) 4	+230 (9) 4	-125 (38) 15	+105 (33) 12
postalveolar	-----	-----	-350 (2) 1	+145 (4) 2
Apicolaminal				
dental	+190 (22) 11	+185 (26) 10	-10 (3) 2	+140 (2) 2
alveolar	+155 (9) 6	+115 (5) 3	-115 (6) 3	+135 (9) 4
postalveolar	-----	-----	-----	-----
Laminal				
dental	+225 (7) 6	+215 (9) 4	-150 (1) 1	+195 (7) 3
alveolar	+135 (13) 7	+165 (8) 6	-60 (5) 3	+25 (1) 1
postalveolar	-----	-----	-----	-----

F3 and F4

Although the F3 values did not appear to change significantly according to place of articulation, F4 transition values were higher in dentals than in alveolars, exactly as was found in the fricative data. This difference was very substantial in French, but so slight as to be nearly negligible in English, indicating that there is a much larger difference in sublingual cavity size between French dentals and alveolars. This was so even though, just from looking at the actual F4 values, it is clear that English tends to have a larger sublingual cavity than French in both dental and alveolar stops and nasals. In both apical and laminal articulations, even the English dentals have lower F4 values than French alveolars.

Table 3.17. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F3 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Apical				
dental	-40 (3) 1	+150 (5) 3	+15 (4) 2	+65 (4) 2
alveolar	+50 (8) 4	+105 (9) 4	+80 (38) 15	+85 (33) 12
postalveolar	-----	-----	-175 (2) 1	-15 (4) 2
Apicolaminal				
dental	+65 (23) 11	+185 (26) 10	+210 (3) 2	+215 (2) 2
alveolar	+145 (9) 6	+20 (5) 3	+110 (6) 3	+105 (9) 4
postalveolar	-----	-----	-----	-----
Laminal				
dental	+165 (7) 6	+150 (9) 4	0 (1) 1	+80 (7) 3
alveolar	+10 (13) 7	+45 (8) 6	+90 (5) 3	+150 (1) 1
postalveolar	-----	-----	-----	-----

Table 3.18. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F4 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Apical				
dental	+350 (3) 1	+435 (5) 3	-65 (3) 1	+150 (2) 1
alveolar	+200 (8) 4	+185 (8) 4	+5 (32) 13	+50 (28) 11
postalveolar	-----	-----	+150 (2) 1	+165 (3) 1
Apicolaminal				
dental	+325 (21) 11	+375 (23) 9	+150 (3) 2	+125 (2) 2
alveolar	+35 (9) 6	-425 (4) 3	+105 (6) 3	+110 (7) 4
postalveolar	-----	-----	-----	-----
Laminal				
dental	+350 (7) 6	+440 (9) 4	+150 (1) 1	+95 (7) 3
alveolar	+210 (13) 7	+160 (8) 6	+130 (5) 3	-----
postalveolar	-----	-----	-----	-----

Spectra

Figures 3.11-3.13 show representative spectra from the burst transients of apical, apicolaminal and dental stops in 2 or 3 places of articulation. In French, the apical dental and alveolar burst transient spectra are nearly identical, except for slightly lower amplitude energy in the lower frequencies of the dental spectrum, which was also

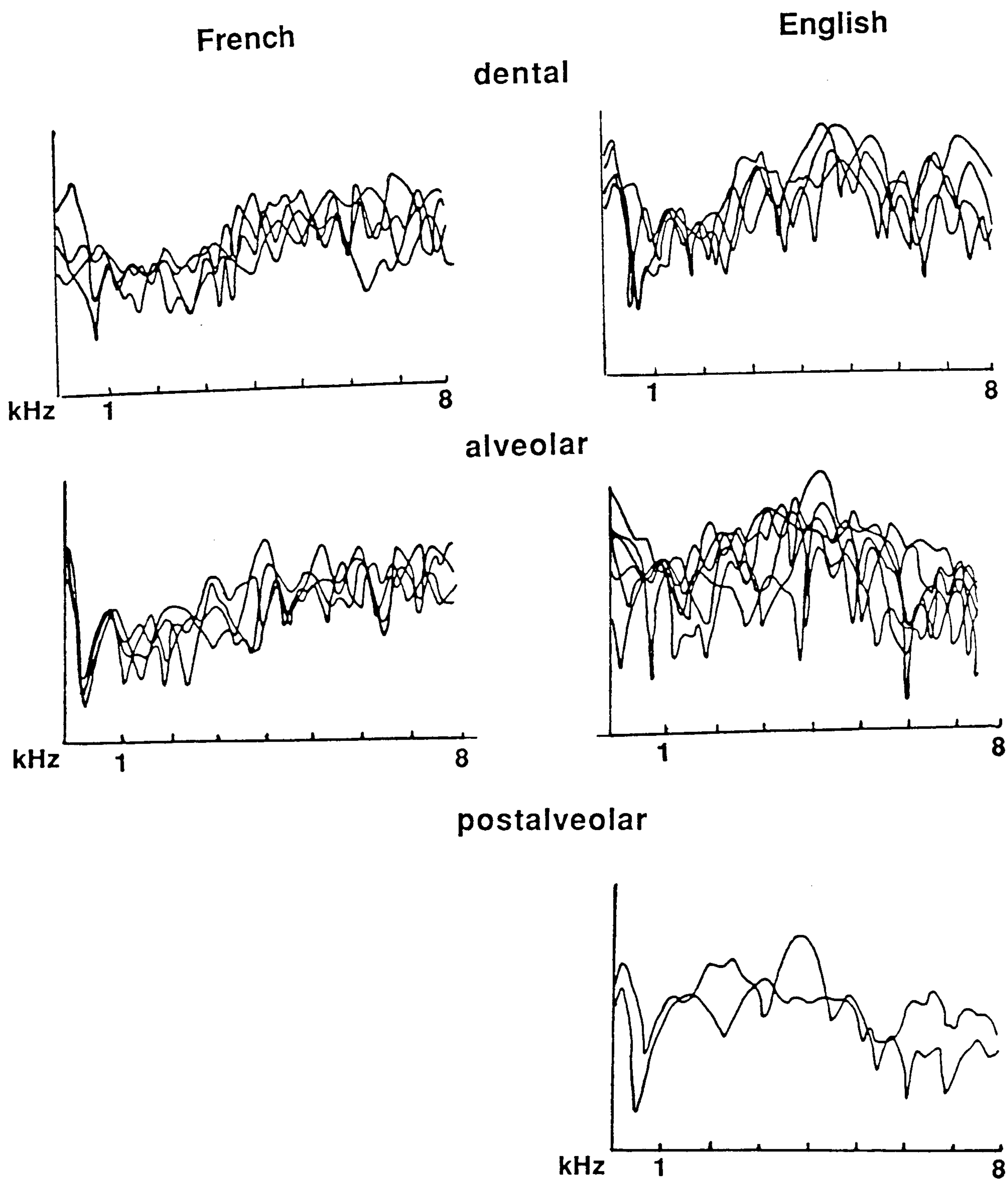


Figure 3.11. Spectra of the burst transients of voiceless apical stops in three places of articulation.

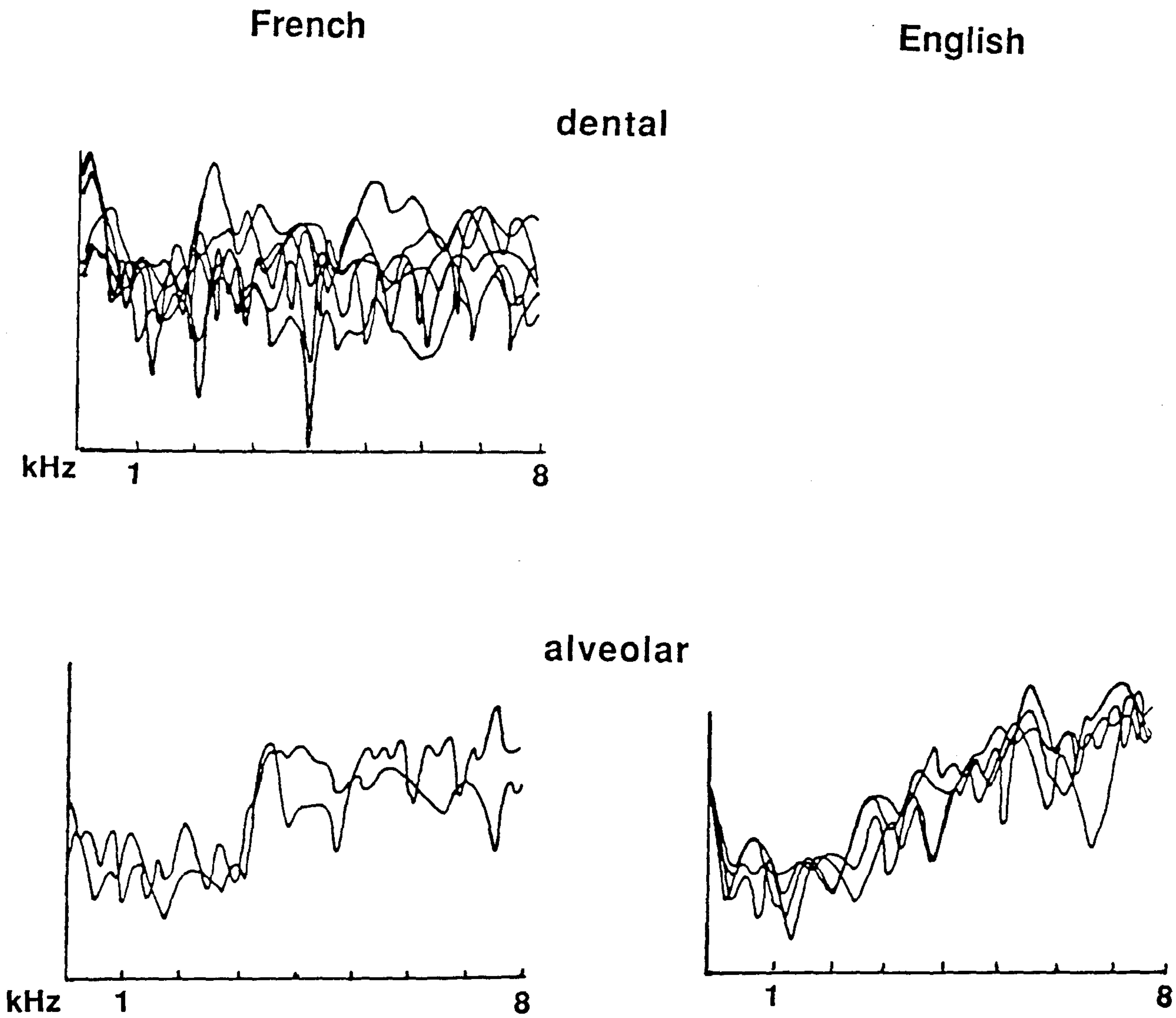


Figure 3.12. Spectra of the burst transients of voiceless apicolaminal stops in two places of articulation.

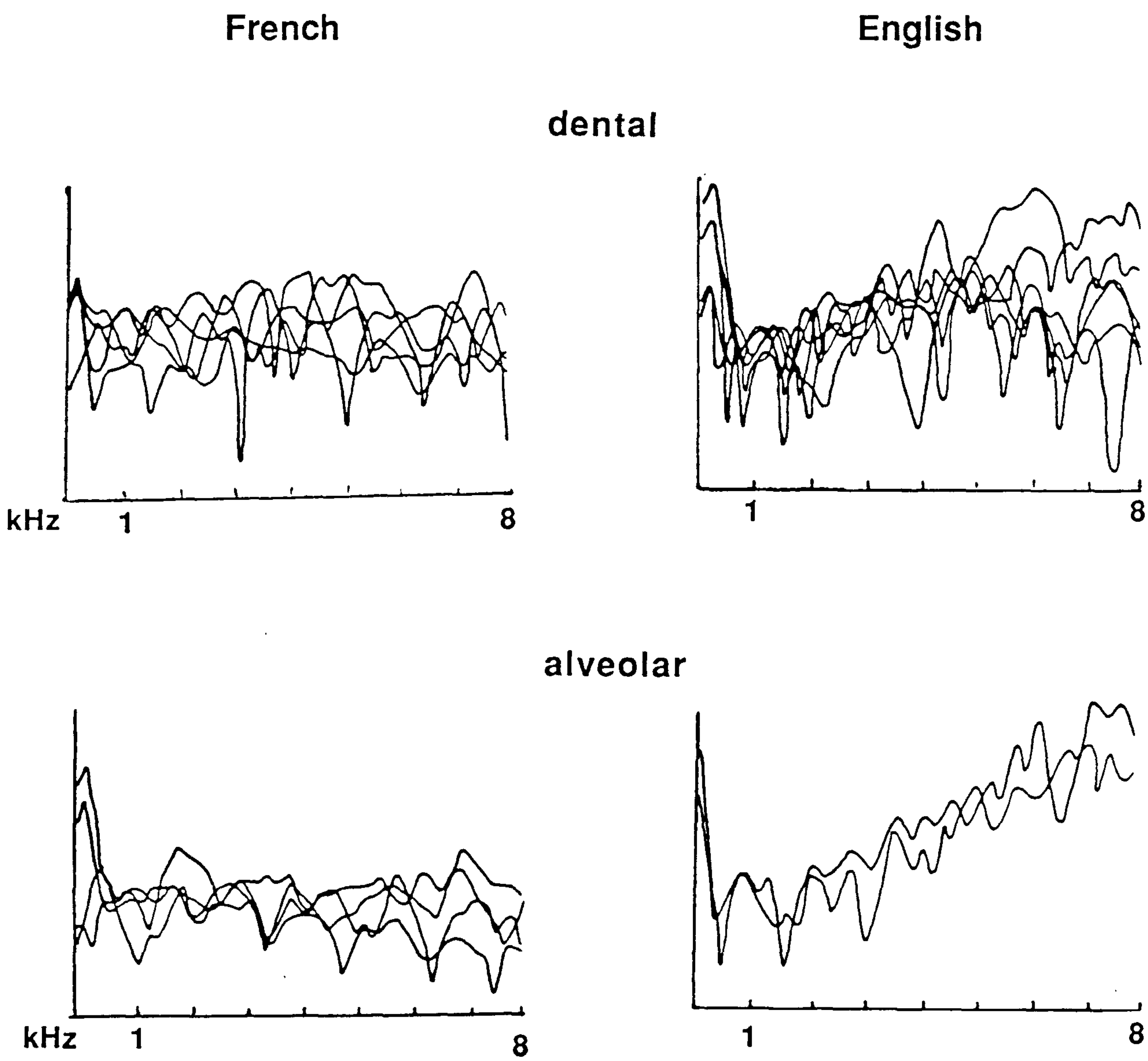


Figure 3.13. Spectra of the burst transients of voiceless laminal stops in two places of articulation.

evident in English. In addition to this, the English apical alveolars had less energy in the higher frequencies of the burst than did the apical dentals. The two tokens of apical postalveolar stop bursts were not different from the alveolars.

The apicolaminal dental stop burst transients in French had an essentially flat spectrum in comparison to the apicolaminal alveolars in both the languages, which had more energy in the frequencies above 3000 Hz.

In French, both the laminal dental and the laminal alveolar stop bursts had flat spectra. This was not the case in English laminals, where the lower frequencies had clearly less energy than the higher frequencies. In the two tokens available of a laminal alveolar in English (from a single speaker) there was also greater amplitude in the high frequencies above 6000 Hz in the alveolar burst.

3.2.4 Stops and nasals: Apical vs. laminal vs. apicolaminal

Closure duration

There were no consistent differences in the closure duration of the three linguagraphic categories of the French and English /t,d,n/ data.

Voice onset time

Table 3.19 gives the means, standard deviations and token counts for voice onset time in the three linguagraphic classifications for English and French word-initial /t/.

Table 3.19. Voice onset time for apical, apicolaminal and laminal word-initial /t/ in English and French in msec.

	French	English
apical		
mean	21	71
s.d.	8.25	20.86
count	4	13
apicolaminal		
mean	16	75
s.d.	7.3	12.2
count	11	3
laminal		
mean	22	89
s.d.	2.19	13.2
count	6	4

Laminal voiceless stops in English have the longest mean VOT, the apicolaminals the next longest and the apicals the shortest. The significance levels, however, are low, and no such pattern is seen in the French data.

Formant transitions

F1

It was hypothesized in the discussion at the beginning of this chapter that laminals would have a lower first formant because of both a wider pharynx and perhaps a smaller jaw opening than apicals. In both English and French, however, most laminal stop and nasal tokens have <u>higher</u> F1 values than the corresponding apical tokens, as can be seen in Table 3.20 below. This is particularly evident in the alveolars and is contrary to the results of the fricative data where laminals had lower F1 values than apicals. In French alveolars, apicolaminals always have a higher F1 value than apicals and usually a higher value than the laminals as well. In English the apicolaminal F1 values are nearly always lower than the laminal values in both dental and alveolar articulations.

Table 3.20. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F1 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value.

<u>French</u>

	-t	t-	-d	d-	-n	n-
<u>Dental</u>						
apical	-275 (1)	-515 (2)	-365 (1)	-340 (2)	-250 (1)	-250 (1)
apicolaminal	-285 (8)	-205 (10)	-375 (7)	-380 (8)	-240 (7)	-205 (8)
laminal	-170 (3)	-235 (3)	-440 (2)	-415 (2)	-165 (2)	-225 (4)
<u>Alveolar</u>						
apical	-365 (2)	-475 (2)	-475 (3)	-565 (3)	-225 (3)	-215 (4)
apicolaminal	-215 (3)	-225 (1)	-300 (5)	-315 (3)	-200 (1)	-150 (1)
laminal	-280 (4)	-240 (3)	-320 (3)	-325 (3)	-165 (6)	-225 (2)
<u>Postalveolar</u>						
apical	-----	-----	-----	-----	-----	-----
apicolaminal	-----	-----	-----	-----	-----	-----
laminal	-----	-----	-----	-----	-----	-----

English

	-t	t-	-d	d-	-n	n-
Dental						
apical	-40 (2)	-25 (2)	-250 (1)	-450 (1)	-200 (1)	-75 (1)
apicolaminal	-125 (1)	-25 (1)	-350 (1)	-----	0 (1)	-175 (1)
laminal	+50 (1)	-35 (3)	-----	-350 (3)	-----	-150 (1)
Alveolar						
apical	-55 (10)	-135 (10)	-265 (14)	-340 (12)	-140 (14)	-185 (11)
apicolaminal	-100 (1)	-250 (2)	-250 (2)	-365 (3)	-115 (3)	-150 (4)
laminal	-10 (3)	-100 (1)	-200 (1)	-----	-50 (1)	-----
Postalveolar						
apical	-50 (1)	-75 (1)	-200 (1)	-375 (1)	-----	-215 (2)
apicolaminal	-----	-----	-----	-----	-----	-----
laminal	-----	-----	-----	-----	-----	-----

The physiological correlate to F1 is less clear in stops and nasals than in fricatives, where we assumed the articulation would dictate a fairly consistent (closed) jaw position for all the /S/ and /Z/ tokens regardless of linguagraphic classification or place of articulation, and where there was very little difference in constriction area. When the possibility of varying jaw position and constriction area is introduced, they are confounded with the pharynx width differences, which makes it difficult to say which articulatory factor is contributing to F1 variation. While it is possible that in contrast to the fricative data, during stops and nasals the pharynx is narrower for laminals than apicals, the other possibilities must also be considered. Laminals may have a more open jaw position than apicals, although the admittedly inconclusive x-ray data appeared to indicate the contrary. The most likely cause of a higher F1 in laminals is one which can also be documented by articulatory measurements, namely, the larger mean constriction area noted for these segments. Recall that in French, the mean constriction length for stops, nasals and laterals was 5.69 mm for apicals and 9.39 mm for laminals. In English the same trend was shown by a mean constriction length of 6.6 mm for apicals and 9.9 mm for laminals. The fact that apicolaminal alveolars in French had generally the highest F1 values supports this hypothesis, since apicolaminals were found to have the longest mean constriction length in French (13.02 mm). In English, where mean apicolaminal constriction length was very close to the laminal value (10.3 mm), the apicolaminal F1 values were generally lower than those of the laminals. The F1 difference may be largely due to this constriction length difference, although there may also be differences in pharynx width and jaw opening contributing to the effect.

F2

Recall that in the fricative data, French apicals tended to have higher F2 values than laminals, and the reverse was true in English, but in both cases the differences were not very great. In the stop and nasal data as well, the apicals tend to have the higher F2 values in French, and the English results are mixed. At the beginning of the chapter, a higher F2 was posited for laminal articulations because of a higher tongue position which would reduce the cavity size directly behind the constriction. This is obviously not the case in French. The mean differences between transition and steady-state F2 values are given in Table 3.21 below.

Table 3.21. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F2 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Dental				
apical	+120 (3) 1	+285 (5) 3	-50 (4) 2	+30 (4) 2
apicolaminal	+190 (22) 11	+185 (26) 10	-10 (3) 2	+140 (2) 2
laminal	+225 (7) 6	+215 (9) 4	-150 (1) 1	+195 (7) 3
Alveolar				
apical	+185 (8) 4	+230 (9) 4	-125 (38) 15	+105 (33) 12
apicolaminal	+155 (9) 6	+115 (5) 3	-115 (6) 3	+135 (9) 4
laminal	+135 (13) 7	+165 (8) 6	-60 (5) 3	+25 (1) 1
Postalveolar				
apical	-----	-----	-350 (2) 1	+145 (4) 2
apicolaminal	-----	-----	-----	-----
laminal	-----	-----	-----	-----

F3 and F4

F3 and F4 values have been discussed in terms of their relation to the size of the sublingual cavity. One would expect to see a lower value in articulations, such as apicals, where the tip and blade of the tongue are raised, thereby creating a resonance cavity underneath the tongue. Tables 3.22 and 3.23 give the mean F3 and F4 transition values both going in and coming out of the different segment types in French and English.

