UNIVERSITY OF CALIFORNIA

Los Angeles

Giving Weight to Phonetic Principles:

The case of Place of Articulation in Western Arrernte

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Linguistics

by

Victoria Balboa Anderson

2000

This dissertation is dedicated to Richard Lyle Welsh.

Inceptor

Guide me.

Though I may not see the road.

Quiet presence

Lead on.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgments

I would like to thank my doctoral committee: Sandro Duranti, Bruce Hayes, Peter Ladefoged and Ian Maddieson. Sandro Duranti's scholarship helped me cultivate my love of fieldwork. I am grateful to Bruce Hayes for steady steerage and valuable advice on getting through a Ph.D. program. I have admired his seemingly effortless grasp of both the big picture and the small pictures within my dissertation; his ideas have significantly improved this work. My co-chairs embody a rare combination of the highest level of scholarship with a spirit of easy-going accessibility and kindness. I thank both for their wise direction, and for teaching me so much more than phonetics. Peter Ladefoged's gentle encouragement and powerful intellect have contributed much to this dissertation as well as to my professional development. His consistently graceful good humor and incisive input have been a profound influence. Ian Maddieson's contributions have been too numerous and diverse to describe. The depth of knowledge he brings to bear at a moment's notice have been a continual source of astonishment. I hold dear his generous mentorship and patient guidance over the years, in helping me move through my own hundred-miler.

I am indebted to Pat Keating for her help in being an advisor-on-the-ground, while Ian and Peter were on various trips collecting SOWL. She has also been the model Lab Director that many of us aspire to. I thank Donca Steriade for sharing her acuity, her insights and her encouragement.

My affection and gratitude go to my colleagues at the UCLA Phonetics Lab. Current and former lab members have made the lab a special environment—both intellectually rich, and rich in camaraderie. For stimulating conversation, technical assistance, support and friendship (as well as chocolate and kimchee) I am grateful to Adam Albright, Barbara Blankenship, Taehong Cho, John Choi, Melissa Epstein, Edward Flemming, Christina Foreman, Suzi Fosnot, Cécile Fougeron, Matt Gordon, Robert Hagiwara, Chai-Shune Hsu, Keith Johnson, Sun-Ah Jun, Jenny Ladefoged, Hyuck-Joon Lee, Peggy MacEachern, Bonny Sands, Amy Schafer, Aaron Shryock, Caroline Smith, Sinisa Spajic, Sumiko Takayanagi, Henry Tehrani, Kimberly Thomas, Siri Tuttle, Richard Wright and Jie Zhang.

For administrative assistance above and beyond the call, both at UCLA and remotely, I thank Ed Keenan, Russ Schuh, Anna Meyer, John Bulger, Natasha Brown and Patrick Manalastas.

For their multifaceted assistance and direction, I am profoundly grateful to my parents, James and Emerald Anderson. They have been both a long-term and short-notice source of moral, financial and culinary support, and have been great friends besides. My sisters Pia and Rica Anderson have been role models, sources of strength and wonderful chums. I would also like to acknowledge my appreciation to Catherine Balboa, Zosimo and Loretta DeVeas, Teri English, Mary Welsh and Jon Ah You for their precious encouragement. My special thanks go to Alan, Beth, Colette, Jennifer, Kay, Liz, Omar, Robert, Suzanne, and Laura.

Paul Tibbetts has been patient, gentle company and has made substantive input to this project. For his constant equanimity, his loving help, and his cheerful support while enduring late hours, riots, earthquakes, campdogs, and repeatedly having his tongue painted black, I can't be grateful enough.

I am also mindful of my many debts of gratitude in Australia. Foremost are the Western Arrernte language consultants who participated in the project. All were patient, interested, good humored and cooperative. Many of them provided hospitality in their homes and on their lands. For the aspects of their language and culture they have shared with me, I am in their debt. Although I may not name them individually, I cherish the friendship of the "blue-tongue mob", as they came to refer to themselves.

Bob Dixon, Ian Greene, Harold Koch and Phil Rose set me on the right course when I first arrived. Beverly Lee and Linda Holland at Ntaria School made my work much easier by allowing me to use schoolrooms, and by occasionally putting me up in their home.

The Institute for Aboriginal Development generously provided me with office space and a positive, collegial environment in Alice Springs, not to mention several dear friendships. Gavan Breen shared his wealth of knowledge and his detailed Western Arrernte wordlists, discussed points of phonology and graciously shared an office. Robert Hoogenraad gave me suggestions and direction on many aspects of the project, from grant applications to life out bush. He talked out ideas over tea and was a source of intellectual and often physical support. I am also fondly indebted to Penny Evans, Margaret Heffernan, Heather King, Jenny Tindale and Myf Turpin for their friendship and support.

I would like to express my gratitude to Andy Butcher for making available his excellent data, and sharing his valuable thoughts on Arrernte language and culture. He and Christl Butcher have the talent of offering wonderful hospitality, and at the same time making one feel at ease accepting it.

This research would not have been possible without generous financial support from the Fulbright Commission, a National Science Foundation Dissertation Improvement Grant, the UCLA Graduate Division and the Aboriginal and Torres Strait Islander Language Initiatives Program of the Australian Government.

And lastly, my thanks to (s)he who makes all things possible.

VITA

	Born, Los Angeles, California
1983	A.B., Linguistics University of California Berkeley, California
1990-94	UC Office of the President Graduate Fellowship University of California Los Angeles, California
1993	Graduate Student Researcher Department of Linguistics University of California Los Angeles, California
1993	Contractor, Speech Technology Apple Computer Cupertino, California
1994	M.A., Linguistics University of California Los Angeles, California
1994-1996	Fieldwork, Australia, under Fulbright (IIE) Scholarship, National Science Foundation Dissertation Improvement Grant (Prof. Ian Maddieson, P.I.), Aboriginal and Torres Strait Islander Language Initiatives Program Research Grant (Australian Government)
1996	Contractor, Speech Technology Apple Computer Cupertino, California
1996-97	Teaching Assistant Department of Linguistics University of California Los Angeles, California
1997-98	Dissertation Year Fellowship, Graduate Division University of California Los Angeles, California

1998-2000 Senior Scientist, Speech Technology
Fonix Corporation
Cupertino, California

PUBLICATIONS AND AND PRESENTATIONS

Anderson, Victoria B. 1997. "The perception of coronals in Western Arrernte." In *Proceedings of the 5th European Conference on Speech Communication and Technology*, ed. by G. Kokkinakis et al. University of Patras, Greece: 1: 389-392.

Anderson, Victoria B. 1998. "Testing opposing phonetic structural principles: Polarization and Gestural Economy." In *Proceedings of the Twenty-Fourth Annual Meeting of the Berkeley Linguistics Society, Parasession on Phonetics and Phonological Universals,* ed. by B. Bergen et al. Berkeley Linguistics Society, Berkeley: 309-319.

Anderson, Victoria B. and Ian Maddieson. 1994. "Acoustic characteristics of *Tiwi* coronal stops." *UCLA Working Papers in Phonetics* 87: 131-162.

Breen, J. Gavan and Victoria Anderson. 1995. "A reanalysis of English initial Cr clusters." Paper presented at the meeting of the Australian Linguistic Society, Melbourne, Australia.

Maddieson, Ian and Victoria Anderson. 1995. "Some phonetic characteristics of Iaai." In *Proceedings of the Thirteenth International Congress of Phonetic Sciences.* Royal Institute of Technology, Stockholm: 4: 540-543.

ABSTRACT OF THE DISSERTATION

Giving Weight to Phonetic Principles:

The case of Place of Articulation in Western Arrernte

by

Victoria Balboa Anderson

Doctor of Philosophy in Linguistics

University of California, Los Angeles, 2000

Professor Peter Ladefoged, Co-chair

Professor Ian Maddieson, Co-chair

This dissertation investigates articulation and perception of Western Arrernte coronals, which employ an apical contrast intervocalically but not initially. The articulatory study seeks evidence of Polarization or Gestural Economy in the domain of consonant Place of Articulation. Polarization holds that adjacent contrasts on a phonetic continuum are articulated so as to be maximally perceptually distinct. Gestural economy contends that articulations embodying harmonious trade-offs between

articulatory ease and auditory distinctiveness are used at the expense of maximal distinctiveness, and used repeatedly, maximizing pattern congruity.

The perception study seeks evidence of phonological Cue Licensing, which highlights the need for auditory distinctiveness, sometimes at the cost of numbers of contrasts. Contrast neutralization is predicted where auditory cues are lacking.

Flemming (1997) suggests that the cost of a phonetic solution is a sum of numerically weighted phonetic constraints. *Domain-specific weighting* extrapolates from this, restricting the hypothesis space for possible sound structures by postulating that phonetic domains may inherently prefer different weight valuations on constraints.

Previous literature on consonant Place shows clear evidence for gestural economy, but not polarization. This study seeks such evidence by quantitatively characterizing palatographic data. ANOVA and χ^2 analysis demonstrate that alveolar and non-contrastive apicals are statistically indistinguishable, as are nasal and oral segments of a given Place. Use of alveolars over postalveolars in more contexts indicates re-use of efficient gestures. Thus, results again provide evidence for gestural economy, implying that consonant Place gives higher weighting to articulatory ease and pattern congruity, over auditory distinctiveness. An implicational hypothesis for further verification is that languages in which gestural economy strongly constrains consonant Place will greatly outnumber those in which polarization strongly constrains this domain.

The perception experiment compares listeners' identifications of consonants in V_1CV_2 versus CV_2 contexts. Cue licensing is strongly empirically demonstrated. Removing V_1 inhibits correct identification of apicals. Moreover, acoustic analysis of experimental tokens shows that for apicals, distinguishing acoustic characteristics exist only within V_1. For laminals, acoustic characteristics within the consonant and/or within transitions to both flanking vowels separate contrastive segments. Thus, phonotactic distribution of apicals in W. Arrernte relates directly to distribution of auditory cues.

Chapter One: Introduction

1.1 Foreground: Focus of the present study

In their comprehensive treatment of consonant places of articulation in the languages of the world, Ladefoged and Maddieson (1996) begin by defining the set of possible active articulators, and their potential target areas on the upper surface of the vocal tract. They then discuss and exemplify each of the articulator-target matches that serve to differentiate lexical items in languages, and sum up by presenting an exhaustive matrix of 134 potentially contrastive pairs of places, noting where and why gaps occur. In concluding this review of the current state of knowledge about places of articulation in language, they mention some of the phonetic forces which constrain linguistic articulations. They end with the following paragraph:

> "Ladefoged (1993) has suggested considerations that may be relevant in the production of some non-modal places of articulation. His notion is that in situations where there is a contrast between two similar articulations, speakers will tend to use more extreme forms of the gestures involved. If this view is correct, the situation for articulatory gestures may be analogous to that described by Keating (1984a) for Voice Onset Time. Keating noted that within the continuum of possible VOTs, languages choose among three modal possibilities: voiced, voiceless unaspirated, and aspirated. She also proposed that there is a polarization principle by which languages keep adjacent pairs within these possibilities further apart... We might also hypothesize that the same polarization principle occurs in the realization of some differences in places of articulation."

The issue of whether the polarization principle affects consonant place of articulation, or does not apply in this phonetic domain, is one of the subjects of this dissertation.

This introductory chapter will first present four overarching forces which shape the sound structures of languages. A few examples will follow, showing how phonetic models have incorporated these meta-principles and attempted to reconcile tensions among them. The value of an approach similar to that of Optimality Theory will be discussed, and the idea of domain-specific weighting introduced. Returning to questions at issue here, polarization, gestural economy, and licensing by cue will be explicated, with evidence for domains in which they seem to apply. Predictions for the language investigated here will be treated. The chapter concludes with a brief outline of the rest of the dissertation.

1.2 Background: Situating the problem in context

1.2.1 Meta-Principles

At least as far back as Martinet (1952) linguists have been seeking not just to describe sounds and their patterning across languages, but to find principled ways of explaining the sound structures of language. In studies addressing the forces which shape cross-linguistic patterns, four phonetic meta-principles repeatedly emerge. By analogy with the selection pressures shaping biological adaptation, these principles can be thought of as ecological pressures to which languages must adapt (Lindblom 1986; 1990, Ladefoged 1996, Maddieson 1997.) These meta-principles have in turn informed phonetic theories and models in varying combinations and degrees.

Ease of articulation pressures languages to minimize articulatory effort. Sounds used in a language should be easy for its speakers to articulate. As noted elsewhere (Lindblom 1983, Flemming 1997), this desirable principle is not specific to language, but is generally true of human motor behavior (Zipf 1949.) Corollaries of this principle correctly suggest that cross-linguistically, there will be more languages with simple sounds than with complex ones (Maddieson 1984, Lindblom and Maddieson 1988), and that segment types will make greater use of “neutral” articulations, while “a smaller number of segment types (will be) made with what is called **displaced articulation**, where the active articulator is displaced from its anatomically neutral position.” (Laver 1994, p 137.)

Ease of perception (auditory distinctiveness) is another meta-principle. Since the goal of language is to transfer information, the contrastive sounds of a language should be easy for listeners to differentiate from one another. This principle correctly accounts for the fact that languages prefer sounds which are auditorily widely spaced rather than closely spaced (Lindblom 1986), and that, given articulations of roughly equal ease (e.g. apical dentals and apical alveolars, or laminal dentals and laminal alveolars), languages will more often contrast articulations which yield greater auditory differences (i.e. apical alveolars versus laminal dentals, rather than apical dentals versus laminal alveolars; Ladefoged 1997b.)

A third desirable principle for a well-adapted language involves maximizing the number of contrasts, in order to allow for a large number of lexical items which sound sufficiently different from each other. (Ladefoged 1996, Flemming 1997.) This principle correctly predicts that there will be few languages like Hawaiian, which contrast fewer than ten consonants, and few languages like Abkhaz, which contrast fewer than three vowels.

The fourth overarching constraint on language is a pressure toward simplicity, through the use of organizing patterns (Hockett 1963, Ohala 1980, Maddieson 1996, Ladefoged 1996, Hayes 1999.) Once again, this is part of a more general human tendency, in this case to categorize experience. Ohala points out the “maximum use of available features” in many consonant systems, and along the same lines, Ladefoged reasons that “less strain (is placed) on our cognitive abilities if sounds are organized into groups that are articulated in the same way” (Ladefoged 1996.) Maddieson (1997) discusses the tendency languages have of “replicating motor images” and using “intersecting repeated characteristics”, so that basic components of articulation are re-used in an economical way. Hayes (1999) argues that the language learner builds a set of features with an eye to formal structural symmetry just as much as phonetic ease: “Real constraints seldom achieve such a perfect fit (with phonetic ease), rather they deviate in the direction of structural simplicity.” (Hayes 1999, section 9.)

The results of such a drive toward what Hockett called pattern congruity can be seen in the fact that most languages which contain the stops /p/, /t/ and /k/ also contain the nasals /m/, /n/, and /ŋ/, which differ from these stops in position of the velum, rather than /ɱ/, /≠/, /ɴ/ which differ in the position of the velum and also in place of articulation. Moreover, Hayes observes that “even though the phonetic mechanisms needed to produce a voiced intervocalic stop in Korean are not exactly the same for all the Korean places of articulation” (thus differing in articulatory ease), “the fact that all of the places participate in parallel in an intervocalic voicing process suggests that [voice] is an authentic phonological feature of Korean” (Hayes 1999, section 15) and more germane to our focus here, suggests that [voice] is a simplifying generalization.

1.2.2 Interconnection of phonetics and phonology

While maximizing the number of contrasts might be considered a strictly phonological principle, the other three principles we have introduced might be expected to have effects at both phonetic and phonological levels. Phonetic effects of the drive toward ease of articulation are widespread, for example in coarticulation processes. Negative evidence like the cross-linguistic markedness of clicks or the absence of articulations like dorsal-velar trills can also be argued to reflect this ecological force, both in phonetics and in the resulting composition of phonological inventories. In addition, the phonotactic behavior of phonological units is affected by this principle; for instance, the strong cross-linguistic tendency of postnasal stops be voiced (Hayes and Stivers, in progress) can be attributed to the aerodynamic requirements of voicing.

As regards pattern congruity, the mental features that learners build by categorizing their experience are phonological, and yet the fact that languages "replicate motor images" (Maddieson 1997) means that this simplifying force also affects phonetic implementation. Turning to auditory distinctiveness, phonological structure is limited by the auditory ability of listeners to identify the meaningful distinctions in sounds, and many investigators (Ohala 1980, Steriade 1995, among others) have shown how auditory phonetic considerations shape phonologies. Driven by the same principle, phonetic variability must be limited by the need to faithfully represent contrastive segments within their appropriate target ranges, so that contrasts can be accurately retrieved by listeners. In this way phonology also shapes phonetic implementation (Keating 1996.)

The fact that these principles affect phonetic as well as phonological patterns of languages necessitates that phonetics and phonology are closely associated and mutually limiting.

1.2.3 Conflicting Goals

Though each of the above-mentioned principles governing sound structures is desirable, these forces have different, often conflicting goals, and cannot all be satisfied at once. As has long been recognized, ease of articulation is often at odds with ease of perception; to the extent that segments are auditorily distinct from each other for listeners, speech is effortful and not maximally easy for speakers. Conversely, the more the articulators approximate a neutral, resting position, the less distinct from each other they will be, and the harder listeners will have to work to recover contrastive segments. Flemming (to appear) points out that the principle of maximizing numbers of contrasts is also at odds with that of auditory distinctiveness; contrasts cannot be as far apart in a phonetic space if there are more of them. The principle of pattern congruity is also potentially in conflict with auditory distinctiveness; segments of different types often involve different enhancing characteristics to make them maximally auditorily distinct (Stevens and Keyser 1989.) Ease of articulation may conflict with maximizing the number of contrasts, in that a greater number of contrasts means a greater number of articulatory configurations to coordinate dynamically, as well as greater precision in articulations. Ease of articulation may be in conflict with pattern congruity, as discussed with respect to the feature [voice] above: all voiced segments are not equivalently easy (e.g. it is more difficult to voice [g] than [b]), but it makes for a simpler mental pattern to have voiced segments behave in similar ways phonologically.

On the other hand, maximizing the number of contrasts is not necessarily in conflict with pattern congruity, and this pair of principles, more than other pairings, may be mutually enhancing. Relationships among these principles are summarized in Figure 1.1.

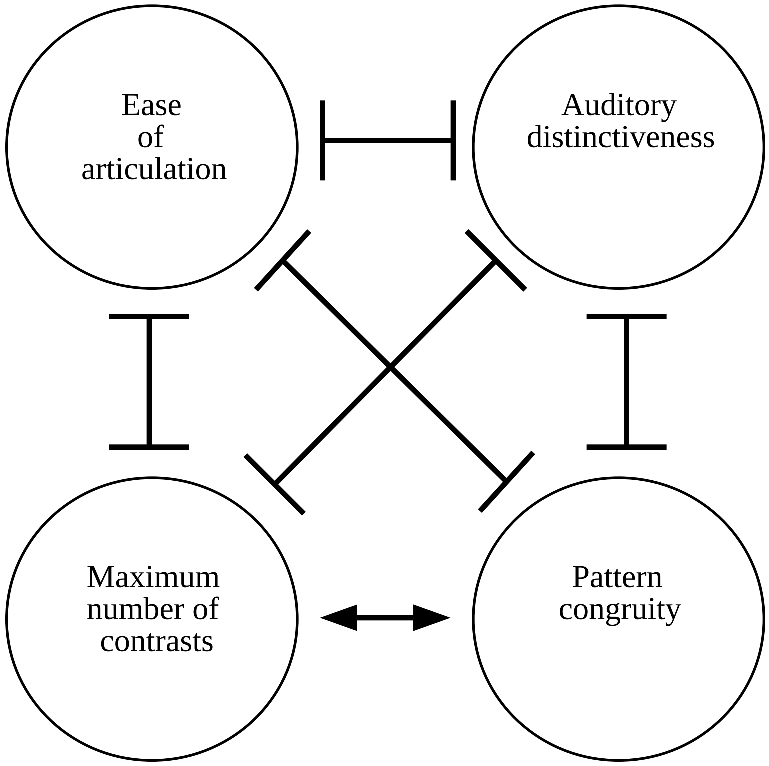


Figure 1.1: Relationships among four meta-principles governing linguistic sound structures. The double-headed arrow links the "harmonious" pair of principles; other pairings are likely to conflict.

1.2.4 Phonetic Models

As mentioned above, phonetic theories and models have repeatedly referred to these meta-principles, and linguists have addressed their efforts to how these forces might interact, be reconciled or dominate each other when in conflict. Thus, Keating (1990), in developing her Window Model of Phonetic (Under)Specification, observes that the spatial range of a particular target is a function of how precise an articulation needs to be, which is defined by the presence or absence of phonological contrast (thus the need for auditory distinctiveness.) Less variability is expected where a contrast must be maintained. Where no contrast exists, greater variability can be expected, because gradient, temporal interpolation (responding to ease of articulation) can step in to govern implementation. This "allows an interaction between the constraints imposed by phonological contrast and phonetic constraints such as mechanical linkages or aerodynamic requirements" (Keating 1996.) In the same vein, Manuel (1990) notes that "contextual variation is subject to a distinctiveness constraint", and Cho (1998a) invokes this interplay to account for differences in the implementation of palatalization in Korean stops and nasals.

The work of Lindblom and Maddieson (1988) is perhaps the most commonly cited among linguists investigating the tension between ecological forces affecting speech. A frequently quoted statement of theirs suggests that "inventories tend to evolve so as to achieve maximal perceptual distinctiveness at minimum articulatory cost" (p. 72.) They observe that in bending to these pressures, languages tend to exhaust simple articulations before making use of more elaborated or complex articulations, and that part of the strategy of using more complex articulations is to be sure that auditory distinctiveness is retained. The notion of trade-off implicit here is a movement away from Lindblom's earlier hypothesis that "maximal distinctiveness" shapes vowel systems (Lindblom 1986), toward "optimal" distinctiveness here. Maddieson (1996, 1997) continues to rebalance the relative weight of auditory distinctiveness, articulatory ease and pattern congruity, in developing his theory of gestural economy, which is explained in detail below. Rather than being "optimal", he suggests it is possible for auditory differences among contrastive sounds to be merely "sufficient", citing evidence from small vowel systems and tone systems. Moreover, in explicating a desideratum of language sounds that he calls "contrastivity", he suggests that <u>articulatory</u> distinctiveness, just as much as auditory distinctiveness, is to be desired for reasons of structural economy. Thus, he points out that, like sensory patterns, motor patterns are perceived by the speaker, and must be perceptually distinct to the speaker. Optimally contrastive units are those that can be "differentiated from each other and (be) recognizable when they recur... elements (must have) good characteristic 'signatures' in both their motor and auditory patterns so that they may be recognized and memorized" (p. 634.)

Steriade's Production Hypothesis (1993, 1995) and similar ideas also represent a resolution of the tension between these ecological forces. As Jun (1995) puts it, "Speakers make more effort to preserve the articulation of speech sounds with powerful acoustic cues, whereas they relax in the articulation of sounds with weak cues"; or to paraphrase Kohler (1990, 1991) the more vulnerable targets of place assimilation are those that are less auditorily salient than others. The notion is that speakers will economize on articulatory effort especially where there is not a good return in terms of auditory contrast. In support of this, in documenting supraglottal gestural reduction in Taiwanese stops, Hsu (1998) finds that "only the perceptually less salient non-initial positions allow ease-of-articulation considerations to override the ease-of-perception principle, yielding variable articulations across prosodic environments" (p. 2.) In a different but related effect of interaction among these forces, Flemming (to appear) suggests that "a constraint on the minimum distinctiveness that is adequate to support a contrast can account for the absence of this contrast." To paraphrase Steriade (1995), contrasts will be lost first where they are more difficult to keep, whether the difficulty is auditorily or articulatorily induced.

1.2.5 Optimality Theory

Each of the models and hypotheses mentioned in the preceding section attempts to find an optimal solution in terms of ecological forces taken together, rather than in terms of any single principle. Such an approach lends itself to constraint analysis along the lines of phonological Optimality Theory (Prince and Smolensky 1993.) In fact, phonetically grounded constraints are the core of the research program which has come to be known as “Phonetically-Driven Optimality-Theoretic Phonology” (Kirchner 1998, Hayes 1999. See the latter for an overview and references.)

In Optimality Theory, conflicting constraints are ranked, with higher, more important constraints strictly dominating lower-ranked ones. Phonological forms that appear in languages are those violating the fewest highly-ranked constraints. A crucial characteristic of OT, and one which will be highlighted here, is that the relative importance of constraints is flexible. This allows for cross-linguistic variation: languages arrange constraints in different ways.

In applying OT to phonetic optimization, Flemming (1997) suggests that a model that better suits phonetic behavior is one in which constraints do not strictly dominate each other, but instead are numerically weighted with respect to each other. The sum of these weighted constraints yields a single, total-cost value; low total-cost values represent good phonetic solutions. Taking the gist of Flemming’s idea, we might apply such a notion to the forces discussed here as follows:

w_e (violation of **ease** of articulation metric)
\+ w_d (violation of auditory **distinctiveness** metric)
\+ w_n (violation of maximization of **numbers** of contrasts metric)
\+ w_c (violation of pattern **congruity** metric)
= **cost**

where the terms in parentheses are ways of measuring how much a given meta-principle is violated, and the *‘w’* terms are the different weight factors given to each principle. A high weight factor means that it is relatively important not to violate the principle.

Note that the equation above is overly simplistic, and that each of the meta-principles could potentially be represented by many constraints. Conversely, one constraint might represent more than one meta-principle: for example, one of Flemming's exemplars, "Don't deviate from targets" could represent perceptual distinctiveness, pattern congruity, or both. Furthermore, Flemming mentions that different speech rates would assign different weight factors to the relevant constraints, as would different combinations of segments, and possibly even environmental circumstances. These variables quickly add complexity, and in the interests of focusing on the problem at hand, will not be considered in this study.

1.2.6 The Domain-Specific Weighting Hypothesis

Even when we exclude from consideration the many-to-many relationship between overarching principles and specific constraints, the influence of speech rate, etc., the number of combinatorial possibilities of such a cost equation is huge. The hypothesis space would be usefully restricted if, instead of representing entirely language-specific compromises among these forces, relative weighting of constraints could arise at least in part from the principled, inherent preference of certain phonetic domains for certain ecological forces. For example, the issue of whether vowel and consonant inventories are built on the same principles has been debated (Ohala 1980, Lindblom 1986, Lindblom and Maddieson 1988; Stevens and Blumstein 1975, Ladefoged and Bhaskararao 1983.) Principled differences in the behavior of vowels and consonants would be easily captured by assigning different relative weight factors to different constraints in the case of vowels versus consonants. If it is true that vowels are more naturally defined on auditory rather than articulatory targets, it would seem to follow that the cost of violating auditory distinctiveness constraints would be relatively high. The implication for a total cost equation would be that constraints involving auditory distinctiveness would have higher weight factors than those involving articulatory ease. On the other hand, consonants are very commonly defined with regard to landmarks in the mouth. It may be that in defining consonant place of articulation, the principle of pattern congruity is more heavily weighted than auditory distinctiveness. In this case, constraints on re-use of the same articulatory gestures would receive high weight factors.

A second example of two phonetic domains in which specific weighting of constraints might differ is articulatory gestures per se versus the relative timing of articulatory gestures. It may be that pattern congruity figures heavily in the former, while auditory distinctiveness plays more of a role in the latter. In both of these examples, a total cost function would provide a way in which the drives to "save on articulatory effort", "save on auditory effort", "use a wide variety of different sounds" and "re-use features" could come to different compromises in different areas. We will refer to this hypothesis that phonetic domains can assign different relative values to ecological constraints as "domain-specific weighting."

1.3 "Derivative" Mechanisms: Polarization, Gestural Economy, Licensing by Cue

This dissertation will focus on three adaptive phonetic mechanisms, each of which can be said to derive from consideration of one or more of the four meta-principles mentioned above. Polarization can be considered a phonetic implementation principle deriving from the ecological meta-principle of ease of auditory perception; in response to this force, segments are articulated so as to be maximally perceptually distinct, as will be explicated below. Similarly, Maddieson's articulatory theory of gestural economy is a pair of hypotheses that respond a) to the need for compromise between articulatory ease and auditory ease, and b) to the drive toward pattern congruity. As adaptive mechanisms in language, polarization and gestural economy make predictions about articulation of speech sounds. On the other hand, Steriade's principle of phonological licensing by cue makes predictions about the phonotactic distribution of contrastive elements. This adaptive mechanism responds to the need for auditory distinctiveness, sometimes at the cost of numbers of contrasts. Thus, where there is a relative paucity of auditory cues, contrasts will tend to be neutralized. A brief exposition of the three derivative principles follows.

1.3.1 Polarization

The original inspiration behind the polarization principle (Keating 1984a) was the observation that segments which belonged to the same phonetic categories in different languages were nevertheless phonetically different from each other. In treating the implementation of Voice Onset Time (VOT) across languages, Keating noticed that firstly, three and only three VOT categories seemed to exist across languages which had been described: {voiced}, {voiceless unaspirated}, and {voiceless aspirated}. Secondly, irrespective of whether a given language employed two or three contrasts, only adjacent categories were used. Thus, Keating suggested that along a given phonetic continuum, phonological oppositions are instantiated by a fixed number of phonetic categories. Moreover, phonological oppositions can be mapped to different phonetic categories in different languages. Keating observed that English and Polish word-initial stops both employ two of the three contrastive types along the VOT continuum, and both make use of the {voiceless unaspirated} category. However, in Polish the opposing stop is in the {voiced} category, whereas in English the opposing stop is in the {voiceless aspirated} category, as shown schematically for labials in Figure 1.2.

Voice Onset Time continuum-->

Phonetic Category	***{voiced}***	***{voiceless unaspirated}***		***{voiceless aspirated}***
Polish	**b**		**--->p**	
English		**b̥<---**		**p^h**

Figure 1.2: Schematized VOT in Polish and English word-initial labial stops

The central idea behind polarization is that once phonetic categories have been chosen to instantiate the phonological oppositions in a language, actual phonetic values will be positioned within those categories so as to maximize the difference between the contrastive segments. Thus, the stops in the {voiceless unaspirated} category in English and Polish are not identical, but are displaced with respect to each other, as shown in Figure 1.2. This has the effect of maximizing the difference with the other member of the contrastive pair; the {voiced} stop in the case of Polish, and the {voiceless aspirated} stop in the case of English. Keating makes no claim about displacement of the end categories; her focus is the displacement observed in the {voiceless unaspirated} category.

Note that polarization implicitly places a higher value on perceptual ease in distinguishing among contrasts than on articulatory ease in producing them, in the sense that articulations will be polarized even if this means articulations are more displaced from a neutral vocal tract position, or means storing more than one articulatory gesture for a contrast. ("Gesture", as in the usage of Maddieson 1996, here refers to the characteristic path of an articulator to its target, rather than to a phonological feature.)

As a point of clarification, it should be mentioned that while polarization can be considered a subset of dispersion theory (Lindblom 1986, 1990; Flemming 1997) Keating's usage of the term strictly involved implementation within the boundaries of a given phonetic category, while dispersion theory refers to separation of segments within the phonetic space as a whole. In general, we will conflate these two ideas in our discussion; the important aspect here being separation of contrasts along a given phonetic dimension. However, we will exclude from our understanding of polarization the concept of enhancement, defined in Stevens and Keyser's sense as the use of secondary features to separate contrasts.

Considerations of perceptual distinctiveness, which can be inferred where there is evidence of polarization, may play a dominant role in the implementation of relative timing of gestures (of which Voice Onset Time may be considered a specific case) and in the distribution of most vowel systems within the auditory space. Hsu and Jun (1998) extend Keating's finding of polarization in VOT to Taiwanese stops, in which all three phonetic categories ({voiced}, {voiceless unaspirated}, {voiceless aspirated}) are used contrastively. They find that in prosodically strong positions, the end categories {voiced} and {voiceless aspirated} are polarized, as compared with prosodically weaker positions. That is, at the beginning of a syllable (and cumulatively more so at the beginning of a word or intonational phrase), {voiced} stops have longer lead times and {voiceless aspirated} stops have longer lag times. Interestingly, in this case the middle category ({voiceless unaspirated}) remains unaffected in different prosodic positions, presumably to remain equidistant from both of the end categories.

Again in the temporal domain, Cho (1998a, 1998b) finds in an instrumental articulatory study that Korean alveolar stops and nasals behave differently before /i/ in non-derived environments. The /t+i/ sequence allows only minimal intergestural overlap, whereas the /n+i/ sequence allows a great deal more overlap. This difference in behavior can be explained by reference to polarization. An important fact about Korean phonology in this regard is that a contrastive segment /tʃ/ exists, but no corresponding contrastive nasal /≠/ exists. Thus, /t+i/ and /tʃ+i/ must be kept polarized in their phasing, so as to remain perceptually distinct. In contrast, the alveolar nasal is not constrained by a neighboring contrastive palatal(ized) segment, and can overlap to a much greater degree.

It should be mentioned that, because relative timing of gestures is strongly correlated with relative magnitude of gestures, we could expect to find polarization in magnitude of gestures as well; i.e. greater magnitude in strong positions, less in weaker positions. Such a result has been borne out for a number of languages (Hsu and Jun, 1998; Fougeron and Keating 1997.)

Large and small vowel systems will be discussed together below.

1.3.2 Gestural Economy

Gestural economy (Maddieson 1996) represents another view of the possible relationship between phonological patterning and phonetic implementation. First, high value is placed on the use of inherently efficient gestures; in the terms presented here, these are gestures for which there is a relatively harmonious (i.e. low-cost) trade-off between the meta-principles of ease of articulation and auditory distinctiveness. Secondly, high value is placed on re-use of these efficient gestures, so that speakers need not internalize a greater number of motor programs than is necessary to convey the phonological oppositions of their language. This second point reflects the ecological constraint of pattern congruity.

Maddieson presents instrumental evidence for the use of inherently efficient gestures from Sele and Ewe, two languages of West Africa. Sele employs a single labiodental fricative which does not contrast with another labial fricative. Ewe, on the other hand, has a labiodental fricative in contrast with a bilabial fricative. On the continuum of upper lip height, Maddieson establishes instrumentally that in the Sele labiodental, the upper lip is in a neutral position, neither lowered nor raised. Elsewhere, Maddieson (1984) gives evidence that labiodental fricatives are frequent members of consonant inventories, and proposes that this is because they require "precise positioning of only one active articulator" and "a relatively small movement", while at the same time remaining acoustically distinct from other fricatives (Maddieson 1996.) Thus, they are inherently efficient.

In Ewe, the bilabial fricative shows upper lip lowering as both lips approach each other for the constriction. However, even though it contrasts with this bilabial, the Ewe labiodental fricative is not appreciably different from the Sele labiodental. (The distribution of these segments is schematized in Figure 1.3.) Maddieson takes this to constitute evidence that in Ewe, an inherently efficient segment is used over a potentially more distinctive one because the value of efficiency outweighs maximal distinctiveness in this case. ("Maximal distinctiveness" can refer to either perceptual or articulatory distinctiveness, for the sake of the present argument.) Recall that under polarization, one would expect Sele and Ewe labiodentals to differ; the Ewe labiodental would involve a higher lip position, in order to maximize its difference from the bilabial, as was previously postulated by Ladefoged (1990).

Upper lip height--->

Phonetic Category	***{low}***	***{neutral}***	***{raised}***
Sele		**f**	
Ewe	**ɸ**	**f-->*f***	

Figure 1.3: Schematized upper lip height positions for Sele and Ewe labial fricatives. (Italicized symbol shows hypothesized position under polarization.)

Maddieson cites two types of evidence in support of re-use of gestures. First, as mentioned above, the fact that languages very commonly employ stops, nasals and laterals having the same places of articulation is, in Maddieson's view, an indication that economical component "motor images" are being re-used, minimizing the number of articulatory motor programs needed to implement phonological contrasts. However, here Maddieson's evidence comes from the UCLA Phonological Segment Inventory Database (Maddieson 1984) in which segments are categorized phonologically; phonetic detail is purposely underplayed. Thus, it remains an empirical question for the majority of languages whether stops and nasals, for instance, are articulated in a non-distinguishable way, or whether they are articulated with distinct motor images, but simply categorized together phonologically. This point is schematized in Figure 1.4.

Given these stops:	**p**	**t**	**k**
Nasals: Pattern congruity	**m**	**n**	**ŋ**
Nasals: Different gestures	**ɱ**	**ɳ**	**ɴ**

Figure 1.4: Stops and Nasals—Economy of number versus use of different gestures for different manners of articulation

A more empirically robust type of evidence for re-use of gestures involves doubly articulated stops. Maddieson (1993) shows with the use of electromagnetic articulography that labial-velar consonants in Ewe are made with the same component gestures as single labials and single velars.

Harmonious trade-offs between the forces of auditory distinctiveness and articulatory ease, which can be inferred where there is evidence of use of efficient gestures, may govern very small vowel systems, as discussed immediately below. Pattern congruity, evidenced by re-use of gestures, may govern tone systems, as discussed in the following paragraph.

Contrastive members of large vowel systems seem to show evidence of polarization when compared with members of small vowel systems. Maddieson (1997) compares /i/, /a/ and /u/ in Bavarian German, which has a large number of contrastive vowels, with /i/, /a/, and /u/ in Tausug, for which these are the only contrastive vowels. In Bavarian, average formant values for /i/, /a/ and /u/ are more widely dispersed from each other than are average formant values for the three Tausug vowels: this may be due to the fact that the three Bavarian vowels must each contrast with closely neighboring segments, and in response to this, considerations of auditory distinctiveness take precedence. In Tausug, the three vowels are substantially closer together in the vowel space, presumably because it is not so difficult to separate only three vowels; thus, considerations other than maximizing auditory distinctiveness take precedence. In this case, the use of more efficient, less extreme gestures could be seen to weigh more heavily. The differences between large and small vowel inventories may reflect different relative weightings among the meta-principles of ease of articulation, auditory distinctiveness and maximizing the number of contrasts.

Evidence from both Asian and African tone systems seem to reflect a high relative weighting of pattern congruity. Rose (1993) compares normalized Shanghai and Zhenhai tones over multiple speakers. He finds that, contrary to expectation, "the phonetic aspect of the degree to which speakers' normalized values cluster (reflected in the mean normalized standard deviation) is independent of the number of tones in the system... Shanghai, with five tones, has the same degree of clustering as Zhenhai, or North Vietnamese, with six" (p. 217.) Such clustering, unaffected by number of phonological tones, implies re-use of an articulatory and/or auditory pattern, rather than a drive toward auditory distinctiveness. "Secondly, it might be thought that lack of contrastivity in tone features might result in greater between-speaker latitude in tone production. (However), speakers are producing their tones with considerable precision, irrespective of the number of tones, or distinctive features, in the system" (p. 218.) Maddieson (1991) shows a similar situation in comparing tones in Hausa and Nupe. Rather than showing different distributions of tones in response to different numbers of contrasts, Maddieson finds that two tones in Hausa and Nupe are essentially identical, and that Nupe adds a third contrastive tone without adjusting the other two. Thus, at least for these languages, tones seem to be governed more heavily by considerations of pattern congruity than perceptual distance.

1.3.3 Licensing by Cue

As mentioned earlier, Steriade's principle of licensing by cue affects phonotactic patterns of segments: contrasts need to be distributed in a way that does not overtask the ability to discriminate between sounds. As Steriade puts it, "Avoid degenerate cues: Do not deploy a feature in positions where its defining cues are necessarily absent or diminished." Thus, in languages such as English and Guarani, stressed syllables support more vowel contrasts than stressless syllables. In English, the back/round contrast in vowels disappears in stressless syllables; in Guarani the nasality contrast in vowels disappears in stressless syllables. Steriade maintains that the reason for this is that the longer duration concomitant with stress facilitates both perception and production of these contrasts, whereas unstressed syllables do not allow enough phonetic material to reliably support production or perception of such contrasts.

1.4 Consonant Place of Articulation

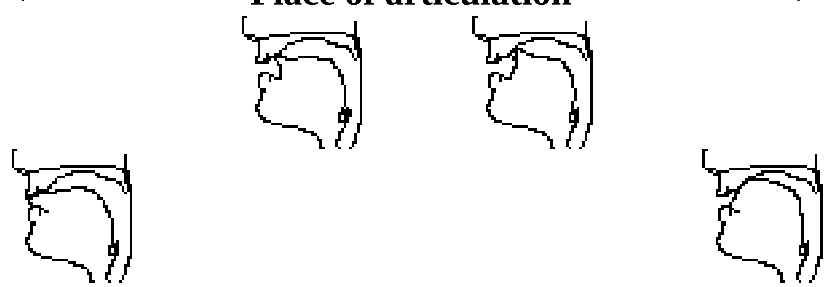
In our discussion so far, we have not yet seen examples of polarization in the domain of consonant place of articulation (hereafter Place.) However, Ladefoged and Maddieson (1996) touch on several tentative examples in which this may be the case. They note early reports of polarization of contrastive labials in Ewe, auditory evidence for polarization of contrastive velars in Yanyuwa, and visual evidence for polarization of nasals as compared with stops in Malayalam. Instrumental work has since shown that Ewe seems to be better modeled by gestural economy, as discussed above. Moreover, Breen (personal communication) is doubtful of the phonological analysis of front and back velars as places of articulation in Yanyuwa, and suggests that the front velar is instead a sequence of prepalatalized vowel and velar. Evidence for the Yanyuwa case remains as yet unclear.

The Malayalam case does seem to be true of several speakers. Since, in the crucial respects, Malayalam has a similar phonology to the language in focus here, we will be able to investigate a parallel case comparing stops and nasals. Thus, to restate more precisely the first research question at issue here, we wish to ask whether polarization is preferentially weighted vis-a-vis other constraining factors, in the phonetic domain of consonant Place.

1.5 Western Arrernte: Predictions

The language examined here is Western Arrernte, an Arandic language of Central Australia, which makes use of four contrastive coronal places of articulation in the stops, nasals, laterals and prestopped nasals. Coronals will be discussed in more detail in Chapter Two; briefly, they are sounds made by an articulation of the tongue tip or blade with the upper surface of the vocal tract. Common impressionistically-based descriptions of tongue configurations for these four places of articulation are shown in Figure 1.5.

<——————Place of articulation——————>



Apicals		(drawing)	(drawing)	
Laminals	(drawing)			(drawing)
Conventional Australian Nomenclature	***Laminal*** Dental	***Apical*** Alveolar	***Apical*** Post-alveolar	***Laminal*** Palato-alveolar
Features	**[-apical] [+anterior]**	**[+apical] [+anterior]**	**[+apical] [-anterior]**	**[-apical] [-anterior]**

Figure 1.5: Impressionistically-based descriptions of tongue configurations for W. Arrernte coronals

Butcher (to appear) instrumentally verifies stop articulations for one speaker of <u>Eastern</u> Arrernte, who employs an apical alveolar /**t**/, sublaminal prepalatal /**ʈ**/, laminal interdental /**t̻**/([t̟]), and a laminal alveolar-postalveolar [**t̻**].

Intervocalically, this four-way contrast holds. However, in word-initial position, there is no place contrast between the apicals. Examples of words showing the coronal contrasts and their distribution are shown for stops and nasals in Table 1.1. The non-IPA symbols ‘T’ and ‘N’ are used to refer to word-initial non-contrastive apicals.

Table 1.1: W. Arrernte stops and nasals, word-initially and between vowels

		Coronal places of articulation				
	Bilabial	*Laminal* Dental	*Apical* Alveolar	*Apical* Post-alveolar	*Laminal* Palato-alveolar	Dorsal Velar
Stops	**p**	**t̪**	**t**	**ʈ**	**t̻**	**k**
Word-initially	**pət̪ə** *pouch (n)*	**t̪əmə** *grind (vt)*	**Təpə** *back (n)*		**t̻ənə** *friend (n)*	**kəpə** *firestick (n)*
Between vowels	**mapə** *many (n)*	**at̪ə** *I (pr, tr.)*	**l̻atə** *today (n)*	**kwaʈə** *egg (n)*	**kwat̻ə** *water (n)*	**makə** *elbow (n)*
Nasals	**m**	**n̪**	**n**	**ɳ**	**n̻**	**ŋ**
Word-initially	**'məɳə** *veg. food (n)*	**'n̪əmə** *rain is falling (vt)*	**'Nəmə** *is sitting (vi)*		**'n̻əlkŋə** *steal (vt)*	**ŋəmə** *fly (n)*
Between vowels	**mamə** *sore (n)*	**lan̪ə** *there-mid (n)*	**manə** *money (n)*	**aɳə** *ground (n)*	**mpan̻ə** *marriage (n)*	**paŋə** *blind (n)*

Polarization makes two predictions about the distribution of segments on the place continuum. First, the two contrastive apicals will be widely distributed with respect to the non-contrastive apical, in order to maximize distinctions between them. The advantage here is that listeners economize on perceptual effort in recognizing the contrastive segments. The disadvantage is that speakers must control three different gestures for apical segments, instead of just two, which is high-cost in terms of pattern congruity.

Place dimension -->

Non-contrastive apical segment	**T**
Contrastive apical segments	**t<--------------------- • ---------------------->ṭ**

Figure 1.6: Arrernte Polarization Scenario--contrastive versus non-contrastive apicals

A second prediction involving polarization compares stops at each place of articulation with their corresponding nasals. Ohala (1980, 1990) has presented evidence that nasals are less auditorily robust than stops because they do not have as many acoustic cues. In response to this, it may be that nasals are polarized from each other on the place continuum vis-a-vis stops, in order to redress this relative perceptual deficiency. Anecdotal evidence for such a possibility has been reported in Malayalam, which, like Arrernte, employs four contrastive oppositions for tongue-palate articulations in both stops and nasals. Ladefoged and Maddieson (1996) observe that for some speakers of Malayalam, dental nasals are articulated as interdentals, while dental stops are articulated as post-dentals. For these speakers, dental nasals are articulated further forward on the place continuum than dental stops. In Figure 1.7, positions for the other stops and nasals have been hypothesized, and are shown in italics, but only the dentals are explicitly mentioned by Ladefoged and Maddieson.

Place of articulation continuum-->

Phonetic Category	***{dental}***	***{alveolar}***	***{postalveolar}***	***{palatal}***
Stops	**t̪**	***t***	***Ê***	***t4***
Nasals	**n̪**	***n***	***=***	***n4***

Figure 1.7: Polarization scenario: places of articulation for some speakers of Malayalam

Gestural economy makes different predictions in both of these cases. In the case of contrastive versus non-contrastive apicals, re-use of gestures suggests that an articulation will appear in both contrastive (word-medial) and non-contrastive (word-initial) environments. That is, an articulation representing the non-contrastive apical will reappear as one of the contrastive apicals, as shown in Figure 1.8.

Place dimension --->

Non-contrastive apical segment	**T**
Contrastive apical segments	**t** |-----------------| **t**

or

Non-contrastive apical segment	**T**
Contrastive apical segments	**t** |----------------------| **t**

Figure 1.8a (top) and 1.8b (bottom): Arrernte Gestural Economy Scenario--contrastive versus non-contrastive apicals

Moreover, use of efficient gestures assigns the segment that is less displaced from a neutral position to the greater number of contexts (i.e. the scenario in ‘8b’, in which it is the alveolar that is reused.)

The advantage here is that speakers economize on motor programming; only two oral configurations exist for apical segments. The disadvantage is that the contrastive articulations are not so widely divergent on the place continuum, which is high-cost in terms of auditory distinctiveness.