Table 3.22. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F3 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Dental				
apical	-40 (3) 1	+150 (5) 3	+15 (4) 2	+65 (4) 2
apicolaminal	+65 (23) 11	+185 (26) 10	+210 (3) 2	+215 (2) 2
laminal	+165 (7) 6	+150 (9) 4	0 (1) 1	+80 (7) 3
Alveolar				
apical	+50 (8) 4	+105 (9) 4	+80 (38) 15	+85 (33) 12
apicolaminal	+145 (9) 6	+20 (5) 3	+110 (6) 3	+105 (9) 4
laminal	+10 (13) 7	+45 (8) 6	+90 (5) 3	+150 (1) 1
Postalveolar				
apical	-----	-----	-175 (2) 1	-15 (4) 2
apicolaminal	-----	-----	-----	-----
laminal	-----	-----	-----	-----

Table 3.23. Mean difference in Hz (rounded off to the nearest 5 Hz) between transition F4 formant values and those of the steady-state vowel for each speaker in each category. The token count is given in parentheses after each value, followed by the number of different speakers represented.

	French		English	
	-t, -d, -n	t-, d-, n-	-t, -d, -n	t-, d-, n-
Dental				
apical	+350 (3) 1	+435 (5) 3	-65 (3) 1	+150 (2) 1
apicolaminal	+325 (21) 11	+375 (23) 9	+150 (3) 2	+125 (2) 2
laminal	+350 (7) 6	+440 (9) 4	+150 (1) 1	+95 (7) 3
Alveolar				
apical	+200 (8) 4	+185 (8) 4	+5 (32) 13	+50 (28) 11
apicolaminal	+35 (9) 6	-425 (4) 3	+105 (6) 3	+110 (7) 4
laminal	+210 (13) 7	+160 (8) 6	+130 (5) 3	-----
Postalveolar				
apical	-----	-----	+150 (2) 1	+165 (3) 1
apicolaminal	-----	-----	-----	-----
laminal	-----	-----	-----	-----

The most consistent F3 pattern in terms of linguagraphic classification is a higher F3 for apicolaminals than apicals. Except for French postconsonantal alveolar tokens this is true in both languages.

F4, however, patterns differently in the two languages. In French, apical and laminal stops and nasals have more or less equal F4 transition values both before and after the consonant closure. The apicolaminal F4 transitions are lower, especially the alveolars. In English, especially in preconsonantal tokens, it is the apicolaminal and laminal tokens which group together with the higher F4 values and the apicals with the lower values. In French, then, the apicolaminal stops and nasals can be supposed to have the largest sublingual cavities, whereas in English that is the property of the apicals. This is particularly clear in alveolars, which is not surprising, given the smallness of any possible sublingual cavity in a dental articulation.

Spectra

Figures 3.14 and 3.15 show the spectra representing the three linguagraphic categories in two places of articulation. Apical dentals in French are clearly distinguished from laminal dentals in the burst transient spectra. The laminals have an essentially flat spectrum, whereas the apicals have more energy in the higher frequencies above 3500 Hz. In English, there is no obvious difference between the two. The French apicolaminal dental stop burst spectrum closely resembles the spectrum of the laminal burst transient, perhaps indicating that the dental stops were released from front to back, with the blade therefore released last.

The French alveolars show a similar apical-laminal difference to that found in the dentals. Again, the laminal stop burst spectrum is flat, and differs from the apical by having less high frequency energy. In this case, the apicolaminal spectrum resembles that of the apical, rather than the laminal, perhaps an indication that the alveolar stops were released from back to front, with the tip being the last part released.

In English alveolars, both the apicolaminal and the laminal stop bursts have a steeply sloping spectrum with a similar shape, yet more high frequency energy (above 6000 Hz.) than is found in French apicals or apicolaminals. The English apical alveolars do not have this high frequency energy, but instead have high amplitude in the mid frequencies and a steep drop-off above 5000 Hz.

3.2.5 Convergence of formants

F2-F3

A convergence of F2 and F3, although typically associated with velar transitions, was noted adjacent to some of the consonants in the French and English data. In order to quantify this, the distance in Hertz between the two formants at the moment adjacent to the closure was computed and this was subtracted from the F2-F3 distance in the steady-state vowel for each speaker. Any tokens which had a difference of 100 Hz or more between steady-state and transition values were considered as converging. Given these criteria, the results are as given in the bar graphs in Figure 3.16 below. The vertical dimension indicates the percentage of all tokens (for both

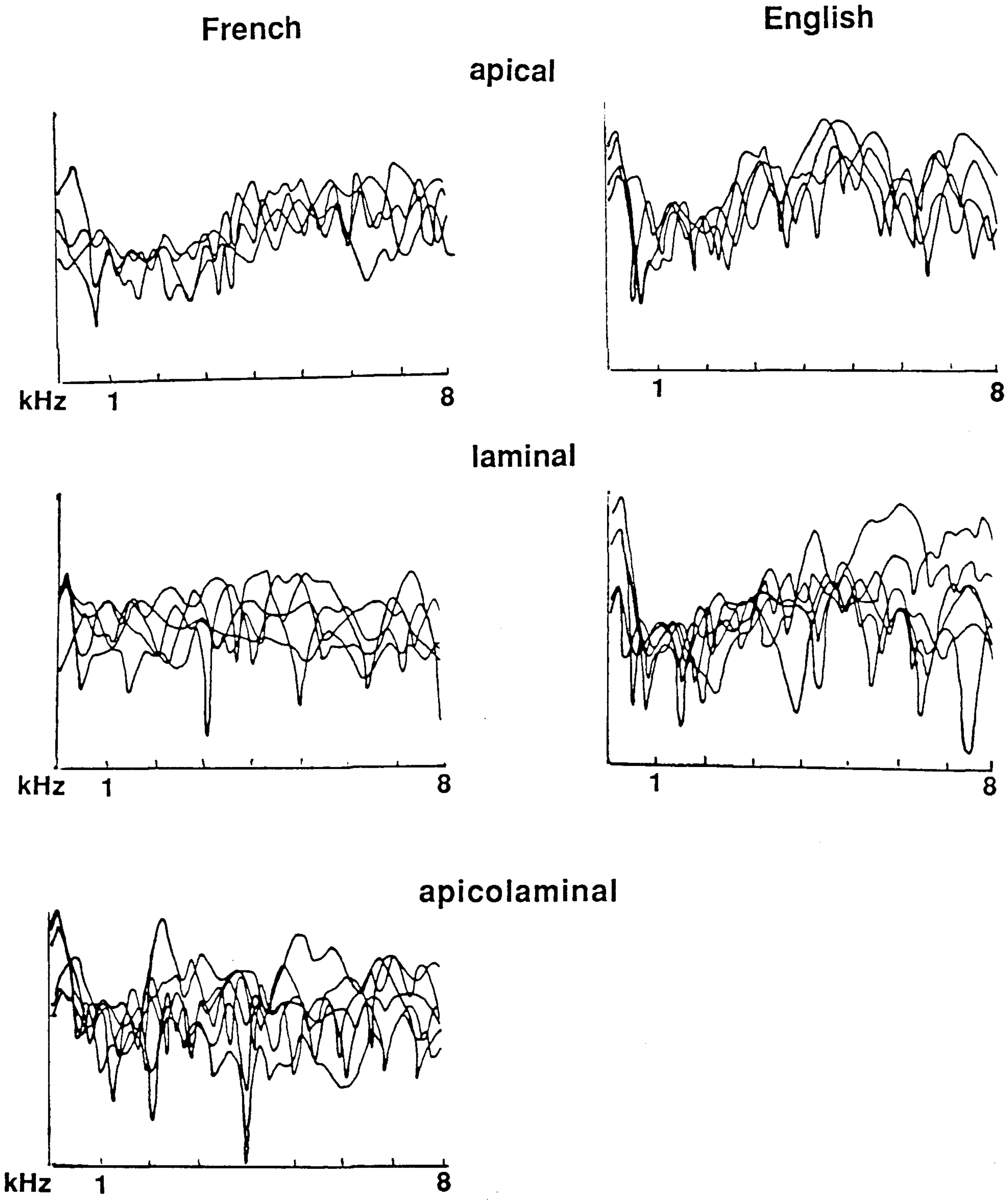


Figure 3.14. Spectra of the burst transients of voiceless dental stops of three different linguagraphic categories.

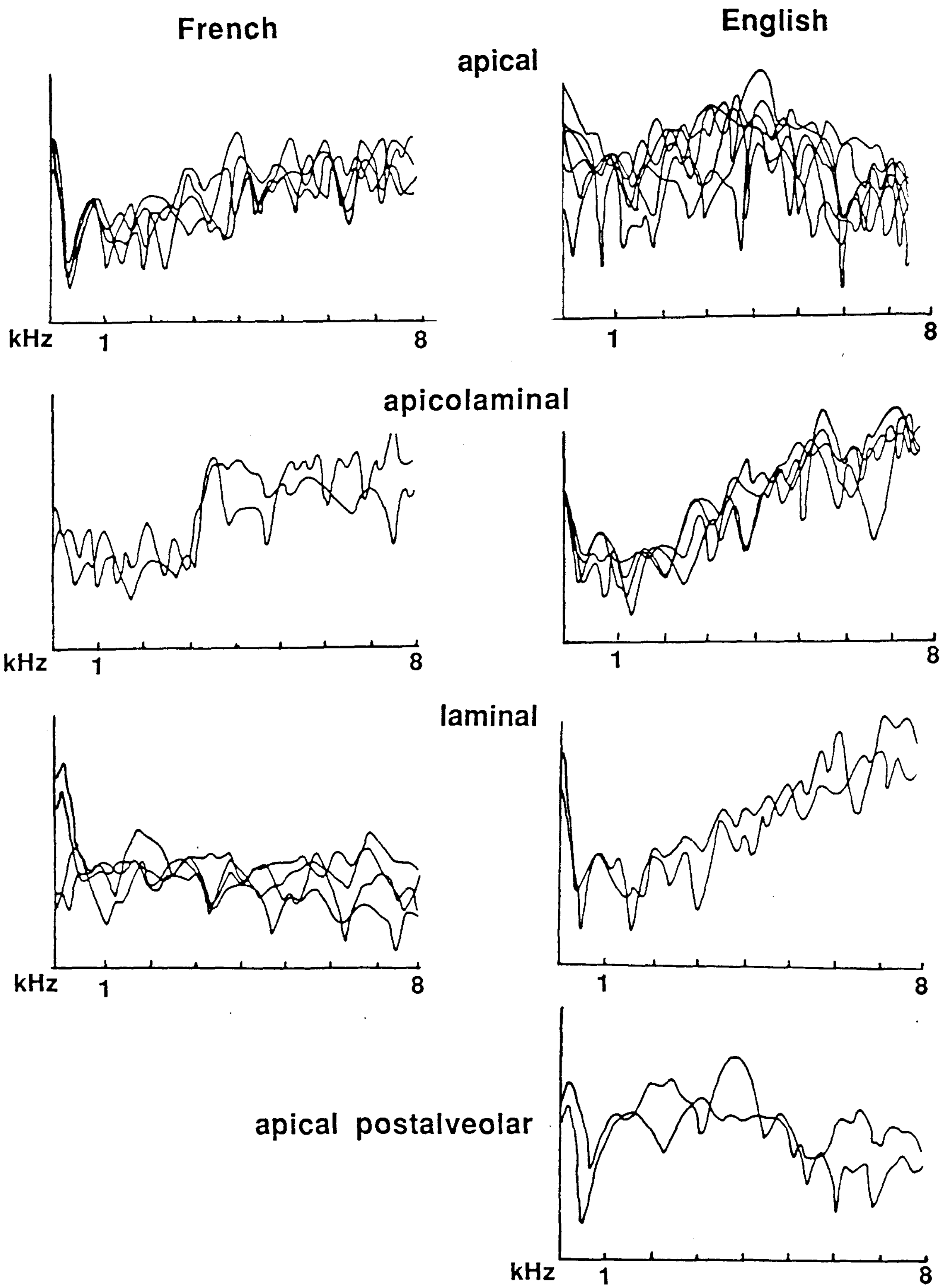


Figure 3.15. Spectra of the burst transients of voiceless alveolar stops of three different linguagraphic categories. English apical postalveolar stop burst spectra are also included.

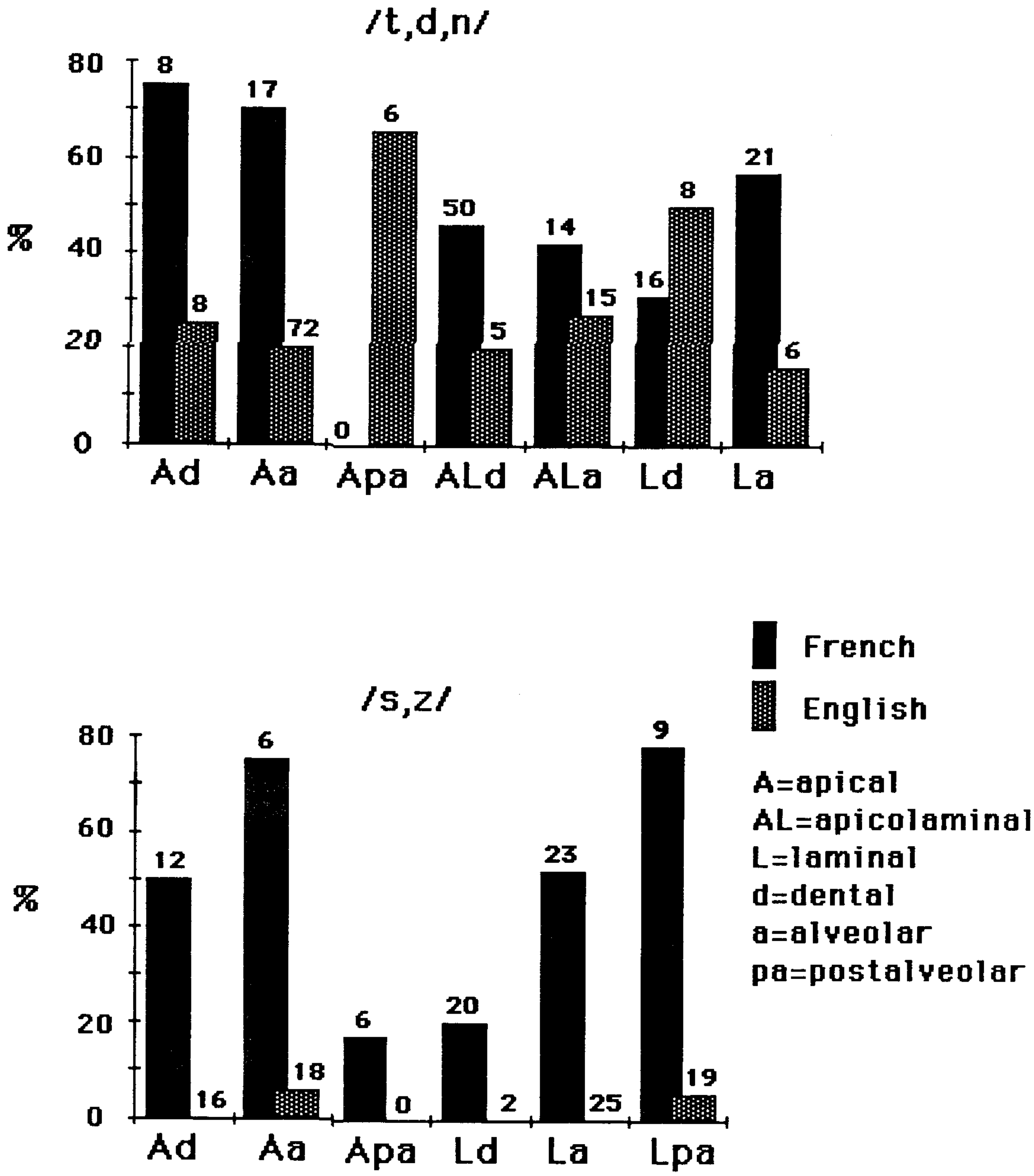


Figure 3.16. Percentage of tokens in various segments types which had converging F2 and F3. The total number of exemplars of each category from which the percentages were taken is given at the top of each column.

word-initial and word-final consonants) in each language which had converging F2 and F3. To give a better idea of the significance of each percentage, the total number of tokens in each category from which the percentages were taken is given above the columns. If a category is not listed, it is because there were no converging F2 and F3 tokens of that segment type in either language.

The results clearly differ between the two languages. In general, converging F2 and F3 were found more often in French than in English, particularly in fricatives. It is worthwhile mentioning here that a converging F2 and F3 could come either from a high F2 value or a low F3 value and the graphs contain examples of both these possibilities. The generally high F2 in the French apicals and alveolars noted in previous sections results in a high incidence of F2-F3 convergence, as does the low F3 in English apical postalveolar stops and French laminal postalveolar fricatives. Inasmuch as it is a result of a high second formant, the higher incidence of F2-F3 convergence in French supports the notion of a higher tongue body in that language.

F3-F4

At the beginning of this chapter, a convergence of F3 and F4 was predicted for apical and apicolaminal segments because of the spectral prominence in the region of F3 caused by the sublingual resonance cavity. Fant (1973, p.28) also says that the retroflex modification of an alveolar lowers F4 to come close to F3, so we would expect to see this in apical postalveolars as well. The distance between F3 and F4 was measured for all tokens and subtracted from the F3-F4 distance in the steady-state vowel for each speaker in the same manner as that outlined above for F2-F3 convergence. The results can be seen in Figure 3.17 below. With the exception of apicolaminal alveolars, which had significantly lower F4 values, very few tokens in the French data met this criterion and these tokens were not grouped under any one segment type. In English, the greatest concentration of such tokens was in apical and apicolaminal stops and nasals, where the tongue tip was up, creating a sublingual cavity. There was no convergence in the 6 apical postalveolar tokens, presumably because F3 was also lowered significantly. No French fricative tokens and very few English ones showed converging F3 and F4. It can be seen in the graph that it is the English laminal alveolar and postalveolar fricatives which show the highest incidence of this convergence (there was no F3-F4 convergence observed in laminal dental fricatives), not surprisingly, precisely those tokens which were found to have the lowest F4 values. Recall that Stevens (1989) suggested that convergence of F3 and F4 would not occur if the sublingual resonance cavity was too small and therefore the resonance too high to couple with one of the back cavity resonances. The fact that this convergence is much more common in English tokens than in French supports the idea advanced earlier that the sublingual cavity is generally larger in English coronal articulations.

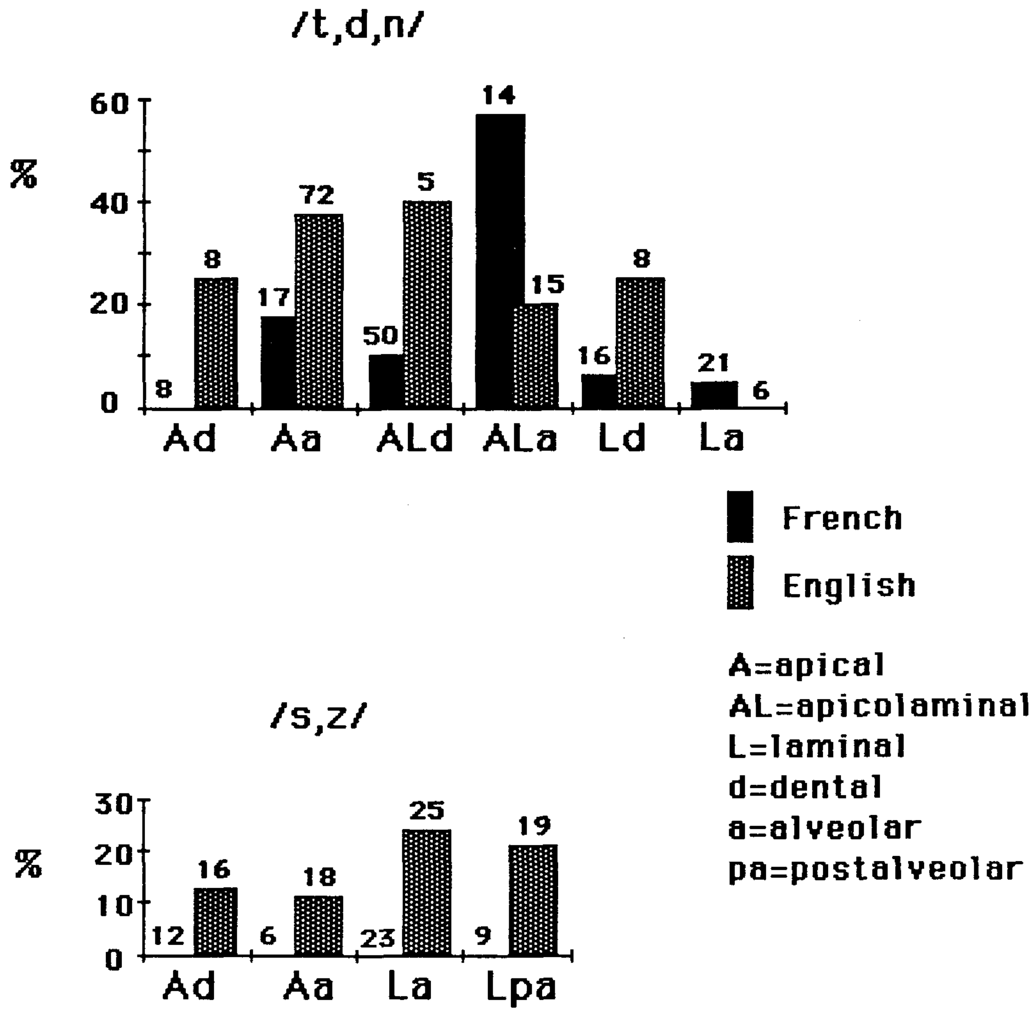


Figure 3.17. Percentage of tokens in various segments types which had converging F3 and F4. The total number of exemplars of each category from which the percentages were taken is given at the top of each column.

3.2.6 Double bursts

The prediction that laminals and apicolaminals would have more double bursts than apicals, due to a Bernoulli effect in the long constriction, was only weakly supported by the acoustic data. In fact, there were very few examples of double bursts in the data. Out of the 82 examples of initial /t/ in both languages, only 13 had double bursts (6 French and 7 English). Of these, 4 were apical, 6 laminal and 3 apicolaminal. Considered as percentages of the total number of apical, laminal and apicolaminal tokens of initial /t/, the results are easier to see. 11.76% of the apical tokens, 30% of the laminals and 10.71% of the apicolaminals had double bursts (see Table 3.24 below). Although it is true that a greater percentage of the laminals had double bursts, and in that sense the tendency towards such a phenomenon can be said to be greater for the laminals, it is also true that most of the laminal articulations resulted in single bursts. A double burst, then, cannot be taken as an identifying characteristic of laminal release, since a fair number of apicals, and a surprisingly small number of apicolaminals (considering that they have the longest mean constriction), also had double bursts. This phenomenon appeared to be more of a variable occurrence from token to token than an individual characteristic of any particular speaker.

Table 3.24 Incidence of double bursts in the French and English voiceless stop data by linguagraphic type.

	Apical	**Apicolaminal**	**Laminal**
count	4	3	6
% total	11.76	10.71	**30**

3.2.7 Laterals

Since 81% of the laterals in the French and English data were apical, it was hard to get a reliable indication of what effect different linguagraphic classifications have upon lateral articulation.

Ladefoged and Maddieson (1986) suggest that laminal and dorsal laterals may not have as abrupt a change in formants to and from adjacent vowels, presumably because the articulatory gesture is slower than when the tip of the tongue is used. This generalization was upheld in the present study although, as just mentioned, the number of non-apical laterals is small (15 in all). Considering French and English together, 33 of the 41 speakers had initial apical laterals. Of these, 8 (24.24%) had visibly slow transitions to and from the surrounding vowels. This means that 25 (75.76%) of the apical laterals had the predicted abrupt formant changes. There were 8 speakers with apicolaminal or laminal initial /l/ production. Of these, 6 (75%) showed slow formant transitions as expected and 2 (25%) had abrupt transitions.

Thus 75% of the time, the predictions are upheld. Figure 3.18 illustrates this finding.

Bladon (1979) claimed that F1 rises with the increase in cross-sectional area of the lateral constriction. This would presumably mean that laminal and apicolaminal laterals would have higher first formants than apicals. Ladefoged and Maddieson (1986) found only partial confirmation of this prediction in their data and the present data also serve to cast doubt on this prediction. There are too few tokens of apicolaminal and laminal laterals for conclusive evidence, but such as it is, the results of the present study run exactly contrary to the prediction for both English and French male and female speakers, as can be seen in Table 3.25. It is possible that other factors affecting F1, such as a wider pharynx or a more closed jaw for laminal and apicolaminal laterals, may counteract any effect from lateral constriction area.

Table 3.25. Mean F1 values for word-initial laterals in English and French (number of speakers in parentheses).

	French		English	
	male	female	male	female
Apical				
dental	--------	--------	375 (4)	363 (4)
alveolar	360 (5)	345 (10)	367 (3)	500 (3)
postalveolar	438 (2)	450 (1)	--------	550 (1)
Apicolaminal				
dental	--------	325 (2)	317 (3)	--------
alveolar	--------	--------	--------	375 (2)
Laminal				
alveolar	350 (1)	--------	--------	--------

A third observation Ladefoged and Maddieson made, based on their data from Kaititj and Alyawarra, is that the frequency of the second formant is inversely related to the volume of the oral-pharyngeal cavity behind the constriction, as stated by Bladon (1979). In their data, the apical alveolar had the lowest F2, the (apico)laminal dental and the apical postalveolar laterals had a higher F2 and the laminal postalveolar had the highest F2. Although the English data was somewhat complicated by velarization in some of the speakers, a similar pattern can be seen in all but the French male speakers in the present study, as is evident from Table 3.26.

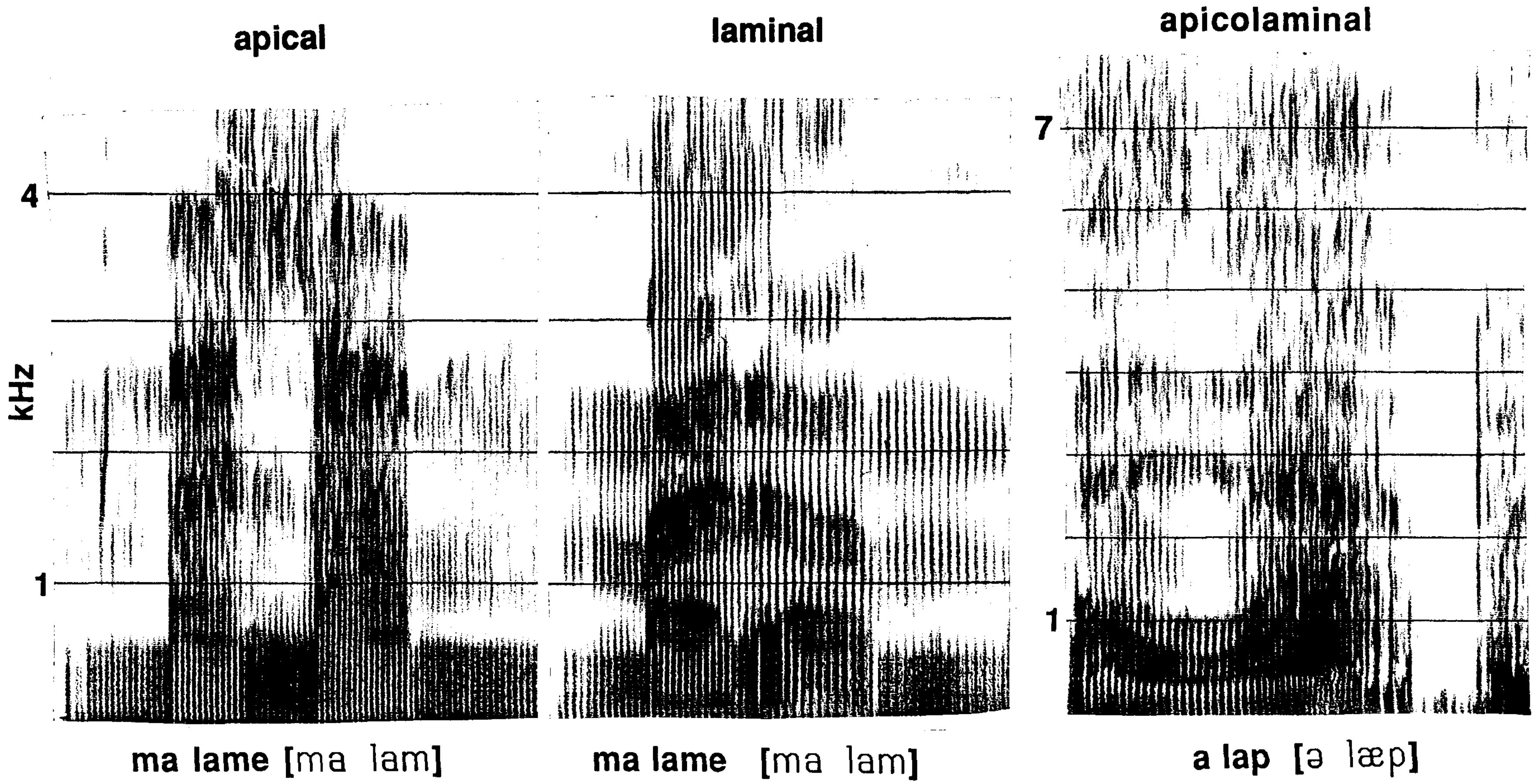


Figure 3.18. Spectrograms of apical, apicolaminal and laminal laterals illustrating the difference in speed of formant change.

Table 3.26. Mean F2 values for word-initial laterals in English and French.

	French		English	
	male	female	male	female
Apical				
dental	--------	--------	944 (4)	1300 (3)
alveolar	1469 (4)	1703 (10)	1217 (3)	1350 (3)
postalveolar	1438 (2)	1925 (1)	--------	1650 (1)
Apicolaminal				
dental	--------	1838 (2)	658 (3)	--------
alveolar	--------	--------	--------	1000 (2)
Laminal				
alveolar	1550 (1)	--------	--------	--------

In the lateral tokens where F3 and F4 were visible (which was most of them), the values are, for the most part, inversely proportional to the size of the sublingual cavity as determined by place of articulation, with the highest values for the dental laterals and the lowest values for the alveolar or postalveolar laterals, as presented in Table 3.27 below. In the instance where both are present (French males) the laminal alveolar has a lower F3 and F4 than the apical alveolar, possibly indicating a larger sublingual cavity, although tokens from only one speaker were available to represent the laminal alveolar articulation. Recall that the same pattern was observed in the fricative data for apical and laminal alveolars. From the data for English males, the apical dentals would appear to have smaller sublingual cavities than the apicolaminal dentals. This makes sense when we recall that all apical dental articulations in this study appear to be actually apical and sublaminal, in which case it is easy to see that the area beneath the constriction would be largely occupied by the sublaminal part of the tongue, thereby giving a higher frequency resonance.

Table 3.27. Mean values of F3 and F4 in French and English initial laterals.

	French				English			
	male		female		male		female	
	F3	F4	F3	F4	F3	F4	F3	F4
Dental								
apical	--------	--------	--------	--------	2825	3715	3525	4200
apicolaminal	--------	--------	2975	4700	2688	3688	--------	--------
Alveolar								
apical	2581	4085	2769	4174	2550	3650	3100	4150
laminal	2400	3575	--------	--------	--------	--------	--------	--------
apicolaminal	--------	--------	--------	--------	--------	--------	3150	4000
Postalveolar								
apical	2538	3950	3150	4300	--------	--------	2500	--------

3.2.8 Comparison of French and English data

Throughout the chapter various observations have been made on what appear to be fundamental differences between French and English coronal stop production. Basic tongue shape differences have been inferred from the formant frequency data. In particular, the overall lower F1 values and higher F4 values in French suggest that French is spoken with a wider pharynx and a smaller sublingual cavity than English. In addition to these general characteristics, a specific tongue shape difference between apical alveolar articulations in the two languages was noted, particularly in fricatives. French apical alveolar fricatives have lower transitional F1 values and higher transitional F2 values than do apical dental fricatives, whereas the reverse is true for English. Similarly, French apical consonants have higher F2 values than laminals, whereas in English F2 is higher in laminals.

One interpretation of these facts would be to posit a differently shaped tongue behind the constriction in the apical and alveolar articulations in the two languages. The F1 and F2 evidence suggests that the body of the tongue in French is high and forward during these consonants, thereby diminishing the area of the cavity directly behind the constriction and enlarging the pharyngeal cavity. The English apicals, on the other hand, would come up to the constriction from a lower and more posterior position in the mouth, thus creating a larger cavity behind the constriction and a more constricted pharynx. Both kinds of apical alveolar articulations can be seen in the x-ray literature, as exemplified by the two tracings in Figure 3.19. The tracing on the top is of French /S/ (after Bothorel et al. 1986) and resembles an apical alveolar tongue position like that posited for the French speakers, and the tracing on the bottom is of English /S/ (after Subtelny et al. 1972), and has a descending tongue shape as posited for the English speakers in the present study.

In order to explore the possibility of such an articulatory difference as that suggested by the acoustic data, additional articulatory measurements were taken from the palatographic data. It was presumed that a higher tongue position would show up on the palatograms as a wider contact area behind the constriction and, indeed, such a difference seemed to be evident from the palatograms as illustrated in Figure 3.20. Accordingly, the contact area from each articulation was measured inwards from the base of the first molar, by mapping the evidence from the palatograms onto the casts in the same manner as that described in the last chapter for the other articulatory measurements. If contact area differed on the two sides, the measurement was taken on the side with the greater amount of contact. In order to normalize for palates of different sizes, this measurement is given as the ratio of the contact area on one side to half of the total distance following the curve of the palate from first molar to first molar. The results can be seen in Table 3.28 below.

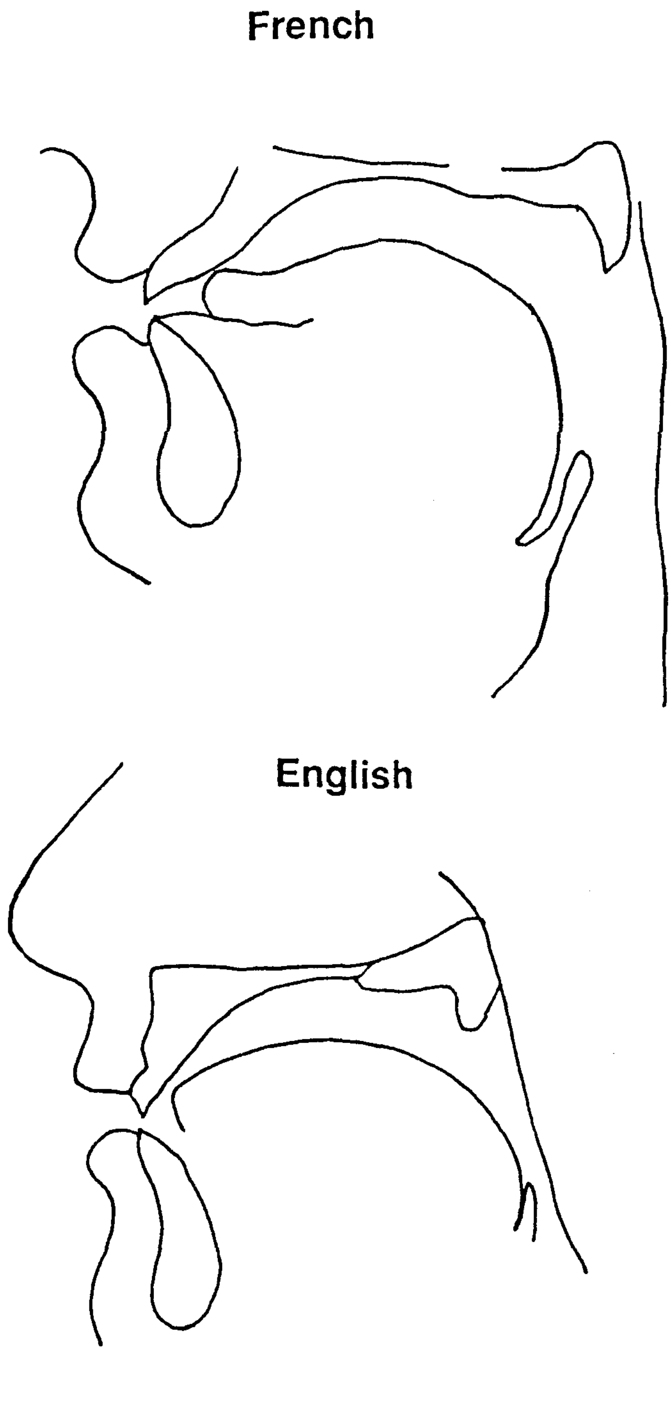


Figure 3.19. X-ray tracings of French (after Bothorel et al. 1986) and English (after Subtelny et al. 1972) showing two different tongue shapes in apical alveolar /s/.

French

English

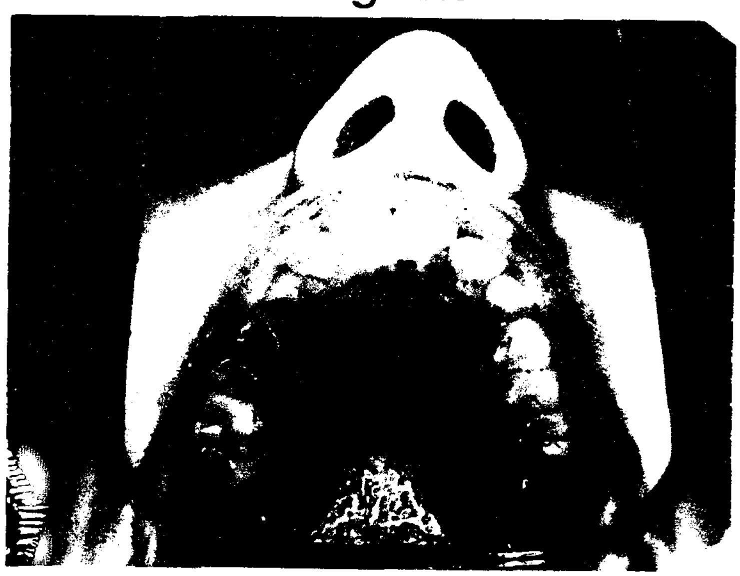


Figure 3.20. Palatograms of French (top) and English (bottom) stop production illustrating the wider contact area behind the constriction in the French articulation.

Table 3.28. Mean and standard deviation values for ratio of the width (in mm) of the contact area at the first molar to half of the entire palate measurement at that point for French and English consonants of different articulation types.

	apicals	apicolaminals	laminals	dentals	alveolars	postalveolars
Stops and nasals						
Word-final						
French						
mean	.506	.41	.395	.504	.369	----
s.d.	.19	.125	.154	.192	.141	----
English						
mean	.244	.337	.313	.344	.213	.375
s.d.	.112	.084	.069	.051	.089	.078
Word-initial						
French						
mean	.459	.405	.344	.472	.379	----
s.d.	.179	.132	.084	.157	.166	----
English						
mean	.257	.356	.345	.358	.195	.308
s.d.	.123	.12	.166	.142	.064	.099
Fricatives						
Word-final						
French						
mean	.414		.356	.413	.37	.366
s.d.	.112		.101	.124	.131	.115
English						
mean	.229		.273	.253	.22	.297
s.d.	.081		.09	.072	.101	.045
Word-initial						
French						
mean	.46		.417	.469	.407	.377
s.d.	.113		.142	.127	.138	.166
English						
mean	.215		.297	.241	.236	.346
s.d.	.081		.076	.099	.116	.05

These inter-language differences were shown to be significant in one factor, repeated measures analyses of variance (as shown in Table 3.29 below) for all apicals and alveolars, as well as for laminal and dental fricatives, where French also has the wider contact area. The articulatory data thus supports the theory of a language-specific difference in tongue shape behind the constriction during apical and alveolar articulations.

Table 3.29. Significance values from one factor repeated measures analyses of variance, testing variation between French and English values of contact width at the first molar.

	apicals	apicolaminals	laminals	dentals	alveolars	postalveolars
final /t,d,n/	.0005	.1351	.2931	.0407	.0001	
initial /t,d,n/	.0017	.3941	.9854	.036	.0001	
final /s,z,/	.0005		.0015	.0121	.0024	.2037
initial /s,z/	.0001		.0008	.0009	.0069	.6502

The overall picture described above leads us to posit a basic tongue shape difference between the two languages, which, interestingly enough, resembles that posited by the proponents of the base of articulation theory (see Honikman 1964). This theory claims that French is spoken with a convex, fronted tongue shape and English with a concave tongue. Even during laminal articulations, English appears to have more of a front cavity than French, and the higher formants have much lower transition values. This is further supported by the formant convergence data where French had the greater amount of F2-F3 convergence, due to high F2 values and English had the greater amount of F3-F4 convergence, due to low F4 values.

3.2.9 Summary and discussion

It is worthwhile to stop here and look at how far the predictions made at the beginning of the chapter are upheld by the acoustic data in the present study. The claim that laminal stops have a longer release time than apical stops because of the greater mobility of the tongue tip is only weakly supported by the English data and not at all by the French data. The mean voice onset time of voiceless laminal stops is longer than that of apicals in both cases, but not significantly so. Similarly, although laminals were found to have the highest percent of double bursts, the percentage was low (30%) and double bursts were also found to a more limited extent in both apical and apicolaminal stops.

The prediction that laminals would have lower F1 transitions than apicals because of a wider pharynx was upheld for fricatives, but not for stops and nasals. In stop production other factors influencing F1 come into play, notably a larger constriction area for laminals and apicolaminals which raises F1 in these articulations.

A higher F2 in laminal consonants was found only in English fricatives, and the apical-laminal difference was very small. In French, the apicals tended to have the higher F2 values, which led us to posit a different tongue shape for apicals in the two languages as was illustrated in Figure 3.19.

The predicted lower F3 and F4 in apicals and apicolaminals was true only in dental articulations for fricatives. For alveolar and postalveolar fricatives it was the laminals which had the lower formant values. English stops and nasals had the expected low F4 values for apicals, but in French there was very little difference between apical and laminal articulations in this dimension. It was the apicolaminals which showed evidence of a larger sublingual cavity in French.

With these facts taken together, there appear to be language-specific characteristics affecting the formant values, which are associated with vocal tract shapes that are not fully specified by simply characterizing the segments in terms of the articulatory contact involved. The whole shape of the tongue has to be determined, which makes universal generalizations on segment types difficult to substantiate.