As to the stop-nasal comparison, re-use of gestures also predicts that nasals will differ from stops in the position of the velum, but will be identical in terms of the gestures used to achieve the oral configuration, as schematized below.

Place of articulation continuum--->

Phonetic Category	*{dental}*	*{alveolar}*	*{postalveolar}*	*{palatal}*
Stops	**t̪**	**t**	**ʈ**	**t̻**
Nasals	**n̪**	**n**	**ɳ**	**n̻**

Figure 1.9: Gestural economy: schematized coronal places of articulation in Arrernte

While licensing by cue does not make predictions about the articulation of Arrernte coronals, it does make predictions about the distribution of coronal contrasts. We have shown above that Arrernte apicals are neutralized initially; cue licensing allows a principled insight into why they are neutralized in this position. Many investigators have noticed asymmetries between offset formant transitions from a vowel preceding a postalveolar, and onset transitions to a following vowel. While formants 2,3 and 4 often have a common locus in the former, they are usually quite separate in the latter. In short, alveolar and postalveolar apicals look different in their formant loci at preceding vowel offset, whereas they look quite similar in their loci at following vowel onset. For this reason, many investigators have suggested that preceding vowel offset loci are a critical cue to postalveolar apicals, and that absence of a preceding vowel would render a contrast between alveolars and postalveolars imperceptible. In what, to our knowledge, is the first study using perception tests with native speakers of an Australian language, we will investigate this hypothesis. This is the second focus of this dissertation.

1.6 Organization of the Dissertation

Chapter Two presents a brief overview of coronals, including current understanding of their historical development in Australian languages, relevant W. Arrernte phonology and a summary of previous instrumental studies of coronals involving an apical/laminal distinction. Chapter Three presents a multispeaker instrumental study of the articulation of W. Arrernte coronals, looking for evidence of polarization or gestural economy. Chapter Four presents a perceptual study of W. Arrernte coronals; in particular the perception of contrastive and non-contrastive apicals. Chapter Five summarizes results and makes conclusions.

Chapter Two: Apicals and Laminals

This chapter begins with a definition of apical and laminal articulations, and goes on to summarize views about their development in Australian languages. Brief relevant background information on Arrernte phonology is followed by a summary of instrumental studies of Australian coronals.

2.1 Multiple Coronals in the World's languages

As mentioned in Chapter One, coronals will be understood to be sounds using the tongue tip and/or blade as the active articulator. Coronals as a whole are not difficult to define, since the tongue tip and blade taken together can be safely said to involve no more than the front third of the tongue (i.e. that portion excluding the body and root.) However, taken separately, as they must be in a discussion of languages making use of an apical/laminal contrast, "tongue tip" and "tongue blade" are not so easily defined; phoneticians have offered quite a few different descriptions of these articulators. The lack of perfect agreement is not surprising, since the tongue is a mass of muscles without many landmarks. A British tradition (e.g. Catford 1977) defines the tip to include only the point along the rim of the tongue at the midsagittal line. An American and Australian tradition (e.g. Butcher to appear) defines the tip as this same point along the rim, plus 5 mm on the upper and lower surfaces of the tongue, in the midsagittal line. Dart (1991) notes that in apical articulations, "only a very fine line of contact is visible, and this on the very tip of the tongue." She employs "upper apical" to designate cases "where it is not the rim, but the upper surface of the apex which has made contact." Ladefoged and Maddieson (1996) define the tip to include the midsagittal point along the rim, plus about 2 mm in the midsagittal line, but only on the upper surface of the tongue. Since this last definition affords us the most specific terminology, we will provisionally use it here. In each of the three types of terminology, “subapical” is used to refer to the portion of the underside of the tongue which is not included in the “tip.”

Catford defines the tongue blade to include an area 10 to 15 mm back from the rim along the upper surface, in the midsagittal line. Butcher defines blade to mean the upper area extending in the midsagittal line from 5 mm to 25 mm back from the rim. Keating (1991) supports the latter definition, on the basis that unambiguous ([+anterior]) coronals use this area of the tongue. However, tongue sizes vary. Moreover, the tongue is pliant and can be stretched or contracted. These considerations make the regions of the tongue elusive when defined in millimeters. Ladefoged and Maddieson (1996) suggest that the most useful definition for the blade is in relation to other landmarks in the mouth; they propose that the center of the blade be considered that portion of the tongue which lies directly below the alveolar ridge when the tongue is at rest, and that the back edge of the blade be delimited by the position of the frenulum. Though this may still not define precisely the same area of the tongue for different speakers, it is likely to be a safer way to define tongue areas than in absolute terms, and will be used here.

Languages with more than two distinctive coronal stop places of articulation are rare. In UPSID (Maddieson 1984, Maddieson & Precoda 1992), a proportional sampling by family of phonological inventories for the world’s living languages, the great majority (81.42%) use a single place of articulation for coronal stops. A further 14.82% have coronal stops at two places. Only 3.54% use three or more distinctive coronal places for stops. (This accounts for 99.78% of languages in UPSID. One language, Hawaiian, has no contrastive coronal stop places of articulation, which brings the total to 100%.) This rare pattern occurs most commonly in the Australian language families; of the 3-coronal languages reported in UPSID, 10 of 12 are Australian. Of the 4-coronal languages, all exemplars are Australian.

While rare elsewhere, multiple coronal contrasts are the norm for Australian languages. Languages making use of up to four meaningfully distinct coronals are analyzed as using two feature oppositions to create contrasts. Thus, [+anterior] segments are articulated in front of the alveolar ridge, while [–anterior] segments are articulated at or behind the alveolar ridge. On the other dimension, [+apical] segments are articulated with the tongue tip, while [–apical] segments are articulated with the tongue blade. W. Arrernte has the 4-way contrast (refer to Figure 1.5 above.) Table 2.1 shows different conventions for symbolizing these contrasts, for stops. Symbols are analogous for nasals and laterals.

Table 2.1: Symbols used to refer to apical and laminal coronal stop contrasts

Feature classifications	[-apical] [+anterior]	[+apical] [+anterior]	[+apical] [-anterior]	[-apical] [-anterior]
Conventional Australian nomenclature	laminal dental	apical alveolar	apical postalveolar	laminal palatal
IPA symbol	**t̪**	**t**	**ʈ**	**t̻**
Common Australian Writing System	**th**	**t**	**rt**	**ty**

Transcriptions in this thesis will use the International Phonetic Alphabet. Moreover, although many traditional descriptions of coronals use terms which refer only to the passive articulator, here both active and passive articulators will be named wherever necessary, to avoid a priori assumptions about the association of place of articulation with tongue articulator.

2.2 Australian historical phonology: apicals and laminals

Australian languages can be divided into "single" and "double" apical languages (languages containing either one or two apical phoneme series) as well as into single and double laminal languages. The number of coronals in proto-Australian (pA) is still under debate. In one scenario, pA contained one apical stop phoneme and one laminal stop phoneme, and analogous nasal and lateral series. In the descendant languages, one or both of these phonemes underwent a split (allophones which had been conditioned by different vowel environments lost those environments when distinctive vowels underwent mergers, for instance) to yield three or four contrastive coronals in the phonologies of some languages. In another scenario, pA contained a richer system of consonants (two laminals and two apicals) and a poorer system of vowels. As acoustic differences were reanalyzed and attributed to vowels, coronal contrasts merged in some languages to yield only two or three contrastive units.

For laminals, Dixon (1970) adduces evidence for the first scenario above. He concludes that pA began with one laminal, which had a laminal palatal (or laminal palatalized) allophone before the high front vowel, and a laminal dental allophone elsewhere. Dixon (1980) extrapolates the historical split scenario to apicals, although he stresses (personal communication) that the case is less clear. Dixon finds for Warrgamay that apical postalveolars occur with greater frequency following the vowel /**u**/ than elsewhere, which may be a relic of pA allophonic distribution. However, this generalization does not hold for other Australian languages, and for Wakaya, the situation may be reversed; apical alveolars may follow /**u**/ more often than apical postalveolars do (Breen, personal communication.) There is still not a clear mechanism by which the apicals can be argued to have developed from a single series.

A second possibility is that a pA four-way coronal contrast underwent mergers in some languages. In this scenario, the finer-grained contrast may initially have been among coronals, instead of vowels, with pA having only three vowels, or instead, a high vowel, a low vowel, and contrastive rounding on consonants. Distinctions among the coronals could have been reinterpreted as belonging to surrounding vowels, yielding more vowel distinctions and fewer coronal distinctions in some languages. Besides the current height-only distinction in Arandic languages such as Kaytetye and Anmatyerre, support for this "many-coronals/few vowels" analysis of pA comes from vowel harmony facts in Warlpiri and Warumungu, spoken to the north of the Arandic family. In these languages, values for the features Round and Back spread from suffix to verb root, implying a point at which /i/ and /u/ may have been conditioned allophones. In Warlpiri the following alternations exist: (for further detail see Evans, 1995):

kit̻i-n̻i	kit̻i-kaɭa	kut̻u-n̻u
throw (nonpast)	throw (irrealis)	throw (past)

Breen (1997) suggests that the time depth for pA may be sufficient to allow for cyclic historical changes.

> "The fact that there are single-apical languages in which the apicals are alveolar (in much of eastern Australia) and others in which they are typically retroflex (e.g. Karrwa and Wanyi) suggests that our present single-apical languages do not just continue an original situation. Perhaps the best we can do is establish a minimal phoneme set:

b	g	d	j	
m	ng	n	ny	
		l		
w		r	y	
u			i	a

> and list those additions that seem to be widespread enough or common enough to be thought of as belonging to the regular cycles, including, say: splitting of /d/--> /d/ and /rr/, merging of /d/ and /rr/, development/loss of a laminal split, development/loss of an apical split, development/loss of extra laterals, development/loss of lenition and a voicing distinction..."

2.3 Relevant Western Arrernte Phonology

Arrernte (also spelled Aranda and Arrarnta) is spoken by up to 5000 people in a continuum of dialects within a 300 km radius of Alice Springs in Australia's Northern Territory. Western Arrernte is spoken by an estimated 2000 people in an area approximately bounded by Papunya and Haasts Bluff to the northwest, Areyonga to the southwest and Alice Springs to the east. (Refer to map, Figure 2.1.) The Arandic languages are considered a healthy group, by Australian standards: children are still learning them as first languages.

W. Arrernte itself had two recognizably different dialects until recently: the MacDonnell Range Tywerretye ("Tjorritja") dialect has all but disappeared; the Hermannsburg dialect is spreading into the MacDonnell Range area. Tywerretye was more like Eastern and Central Arrernte in containing a preponderance of vowel-initial words. The Hermannsburg dialect, like Pertame (a dialect of Southern Arrernte), has a much greater tendency toward consonant-initial words.

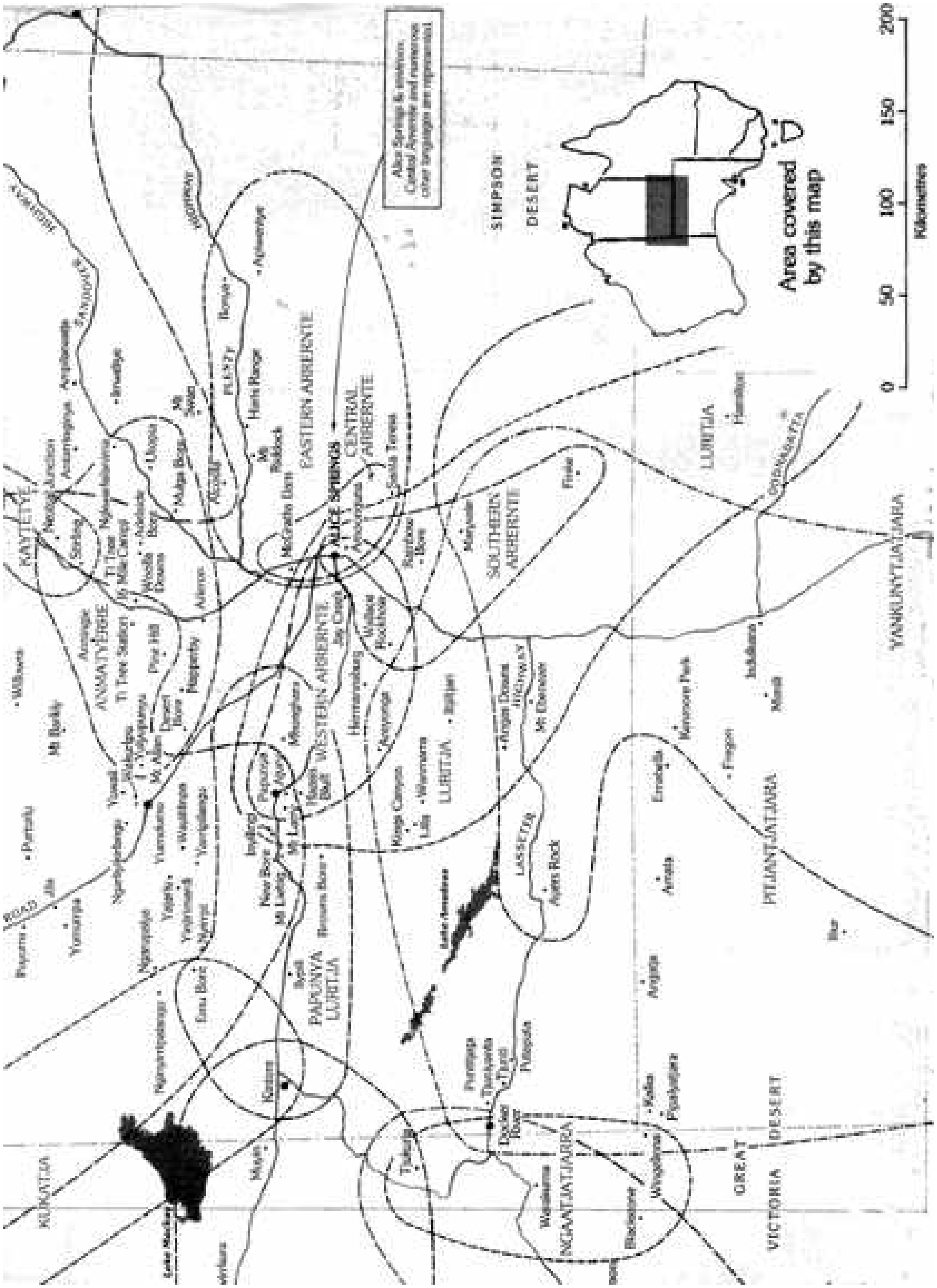


Figure 2.1: Current Distribution of Central Australian Languages (after Hobson, 1990. Used by permission.)

2.3.1 Consonants

The W. Arrernte consonant inventory is shown in Table 2.2 below, while words illustrating the consonant phonemes are shown in Table 2.3.

Table 2.2: W. Arrernte consonant phonemes
(after Wilkins 1989, Breen 1990, Butcher to appear)

		Bilabial	Laminal Dental	Apical Alveolar	Apical Post-alveolar	Laminal Palato-alveolar	Dorsal Velar
Stops	IPA	**p**	**t̪**	**t**	**ʈ**	**t̻**	**k**
	Orthog	**p**	**th**	**t**	**rt**	**ty**	**k**
Nasals	IPA	**m**	**n̪**	**n**	**ɳ**	**n̻**	**ŋ**
	Orthog	**m**	**nh**	**n**	**rn**	**ny**	**ng**
Pre-stopped Nasals	IPA	**pm**	**t̪n̪**	**tn**	**ʈɳ**	**t̻n̻**	**kŋ**
	Orthog	**pm**	**thn/tnh**	**tn**	**rtn**	**tny**	**kng**
Laterals	IPA		**l̪**	**l**	**ɭ**	**l̻**	
	Orthog		**lh**	**l**	**rl**	**ly**	
Approximants	IPA	**(w)**			**ɻ**	**j**	**w or ɣ**
	Orthog	**w**			**r**	**y**	**w**
Tap	IPA			**ɾ**			
	Orthog			**rr**			

With regard to the pre-stopped nasals, it should be mentioned that "nasally released stops" describes the phonetics of these segments more accurately. However, since they are associated with historical nasals, they will be called "pre-stopped nasals" here. These segments have also been written by some as M, N̪, N, etc. but capitals in this thesis will be used to refer to non-contrastive apicals.

Table 2.3: W. Arrernte consonant phonemes in intervocalic position

	Bilabial	Laminal Dental	Apical Alveolar	Apical Post-alveolar	Laminal Palato-alveolar	Dorsal Velar
Stops á_ə	mapə *many (n)*	at̪ə *I (pr, tr.)*	l̺atə *today (n)*	kwaʈə *egg (n)*	kwat̻ə *water (n)*	makə *elbow (n)*
Nasals á_ə	mamə *sore (n)*	lan̪ə *there-mid (n)*	manə *money (n)*	aɳə *ground (n)*	mpan̻ə *marriage (n)*	paŋə *blind (n)*
Pre-stopped Nasals á_ə (í_ə)	apmə *snake (n)*	l̺at̪n̪iɾəmə *multiply (vi)*	atnə *dung (n)*	kaʈɳəmə *wait to kill someone (v)*	it̻n̻ə *dead (n)*	akŋəɾə *angry (n)*
Laterals á_ə		al̪ə *nose (n)*	palə *wrong (n)*	waɭə *house (n)*	wal̻ə *leafy branches (n)*	
Approximants á_ə	(awə *yes)*			paɻə *penis (n)*	tajə *moon (n)*	awə *yes*
Tap á_ə			aɾə *kangaroo (n)*			

2.3.2 Vowels

Vowel phonology in Arandic languages is as yet imperfectly understood. An emerging analytical consensus, following Breen (1990), suggests that W. Arrernte has three vowel phonemes varying in height: /i/, /ə/, /a/; and that contrastive rounding is associated with some syllables, to yield rounded vowels (allophones of /ə/.) Butcher (to appear) notes that in general, as compared with English, the peripheries of the vowel space seem to be underused in Australian languages with small vowel systems. This observation is reminiscent of that made by Maddieson for Tausug, discussed in Chapter One above. However, within the space that is used, two of the W. Arrernte vowels are extremely variable in their realization. An impressionistic vowel space for W. Arrernte is shown in Figure 2.2 (cf. Wilkins 1989 for E. Arrernte.)

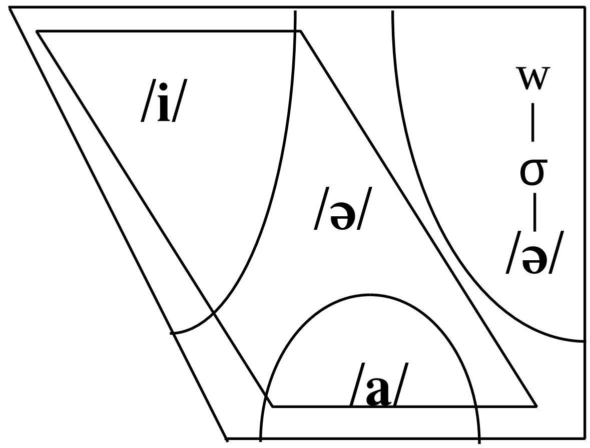


Figure 2.2: Author's impressionistic vowel space for W. Arrernte. The parallelogram shows the allophonic range of unrounded /ə/, while the high back area shows the range for rounded /ə/.

Maddieson (personal communication) has pointed out that (E.) Arrernte vowels show less actual formant variation than English-speaking linguists tend to transcribe; there is a danger that English listeners, with their fuller vowel systems, are prone to overdifferentiate in their perception of these vowels. With this caveat, major allophonic tendencies are described below.

The high vowel varies in quality from [ɛ] to [i]. Breen suggests that lower allophones ([ɛ] or [ɪ]) appear in the environment of labials and [+anterior] coronals. Thus:

labial:	/'t̪ipə/ =	['t̪ɛpɐ]	*'bird'*
laminal dental:	/'il̪t̪ə/ =	['ɛl̪t̪ə]~['ɪl̪t̪ə]	*'house'*
apical alveolar:	/'itnə/ =	['ɛtna]~['ɪtnɐ]	*'they'*

Before velars and [–anterior] coronals a higher allophone is used. Thus:

apical postalveolar:	/in'tiʈə/ =	[ɪn'diʈɐ]	*'rotten'*
laminal palatoalveolar:	/'it̠ə/ =	['it̠a]	*'nothing'*
dorsal velar:	/'tniŋkə/ =	['tniŋkɐ]	*'many'*

However, it must be said that some lexical items seem to be more stable in their allophonic usage than others. Thus, the author has not heard variants for /'t̠ipə/ 'bird' involving other vowels than [ɛ] (although higher variants can occur before labials: /i'palt̠ə/ = [i'balt̠a] 'friend', /'ipəʈə/ = ['ipəʈɐ] 'hole'. On the other hand, as noted above, the words for 'house' and 'they' do use a range of allophones varying in the height of the initial vowel. Wilkins (1989, Chapter 2, pg. 3) mentions the same "problematic" behavior of vowels in E. Arrernte as well:

> It is true, for instance, that in a majority of uses the /i/ in /itəmə/ 'is cooking' and /iləmə/ 'is telling' is pronounced [i] and [ɪ] respectively. However, even in carefully produced citation forms, some speakers may use [ɪ] for the former and [i] for the latter. Thus the association of a particular allophone with a phoneme in a specific environment may be merely a statistical correlate. Similarly, /ə/ before /j/ is realised by a range of pronunciation between [e] and [i], while /i/ before /j/ is always [i]. Here we have an example of a breach of the biuniqueness principle in classical phonology (see Lass 1984:27-30). Just hearing [i] in a form, one would be unable to assign the phone definitively to either /i/ or /ə/, but knowing the range of pronunciations for a form allows one to determine, unambiguously, the particular phoneme.

In contrast to /i/ and /ə/ (the latter is discussed immediately below), the vowel /a/ is restricted to a fairly small space. It usually has the quality [a], though it may be shorter and more centralized [ɐ] when unstressed.   Some /a/ vowels are phonetically long: phonologically, contrastive length for W. Arrernte /a/ is in a transitional phase (Breen, personal communication.) The long vowel /aa/ derives historically from the sequence /aɣə/; the phoneme /ɣ/ is still present in other dialects, but has been completely lost in W. Arrernte.

The mid vowel /ə/ is extremely variable, both in height and backness. Again, allophonic variation for /ə/ is not fully understood. Detailed, but cautious, statements of allophone distributions and token-to-token variability may be found in Breen (in progress) for W. Arrernte, and Wilkins (1989) for E. Arrernte. However, an illustration of phonetic variability in W. Arrernte /ə/ follows:

/'məŋə/ =	['məŋɐ]	*'fly'*
/'kwəjə/ =	['kwiΔ]	*'oops'*
/'pət̪əməwə/ =	['pɪt̪əmo^{ʊ}]	*'come here!*
/'ləwə/ =	['loɐ]	*'how about'*
/'n^{w}əkə/ =	['nʊkɐ]	*'my'*
/'it̪ə/ =	['it̪a]	*'nothing'*

Having made these observations, it should be mentioned that in an instrumental acoustic study of E. Arrernte vowels, Ladefoged and Maddieson (1996) fail to find a clear picture of environmentally conditioned /ə/ allophony. Rather, they find a very large range of variation for tokens of /ə/, which cannot be correlated with any particular preceding consonant environment. (Note that Breen's statement of allophony for /i/ above involved the following consonant.) Moreover, there is substantial overlap of means for /ə/ in different preceding consonant environments. These results imply a large range of free variation in /ə/.

Arrernte also has rounded vowel phones ranging from [o] to [u] which, as mentioned above, are taken to be allophones of /ə/. Breen's analysis of these rounded vowels is to posit a "rounding prosody", which is associated with the syllable as a whole, rather than with a particular vowel or consonant. We will return to this issue after a brief treatment of syllable structure, below.

2.3.3 Syllable Structure

Surface syllable structure in Arrernte is (C)(C)V(C): e.g. /l̻t̻ərpə/=[l̻d̻ər • pɐ] ‘bald’. No word may end in /i/ or /a/, or begin with /ə/. Words may end in [ə] when they occur phrase-finally, but in connected speech [ə] is usually elided. There is no phonemic contrast of /...C/ with /...Cə/. Thus in citation form the word for ‘gap’ appears in two forms: /tʷat̻ə/=[tʷat̻ɐ]~[tʷat̻]. Breen (personal communication) posits underlying /...C/, with optional phrase-final [ə] epenthesis. Vowel sequences are not allowed within a phrase; they occur when a phrase ending in optional [ə] precedes another vowel-initial phrase, as in [/jəŋə/]$_{PP}$ [/anəmə/]$_{PP}$ = [jəŋɐ anəmɐ], versus [/jəŋə anəmə/]$_{PP}$ = [jəŋanəmɐ] ‘I am sitting.’

Breen (1990) has offered an intriguing analysis of Arrernte syllable structure, whereby the only legal underlying syllables are VC(C); i.e. syllables have codas but no onsets. (Part of the evidence for this analysis is the complete predictability of word-final /ə/, as explicated above.) In Breen’s analysis, the mid vowel is epenthesized in final position, as well as in other vowel positions not occupied by /i/ or /a/. This analysis allows for more straightforward accounts of reduplication, affixation and stress assignment (see below), and trivial accounting for forms in a language game called “Rabbit Talk” (Turner and Breen 1984) in which the first underlying rhyme is placed at the end of the word. All of these processes are quite a bit more complicated to account for in a CV analysis.

Underlying structures following Breen’s analysis are shown for a few examples below. The last case involves rounding, which is analyzed as being associated with a syllable, on its own tier (although it has been written above with a raised ‘w’, for convenience.) This analysis captures important regularities concerning the distribution of rounding on consonants and vowels. For details of the analysis and its justification, see Evans (1995.)

Surface form	Gloss	Underlying structure per Breen 1990
[nəmə]	*sit, be*	VC VC | | n m
[n̪t̪əm]	*give*	VCC VC | | | n̪ t̪ m
[aɾat̻ə]	*true*	VC VC | | | | a ɾ a t̻
[ɪŋʊn̪t̪ə]	*morning*	w | σ σ /\ /|\\ VC VCC | | | | i ŋ n̪ t̪

2.3.4 Stress

Primary stress generally falls on the first syllable containing an onset, with secondary stress being associated with every other following syllable, except the final syllable. Wilkins (1989) mentions one source of counter-examples of the shape /#aCə/, in which stress may fall on either /ə/, which has the onset, or the initial /a/. Thus, ‘Arrernte’ can be either [a'ɾəɳʈə] or ['aɾəɳʈə]. Moreover, there is evidence that both /a/

and /i/ seem to attract stress even where they are not initial. Thus, the word for ‘fingernail’ can be produced as ['t̪əpmaɻə] (with stress on the first syllable containing an onset) or [t̪əp'maɻə] (with stress on the syllable whose nucleus is /a/.) For these and other reasons, Breen assigns a different status to /i/ and /a/ than to the mid vowel.

Breen accounts for default stress in his VC analysis by positing that stress falls on the second underlying rhyme of words.

2.4 Instrumental Studies of Australian Coronals

Detailed articulatory studies for Australian languages are scarce. Although a resurgence of work on Australian languages has taken place in the last 30 years (Dixon and Blake 1991 present an overview) nearly all of this work has been based on impressionistic descriptions of sounds, as yet uncorroborated by instrumental studies. One result is that articulatory descriptions vary widely among researchers. Only a few instrumental articulatory studies are known. Jernudd (1974) examined palatograms (but no corresponding linguograms) for three Gunwinjgu speakers. Butcher in a very thorough study (to appear) uses both static and dynamic palatography (electropalatography) to examine articulations for one speaker each of quite a few Australian languages. (The languages examined using static palatography include: Burarra, Eastern Arrernte, Gunwinjgu, Guugu Yimidhirr, Kalaw Kawaw Ya, Murrinh-Patha, Ngaanyatjarra, Nyangumarta, Warlpiri, and Yanyuwa. Electropalatographic records also exist for most of these.) The broad lines of Butcher's findings are summarized below. (The preliminary results summarized here are from work in progress which Professor Andrew Butcher, Flinders University, Adelaide, Australia, has generously made available to the author.)

Apical alveolars: Sounds which have traditionally been called "apical alveolars" in languages examined by Butcher are marked by consistency of articulation across both languages (speakers) and repetitions. Linguograms and palatograms together show these articulations to be uncontroversially apical and alveolar; the tongue apex makes a narrow band of contact (from 2-7 mm at the midline between the central incisors, measured from photographs of the palate) just at or in front of the alveolar ridge. Not much allophonic variation is observed among the articulations, probably because of the freedom of the apex to move relatively independently of the tongue body. EPG shows evidence of a very rapid closing movement of 10-20 milliseconds. ("Closing movement" was defined as the duration from the time of initial movement of the tongue away from the vowel toward the roof of the mouth, until the maximum number of electrode contacts had been reached. Butcher notes that the moment of movement away from vowel position is imprecisely defined because of the nature of EPG records; contact patterns are measured, not actual movement.) Apical alveolars also show a hold phase (measured from maximal closure to evidence of a break in the stop; i.e. beginning of the release) that is stable and static.

Apical postalveolars: Articulations which have been characterized as "apical postalveolar" show greater variability across the languages for which phonemes of this type were examined, as well as allophonically within them. Typically, a 5-12 mm band of contact is made in the postalveolar or prepalatal area, most often sublaminally. Apical postalveolars have slower closing movements than apical alveolars (30-90 ms) and the hold phase, once closure has been made, is dynamic; the tongue moves forward so that release is from a postalveolar or alveolar contact area. Recalling our discussion of cue-licensing of postalveolars from Chapter One, Butcher's observations provide an insight into why postalveolars often have asymmetrical formant transitions. These differences can be attributed to different positions of the tongue at closure and release. Moreover, the slow closing movement for this category of apicals implies particular salience for offset transitions, because of their long duration.

The fact that their occlusions are dynamic prompts the question of whether postalveolars are actually flaps. The Texas Instruments/Massachusetts Institute of Technology (TIMIT) speech database (see Zue et al. 1990 for details) uses the criterion of lack of release burst for defining flaps. By this criterion, postalveolars are not flaps. Moreover, they are much longer in total mean duration (100 ms) than the flaps in TIMIT (mean=29 ms, Byrd 1993.) In addition, they have too significant a VOT and too loud a burst amplitude to be considered [+sonorant]. However, though not flaps, they ought to be considered a dynamic gesture type.

Non-contrastive apicals: Butcher finds non-contrastive initial apicals to be intermediate in articulation between contrastive alveolars and postalveolars, though significantly longer in release duration than either. (The latter may be an effect of prosodic position.) Non-contrastive apicals are like postalveolars in that they form a band of constriction 5-10 mm wide, and that they move forward between closure and release. On the other hand, they are not usually sublaminal, and are intermediate between the alveolar and postalveolar categories in their point of constriction on the roof of the mouth. Thus, these results show evidence for the adaptive mechanism of polarization. Recall that under the polarization scenario summarized in Figure 1.6 of Chapter One, we expect to find both of the contrastive apicals at different places than the non-contrastive apical, and reciprocally, we expect the non-contrastive apical to be intermediate between them.

Laminal dentals: Butcher finds that so-called “laminal dentals” involve the dental and alveolar region of the roof of the mouth, and may be formed in one of three ways. In order of probable frequency, these articulations are: 1) interdental with tongue-tip up—i.e. the tip is visible between the teeth 2) interdental with tongue-tip down—i.e. the tip is behind the lower teeth and the blade is visible between the teeth, or 3) dentialveolar with tongue-tip up—i.e. both tip and blade make contact with the surface behind the upper teeth. Even within the subset of languages with contrasting laminals, there is a range of variation. Moreover, within a given speaker's utterances, all three types of articulation can occur. Variation may in part be attributed to carefulness of speech (with interdentals being careful variants, and dentialveolars being rapid variants.) Whether articulated with the tongue tip up or down, "laminal dentals" create a 13-20 mm band at closure, from the teeth to the alveolar zone.

Laminal palatals: Articulations described in the Australian literature as "laminal palatal" appear to be articulated with the tongue tip down in the majority of cases observed by Butcher, and are similar whether they have phonemic or merely allophonic status. These articulations form a 9-13 mm band of constriction in the alveolar and postalveolar, or postalveolar and prepalatal areas. (Note that this is a narrower midsagittal constriction than for the laminal dental category.) However, additional contact behind the occlusion may be broader at the sides of the tongue, evidence of a raised tongue body. An additional characteristic, which probably affects stop durations of the laminal palatals, is indicated by Butcher's EPG data: at closure, the tongue is initially braced at the lower teeth, and contact is extended from front to back. At release, contact is "peeled" away, from back to front. (For an account of how bracing facilitates tongue movements, see Stone 1991.) This type of articulation is likely to involve slower movements than those in which the tongue tip meets and pushes off the roof of the mouth.

The midsagittal sections in Figure 2.3 (drawn by the author from these descriptions) summarize the articulations that Butcher finds representative of the four categories of Australian stop. Because the overall tongue configuration and resulting shape and volume of the vocal tract as a whole determines the acoustics of these contrasts, Butcher (personal communication) has made the insightful suggestion that convexity versus concavity of the upper surface of the tongue may be as appropriate a feature to use in describing these contrasts as apicality versus laminality. Under such a system, we would predict laminals to be convex, and apicals to be concave, with respect to the occlusal plane.

laminal dental	apical alveolar	apical postalveolar	laminal palatal
convex	concave	concave	convex

Figure 2.3: Representative Australian stops per Butcher (to appear)

Anderson and Maddieson (1994) acoustically differentiate the four phonetic coronal stops of “Traditional Tiwi” (Lee’s term for the stable variant of the language used by speakers over 30 years of age in her 1987 study). They focus on closure and release durations, relative amplitudes at burst transients, and short-term spectral patterns, for two female and three male native speakers. (Data was collected in Australia by Maddieson.) In the following summary of the Tiwi results, articulations are referred to by their traditionally assumed active and passive articulators, but bear in mind that none of these articulations were instrumentally verified.

The **laminal dental** stop has a low-amplitude burst and energy dispersed over a wide range of frequencies in its spectrum, suggesting an articulation with a distributed constriction, made in the front of the mouth. Its **laminal palatal** allophone is differentiated from other segments (including the laminal dental) by a long Voice Onset Time (VOT) and associated frication, implying an especially distributed constriction.

The **apical postalveolar** stop is well differentiated from other segments: it is short in duration, high in burst amplitude, and shows a narrow distribution of spectral energy. These characteristics support Butcher's analysis of a small articulator without much obstruction behind it. There is probably a significantly large front (sublaminal) cavity at closure.

Surprisingly, despite Butcher's evidence of articulatory stability, the **apical alveolar** stop is most difficult to characterize, as it often shows characteristics of one or more of the other stop categories. However, it differs from the apical postalveolar in having longer voiceless closure, longer VOT, and wider bandwidth of its major spectral peak. Thus, it is probably a more forward articulation than the apical postalveolar. It differs from the laminal palatal in VOT, suggesting a lighter articulator. Its greater relative burst amplitude as compared with the laminal dental points to a difference in constriction size between them; however, it is hardest to differentiate from the laminal dental, which is not an isolated difficulty. Dart (1991) found no differences in closure duration for either Malayalam or 'O'odham laminal dentals and apical alveolars, and differences in VOT in the case of only one of three speakers of Malayalam. In Toda, VOT does not distinguish confirmed laminal dentialveolars from apical alveolars (Shalev et al. 1994.)

To summarize these results, recall that in Tiwi only three of the four stops contrast phonologically; the laminal palatal [**t̠**] is an allophone of laminal dental /**t̪**/, before /**i**/. Leaving aside for the moment the clearly important formant transitions to/from surrounding vowels, speculation on additional cues which native speakers might potentially use to identify the contrasts follows. Apical postalveolar /**ʈ**/ may be distinguished from both laminal dental /**t̪**/ and apical alveolar /**t**/ in having a higher burst amplitude, shorter voiceless closure and VOT, and a narrow-bandwidth, isolated spectral peak. Laminal dental /**t̪**/ may be distinguished from apical alveolar /**t**/ by a lower amplitude burst and more distributed spectrum. Apical postalveolar /**ʈ**/ is shorter in voiceless closure and VOT, and higher in burst amplitude than both apical alveolar /**t**/ and laminal palatal [**t̠**]. It has a narrower spectral energy distribution than apical alveolar /**t**/. The apical alveolar and laminal palatal may be distinguished by VOT (longer in the latter.)

With characteristic inclusivity, Ladefoged and Maddieson (1996) provide instrumental acoustic data and analysis of several aspects of E. Arrernte. They treat stop burst spectra (p.30), giving evidence that the active articulator may determine spectral shape; apical spectra seem to be characterized by a midfrequency peak, whereas laminal spectra smoothly decline over the frequency range observed. The center frequencies of Arrernte nasal zeroes (p.116 ff.) are discussed as a way to infer tongue shape in nasals; knowing that large oral cavities have lower–frequency nasal zeroes than smaller oral cavities, they deduce that laminal dentals must have a higher tongue body configuration than apical alveolars, which buttresses Butcher's argument that laminals are convex while apicals are concave. They provide formant frequency data for laterals (p. 194), and note the absence of laminal trills and taps, even in Australian languages where laminals are widespread (p. 240), which constitutes evidence of the difficulty of articulating trills and taps with the tongue blade.

Chapter One provided background on the particular theoretical questions of this dissertation. Chapter Two has introduced the multiple coronal contrasts in Australian languages, relevant facts about the structure of the language to be examined here, and results of previous instrumental investigations into Australian coronals. Chapters Three and Four will respectively address empirical studies into the articulation and perception of W. Arrernte coronals.

Chapter Three: Articulation of W. Arrernte Coronals

Recall that the goals of this study are to determine whether W. Arrernte shows evidence for polarization or gestural economy in the domain of consonant Place, and to find evidence for licensing by cue in native listeners' perception of consonants. This chapter addresses the first of these goals, presenting in turn the methods that were used to collect and analyze articulatory data, and the results of analysis. The chapter begins with a brief description of the language consultants who participated in the study, as well as the logistics of gaining permission to work with them. Following this, a detailed description of static palatographic methods is included for the field linguist. In subsequent sections we describe how video images were processed and measured so that tongue–palate contact patterns could be determined, and the results of those measurements. Separate sections focus on results for palatograms and for linguograms, and a final section summarizes the general tongue–palate contact patterns found for these coronals.

3.1 Making Contact with Language Consultants

The Institute for Aboriginal Development, and in particular Gavan Breen and Robert Hoogenraad of its Central Australian Dictionaries Project, made it possible for the author to be affiliated with the institute during her stay in Australia. Breen generously invited the author on fieldtrips where contact with native speakers of W. Arrernte could be made. From these contacts, relationships with several extended W. Arrernte families in Nthareye (Hermannsburg) and Iwepetheke (Jay Creek) developed. As is often the case with privately-owned aboriginal land, it was necessary to request permission from the Nthareye Council and the traditional custodians at Iwepetheke in order to stay in these communities. The two fieldsites are shown in Figure 3.1.

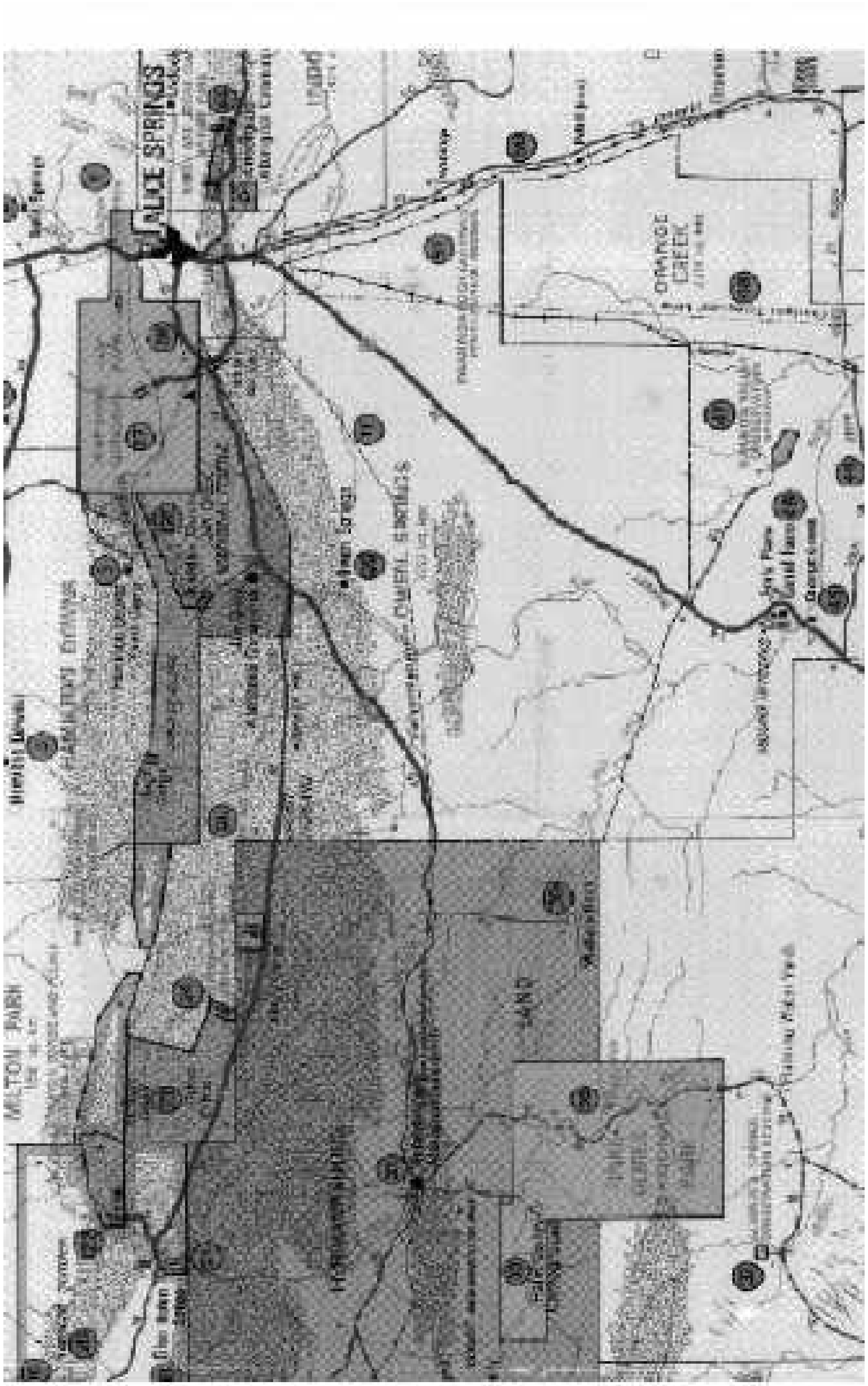


Figure 3.1: Fieldsites at Nthareye (Hermannsburg) and Iwepetheke (Jay Creek). Adapted from Deckert, 1991.

3.1.1 Informed Consent and Payment of Consultants

The investigator helped each potential participant review an informed consent form for the study, reproduced in the Appendix. Each point was explained to consultants and/or translated into W. Arrernte. Though nearly all W. Arrernte people speak Aboriginal English (a dialect of Australian English), a translator was often asked to help convey the meaning of this formal, technical document.

Language consultants were generally paid Au$15 hourly for their participation in the study. Those who participated in palatographic work received $20 per hour. In addition, the author made transportation available to Alice Springs for supplies, to outstations, and for food collection trips on traditionally owned land. Access to a vehicle was both an important compensation for participants, and rewarding for the experimenter.

3.1.2 Language consultants: Demographics

Twenty native speakers of W. Arrernte contributed to the study in different capacities. All 20 provided acoustic records, while a subset of 12 (8 women and four men) provided complete articulatory records, and of these 12, three men and 6 women participated in perception tests. The data included a substantially greater number of women than men, because the investigator had much freer social access to women than men, which is usual for women in Arrernte society.

The youngest speaker was 16; the oldest probably 65. Data for the 6 speakers reported on in this chapter represents three men of approximate age 30, 40 and 65, and three women of approximate age 16, 25 and 55.

3.2 Collecting Articulatory Records

Direct instrumental articulatory data for tongue-palate contact patterns was collected using a method called static palatography, which comprises two types of data: palatograms and linguograms. Briefly, a speaker's tongue or palate is painted with a non-toxic marking material. The speaker utters a word containing the segment of interest, and inserts a mirror into the mouth to reflect the resulting contact area on the palate, or protrudes the tongue to show contact on the tongue. The contact area is photographed or videotaped and the speaker then rinses his or her mouth with water.

Of the types of records collected, articulatory records were the most laborious for language consultants. Articulatory data was obtained only after wordlists were discussed and elaborated, and after acoustic records had been collected, so that speakers could familiarize themselves with the study and decide whether they were interested in a further time commitment. In each case, the author showed potential participants how palatograms, linguograms and dental casts were made, so that they could observe and ask about the procedure before deciding to participate. The experimenter demonstrated procedures on herself or on a consultant already participating in the study.

A detailed version of the procedure for obtaining palatograms, linguograms, dental impressions and dental casts follows, for the benefit of other fieldworkers. This is adapted from methods described in Ladefoged (1997a).

Sessions usually lasted from one to two hours at a time, depending on when the speaker wished to end the session. Palatography is time-consuming and fairly tedious, compared with other types of linguistic consulting work such as finding words, telling stories or singing songs. Several speakers chose not to continue after the first session. Others (including those whose results are reported on here) were quite patient and willing to participate in this aspect of the study.

3.2.1 *Palatography mirrors*

Rectangular, rounded-edged mirrors were made to specification by a glass company in Alice Springs, of glass 4 mm in thickness. Mirrors were 210 mm in length; long enough for the speaker to hold one end in her hand while the other end reflected an articulation, without obscuring the reflection. Four mirrors were made, of width 50, 55, 60 and 65 mm.

3.2.2 *Set-up*

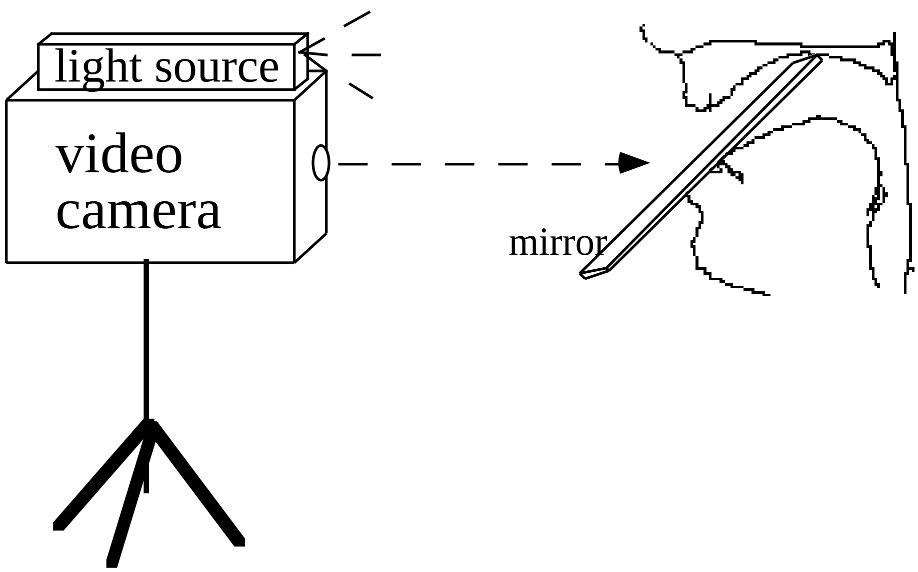


Figure 3.2: Schematic set–up for static palatography

A Sony 8mm video recorder with an attached 30W light source was set up on a tripod about five feet from the speaker. The speaker sat in a chair, preferably with a wall behind her to provide an anchor for her head. On the first session, the speaker chose a palatography mirror which fit comfortably in her mouth, but reflected the teeth on both left and right sides. The palatography mirror, as well as a large hand mirror, tissues, cup and jug of water, and large spittoon (cooking pot) were placed within easy reach. A clean towel was placed over the speaker's chest and shoulders to protect her clothing from stray charcoal. When the speaker was seated comfortably, the video camera was zoomed in to focus on her mouth.

A mixture of olive oil and digestive charcoal was prepared. Powdered charcoal was emptied from digestive charcoal capsules (available in pharmacies) and ground slightly, to make sure that the mixture would be smooth in consistency. Olive oil was added until a thick black paint resulted.

Each speaker had her own paintbrush, labeled with her name for re–use. At the beginning of each session, the speaker's paintbrush and the appropriately–sized palatography mirror were sterilized with boiling water and detergent, followed by antiseptic. The use of boiling water is important not just for sterilization, but for keeping the olive oil mixture smooth. When cold water is used, globules of water remain on the brush and cause the resulting mixture to be lumpy and hard to apply. Wide, soft brushes (about 10 mm in width) were chosen over slimmer brushes or disposable cotton tips because it takes only a few strokes to cover the entire tongue or palate with paint, an advantage for ticklish speakers.

3.2.3 Palatograms

When the speaker was ready, she protruded and relaxed her tongue. The tongue was painted as far back as was comfortable for the speaker, who then returned her tongue to a resting position, keeping her mouth open so that no tongue-palate contact was made. The camera was turned on, the speaker was told the English gloss, and was asked to say the Arrernte word in question. The person was videotaped uttering the single word. During the articulation paint was transferred to the roof of the mouth where the tongue had made contact with the palate. The speaker then placed the palatography mirror in her mouth to reflect the articulation, being directed to position the corners of the mirror behind the back molars, so that the entire pattern of contact could be seen through the videocamera. Participants tended to become fairly adept at placing the mirror in the same way for each palatogram. Nevertheless, the mirror's position would have inevitably changed slightly from token to token, causing angular distortion of the image filmed. Methods for correcting this distortion are discussed below. After being filmed the speaker was free to view the articulation in the hand mirror, and to rinse her mouth with water before her tongue was painted for the next palatogram.

Speaker's tongues differed in their absorbency to the charcoal mixture. For a few speakers, black color began to collect on the tongue despite repeated rinsings. In these cases, subsequent sessions began by obtaining linguograms first, since repeatedly painting the tongue for palatograms caused loss of sufficient contrast on the tongue.

Figure 3.3: Palatogram; still image digitized from video. Orientation: Upper teeth shown at top and reflected in the mirror at bottom. Token: **/pəʈə/** '*rock*'.

3.2.4 Linguograms

The speaker was asked to incline her head back slightly so that her palate could be painted. Again, this worked best when the chair was against a wall where the speaker could rest her head. Although more laborious than palatography in that the palate may be ticklish, and the surface to be painted is less accessible, linguography is also simpler in that a mirror does not have to be used to reflect the resulting pattern. To produce linguograms, the roof of the mouth and inside surfaces of the teeth were carefully painted. The speaker was instructed to relax with her mouth open while the camera was turned on, then directed to say the single word in question, and to put her tongue out so that the pattern could be filmed. Speakers were then instructed to move the tongue up, down or to either side, to show sublingual contact, or contact on the sides of the tongue. Figures 3.4a and 3.4b show two still images digitized from a video clip of a speaker uttering **/pəʈə/** '*rock*', and then showing contact areas on the tongue. In 16a, the speaker has stretched her tongue out and down to show a large portion of the upper surface, including the dorsum; a few moments later in 16b she has brought it in and up so that the underside is visible. Note how different in size and shape the tongue can appear to be. We will address this issue below under <u>Linguography: Image Processing.</u>

Figure 3.4a: Linguogram showing tongue blade and body contact.
Token: /**pəʈə**/ ‘*rock*’

Figure 3.4b: Linguogram showing tongue tip and sublingual contact.
Token: /**pəʈə**/ ‘*rock*’

3.2.5 Dental Impressions

It is important to have three dimensional information about the shape of speakers’ palates, in order to be able to relate palatographic and linguographic patterns to an articulation as a whole, for instance as would be shown in a midsagittal section. For this reason, dental impressions of each speaker’s palate were taken.

“Kromopan” chromatic dental alginate was used to make impressions in negative of speakers’ palates. The material has different color phases during mixing (purple), setting (pink), and set (green), which makes timing while mixing and setting unnecessary. Water was added to several tablespoons of powdered alginate in a flexible plastic container and quickly mixed until a thick pink paste resulted (this meant using slightly less water than the instructions call for when using dental impression trays, to prevent alginate from dripping from the mirror.) The alginate was gathered in a plastic scoop and transferred to the end of a palatography mirror wide enough to include the entire upper dentition. The mirror with its mound of alginate were placed carefully into the speaker’s mouth while she leaned forward over a large cooking pot and breathed through her nose. The speaker was instructed to bite down until the mirror was firmly pinned in the occlusal plane between her upper and lower teeth, to continue to breathe through her nose, and to drool if need be. When the alginate had set (turned green) the speaker was asked to gently remove the impression by rocking the mirror to and fro, and then asked to rinse her mouth. Two alginate impressions were made in this way for each speaker. Impressions were stored in water until they were cut and traced, to prevent shrinkage.

One of the alginate impressions was used to make a topographic drawing of the shape and dimensions of the roof of the speaker's mouth. First, since they do not figure in articulations, impressions of the outer surfaces of the teeth were removed, as shown in Figure 3.5. (In this and the following figures, note that the palatography mirror used for the purposes of these illustrations is not of the type described above.) Next, the impression was removed from the mirror with a metal spatula or knife (Figure 3.6.) The flat portion of the impression (the occlusal plane) was placed on a piece of graph paper, traced and labeled (Figure 3.7.) The impression was then cleft through in the midsagittal plane, between the two central incisors, as shown in Figure 3.8. (Often the bisecting line between the two central incisors had to be estimated. Many Arrernte speakers above 25 years of age have one or more incisors missing. Boys have incisors removed upon reaching adulthood. The reason for women's lack of incisors is not clear.)

Each resulting half was traced in the midsagittal plane, to yield a profile image of the shape and size of the palate (Figures 3.9a and 3.9b.)

Figure 3.5: Removing impressions of outer surfaces of the teeth.

Figure 3.6: Sliding the alginate impression from the mirror.

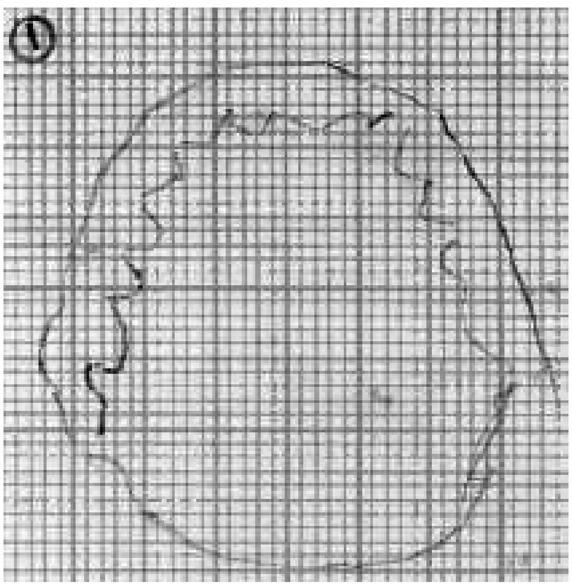


Figure 3.7: A tracing of an alginate impression, in the occlusal plane. The serrated curve shows where inner surfaces of the teeth join the palate.

Figure 3.8: Cutting the impression in the midsagittal plane.

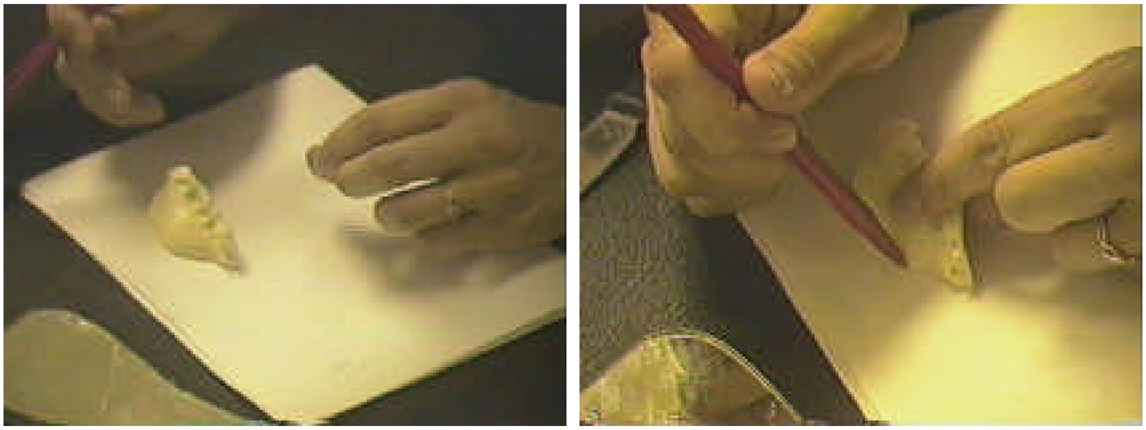


Figure 3.9a and b: Tracing the midsagittal profile of the palate.

Next, both halves were placed back together and bisected in the coronal plane, usually between the second premolar and first molar on each side, resulting in four quadrants. These sagittal and coronal cuts were used to define *x* and *y* axes and an origin on the graph paper, as shown in Figure 3.10.

The alginate mold was then sliced parallel to the occlusal plane at successive 5 mm increments, so that contour lines representing successively higher areas of the mold could be traced. After each slice, the quadrants were re–aligned together at the origin and traced, yielding a contour map of the palate, as shown in Figure 3.11.

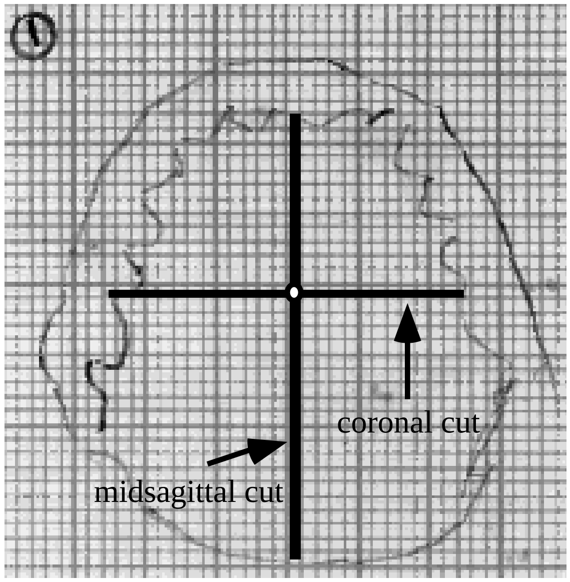


Figure 3.10: Alginate impression cut into four quadrants, in midsagittal and coronal planes.

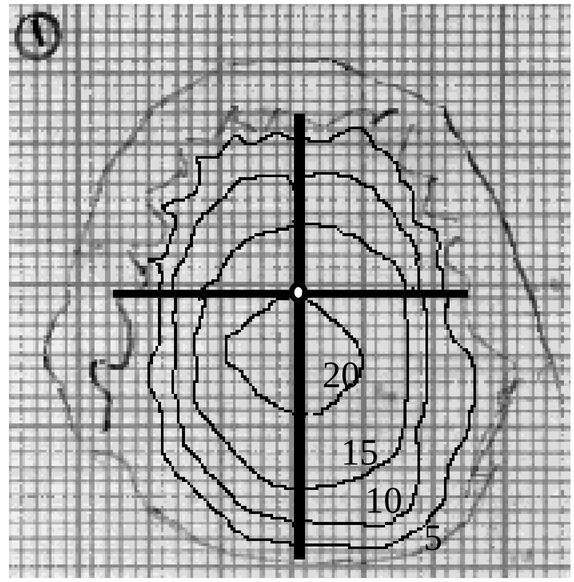


Figure 3.11: Contour map of palate.

3.2.6 Slicing Tool

The tool used to repeatedly slice the alginate mold parallel to the occlusal plane is a slight modification on a tool developed by Sinisa Spajic, consisting of a flat, smooth, 190 mm x 125 mm wooden board. On either side of this, four strips of 1.25 mm cardboard were pasted on top of one another, 70 mm apart, resulting in a two parallel “walls” of height 5 mm. On top of, and perpendicular to the cardboard walls was placed an 80 mm long razor blade, creating a wide slicing area. The dental impression was pushed through this tool so as to cut off the bottom 5 mm of impression material in the occlusal plane. After each slice, the four quadrants were placed together at the origin on the tracing paper, traced, and the process repeated until all of the impression material was drawn in this way (see Figure 3.12.)

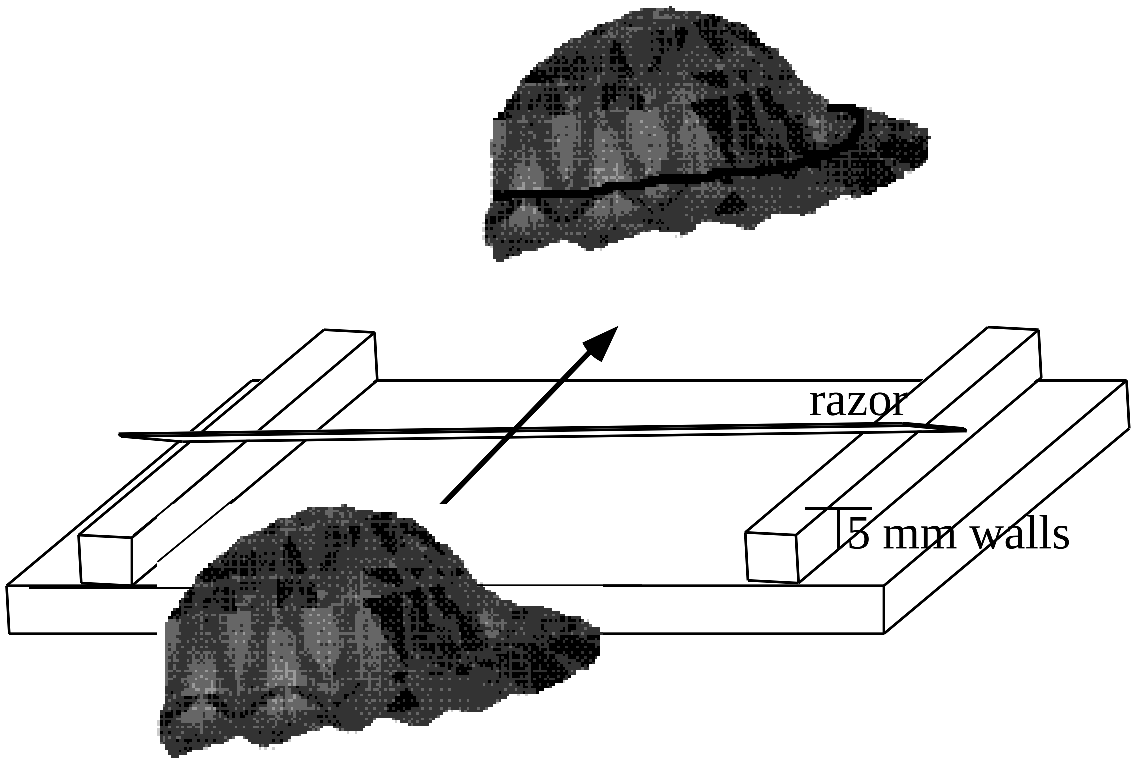


Figure 3.12: Schematic drawing of the slicing tool used in drawing contour maps of palates. The dark line around the upper dental impression shows where the razor has sliced it.

3.2.7 Plaster Casts

It is also useful to preserve a record of landmarks in the mouth such as teeth and ridges on the palate, because these landmarks help to locate where an articulation has taken place when studying palatograms. The second alginate impression was used to create a positive of the palate in hard plaster. A flexible plastic tub was greased with vaseline. Plaster was mixed and poured into the tub, taking care that no air bubbles remained in the plaster which could create air pockets and render the resulting cast imprecise. The alginate cast was greased with vaseline and placed, upside down, in the plaster. After 30 minutes the hardened cast was eased out of the tub and the alginate negative cut and/or pried gently out of the positive plaster mold.

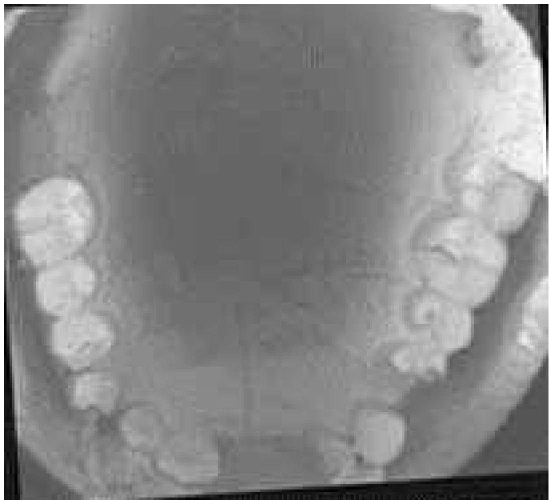


Figure 3.13: Hard plaster cast taken from alginate dental impression.

3.2.8 Palatography Wordlist

As mentioned above, static palatography is a cumulative record of tongue–palate contact during an utterance. Thus, to the extent possible, it is important to choose words containing only non–high vowels and labials in addition to the segment of interest, in order to avoid confounding effects of other tongue-palate contacts. Breen's W. Arrernte wordlist (in progress) was used to find words which include only one coronal contact. The subset of data for coronal stops and nasals which will be analyzed here is shown in Table 3.1. Each of these words is in common use in W. Arrernte. For each speaker, the wordlist was reviewed, and then two palatograms and two linguograms of each word were recorded.

Table 3.1: Static Palatography wordlist: W. Arrernte coronal stops and nasals

	Laminal Dental	*Apical* Alveolar	*Apical* Postalveolar	*Laminal* Palatoalveolar
Stops Between Vowels	**'pət̪ə** *pouch (n)*	**'matə(ɻə)** *cloud (n)*	**'pəʈə** *rock (n)*	**'pet̻əmə** *is coming(vi)*
Stops Word-initially	**'t̪əmə** *grind (vt)*	**'Təpə** *back (n)*		**'t̻apə** *grub (n)*
Nasals Between Vowels	**ip'mən̪ə** *grandmother (n)*	**'manə** *money (n)*	**'məɳə** *veg. food (n)*	**'mpən̻ə** *crumb (n)*
Nasals Word-initially	**'n̪əmə** *rain is falling (vt)*	**'Nəmə** *is sitting (vi)*		**'t̻n̻əmə** *is falling (vi)*

Two cases require discussion. In the word for *'cloud'* /**'matəɻə**/, speakers were instructed to omit the final syllable, in order to avoid potential confounding effects of the /**ɻ**/ on the resulting pattern. Also, since a word completely lacking other coronals or high vowels could not be found for the laminal palatoalveolar word-initial nasal /**n̻**/, a prestopped nasal /**t̻n̻**/ was used. We will discuss this choice further in examining results of measurements on palatograms.

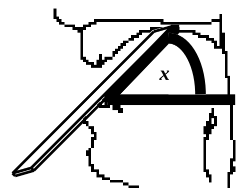
3.3 Palatography: Image Processing

For each token, the relevant video clip was digitized into a computer file from which a high-quality still frame was chosen for analysis. Typically, an 8 to 10 second sequence of videotape had been filmed for every palatogram or linguogram. The sequence was captured at 30 frames per second, and examined frame by frame, to choose frames which most clearly showed the pattern made on the palate or tongue.

3.3.1 Correcting and Measuring Palatograms

Measurements of palatograms were taken using tools in the program NIH Image. As mentioned above, slight differences in the angle at which the mirror is placed in the mouth relative to the occlusal plane (angle *x*, in Figure 3.14) cause the reflected image to be potentially lengthened or shortened, in both vertical and horizontal directions. (Here, 'vertical' and 'horizontal' refer to 'front-to-back' and 'side-to-side' in articulatory dimensions, respectively.) For each still frame, measurements along vertical and horizontal axes were independently corrected for angular distortion by referring to actual millimeter measurements taken from lifesize plaster casts and alginate tracings.

Figure 3.14:
Angle of mirror with respect to occlusal plane.



To obtain the horizontal correction factor for a given palatogram, a horizontal calibration measure was taken at a line between the inner surfaces of the teeth on each side, just forward of the upper first molars on the still frame (line **'h'** in Figure 3.15.) The same measure was taken on the lifesize cast with calipers, and verified with the topographic tracing, to obtain actual mm values. The ratio of the line's apparent to actual size was then used as a correction factor for horizontal measurements on this still frame.

Likewise, to obtain the vertical correction factor for a given palatogram, a calibration measure was taken at a line drawn from the front edge of the front incisors backward to the horizontal calibration line (line **'v'**, Figure 3.16.) Again, this measure was made on the lifesize cast and drawing, to determine actual length of the line in mm. The ratio of apparent to actual size of the line was used as a correction factor for vertical measurements on the frame in question.

Figure 3.15:

Horizontal calibration measure bounded by inside surfaces of teeth.

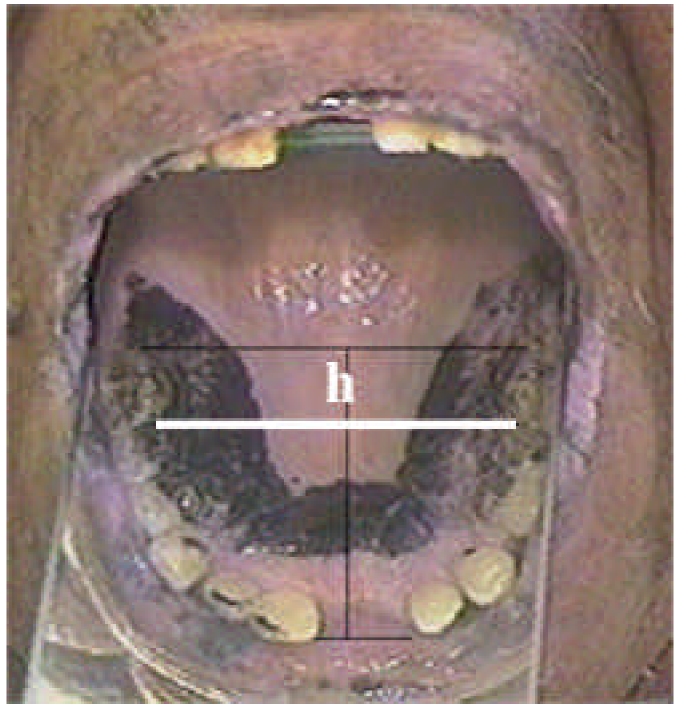
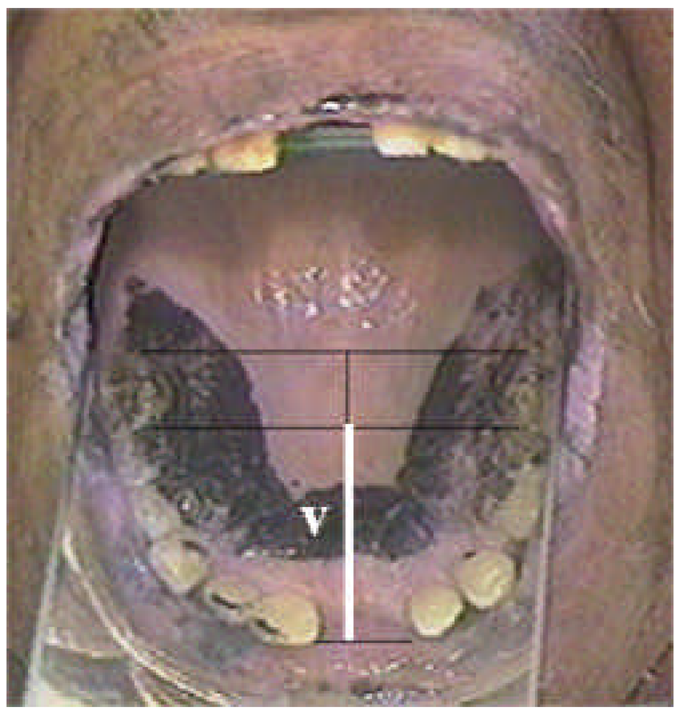


Figure 3.16:

Vertical calibration measure bounded by front edge of front incisors and line **‘h’**.



The corrections described above remove linear distortions along the two axes, and at the same time scale the image to a lifesize projection of the mouth in two dimensions. Note, however, that corrections for three-dimensional "domal distortions" caused by differences in the slope of the palate at different points, were not made. Differences in curvature can clearly be a confounding element, but we judged that the accuracy of static palatography may have an order of error magnitude larger than might be introduced by differences in slope, and this type of correction was not attempted.

Notice that the speaker shown in the preceding figures does not have a complete dentition. In these cases, the reference line at the front edge of the front incisors was estimated as closely as possible, usually by extrapolating a line from the remaining incisor. However, in two cases, the only way that the incisor reference line could be drawn consistently, i.e. with reference to the same known points in each photograph, was to use more idiosyncratic reference points on the teeth. Figures 3.17 and 3.18 show the speakers in question and the incisor reference lines that were drawn.

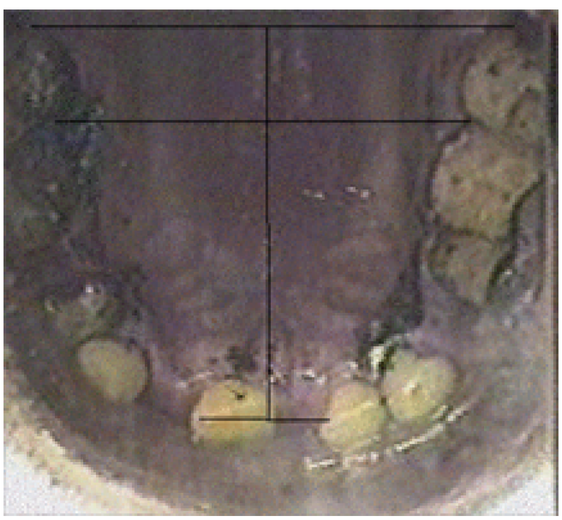


Figure 3.17: Male speaker 1. Placement of incisor reference line: Drawn between left corners of frontmost teeth in midline.

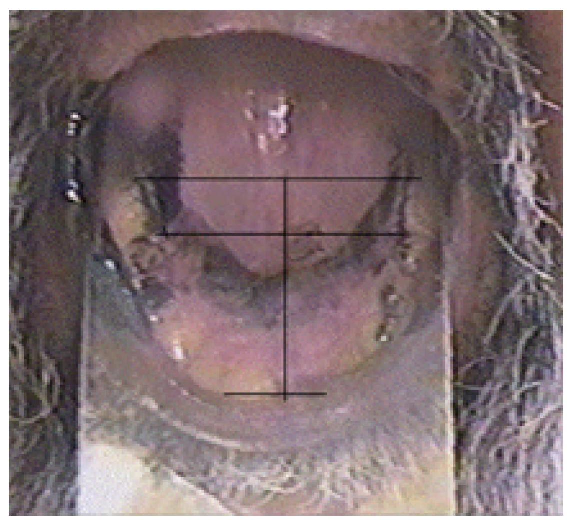


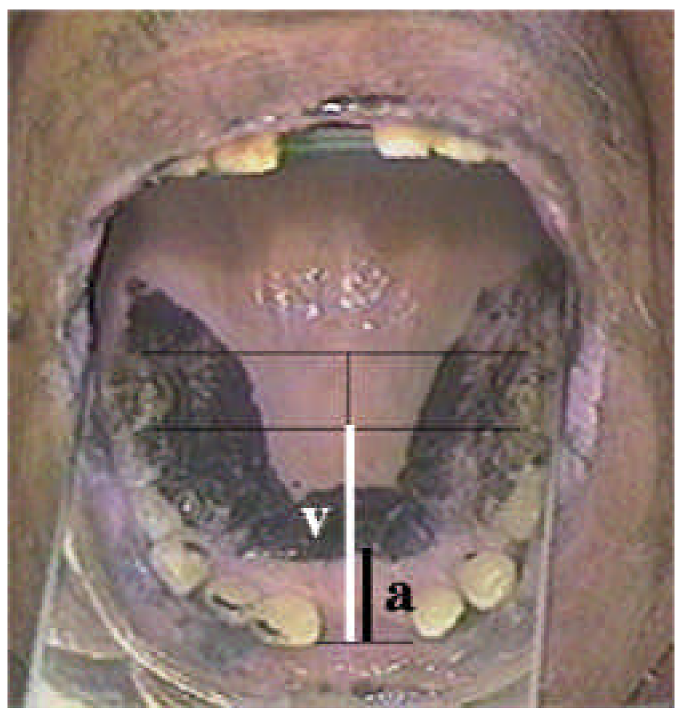
Figure 3.18: Male speaker 2. Placement of incisor reference line: Drawn from left corner of front left incisor, parallel to line **'h'**.

3.3.2 Absolute and relative measurements

Measurements of palatograms were taken in pixels, and converted to both absolute dimensions (millimeters) and relative dimensions (percent.) For example, the point of frontmost contact, shown as distance back from the base of the teeth to the beginning of the black contact pattern, (measurement **‘a’** in Figure 3.19) was converted to millimeters (mm) via its correction factor, and then to a percentage of its calibration measure, in this case line **‘v’** ***(%=[a/v]*100).*** Since speakers mouths vary in size and shape, relative measurements were used to make differences or similarities in contact patterns more comparable between speakers.

Figure 3.19:

“Frontmost contact” (measure **‘a’**) as a percentage of line **‘v’** (line ‘v’ taken to be 100%.)

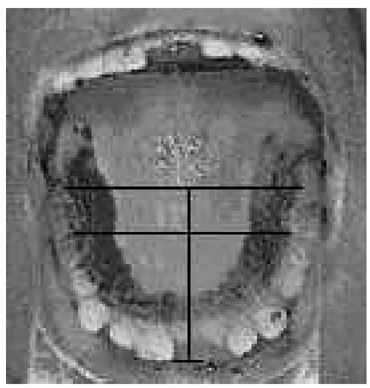


3.4 Analysis of Palatograms: Measurements

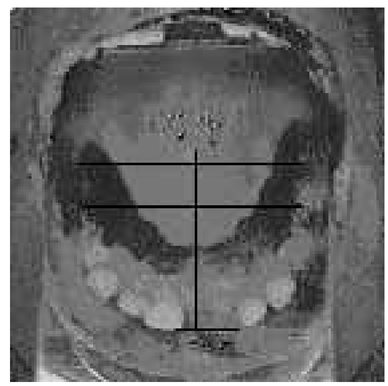
For the purpose of comparison, Figure 3.20 shows a sample palatogram for each of the four categories of intervocalically contrastive stop, for the same speaker. Measurements of palatograms were designed to reflect articulatory characteristics which would also have acoustic consequences. Measurements involved a) where the frontmost contact for each category of coronal was made, b) how broad that contact was, and c) the size of the space behind the constriction. These are illustrated as **‘a’**, **‘b’**, and **‘c’** respectively, in Figure 3.21.

Figure 3.20:

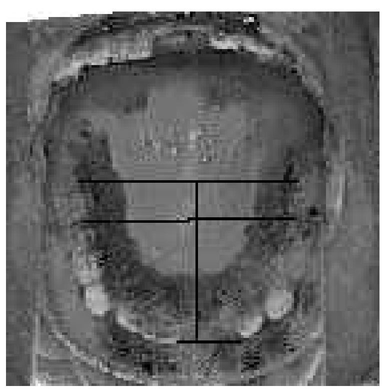
Tokens of the medial stops for one speaker



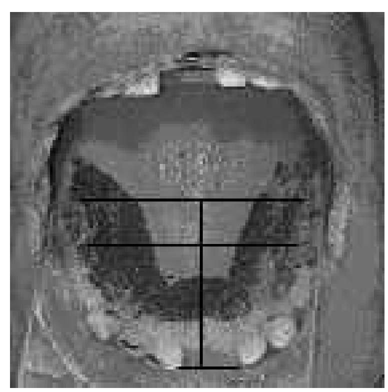
Apical Alveolar /t/



Apical Post-alveolar /ʈ/



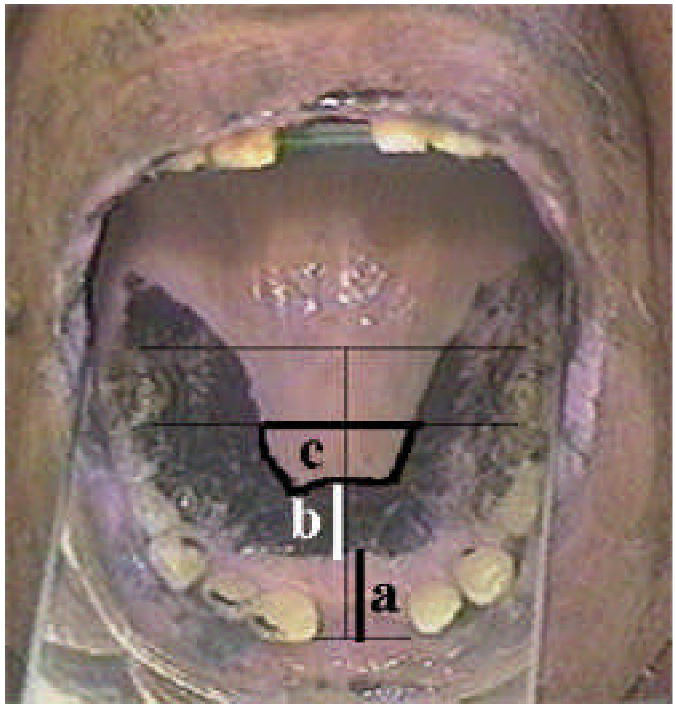
Laminal Dental /t̪/



Laminal Palatoalveolar /t̻/

Figure 3.21:

Measurements of palatograms



3.4.1 Measure ***'a'****: Frontmost Contact*

Comparative inspection of frames showed that *frontmost contact* on the roof of the mouth in the midline was likely to yield differences among categories. Indeed, this metric has been used before by Butcher (to appear), Dart (1991) and others, as an index of place of articulation. Moreover, since this measure reflects the size of the cavity in front of the constriction, it can be taken to be associated with acoustic correlates such as spectral shape (Fant 1960.) Note that in Figure 3.20 the laminal dental shows contact on the surfaces of the incisors. The apical alveolar begins further back, clear of the teeth in the case of this token, and frontmost contact for the apical postalveolar and laminal palatoalveolar begin appreciably further back than the apical alveolar. As mentioned above, frontmost contact was quantified by measuring from a line drawn at the base of the teeth back to the front edge of the contact pattern, in the midline (line **'a'**, Figures 3.19 and 3.21.)

*3.4.2 Measure '**b**': Length of Contact*

The apical/laminal distinction itself leads us to expect differences between apicals and laminals based on length of contact from front to back in the midline. However, there may be significant differences in length of midline contact among each of the place categories, or between stops and nasals in a single category, in addition to the apical/laminal distinction. Observe that the laminal dental and laminal palatoalveolar in Figure 3.20 are very long in midline contact from front to back, although it is not possible to tell from these tokens which may be longer or whether there is a significant difference between them. The apicals, as expected, are much shorter in midline contact. This metric, too, has been used before (Butcher, to appear), and has expected acoustic correlates. Unless evidence of tongue movement during closure is present (e.g. smearing of the contact print), length of midline contact can be associated with the size and mass of the active articulator. The small tongue tip will make a narrow contact; the broader blade will make a longer contact. Moreover, it is reasonable to expect that the tip is a quicker articulator than the blade, because of its lighter mass and because, being on the periphery of the tongue, it is more independent of other parts of the tongue (cf. the lack of laminal trills noted in Ladefoged and Maddieson 1996.) In turn, the relative speed of the active articulator relates to voice onset time, amount of frication at burst release and relative amplitude of bursts (Stevens 1998.)

Each still frame was measured for contact length by drawing a line from the front to rear of the contact in the midline (line **'b'**, Figure 3.21.) Actual contact length was determined by using the vertical correction factor for the frame. To describe contact length in relative terms, **'b'** was once again expressed as a percentage of line **'v'** (Figure 3.19.)

3.4.3 Measure ***'c'****: Back Cavity Index*

Just as the cavity in front of the constriction can be expected to relate to acoustic consequences (spectral shape), the cavity from glottis to the back of the oral closure can be expected to relate to acoustic signatures by which listeners may differentiate coronal places, i.e. formant transition loci at edges of neighboring vowels (Fant 1960.)

As an approximation of the area of the oral cavity behind the constriction, differences in the amount of empty space behind the constriction were measured. The size of this space is affected by raising of the sides of the tongue body as well as how far back the midline constriction extends; the more contact on the palate, the smaller this area will be. To quantify the size of the back cavity, an area bounded by the rear line of contact and the horizontal calibration line was measured (shown as **'c'** in Figure 3.21.) In a way analogous to the linear measurements described above, to obtain an areal correction factor for a given palatogram, a (two-dimensional) areal calibration measure was taken for each speaker, both on two-dimensional photocopies of plaster casts, and on still frames. A reference area was measured, bounded by line **'h'** and the juncture of the teeth with the gumline (this area is outlined in Figures 3.22 and 3.23.) The ratio of apparent to actual size was used as a correction factor to obtain measurements in square millimeters.

Figure 3.22:

Reference area on two-dimensional lifesize copy of speaker's plaster cast.

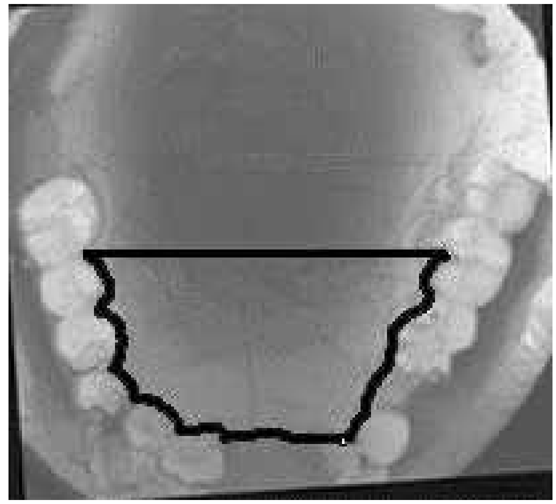
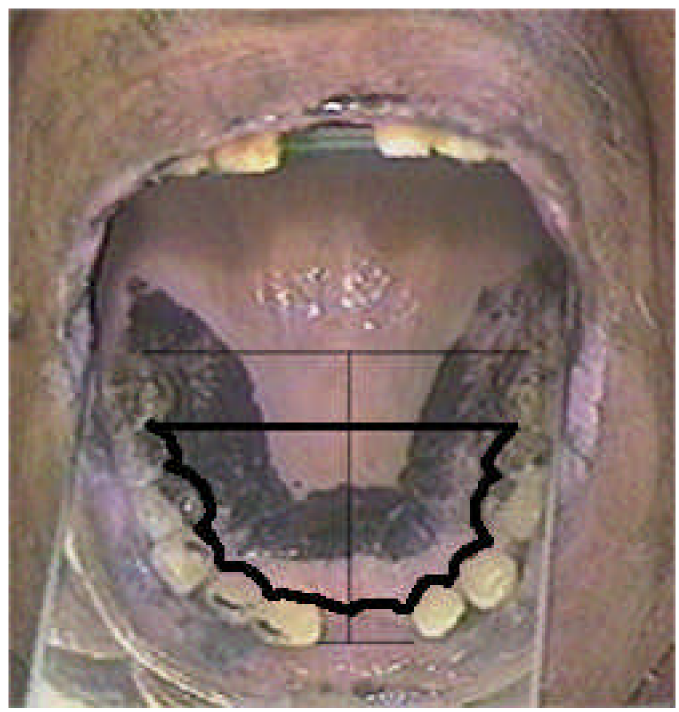


Figure 3.23:

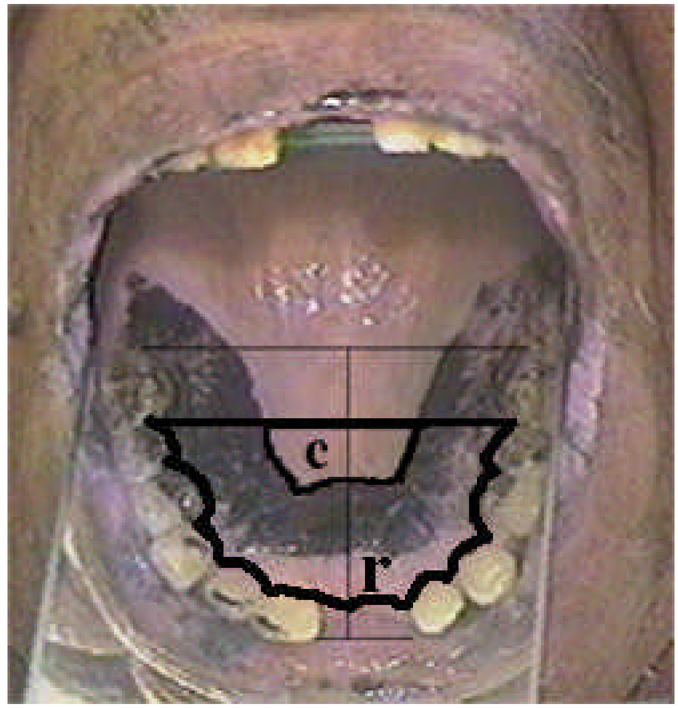
Reference area on still frame in question.



To obtain relative measurements, measure **'c'** was expressed as a percentage of the same "reference" calibration area (labeled **'r'** in Figure 3.24).

Figure 3.24:

Area **‘c’** as a percentage of reference area **‘r’**.



Note the large difference in area **‘c’** when comparing the apical alveolar and the laminal palatoalveolar in Figure 3.20 above. The rearward extent of contact in the midline, as well as the extent of lateral contact on the sides of the palate contribute to this difference.

Results of measures **‘a’**, **‘b’**, and **‘c’** for different coronal categories are discussed under Results: Palatography.

3.5 Linguography: Image Processing

As mentioned above with reference to Figures 3.4a and b, the tongue is extremely flexible. Clearly, measurements of contact patterns on the tongue would be largely dependent on the way in which the speaker was holding the tongue, perhaps more so than the extent of contact of the patterns themselves. For this reason, linguograms were not measured, but were instead described and classified according to various criteria. On a first pass, a subset of 80 linguograms representing 5 speakers were viewed on videotape by the investigator, and described in detail, without applying categorical judgments. Sample descriptions for two linguograms are given in Figures 3.25 and 3.26.

Descriptions included whether the upper, vertical or lower side of the tip was involved in the contact, whether the front or the back of the blade was involved (and for prints involving the blade, how much of the tip was also involved), the relative length of midline contact in the sagittal plane, the rearward extent of contact both in the midline and on the sides of the tongue in sagittal planes, the width of contact on the sides in the coronal plane, and the general shape of the print. From these descriptions, parameters which were likely to be useful in categorically classifying the prints emerged. Observing linguograms on video allowed a number of views of the articulation, beginning with a frontal view at closure, as well as several different positions of the tongue as the speaker was instructed to show the upper and lower surfaces, and in some cases one or both sides. These several views provided a better idea of the entire pattern of tongue contact for a given articulation.

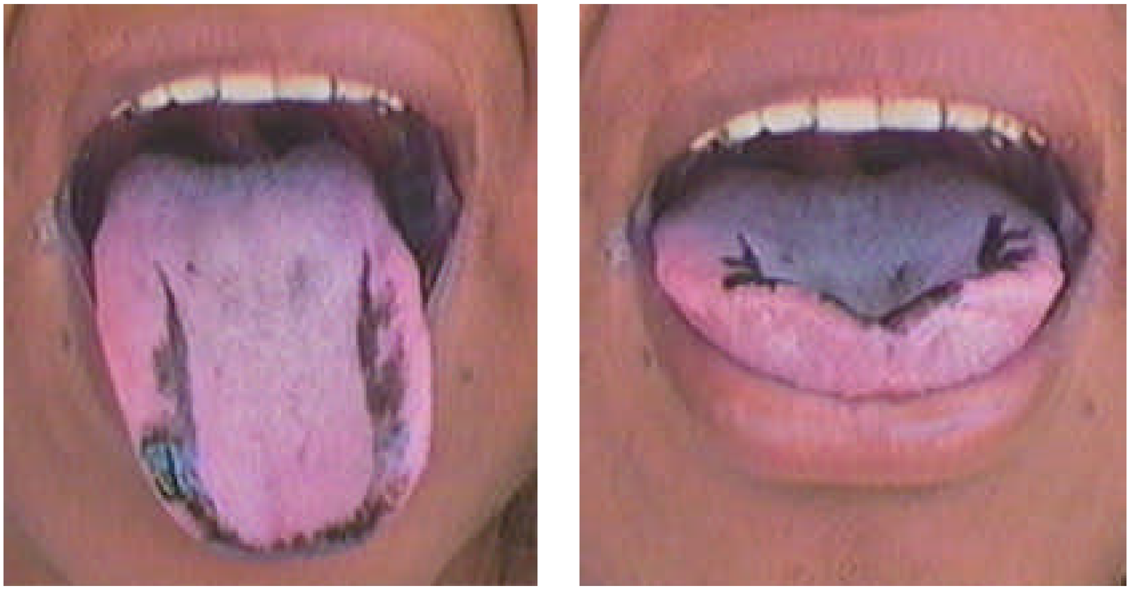


Figure 3.25: Description of linguogram from video (2 frames from the video segment are shown here): "Vertex and upper tip contact, no sublingual contact, thin midline contact, thin contact on sides that extends back past middle of dorsum, u-shaped print."

Figure 3.26: Description of linguogram from video (2 frames from the video segment are shown here): "No tip contact, middle and back of blade involved, long midline contact, wide contact at sides that extends back on the dorsum out of view (sagittal contact in midline is narrower than sagittal contact at sides.) 'Butterfly' shaped."

3.5.1 Independent Verification of Descriptions

On a second pass, for each of the 80 linguograms, two still frames were chosen from digitized videoclips, to show contact on the upper and lower sides of the tongue respectively. Along the lines of Thomas (1999), pairs of frames were randomized, numbered and submitted to the judgments of two other experienced phoneticians, as well as to those of the investigator. Linguograms were described and classified by each judge, without knowledge of the phonological identity of the articulation involved. Our purpose here was to ensure objective and independently verified descriptions and classifications, and to learn which criteria used by the different judges would be most successful in describing differences among phonological categories.

The investigator showed a high degree of internal consistency between first-pass descriptions from video and second-pass still frame judgments. This consistency boosted confidence that describing linguograms from video segments, where phonological categories were known *a priori*, would not bias descriptions. Moreover, within the second situation, the level of agreement shown among the three judges was high, with discrepancies being limited to two matters. First, when naming prints involving both tip and blade, preferential attention was given by two judges to the front rather than the back edge of midline contact. The third judge gave more attention to the back edge. Discussion of these discrepancies, together with further examination of the linguograms in question, showed that two tokens of the same utterance by the same speaker could differ in the location of frontmost contact for these tip-blade articulations, but were more stable in rear contact. That is, the back edge of contact seemed likely to correlate better with linguistic categories than the front edge. Thus, our definition of "apicolaminal" was refined so that linguograms showing fine differences in the front edge of contact could be gathered into this category.