3.3 Results: Contrastive segments: Malayalam

It seems obvious that the segments which contrast in a language must be somehow articulated differently in order to give different acoustic signals. The manner of distinguishing the two segments may not always be the same for each speaker, yet some distinction must be made. In the following section, the manners of distinguishing the contrasting segments in both Malayalam and 'O'odham will be analyzed, speaker by speaker, in an effort to discover if there is or is not an underlying unity which would help give a label to the contrast in question.

3.3.1 Stops

We saw in Chapter 2 that there was a great deal of variation among the three Malayalam speakers in articulation of the contrasting stops. The following section discusses the acoustic aspects of these contrasts. A brief summary of the articulatory results will be given for reference in each section.

/t̪/-/t/

Recall that Speaker 1 produced /t̪/ as an (apico)laminal interdental stop and /t/ as an upper apical alveolar. /t̪/ also had a much longer constriction than /t/, thus making these stops, articulatorily, highly distinct. Acoustically, /t̪/ had a shorter closure duration (125 msec) than /t/ (205 msec), but this is probably due to the fact that /t̪/ is preceded by a phonologically long vowel in /poːt̪ːɨ/ and /t/ by a short vowel in /potːa/. Taken as the sum of the length of the preceding vowel and the consonant, the durations are nearly the same for both sequences (350 msec for /oːt̪ː/ and 330 msec for /otː/). The voice onset time of /t̪/ (average 60 msec) was longer than that of /t/ (average 40 msec) and, in addition, /t̪/ had a double burst, as is clear from the spectrograms in Figure 3.21.

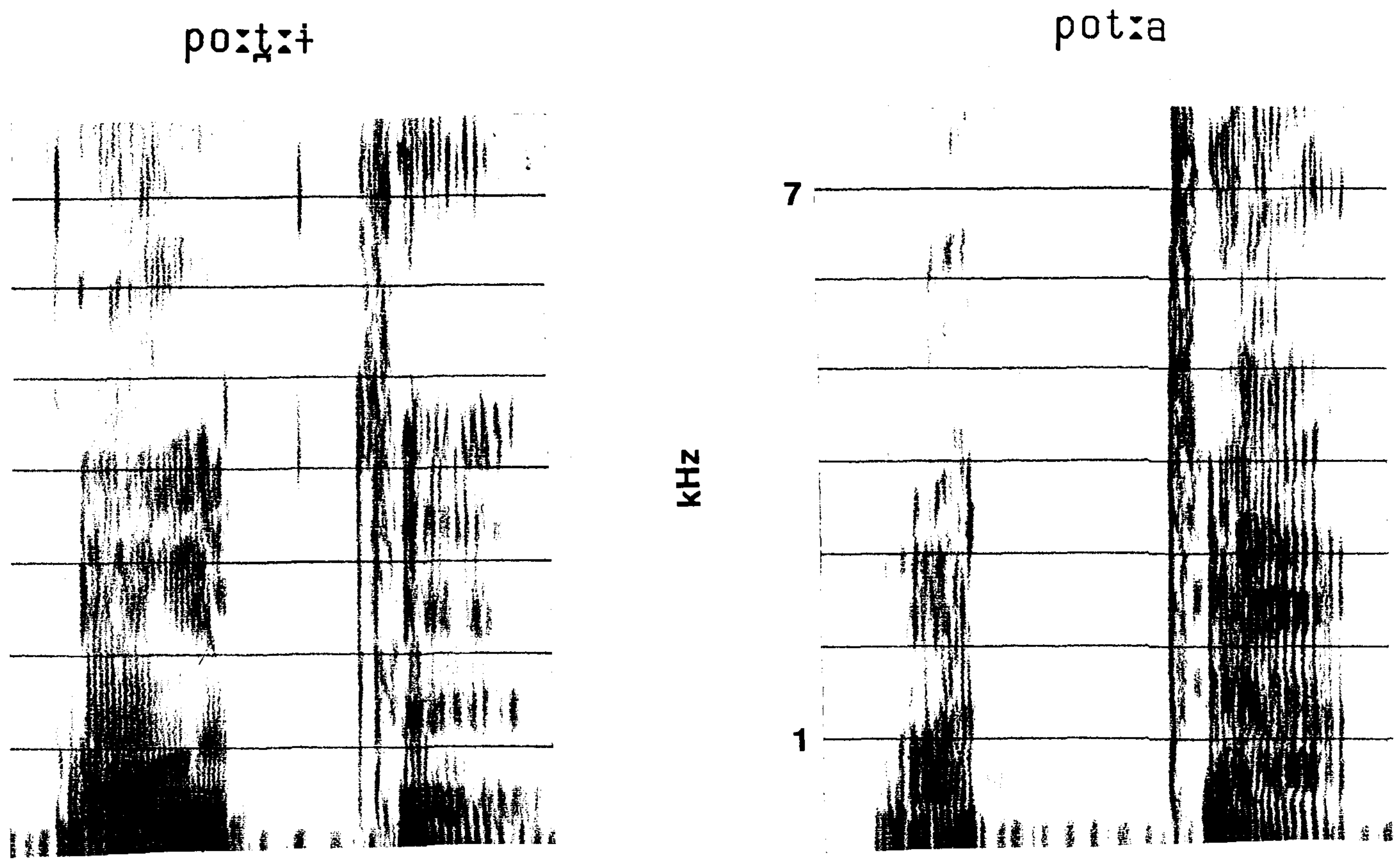


Figure 3.21. Spectrograms of Malayalam /poːt̪ːɨ/ and /potːa/ for Speaker 1.

Since the vowel qualities of phonological /oː/ and /o/ appear to be different, the absolute formant transition frequencies are not as important as their relation to the frequencies of the steady-state vowel. Looking at the two utterances in Figure 3.21, the major difference in formant transition value before the consonant is a lower F4 going into /t/, probably due to the presence of a sublingual resonance cavity, which would naturally be absent in the interdental stop. In the transitions out of the stops, F2 appears to be much higher in /t/ than in /t̪/, perhaps due to a higher tongue body behind the constriction for /t/. The other formant differences can be attributed to the differences in vowel quality in the two utterances.

The general shape of the burst transient spectra, the two tokens of which are shown for each segment in Figure 3.22, are very similar, with a major peak around 4000 Hz followed by a sudden drop in amplitude in the higher frequencies.

To sum up, the acoustic differences between /t̪/ and /t/ for Speaker 1 include a longer VOT and double burst in /t̪/, and a lower F4 preceding and higher F2 following /t/.

Speaker 2 produced an apicolaminal dental stop for /t̪/ and an apicolaminal alveolar stop for /t/, with a minimally longer constriction in /t̪/ than /t/.

Referring to the acoustic data, /t̪/ had a shorter closure duration than /t/, but as with the previous speaker, this was most likely due to the vowel length contrast in the preceding vowels. Both consonants had very short VOT's and neither one had a double burst, but /t/ had clearly a higher amplitude burst than /t̪/. Looking at the spectrograms in Figure 3.23, it can be seen that F2 and F3 come together both before and after the /t/ closure with F2 higher and F3 lower than is the case for /t̪/.

The slope of the burst transient spectra for the two segments (Figure 3.24) is very different. For /t̪/ the spectrum is rather flat, descending gradually in the higher frequencies, whereas for /t/, there is a higher amplitude peak around 4500 Hz, which in one token is maintained in the higher frequencies and in the other is followed by a drop in amplitude.

Although both stops are apicolaminal and differ only in place of articulation, the transition formant structure is very different in the two segments. The second and third formants converge before and after the alveolar stop, as was found in some of the alveolars in the French and English data. The spectra of the burst transients are also different, with the alveolar showing more energy in the middle frequencies.

The articulations of Speaker 3 are the least distinct, with both segments being

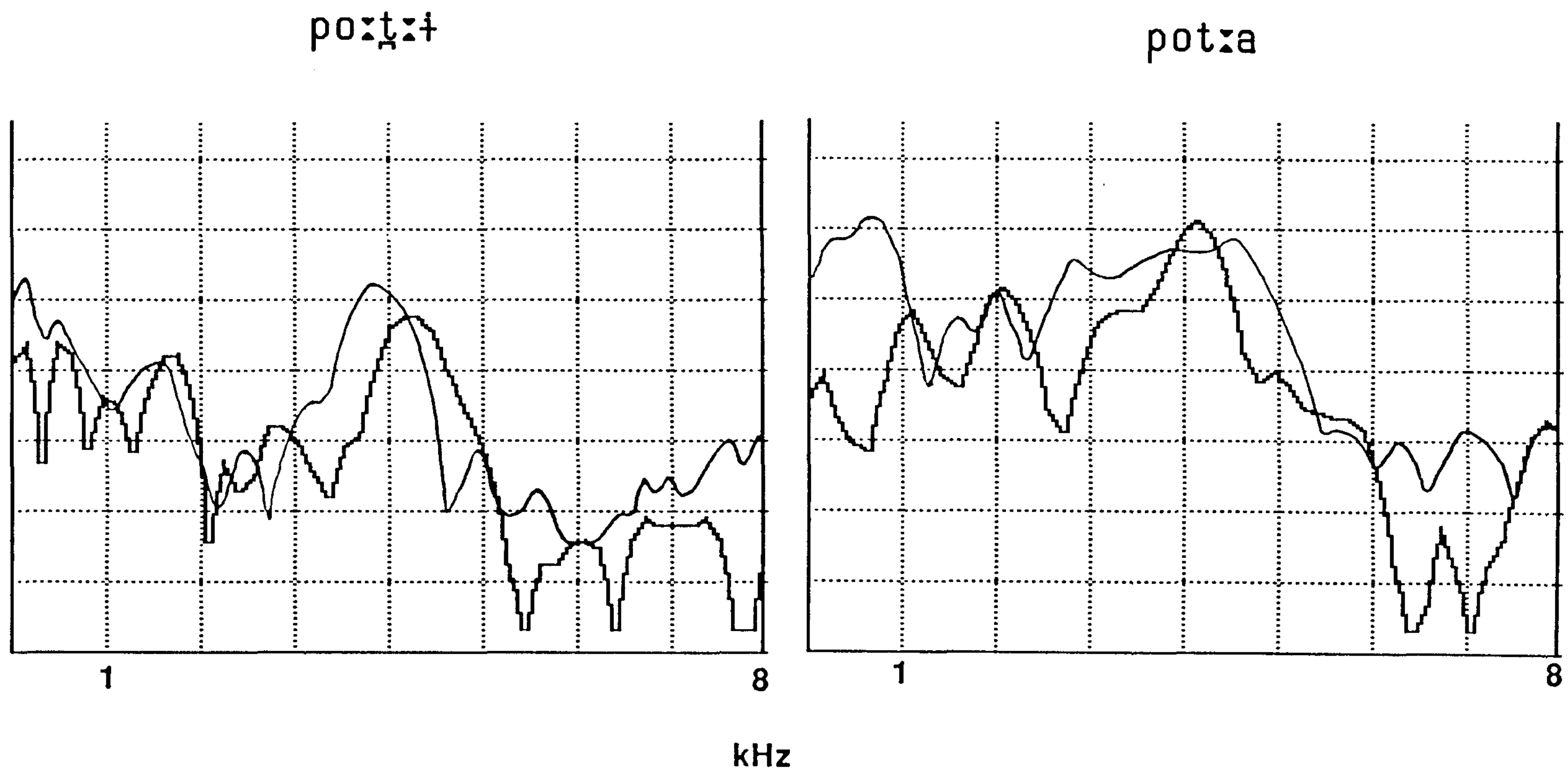


Figure 3.22. Spectra of the release transients of the medial stops in Malayalam /poːt̪ːɨ/ and /potːa/ for Speaker 1.

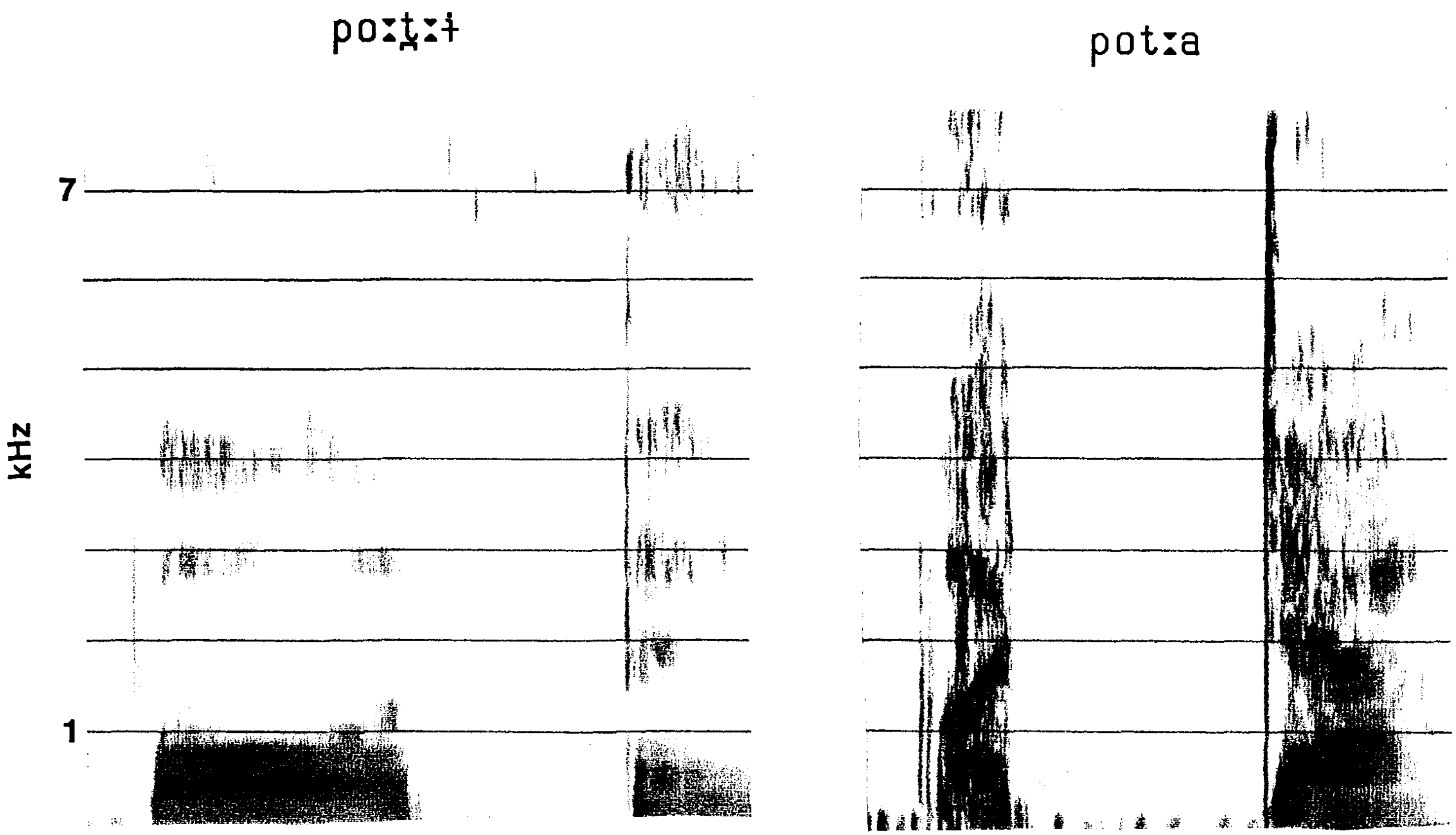


Figure 3.23. Spectrograms of Malayalam /poːt̪ːɨ/ and /potːa/ for Speaker 2.

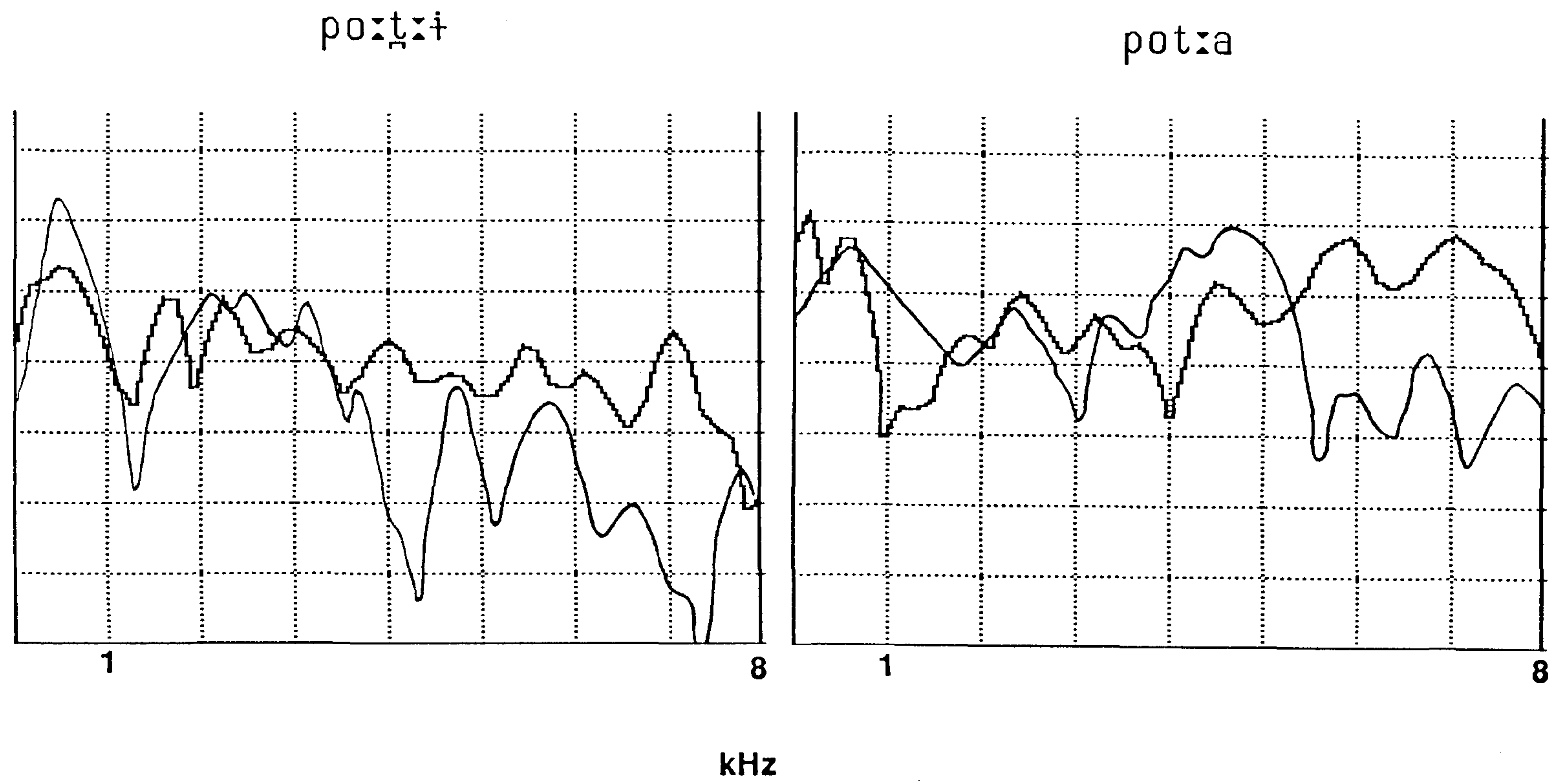


Figure 3.24. Spectra of the release transients of the medial stops in Malayalam /poːt̪ːɨ/ and /potːa/ for Speaker 2.

apicolaminal alveolar, and with an only minimally longer constriction for /t̪/ than for /t/. She was also the speaker, mentioned in the introductory chapter, who had [a] rather than [ɨ] in the test words, so her formant values for /t̪/ and /t/ articulations are more directly comparable.

The acoustic data show the same shorter closure duration for /t̪/ as was found for the other speakers, due again to the phonologically longer vowel preceding it. Voice onset time is very short, as for Speaker 2, and not different between the two segments. The so-called 'dental' stop has a double burst, as it did also for Speaker 1.

Figure 3.25 gives spectrograms of the two utterances. The major difference in formant transition structure between the two is a higher F2 going in and especially coming out of the /t/ transitions, showing that despite the similarity in place of articulation and part of the tongue contacted, the tongue body behind the closure must not be in the same position for the two segments.

The spectra of the two segments, shown in Figure 3.26, have a very similar slope, gradually descending toward the higher frequencies.

Summary /t̪/-/t/

Despite the articulatory diversity among the three speakers, there is one consistent acoustic difference between /t̪/ and /t/ for all three: /t/ always has a higher F2 transition value than /t̪/, as was also found by Stevens et al (1986). The salient distinction between Malayalam "dental" and "alveolar" consonants appears to be neither place of articulation nor apicality, as have been variously claimed, but the shape of the tongue behind the constriction, which is higher for /t/, and which is apparent in the acoustic signal, particularly on release of the consonant. This difference in tongue height was verified by measurement of the contact area adjacent to the first molar in the palatographic data, in the same manner as that described for the French and English data. Speakers 2 and 3 had a wider contact area for /t/ than /t̪/ (and also for /n/ than /n̪/), and Speaker 1, who had the least difference in F2 value between the two, had equal contact area for the two segments, as shown in Table 3.30. For Speaker 1, from a different dialect area, the distinction appeared to rely more on place of articulation differences between the two stops than on tongue height.