The second issue for discussion was the usage of "apical", which varied slightly among the three judges, as it does in the literature (refer to the discussion of "apical" at the beginning of Chapter Two.) Recall that our provisional definition of "tip", following Ladefoged and Maddieson (1996), included the portion of the rim in the midsagittal line (the vertex), and 2 mm on the upper surface. In the present investigation, however, we observed that articulations involving the upper surface of the tip, and optionally the vertex and a small portion of the underside of the tip, generally cooccurred with a continuous u-shaped print which connected midline and side contact (as in Figure 3.25.) In contrast, articulations that had vertex and underside contact without showing any upper surface contact in the midline, virtually always cooccurred with a pattern of two discontinuous, almost parallel lines at the sides of the upper surface of the tongue (as in Figure 3.4.) Because of this pattern of distribution, articulations showing upper apical contact and a u-shaped print were characterized as (supra)apical, even in the cases where the print also included a small portion of the underside of the apex. Where only the lower, or lower and vertical surfaces were used in conjunction with a parallel line pattern on the upper surface of the tongue, the articulation was taken to be subapical. Vanishingly few articulations remained problematic to identify using these criteria.

On a third pass, the investigator used the video data to describe and classify the full set of 322 linguograms using the jointly agreed-upon criteria. Classificatory judgments, as well as factors such as speaker identity, phonological identity, manner of articulation, and position in word were entered in a spreadsheet.

3.5.2 Data Reduction of Linguograms

A balanced subset of the linguographic data was chosen for statistical analysis. For each of five speakers, two iterations of each word in Table 3.1 were included, for a total of 140 tokens. Table 3.1 is reproduced below.

Table 3.1: Static Palatography wordlist: W. Arrernte coronal stops and nasals

	Laminal Dental	*Apical* Alveolar	*Apical* Postalveolar	*Laminal* Palatoalveolar
Stops Between Vowels	**'pət̪ə** *pouch (n)*	**'matə(ɻə)** *cloud (n)*	**'pəʈə** *rock (n)*	**'pet̻əmə** *is coming(vi)*
Stops Word-initially	**'t̪əmə** *grind (vt)*	**'Təpə** *back (n)*		**'t̻apə** *grub (n)*
Nasals Between Vowels	**ip'mən̪ə** *grandmother (n)*	**'manə** *money (n)*	**'məɳə** *veg. food (n)*	**'mpən̻ə** *crumb (n)*
Nasals Word-initially	**'n̪əmə** *rain is falling (vt)*	**'Nəmə** *is sitting (vi)*		**'t̻n̻əmə** *is falling (vi)*

From the normalized descriptions of tokens, four descriptive variables were established. *Midline length* refers to the extent of tongue contact in the midsagittal midline, shown by the white lines in Figures 3.27 and 3.28. Midline length is analogous with palatography measure **'b'**: *length of contact.* Linguograms were assigned to one of five value categories for midline length: vertex only, short, medium, long and extra long. Figures 3.27 and 3.28 show two linguograms from the same speaker; the print in 3.27 was categorized as 'extra long', while the print in 3.28 was categorized as 'vertex only.'

Figure 3.27: Categorization of linguograms according to *midline length:* 'extra long.'

Figure 3.28: Categorization of linguograms according to *midline length:* 'vertex only.'

A second variable, *rear point of contact,* is shown by the crosshairs drawn in Figures 3.29 and 3.30; this variable refers to the point of contact furthest back in the midsagittal midline. Rear point of contact is roughly analogous with palatography measure **'c'**: *back cavity index;* both are ways to indicate the relative size of the cavity behind the constriction. Because the level of detail in the normalized descriptions was high, eight value categories for rear point of contact were available: sublingual, vertex, apex, front of blade, midblade, back of blade, tongue front and tongue center. The linguograms in Figures 3.29 and 3.30 fall into the categories 'tongue center' and 'vertex' respectively.

Figure 3.29: Categorization of linguograms according to *rear point of contact:* 'tongue center.'

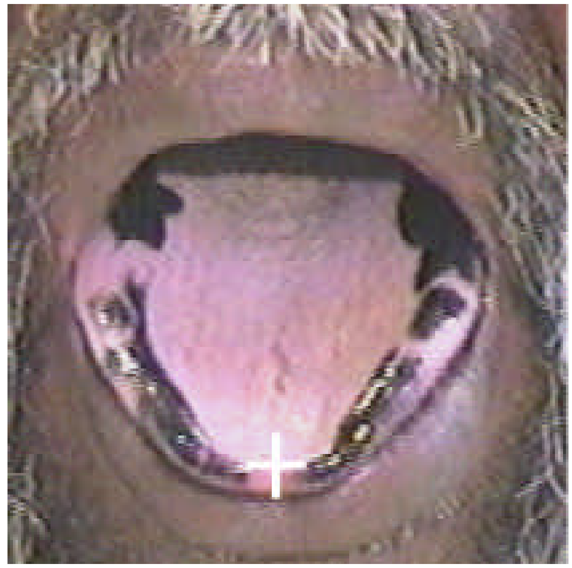


Figure 3.30: Categorization of linguograms according to *rear point of contact:* 'vertex.'

To get an idea of the extent of tongue raising behind the closure, the coronal width of the print was also observed, at roughly the level of the tongue front, as shown in Figures 3.31 and 3.32. Like rear point of contact, coronal width also contributes to an indication of the size of the cavity behind the constriction, in that the degree of tongue raising affects the total volume of the back cavity. Categories for c*oronal width at tongue front* include no contact (i.e. the tongue body is low enough that contact does not extend as far back as the tongue front), narrow, medium, and wide.

Figure 3.31: Categorization of linguograms according to *coronal width at tongue front:* 'wide.'

Figure 3.32: Categorization of linguograms according to *coronal width at tongue front:* 'narrow.' Note that the illustration line is shown at an angle, to reflect the cupped position of the tongue in this frame.

A fourth variable used to classify linguograms was the general shape of the contact print. Shapes fell into four main categories, examples of which are shown in Figures 3.33–3.37. Where there was contact on the vertex or underside of the tongue, a second still frame is included to show this contact. The variable *shape* captures the general stance of the tongue during closure.

Figure 3.33a: Categorization of linguograms according to *shape:* ‘parallel lines.’ Upper surface of tongue.

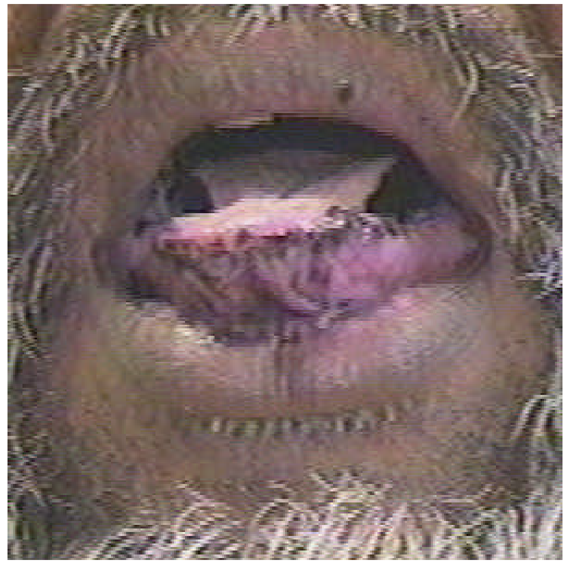


Figure 3.33b: Categorization of linguograms according to *shape:* ‘parallel lines.’ Lower surface of tongue.

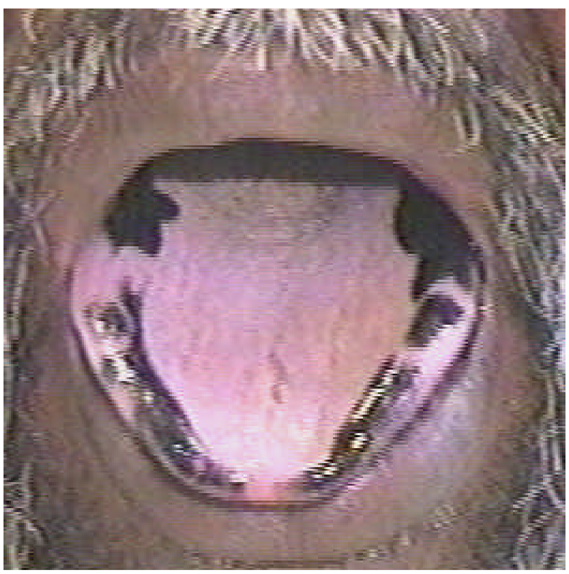


Figure 3.34a: Categorization of linguograms according to *shape:* ‘u.’ Upper surface of tongue.

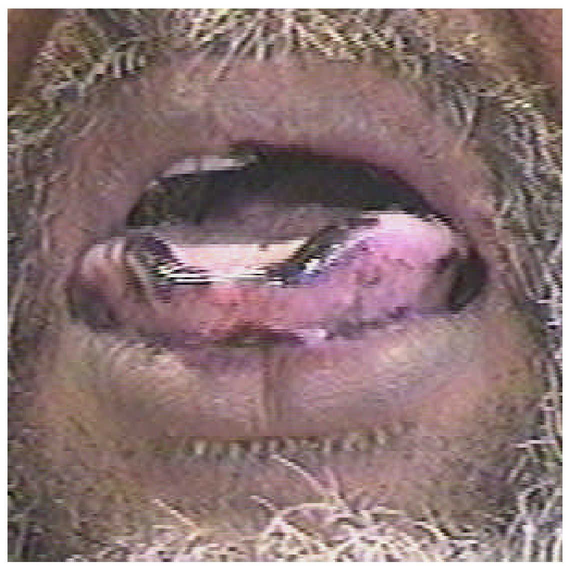


Figure 3.34b: Categorization of linguograms according to *shape:* ‘u.’ Lower surface of tongue.

Figure 3.35a: Categorization of linguograms according to *shape:* ‘triangle.’

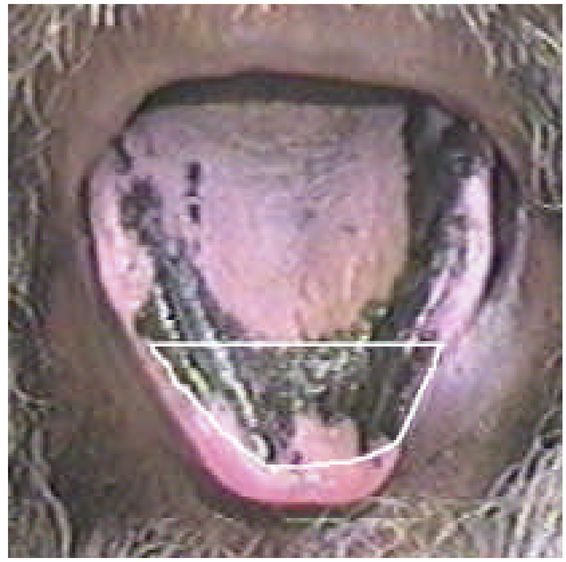


Figure 3.35b: Categorization of linguograms according to *shape:* ‘triangle’.

Figure 3.36a: Categorization of linguograms according to *shape:* ‘triangle.’

Figure 3.36b: Categorization of linguograms according to *shape:* ‘triangle’.

Figure 3.37:

Categorization of linguograms according to shape: ‘butterfly.’

Figures 3.33a and b show the print contact pattern which was given the shorthand ‘parallel lines’. Figure 3.34a and b show the ‘u-shaped’ contact pattern. Note that contact in 45b includes the sublingual surface and vertex, but not the upper side of the apex. In contrast, in 46b the print contact excludes the underside of the tongue.

The four panels in Figures 3.35 and 3.36 show a third shape pattern, which involves a roughly triangular shape covering the tip and blade, with lines of contact extending back at the sides behind the central constriction. Figure 3.35a shows the same male speaker whose linguograms appear throughout this section. Figure 3.36a shows the same shape pattern for a different speaker. For clarity, the triangle has been outlined in the ‘b’ figures, because the speakers’ lack of upper incisors cause the front of the pattern to be somewhat irregular.

Figure 3.37 shows the fourth print pattern, in which broad contact was visible from the blade backward, but characteristically was slightly narrower in the midline than on the sides. This pattern was given the shorthand ‘butterfly’.

Note that while palatography measures **'b'** and **'c'** have rough analogs in the linguographic variables discussed above, palatography measure **'a'**, *frontmost contact*, does not. As discussed above, and as evident in Figures 3.35 and 3.36, the front edge of tongue contact was less reliable than the back edge as a linguographic measure, not least because of missing incisors.

Table 3.2 summarizes the four linguographic variables and their constituent value categories. For the variables *coronal width* and *shape*, some cells were missing. This is noted in Table 3.2 by the term 'not described.' Recall that while descriptions of tokens were fairly detailed, they did not involve forced choice tasks. Thus, value categories could not be assigned in several cases where a token had not been described for a particular variable.

Table 3.2: Linguographic variables and constituent value categories.

Midline length	***Rear point of contact***	***Coronal width at tongue front***	***Shape***
vertex	sublingual	no contact	parallel lines
short	vertex	narrow	u
medium	apex	medium	triangle
long	mid-blade	wide	butterfly
xlong	back of blade	not described	not described
	tongue front		
	tongue center		

3.6 Results: Palatography

To return to the larger picture, recall that our purpose in quantifying these articulatory patterns in W. Arrernte is to investigate whether there is evidence of polarization among contrastive apical coronals as compared with non-contrastive apicals, and to investigate whether there is evidence of polarization of the nasals with respect to the stops. Thus, if we find that non-contrastive apicals have characteristics intermediate between the contrastive apicals, polarization (of the contrastive apicals) is indicated; if non-contrastive apicals cannot be differentiated from one or other contrastive apical, gestural economy is indicated. Similarly, if nasal places of articulation differ from those of stops, polarization is supported, whereas if nasal places are not differentiable from stops, gestural economy is supported.

Palatographic data was submitted to **An**alysis **o**f **Va**riance (ANOVA.) Unless otherwise noted, probabilities ('p' values) of less than .05 that the variation observed is due to chance were considered significant. The Scheffe's procedure for post hoc comparisons was used, because it allows for differences in numbers of tokens in groups, and differing amounts of variability among groups.

In each case below, results are reported in raw (millimeter) values, followed by relative (percent) values. The use of raw versus relative values made no difference to whether or not post hoc comparisons were statistically significant, except in three comparisons, which are discussed under Figures 3.47 and 3.51. The stability of these results is surprising, in light of the differences in the shapes and sizes of speakers' mouths.

We will treat patterns for stops versus nasals first, and then focus on results for contrastive versus non-contrastive apicals.

3.6.1 Stops versus Nasals

3.6.1.1 Measure **'a'**: Frontmost Contact

Figure 3.38 shows raw data for frontmost contact in the stops versus the nasals, for each Place category of coronal. The x-axis shows two columns, one for stops and one for nasals. Units on the y-axis are millimeters. The five points in each of the two columns represent the means of frontmost contact (measure **‘a’** in Figure 3.19) for each category of coronal. In this and the following graphs, the vertical error bars show one standard deviation around each mean. For purposes of comparison, means for each stop–nasal pair at a given Place are linked by a (roughly horizontal) line.

For the analysis shown in Figure 3.38, none of the stop–nasal pairs of means differ significantly from each other (p =.1948.)

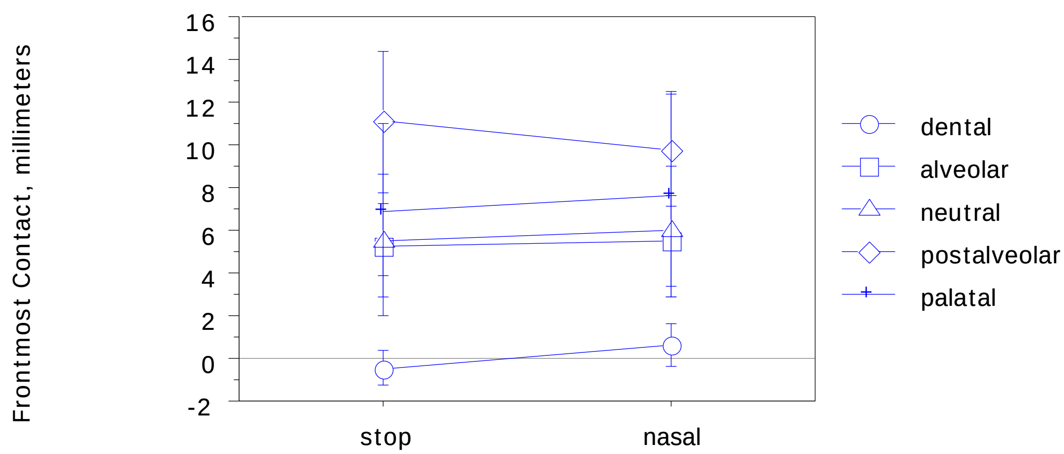


Figure 3.38: Frontmost contact in ***millimeters*** for coronal Place categories: stops versus nasals (p=.1948.)

Figure 3.39 expresses the same measure, frontmost contact, in relative values. Units on the y-axis are percentiles. The five means in each column reflect the proportion of measure **‘a’** to the reference line **‘v’** in percent values (refer to Figure 3.19.) Again, we find no significant differences between pairs of stops and nasals at any given Place (p=.1758.)

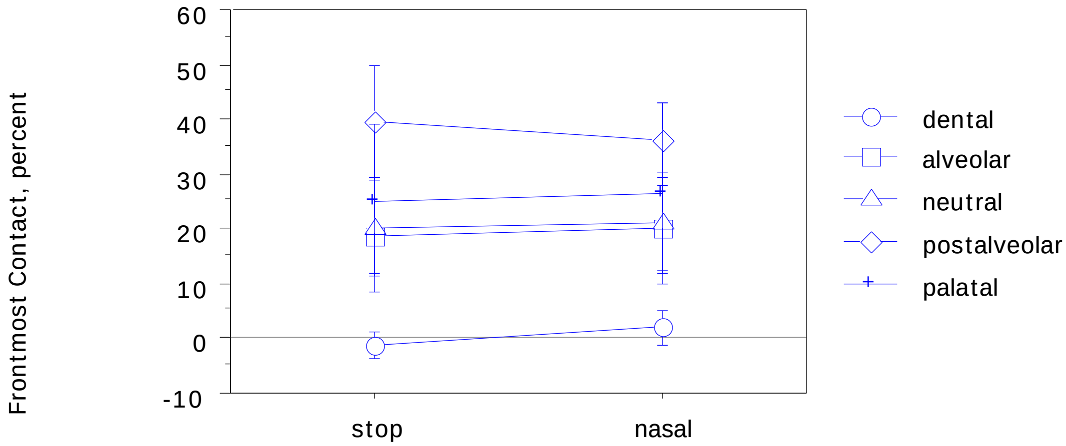


Figure 3.39: Frontmost contact in ***percent*** for coronal Place categories: stops versus nasals (p=.1758.)

Note that the mean of frontmost contact for laminal dental stops has a small negative value. This is caused by an artifact of measurement. Recall that for two of the speakers whose palatograms are examined here, the reference line at the "front edge" of the front incisors had to be constructed in a slightly different way than for other speakers, because of differences in the morphology of these speakers' dentitions (refer to Figures 3.17 and 3.18.) The particular placement of the incisor reference line in these cases made it possible to record contact in front of the reference line. Thus, though the modal result for frontmost contact in laminal dentals for these speakers was 0 mm (i.e. contact usually extended to the tips of the upper teeth) the few negative values that were recorded caused the mean to be slightly negative.

3.6.1.2 Measure **'b'**: Length of Contact

Results for our second metric, length of midline contact in the sagittal plane (measure **'b'** in Figure 3.21) are summarized in Figures 3.40 and 3.41. Length of contact for stops does not differ significantly from length of contact for nasals at any given Place of articulation (p=.0512 for raw millimeter values, p=.0901 for relative values in percent.) However, because the result for raw values almost reaches significance on this test, an analysis of the interaction between Place and Manner was pursued. Note that the slopes of the lines joining stops and nasals differ from each other. In particular, laminal dental stops appear to be longer in midline contact than laminal dental nasals. To determine whether stops and nasals behave differently at different Places, interaction between the factors of Place and Manner was examined in a two-way ANOVA. The resulting interaction term (p=.8546) showed a high probability that differences were due to chance. Though the difference between dental stops and nasals appears to be larger than other stop-nasal pairs, the dental pair does not behave significantly differently from other stop-nasal pairs on this measure.

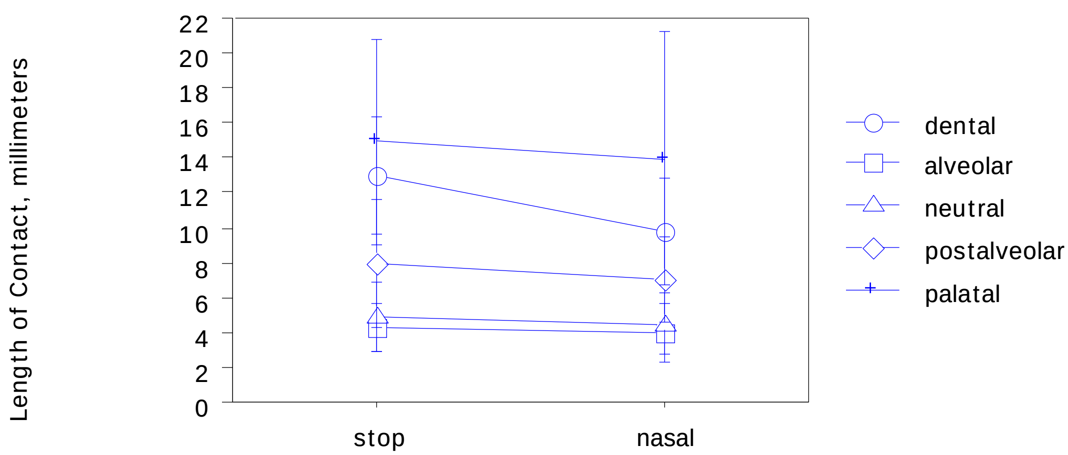


Figure 3.40: Length of contact in ***millimeters*** for coronal Place categories: stops versus nasals (p=.0512.)

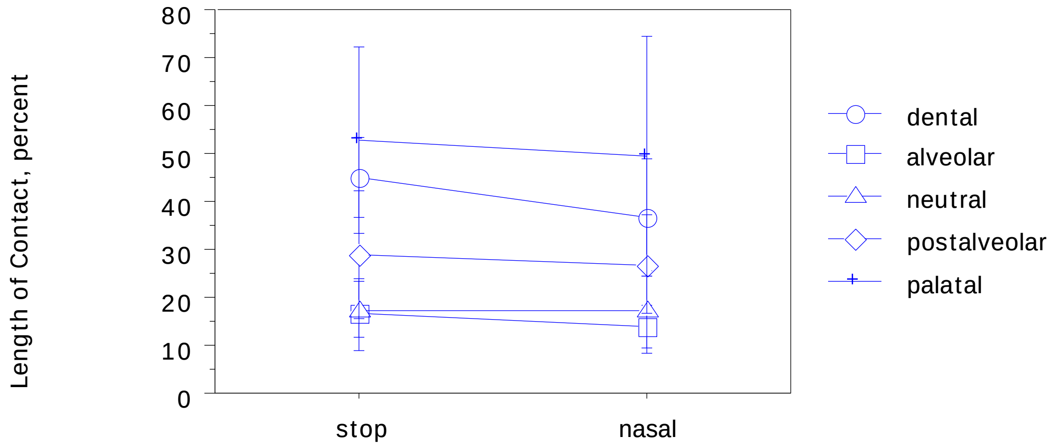


Figure 3.41: Length of contact in ***percent*** for coronal Place categories: stops versus nasals (p=.0901.)

3.6.1.3 Measure **'c'**: Back Cavity Index

Results for the third metric, the back cavity index (measure **'c'** in Figure 3.21) once again show no significant effect in post hoc comparisons between stops and nasals of a given Place category. This result holds whether raw or relative measurements are being considered (p=.4848 and p=.4777 respectively.) Figures 3.42 and 3.43 show results.

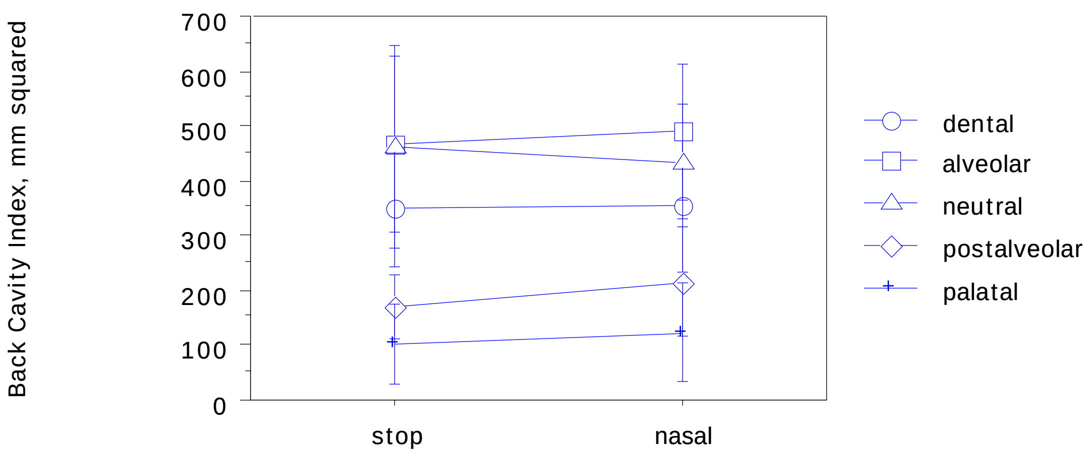


Figure 3.42: Back cavity index in ***millimeters*** for coronal Place categories: stops versus nasals (p=.4848.)

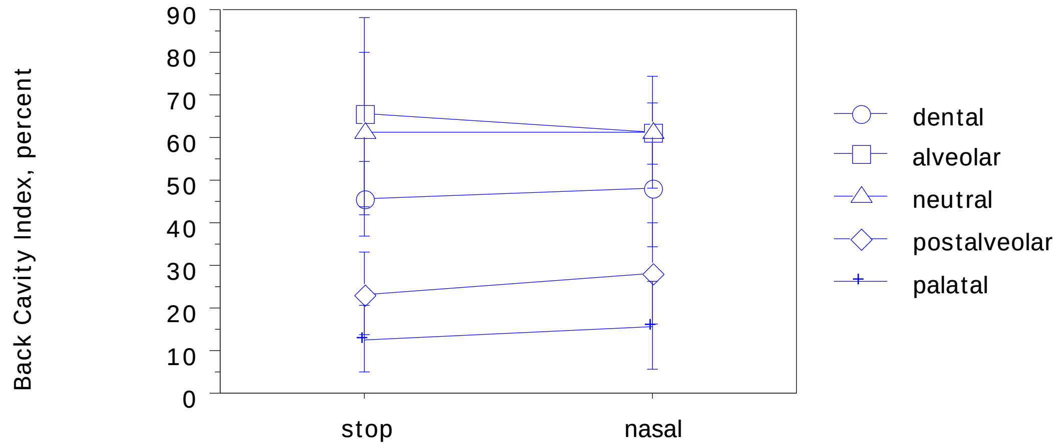


Figure 3.43: Back cavity index in ***percent*** for coronal Place categories: stops versus nasals (p=.4777.)

3.6.1.4 Stops versus Nasals: Analysis and Interpretation

Recall the scenarios outlined under <u>Western Arrernte: Predictions</u> above, with regard to the derivative mechanisms of polarization and gestural economy. Predictions for stops versus nasals, as summarized in Figures 1.7 and 1.9, are reproduced below:

Place of articulation continuum-->

Phonetic Category	***{dental}***	***{alveolar}***	***{postalveolar}***	***{palatal}***
Stops	**t̪**	**t**	**ʈ**	**t̻**
Nasals	**n̪**	**n**	**ɳ**	**n̻**

Figure 1.7: Polarization scenario: stops versus nasals

Place of articulation continuum-->

Phonetic Category	***{dental}***	***{alveolar}***	***{postalveolar}***	***{palatal}***
Stops	**t̪**	**t**	**ʈ**	**t̻**
Nasals	**n̪**	**n**	**ɳ**	**n̻**

Figure 1.9: Gestural economy scenario: stops versus nasals

To summarize the results found for these speakers, Figure 3.44 shows each of the graphs for percentile results, turned clockwise by 90 degrees in order to simulate the schematic continua in Figures 1.7 and 1.9 (error bars have been suppressed for clarity.)

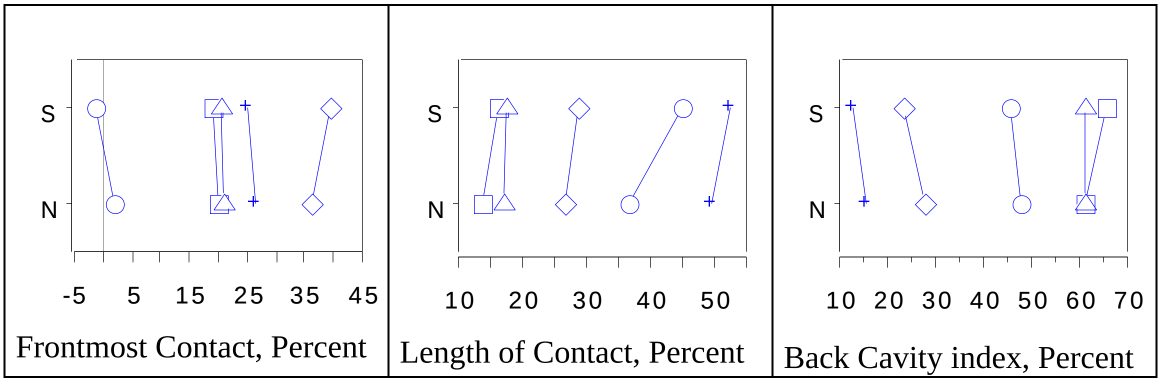


Figure 3.44: Summary of results: stops (top rows) versus nasals (bottom rows.)

In the first and third panels, the means as plotted appear to show slightly expanded continua for stops vis-a-vis nasals. In the middle panel, the spans between maximum and minimum values are very similar, although the nasals seem to show less overlap and perhaps better dispersion within the continuum. However, these small visible differences are nevertheless statistically insignificant. Because we have found that there is no statistical difference between stops and nasals for any Place category on any of the tests done here, we conclude that the same oral gesture is used for stops and nasals of a given Place category.

In the Malayalam scenario outlined in Chapter One, it was suggested that in order to make potentially weaker nasals more auditorily robust, speakers might articulate them more divergently on the place continuum. For W. Arrernte, this is not found to be the case. Instead, gestural economy is suggested by these results. The perception of nasals vis-a-vis stops will be examined in Chapter Four. Meanwhile, in the following discussion of palatographic results for contrastive versus non-contrastive apicals, we will consider data for coronals of a given Place category together, regardless of Manner.

3.6.2 Initial versus Medial Differences

We have thus far observed that *Manner of articulation* does not affect Place of articulation for the palatographic measurements considered here. What follows is a similar comparison of initial versus medial consonants, in order to determine whether *Position in word* affects Place. The purpose of this analysis is to determine whether the comparison between contrastive and non-contrastive apicals is an appropriate one to make. Recall that contrastive apicals only occur medially, whereas non-contrastive apicals only occur initially (Table 1.1.) It may be that these segments involve differences simply because of an overall effect of position in word, whether or not they involve different numbers of contrasts. (Keating et al. 1999, find that initial segments tend to show strengthening compared with medial segments. One of the correlates of strengthening is a larger tongue contact area for consonant segments.) In order to separate the potential effects of these influences, we will examine the laminals, which involve the same numbers of contrasts in initial and medial positions. Figure 3.45 shows a summary of results of ANOVA on the laminal coronals. In the lefthand column, graphs for millimeter values are shown, while in the righthand column, graphs for percentile values are shown. Rows show results for frontmost contact, length of contact and back cavity index, respectively. Within each graph, the x-axis shows mean values and 95% confidence intervals for initial laminals and medial laminals, with a pair of bars for each initial and medial measure. Laminal dentals are shown on the left of

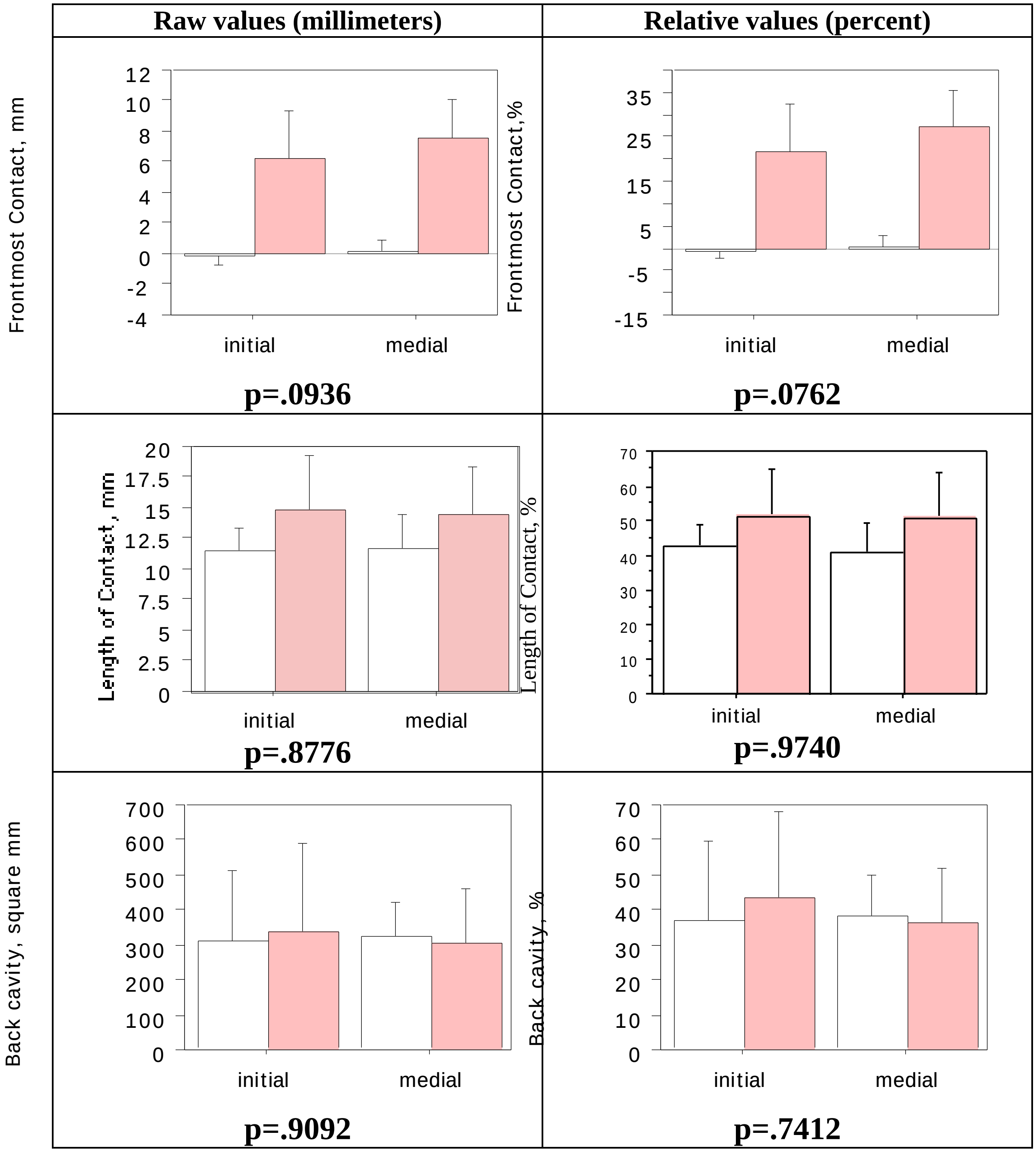


Figure 3.45: Results of ANOVA for effect of position in word on palatographic measurements in laminals. Dentals are the lefthand members of each pair of bars. Palatoalveolars are the righthand members.

each pair (unshaded), while laminal palatoalveolars are shown on the right (shaded.) Probabilities that differences are due to chance are shown beneath each graph.

These results indicate that initial laminals are neither strengthened nor weakened vis-a-vis medial laminals. Means and ranges of variation do not differ significantly depending on position in word, in any of the six comparisons done here. Thus, because laminals provide the closest available control case, we will infer that the absence of positive evidence for initial strengthening/weakening of laminals can be extended to the apicals. We will take the comparison of non-contrastive and contrastive apicals to be an appropriate one, and assume that results are not an artifact of position. Moreover, because they are not statistically differentiable, results for initial and medial laminals will be shown together in the following section. Let us now consider each of the three measures in turn, comparing non-contrastive apicals, contrastive apicals, and laminals.

3.6.3 Contrastive versus Non-Contrastive Apicals

The effect of coronal Place category on the three measures was submitted to ANOVA. For each measure, means are given, followed by results of pairwise comparisons and significance levels. For the post hoc comparisons, the three differences in significance between raw and relative values are shown by shaded cells.

Numerical results are followed by graphical summaries. For each graph, the x-axis shows the five place categories, with non-contrastive apicals placed between the contrastive apicals for ease of comparison. Apical categories are shown with shaded bars, while laminals are shown unshaded. Categories which are not statistically differentiable from each other in pairwise comparisons are grouped with one or more of the ‘approximately equivalent’ signs ≈, ≅, or ~.

3.6.3.1 Measure **'a'**: Frontmost Contact

Table 3.3: Means for Frontmost Contact in ***millimeters***.

Place Category	**Count**	**Mean**	**Std Deviation**
laminal dental	20	-.007	1.031
apical alveolar	10	5.411	2.627
non-contrastive apical	10	5.754	2.335
apical postalveolar	15	10.369	2.960
laminal palatoalveolar	20	7.231	4.317

Table 3.4: Means for Frontmost Contact in ***percent***.

Place Category	**Count**	**Mean**	**Std Deviation**
laminal dental	20	.013	3.187
apical alveolar	10	19.507	8.648
non-contrastive apical	10	20.740	8.236
apical postalveolar	15	37.712	8.474
laminal palatoalveolar	20	25.820	14.726

Table 3.5: Scheffe's post hoc tests of significance.
Variable: Frontmost contact in ***millimeters.***

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-5.418	3.612	.0005	S
lam. dental, N.C. apical	-5.762	3.612	.0002	S
lam dental, ap. postalveolar	-10.377	3.185	<.0001	S
lam. dental, lam. pal-alv.	-7.239	2.949	<.0001	S
ap. alveolar, N.C. apical	-.343	4.171	.9994	
ap. alveolar, ap. postalveolar	-4.958	3.807	.0039	S
ap. alveolar, lam. pal-alv.	-1.821	3.612	.6387	
N.C. apical, ap. postalveolar	-4.615	3.807	.0089	S
N.C. apical, lam. pal-alv.	-1.477	3.612	.7946	
ap. postalv, lam. pal-alv.	3.138	3.185	.0557	

Table 3.6: Scheffe's post hoc tests of significance.
Variable: Frontmost contact in ***percent***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-19.494	11.901	.0001	S
lam. dental, N.C. apical	-20.727	11.901	<.0001	S
lam dental, ap. postalveolar	-37.699	10.495	<.0001	S
lam. dental, lam. pal-alv.	-25.807	9.717	<.0001	S
ap. alveolar, N.C. apical	-1.233	13.742	.9992	
ap. alveolar, ap. postalveolar	-18.205	12.544	.0009	S
ap. alveolar, lam. pal-alv.	-6.313	11.901	.5917	
N.C. apical, ap. postalveolar	-16.972	12.544	.0024	S
N.C. apical, lam. pal-alv.	-5.080	11.901	.7677	
ap. postalv, lam. pal-alv.	11.892	10.495	.0176	**S**

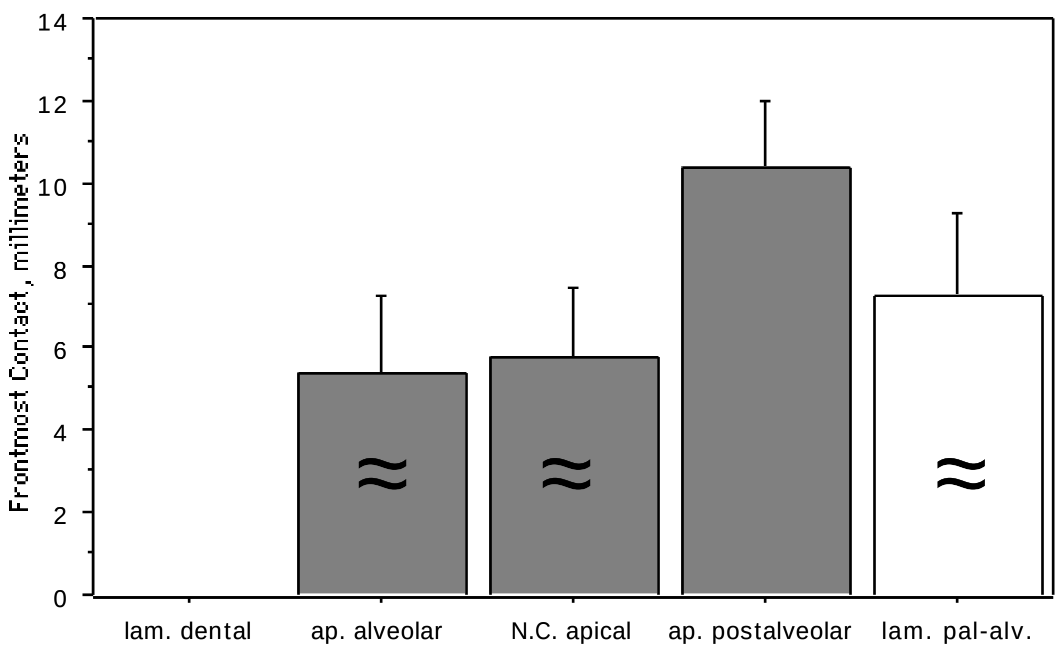


Figure 3.46: Frontmost contact in ***millimeters*** for coronal Place categories

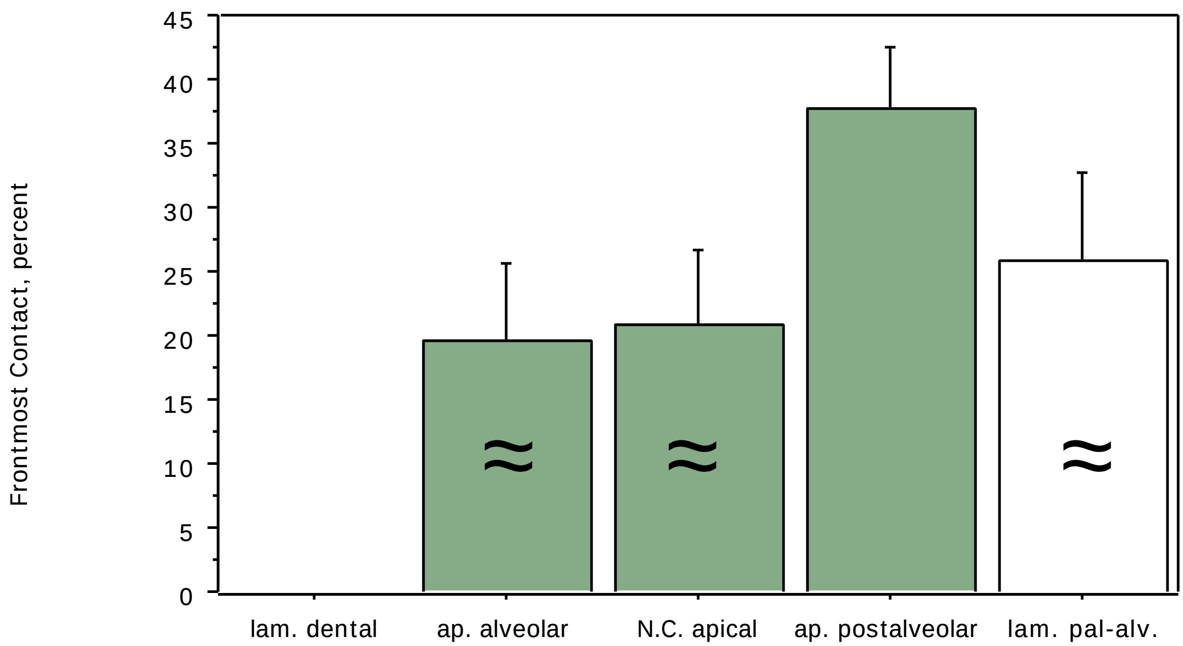


Figure 3.47: Frontmost contact in ***percent*** for coronal Place categories

Tables 3.3 through 3.6 and Figures 3.46 and 3.47 show results for frontmost contact. Measurements on the y-axis are reported as millimeters in Figure 3.46, and as percent of the vertical calibration line in Figure 3.47. For both raw and relative measures, the overall effect of Place is highly significant (raw values: $F(4,70)=29.44$, $p<.0001$; relative values: $F(4,70)=35.46$, $p<.0001$.)

As expected, laminal dentals have contact the furthest forward of the five segment categories. (Bars do not appear for the laminal dental category in Figures 3.46 and 3.47 because means are so close to zero in both cases.) In pairwise comparisons, laminal dentals differ significantly from each of the other Place categories. The apical alveolar and non-contrastive apical categories are not statistically differentiable (raw: $p=.9994$; relative: $p=.9994$.) Both categories are statistically differentiable from the apical postalveolar.

The front edge of the apical postalveolar is further back than that of any of the other Place categories. Pairwise comparisons involving postalveolars show significant differences in all comparisons but one: raw values for apical postalveolars and laminal palatoalveolars do not quite reach significance (p=.0557.) This is indicated by the ≅ symbol in these two cells.

The laminal palatoalveolar is not distinct in frontmost contact from the alveolar and non-contrastive apicals on this measure, as shown by the ≈ symbol in each cell.

3.6.3.2 Measure **'b'**: Length of Contact

Table 3.7: Means for Length of Contact in ***millimeters***.

Place Category	Count	Mean	Std Deviation
laminal dental	20	11.658	3.555
apical alveolar	10	4.140	1.475
non-contrastive apical	10	4.702	1.788
apical postalveolar	15	7.445	2.968
laminal palatoalveolar	20	14.468	6.364

Table 3.8: Means for Length of Contact in ***percent***.

Place Category	Count	Mean	Std Deviation
laminal dental	20	41.683	10.592
apical alveolar	10	15.075	5.946
non-contrastive apical	10	17.270	6.987
apical postalveolar	15	27.770	11.410
laminal palatoalveolar	20	51.203	21.396

Table 3.9: Scheffe's post hoc tests of significance.
Variable: Length of contact in ***millimeters***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	7.518	5.034	.0006	S
lam. dental, N.C. apical	6.956	5.034	.0018	S
lam dental, ap. postalveolar	4.212	4.439	.0720	
lam. dental, lam. pal-alv.	-2.810	4.110	.3315	
ap. alveolar, N.C. apical	-.562	5.813	.9989	
ap. alveolar, ap. postalveolar	-3.305	5.306	.4290	
ap. alveolar, lam. pal-alv.	-10.328	5.034	<.0001	S
N.C. apical, ap. postalveolar	-2.743	5.306	.6157	
N.C. apical, lam. pal-alv.	-9.766	5.034	<.0001	S
ap. postalv, lam. pal-alv.	-7.023	4.439	.0002	S

Table 3.10: Scheffe's post hoc tests of significance.
Variable: Length of contact in ***percent***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	26.608	16.960	.0003	S
lam. dental, N.C. apical	24.413	16.960	.0010	S
lam dental, ap. postalveolar	13.913	14.958	.0818	
lam. dental, lam. pal-alv.	-9.519	13.848	.3261	
ap. alveolar, N.C. apical	-2.195	19.584	.9981	
ap. alveolar, ap. postalveolar	-12.695	17.878	.2932	
ap. alveolar, lam. pal-alv.	-36.128	16.960	<.0001	S
N.C. apical, ap. postalveolar	-10.500	17.878	.4904	
N.C. apical, lam. pal-alv.	-33.933	16.960	<.0001	S
ap. postalv, lam. pal-alv.	-23.432	14.958	.0003	S

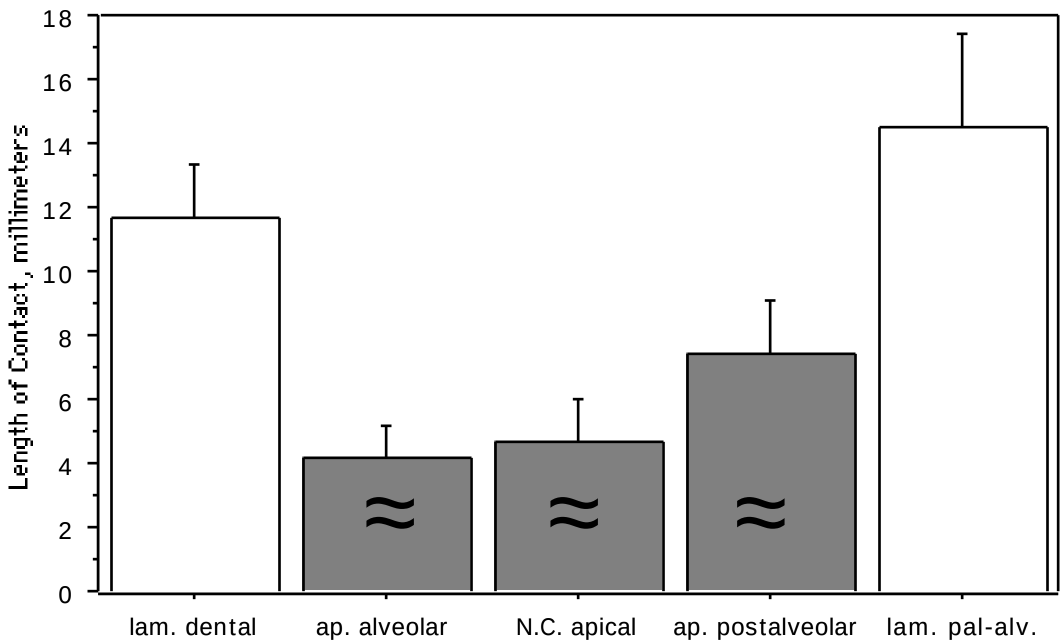


Figure 3.48: Length of contact in ***millimeters*** for coronal Place categories

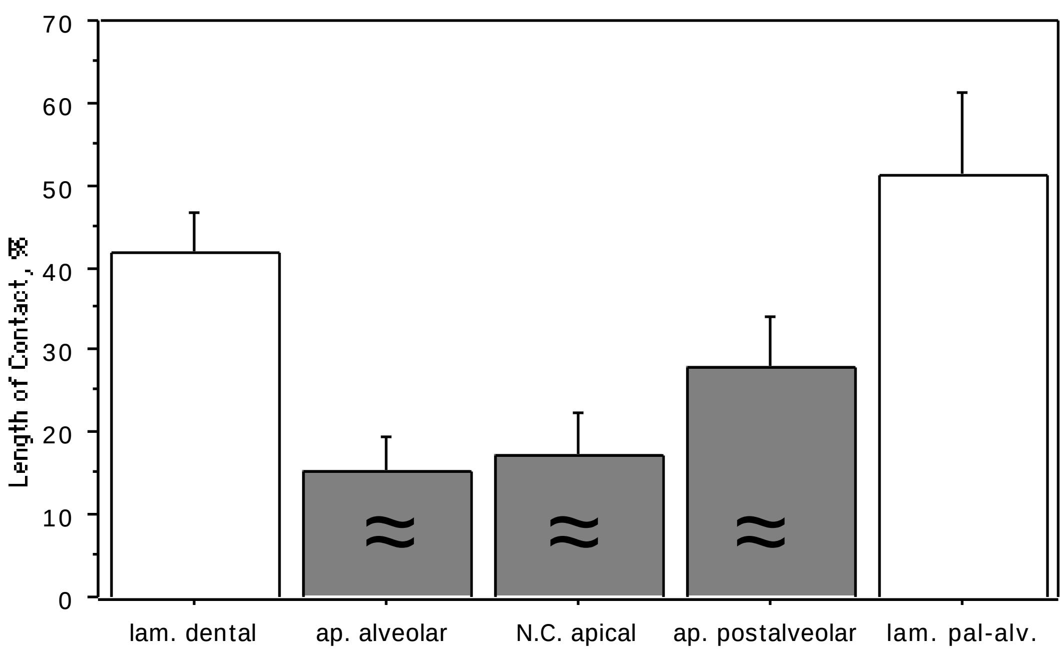


Figure 3.49: Length of contact in ***percent*** for coronal Place categories

Results for contact length are shown in Tables 3.7 through 3.10 and Figures 3.48 and 3.49. In Figure 3.48 the ordinate shows contact length in millimeters, while in Figure 3.49 the ordinate indicates contact length in percent of the vertical calibration line. Overall results are highly significant ($F[4,70]=17.28$, $p<.0001$ for millimeter values; $F[4,70]=18.31$, $p<.0001$ for percent values.) As expected, we find that the laminal categories have much broader midline contact than the apical categories. However, the two laminal categories are not statistically differentiable from each other, as indicated by the symbol ≅ ($p=.3315$ for raw values, $p=.3261$ for percent values.) Neither are the apical alveolar and non-contrastive apical differentiable on this measure, as shown by the symbol ≈ ($p=.9989$ for raw values, $p=.9981$ for relative values.) Thus, two clear groupings emerge for length of contact; a short contact group (≈) and a long contact group (≅). The apical postalveolar falls in between, with a mean contact length of 7.4 mm (27.8%). It is not statistically differentiable from the other apicals, but at the same time, it cannot quite be distinguished from the laminal dentals ($p=.0720$ for raw values, $p=.0818$ for percent values.)

3.6.3.3 Measure **'c'**: Back Cavity Index

Table 3.11: Means for Back Cavity Index in ***millimeters squared***.

Place Category	**Count**	**Mean**	**Std Deviation**
laminal dental	20	352.152	109.658
apical alveolar	10	477.990	134.977
non-contrastive apical	10	447.903	142.774
apical postalveolar	14	196.298	85.877
laminal palatoalveolar	19	111.139	78.736

Table 3.12: Means for Back Cavity Index in ***percent***.

Place Category	**Count**	**Mean**	**Std Deviation**
laminal dental	20	46.555	10.540
apical alveolar	10	63.400	15.785
non-contrastive apical	10	61.120	15.463
apical postalveolar	14	26.022	10.937
laminal palatoalveolar	19	14.053	8.911

Table 3.13: Scheffe's post hoc tests of significance.
Variable: Back Cavity Index in ***millimeters squared***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-125.837	131.628	.0685	
lam. dental, N.C. apical	-95.751	131.628	.2690	
lam dental, ap. postalveolar	155.854	118.430	.0035	S
lam. dental, lam. pal-alv.	241.013	108.879	<.0001	S
ap. alveolar, N.C. apical	30.086	151.991	.9827	
ap. alveolar, ap. postalveolar	281.692	140.716	<.0001	S
ap. alveolar, lam. pal-alv.	366.851	132.777	<.0001	S
N.C. apical, ap. postalveolar	251.605	140.716	<.0001	S
N.C. apical, lam. pal-alv.	366.765	132.777	<.0001	S
ap. postalv, lam. pal-alv.	85.159	119.707	.2909	

Table 3.14: Scheffe's post hoc tests of significance.
Variable: Back Cavity Index in ***percent***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-16.845	14.487	.0138	**S**
lam. dental, N.C. apical	-14.565	14.487	.0481	**S**
lam dental, ap. postalveolar	20.533	13.035	.0003	S
lam. dental, lam. pal-alv.	32.502	11.983	<.0001	S
ap. alveolar, N.C. apical	2.280	16.729	.9958	
ap. alveolar, ap. postalveolar	37.378	15.488	<.0001	S
ap. alveolar, lam. pal-alv.	49.348	14.614	<.0001	S
N.C. apical, ap. postalveolar	35.098	15.488	<.0001	S
N.C. apical, lam. pal-alv.	47.067	14.614	<.0001	S
ap. postalv, lam. pal-alv.	11.969	13.175	.0945	

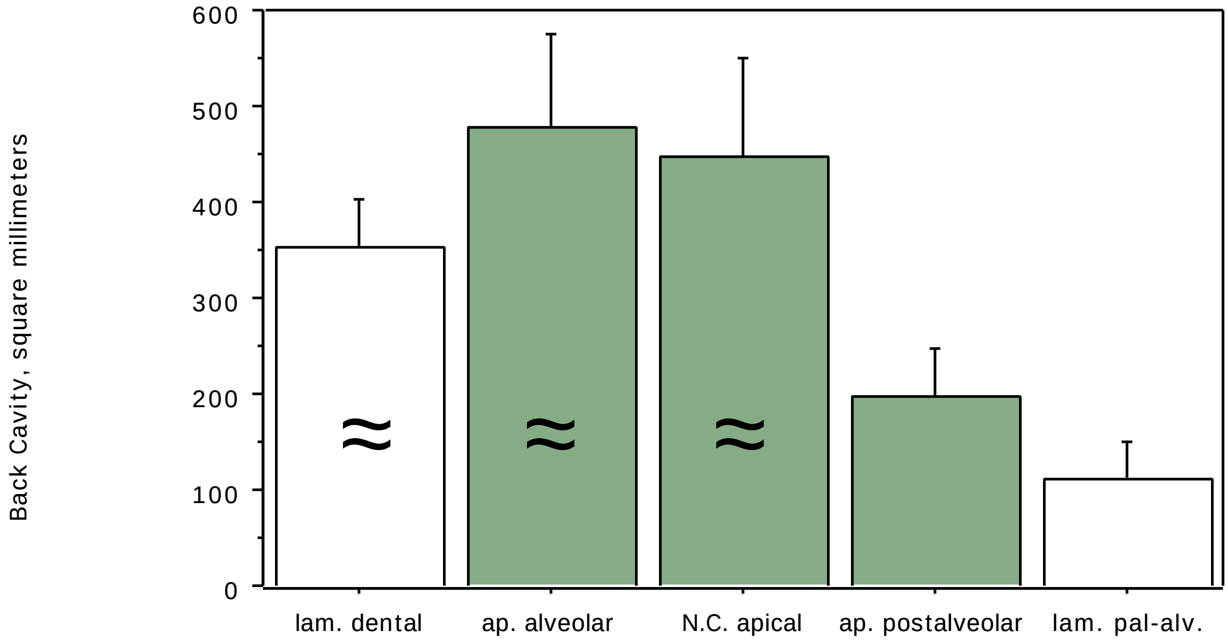


Figure 3.50: Back cavity index in ***millimeters*** for coronal Place categories

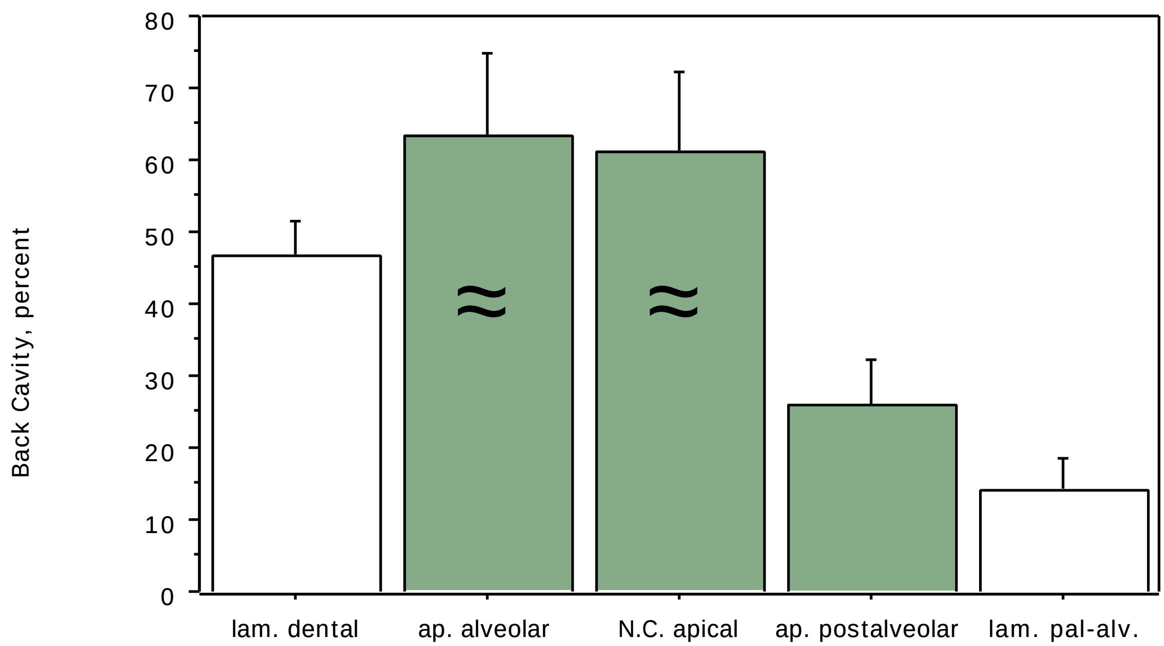


Figure 3.51: Back cavity index in ***percent*** for coronal Place categories

Tables 3.11 through 3.14 show central tendencies and numerical results of ANOVA for the Back Cavity variable. In Figures 3.50 and 3.51, y-axes show the back cavity index in millimeters squared and as percentages of calibration area **'r'** (refer to Figure 3.24.) As in the preceding tests of the effect of Place, overall significance values were high (raw values: $F(4,68)=30.6$, $p<.0001$; relative values: $F(4,68)=46.85$, $p<.0001$.)

Here we find that once again the apical alveolars and non-contrastive apicals cannot be statistically differentiated (p=.9827 for mm values, p=.9958 for percent values.) Apical postalveolars and laminal palatoalveolars also behave as a group (p=.2909 for mm values, p=.0945 for percent values.) Laminal dentals group with the other [+anterior] segments when raw values are considered, but are statistically differentiable from all other categories when relative values are considered.

3.6.3.4 Contrastive versus Non-Contrastive Apicals: Analysis and Interpretation

In each comparison of contrastive apicals with non-contrastive apicals in the results above, apical alveolars and non-contrastive apicals are indistinguishable from each other. On two of the three measures, both are statistically distinct from apical postalveolars. In the case of Length of Contact, all apicals behave as a group. Once again, let us review the predictions discussed in Chapter One:

Place dimension --->

Non-contrastive apical segment	**T**
Contrastive apical segments	**t<--------------------- • --------------------->ʈ**

Figure 1.6: Arrernte Polarization Scenario--contrastive versus non-contrastive apicals

Place dimension -->

Non-contrastive apical segment	**T**
Contrastive apical segments	**t |-----------------| t**

or

Non-contrastive apical segment	**T**
Contrastive apical segments	**t |----------------------| t**

Figure 1.8a (top) and 1.8b (bottom): Arrernte Gestural Economy Scenario--contrastive versus non-contrastive apicals

The results found here are compatible with the predictions of gestural economy, and in particular, scenario 8b, in which the less displaced articulation is re-used.

As a side issue, for Length of Contact it was observed that apicals form a short contact group and laminals form a long contact group (though postalveolar apicals could not be statistically significantly distinguished from dental laminals.) Although significant differences in length of midline contact between the two laminals or among the three apicals would not be surprising, the coronal categories seemed to group themselves along the lines of feature values for Apical, on this variable. Similarly, Back Cavity Index tended to group the coronal categories along the lines of the feature Anterior. These results present the question of whether polarization and gestural economy scenarios could be extended from Places of Articulation, as in our hypotheses here, to the component features of coronal Places. However, when we examine Frontmost Contact, we fail to find a division of categories along featural lines (for example, the apical alveolar and laminal palatoalveolar categories group together for this variable, even though they differ in values for both Apical and Anterior.)

In order to examine more closely the possibility that coronal Place targets may be defined by features, a further variable was examined by ANOVA: the midpoint of contact in the midline. Though this measure is less likely to be associated directly with acoustic effects, it may approximate an intended articulatory Place target more closely than Frontmost Contact. Results are shown in Tables 3.15 through 3.18, and summarized graphically in Figures 3.52 and 3.53.

Table 3.15: Means for Midpoint of Contact in ***millimeters***.

Place Category	Count	Mean	Std Deviation
laminal dental	20	5.821	1.562
apical alveolar	10	7.481	2.920
non-contrastive apical	10	8.105	2.730
apical postalveolar	15	14.092	2.668
laminal palatoalveolar	20	14.466	5.158

Table 3.16: Means for Midpoint of Contact in ***percent***.

Place Category	Count	Mean	Std Deviation
laminal dental	20	20.855	4.821
apical alveolar	10	27.045	9.238
non-contrastive apical	10	29.375	9.234
apical postalveolar	15	51.597	7.867
laminal palatoalveolar	20	51.421	17.114

Table 3.17: Scheffe's post hoc tests of significance.
Variable: Midpoint of Contact in ***millimeters***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-1.660	4.131	.8051	
lam. dental, N.C. apical	-2.284	4.131	.5516	
lam dental, ap. postalveolar	-8.271	3.643	<.0001	S
lam. dental, lam. pal-alv.	-8.644	3.373	<.0001	S
ap. alveolar, N.C. apical	-.624	4.770	.9964	
ap. alveolar, ap. postalveolar	-6.611	4.354	.0005	S
ap. alveolar, lam. pal-alv.	-6.985	4.131	<.0001	S
N.C. apical, ap. postalveolar	-5.987	4.354	.0019	S
N.C. apical, lam. pal-alv.	-6.361	4.131	.0004	S
ap. postalv, lam. pal-alv.	-.373	3.643	.9986	

Table 3.18: Scheffe's post hoc tests of significance.
Variable: Midpoint of Contact in ***percent***.

Comparison	**Mean Diff.**	**Critical Diff.**	**P-value**	**Significant?**
lam. dental, ap. alveolar	-6.190	13.430	.7129	
lam. dental, N.C. apical	-8.521	13.430	.4097	
lam dental, ap. postalveolar	-30.743	11.844	<.0001	S
lam. dental, lam. pal-alv.	-30.567	10.966	<.0001	S
ap. alveolar, N.C. apical	-2.331	15.508	.9939	
ap. alveolar, ap. postalveolar	-24.553	14.157	<.0001	S
ap. alveolar, lam. pal-alv.	-24.377	13.430	<.0001	S
N.C. apical, ap. postalveolar	-22.222	14.157	.0003	S
N.C. apical, lam. pal-alv.	-22.046	13.430	.0001	S
ap. postalv, lam. pal-alv.	.176	11.844	>.9999	

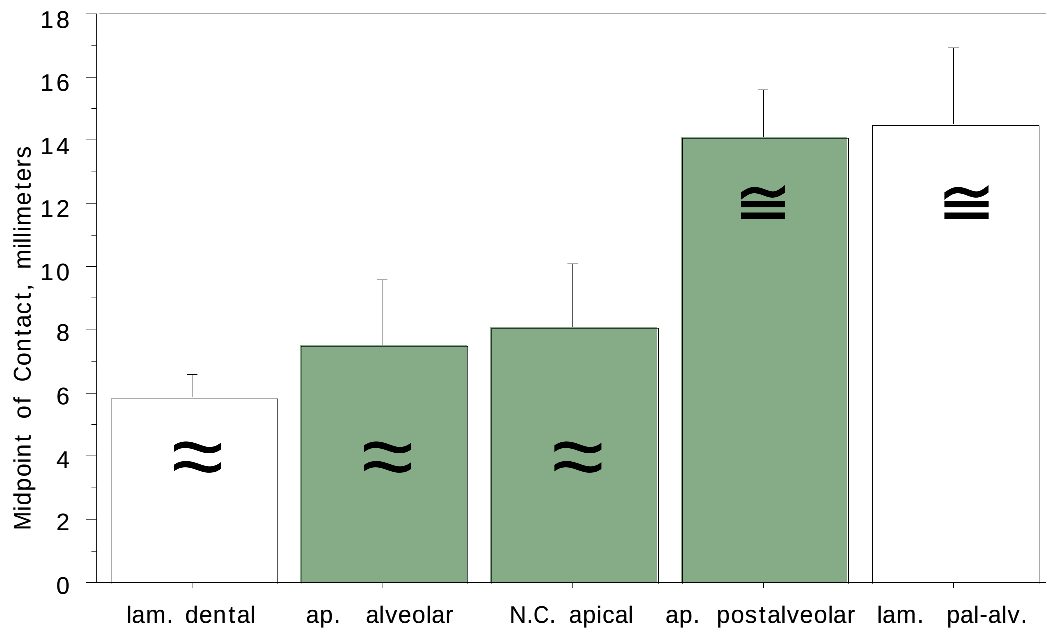


Figure 3.52: Midpoint of Contact in ***millimeters*** for coronal Place categories

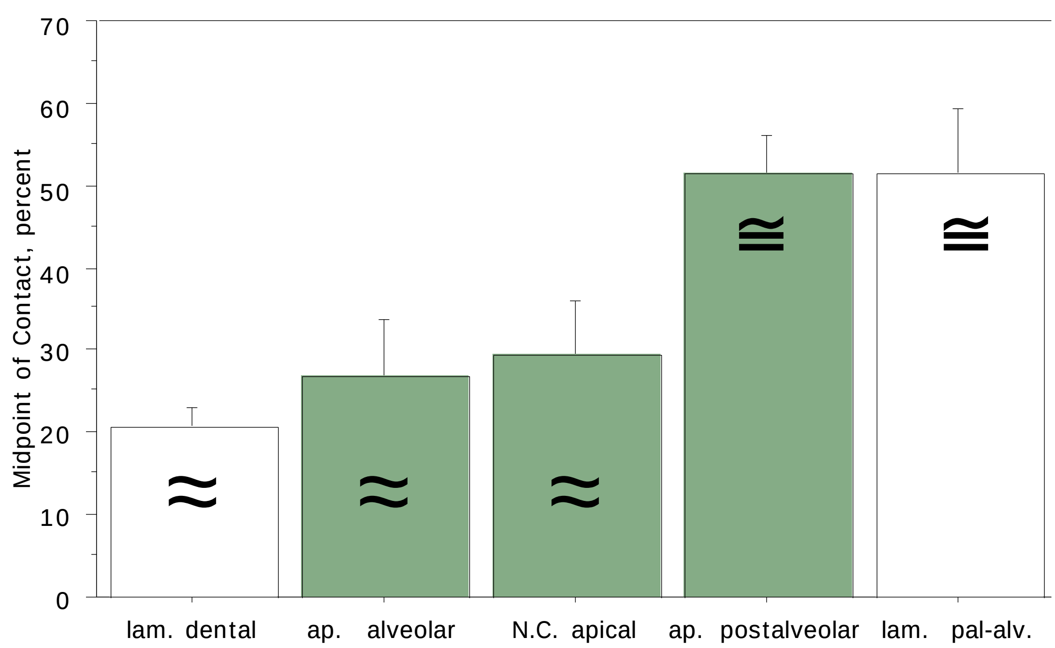


Figure 3.53: Midpoint of Contact in ***percent*** for coronal Place categories

For both millimeter and percentile measures, the overall effect of coronal Place category on the midpoint of contact is highly significant (raw values: $F(4,70)=24.016$, $p<.0001$; relative values: $F(4,70)=29.431$, $p<.0001$.) Moreover, pairwise comparisons show robustly significant differences in cases where the paired categories have different values for Anterior, but show very large p-values, in some cases nearly approaching unity, in cases where the paired categories share the same value for Anterior. Thus, though tangential to our discussion of the relative weightings of polarization and gestural economy as presented above, here is some evidence that gestural economy may also apply to component features of coronal Place categories. Mean midpoints of contact for the two [+anterior] categories are not statistically differentiable, and the mean midpoints of contact for the two [-anterior] categories are nearly identical. Note once again that the apical which is not contrastive for Anterior groups with the [+anterior] categories.

3.6.4 Summary of Palatographic Results

In this part of the study we examined evidence for relative weighting of polarization and gestural economy in the domain of consonant Place of Articulation, by quantitatively characterizing palatograms of W. Arrernte coronal articulations. Stops and nasals of given Place categories were compared on three measures, and found not to differ from each other along any of these measures. These results indicate a heavy relative weighting of gestural economy. Results of four articulatory measures were examined, to analyze differences between contrastive and non-contrastive apicals. In comparing *length of contact* in contrastive versus non-contrastive apicals, results were compatible with both polarization and gestural economy, and so did not bear on the issue of how these derivative principles may compromise or be weighted. However, results for *frontmost contact*, *cavity behind constriction* and *midpoint of contact* indicated that in terms of the cavities in front of and behind the constriction, and arguably in terms of the articulatory target itself, alveolar and non-contrastive apicals are not statistically differentiable, which is evidence for re-use of gestures. Moreover, the fact that the alveolar rather than the postalveolar was used in the greater number of contexts indicates the re-use of less displaced (articulatory easy) gestures. These results point to a relatively high weighting of articulatory ease and pattern congruity in consonant Place.

Categories sharing values for Anterior seemed to be distinguished simply on the basis of length of contact (apicality) in these results, with the same center point of contact on the roof of the mouth. Similarly, categories sharing values for Apical seemed to be distinguished only by their value for Anterior, but not by length of contact. While not the main focus of this study, these results are a first indication that gestural economy may extend to component features of consonant Place categories.

3.7 Results: Linguography

The categorized set of data discussed under <u>Data Reduction of Linguograms</u> was submitted to chi squared analysis, to determine whether phonological types could be differentiated on the basis of descriptive variables in a statistically significant manner. As the null hypothesis we assumed that phonological groupings were unrelated to these variables. Under the null hypothesis, descriptions of linguograms belonging to a common phonological grouping should be randomly and evenly distributed among the categories within a descriptive variable.

As in the previous section which treats palatographic results, we will first examine differences in Manner, and then differences in Place.

3.7.1 Stops versus Nasals

Because results were similar for *rear point of contact*, *coronal width at tongue front*, and *shape*, we will focus on these variables before turning to results for *midline length*. There was no difference in the behavior of stops and nasals with regard *to rear contact, coronal width* or *shape*. In each case, the observed and expected frequencies of distribution among variable categories did not differ significantly between stops and nasals; manner is unrelated to the three variables.

3.7.1.1. Rear Point of Contact

Recall from Table 3.1 that our data do not include a laminal palatoalveolar nasal in initial position. Thus, we will first restrict our attention to the balanced subset of medial stops and nasals. There was no significant difference between stops and nasals in rear point of contact (df:6, X^2=2.600, p=.8571.) Observed frequencies for each cell are very near expected values given the null hypothesis, as shown in Tables 3.19a and b. (Note that observed frequencies reported throughout this section are integers by definition. On the other hand, expected values can be fractional because they depend on row and column totals, and on the number of categories in a given test. However, row and column totals in every case are integers. The three decimal places shown are not salient, but are automatically generated by the statistical program used here.)

Table 3.19a: Observed frequencies for distribution of medial nasals and stops. Variable: rear point of contact.

Observed Frequencies: Rear Contact
Medial Nasals and Stops

	N	S	Totals
sublingual	4	6	10
vertex	10	8	18
apex	6	6	12
midblade	1	1	2
backofblade	9	9	18
tongue front	5	8	13
tongue center	5	2	7
Totals	40	40	80

Table 3.19b: Expected values for distribution of medial nasals and stops. Variable: rear point of contact.

Expected Frequencies: Rear Contact
Medial Nasals and Stops

	N	S	Totals
sublingual	5.000	5.000	10.000
vertex	9.000	9.000	18.000
apex	6.000	6.000	12.000
midblade	1.000	1.000	2.000
backofblade	9.000	9.000	18.000
tongue front	6.500	6.500	13.000
tongue center	3.500	3.500	7.000
Totals	40.000	40.000	80.000

A chi squared test on initial stops and nasals, excluding laminal palatoalveolars, revealed similar results: no statistically significant effect of manner (df:5, X^2=7.535, p=.1838.)

Table 3.20a: Observed frequencies for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: rear point of contact.

Observed Frequencies: Rear Contact
Initial Nasals and Stops
[-Ant] Laminals excluded

	N	S	Totals
sublingual	0	1	1
vertex	0	4	4
apex	9	5	14
frontofblade	1	0	1
midblade	1	2	3
backofblade	9	8	17
Totals	20	20	40

Table 3.20b: Expected values for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: rear point of contact.

Expected Frequencies: Rear Contact
Initial Nasals and Stops
[-Ant] Laminals excluded

	N	S	Totals
sublingual	.500	.500	1.000
vertex	2.000	2.000	4.000
apex	7.000	7.000	14.000
frontofblade	.500	.500	1.000
midblade	1.500	1.500	3.000
backofblade	8.500	8.500	17.000
Totals	20.000	20.000	40.000

3.7.1.2 Coronal Width at Tongue Front

No significant differences were found in the behavior of medial stops and nasals, or in that of initial stops and nasals. Results for medials are given in Tables 3.21a and b (df:3, X^2=5.467, p=.1406.)

Table 3.21a: Observed frequencies for distribution of medial nasals and stops. Variable: coronal width at tongue front.

Observed Frequencies: Coronal Width
Medial Nasals and Stops

	N	S	Totals
none	1	7	8
narrow	12	11	23
medium	2	5	7
wide	11	9	20
Totals	26	32	58

Table 3.21b: Expected values for distribution of medial nasals and stops. Variable: coronal width at tongue front.

Expected Frequencies: Coronal Width
Medial Nasals and Stops

	N	S	Totals
none	3.586	4.414	8.000
narrow	10.310	12.690	23.000
medium	3.138	3.862	7.000
wide	8.966	11.034	20.000
Totals	26.000	32.000	58.000

Results of the chi squared test for initials (excluding laminal palatoalveolars) follow in Tables 3.22a and b (df:3, X^2=3.130, p=.3721.)

Table 3.22a: Observed frequencies for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: coronal width at tongue front.

Observed Frequencies: Coronal Width
Initial Nasals and Stops
[-Ant] Laminals excluded

	N	S	Totals
none	3	1	4
narrow	10	8	18
medium	3	7	10
wide	2	1	3
Totals	18	17	35

Table 3.22b: Expected values for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: coronal width at tongue front.

Expected Frequencies: Coronal Width
Initial Nasals and Stops
[-Ant] Laminals excluded

	N	S	Totals
none	2.057	1.943	4.000
narrow	9.257	8.743	18.000
medium	5.143	4.857	10.000
wide	1.543	1.457	3.000
Totals	18.000	17.000	35.000

3.7.1.3 Shape

Once again, there was no difference in the behavior of stops and nasals, either in the medials or in initials excluding laminal palatoalveolars. Results for medials (df:3, X^2=.362, p=.9480) and initials (df:2, X^2=1.846, p=.3973) respectively are given in Tables 3.23 and 3.24.

Table 3.23a: Observed frequencies for distribution of medial nasals and stops. Variable: shape.

Observed Frequencies: Shape
Medial Nasals and Stops

	N	S	Totals
parallel lines	7	9	16
u	9	10	19
triangle	1	2	3
butterfly	10	10	20
Totals	27	31	58

Table 3.23b: Expected values for distribution of medial nasals and stops. Variable: shape.

Expected Frequencies: Shape
Medial Nasals and Stops

	N	S	Totals
parallel lines	7.448	8.552	16.000
u	8.845	10.155	19.000
triangle	1.397	1.603	3.000
butterfly	9.310	10.690	20.000
Totals	27.000	31.000	58.000

Table 3.24a: Observed frequencies for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: shape.

Observed Frequencies: Shape
Initial Nasals and Stops
[-ant] laminals excluded

	N	S	Totals
parallel lines	0	1	1
u	7	7	14
triangle	6	3	9
Totals	13	11	24

Table 3.24b: Expected values for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: shape.

Expected Frequencies: Shape
Initial Nasals and Stops
[-ant] laminals excluded

	N	S	Totals
parallel lines	.542	.458	1.000
u	7.583	6.417	14.000
triangle	4.875	4.125	9.000
Totals	13.000	11.000	24.000

3.7.1.4 Midline Length

To summarize results thus far, on three of the four criteria used to attempt to differentiate among phonological categories in the linguograms, the stops and nasals behave as a group. This result was also true of the subset of initial stops and nasals in the case of the fourth variable, *midline length* (df:4, X^2=5.867, p=.2093.) However, the medial nasals did show significant differences from the medial stops, on the measure of *midline length* (df:4, X^2=10.902, p=.0277.) Results for medials and initials on this variable are shown in Tables 3.25 and 3.26 respectively.

Table 3.25a: Observed frequencies for distribution of medial nasals and stops. Variable: midline length.

Observed Frequencies: Midline Length
Medial Nasals and Stops

	N	S	Totals
vertex	5	4	9
short	14	14	28
medium	3	12	15
long	13	10	23
xlong	5	0	5
Totals	40	40	80

Table 3.25b: Expected values for distribution of medial nasals and stops. Variable: midline length.

Expected Frequencies: Midline Length
Medial Nasals and Stops

	N	S	Totals
vertex	4.500	4.500	9.000
short	14.000	14.000	28.000
medium	7.500	7.500	15.000
long	11.500	11.500	23.000
xlong	2.500	2.500	5.000
Totals	40.000	40.000	80.000

Table 3.26a: Observed frequencies for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: midline length.

Observed Frequencies: Midline Length
Initial Nasals and Stops
[-ant] laminals excluded

	N	S	Totals
vertex	0	4	4
short	9	6	15
medium	2	3	5
long	8	7	15
xlong	1	0	1
Totals	20	20	40

Table 3.26b: Expected values for distribution of initial nasals and stops (laminal palatoalveolars excluded.) Variable: midline length.

Expected Frequencies: Midline Length
Initial Nasals and Stops
[-ant] laminals excluded

	N	S	Totals
vertex	2.000	2.000	4.000
short	7.500	7.500	15.000
medium	2.500	2.500	5.000
long	7.500	7.500	15.000
xlong	.500	.500	1.000
Totals	20.000	20.000	40.000

In Table 3.25a, we find that more nasals fall into the 'long' and 'extra long' categories than do stops. This is puzzling, given the results for the palatograms, which showed no significant effect of manner on *length of contact.* We will pursue the question of which nasal place categories are longer than their corresponding stop categories in the following section, where we focus on differences in Place of articulation.

3.7.2 Place of Articulation

In the following discussion we will not conflate manner categories, in order to be able to observe differences in distribution between nasals and stops of a given Place category. Standard Arrernte orthography (refer to Table 2.2) is used in the column heads in Tables 3.27 through 3.41.

3.7.2.1 Midline length

Observed and expected frequencies for the variable *midline length*, for medial stops and nasals, are given in Table 3.27a and b. Results are highly significant (df:28,

X^2=100.434, p<.0001.) In order to show how phonological categories distribute themselves with respect to descriptive categories within this variable, frequencies of more than two are highlighted.

Table 3.27a: Observed frequencies for distribution of medial nasals and stops by Place. Variable: midline length. **Frequencies of more than two are highlighted.**

	th	nh	t	n	rt	rn	ty	ny	Totals
vertex	0	0	4	4	0	1	0	0	9
short	0	0	5	6	7	8	2	0	28
medium	4	1	1	0	3	1	4	1	15
long	6	8	0	0	0	0	4	5	23
xlong	0	1	0	0	0	0	0	4	5
Totals	10	10	10	10	10	10	10	10	80

Table 3.27b: Expected values for distribution of medial nasals and stops by Place. Variable: midline length.

Expected Frequencies: Midline Length
Medial Nasals and Stops by Phonological Category

	th	nh	t	n	rt	rn	ty	ny	Totals
vertex	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	9.000
short	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	28.000
medium	1.875	1.875	1.875	1.875	1.875	1.875	1.875	1.875	15.000
long	2.875	2.875	2.875	2.875	2.875	2.875	2.875	2.875	23.000
xlong	.625	.625	.625	.625	.625	.625	.625	.625	5.000
Totals	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	80.000

Analogous results for the initial stops and nasals follow. Again, results are highly significant (df:12, X^2=44.267, p<.0001.)

Table 3.28a: Observed frequencies for distribution of initial nasals and stops by Place. Variable: midline length. **Frequencies of more than two are highlighted**.

	th	nh	#T	#N	Totals
vertex	0	0	4	0	4
short	1	0	5	9	15
medium	2	1	1	1	5
long	7	8	0	0	15
xlong	0	1	0	0	1
Totals	10	10	10	10	40

Table 3.28b: Expected values for distribution of initial nasals and stops by Place. Variable: midline length.

Expected Frequencies: Midline Length
Initial Nasals and Stops by Phonological Category
[-ant] laminals excluded

	th	nh	#T	#N	Totals
vertex	1.000	1.000	1.000	1.000	4.000
short	3.750	3.750	3.750	3.750	15.000
medium	1.250	1.250	1.250	1.250	5.000
long	3.750	3.750	3.750	3.750	15.000
xlong	.250	.250	.250	.250	1.000
Totals	10.000	10.000	10.000	10.000	40.000

For these results, observe that the data divide themselves along the lines of the feature Apical. The [+apical] stops and nasals fall into the ‘vertex’, ‘short’ and occasionally ‘medium’ categories, while the [-apical] stops and nasals fall into the ‘long’, ‘extra long’ and occasionally ‘medium’ categories. This accords well with palatographic results for length of contact, which also differentiates stops and nasals along the lines of the feature Apical.

As a side point, we return to the question of which nasals are longer than their stop counterparts. From Tables 3.27a and 3.28a we see that only the laminal nasals have the tendency to be categorized in the ‘long’ and ‘extra long’ categories more often than their corresponding stops; this is not true of the [+apical] nasals. Returning to the polarization hypothesis explicated in Chapter One, we predicted that if differences were found with respect to manner, they would show polarization of the nasals vis-a-vis the stops. On the measure of *midline length* we might expect polarization to translate into laminal dental nasals that are shorter than laminal dental stops, and laminal palatoalveolar nasals that are longer than laminal palatoalveolar stops, as in Figure 1.7, reproduced for the laminals below.

Place of articulation continuum--->

Phonetic Category	***{dental}***	***{alveolar}***	***{postalveolar}***	***{palatal}***
Stops	**t̪**			***t4***
Nasals	**n̪**			***n4***

Figure 1.7: Polarization scenario for laminal nasals versus stops.

However, results on this measure instead suggest a uniform direction of difference between laminal nasals and stops:

Place of articulation continuum--->

Phonetic Category	***{dental}***	***{alveolar}***	***{postalveolar}***	***{palatal}***
Stops	**t̪**			***t4***
Nasals	**n̪**			***n4***

Figure 3.54: Laminal stops versus laminal nasals in W. Arrernte linguograms on the variable *midline length*.

The question still remains: how can nasals and stops differ significantly from each other in the linguographic evidence, when they do not differ in the palatographic evidence? We return to this issue under <u>Linguography: Analysis and Interpretation</u>.

3.7.2.2 Rear point of contact

For *rear contact*, results for medials as well as initials are highly statistically significant. Tables 3.29a and b show results for medials (df:42, X^2=214.845, p<.0001.)

Table 3.29a: Observed frequencies for distribution of medial nasals and stops by Place. Variable: rear contact. **Frequencies of more than two are highlighted.**

	th	nh	t	n	rt	rn	ty	ny	Totals
sublingual	0	0	0	0	6	4	0	0	10
vertex	0	0	4	4	4	6	0	0	18
apex	0	0	6	6	0	0	0	0	12
midblade	1	1	0	0	0	0	0	0	2
backofblade	9	9	0	0	0	0	0	0	18
tonguefront	0	0	0	0	0	0	8	5	13
tonguecenter	0	0	0	0	0	0	2	5	7
Totals	10	10	10	10	10	10	10	10	80

Table 3.29b: Expected values for distribution of medial nasals and stops by Place. Variable: rear contact.

Expected Frequencies: Rear Contact
Medial Nasals and Stops by Phonological Category

	th	nh	t	n	rt	rn	ty	ny	Totals
sublingual	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	10.000
vertex	2.250	2.250	2.250	2.250	2.250	2.250	2.250	2.250	18.000
apex	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	12.000
midblade	.250	.250	.250	.250	.250	.250	.250	.250	2.000
backofblade	2.250	2.250	2.250	2.250	2.250	2.250	2.250	2.250	18.000
tongue front	1.625	1.625	1.625	1.625	1.625	1.625	1.625	1.625	13.000
tongue center	.875	.875	.875	.875	.875	.875	.875	.875	7.000
Totals	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	80.000

Tables 3.30a and b show results for initials (df:15, X^2=55.070, p<.0001.)

Table 3.30a: Observed frequencies for distribution of initial nasals and stops by Place. Variable: rear contact. **Frequencies of more than two are highlighted.**

	th	nh	#T	#N	Totals
sublingual	0	0	1	0	1
vertex	0	0	4	0	4
apex	0	0	5	9	14
frontofblade	0	0	0	1	1
midblade	2	1	0	0	3
backofblade	8	9	0	0	17
Totals	10	10	10	10	40

Table 3.30b: Expected values for distribution of initial nasals and stops by Place. Variable: rear contact.

Expected Frequencies: Rear Contact
Initial Nasals and Stops by Phonological Category
[-ant] laminals excluded

	th	nh	#T	#N	Totals
sublingual	.250	.250	.250	.250	1.000
vertex	1.000	1.000	1.000	1.000	4.000
apex	3.500	3.500	3.500	3.500	14.000
frontofblade	.250	.250	.250	.250	1.000
midblade	.750	.750	.750	.750	3.000
backofblade	4.250	4.250	4.250	4.250	17.000
Totals	10.000	10.000	10.000	10.000	40.000

The results in Tables 3.29a and 3.30a confirm that different parts of the tongue are involved in the articulation of different Place categories. While a tip/rear-of-tip distinction is plainly visible, again along the lines of the feature Apical, there are also very consistent differences within the apical categories and within the laminal categories. The range for rear point of contact in the laminal dentals lies squarely within the tongue blade, while rear contact in laminal palatoalveolars consistently extends as far back as the tongue body. The apical postalveolars extend only as far back as the vertex (i.e. involve no upper surface contact in the midline at all), while apical alveolars extend back no further than the apex. Note that in the non-contrastive apicals, rear contact is in the same range as in the apical alveolars, with two exceptions: one non-contrastive apical showed only sublingual contact while another showed contact as far back as the front of the tongue blade. We will return to this issue under Contrastive versus Non-Contrastive Apicals.

3.7.2.3 Coronal Width at Tongue Front

Results for medials on the measure of *coronal width* were highly significant (df:21, X^2=82.530, p<.0001.)

Table 3.31a: Observed frequencies for distribution of medial nasals and stops by Place. Variable: coronal width.

Observed Frequencies: Coronal Width
Medial Nasals and Stops by Phonological Category

	th	nh	t	n	rt	rn	ty	ny	Totals
none	0	0	5	1	2	0	0	0	8
narrow	4	2	5	9	2	1	0	0	23
medium	4	2	0	0	1	0	0	0	7
wide	0	2	0	0	0	0	9	9	20
Totals	8	6	10	10	5	1	9	9	58

Table 3.31b: Expected values for distribution of medial nasals and stops by Place. Variable: coronal width.

Expected Frequencies: Coronal Width
Medial Nasals and Stops by Phonological Category

	th	nh	t	n	rt	rn	ty	ny	Totals
none	1.103	.828	1.379	1.379	.690	.138	1.241	1.241	8.000
narrow	3.172	2.379	3.966	3.966	1.983	.397	3.569	3.569	23.000
medium	.966	.724	1.207	1.207	.603	.121	1.086	1.086	7.000
wide	2.759	2.069	3.448	3.448	1.724	.345	3.103	3.103	20.000
Totals	8.000	6.000	10.000	10.000	5.000	1.000	9.000	9.000	58.000

Note, however, the lack of available descriptions of apical postalveolars in these data; only one nasal and five stops were described. Because the relatively large number of missing cells for apical postalveolars may skew results, the test was repeated with these categories excluded. Results for the remaining Places remain highly significant (df:15, X^2=76.671, p<.0001.)

Table 3.32a: Observed frequencies for distribution of medial nasals and stops by Place. Variable: coronal width. Postalveolar apicals excluded.
Frequencies of more than two are highlighted.

	th	nh	t	n	ty	ny	Totals
none	0	0	5	1	0	0	8
narrow	4	2	5	9	0	0	23
medium	4	2	0	0	0	0	7
wide	0	2	0	0	9	9	20
Totals	8	6	10	10	9	9	58

Table 3.32b: Expected values for distribution of medial nasals and stops by Place. Variable: coronal width. Postalveolar apicals excluded.

Expected Frequencies: Coronal Width
Medial Nasals and Stops by Phonological Category
[-ant] apicals excluded

	th	nh	t	n	ty	ny	Totals
none	.923	.692	1.154	1.154	1.038	1.038	6.000
narrow	3.077	2.308	3.846	3.846	3.462	3.462	20.000
medium	.923	.692	1.154	1.154	1.038	1.038	6.000
wide	3.077	2.308	3.846	3.846	3.462	3.462	20.000
Totals	8.000	6.000	10.000	10.000	9.000	9.000	52.000

Results for two initial categories included in the test do not differ significantly (df:9, X^2=11.685, p=.2317.)

Table 3.33a: Observed frequencies for distribution of initial nasals and stops by Place. Variable: coronal width. **Frequencies of more than two are highlighted.**

	th	nh	#T	#N	Totals
none	0	0	1	3	4
narrow	3	5	5	5	18
medium	3	2	4	1	10
wide	1	2	0	0	3
Totals	7	9	10	9	35

Table 3.33b: Expected values for distribution of initial nasals and stops by Place. Variable: coronal width.

Expected Frequencies: Coronal Width
Initial Nasals and Stops by Phonological Category
[-ant] laminals excluded

	th	nh	#T	#N	Totals
none	.800	1.029	1.143	1.029	4.000
narrow	3.600	4.629	5.143	4.629	18.000
medium	2.000	2.571	2.857	2.571	10.000
wide	.600	.771	.857	.771	3.000
Totals	7.000	9.000	10.000	9.000	35.000

These results indicate that the laminal palatoalveolars consistently have wide contact at the sides of the tongue behind the central stricture, which implies tongue body raising. In the apical alveolars, side contact is narrow or not present, which suggests a relatively low tongue body behind the constriction. Results for laminal dentals indicate varying degrees of tongue body raising.

3.7.2.4 Shape

The highly significant results of the chi squared test for medial stops and nasals follow in Table 3.34a and b (df:21, X^2=121.253, $p<.0001$.) Results for initials excluding laminal palatoalveolars were also significant, and are given in Tables 3.35a and b (df:6, X^2=21.314, p=.0016.)

Table 3.34a: Observed frequencies for distribution of medial nasals and stops by Place. Variable: shape. **Frequencies of more than two are highlighted.**

	th	nh	t	n	rt	rn	ty	ny	Totals
parallel lines	0	0	0	0	9	7	0	0	16
u	5	2	5	6	0	1	0	0	19
triangle	2	1	0	0	0	0	0	0	3
butterfly	0	0	0	0	0	0	10	10	20
Totals	7	3	5	6	9	8	10	10	58

Table 3.34b: Expected values for distribution of medial nasals and stops by Place. Variable: shape.