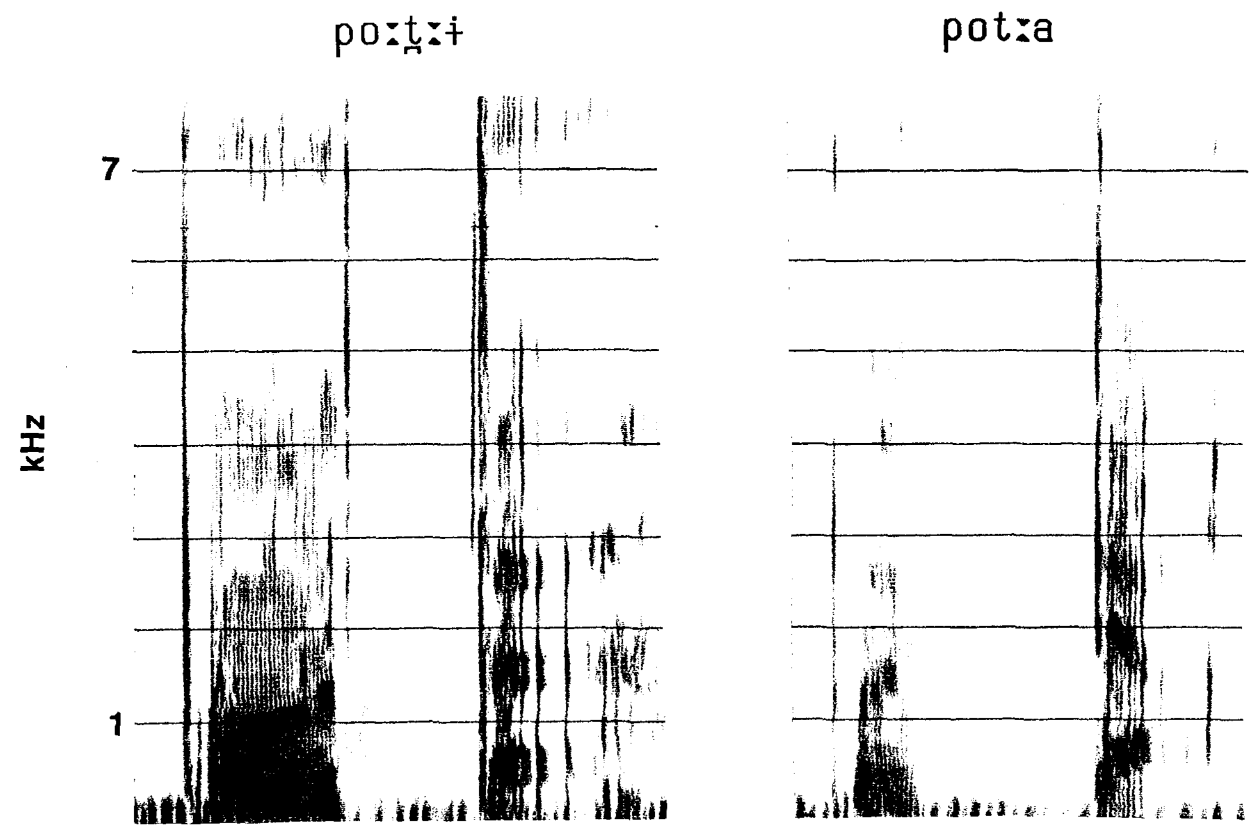


Figure 3.25. Spectrograms of Malayalam /po:t̪:ɨ/ and /pot:a/ for Speaker 3.

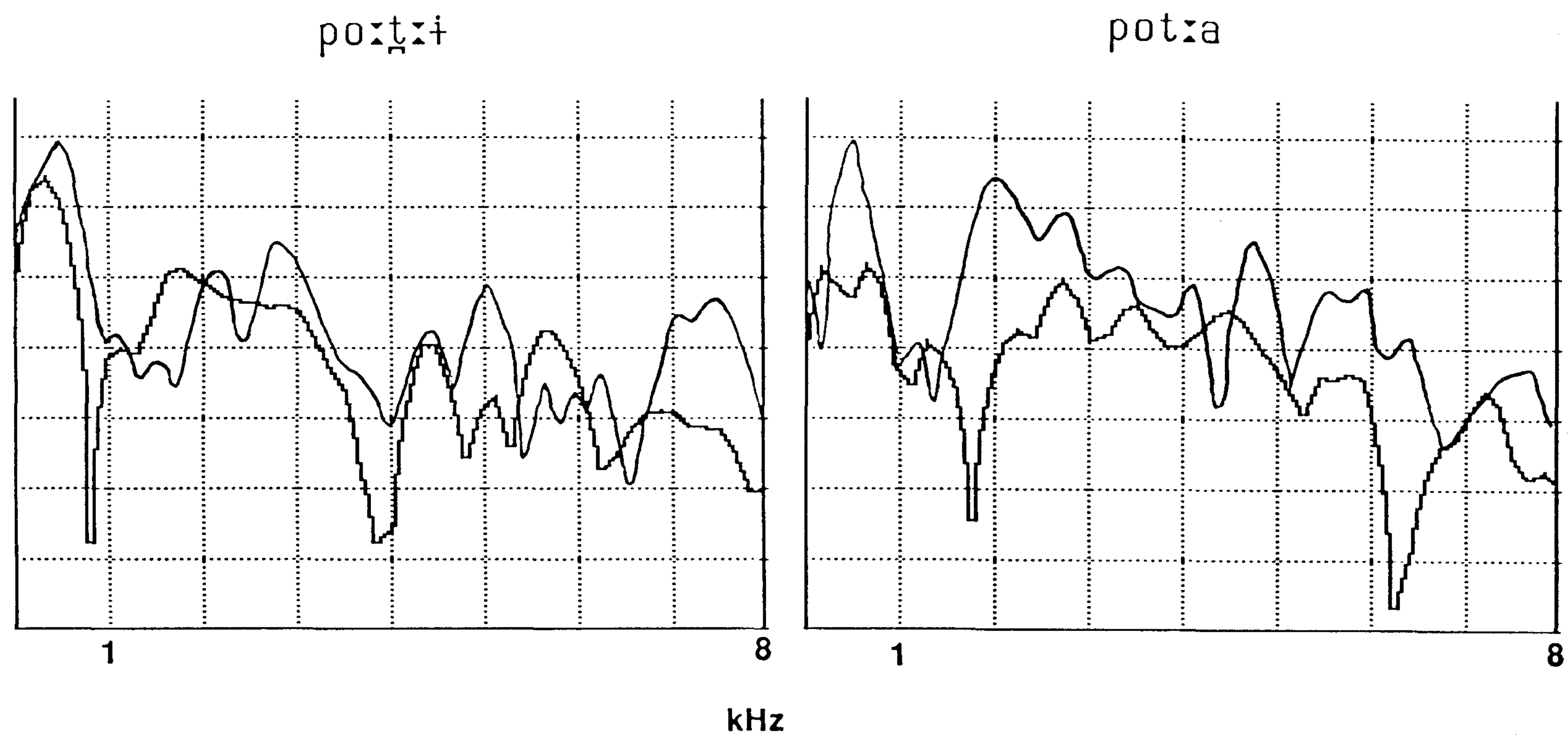


Figure 3.26. Spectra of the release transients of the medial stops in Malayalam /poːt̪ːɨ/ and /potːa/ for Speaker 3.

Table 3.30. Width of the constriction (in mm) on one side at the first molar for three speaker's articulation of Malayalam /t̪/, /t/, /n̪/ and /n/.

	/t̪/	/t/	/n̪/	/n/
Speaker 1	**8**	**8**	10.5	9.5
Speaker 2	11.5	13.5	9	12
Speaker 3	5.5	**9.5**	8.5	11

/t/-/ṭ/

For Speaker 1 the /t/-/ṭ/ contrast was between upper apical alveolar and apical and sublaminal postalveolar stops. There is no difference in closure duration between the two stops, but the alveolar has a longer VOT (40 msec vs. 15 msec for /ṭ/). In this case, the preceding vowels are of the same quality, so it is easy to see the clear difference in F3 and F4 transition value going into the stops (compare /ṭ/ in Fig. 3.27 with /t/ in Fig. 3.21). Both of these formants are lower before /ṭ/, presumably because of the increase in the size of the sublingual cavity.

Comparing the spectra given in Fig. 3.27 with those of /t/ from Fig. 3.22, the major difference seems to be a low frequency peak around 1500-2000 Hz in /ṭ/ which is not found in /t/.

For Speaker 1, these two stops are thus distinguished acoustically by VOT, F3 and F4 transitions and spectral shape of the burst transient.

Speaker 2 also made the /t/-/ṭ/ contrast between alveolar and postalveolar stops. The alveolar stop was apicolaminal and the postalveolar stop was apical and sublaminal, with a much shorter constriction for /ṭ/. The mean duration of the two consonants is nearly the same, but the VOT is shorter for /ṭ/ (mean of the two utterances for each segment is 5 msec for /ṭ/ vs. 15 msec for /t/). Both F2 and F4 are lower in the transitions before /ṭ/ (compare Figure 3.28 with Figure 3.23). Within each segment, the two spectrum tokens differ quite a bit for this speaker, so it is difficult to find a consistent difference between the bursts of /t/ and /ṭ/.

The acoustic differences between these two stops for Speaker 2 are a shorter VOT and lowered F4 in /ṭ/, as well as the raised F2 in /t/ noted in the last section.

For Speaker 3, both stops were alveolar, with /t/ apicolaminal and /ṭ/ apical, with a shorter constriction for /ṭ/. As with the other two speakers, there is no difference in

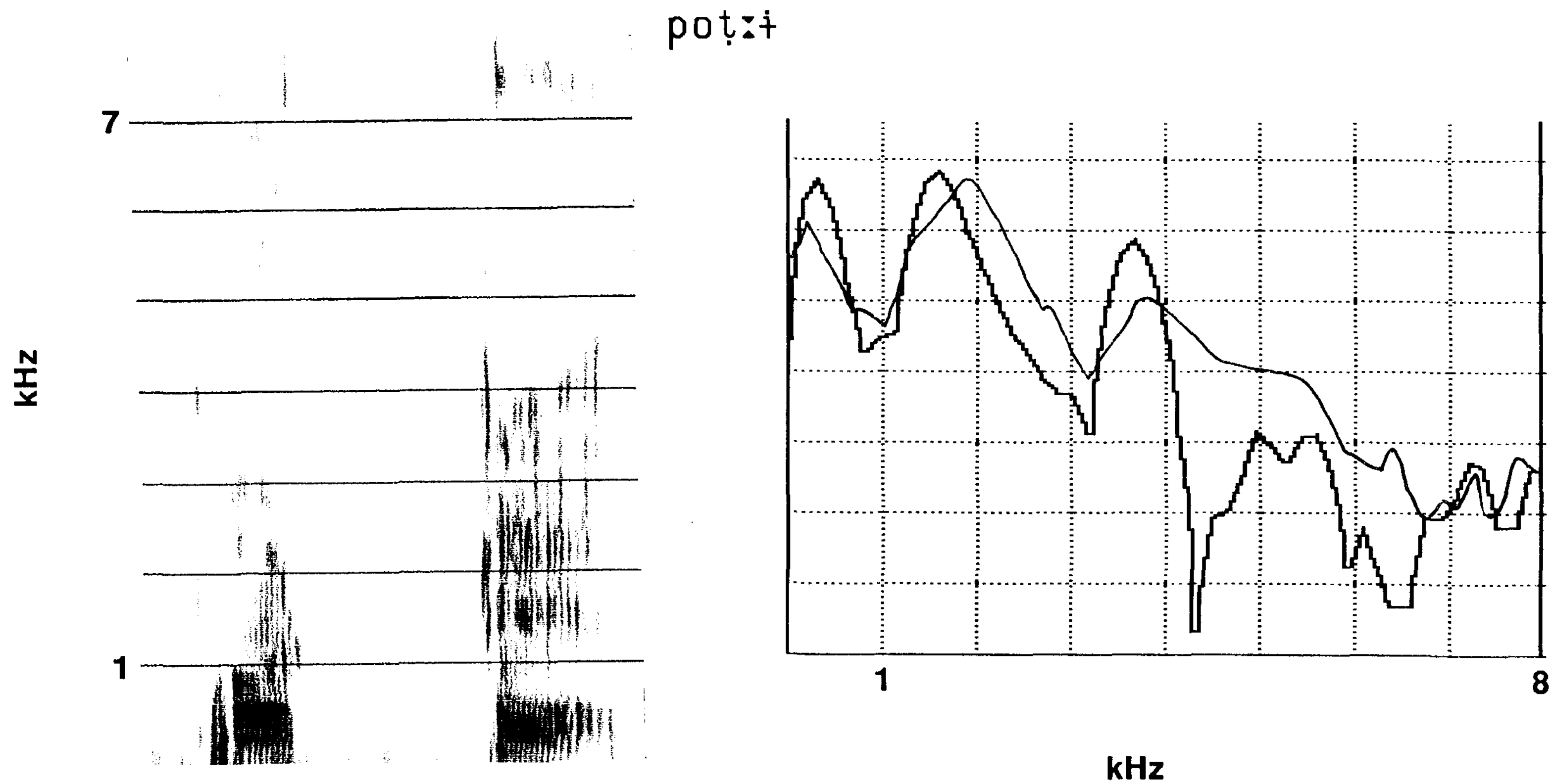


Figure 3.27. Spectrogram and transient spectrum of the medial consonant in Malayalam /poṭːɨ/ for Speaker 1.

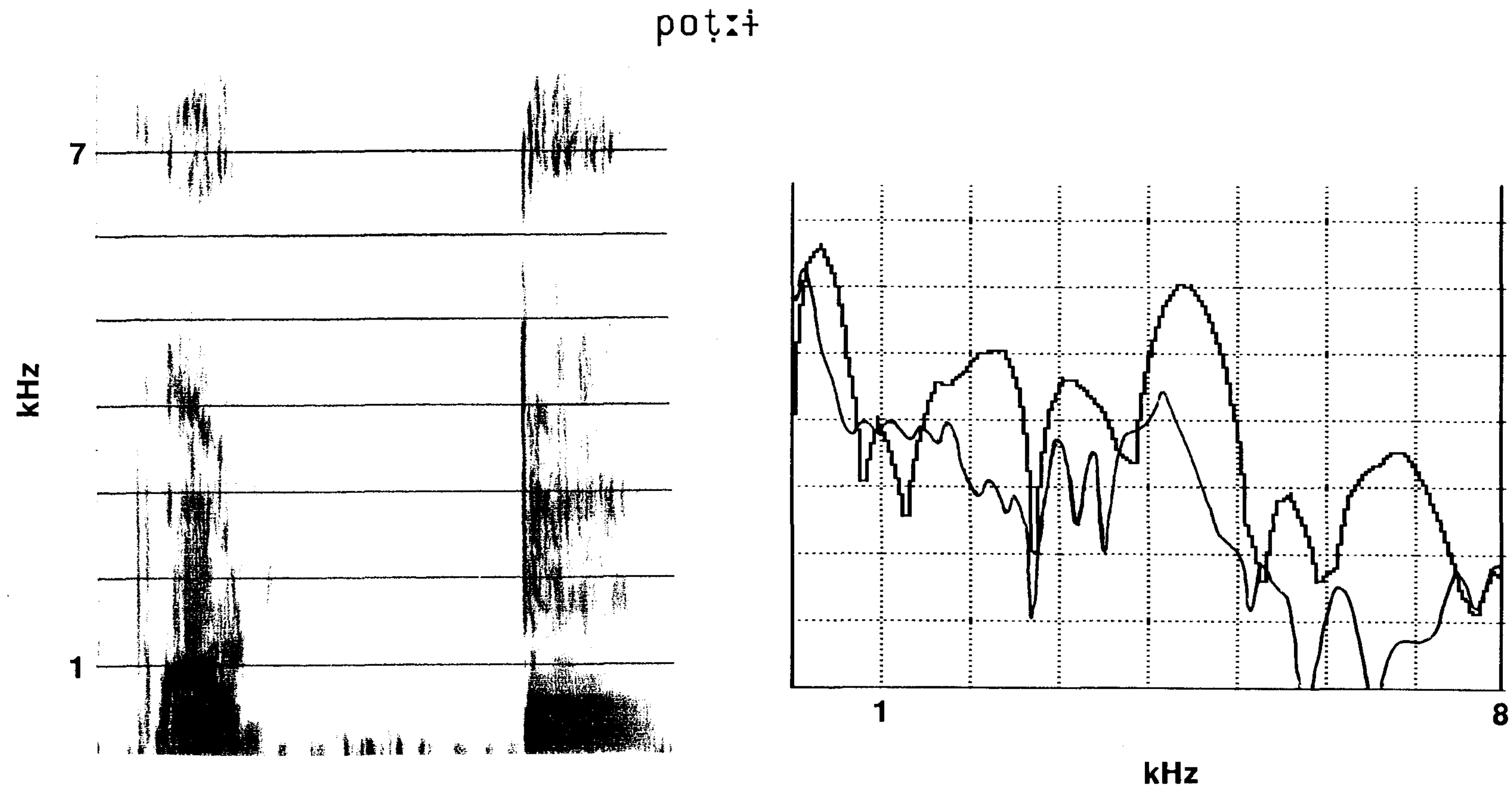


Figure 3.28. Spectrogram and transient spectrum of the medial consonant in Malayalam /poṭːɨ/ for Speaker 2.

closure duration, but /ṭ/ has the shorter mean VOT (although, as can be seen in the spectrograms in Figures 3.25 and 3.29, VOT is quite short in both segments). Again, the major difference in formant transitions is a lowering of F3 and F4 before /ṭ/. In the burst transient spectrum, /t/ has much more energy above 2000 Hz than does /ṭ/, which has a falling spectrum.

Summary /t/-/ṭ/

The consistent acoustic differences between /t/ and /ṭ/ for all three speakers are a shorter VOT in /ṭ/ as well as a lowered F4 (and for two speakers F3 also), probably caused by the increase in sublingual cavity size.

/t/-/c/

Both /t/ and /c/ were alveolar for all three speakers, which gives an excellent opportunity for contrasting articulations involving the tip of the tongue with those only involving the blade.

Speaker 1 contrasted an upper apical alveolar /t/ with a laminal alveolar /c/. There was very little difference in constriction length. Average closure duration for /c/ is shorter than for /t/ (160 msec vs. 205 msec) but VOT is longer (100 msec vs. 40 msec), so the total consonant duration is about the same for the two.

In the case of [potːa] and [ocːa] the vowels both before and after the consonants are of the same quality, so the formant values shown in Figure 3.30 can be compared straightforwardly to those in Figure 3.21. The most striking difference is the coming together of F2 and F3 both before and after the /c/ closure. This is the result of a lowering of F3 in both places and a raising of F2 in preconsonantal position. The burst transient spectra are different in that there is more energy in the higher frequencies (above 5000 Hz) in the /c/ burst. /t/ and /c/ are thus distinguished for Speaker 1 by VOT, F2 and F3 transitions and spectrum of the burst transient.

Speaker 2 contrasted apicolaminal alveolar /t/ with laminal alveolar /c/, with /c/ having a slightly shorter constriction. The mean closure duration is not different between the two segments. As with Speaker 1, /c/ has a longer mean VOT than /t/ (50 msec vs. 15 msec), although the difference for this speaker is not so great. /c/ is also characterized by multiple bursts.

Comparing the spectrogram of /c/ in Figure 3.31 with that of /t/ in Figure 3.23, it can be seen that this speaker had an F2-F3 convergence in both segments, and the transitions coming out of the two consonants are almost identical. In preconsonantal position, both F2 and F4 are higher in the /c/ tokens: F2 presumably because of a higher tongue body behind the constriction and F4 because of a smaller sublingual pot̪ːɨ

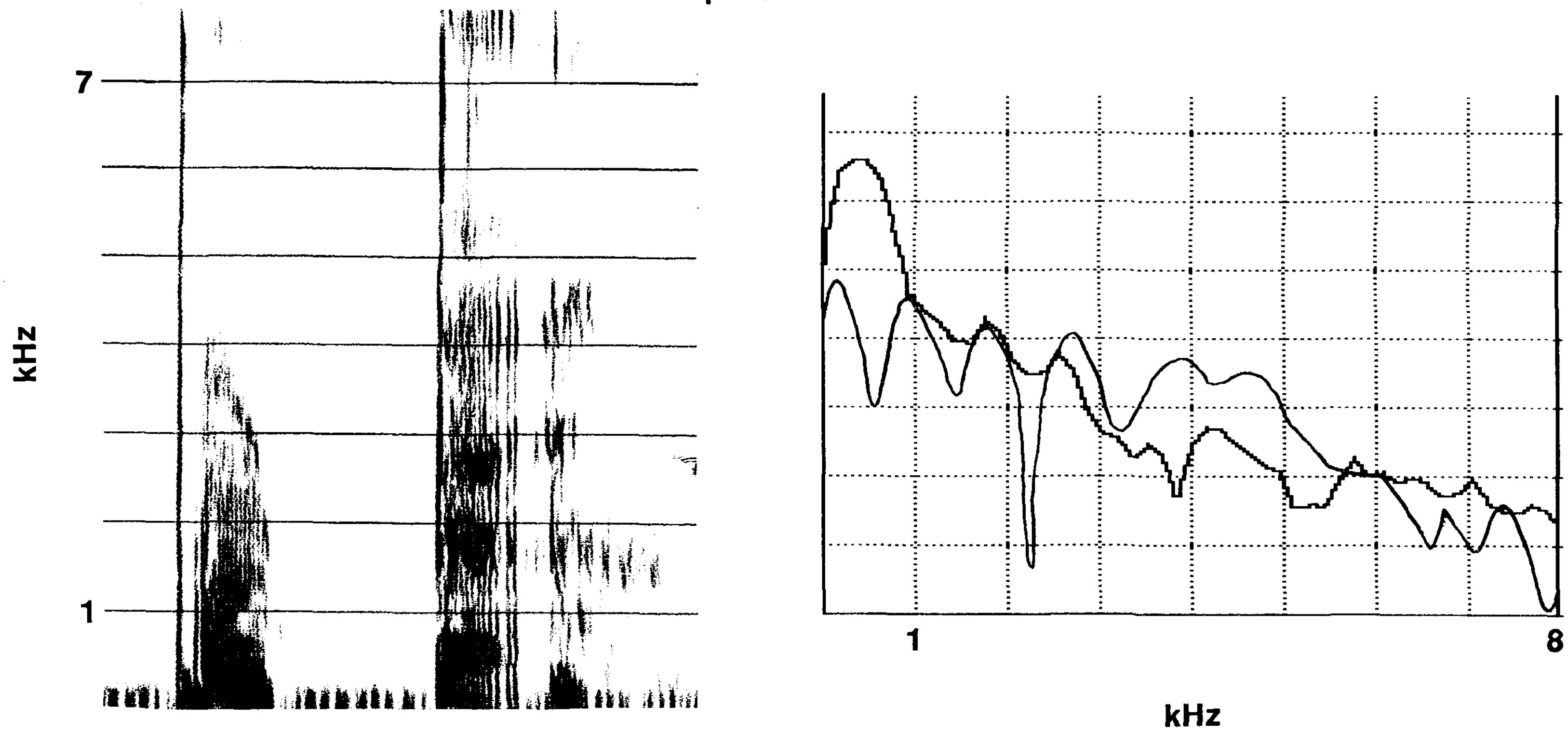


Figure 3.29. Spectrogram and transient spectrum of the medial consonant in Malayalam /pot̪ːɨ/ for Speaker 3.