Expected Frequencies: Shape
Medial Nasals and Stops by Phonological Category

	th	nh	t	n	rt	rn	ty	ny	Totals
parallel lines	1.931	.828	1.379	1.655	2.483	2.207	2.759	2.759	16.000
u	2.293	.983	1.638	1.966	2.948	2.621	3.276	3.276	19.000
triangle	.362	.155	.259	.310	.466	.414	.517	.517	3.000
butterfly	2.414	1.034	1.724	2.069	3.103	2.759	3.448	3.448	20.000
Totals	7.000	3.000	5.000	6.000	9.000	8.000	10.000	10.000	58.000

Table 3.35a: Observed frequencies for distribution of initial nasals and stops by Place. Variable: shape. **Frequencies of more than two are highlighted.**

	th	nh	#T	#N	Totals
parallel lines	0	0	1	0	1
u	2	0	5	7	14
triangle	3	6	0	0	9
Totals	5	6	6	7	24

Table 3.35b: Expected values for distribution of initial nasals and stops by Place. Variable: shape.

Expected Frequencies: Shape
Initial Nasals and Stops by Phonological Category
[-ant] laminals excluded

	th	nh	#T	#N	Totals
parallel lines	.208	.250	.250	.292	1.000
u	2.917	3.500	3.500	4.083	14.000
triangle	1.875	2.250	2.250	2.625	9.000
Totals	5.000	6.000	6.000	7.000	24.000

Again, laminal palatoalveolars present the clearest results; 100% of those shown here are 'butterfly' shaped. (This is also true of the 20 initial laminal palatoalveolar stops and pre-stopped nasals which were excluded from consideration in these statistical tests.) Apical alveolars fall into the 'u' pattern. Apical postalveolars fall into the 'parallel lines' pattern, with a single exception. Results for laminal dentals, however, are more variable. While many fall into the 'triangle' pattern which indicates an apico-laminal articulatory strategy, in the medials quite a few also show the 'u' pattern, which indicates an interdental articulatory strategy. This will be discussed in further detail under Linguography: Analysis and Interpretation.

3.7.3 Contrastive versus Non-Contrastive Apicals

For purposes of our discussion here, we will refer to apical alveolars, apical postalveolars and non-contrastive apicals as three "categories" of apical. Although the issue of category membership is precisely the question at hand, we adopt this term as a convenience.

3.7.3.1 Midline Length

Results for *midline length* are given in Tables 3.36a and b below. As no significant difference was found in the behavior of the three apical categories (df:10, X^2=15.758, p=.1068), a chi squared test including only the contrastive apical categories was done. No significant difference was found (df:6, X^2=10.236, p=.1151.) Thus, as is the case for *length of contact* in the palatographic results above, the *midline length* metric is neutral with respect to evidence for polarization or gestural economy, since the contrastive apicals themselves behave in a non-differentiable manner.

Table 3.36a: Observed frequencies for distribution of apical nasals and stops. Variable: midline length. **Frequencies of more than two are highlighted.**

	t	n	#T	#N	rt	rn	Totals
vertex	4	4	4	0	0	1	13
short	5	6	5	9	7	8	40
medium	1	0	1	1	3	1	7
Totals	10	10	10	10	10	10	60

Table 3.36b: Expected frequencies for distribution of apical nasals and stops.

Variable: midline length.

Expected Frequencies: Midline Length
Apical Nasals and Stops

	t	n	#T	#N	rt	rn	Totals
vertex	2.167	2.167	2.167	2.167	2.167	2.167	13.000
short	6.667	6.667	6.667	6.667	6.667	6.667	40.000
medium	1.167	1.167	1.167	1.167	1.167	1.167	7.000
Totals	10.000	10.000	10.000	10.000	10.000	10.000	60.000

3.7.3.2 Rear Point of Contact

Results for *rear contact* show significant differences among the three apical categories (df:15, X^2=43.259, p=.0001.) Restricting our attention again to the pair of contrastive apicals, a chi squared test shows significant differences between them (df:6, X^2=23.467, p=.0007.) While apical alveolars extend rearward as far as the apex, apical postalveolars extend only as far back as the vertex, and half show only sublingual contact. Non-contrastive apicals are not differentiable from apical alveolars on a chi squared test of these two categories (df:9, X^2=11.385, p=.2503.) However, non-contrastive apicals are quite significantly distinct from apical postalveolars (df:9, X^2=32.987, p=.0001.) As mentioned above, the non-contrastive apicals show a little more variability than either of the contrastive places. One token records sublingual contact, and another extends further back than the apex.

Table 3.37a: Observed frequencies for distribution of apical nasals and stops. Variable: rear contact. **Frequencies of more than two are highlighted.**

	t	n	#T	#N	rt	rn	Totals
sublingual	0	0	1	0	6	4	11
vertex	4	4	4	0	4	6	22
apex	6	6	5	9	0	0	26
front of blade	0	0	0	1	0	0	1
Totals	10	10	10	10	10	10	60

Table 3.37b: Expected frequencies for distribution of apical nasals and stops. Variable: rear contact.

Expected Frequencies: Rear Contact
Apical Nasals and Stops

	t	n	#T	#N	rt	rn	Totals
sublingual	1.833	1.833	1.833	1.833	1.833	1.833	11.000
vertex	3.667	3.667	3.667	3.667	3.667	3.667	22.000
apex	4.333	4.333	4.333	4.333	4.333	4.333	26.000
frontofblade	.167	.167	.167	.167	.167	.167	1.000
Totals	10.000	10.000	10.000	10.000	10.000	10.000	60.000

3.7.3.3 Coronal Width at Tongue Front

Results for *coronal width* are given below in Tables 3.38a and b. Significant differences were not found when all three apical categories were included in a chi squared test (df:10, X^2=15.671, p=.1094.) But recall that the coronal width data do not contain many observations of apical postalveolars. When just alveolar and non-contrastive apicals are included, they do show significant differences (df:6, X^2=14.578, p=.0238.) Both types of apicals show tokens in which there is only narrow contact or none at all on the sides of the tongue. However, about 20% of non-contrastive tokens described for this variable show a ‘medium’ amount of contact, suggesting tongue raising behind the central constriction. None of the apical alveolars show this thickened contact. This may be an indication of initial strengthening in the case of the (initial) non-contrastive apicals.

Table 3.38a: Observed frequencies for distribution of apical nasals and stops. Variable: coronal width. **Frequencies of more than two are highlighted.**

	t	n	#T	#N	rt	rn	Totals
none	5	1	1	3	2	0	12
narrow	5	9	5	5	2	1	27
medium	0	0	4	1	1	0	6
Totals	10	10	10	9	5	1	45

Table 3.38b: Expected frequencies for distribution of apical nasals and stops. Variable: coronal width.

Expected Frequencies: Coronal Width
Apical Nasals and Stops

	t	n	#T	#N	rt	rn	Totals
none	2.667	2.667	2.667	2.400	1.333	.267	12.000
narrow	6.000	6.000	6.000	5.400	3.000	.600	27.000
medium	1.333	1.333	1.333	1.200	.667	.133	6.000
Totals	10.000	10.000	10.000	9.000	5.000	1.000	45.000

3.7.3.4 Shape

Once again, in addition to a test of all three apical categories together, chi squared tests involving pairs of apical categories were done. The test on the contrastive apicals shows very significant differences between these two categories (df:3, X^2=24.427, p<.0001). Similarly, the test including all three categories reflects significant differences (df:5, X^2=33.961, p<.0001.) The non-contrastive apicals are also very significantly different from apical postalveolars (df:3, X^2=23.043, p<.0001.) However, when alveolar and non-contrastive apicals are compared, no significant difference appears (df:3, X^2=3.130, p=.3719.)

Table 3.39a: Observed frequencies for distribution of apical nasals and stops. Variable: shape. **Frequencies of more than two are highlighted.**

	t	n	#T	#N	rt	rn	Totals
parallel lines	0	0	1	0	9	7	17
u	5	6	5	7	0	1	24
Totals	5	6	6	7	9	8	41

Table 3.39b: Expected frequencies for distribution of apical nasals and stops. Variable: shape.

Expected Frequencies: Shape
Apical Nasals and Stops

	t	n	#T	#N	rt	rn	Totals
parallel lines	2.073	2.488	2.488	2.902	3.732	3.317	17.000
u	2.927	3.512	3.512	4.098	5.268	4.683	24.000
Totals	5.000	6.000	6.000	7.000	9.000	8.000	41.000

To summarize, in the case of *midline length*, even the contrastive apicals do not differ from each other. Where these two categories do differ, on the metrics of *rear contact* and *shape*, non-contrastive apicals group with apical alveolars but not with apical postalveolars. For *coronal width* the non-contrastive apicals are distinct from apical alveolars in having more contact on the sides of the tongue behind the constriction, which may be an indication of initial strengthening.

3.7.4 Linguography: Analysis and Interpretation

3.7.4.1 Stops and Nasals

A statistically significant effect of Manner was found for only one of the criteria examined here. For *midline length*, laminal nasals fall into the ‘long’ categories more often than do stops. Given the absence of such an effect of Manner in the palatograms, this phenomenon was pursued.

The obvious articulatory difference between stops and nasals is in the position of the velum. It has been repeatedly observed in x-ray studies that as the velum lowers, the position of the tongue body also lowers. An exaggerated schematic of this coordinated movement is shown in Figure 3.55a. To illustrate the potential effect of velum lowering on tongue stance in nasal articulations, let us assume that a marker $\boldsymbol{p_s}$ is placed on the tongue body. When the velum is lowered, the pellet moves down and back, to position $\boldsymbol{p_n}$. Figure 3.55b shows the area of tongue-palate contact during the nasal in greater detail. Let us assume that the midpoint of midsagittal contact for a given stop is indicated by marker pellets on both passive and active articulators. Pellet $\boldsymbol{y}$ is attached to the roof of the mouth; pellet $\boldsymbol{x_s}$ *is* attached to the tongue. The two pellets are in contact during stop closure. However, if the tongue body moves down and back in tandem with velic opening, other points along the tongue may also move rearward, including pellet $\boldsymbol{x_s}$. Thus, contact with Place target $\boldsymbol{y}$ on the roof of the mouth will no longer occur at pellet $\boldsymbol{x_s}$, but will occur at a point further forward on the tongue, shown here as point $\boldsymbol{x_n}$. Note that the same area of contact on the palate is involved, even though the tongue configurations differ slightly.

The coordinated movement between velum and tongue body postulated here is likely to make more of a difference in [–anterior] articulations, which are closer to the tongue body, and which have less stretch and mobility than the tip. Thus, we focus on the laminal palatoalveolars to test the hypothesis that tongue contact for nasals is further forward than that for stops.

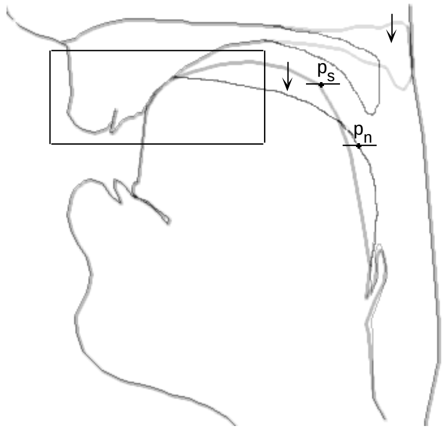


Figure 3.55a: Hypothesized positions of velum and tongue during a laminal palatoalveolar stop and nasal. A stationary pellet on the tongue body shows downward and rearward movement in response to velic lowering. The rectangular area is shown enlarged in the top half of Figure 3.55b.

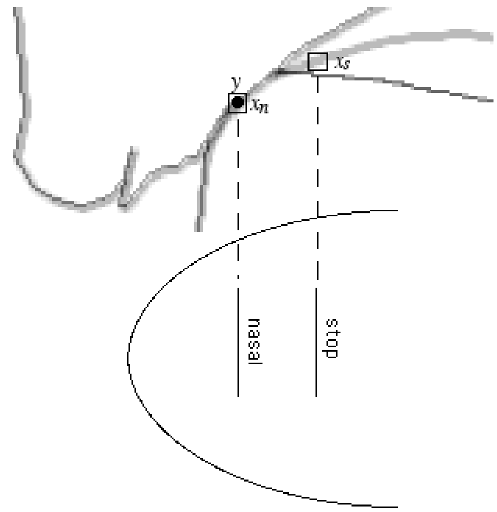


Figure 3.55b: The upper portion of this diagram shows a close-up of the constriction area during the nasal; pellet $\boldsymbol{x_s}$ is displaced rearward. Note that the same area of the palate is contacted even though the tongue configuration differs from that of the stop. The lower part of the diagram illustrates how a linguogram is affected when the tongue is protruded; contact is further forward for the nasal.

A chi squared test for categorization of the point of *front* contact on the tongue was done on medial laminal palatoalveolar stops and nasals. Results are given in Tables 3.40a and b. The same pattern that emerged in Table 3.25a is visible in Table 3.40a. Note that the nasals include three tokens for which front contact is described as ‘front’, whereas none of the corresponding stops are described this way. However, perhaps because of the paucity of data points, this effect does not reach significance (df:2, X^2=4.286, p=.1173.)

Table 3.40a: Observed frequencies for distribution of medial /t̻/ and /n̻/. Variable: Front point of contact.

Observed Frequencies: Front Contact
[-Ant] Laminal Nasals and Stops
Excluded: Stops in Initial Position

	ty	ny	Totals
front	0	3	3
mid	5	2	7
back	5	5	10
Totals	10	10	20

Table 3.40b: Expected values for distribution of medial /t̻/ and /n̻/. Variable: Front point of contact.

Expected Frequencies: Front Contact
[-Ant] Laminal Nasals and Stops
Excluded: Stops in Initial Position

	ty	ny	Totals
front	1.500	1.500	3.000
mid	3.500	3.500	7.000
back	5.000	5.000	10.000
Totals	10.000	10.000	20.000

Unexpectedly, when we re-examine *rear* point of contact in the laminal palatoalveolars, we find the opposite: nasal linguograms show contact further back than stop linguograms, rather than contact further forward. However, once again this effect turns out to be non-significant (df:1, X^2=1.978, p=.1596.) Results are shown in Tables 3.41a and b.

Table 3.41a: Observed frequencies for distribution of medial /t̻/ and /n̻/. Variable: Rear point of contact.

Observed Frequencies: Rear Contact
[-Ant] Laminal Nasals and Stops
Excluded: Stops in Initial Position

	ty	ny	Totals
tongue front	8	5	13
tongue center	2	5	7
Totals	10	10	20

Table 3.41b: Expected values for distribution of medial /t̻/ and /n̻/. Variable: Rear point of contact.

Expected Frequencies: Rear Contact
[-Ant] Laminal Nasals and Stops
Excluded: Stops in Initial Position

	ty	ny	Totals
tongue front	6.500	6.500	13.000
tongue center	3.500	3.500	7.000
Totals	10.000	10.000	20.000

Thus, it appears that tongue position may differ slightly but not significantly for stops and nasals in these data. If a more general trend were established for longer tongue contact in the nasals, this would imply that the tongue is compressed during contact in nasals as compared with stops, since their constriction lengths recorded on the palate are comparable. Though outside the scope of this study, this is a topic for further clarification.

3.7.4.2 Place of Articulation

In accord with palatographic results for *length of contact*, linguographic data for *midline length* and *rear point of contact* divide themselves along the lines of the feature Apical. But unlike the palatographic results, none of the metrics explored here reveal groupings along the lines of the feature Anterior. This is not surprising; values for Anterior are more clearly defined with respect to a relatively stationary passive articulator than a flexible and mobile one.

For the *shape* metric, the apical alveolars, apical postalveolars and laminal palatoalveolars each consistently fall into a single pattern, reflecting the general stance of the tongue during closure. However, laminal dentals fall into two shape categories, a ‘triangle’ pattern which implies an apico-laminal denti-alveolar articulatory strategy, and a ‘u’ pattern corresponding to a laminal (inter)dental strategy. There is an effect of position associated with these strategies; more initials are postdental, more medials are interdental (df:1, X^2=5.743, p=.0166.)

Table 3.42a: Observed frequencies for distribution of initial versus medial laminal dentals. Variable: shape.

Observed Frequencies: Shape
Initial versus Medial Laminal Dentals

	i	m	Totals
u	2	7	9
triangle	9	3	12
Totals	11	10	21

Table 3.42b: Expected values for distribution of initial versus medial laminal dentals. Variable: shape.

Expected Frequencies: Shape
Initial versus Medial Laminal Dentals

	i	m	Totals
u	4.714	4.286	9.000
triangle	6.286	5.714	12.000
Totals	11.000	10.000	21.000

If we attribute these positional differences to initial strengthening, and if we associate initial strengthening with careful speech, these findings do not agree with Butcher's findings that laminal interdental articulations are careful variants, while apico-laminal dentialveolars are rapid variants. This is another area for future research.

3.7.4.3 Contrastive versus Non-Contrastive Apicals

On two of the four criteria examined for linguograms, non-contrastive apicals are distinguishable from apical postalveolars, but not from apical alveolars. The non-contrastive apicals do differentiate themselves from apical alveolars on the criterion of *coronal width*, which may indicate initial strengthening. As in the palatography results, all three apical categories are statistically indistinguishable on the criterion of *midline length.* However, both palatographic and linguographic results point to the same (non-significant) tendency for *midline length:* a tendency of apical alveolars and non-contrastive apicals to be more similar to each other than either is to postalveolars. (Refer to Figures 3.48 and 3.49, and to Table 3.36a.) The apical postalveolars show tendencies toward longer midline contact than the other two groups, because the underside of the tongue is often the active articulator.

3.7.5 Summary of Linguographic Results

Chi squared statistical tests on categorized linguographic data were used to examine evidence for relative weighting of polarization and gestural economy in the domain of consonant Place. Results were in close accord with those for palatography, adducing evidence for the re-use of less displaced (articulatorily easy) gestures; i.e. a heavier relative weighting of gestural economy. Nasals did show some (non-significant) tendency toward longer lingual contact in the sagittal midline than stops, which seems to controvert the idea of re-use of gestures. However, if there is a velic lowering constraint on the tongue body as explicated above, an exact Place target on the tongue may have to be compromised in favor of an exact Place target on the stationary passive articulator. This idea is in line with the fact that none of the criteria examined here separated linguograms along the lines of the feature Anterior.

3.8 Midsagittal sections

The midsagittal sections that follow summarize production strategies for the coronal places of articulation in Western Arrernte. Chi squared tests were done to investigate the possible effect of speaker on linguographic descriptive variables; no such effects were found for the five speakers investigated here (*midline length* df:8, χ^2=15.872, p=.0617; *rear point of contact* df:12, χ^2=6.997, p=.8578; *coronal width* df:12, χ^2=7.952, p=.7888; *shape* df:12, χ^2=10.965, p=.5794.) Similarly, ANOVA on relative (percent) values for the palatographic measures showed no significant effect of speaker (*frontmost contact* F[4,62]=1.435, p=.2330; *length of contact* F[4,62]=.597, p=.6659; *back cavity index* F[4,62]=1.065 p=.3813.) Thus, since speakers' articulatory strategies were similar, exemplars for a single speaker follow.

A word on the arrangement of the following figures is in order. The midsagittal diagrams in Figures 3.56–3.61 are reconstructed from the palatogram and linguogram(s) shown below each diagram. In each midsagittal section, the portion of the roof of the mouth outlined in black is drawn from the alginate tracing (refer to Figure 3.9.) Palatograms have been corrected to lifesize on both horizontal and vertical axes, and contrast has been increased to show contact prints more clearly in black and white. On each palatogram, the speaker's topographic contour map has been superimposed (refer to Figure 3.11.) Recall that the concentric traces on the contour map were drawn at 5 mm intervals. These traces correspond to the horizontal lines drawn at 5 mm intervals on the midsagittal section. Heavy black perpendicular lines on the palatogram indicate the axes along which the alginate impression was cut. Palatographic photos are not retouched other than overall contrast enhancement, and still include calibration guidelines used in the palatography study. These are extraneous in the current diagrams.

Each palatogram has been rotated so that the lips point left, as in the midsagittal section. In addition, each palatogram is vertically aligned with the alginate tracing, by using the topographic contour map and the horizontal lines drawn on the midsagittal diagram. A graphics program with horizontal and vertical rulers, grid lines and cross hairs was used to match points on the palatogram and midsagittal section.

Linguograms have not been corrected for size, since as discussed earlier, the tongue itself can change size, shape and orientation in these photographs. Contrast has not been enhanced on linguograms.

As mentioned above, in each midsagittal section, the portion of the roof of the mouth outlined in black has been drawn from the alginate tracing, and thus is known with certainty. Location and length of contact on the palate have been drawn to match the contact print on the palatogram, as explained in the next paragraph, and are thus also fairly accurate. To some extent the position of the tongue body behind the palate can also be gleaned from the relationship of the contact print to the contour map. However, apart from the midsagittal contact area itself, traces in gray are inferred rather than known with certainty.

In order to accurately reproduce the midsagittal contact area, vertical guidelines were drawn upward from the front and rear points of contact on the palatogram, to the aligned points on the alginate tracing. In each figure, short vertical lines above the alginate tracing show where guidelines were positioned. After the contact area was in place, linguograms and palatograms together were used to infer the position of the rest of the tongue during closure.

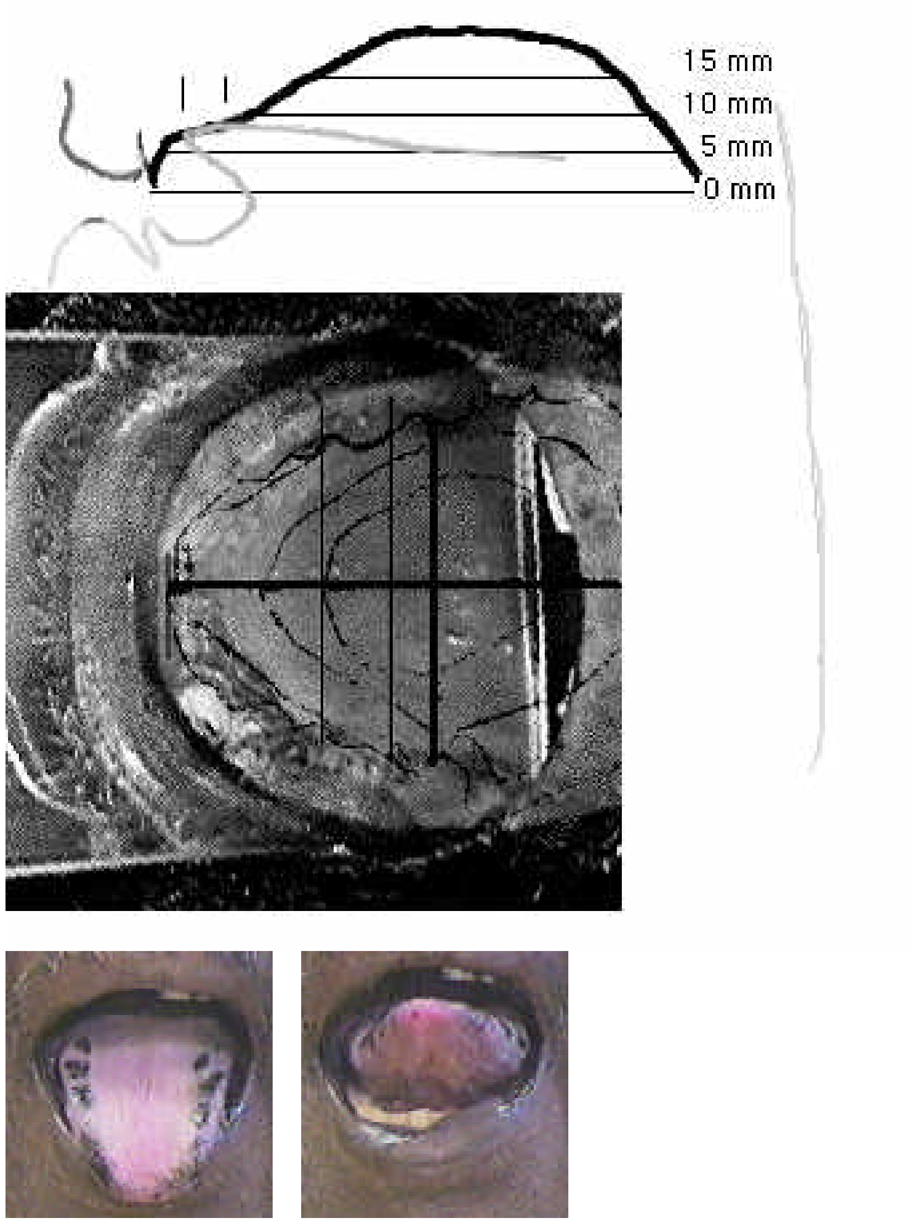


Figure 3.56: Palatogram, linguograms and reconstructed midsagittal section for a phonologically [+apical] [+anterior] nasal.
Articulation: apical alveolar.
Token: /**'manə**/ *money (n.)*

Figure 3.56 shows a reconstructed midsagittal section for a phonologically [+apical] [+anterior] nasal. Notice that tongue contact involves the upper portion of the tip, while palate contact occurs between the 5 and 10 mm lines.

Figure 3.57, showing a [+apical] stop which is non-contrastive for Anterior, is similar to the articulation shown in Figure 3.56. Contact begins slightly further back on the roof of the mouth, but still lies between the 5 and 10 mm lines. The pattern of contact on the tongue is also similar, involving the tip and a narrow region around the sides. Both the linguograms and the palatogram show heavier contact at the sides than in the preceding figure; the tongue body is raised slightly as compared with its position in Figure 3.56.

Figure 3.58 shows a [+apical] [-anterior] nasal. Tongue contact involves the vertex and underside of the apex, and extends from about 7.5 mm to slightly above the 10 mm line; just at the alveolar ridge. (Recall from Chapter Two that [+anterior] segments are considered to be articulated in front of the alveolar ridge, while [–anterior] segments are considered to be articulated at or behind the alveolar ridge.) The tongue body is lower than in either of the articulations discussed above, as can be seen from the comparative lack of contact at the sides of the tongue in the linguogram, and in the canine and pre-molar area in the palatogram.

Figures 3.59 and 3.60 show phonologically [-apical] [+anterior] stops. The articulation in Figure 3.59 is apicolaminal dentialveolar; midsagittal contact on the palate is between 0 and approximately 8 mm. The interdental stop in Figure 3.60 is also dentialveolar in its midsagittal contact area on the palate, which extends between 0 and approximately 7 mm. In both of these anterior laminals the tongue body remains fairly flat--contact at the sides of the palate generally remains below the 10 mm line.

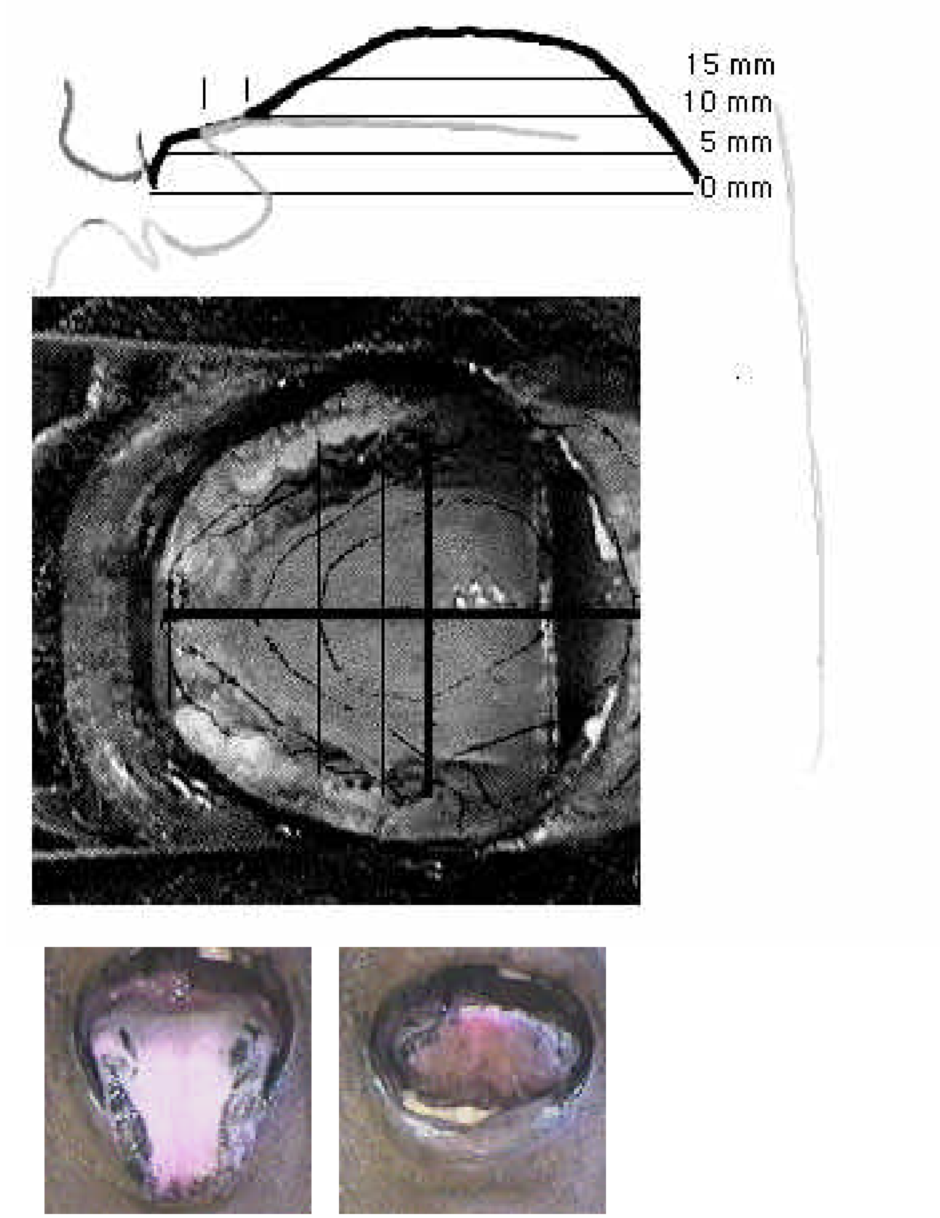


Figure 3.57: Palatogram, linguograms and reconstructed midsagittal section for a stop which is phonologically [+apical] and non-contrastive for Anterior.
Articulation: apical alveolar.
Token: /**'Təpə**/ *back (n.)*

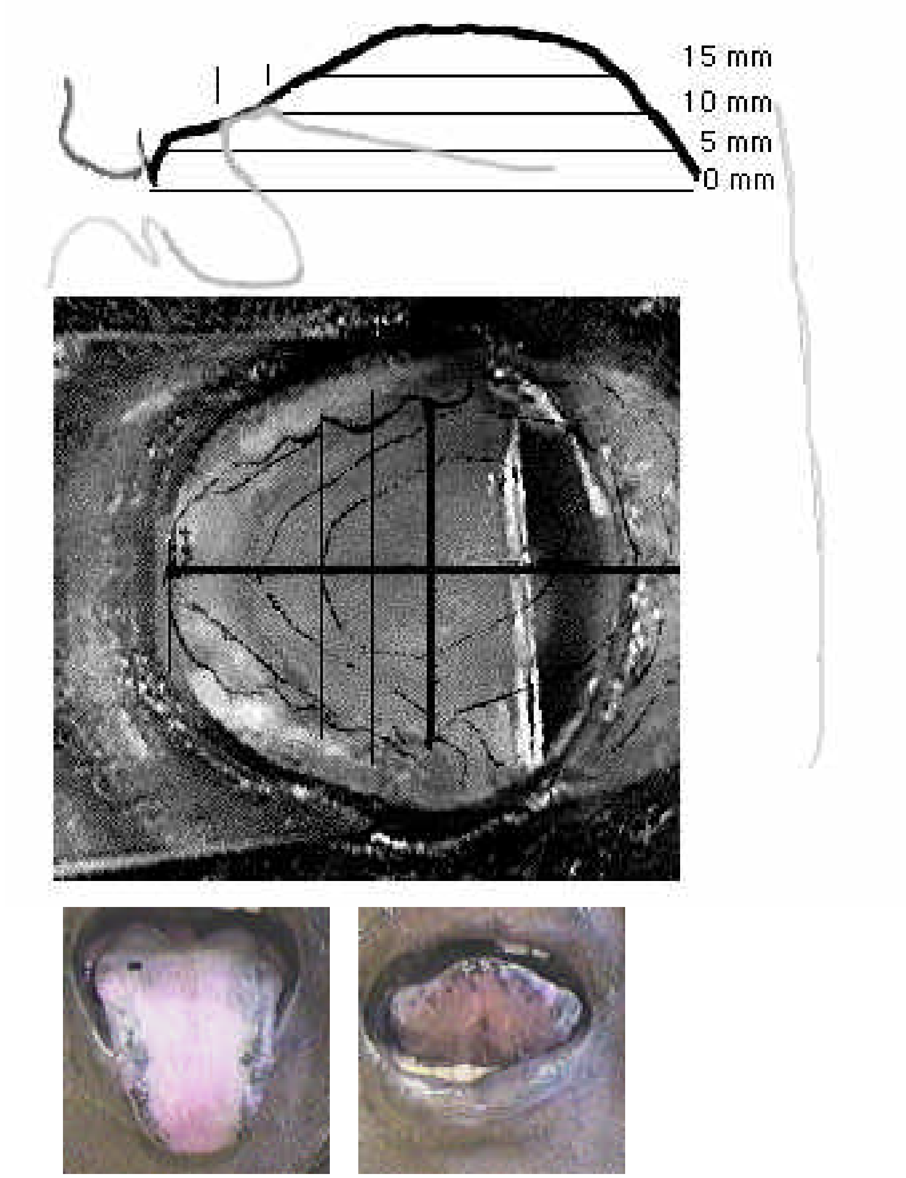


Figure 3.58: Palatogram, linguograms and reconstructed midsagittal section for a phonologically [+apical] [-anterior] nasal.
Articulation: sublaminal alveolar or postalveolar.
Token: /**'məɳə**/ *veg. food (n.)*

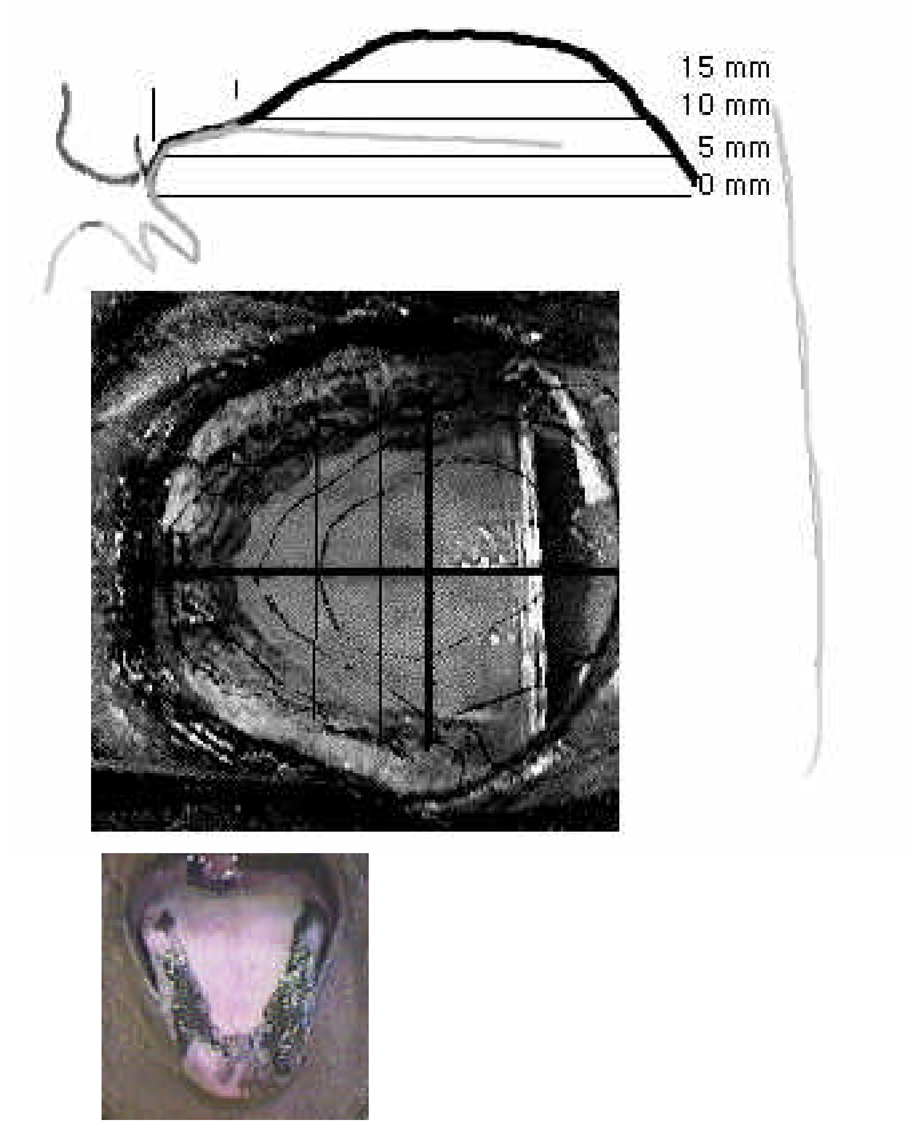


Figure 3.59: Palatogram, linguogram and reconstructed midsagittal section for a phonologically [-apical] [+anterior] stop.
Articulation: apicolaminal dentialveolar.
Token: /**'t̪əmə**/ *grind (vt)*

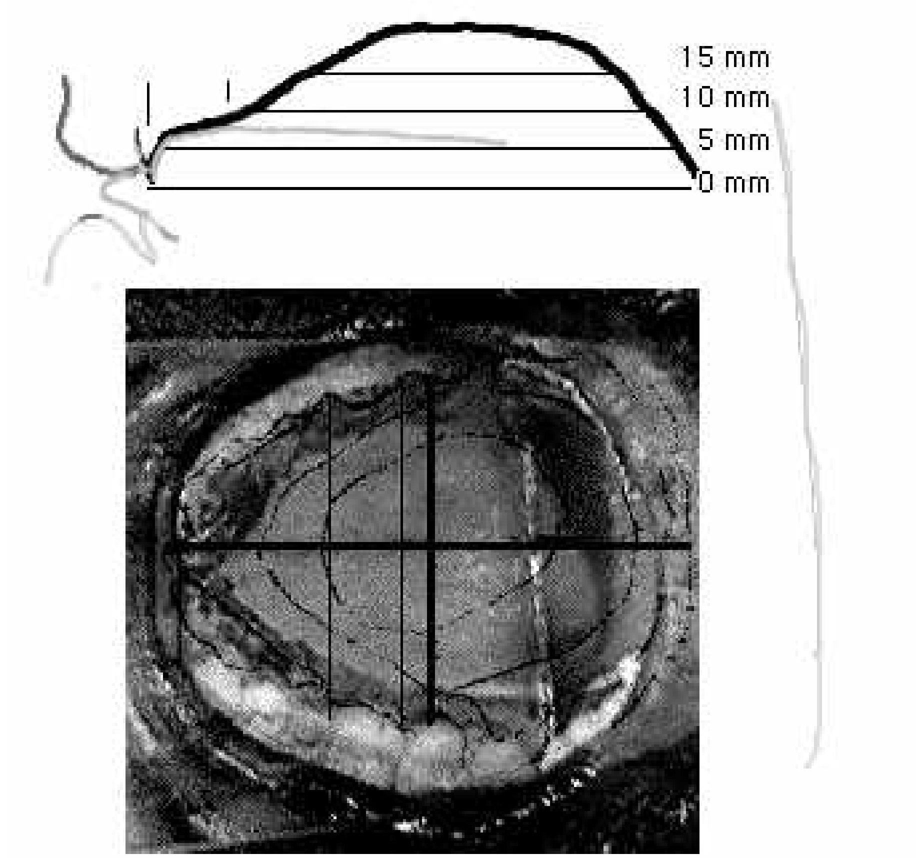


Figure 3.60: Palatogram and reconstructed midsagittal section for a phonologically [-apical] [+anterior] stop. The interdental linguogram is not available.
Articulation: laminal interdental.
Token: /'**pət̪ə**/ *pouch (n.)*

Figure 3.61 shows a phonologically [-apical] [-anterior] stop. Notice that the midsagittal contact area on the palate is similar to that in the [+apical] [-anterior] stop shown in Figure 3.58, but the area of the tongue making contact, and the general shape of the tongue during closure, are quite different, as evinced by the wide areas of contact in the coronal plane. On the palatogram, contact at the sides extends nearly to the 15 mm line. On the linguogram, the broad bands of contact at the sides of the tongue also indicate a raised tongue body.

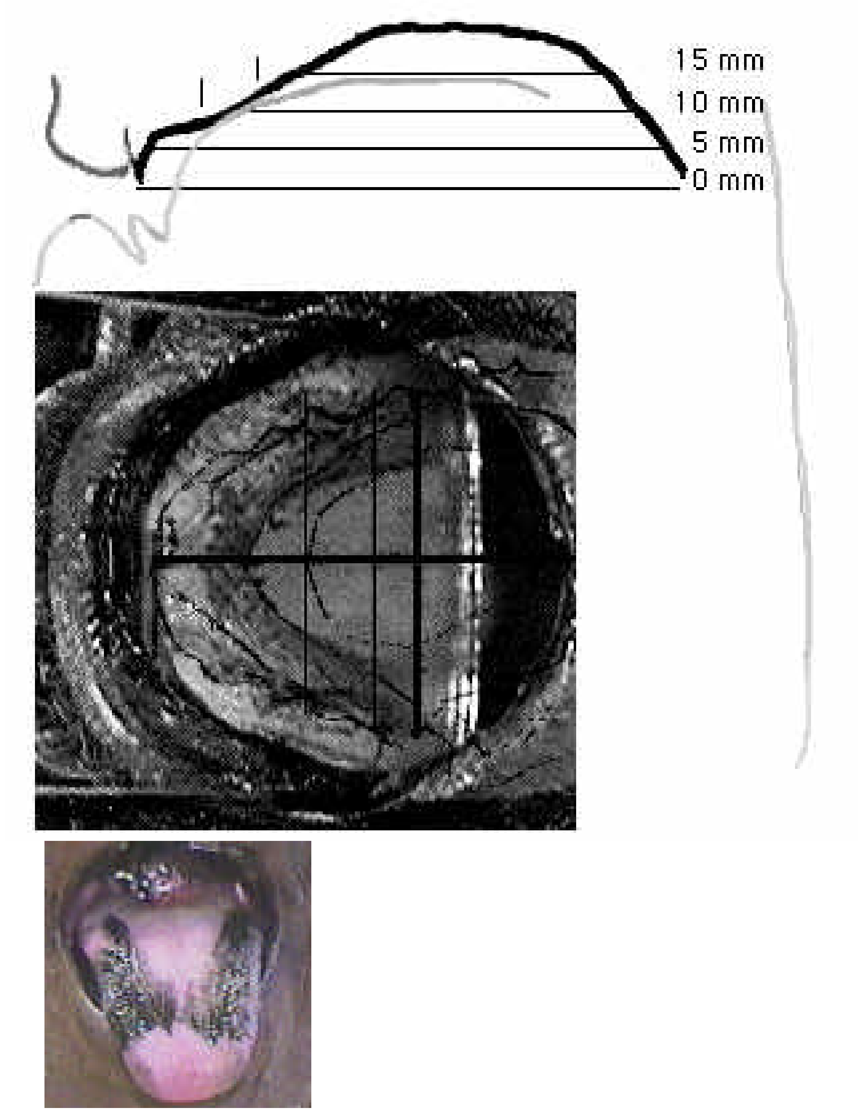


Figure 3.61: Palatogram, linguogram and reconstructed midsagittal section for a phonologically [-apical] [-anterior] stop.
Articulation: laminal postalveolar.
Token: /**'pet̪əmə**/ *is coming(vi)*

Chapter Four: Perception of W. Arrernte Coronals

Instrumental studies in Chapter Three showed that the phonologically non-contrastive apical is phonetically alveolar, and that consequently segments of this type are used in a larger number of contexts than are apical postalveolars. Thus, we found evidence for a high relative weighting of gestural economy in the domain of consonant Place of Articulation. Both principles of gestural economy were corroborated: gestures were re-used, and a "simpler" gesture was chosen for re-use over a more displaced one. Retracing these principles to their fundamental ecological forces, the first reflects the drive toward pattern congruity, while the second indicates the drive toward ease of articulation.

In the present chapter we turn to the question of why the apical contrast has the distributional properties it does, with the goal of finding evidence for *licensing by cue* in native speakers' perception of consonants. Goals and hypotheses to be tested will first be laid out, followed by a description of methods that were used to test native speakers' perceptions. The third section presents results and analysis.

4.1 Goals and Hypotheses

As mentioned in Chapter One, Ohala (1980, 1990) has presented evidence that nasals are auditorily less robust than stops because they do not have as many acoustic cues. For non-native speakers of W. Arrernte, coronal place distinctions are difficult to hear, particularly in the nasals and laterals which lack burst information. One goal of the perception study is to determine whether these difficulties are artifacts of second language acquisition, or are due to inherent weaknesses in cues. Though we have restricted our attention so far to stops and nasals, we add laterals to our investigation here, and assume that they share the articulatory place strategies discussed above in

Chapter Three. Thus, a first objective is to determine the reliability with which native speakers can differentiate among places of articulation in the stops, the nasals and the laterals, without benefit of context. If the difficulty encountered by non-native speakers is an artifact of late acquisition, we expect native speakers to correctly identify place contrasts in the nasals and laterals as easily as they do in the stops. On the other hand, if nasals and laterals are inherently less robust in their complement of acoustic cues, we expect native speakers to differentiate more easily among places in the stops than among places in the nasals or laterals.

Breen (1990) and others observe that the apical contrast bears a lower functional load than other contrasts in W. Arrernte. Given this observation, we postulate that native speakers will show measurably poorer correct identification of apical segments than other segments, although we leave aside the question of whether functional load is a cause or an effect of this putative weaker identifiability in apicals. Our second aim is to quantitatively compare perception of apical and non-apical segments.

The third objective of the perception study focuses on any differences in native speakers' ability to identify apical postalveolars under two conditions: the case in which the preceding vowel is present, and the case in which it is absent. This goal goes to the heart of the question of *licensing by cue:* here we try to adduce evidence that the pattern of phoneme distribution observed depends on the strength of auditory cues. As mentioned in Chapter One, investigators have long proposed that a preceding vowel's formant transitions provide an important acoustic cue signaling postalveolar place. Steriade makes the stronger claim that the reason the two apicals do not contrast in initial position in many Australian and Indian languages is that there are no preceding vowel transitions to cue the difference between them. "Positional neutralization affects contrasts that are, to begin with, harder to perceive or execute, in positions that further add to an initial difficulty." (Steriade, to appear.) Butcher's electropalatographic articulatory studies of Australian languages (Butcher, to appear) show results in concert with the idea of asymmetrical vowel formant transition cues: apical postalveolar stops often shift forward in place of articulation between articulatory closure and release. At release, such stops are more anterior than they are at closure, and have formant transitions more like alveolars. In light of such observations, we hypothesize that listeners will have greater difficulty in correctly identifying the place of articulation of apical postalveolars when preceding vowel information is removed.

To summarize, our three objectives place emphasis on differences in auditory robustness among 1) Manners of Articulation, 2) Places of Articulation, and 3) different environmental conditions, respectively. For each of the goals explicated above, we will take "auditory robustness" to mean that speakers are able to demonstrate a high proportion of success in identifying contrastive segments. In measuring relative auditory robustness, we posit that the most robust segments will be identified 100% of the time, even out of context.

4.2 Method

4.2.1 Constructing Tokens for Perception Tests

Perception tests were of two types. In the first, listeners heard /ˈaCə/ nonsense disyllables with the task of identifying the consonant. In the second, listeners heard /Cə/ nonsense monosyllables, once again focusing on identifying the consonant. Stimuli were constructed as follows. One male speaker and one female speaker from the palatography study recorded several repetitions of each of the words and associated /ˈaCə/ word fragments in Table 4.1. These comprise the stops, nasals and laterals at each place of articulation, including labials and velars. In each case, the speaker repeated the whole word, followed by the /'aCə/ fragment several times, so that he or she was satisfied that the fragment sounded as similar to the word as possible. The disyllabic stimuli were recorded in this way rather than being excised from recordings of whole words, so that formant offglides from initial consonants would not potentially affect choice of a word's identity in the perception tests.

Table 4.1: Utterances recorded for construction of perception tests.

	Bilabial	Laminal Dental	Apical Alveolar	Apical Postalveolar	Laminal Palatoalveolar	Dorsal Velar
Stops 'aCə	'mapə 'apə	'at̪ə 'at̪ə	'l̻atə 'atə	'kwaʈə 'aʈə	'kwat̻ə 'at̻ə	'makə 'akə
gloss	*many (n)*	*I (pr, tr.)*	*today (n)*	*egg (n)*	*water (n)*	*elbow (n)*
Nasals 'aCə	'mamə 'amə	'lan̪ə 'an̪ə	'manə 'anə	'aɳə 'aɳə	'mpan̻ə 'an̻ə	'paŋə 'aŋə
gloss	*sore (n)*	*there-mid (n)*	*money (n)*	*ground (n)*	*marriage (n)*	*blind (n)*
Laterals 'aCə		'al̪ə 'al̪ə	'palə 'alə	'waɭə 'aɭə	'wal̻ə 'al̻ə	
gloss		*nose (n)*	*wrong (n)*	*house (n)*	*leafy branches (n)*	

For each speaker, two utterances from each cell in Table 4.2 were sampled at 22 kHz and 8 bits, using Signalyze 3.0. To produce the CV stimuli, the initial vowel was removed from VCV tokens.

Table 4.2: VCV ('aCə) stimuli used for perception tests.

	Bilabial	Laminal Dental	Apical Alveolar	Apical Postalveolar	Laminal Palatoalveolar	Dorsal Velar
Stops	**'apə**	**'at̪ə**	**'atə**	**'aʈə**	**'at̠ə**	**'akə**
Nasals	**'amə**	**'an̪ə**	**'anə**	**'aɳə**	**'an̠ə**	**'aŋə**
Laterals		**'al̪ə**	**'alə**	**'aɭə**	**'al̠ə**	

Table 4.3: Cə syllables excised from VCV stimuli for use in perception tests.

	Bilabial	Laminal Dental	Apical Alveolar	Apical Postalveolar	Laminal Palatoalveolar	Dorsal Velar
Stops	**pə**	**t̪ə**	**tə**	**ʈə**	**t̠ə**	**kə**
Nasals	**mə**	**n̪ə**	**nə**	**ɳə**	**n̠ə**	**ŋə**
Laterals		**l̪ə**	**lə**	**ɭə**	**l̠ə**	

4.2.2 Identification Task

In each test, the listener's identification task was a forced choice picture selection task. For example, in testing stops, six pictures were arrayed in front of the listener, each representing one of the words in the first row of Table 4.1. Two of the six possible choices for stops are shown in Figure 4.1. If the listener heard the consonant /**ʈ**/ in the word for *egg*, he pointed to the picture of the egg. If however, he heard the consonant /**k**/, he pointed to the word containing the velar, the word for *elbow*. Listeners were directed to choose the word fragment they heard only from among the available pictures. Moreover, they were instructed that they must make a choice for each stimulus. Listeners were allowed to request repetitions of a token if required, but most choices were made quickly after a single hearing.

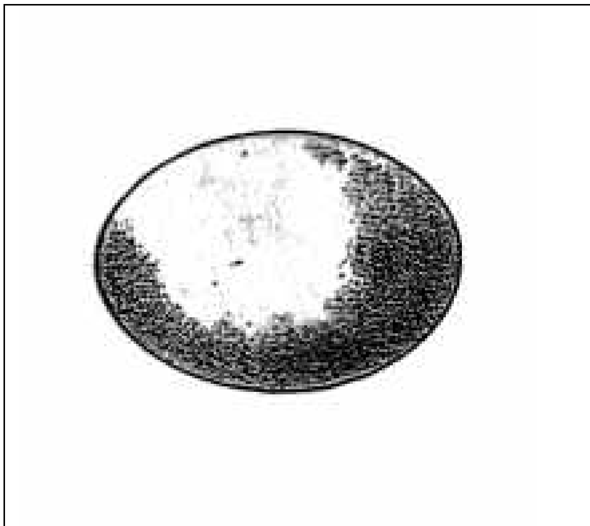
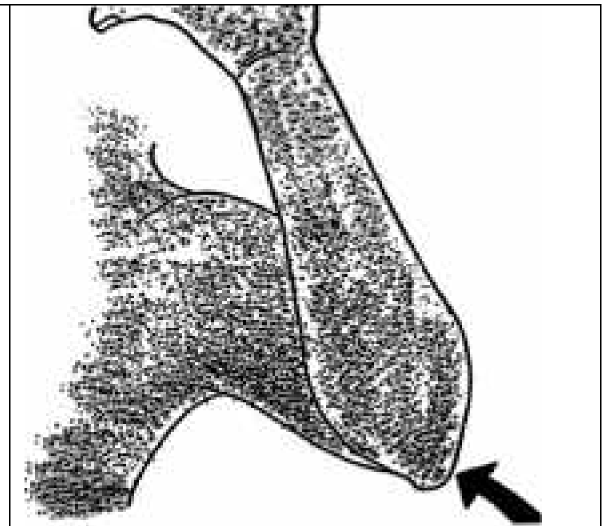
	
Listener hears [aʈə], chooses picture of /kwaʈə/ *{egg}*	Listener hears [akə], chooses picture of /makə/ *{elbow}*

Figure 4.1: Samples of pictures used for stop identification tasks.

4.2.3 Presenting Tests

In both VCV and CV tests, manners of articulation were administered separately; i.e. listeners knew beforehand that the sound in question was one of the six stops, or one of the six nasals, or one of the four laterals. Moreover, for each test the speaker was held constant. Thus, in each case the listener's task was restricted to identification of the place of articulation of the stimulus. All VCV tests were administered before all CV tests, but the order of presentation of stops, nasals and laterals was varied, to reduce possible training effects. Within a test, stimuli were randomized and presented in the same order to each listener. Each token was presented for identification six times.

Each listener completed twelve tests, characteristics of which are summarized in Table 4.4. The listener controlled how many tests he or she completed during any single session.

Table 4.4: Characteristics of the twelve tests presented to listeners.

Condition	Speaker	Manner	Number of stimuli
VCV	Female	Stops	2 tokens x 6 reps x 6 POA=72
VCV	Female	Nasals	2 tokens x 6 reps x 6 POA=72
VCV	Female	Laterals	2 tokens x 6 reps x 4 POA=48
VCV	Male	Stops	72
VCV	Male	Nasals	72
VCV	Male	Laterals	48
CV	Female	Stops	72
CV	Female	Nasals	72
CV	Female	Laterals	48
CV	Male	Stops	72
CV	Male	Nasals	72
CV	Male	Laterals	48

Tests were presented via HyperCard stacks on a Macintosh PowerBook computer in a relatively quiet room in a house. Each listener performed tests by him or herself, hearing stimuli over high quality headphones. The experimenter did not hear the stimuli, but recorded responses in the HyperCard stack as listeners pointed to pictures.

4.2.4 Choosing Listeners

Before carrying out the identification tests described above, prospective participants took two training/screening tests, in order to rule out subnormal hearing or non-comprehension of the task involved. In the first screening test, participants heard randomized repetitions of six common, multisyllabic words which differ widely in phonetic shape. Thus, actual comprehension of stimuli was unlikely to be in question. None of the words in Table 4.1 were used in these screening tests. Six pictures representing the words were placed in front of the listener, who was instructed to point to the word he heard after each stimulus. In the second screening test, listeners heard stimuli in which the initial consonant of each multisyllabic word had been removed, to allow participants to get used to identifying words from word fragments.

Three male and six female native speakers participated in the study. Three of these were also participants in the palatography study. The speakers who recorded the tokens were excluded from perception tests.

4.3 Results and Discussion

4.3.1 VCV Results

Despite good performance in the screening tests, one listener had to be excluded from result summaries due to consistently poorer performance in correct responses, as well as zero percent correct responses in two nasal categories. These results led to doubt about her ability to perform the task. Results discussed below summarize eight listeners' responses.

Tables 4.5a, b and c summarize overall results for the VCV condition, for stops, nasals and laterals respectively. Actual place of articulation of stimuli is shown across the top row of each table; percent distribution of responses is shown in each column underneath. (In these tables, percentages have been rounded to the nearest integer. As such, column totals may equal 99, 100 or 101.) Boxes enclosed in double lines show correct responses. Shaded boxes show substantial misperception of tokens as another category.

Table 4.5a: VCV responses for stops, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	p	**t̪**	**t**	**ʈ**	**t̻**	**k**
p-R	**85**	1	1	0	0	0
t̪-R	12	**96**	10	1	1	3
t-R	3	1	**70**	24	0	1
ʈ-R	0	1	19	**74**	0	2
t̻-R	0	1	0	0	**99**	1
k-R	0	1	0	0	0	**94**

Table 4.5b: VCV responses for nasals, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	m	**n̪**	**n**	**ɳ**	**n̻**	**ŋ**
m-R	**94**	0	0	0	1	0
n̪-R	1	**75**	8	0	5	3
n-R	4	9	**62**	3	5	1
ɳ-R	1	13	28	**96**	0	0
n̻-R	1	3	1	1	**88**	2
ŋ-R	0	0	1	0	2	**94**

Table 4.5c: VCV responses for laterals, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	l̪	**l**	**ɭ**	**l̻**
l̪-R	**91**	8	2	3
l-R	6	**62**	12	2
ɭ-R	2	29	**84**	1
l̻-R	1	1	2	**95**

Log linear tests of statistical significance were applied to these results. In a way similar to the chi squared tests applied to linguographic data, observed values were compared with expected values in determining statistical significance. However, because these are by definition contrastive segments, we expect native speakers to perform with a high success rate, rather than to perform according to chance. Thus, unlike in the case above, the null hypothesis adopted in these statistical comparisons was that contrastive segments would be perfectly perceived; i.e. show 100% correct responses.

All results discussed in this and following sections are statistically significant in log linear tests using Pearson's chi squared, at a 'p' value of less than .01.

4.3.1.1 Correct Identification of VCV Tokens

Correct responses are reproduced graphically in Figures 4.2a-c. Place of articulation from front to back is shown on the x-axis, with apicals, laminals and peripherals (labials and velars) labeled accordingly. The y-axis shows percent correct identification of each segment category, summed over the eight listeners. (100% represents 576 responses for stops and nasals. 100% represents 384 responses for laterals.)

Once again, as in the articulatory study, we first address differences in Manner, and then differences in Place. Taking all places of articulation together, stops did not show a higher overall rate of correct identification than nasals or laterals. Therefore, in terms of our first objective, we find nasals and laterals to be as auditorily robust as stops. We cannot establish that for native speakers nasals and laterals have inherently weaker cues. A cursory inspection of spectra is included at the end of this chapter, where we look in further detail at possible cues provided by nasal and lateral murmur spectra.

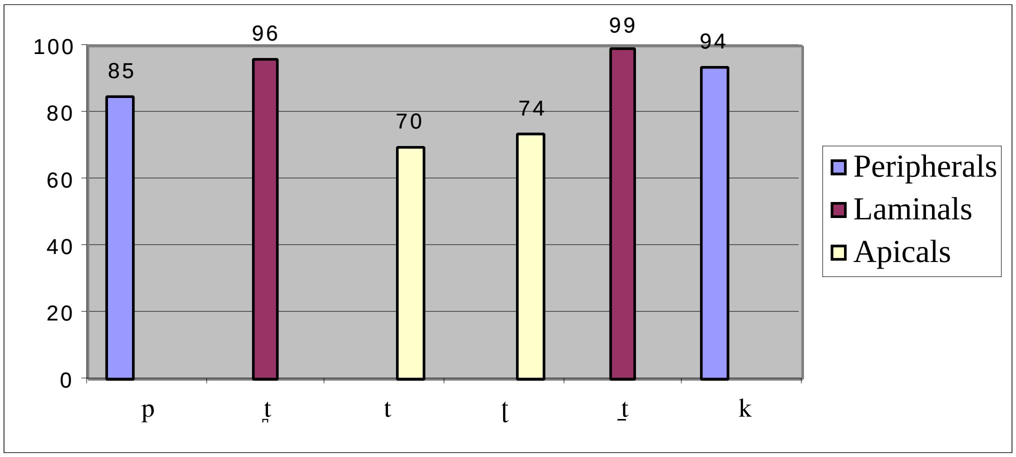


Figure 4.2a: Percent correct identification of stops—VCV condition

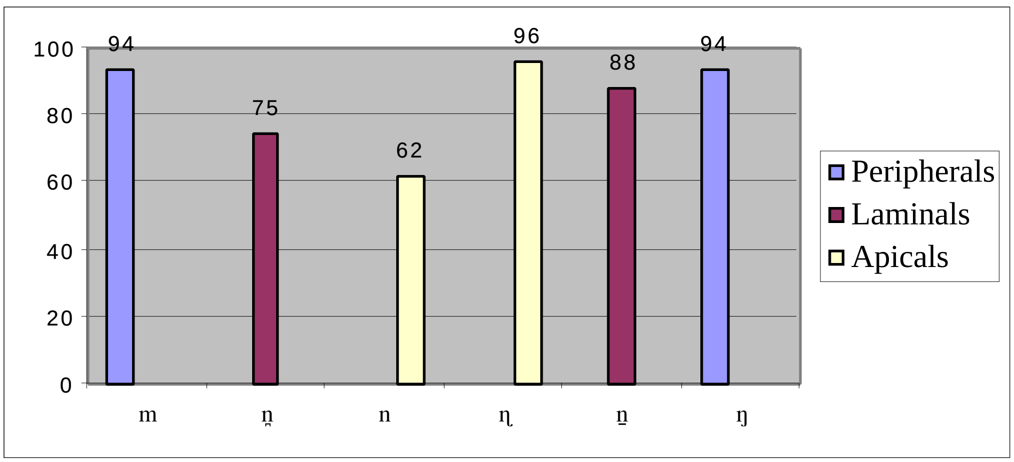


Figure 4.2b: Percent correct identification of nasals—VCV condition

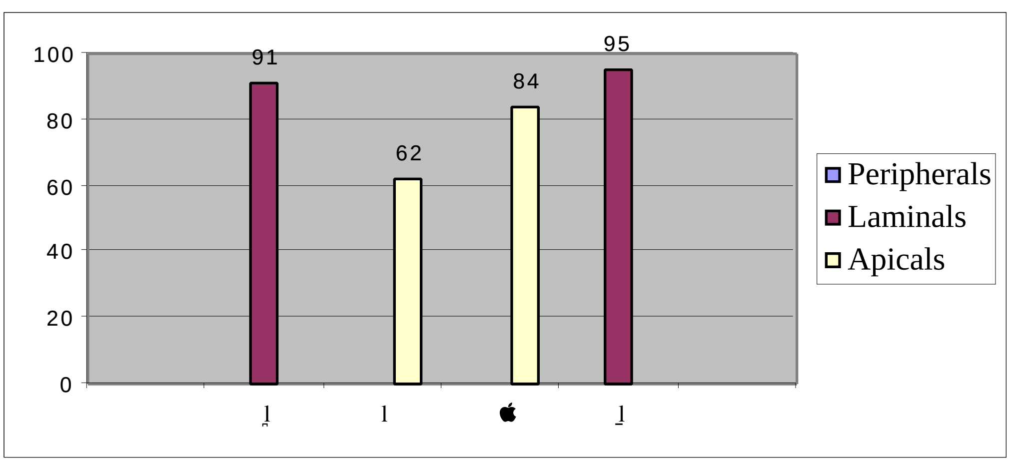


Figure 4.2c: Percent correct identification of laterals—VCV condition

Looking across manner of articulation, several results emerge. First, peripherals are identified correctly a high proportion of the time. For all peripherals except /**p**/ correct identification was over 90%. (The 85% success rate for /**p**/ is attributable to one listener, who had a very uncharacteristic correct identification rate of only 21% for /**p**/. This listener's results were not excluded, since our focus here is on coronals rather than peripherals.) Results for peripherals thus provide a control situation demonstrating that most listeners did not have trouble with the test procedures *per se.* Second, turning to coronals, laminal palatoalveolars are consistently robust in correct identification, across manners, although the laminal palatoalveolar nasals are significantly less robust than the stops (stops 99%, nasals 88%, laterals 95%.) Third, apical alveolars fare worst in correct identification, for stops (70%), nasals (62%) and laterals (62%) alike. Fourth, taking the laminal dentals and apical postalveolars under consideration, we observe a place–manner interaction for these segments. For laminal dentals, the stops and laterals show high proportions of correct identification; 96% and 91% respectively. The laminal dental nasals are significantly less robust (75% correct identification.) For the apical postalveolars the reverse is true: nasals are very robust (96% correct identification), significantly more so than laterals (84%), which are again significantly more robust than stops (74%). However, note that the /ˈaCə/ disyllables involving /**t̪, ɳ, l̪**/ are the only three stimuli that are identical to the actual words; they are not nonsense forms. This difference may well enhance the salience of these disyllables, or reduce the difficulty of the identification task by eliminating the need to recognize a word fragment.

Thus, in terms of our second goal for the perception study, we cannot definitively conclude that both apical places are less auditorily robust than others. We can conclude that apical alveolar segments are significantly less auditorily robust than segments at other places of articulation.

4.3.1.2 Incorrect Identification of VCV Tokens

Apical segments show substantial misperception in other categories. Figure 4.3 summarizes correct responses as well as the distribution of misperceptions in the apicals. The x-axis shows each apical and the division of responses into laminal dental, apical alveolar, apical postalveolar, and laminal palatoalveolar categories respectively. (Note that although the articulation illustrated in Figure 3.61 of Chapter Three is described as laminal postalveolar, we will continue to use the traditional term 'palatoalveolar' in this discussion, to avoid confusion with the apical postalveolar.) On the y-axis is the percent distribution of identifications. Looking at misperceptions in /**t**/, /**n**/, and /**l**/, the apical postalveolars predominate, followed by laminal dentals; this effect holds across manners of articulation, with the alveolar nasals and laterals being nearly identical in their distribution of responses. Misperceptions of /**t**/, /**n**/, and /**l**/ as laminal palatoalveolars are nearly negligible.

In the apical postalveolars, there are far fewer misperceptions in the nasals than in the laterals or stops. Again, a contributing factor may be the status of /'aɳə/ as a meaningful word. However, for each manner of articulation in the apical postalveolars, misperception as the apical alveolar predominates, followed by nearly negligible responses in each of the laminal categories.

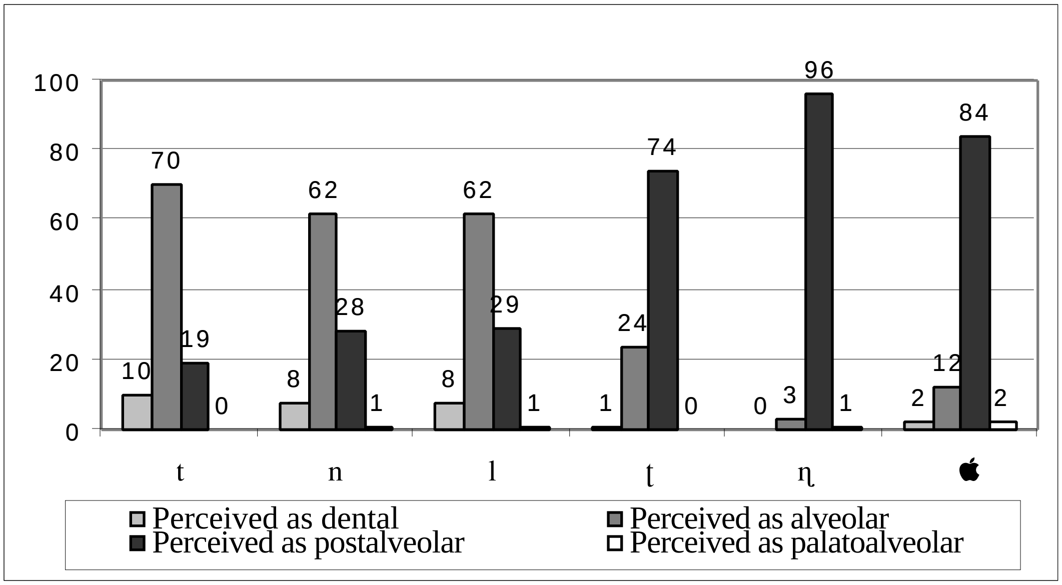


Figure 4.3: Distribution of responses to apical stimuli among correct and incorrect categories for VCV tests.

To summarize the VCV results, native speakers distinguish among nasals and laterals as reliably as they distinguish among stops. Thus, in considering Manner of Articulation, we do not find a basis on which to conclude that overall, sonorants are inherently weaker than stops in their complement of auditory cues. We will return to this topic in our examination of spectra. Secondly, while listeners identify peripherals and laminal palatoalveolars very reliably, apical alveolars are significantly less robust in correct identification. Thus, as concerns Place, we can establish that for native speakers, apical alveolars are inherently more difficult to identify than other places of articulation. A potential confound in the apical postalveolars, due to the presence of a real word among the VCV stimuli, prevents this conclusion for the apical postalveolars.

4.3.1.3 Acoustic Analysis

Acoustic analysis of the tokens used in this experiment provides instructive clues as to the cues listeners may have been using to correctly identify tokens. Analysis of Variance showed that Place of Articulation has a significant main effect on formant transition values, formants during nasal/lateral murmur, duration of voiceless closure, voice onset time and "affrication quotient." The latter is a measure of the duration ratio between high frequency frication during voice onset, and total voice onset time. In addition, ANOVA showed that a segment's value for the feature Apical has a significant main effect on sonorant murmur duration, and duration of the preceding vowel. Unless otherwise indicated, all results discussed below are significant in Fisher's PLSD post hoc comparisons, at a p=.05 level or less. Recall, however, that each category mean reflects only four tokens.

In the following discussion, the terms 'V1' and 'V2' will be used for convenience, to refer respectively to the vowel preceding the consonant in question, and the vowel following the consonant in question. Taking durations in apicals and laminals first, across Manners of Articulation V1 is significantly longer before apicals than it is before laminals. In the sonorants, murmurs are significantly shorter in duration for apicals than they are for laminals.

Let us turn to the laminal palatoalveolars, which proved to be the most robust coronal segments. We find that across Manners of Articulation, laminal palatoalveolars have significantly lower F1, and significantly higher F2 and F3 formant transitions on both sides of the consonant than do other coronals. Palatoalveolar sonorants have a higher F2 during the murmur than do other places of articulation. Among the stops, laminal palatoalveolars have a significantly longer VOT than other coronals. Moreover, affrication occurs over the entire duration of voice onset (affrication quotient =1.) These results are summarized in Figures 4.4–4.6.

Laminal dental stops, laminal dental laterals and apical postalveolar nasals were the other robust coronals. The status of /**'at̪ə**/, /**'aɳə**/, and /**'al̪ə**/ as meaningful words is likely to have had a salience-enhancing effect on these VCV tokens. However, leaving their status as words aside, let us address the acoustic properties that were statistically differentiable among these tokens. The /**t̪**/ has the longest voiceless closure duration of any of the coronals. This is presumably an important cue for intervocalic /**t̪**/, since as will be shown in the following section, the excised token loses a significant amount of identifiability (13%) in the CV condition, when the closure is absent. On the side of the consonant facing V2, /**t̪**/ has the lowest ratio of high energy frication to VOT. While /**t̻**/ is fricated for the entire length of its VOT, /**t̪**/ is only fricated for slightly more than half its VOT (affrication quotient=0.6.) Moreover, three of four tokens of /**t̪**/ had double bursts, which was not true of any of the other coronal stops. On the other hand, /**n̪**/ and /**l̪**/ could not be completely separated statistically from other place categories in any ANOVA. This accounts for the less robust perception of some nasals, but leaves acoustically unexplained the high performance of listeners on laminal dental laterals. We will revisit the issue of possible contributing cues for these sonorants in the section on spectra below.

The /**ɳ**/ was characterized by significantly lower F3 transitions than for other nasals, on both sides of the segment. Interestingly for /**ʈ**/ and /ɭ/, though F3 offsets from V1 were indeed significantly lower in frequency than those of other coronals, transitions to V2 were not significantly differentiable from those of alveolars or dentals.

An interesting segment–speaker interaction provides clues to important cues for laminal dental and apical postalveolar stops. Most listeners who misperceived /**t**/ as /**t̪**/

did so while hearing the speaker whose tokens of /**t**/ include a voiceless closure. On the other hand, listeners who mistook /**t**/ for /**ʈ**/ were listening to the speaker whose tokens of /**t**/ were completely voiced through the closure. The directions of these misperceptions add to the implication that a salient voiceless closure is expected for /**t̪**/ but not for /**ʈ**/.

Acoustic characteristics that are statistically differentiable within each manner of articulation are summarized in Figures 4.4–4.6, along with sample spectrograms of the coronal stops, nasals and laterals. (Overloading has caused lower formants to appear as white bands rather than black bands in these spectrograms.)

Laminal dental: /'at̪ə/ 1. longest voiceless closure 2. lowest affrication quotient 3. double bursts	**Laminal palatoalveolar: /'at̠ə/** · lowest F1 offset and onset · highest F2 and F3 offsets and onsets · longest VOT · highest affrication quotient
Both laminals: Preceding vowel shorter than in apicals	
Apical alveolar: /'atə/	**Apical postalveolar: /'aʈə/** · lowest F3 offset
Both apicals: Preceding vowel longer than in laminals	

Figure 4.4: Spectrograms of four stop tokens for one speaker.

<table>
<tr><td></td><td></td></tr>
<tr><td>Laminal dental: /'an̪ə/</td><td>Laminal palatoalveolar: /'an̠ə/
· lowest F1 offset and onset
· highest F2 and F3 offsets and onsets
· highest F2 during murmur</td></tr>
<tr><td colspan="2">Both laminals:
· Preceding vowel shorter than in apicals
· Murmur duration longer than in apicals</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Apical alveolar: /'anə/</td><td>Apical postalveolar: /'aɳə/
· lowest F3 offset and onset</td></tr>
<tr><td colspan="2">Both apicals:
· Preceding vowel longer than in laminals
· Murmur duration shorter than in laminals</td></tr>
</table>

Figure 4.5: Spectrograms of four nasal tokens for one speaker.

<table>
<tr><td></td><td></td></tr>
<tr><td>Laminal dental: /'al̪ə/</td><td>Laminal palatoalveolar: /'al̻ə/
· lowest F1 offset and onset
· highest F2 and F3 offsets and onsets
· highest F2 during murmur</td></tr>
<tr><td colspan="2">Both laminals:
· Preceding vowel shorter than in apicals
· Murmur duration longer than in apicals</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Apical alveolar: /'alə/</td><td>Apical postalveolar: /'aɭə/
· lowest F3 offset</td></tr>
<tr><td colspan="2">Both apicals:
· Preceding vowel longer than in laminals
· Murmur duration shorter than in laminals</td></tr>
</table>

Figure 4.6: Spectrograms of four lateral tokens for one speaker.

4.3.2 CV Results

Tables 4.6a, b and c summarize overall results for the CV condition, for stops, nasals and laterals respectively.

Table 4.6a: CV responses for stops, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	p	**t̪**	**t**	**ʈ**	**t̻**	**k**
p-R	**83**	3	1	5	1	1
t̪-R	11	**83**	27	47	3	2
t-R	1	4	**35**	18	1	1
ʈ-R	3	4	28	**19**	1	3
t̻-R	1	1	1	2	**94**	2
k-R	1	6	8	9	1	**92**

Table 4.6b: CV responses for nasals, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	m	**n̪**	**n**	**ɳ**	**n̻**	**ŋ**
m-R	**93**	1	1	2	2	1
n̪-R	3	**70**	19	41	3	2
n-R	1	8	**45**	21	2	2
ɳ-R	1	14	30	**28**	1	3
n̻-R	1	3	2	5	**87**	3
ŋ-R	2	4	5	4	6	**90**

Table 4.6c: CV responses for laterals, summed over eight listeners.
Tokens for both speakers are included. Columns show the stimulus and rows the percentage responses.

	l̪	**l**	**ɭ**	**l̻**
l̪-R	**55**	29	27	3
l-R	17	**32**	24	2
ɭ-R	20	37	**45**	3
l̻-R	7	2	4	**92**

4.3.2.1 Correct Identification of CV Tokens

Figure 4.7 shows CV results for each manner, preceded by the respective results in the VCV condition, for ease of comparison.

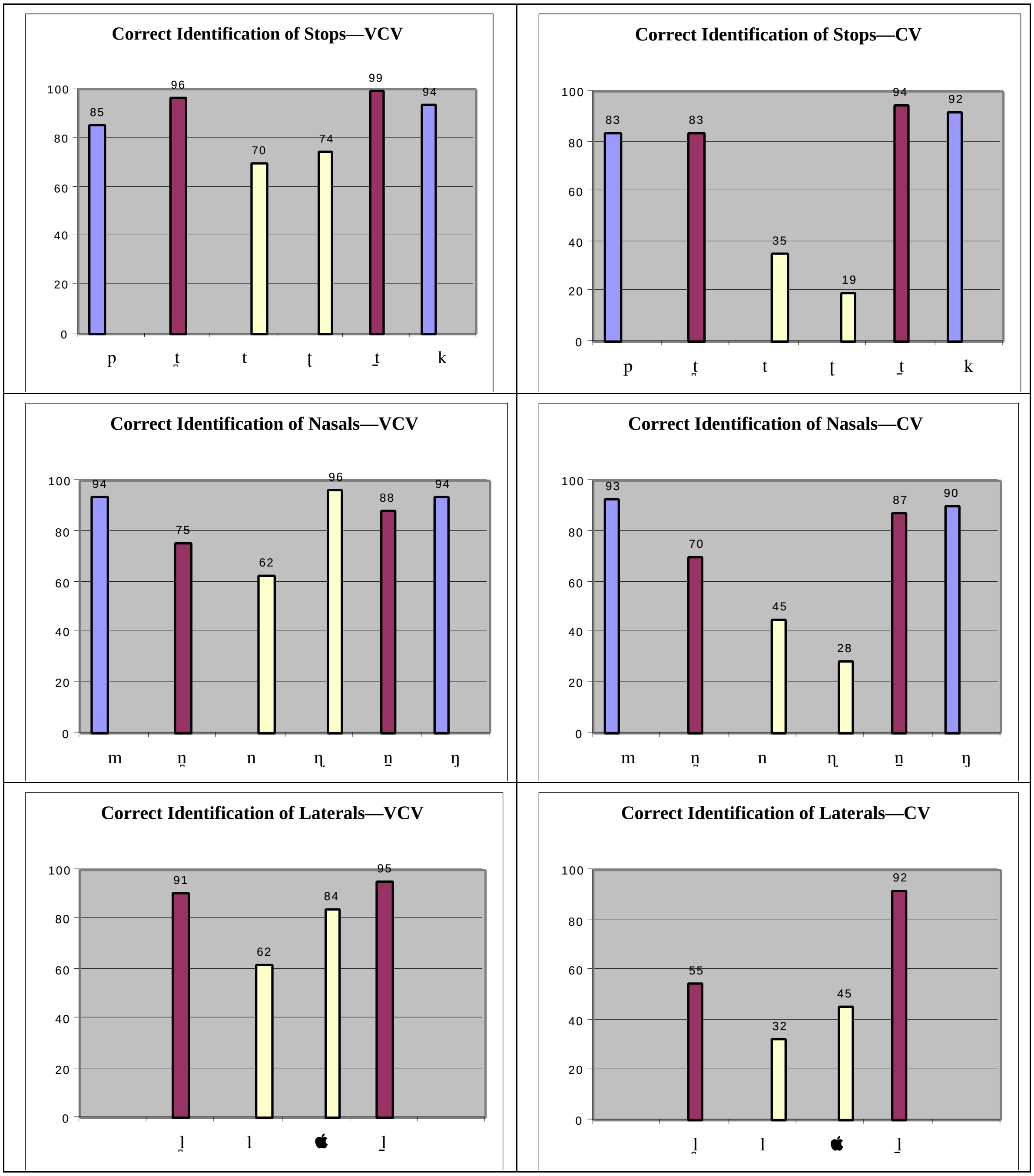


Figure 4.7: Rates of correct identification of stops, nasals and laterals. VCV responses are shown at left; CV responses at right.

Looking first at rates of successful identification in the peripherals and laminal palatoalveolars, it is striking to observe that in every VCV–CV comparison, correct identification rates remain statistically unchanged. The fact that **/p/**, **/m/**, **/k/**, **/ŋ/**, **/t̠/**, **/n̠/**, and **/l̠/** do not differ significantly in their percent correct responses under these two conditions means that each segment is as robust without the benefit of characteristics associated with V1, as it is when those characteristics are present. Such a result implies that the critical acoustic cues used by listeners to identify peripherals and laminal palatoalveolars are associated with the consonant itself, and/or with its transitions to V2.

Laminal dentals, /**l̪**/, and to a lesser extent /**t̪**/, lose a significant amount of identifiability in the CV situation as compared with the VCV situation. Losses in correct identification are 36% for /**l̪**/, and 13% for /**t̪**/. Laminal dental nasals, which are identified less well in the VCV condition to begin with, do not change significantly in the CV condition. These results indicate that intervocalic laminal dentals contain at least some important cues that depend on the presence of V1, such as long voiceless closure in /**t̪**/, and the duration of V1 itself.

The most dramatic differences are in the apicals, however. In the CV condition, the perception of all apicals drops below a 50% correct identification rate. These results have high significance levels (p=.002 or less) in every apical VCV–CV comparison. From this we conclude that, unlike peripherals and palatoalveolars, the critical cues for apical segments reside with the preceding vowel; when V1 is excised, the apicals can no longer be identified correctly.

4.3.2.2 Incorrect Identification of CV Tokens

Let us look at misidentifications of CV tokens in closer detail. Figure 4.8 shows the distribution of responses to apicals in the CV condition, with Figure 4.3 reproduced immediately above it for ease of comparison.

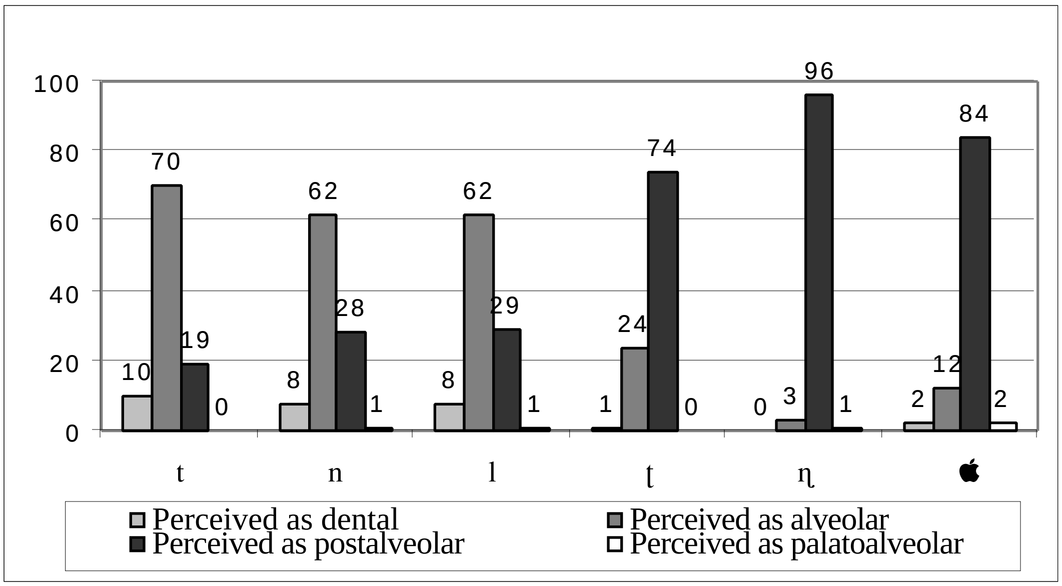


Figure 4.3: Distribution of responses to apical stimuli among correct and incorrect categories for VCV tests.

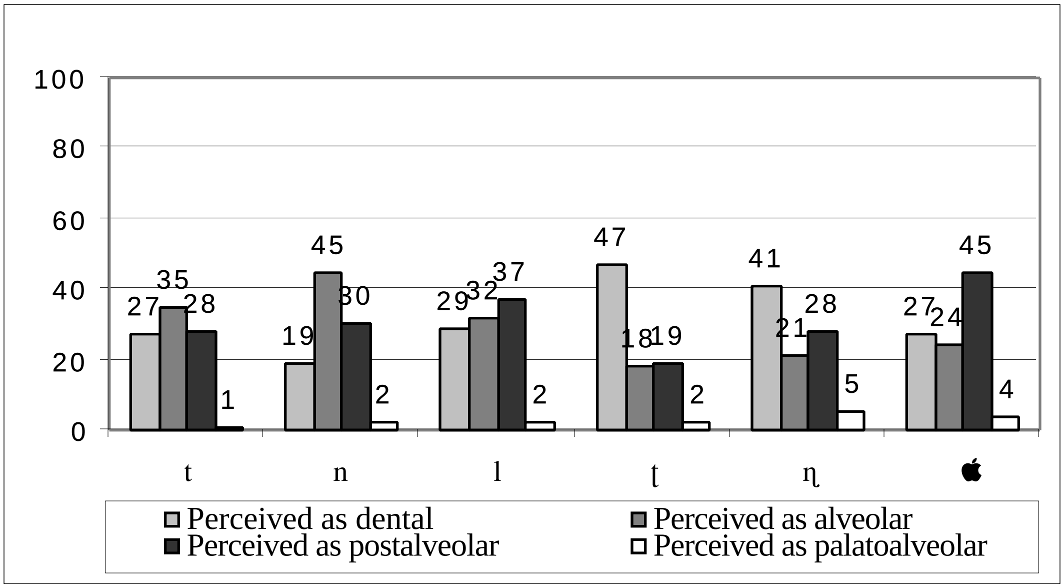


Figure 4.8: Distribution of responses to apical stimuli among correct and incorrect categories for CV tests. All distributions except those of **/n/** and **/ʈ/** are random distributions among dentals, alveolars and postalveolars.

Here we see a clear disturbance in listeners' perceptions. As compared with the VCV condition, there is much more intrusion of the incorrect percept of laminal dental; not only for alveolars, where the effect was significant but small before, but for postalveolars as well. In fact, identification becomes statistically random among the three categories laminal dental, apical alveolar and apical postalveolar, in four of the six CV cases. Only /**n**/ and /**ʈ**/ do not show random distribution among these three categories. However, perceptions of /**ʈ**/ are just as corrupted: here, laminal dentals account for more responses than the correct category itself. Once again, these results for /**ʈ**/ are in line with Butcher's observation that postalveolar articulations may be further forward at release than at closure.

Laminal dentals, too, lose identifiability when the preceding vowel is excised. Figure 4.9 compares responses in the VCV condition to responses in the CV condition, for /t̪/, /n̪/, and /l̪/ respectively. The first member of each pair shows VCV responses, while the second shows CV responses. For /t̪/, there is a significant decline in correct responses when V1 is removed, with misperceptions being about equally distributed between the apicals. The same tendency occurs in /n̪/, although this does not reach statistical significance. For the laterals, there is an additional significant element of misperception as the laminal palatoalveolar, which may have to do with the loss of higher formant information associated with laterals in general.

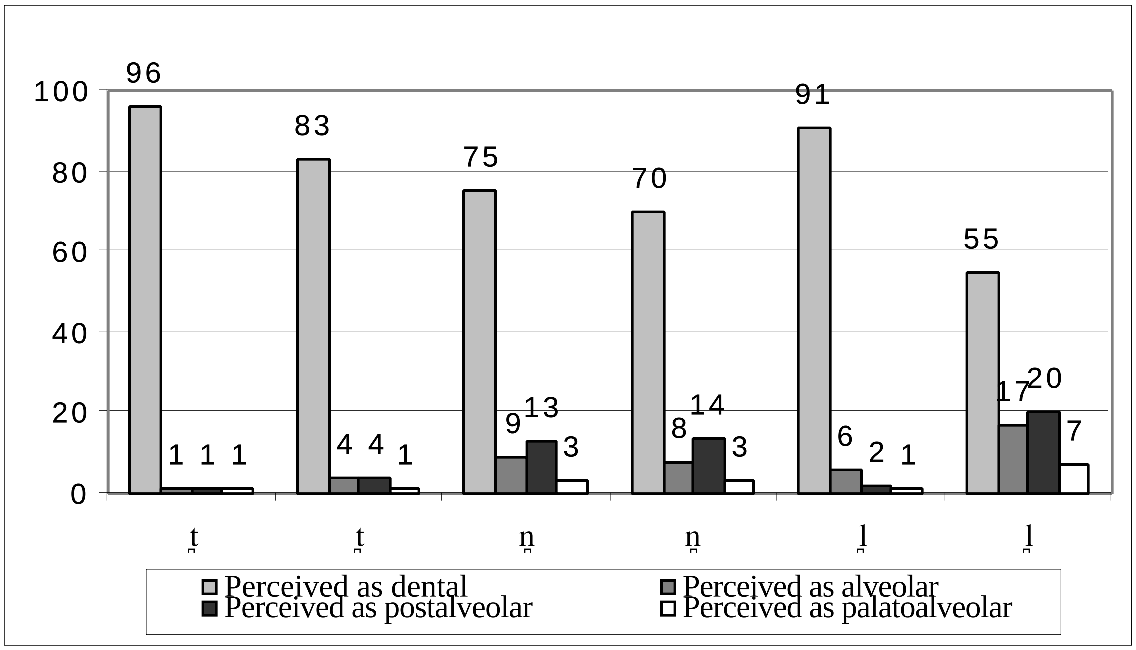


Figure 4.9: Correct and incorrect identifications of laminal dentals—VCV and CV conditions compared. First member of each pair shows VCV responses; second member shows CV responses.

Thus, results of CV tests imply that V1 information is used to some extent in identifying intervocalic laminal dentals. Much more importantly for our purposes here though, results of CV tests confirm our hypothesis that postalveolars would demonstrate reduced correct identification with removal of preceding vowel information. Indeed, this behavior was also unexpectedly observed for apical alveolars. Listeners require V1 information in order to correctly identify apicals, and for this reason the language cannot contrast apicals in initial position.

4.3.2.3 Acoustic Analysis

Important acoustic cues that depend upon the presence of V1 and that are thus lost in the CV condition include duration information. As mentioned above, across manners, preceding vowels are significantly longer before apicals than before laminals. Duration of voiceless closure for stops, and duration of murmur for sonorants, is also important. In the stops, voiceless closures are longest for /t̪/. In the sonorants, murmurs are significantly shorter in duration for apicals than they are for laminals. Voiceless closure is lost altogether in the CV condition, explaining the drop in correct percent identification of /t̪/. As for the sonorants, murmurs remain in the CV situation, but their duration cues may lose some salience when the listener cannot normalize against the duration of a preceding vowel.

The most visible difference between VCV and CV cases is the lack of V1 formant transition information in the CV condition. The apical postalveolar tokens examined here do reflect the characteristic pattern of formant proximity in F2, F3 and F4 at V1 offset that is noted by other researchers, and for /ʈ/, /ɳ/, and /ɭ/ F3 is significantly lower than in other members of the coronals. (F4 was not included in acoustic measurements for this study.) A common onset locus of F2, F3 and F4 is absent on the side of the consonant facing V2, except in tokens of /ɳ/. On the V2 side, laminal dentals, apical alveolars and apical postalveolars are all much more similar in their formant transitions than they are on the V1 side. Figure 4.10 shows spectrograms of four stop tokens for one speaker with formant tracings added for clarity.

Laminal dental: /'at̪ə/	**Laminal palatoalveolar: /'at̻ə/**
Apical alveolar: /'atə/	**Apical postalveolar: /'aʈə/**

Figure 4.10: Spectrograms of four stop tokens for one speaker with formant tracings added.

4.3.2.4 Spectra

The acoustic characteristics we have examined thus far have not conclusively separated **/n̪/** and **/n/** from other nasals (see Figure 4.5), nor **/l̪/** and **/l/** from other laterals (see Figure 4.6.) This fact, coupled with the lack of significant differences in correct identification rates among the Manner classes, makes appropriate an examination of spectral characteristics of tokens used in this experiment. Sonorants may indeed contain fewer potential cues than stops, but may still be enough different in their spectral structures to furnish native speakers with Place information that renders the sonorants as reliably identifiable as stops. The observations below are preliminary and are not corroborated by statistical tests.

Figures 4.11 and 4.12 show stop burst spectra for the male and female speakers' tokens respectively. Recall that two tokens represented each segment for each speaker; the spectrum shown is an average over both tokens. Lines have been smoothed using a 10-point moving average of values, to highlight major peaks and valleys. In each case, the x-axis is presented on a logarithmic scale, to give greater weight to frequencies important in the hearing range. The y-axis shows amplitude in dB. Figure 'a' in each case shows frequencies between 100 and 10000 Hz, while Figure 'b' displays a close-up of frequencies between 1000 and 5000 Hz.

For the male speaker, in the lower frequency region below 1000 Hz we see a clear separation of spectra into two groups: high energy /**p, t, ʈ**/ and low energy /**t̪, t̻, k**/, as labeled in Figure 4.11a. This separation is not nearly as clear for the female's stop bursts, though a similar trend exists, with /**p, ʈ**/ in a higher energy group and /**t̻, k**/ in a lower energy group.

In the higher frequency half of the graph, and in particular the area between 1000 and 4000 Hz, it is the female's stop bursts that show greater visible differences than those of the male. In Figure 4.12a, prominent high energy peaks stand out for /**ʈ**/ (centered around 2000 Hz), and /**t̻**/ (centered between 3000 and 5000 Hz.) High energy regions are less conspicuous for the other places. For both speakers, the lowest-frequency peak in the region above 1000 Hz is for /**p**/, while the highest frequency peak is for /**t̻**/. For other places there is less consistency between the speakers. Frequency order of lowest-frequency peaks for the male is as follows: 1) /**p**/, 2) /**t**/ and /**ʈ**/, 3) /**t̪**/, 4) /**k**/, 5) /**t̻**/ (refer to Figure 4.11b.) Frequency order of lowest frequency peaks for the female is: 1) **/p/,** 2) **/t̪/,** 3) **/k/,** 4) **/ʈ/** and **/t/**, 5) **/t̻/** (refer to Figure 4.12b.) If we disregard strict frequency order, we can generalize further. For both speakers the laminal dental has a flat, falling spectrum, while **/t/, /ʈ/**, and **/k/** show two peaks, the first in the vicinity of 1500-3000 Hz, and the second in the vicinity of 3000-5000 Hz. On the basis of the data presented here, however, it seems that spectral bursts do not provide a very clear way of distinguishing coronal stops.