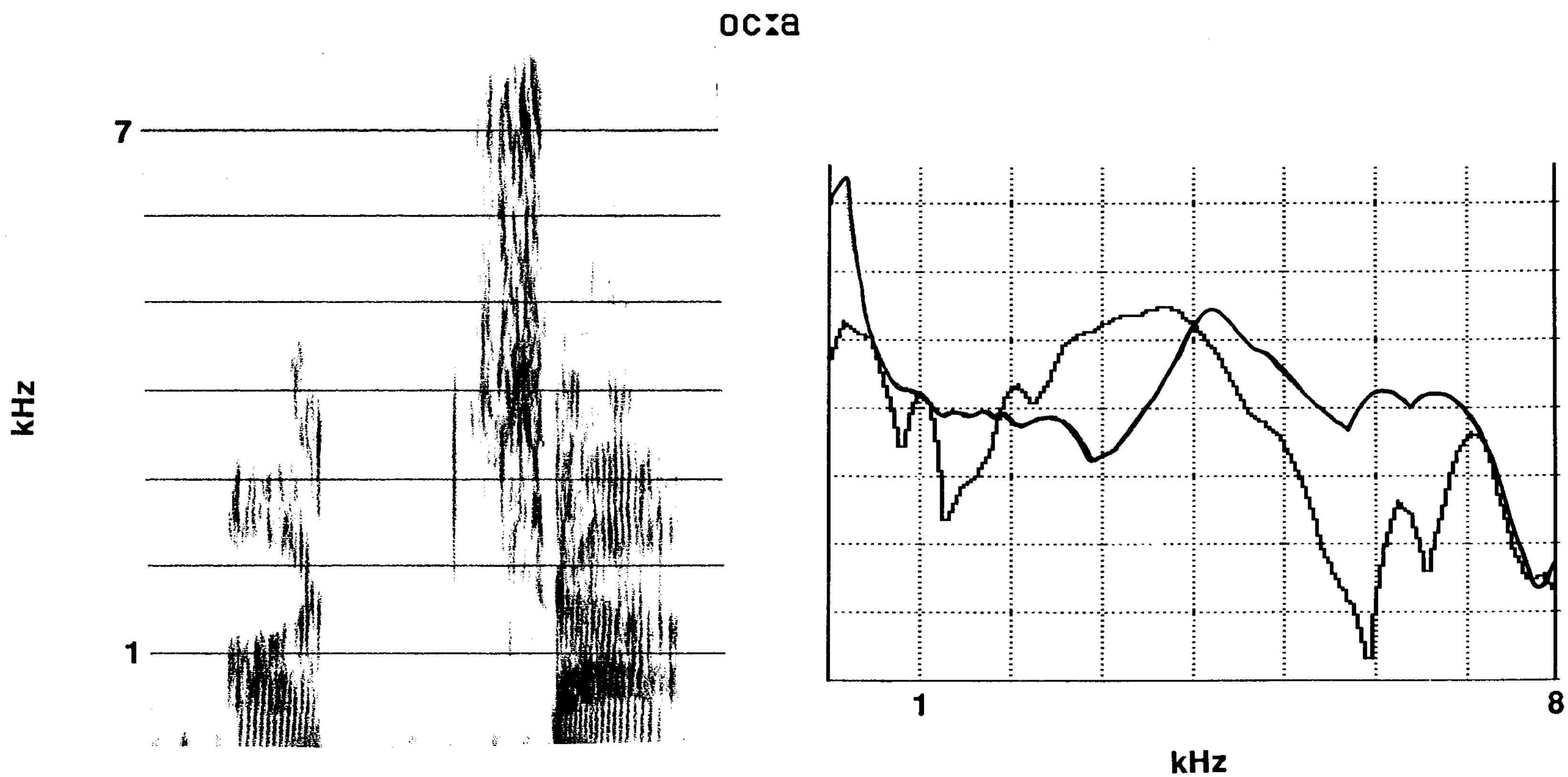


Figure 3.30. Spectrogram and transient spectrum of the medial consonant in Malayalam /ocːa/ for Speaker 1.

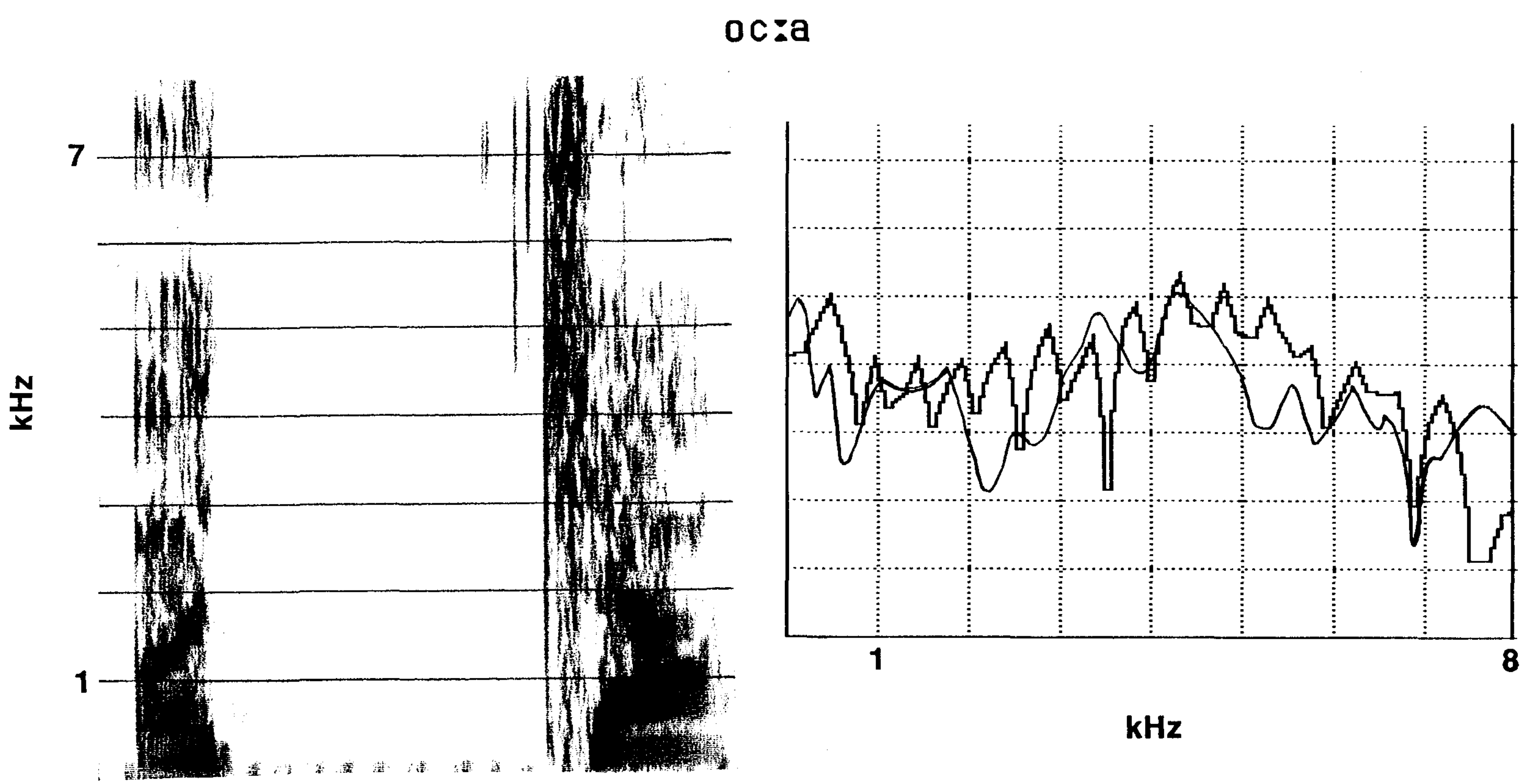


Figure 3.31. Spectrogram and transient spectrum of the medial consonant in Malayalam /ocːa/ for Speaker 2.

cavity, due to the fact that the tip of the tongue is in front of the constriction. The energy in the /c/ burst spectrum is centered in the mid frequencies, with a peak between 4000 and 5000 Hz, sloping down gradually on both sides. In one of the /t/ tokens (Figure 3.24) there is higher amplitude noise in the frequencies above 5000 Hz, which is not present in the /c/ burst (Figure 3.31). Because of the variation in the spectra of the two /t/ tokens, it is difficult to cite reliably any differences between the two segments.

/t/ and /c/ are thus distinguished acoustically by Speaker 2 in VOT and the second and fourth formant frequencies.

Speaker 3 also distinguished an apicolaminal alveolar /t/ from a laminal alveolar /c/, with /t/ having a slightly longer constriction. Closure duration is not different for the two segments, but /c/ has a slightly longer mean VOT (40 msec vs. 10 msec for /t/). Going into the consonant, as can be seen in the spectrogram in Figure 3.32, F2 is higher in /c/ than in /t/ (Figure 3.25). There is again so much variation in the burst transient spectrum (Figure 3.26 and 3.32) within each segment that it is difficult to state confidently any differences beween them.

Summary /t/-/c/

For all the three speakers, this was a contrast between tip up (either upper apical or apicolaminal) alveolars and laminal alveolars where the tip was either down behind the lower incisors or up near, but not touching, the upper incisors. All three had a longer VOT for the laminal segment, although it was not clear whether this segment could be called an affricate for all speakers. In each case F2 was also higher before the /c/ closure, indicating a higher tongue body behind the constriction.

3.3.2 Nasals

Comparing the apical, apicolaminal and laminal nasals in the Malayalam data is rather difficult because of the unfortunate differences in vowel quality, but a careful study of the spectrograms in Figure 3.33 seems to offer evidence that F1 is lowest in the laminal nasal, higher in the apicolaminal nasal and highest in the apical nasal, presumably due to diminishing pharynx width from laminal to apicolaminal to apical. Similarly, F2 appears to increase in the order apical-apicolaminal-laminal, indicating a progression in tongue body height behind the constriction.

In Chapter 2, it was noted that Malayalam nasals had more extreme tongue positions than the equivalent stops and it was hypothesized that this would lead to more extreme formant transition values. In the acoustic data, however, there seems to be less difference in the formant transitions for nasals than for stops. Looking at the spectrograms in Figures 3.34-3.36 it can be seen that, although each speaker makes differences between the four segments, they are not consistent with the contrasts

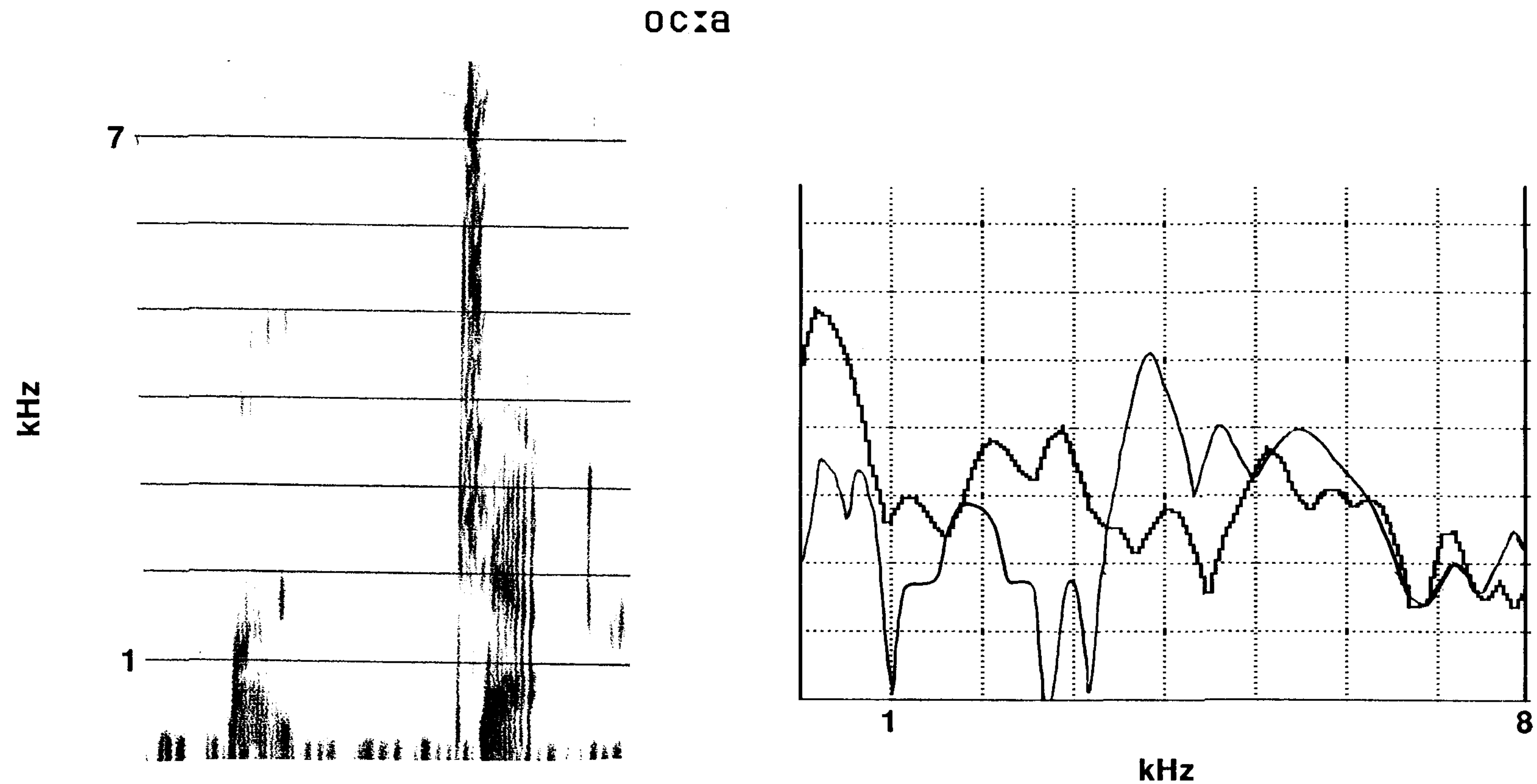


Figure 3.32. Spectrogram and transient spectrum of the medial consonant in Malayalam /ocːa/ for Speaker 3.

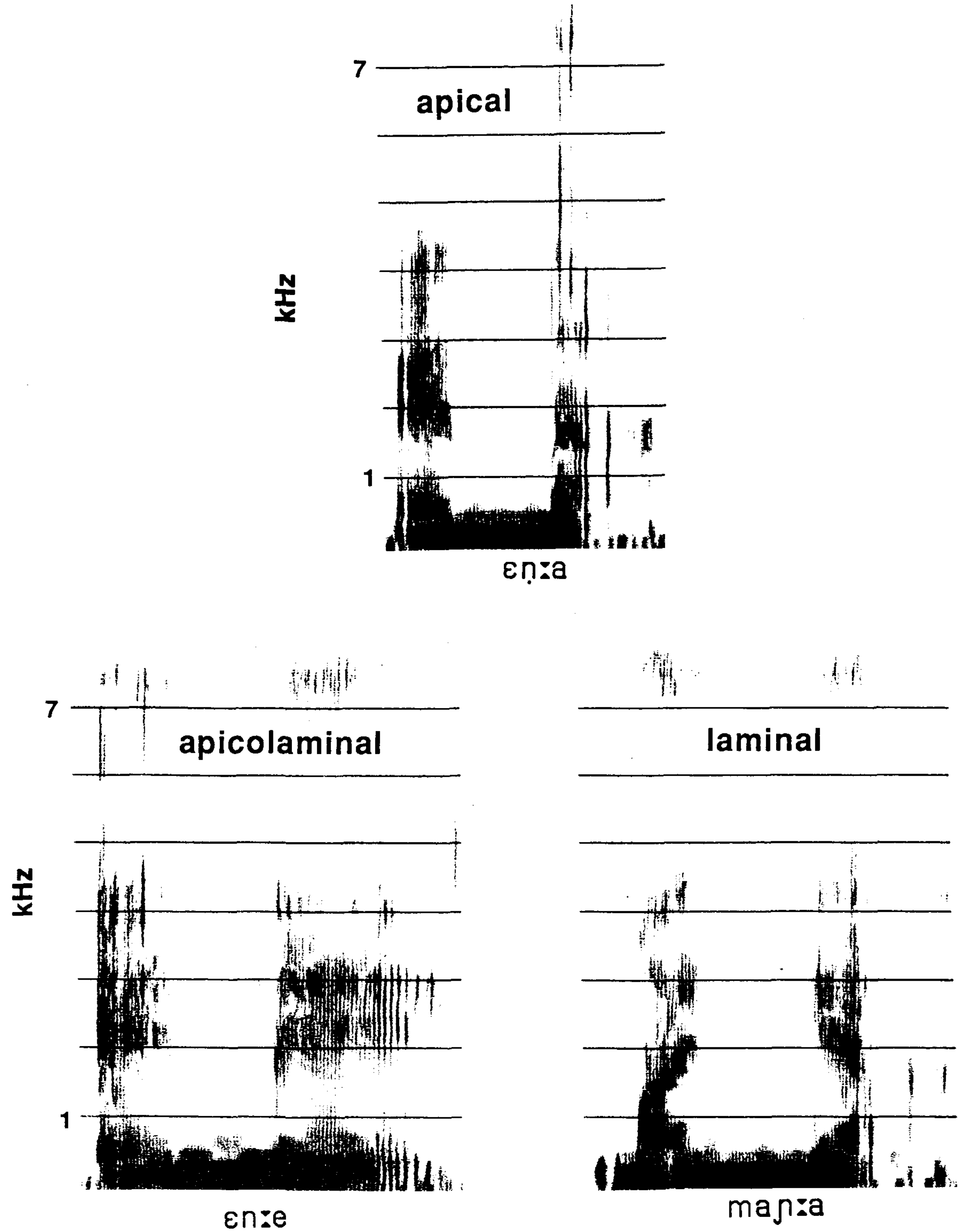


Figure 3.33. Spectrograms of words with apical, apicolaminal and laminal nasals from one Malayalam speaker.

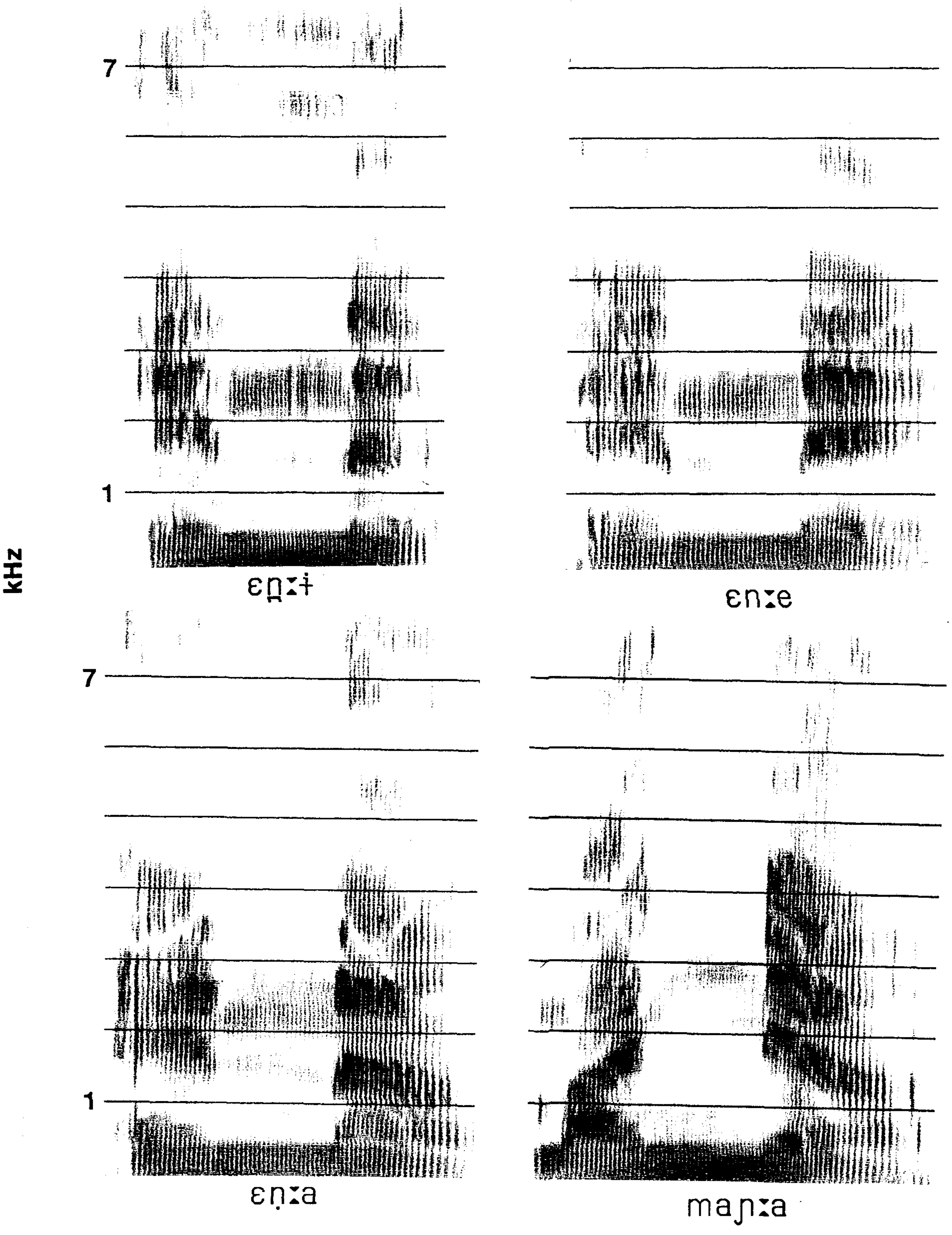


Figure 3.34. Spectrograms of words containing four contrasting nasals for Speaker 1.

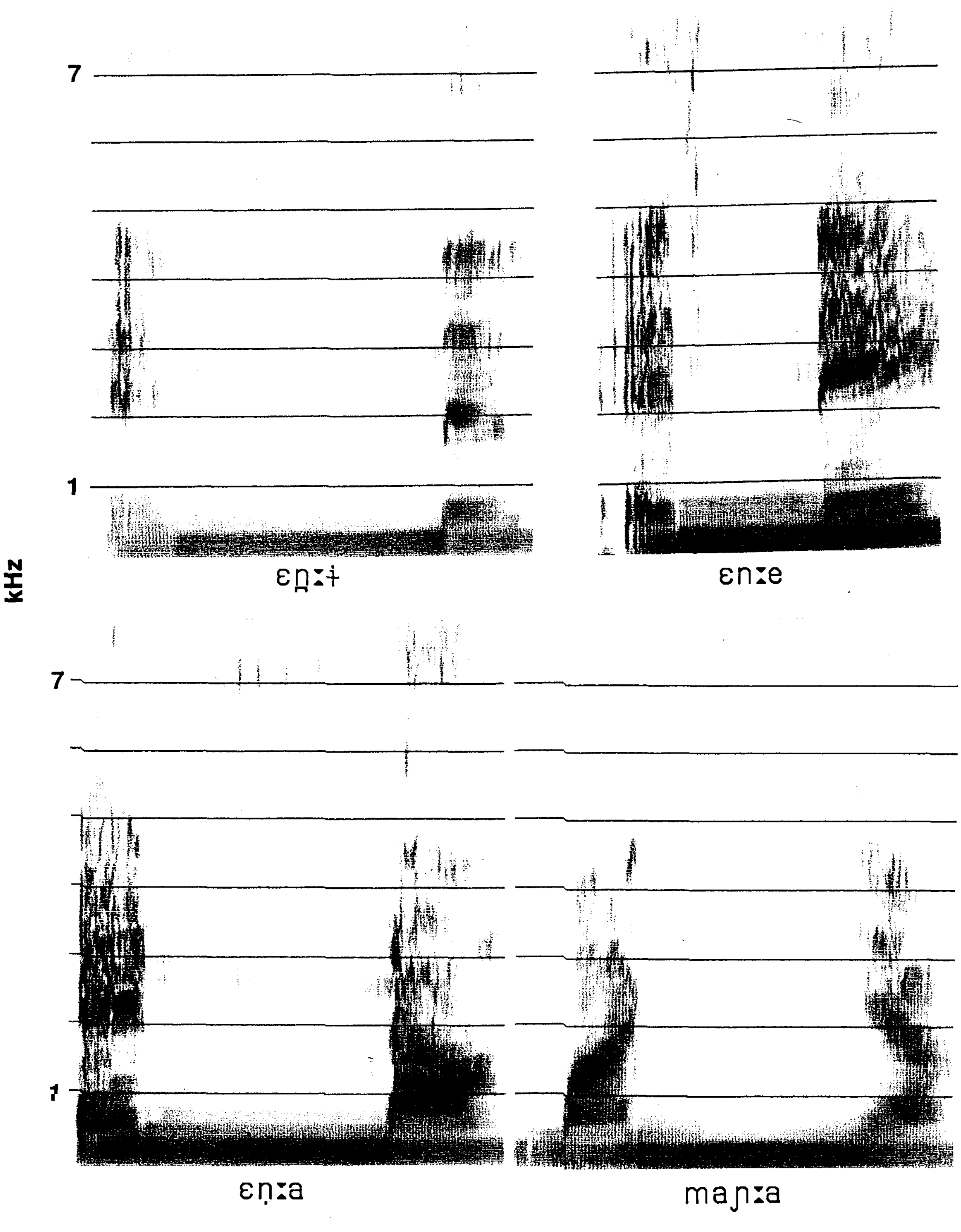


Figure 3.35. Spectrograms of words containing four contrasting nasals for Speaker 2.

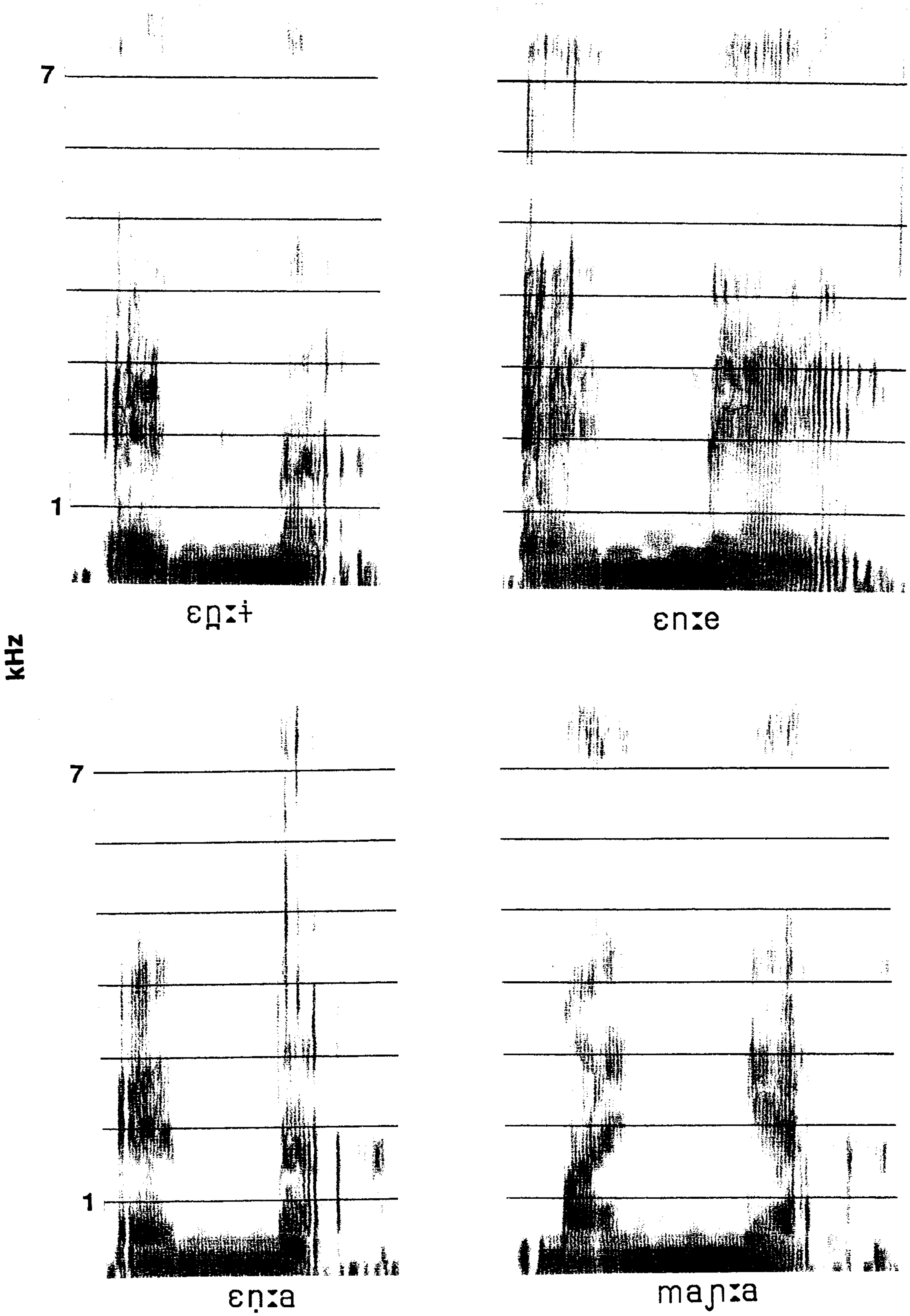


Figure 3.36. Spectrograms of words containing four contrasting nasals for Speaker 3.

made by the other speakers.

Speaker 1, for example, has very similar transitions from the vowel /ɛ/ into /n̪/, /n/ and /ṇ/. /n/, however, has the highest F1 and /n̪/ perhaps the highest F2. /ɲ/ is more distinct, with clearly the highest F2 and a low F1.

The formants of Speaker 2 (Figure 3.35) are harder to see, but it appears that the chief difference between /n̪/, /n/ and /ṇ/ is a higher F3 and F4 for /n/, not only in comparison with the postalveolar /ṇ/, which one would expect because of the difference in sublingual cavity size, but also in comparison to /n̪/. Both segments were apicolaminal, the only difference being that /n̪/ was dental and /n/ alveolar, so it is odd that the dental should appear to have the larger sublingual cavity. As with the previous speaker, /ɲ/ has a clearly higher F2 than the other segments when we take into account the differences in vowel quality.

Only Speaker 3 has the same F2 difference between the dental and alveolar segments that was observed in the voiceless stops, that is, a higher F2 before alveolar closure. This was the speaker with the least difference in the apicality and place of articulation measures, but with a large difference in width of contact behind the constriction. In /ɲ/ F2 is high especially after consonant release (Figure 3.36).

The only consistent difference between nasal segments for all speakers was a higher F2 in the laminal alveolar /ɲ/. There is very little differentiation in transition frequencies among the other three segments, which is surprising, given the fact mentioned in Chapter 2 that the contrasting Malayalam nasals were found to have more of an articulatory difference than the contrasting stop pairs. As previously mentioned, one would expect to see more of a difference in tongue shape in nasals because of the lack of burst characteristics to help differentiate the contrasting segments. There is clearly more work which needs to be done on the acoustic differences between these nasal phonemes. It might be useful to combine an acoustic analysis with an auditory recognition test, to check which samples were more readily identifiable by native speakers.

Before concluding the discussion of Malayalam, notice that Speaker 3 provides interesting contrasting data for the different linguagraphic categories. Her /ṭ/ is apical alveolar (5) and /c/ laminal alveolar (5), the only difference being apical or laminal articulation. Similarly, in the nasals she contrasts three linguagraphic categories in the same place of articulation (alveolar 5): apical /ṇ/, apicolaminal /n/ and laminal /ɲ/.

Comparing apical with laminal (/ṭ/ with /c/ and /ṇ/ with /ɲ/) the following profile emerges. The laminal segment has a lower F1 and a higher F2, and in the voiceless stop series, the apical segment also has lower F3 and F4 transitions. This agrees exactly with the predictions at the beginning of this chapter and suggests that the laminal segment is produced with a wider pharynx, a higher tongue body and a smaller sublingual cavity than the corresponding apical segment for the same speaker. These are not, as we have seen, necessary properties of all laminals, but within the speech of this one individual, the formant values are in agreement with the hypothesized articulatory differences.

3.4 Results: Contrastive segments: 'O'odham

3.4.1 Stops and affricates

/d̪/-/d/

Recall from the discussion in Chapter 2 that for 6 out of the 7 speakers who made this distinction, /d̪/ in [aʔad̪a] was articulated farther forward than /d/ in [adawi̥]. Three speakers made a contrast between apicolaminal dental /d̪/ and apical alveolar /d/; two speakers between laminal dental /d̪/ and upper apical alveolar /d/, one speaker between apicolaminal dental /d̪/ and apical postalveolar /d/ and the last speaker with no place of articulation difference, between apicolaminal alveolar /d̪/ and laminal alveolar /d/, thus all but one having a contrast between a blade articulation for /d̪/ and a tongue tip articulation for /d/. All speakers had a longer constriction for /d̪/. The question now arises as to whether there is a constant acoustic difference between these two segments, despite the variation in articulation, particularly in linguagraphic classification.

There was no difference in the mean closure duration of /d̪/ and /d/ (120 msec for /d̪/ and 115 msec for /d/. The mean differences between transition and steady-state vowel formant frequencies both before and after /d̪/ and /d/ are given in Table 3.31. Not all of the formants were visible in the spectrograms of all of the speakers. The number of speakers represented in each mean is given in parenthesis.

Table 3.31. Mean difference between formant transition and steady-state vowel frequencies for 'O'odham /d̪/ and /d/ (7 speakers for /d̪/, 8 speakers for /d/, two tokens each), rounded off to the nearest 5 Hz.

	F1	**F2**	**F3**	**F4**
/d̪/				
--C	-220 (7)	+155 (7)	+135 (7)	+295 (6)
C--	-270 (6)	+210 (6)	+155 (6)	+375 (5)
/d/				
--C	-220 (8)	+240 (8)	+15 (8)	+50 (6)
C--	-280 (8)	+195 (8)	-115 (8)	+40 (7)

There was no significant difference in F1 between /d̪/ and /d/. There was, however, a substantially higher F2 on the transition into /d/, but very little difference in F2 on the transition out. Six out of the seven speakers made the difference in this direction preconsonantally. The other speaker had higher F2 transition values for /d̪/. This was one of the two speakers (Speaker 2) who had a laminal dental articulation for /d̪/ contrasting with upper apical alveolar articulation for /d/.

Both preconsonantal and postconsonantal F3 transitions had lower mean values for /d/ than /d̪/. This was true individually for six of the seven speakers. One speaker had higher F3 values for /d/ (Speaker 7, who had a laminal alveolar /d/ articulation contrasting with an apicolaminal /d̪/ in the same place of articulation).

Five speakers had lower F4 for /d/ in both preconsonantal and postconsonantal transitions. The other two speakers did not have a visible fourth formant in one or the other of the segments, so they could not be compared.

The burst transient spectra from different types of /d̪/ and /d/ are given in Figure 3.37. The spectra of the laminal dental /d̪/ burst are different for the two speakers, so those of one speaker appear on the figure as dotted lines, to differentiate the two. The major difference between the two segments, no matter what the type of articulation, was a steeper slope leading to lower amplitude noise in the higher frequencies above 6000 Hz for /d/. The slope of the /d̪/ burst spectra was flatter. The exception to this is the speaker (Speaker 7) who had no place of articulation difference between these two segments. Comparing this speaker's apicolaminal alveolar /d̪/ burst spectra with her laminal alveolar /d/ spectra, the major difference appears to be more energy in the mid frequencies between 4000 and 6000 Hz in the /d/ burst.

Except for this one speaker, the consistent acoustic differences for all speakers between /d̪/ and /d/ are a lower amplitude spectrum in the higher frequencies of the /d/ burst, and a higher F2 and lower F3 and F4 transition both into and out of /d/. The lowering of the higher formants appears to be clearly a place of articulation difference, since the only speaker who differed was the one for whom both segments were alveolar. It would be interesting to use these data in an auditory identification experiment with 'O'odham listeners, to see whether this speaker produced words that were more difficult to identify correctly.

Recall that in the Malayalam data the consistent difference between /t̪/ and /t/ was a higher F2 for /t/, which corresponded also with a greater width of contact behind the constriction. Table 3.32 gives the width of contact on one side behind the constriction measured on the palate casts from the contact shown in the palatograms for the seven

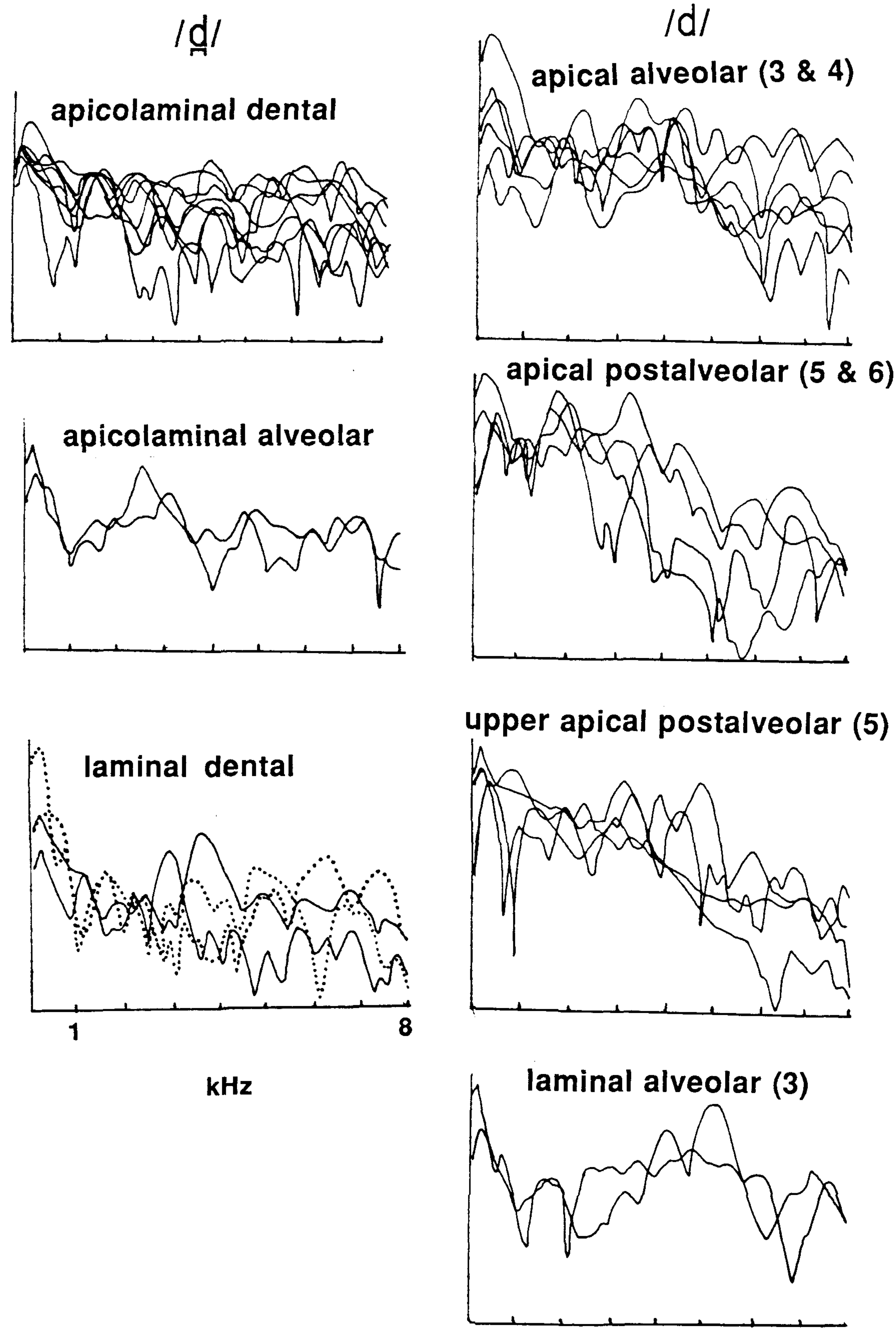


Figure 3.37. Burst transient spectra from different types of articulation of 'O'odham /d̪/ and /d/. The numbers in parenthesis refer to place of articulation classifications.

speakers who made the /d̪/ - /d/ distinction. Except for Speaker 7, there is more contact for all speakers during the /d/ articulation, further evidence for a higher tongue body.

Table 3.32. Width of contact at the first molar for seven 'O'odham speakers' articulation of /d̪/ and /d/ (in mm).

Speaker	**2**	**3**	**4**	**5**	**6**	**7**	**8**
/d̪/	4.5	5	9	11	7	5	6.5
/d/	7	7	12	15	12.5	2	12

/d/-/ɟ/

Six of the 8 speakers had a laminal articulation for /ɟ/, ranging in place from dental (1 speaker) to alveolar (4 speakers) to postalveolar (1 speaker). Two speakers produced this segment as an apicolaminal alveolar. Unlike the /d̪/-/d/ distinction, which was basically a place of articulation distinction for all but one speaker, the /d/-/ɟ/ distinction for most speakers is one of apicality. For one speaker both segments are laminal, but /ɟ/ is farther back, and one speaker makes a difference in both variables.

Since /ɟ/ was utterance initial in the data (the test word was [ɟɨʔɨ]), closure duration could not be measured. Mean time from stop release to the resumption of the periodic voicing of the vowel (to parallel the VOT measurement in the Malayalam data) for /ɟ/ was 65 msec (ranging from 50 msec to 95 msec) and for /d/ was 11.5 msec (ranging from 0 to 25 msec), illustrating the slower or more turbulent release for the blade articulation (either laminal or apicolaminal).

Table 3.33 compares the postconsonantal formant transitions values of /d/ and /ɟ/ for all speakers. The number of speakers represented in each mean is given in parenthesis.

Table 3.33. Mean difference between postconsonantal formant transition and steady-state vowel frequencies for 'O'odham /d/ and /ɟ/ (8 speakers, two tokens each), rounded off to the nearest 5 Hz.

	F1	**F2**	**F3**	**F4**
/d/				
C--	-280 (8)	+195 (8)	-115 (8)	+40 (7)
/ɟ/				
C--	0 (8)	+330 (8)	-80 (8)	-225 (7)

Since the vowel qualities following the two consonants are different, mean formant values for the steady-state portion of the vowel which follows each consonant were computed, to see where the two vowels differed. These values are given in Table 3.34.

Table 3.34. Mean formant values for steady-state [ɑ] and [ɨ] for seven female 'O'odham speakers.

	F1	F2	F3	F4
[ɑ]	820	1365	2900	3865
[ɨ]	465	1360	2920	3920

It can be seen from this table that the major difference between the two vowels is in the first formant values, which are considerably higher for /ɑ/ than for /ɨ/. Keeping this in mind, it is clear that /d/ has, on the average, a much lower F1 in relation to the F1 of the following vowel, yet still a higher absolute value of F1 than /ɟ/. This could indicate a wider pharynx during the /ɟ/ articulation, or could be a reflection of a smaller jaw opening (or both possibilities). From a visual examination of the speakers during /ɟ/ articulation, many of them did appear to produce this sound with the teeth clenched.

Mean F2 value was higher for /ɟ/ than /d/, just as was found for Malayalam /c/ vs. /t/. This was true individually for 6 of the 8 speakers. Mean F3 was also slightly higher for /ɟ/, but this was the case for only half of the speakers. A lower mean F4 after /ɟ/ was also found, the opposite to what one might expect, since F4 lowering should indicate an increase in sublingual cavity size. Four speakers individually had a lower F4 for /ɟ/, one lower for /d/ and one no difference (two speakers' F4 values were unreadable for one of the segments).

Figure 3.38 shows burst transient spectra for 'O'odham /ɟ/. In general, the laminal /ɟ/ burst spectra tend to have more energy in the higher frequencies than those of /d/ (Figure 3.37), and some /ɟ/ tokens also have a high amplitude peak around 3000-5000 Hz. The difference is not so clear for the apicolaminal /ɟ/ tokens. Both speakers contrasted this with an apical alveolar /d/, the main difference being a higher amplitude peak in the mid frequencies for /ɟ/.

The most consistent acoustic differences between 'O'odham /d/ and /ɟ/ are a lower F1 and a higher F2 for /ɟ/, as well as a longer time from release to resumption of the vowel for /ɟ/ (as in Malayalam, it was unclear whether these segments should be called affricates or stops). Recall that for 7 of the 8 speakers, /ɟ/ was a blade articulation and /d/ was not. The formant values can be explained by a wider pharynx, more closed jaw and higher tongue body in the laminal segment, following exactly the predictions given at the beginning of the chapter.

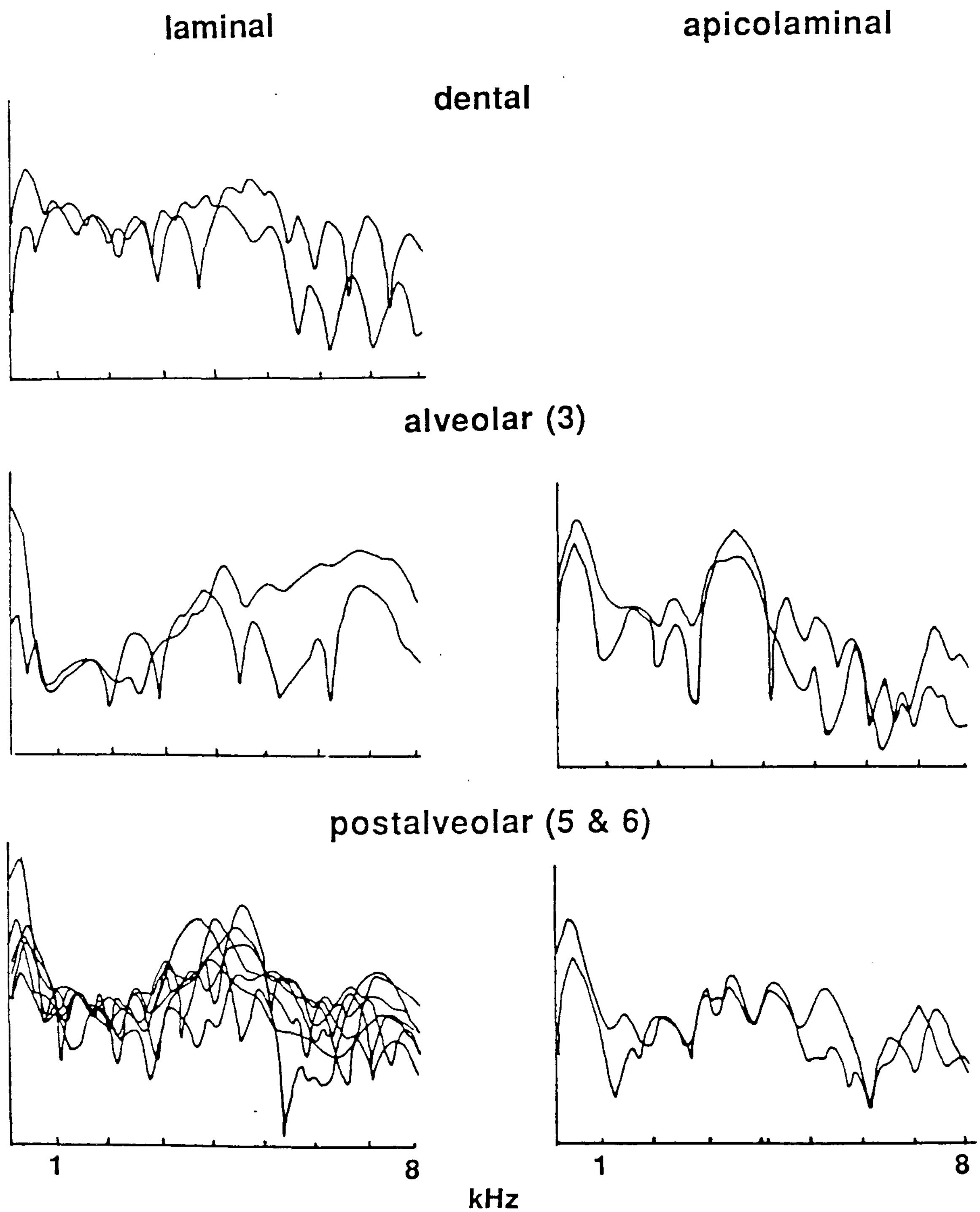


Figure 3.38. Burst transient spectra from different types of articulation of 'O'odham /ɟ/.

3.4.2 Fricatives

/s/-/ṣ/

For all 8 speakers, /ṣ/ in [haṣaba] was apical and quite far back (place classifications 5-7). /s/ in [haʔasa] was more varied, with 5 speakers producing a laminal alveolar fricative, 2 an apical alveolar and one an apical dental. There was no significant difference in constriction duration between /s/ and /ṣ/. The essential articulatory difference between the two fricatives was place of articulation.

Table 3.35 gives the mean formant transition values of all the speakers for /s/ and /ṣ/.

Table 3.35. Mean difference between formant transition and steady-state vowel frequencies for 'O'odham /s/ and /ṣ/ (8 speakers, two tokens each), rounded off to the nearest 5 Hz. The number of speakers represented is given in parenthesis.

	F1	F2	F3	F4
/s/				
--C	-20 (8)	+185 (8)	+205 (8)	+450 (7)
C--	-225 (8)	+25 (8)	+195 (8)	+245 (6)
/ṣ/				
--C	-45 (8)	+205 (8)	-225 (8)	-150 (7)
C--	-220 (8)	+130 (8)	-585 (8)	-490 (7)

The obvious difference between these two fricatives in terms of formant transitions is the dramatically lower F3 and F4 values preceding and following /ṣ/, no doubt due to the much larger sublingual cavity in the postalveolar fricative, because of the more posterior place of articulation. Every speaker had a large difference in these values, particularly in the postconsonantal transitions. The higher mean F2 value for /ṣ/ was mainly a consequence of the large difference made by two of the speakers for whom both of the fricatives were apical.

Figure 3.39 gives the spectra of the two fricatives. It can be seen that the spectra are very consistent, whatever the articulatory strategy employed. /s/ has a very flat spectrum which, in the laminal fricative, rises in the higher frequencies. The /ṣ/ spectrum has the greatest amount of amplitude between 1500 and 5000 Hz and then drops off in the higher frequencies.

The /s/-/ṣ/ distinction is thus clearly marked acoustically by F3 and F4 transition values and spectrum of the fricative noise itself.

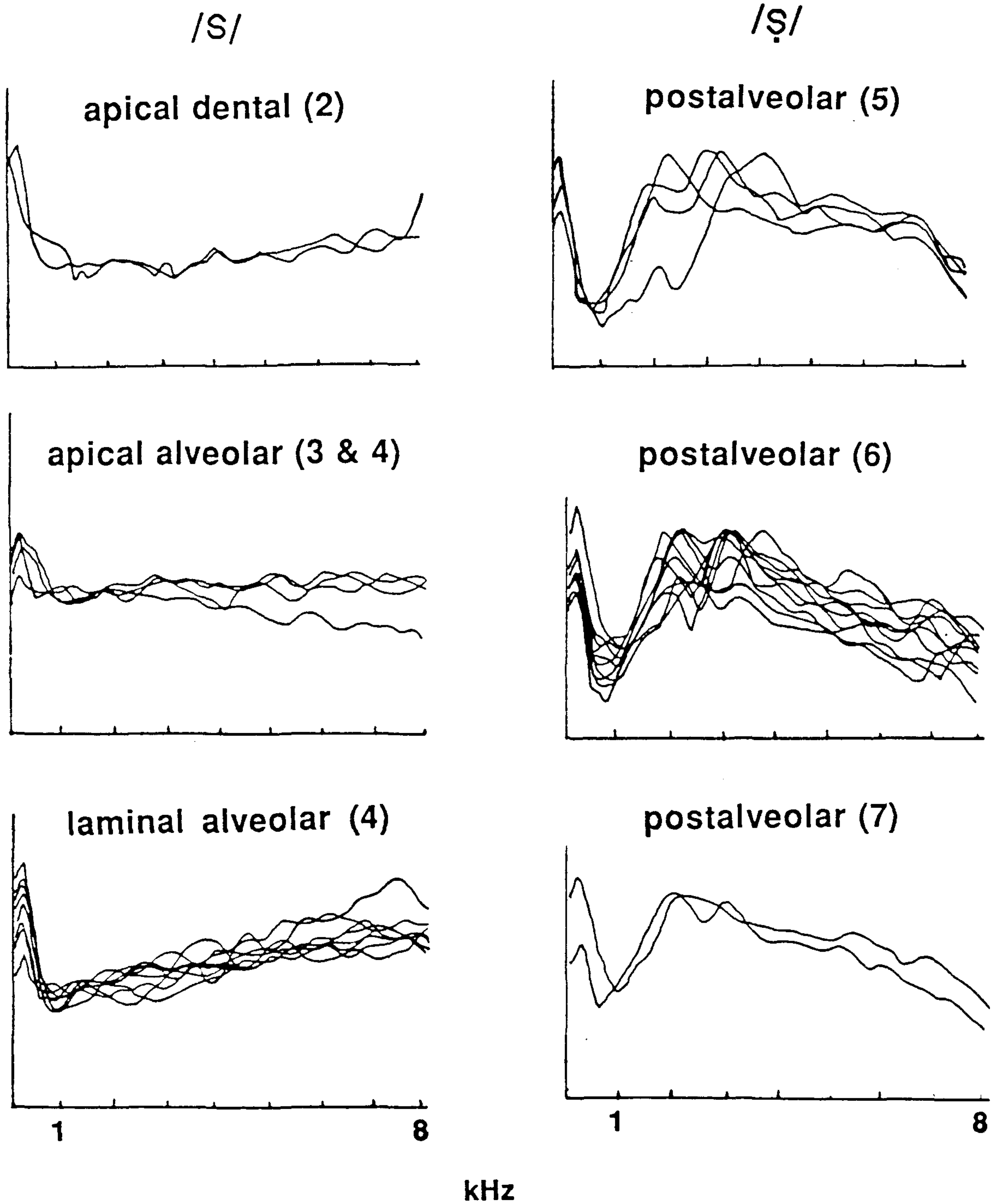


Figure 3.39. Spectra from different types of articulation of 'O'odham /s/ and /ṣ/. The numbers in parenthesis refer to place of articulation classifications.

3.5 Summary of contrastive data

Tables 3.36 and 3.37 summarize the acoustic and articulatory differences in the voiceless stop series in Malayalam and the voiced stop and voiceless fricative contrasts in 'O'odham.

Table 3.36. Differences and similarities in the articulation and the acoustics of the four Malayalam stops as pronounced by three speakers.

	/t̪/	/t/	/ṭ/	/c/
Speaker 1	(apico)laminal interdental	upper apical alveolar	sublaminal postalveolar	laminal alveolar
Speaker 2	apicolaminal dental	apicolaminal alveolar	sublaminal postalveolar	laminal alveolar
Speaker 3	apicolaminal alveolar	apicolaminal alveolar	apical alveolar	laminal alveolar
All speakers	apicolaminal lower tongue body	alveolar higher tongue body	sublingual cavity	laminal alveolar
VOT		shorter	even shorter	longer
Formants	F2 lower	F2 higher	F4 (&F3) lower	F2 even higher

Table 3.37. Summary of the articulatory and acoustic properties of the 'O'odham consonant contrasts for most speakers.

/d̪/	/d/	/ɟ/	/s/	/ṣ/
blade articulation	tip articulation	blade articulation		apical articulation
			alveolar	postalveolar
longer constriction	shorter constriction			
flat spectrum	falling spectrum		flat spectrum	high amplitude in mid frequencies
	shorter release	longer release		
	F1 higher	F1 lower		
F2 lower	F2 higher	F2 even higher		
F3, F4 higher	F3, F4 lower		F3, F4 higher	F3, F4 lower

In both Malayalam and 'O'odham, most of the speakers had a higher F2 adjacent to the "alveolar" stop than to the "dental" stop. Some of the speakers in both languages also had lower F3 and F4 values for the "alveolar" stop.

In the "apical alveolar" vs. "laminal alveolar" contrast, one difference found in both languages was a longer time from stop release to resumption of the periodic voicing of the vowel. In the formant transition data, both languages also had a higher F2 value for the laminal segment.

It appears that any comparison of what are described as the "same" contrasts in different languages is more reliably done in terms of acoustic parameters than articulatory ones. Although speakers in the two languages had a variety of place of articulation, apicality and constriction length differences, the formant frequency data was more uniform, suggesting that it is the overall tongue shape which is important in the distinction, rather than the exact location or size of contact between the passive and active articulators.

In the concluding chapter which follows, the data presented in the foregoing chapters will be summarized and discussed in terms of its relevance to current phonetic theory.

Chapter 4. Conclusion

4.0 Language-specific generalizations

The questions raised in the introduction can now be reconsidered in the light of the data set forth and analyzed in the subsequent chapters. Perhaps the easiest question to answer concerns the amount of variation within any one language. Are the speakers of a particular language consistent in using one kind of articulation, for example, apical or laminal? Is it possible to say that English is pronounced in a certain specific way and French in some other? In a general way, the statements that have been made about the production of English and French coronal consonants can be said to have some truth. It was demonstrated that there is a difference between apicality and place of articulation in the two languages, if one looks at the general statistical trend. French /t/, /d/ and /n/ were shown to be mostly dental and mostly apicolaminal, while the corresponding English segments were mostly alveolar and apical. In this broader sense, then, one can speak about a particular way that most speakers of a language behave in terms of these two variables. However, one must remain constantly aware that within one general category there also is a great deal of individual variation, so much that it is impossible to consider some particular articulation and say either that it must be or that it may not be an example from any specific language.

It follows that it would be a mistake, for example, to gather a group of speakers at random and profess to study a certain element of their speech production, assuming that they form an articulatorily homogeneous group simply because they are all native speakers of one language. There is every probability that some speakers will fall in with the general pattern and some will not. An example of this is the study of the acoustic properties of dental and alveolar consonants conducted by Jongman, Blumstein and Lahiri (1985), where the metric, devised to distinguish Malayalam "dental" and "alveolar" stops, accounted for only 2/3 of English "alveolar" and 2/3 of Dutch "dental" stops. Those speakers whose articulations failed to be correctly categorized by the metric were very likely articulating in another way. One point that emerges clearly from the present study is that in order to study the acoustic cues for a particular articulation, one must first make some attempt to verify that the actual method of articulation of the speakers used is indeed as predicted.

There is evidence from the acoustic study detailed in Chapter 3 that the general shape of the tongue body may be more important in determining both language-specific characteristics and within-language contrasts than the actual location of the constriction or the part of the articulators which make contact. It is possible to find, for example, both English and French speakers whose articulations of a particular consonant are virtually identical in terms of apicality and place of articulation. The acoustic characteristics of these articulations, however, are not identical and suggest that French is spoken with a higher tongue body behind the constriction and with less of a sublingual cavity than English. This evidence gives support to the notion of a language-specific "base of articulation" which is independent of the location of the constriction. Similarly, although there was variation in apicality and place of articulation among Malayalam and 'O'odham speakers, the acoustic data suggest that the contrasts are more consistently described by tongue body features, such as tongue height behind the constriction, or size of the sublingual cavity. Such evidence leads us to believe that a slight refining of what is meant by apical and laminal, so that it refers to overall tongue shape rather than contact portion of the tongue, would provide a more descriptively accurate feature.

4.1 Universal properties of the features apical and laminal

Disregarding differences related to the characteristics of specific languages, are there universal properties of apical and laminal consonants which inevitably result from these articulatory strategies? Looking first at the articulatory properties, we can now consider the interrelatedness of apical and laminal tongue shapes with place of articulation and constriction length. Are these three parameters independently variable or does one necessarily imply one or more of the others? The closest one can come to predicting one of these parameters on the basis of another is the necessary physiological constraints that make it difficult for a person with average oral morphology to make a dental articulation without also making a long constriction. In this sense it can be said that dental articulations, be they apicolaminal, apicosublaminal or laminal, have generally long constrictions, and are thereby justifiably called [+distributed]. This specification, of course, could only really be justified if some other group of sounds could be said to be consistently [-distributed]. Such a generalization cannot be made for alveolar consonants, since speakers can and do make closures in the alveolar region with either the apex or the blade, or with both together. By the same token these alveolar articulations can have constrictions of widely varying lengths and still be called 'alveolar'. It is evident then, that place of articulation does not necessarily determine either constriction length or part of the tongue used.

The more general question of whether laminals actually do have longer constrictions than apicals can only be answered in the affirmative if by laminals, apicolaminals are meant. The laminals have varying constriction lengths that can be quite short, especially if the part of the palate contacted is a very prominent alveolar ridge, or quite long, as in the case of a laminal dental stop or affricate, or an alveolar stop in a speaker with a smooth palate shape.

There is no one acoustic property which consistently differentiates the apical from the laminal articulations, given the narrow definition of these terms as referring to the part of the tongue contacted during the articulatory constriction. If, as suggested earlier, the terms *apical* and *laminal* are used to describe overall tongue shapes, then the picture becomes clearer. In the contrastive data, the laminal member of the pairs /ʈ/-/c/ and /ɖ/-/ɟ/ has a higher F2 and usually lower F1 than the apical, because of a high front tongue position. The apical segment, in turn, has lower F3 and F4 values, due to the presence of a sublingual cavity. These same differences were observed between a "laminal" language (French) and an "apical" language (English).

This generalization does not extend to the dental-alveolar distinction, which has also often been termed laminal-apical. While the "alveolar" segment (often referred to as "apical") has a lower fourth formant value than the "dental" ("laminal"), it also has the higher F2. A higher F2 and lower F4 (and F1) occurred also in alveolars in the French and English data, especially in French. In the case of these segments, both the F2 and F4 values seem to be due to the place of articulation difference, which results in a larger sublingual cavity and consequent lower F4 and a higher tongue body and consequent higher F2 in the more retracted segment. This distinction, then, appears to be more appropriately described as one of place of articulation in both Malayalam and 'O'odham and indeed, nearly all speakers made a difference in this measure, however small.

4.2 Proposed features

The reinterpretation of *apical* and *laminal* as tongue body features, rather than features referring to either the part of the tongue contacted or constriction length, is justified by both the articulatory and acoustic results presented in this study. It has been demonstrated that place of articulation, apicality and constriction length can and do vary from speaker to speaker within one phonological segment, and thus cannot be descriptive of the general phonetic event. Judging by the formant frequency data, there is more unity in overall tongue shapes than in specific articulatory contact patterns, both between contrasting segments in one language and inter-language comparisons of corresponding phonemes.

4.3 Suggestions for further study

The present study has served to clarify some of the terms which have been used, often without precision, in the general phonetic and phonological literature. It has also shown that there is a great deal more individual variation in language production than was previously supposed, a fact which must be taken into account when making phonetic generalizations. More studies need to be done on the perception of the contrasts by native speakers to account for comprehension despite individual differences in production. Such work could help to isolate those factors which are of the greatest importance in a given phonological distinction, as well as clarify what makes a native speaker sound "native", whereas a speaker of another language, articulating with the same part of the tongue on the same part of the palate, would presumably sound "foreign".

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