Let us turn to the nasal murmurs. Kurowski and Blumstein (1984) and others demonstrate the importance of nasal pole-zero patterns as place cues. In our data, however, the poles preceding zeroes (those occurring in the vicinity of 500 Hz) are less separated in frequency than the poles following zeroes. In Figures 4.13 and 4.14, each spectrum is characterized by a prominent valley, closely followed by a prominent peak. When examining peaks or valleys alone, a local high or low does not stand out as clearly as when these zero-pole combinations are considered together as a unitary feature. For example, in Figure 4.13, zeroes for **/n/** and **/n̪/** seem to converge, but their peaks are staggered. On the other hand, peaks for **/n̪/** and **/ɳ/** overlap, but their zeroes are staggered. Looking at the sequence of zero and pole together, a cascade pattern emerges. Results are consistent between the speakers: **/m/** shows the zero-pole sequence at the lowest frequency, followed by 2) **/n/**, 3) **/n̪/,** 4) **/ɳ/**, 5) **/n̻/**, and 6) **/ŋ/** (refer to Figures 4.13b and 4.14b.) Incidentally, this frequency ordering is also found for nasal zeroes in Eastern Arrernte (Ladefoged and Maddieson, 1996.)

Laterals also exhibit a staggered pattern of zeroes and poles in close proximity, and thus are also reasonably separable (visually) from each other. As shown in Figures 4.15 and 4.16, the frequency order of these sequences for both speakers is 1) **/l/,** 2) **/l̪/** and **/ɭ/,** 3) **/l̻/**. Again, this frequency ordering is in concert with that found by

Ladefoged and Maddieson (1996) for the frequency order of F2 in E. Arrernte, as well as the related Arandic languages Kaititj and Alyawarra.

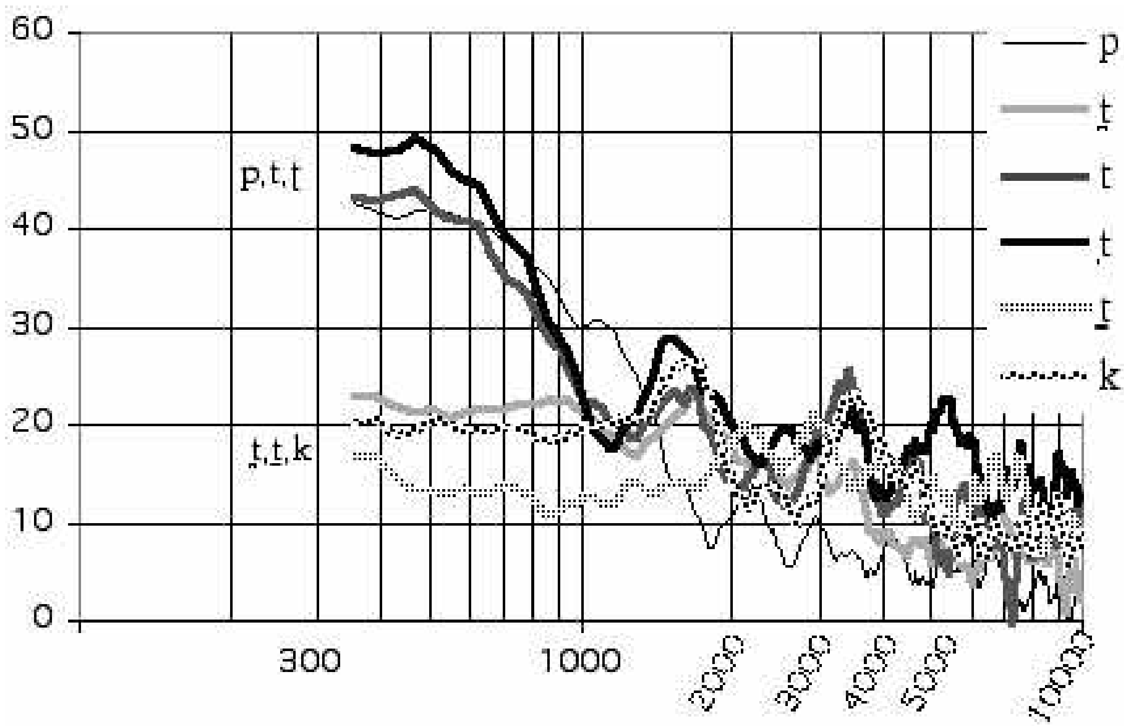


Figure 4.11a: Male speaker's stop burst spectra, 100-10000 Hz.

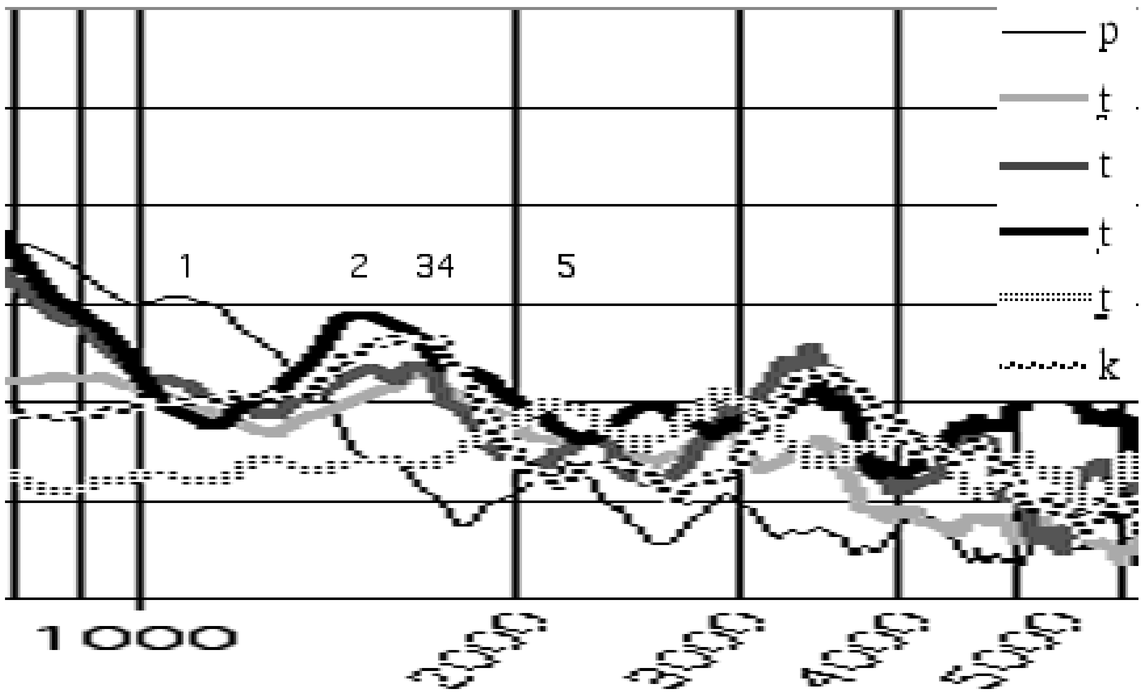


Figure 4.11b: Male speaker's stop burst spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

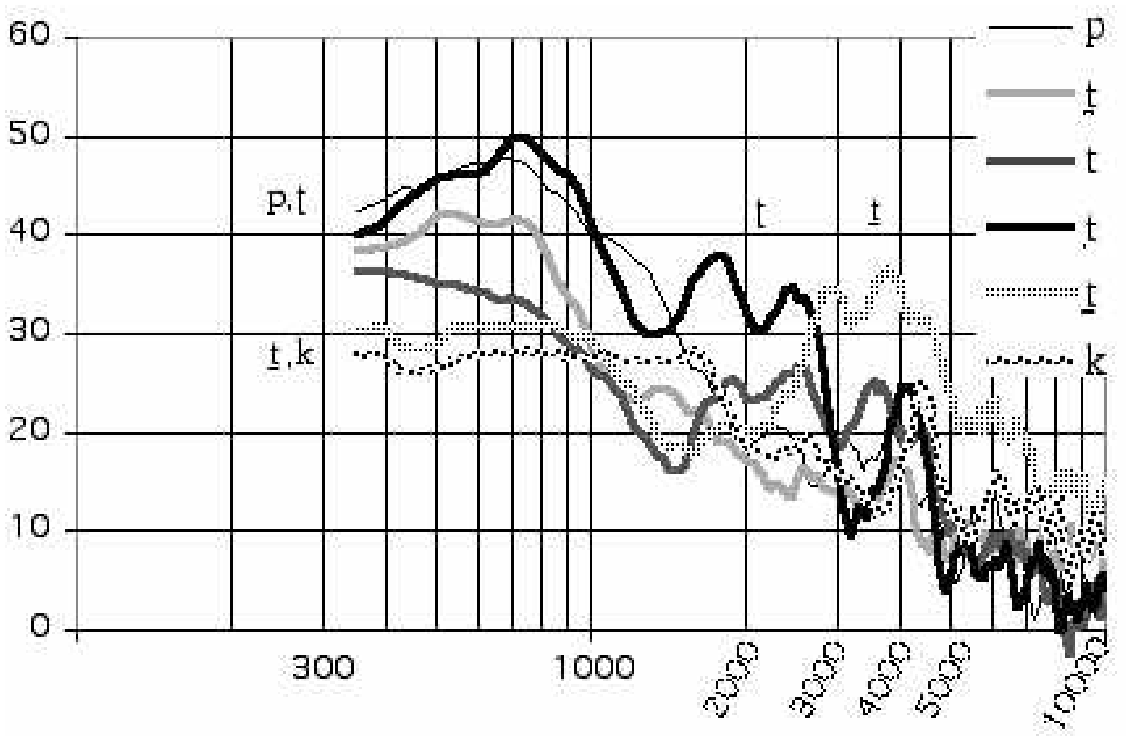


Figure 4.12a: Female speaker's stop burst spectra, 100-10000 Hz.

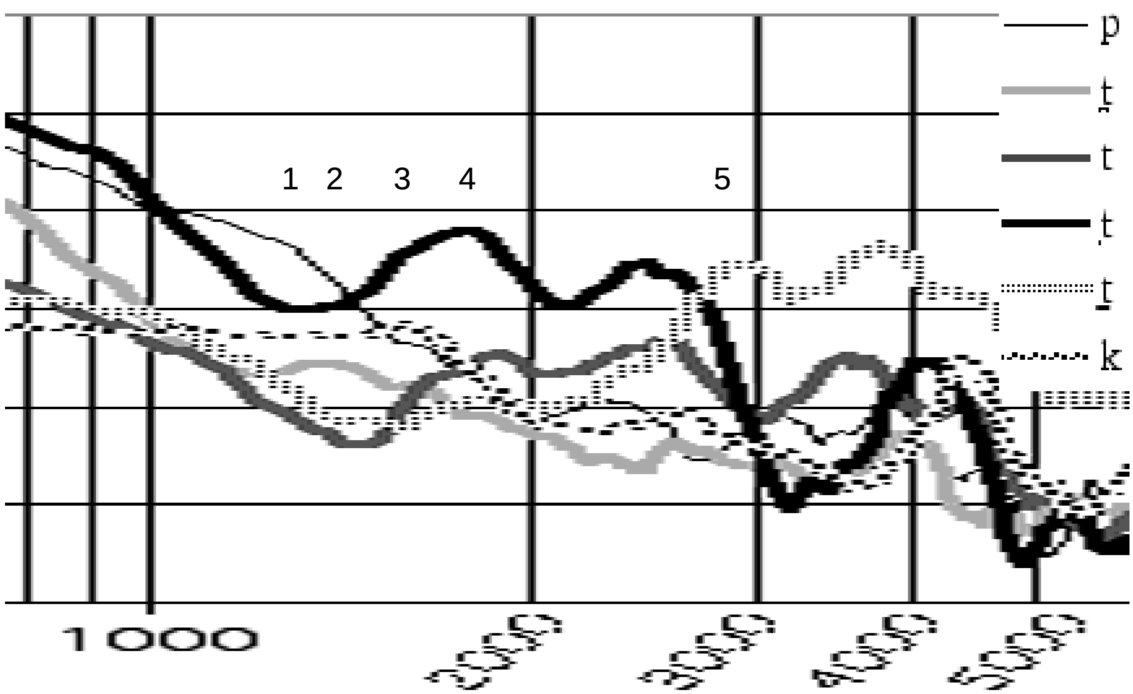


Figure 4.12b: Female speaker's stop burst spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

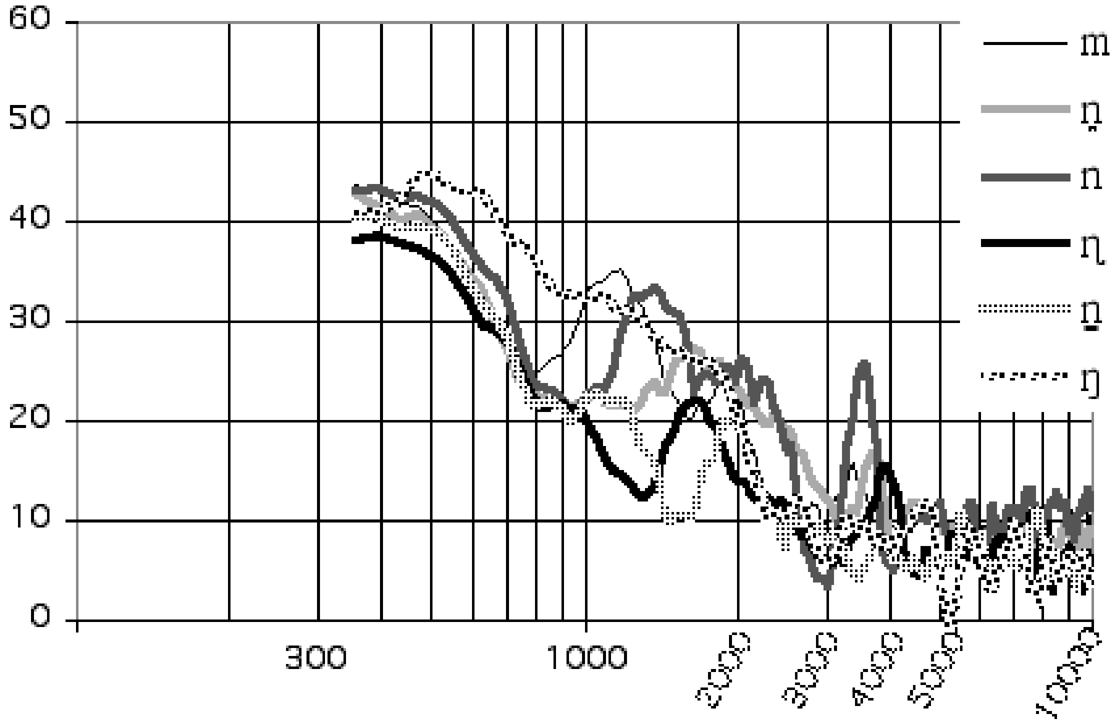


Figure 4.13a: Male speaker’s nasal murmur spectra, 100-10000 Hz.

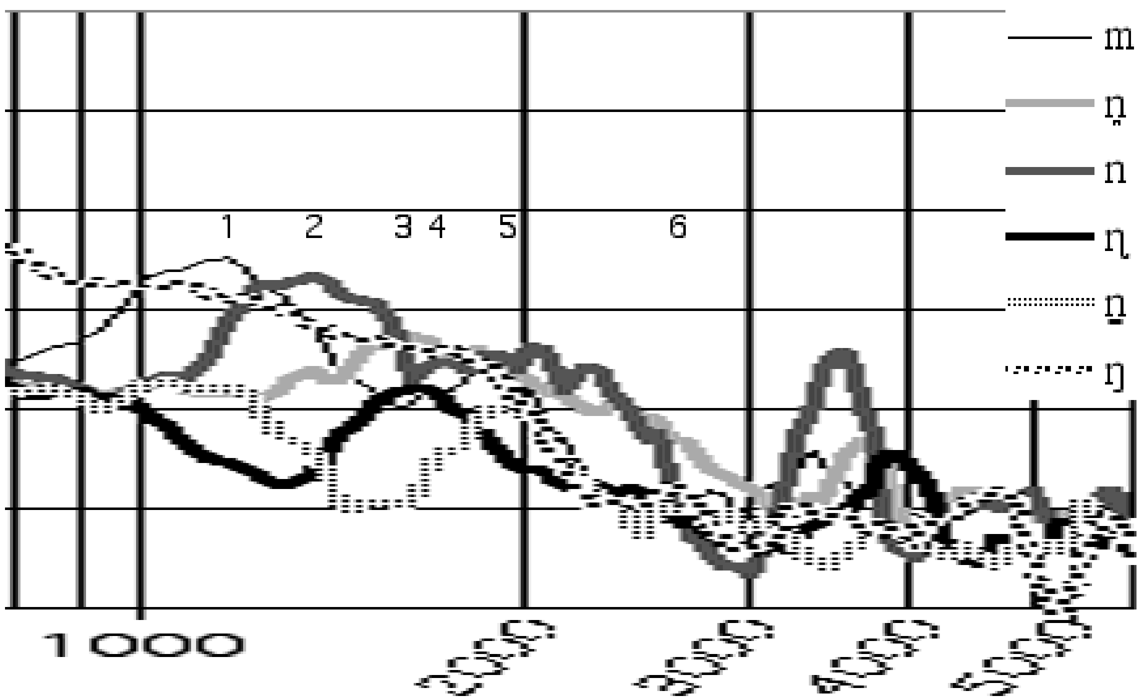


Figure 4.13b: Male speaker’s nasal murmur spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

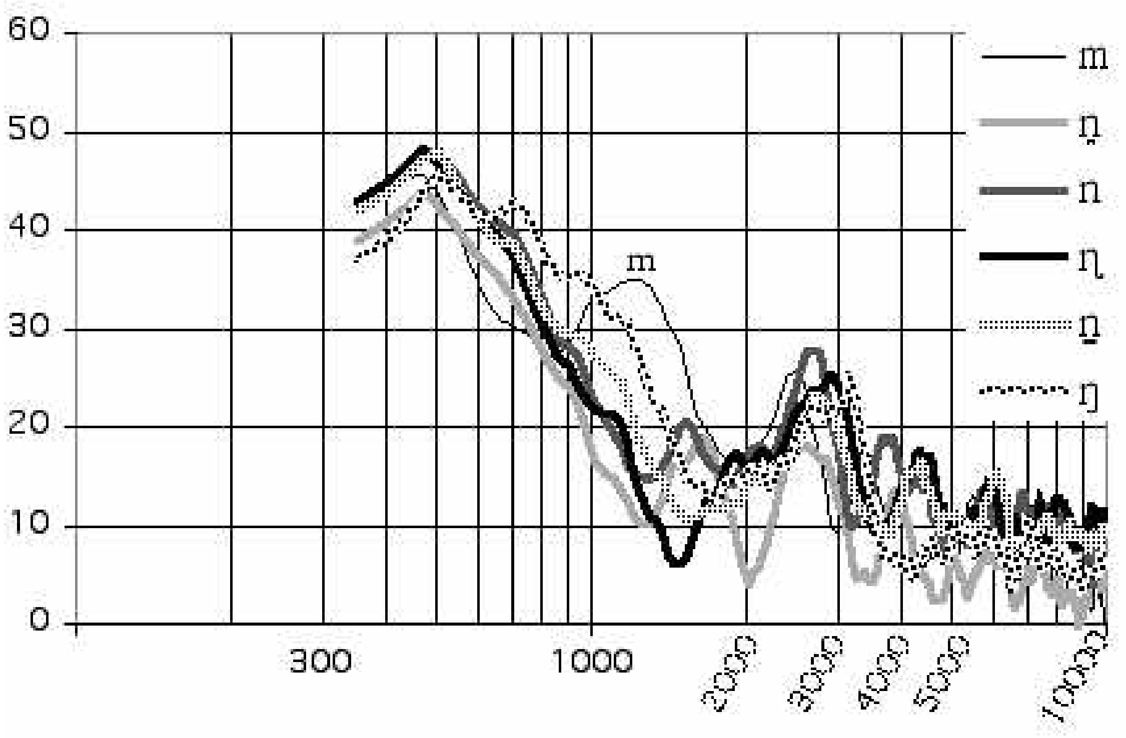


Figure 4.14a: Female speaker's nasal murmur spectra, 100-10000 Hz.

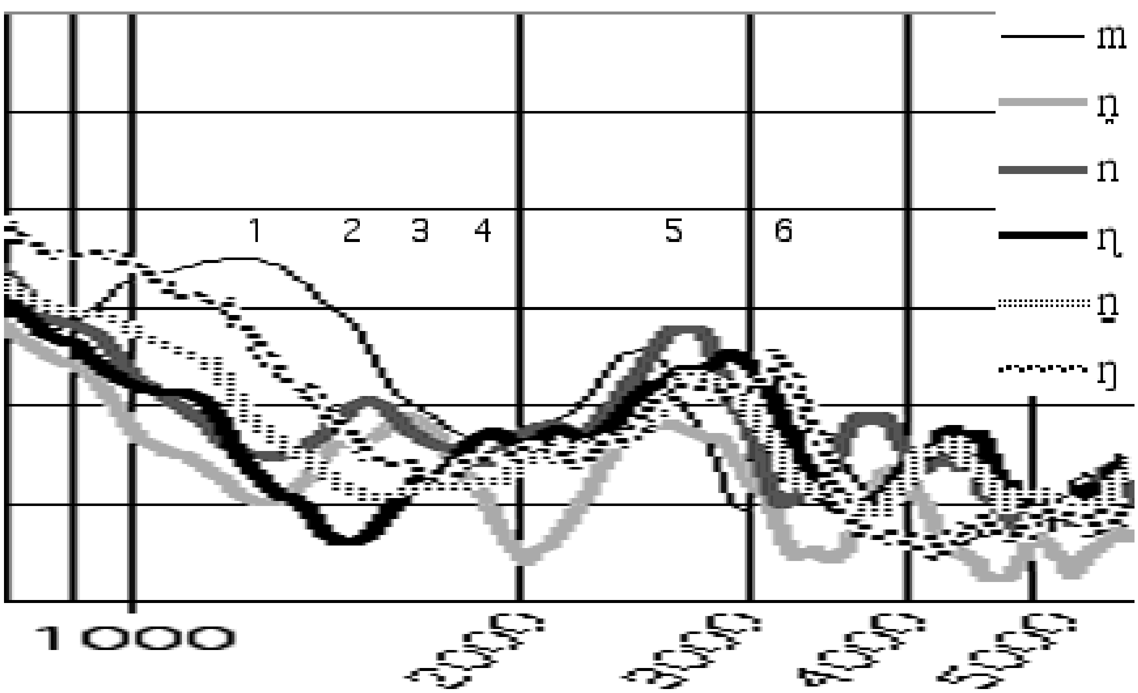


Figure 4.14b: Female speaker's nasal murmur spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

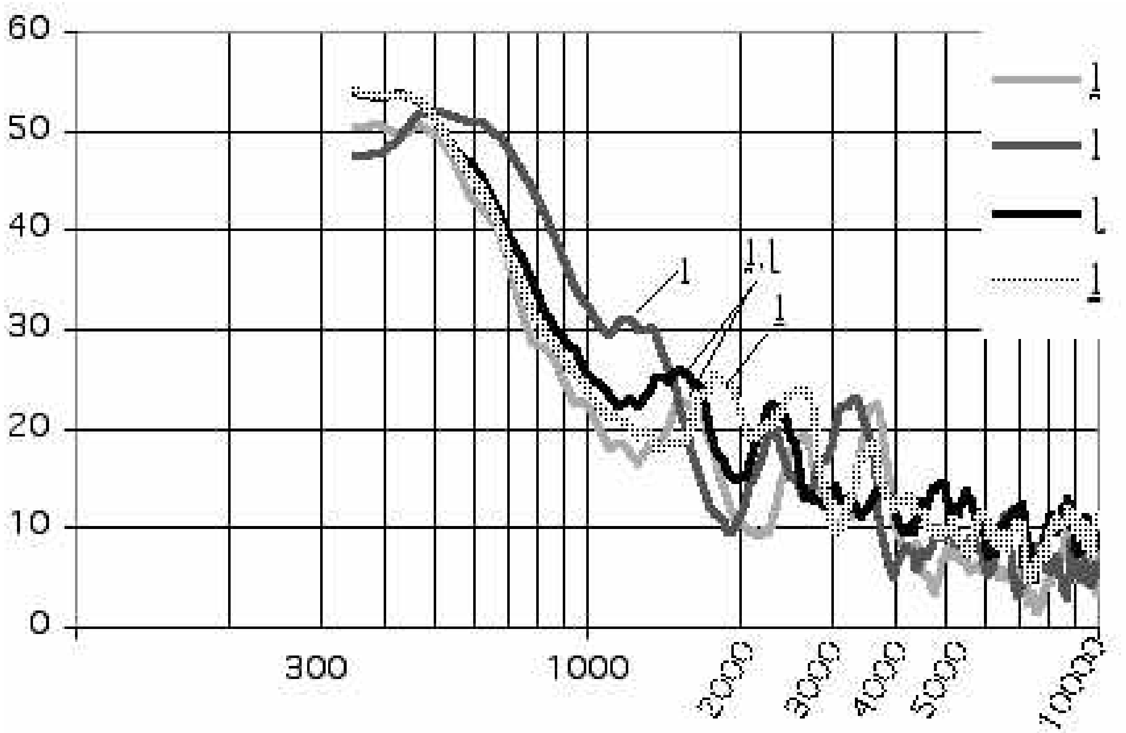


Figure 4.15a: Male speaker's lateral murmur spectra, 100-10000 Hz.

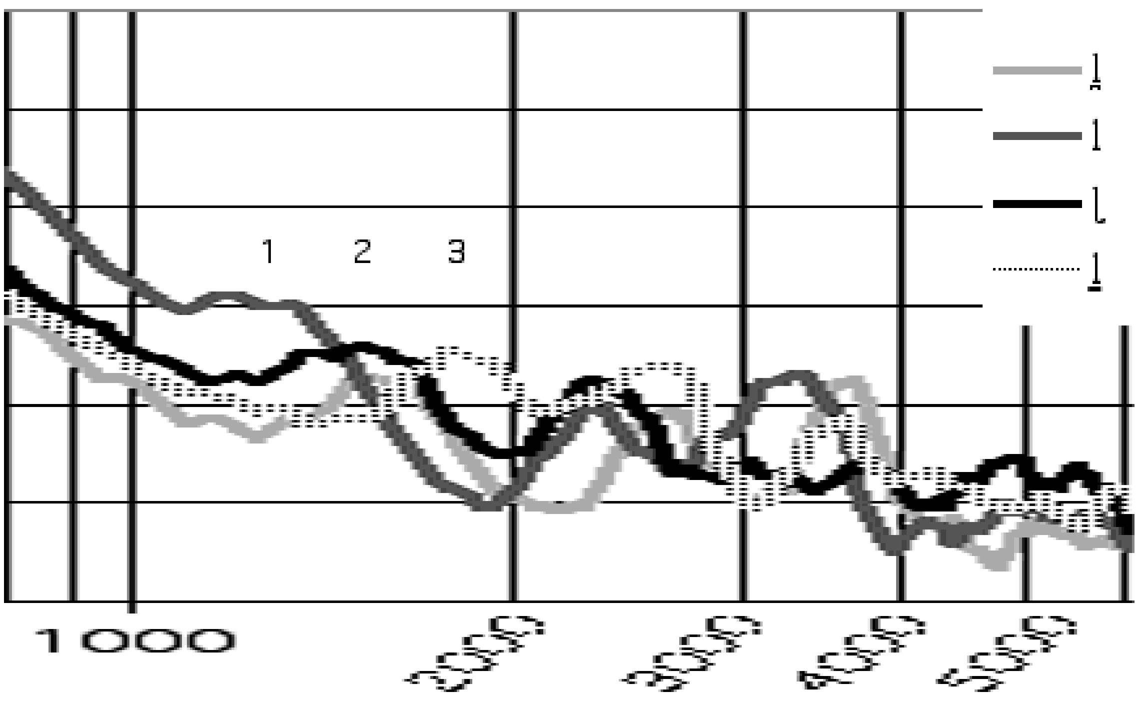


Figure 4.15b: Male speaker's lateral murmur spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

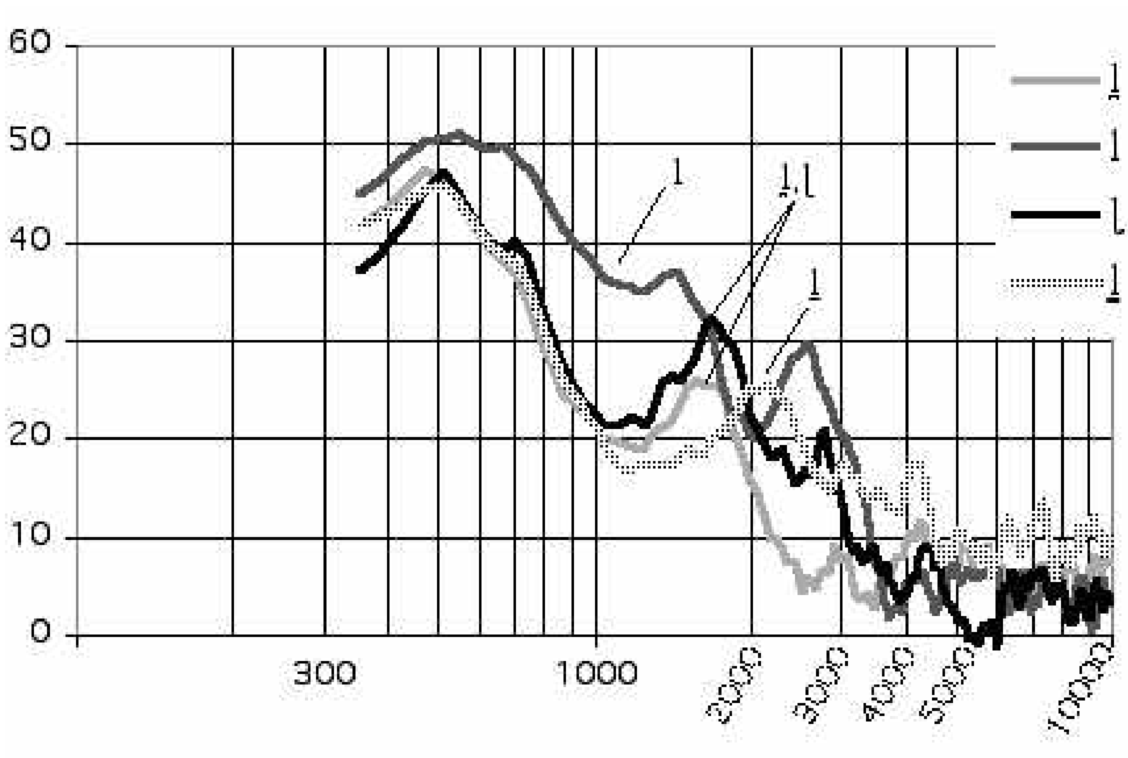


Figure 4.16a: Female speaker's lateral murmur spectra, 100-10000 Hz.

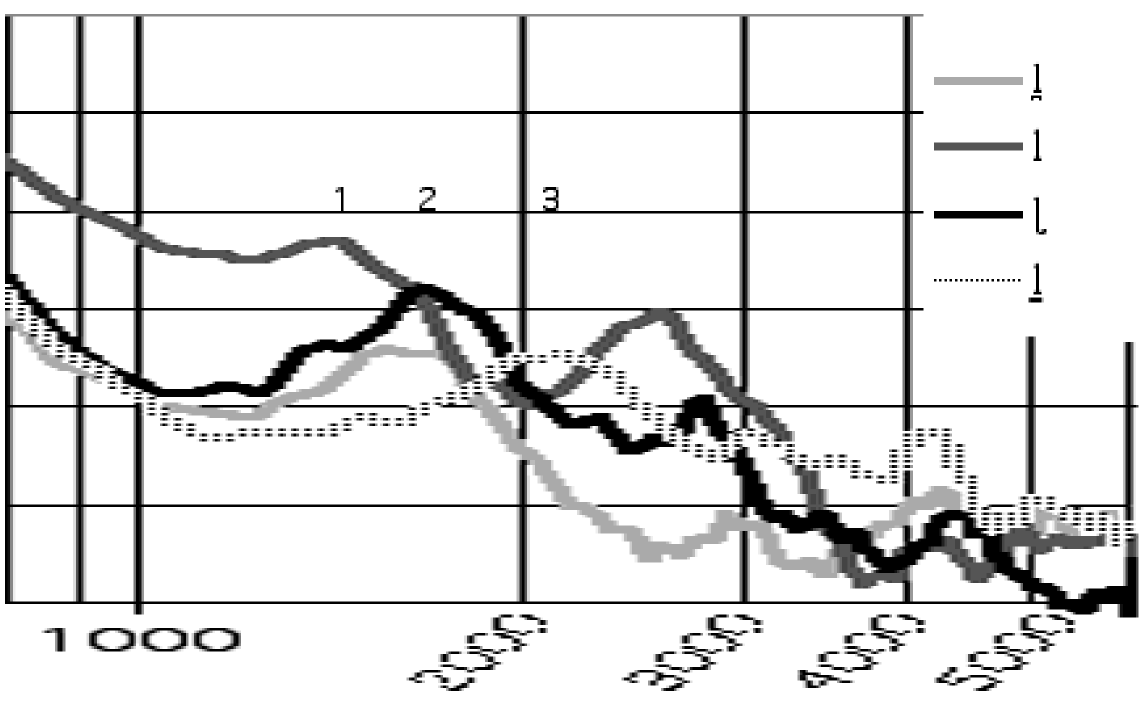


Figure 4.16b: Female speaker's lateral murmur spectra, 1000-5000 Hz. Numbers are vertically aligned with peaks discussed in the text.

To summarize, there is both inter-speaker consistency in the ordering of nasal and lateral zero-poles, and surprisingly, consistency between nasals and laterals. Such consistency does not hold of the stops. The frequency at which a zero-pole occurs is characteristic of a certain place. The uniformity of these place cues may compensate for relative deficiencies vis-a-vis stops in numbers of cues.

Turning to spectral characteristics of apicals for a moment, results of perception tests prepare us for the observation that the two apical stop burst spectra are similar in shape. Both apicals have peaks at around 1600 Hz and 3500 Hz for the male speaker, and peaks centered around 2000 Hz, and 3500-4000 Hz, for the female speaker. (The male has an additional resonance for /ʈ/ at 5500 Hz.) Interestingly though, due to the locations of zeroes in the nasals and laterals, it is the apical postalveolars and laminal dentals that look most similar to each other in the sonorants. Such similarities help to explain results of the CV perception tests in which postalveolars lacking their V1 cues were identified most often as laminal dentals.

Thus, in W. Arrernte, where native speakers are accustomed to discriminating among a large number of places of articulation, locations of closely conjoined spectral zeroes and poles in murmurs may provide sufficient acoustic differences to make up for the lack of cues that are available in stops. However, we still see a lack of unambiguously distinguishing characteristics between laminal dentals and apical postalveolars. Both sets of observations provide topics for further research.

4.4 Summary of Perception Results

In this chapter we set out with three goals: 1) to determine the relative auditory robustness of different manners of articulation, 2) to confirm or refute the hypothesis that apical segments are less auditorily robust than others, and 3) to confirm or refute the hypothesis that the phonotactic distribution of apicals in W. Arrernte relates directly to the presence or absence of auditory cues. In terms of the first goal, we found that listeners are equally successful in identifying the place of articulation of stops, nasals and laterals. Consistent spectral place characteristics in the form of zero-pole pairs during murmur steady states may contribute to the auditory robustness of nasals and laterals.

In terms of our hypothesis that apicals would be less auditorily robust than other segments based on the observation of their lower functional load, results were indeterminate for postalveolars, but held true of alveolars. The possibility of higher level processing in the identification of VCV tokens that constituted actual words posed a potential confound for some postalveolars.

The cue licensing hypothesis was strongly borne out in this auditory perception experiment. Loss of a preceding vowel drastically inhibits correct identification of both apicals. Specifically, without V1 information, listeners choose randomly among apical alveolar, laminal dental and apical postalveolar places of articulation.

Let us summarize perception test results and acoustic characteristics found for experimental tokens, in terms that relate to cue licensing. Laminal palatoalveolars do not lose salience in the CV condition. This is because each of the laminal palatoalveolar segments contains acoustic characteristics that separate it from other members of its manner class, and importantly, these acoustic characteristics inhere in both flanking vowels and in the consonant itself. Statistically differentiable characteristics include the lowest F1 and highest F2 and F3 formant transitions in both offsets and onsets. Laminal palatoalveolar sonorants are long in duration, and have the highest F2 during murmurs. Moreover, in **/t̻/,** the longest VOT of the four coronal stops, and a release that is affricated for virtually the entire VOT, add to cues on the side facing V2. Finally, though statistical significance is not known for the spectra, both **/n̪/** and **/l̪/** have higher zero-pole sequences than other coronals.

Laminal dentals do lose some salience in the CV condition. Again, we find potential cues in both flanking vowels, as well as within the segment itself, but not the profusion of cues provided by the palatoalveolar. On the side facing V1, like palatoalveolars, laminal dentals contain a short preceding vowel. Moreover, the laminal dental stop has the longest voiceless closure duration of the coronals. In terms of the consonant itself, laminal dental sonorants involve a long murmur, similar to palatoalveolars, but without the high F2 (during murmur) and the high F2 and F3 transitions that characterize the latter. (Thus, within the laminals, dentals may be identified on negative evidence.) On the V2 side, stops have a release that is affricated for the lowest proportion of the total VOT, and three of four tokens have a double burst. Thus, even with V1 removed, differentiating cues remain within the release of **/t̪/,** and within the long, negatively identified **/n̪/** and **/l̪/.**

Apicals clearly lose their salient cues when V1 is excised. The random nature of responses in the CV tests suggests that listeners are guessing in their attempts to identify apicals in this condition. At the same time, for alveolars and postalveolars alike, we fail to find acoustic characteristics either within the consonant or within transitions to V2 that categorically set these segments off from other members of their manner cohort. Apical segments involve a long preceding vowel, and sonorants are characterized by a short murmur. Moreover, postalveolars are positively characterized by their unique formant offglides from V1, while alveolars, like dental segments with respect to laminals, are identified by negative evidence—the lack of the postalveolar’s formant offglides. However, all transition and V1 duration information is lost when V1 is excised. Further, duration information regarding length of murmur does not separate the apicals from each other even in the VCV condition, and may well be compromised in the absence of V1, making confusion with the dental more likely. Spectra of alveolars and postalveolars are visually distinct in nasals and laterals, but whether these differences are statistically significant is not known. Apart from this spectral difference, with V1 removed, neither alveolar nor postalveolar tokens show acoustic characteristics that statistically separate them completely from other coronals. Alveolar stops are particularly variable—they can be voiced or voiceless, can have high or low energy bursts, and across manners alveolars do not have V2 formant onset transitions distinct from postalveolars, or indeed formant transitions to either flanking vowel that are distinct from laminal dentals. In the same vein, postalveolars in the CV condition have no acoustic characteristics that statistically distinguish them from alveolars or dentals, and worse, the murmur spectra of dental and postalveolar sonorants are extremely similar. Again, the extent to which listeners rely on spectral characteristics within the murmur is not clear, but the similarity between postalveolars and dentals helps explain why more postalveolars are identified as dental than other categories when offset transitions are removed.

Thus, results of this chapter demonstrate that the phonotactic distribution of coronal segments dovetails well with distribution of their acoustic characteristics.

Chapter Five: Conclusion

As a point of departure, this dissertation reviewed four competing forces which constrain the sound structures of languages: ease of articulation, auditory distinctiveness, maximization of numbers of contrasts, and pattern congruity. Some examples of interactions among these forces were explored, to show how tensions among the forces are resolved. Phonetic models that incorporate one or more of these forces were presented, including Keating's Polarization principle (1984), Keating's Window Model of Phonetic (Under)Specification (1990), Lindblom and Maddieson's Size/Structure Hypothesis (1988), Maddieson's Theory of Gestural Economy (1996, 1997), Steriade's Production Hypothesis (1993, 1995), and Steriade's principle of Licensing by Cue (1999.)

Extrapolating from Flemming's (1997) suggestion that it is possible to calculate an overall cost value for phonetic solutions, namely the sum of numerically weighted phonetic constraints, we presented the notion of domain-specific weighting, which supposes that different weight valuations are preferred in different phonetic domains. Thus, in the following cost equation, each of the weight terms is specific to the phonetic domain in question.

w_e (violation of **ease** of articulation metric)
\+ w_d (violation of auditory **distinctiveness** metric)
\+ w_n (violation of maximization of **numbers** of contrasts metric)
\+ w_c (violation of pattern **congruity** metric)
= **cost**

Gestural Economy, Polarization, and Licensing by Cue implicitly give the four metrics expressed in the above equation different weights. It is these three principles we focused on in this thesis. While evidence has accrued in previous literature for gestural economy in the domain of consonant Place of Articulation, the literature does not present clear evidence of polarization in this domain. We looked for that evidence, by empirically investigating the articulation and auditory perception of coronals in W. Arrernte, a Central Australian language that makes use of an apical contrast intervocalically but not initially.

Main results of the articulation study provided evidence of gestural economy, but not evidence of polarization in the domain of consonant Place. In terms of the four ecological forces mentioned above, evidence was found for stronger relative weightings of ease of articulation and pattern congruity over auditory distinctiveness, in this domain. Specifically, both palatographic and linguographic results showed that speakers re-use the same apical articulations in both contrastive and non-contrastive environments, and the same apical articulations in both stops and nasals. Moreover, the less displaced (alveolar) segment is used in the larger number of contexts.

It appears that the articulatorily "default" alveolar segments are also perceived by default. When compared with other coronals, apical alveolar tokens were relatively variable in their acoustic characteristics, contained less positive acoustic evidence, and were significantly less auditorily robust than other coronals. Here again is evidence that auditory distinctiveness is sacrificed in favor of ease of articulation in the domain of Place.

Licensing by cue was empirically demonstrated. This principle explains the reason for the particular phonotactic distribution of apicals in W. Arrernte. In these apicals, cues used by listeners reside in the preceding vowel. The major cue to apical postalveolar place is a common offset locus of F2, F3 and F4 in the preceding vowel, while the major cue to apical alveolar place is the lack thereof. Where these cues are lost, contrast is lost.

Thus, here again, as in previous literature, we found evidence for gestural economy but not for polarization in the domain of consonant Place. This study constitutes preliminary evidence that the domain of consonant Place gives higher weighting to ease of articulation and pattern congruity, over auditory distinctiveness. More work is necessary to determine whether certain phonetic domains show clear preference for certain ecological forces, and to determine what motivates the division of labor between desirable principles like polarization and gestural economy. For instance, it may be that consonant Place weights the latter highly because of the presence of oral landmarks, which presumably are especially salient in stop, nasal and lateral production. Thus, stops, nasals and laterals are articulatorily defined. On the other hand, because vowel systems seem to be largely auditorily defined, it stands to reason that vowels should involve a higher relative weighting of auditory distinctiveness. Domains such as gestures per se versus timing of gestures, or segments versus material superimposed on those segments, may show different specific weightings—different preferences for the ecological forces affecting sound systems in language.

In summary, it appears that an overall model of the role played in phonetic systems by the various forces considered here must be designed to give different weights to different factors according to the phonetic domain being evaluated.

Appendix: Informed Consent Form

December 26, 1994 Informed Consent Form

<u>A Study of the Sounds and Articulations of W. Arrernte and Murrinh-Patha</u>

Victoria Anderson, C. Phil., a member of the UCLA Phonetics Laboratory, is doing research on the ways in which speech sounds are produced in Western Arrernte and in Murrinh-Patha, and how this is related to the way they sound. These languages contain rare sets of sounds, and the general scientific benefits from this research will include more specific knowledge about these sounds. I am being asked to help by doing some of the tasks listed below. If there are any tasks I do not want to do, I will draw a line through them below.

I was chosen because I am a native speaker of W. Arrernte or Murrinh-Patha. The tasks will take about ten hours of my time, in total. Each session will last no more than an hour. I will meet the investigator at my convenience about once a month. All the procedures in this study will be administered by Victoria Anderson. She will always try to answer any questions I have about this work. If I wish to stop taking part in the study, I am free to do so at any time, for any reason. Victoria Anderson can be reached at the Institute for Aboriginal Development, Alice Springs, or after December 1995 at the Department of Linguistics, Campbell Hall 2101, UCLA, Los Angeles, CA 90024-1543. (Telephone: 310-206-2808.)

I will be asked to do the tasks listed in 1 through 5 below (I have deleted any tasks that I do not wish to do):

1.) List words in W. Arrernte or Murrinh-Patha as requested.

2.) Allow Ms. Anderson to make tape recordings of my voice.

3.) Listen to tape recordings and comment on them.

(Before I am asked to do any of the tasks listed below, a full demonstration of the procedure will be given by Victoria Anderson, using herself as a subject.)

4.) Allow Ms. Anderson to paint the roof of my mouth with a mixture of olive oil and digestive charcoal powder, and then examine or photograph the inside of my mouth and my tongue after I have said a word.

5.) Allow Ms. Anderson to make an impression of the front part of my mouth. This means placing a small amount of soft dental impression material in the space above my tongue, behind my upper front teeth. This material has a mild mint flavor and takes about a minute to firm up into an impression. I can remove it at any time if I find the process unpleasant.

I understand that tasks 4 and 5 may tickle or be slightly uncomfortable, since they involve having something unusual in my mouth, but that they are not harmful to me.

I understand that I may refuse to participate or may withdraw from this study at any time without any negative consequences. I understand that I will be paid for the complete amount of time during which I remain a subject.

I understand that audio and video recordings of my speech and mouth will be made and that these recordings will be kept for research and/or teaching purposes when the study ends. I understand that I have a right to review, edit or erase the recordings in whole or in part.

The investigator may stop the study at any time.

I also understand that no information which identifies me will be released without my separate consent except as specifically required by law.

If the study design or the use of the data is to be changed, I will be so informed and my consent re-obtained.

I understand that if I have any questions, comments, or concerns about the study or the informed consent process, I may write or call the office of the Vice Chancellor-Research Programs, 3134 Murphy Hall, University of California, Los Angeles, CA 90024-1405. (Telephone: 310-825-8714.)

I acknowledge that I have received a copy of this form.

______________________________________(Signature) ________________(Date)

______________________________________(Witness)

HSPC #G93-07-087

References

Anderson, Victoria B. 1997. "The perception of coronals in Western Arrernte." In *Proceedings of the 5th European Conference on Speech Communication and Technology*, ed. by G. Kokkinakis et al. University of Patras, Greece: 1: 389-392.

Anderson, Victoria B. 1998. "Testing opposing phonetic structural principles: Polarization and Gestural Economy." In *Proceedings of the Twenty-Fourth Annual Meeting of the Berkeley Linguistics Society, Parasession on Phonetics and Phonological Universals,* ed. by B. Bergen et al. Berkeley Linguistics Society, Berkeley: 309-319.

Anderson, Victoria B. and Ian Maddieson. 1994. "Acoustic characteristics of *Tiwi* coronal stops." *UCLA Working Papers in Phonetics* 87: 131-162.

Blumstein, Sheila E. and Kenneth N. Stevens. 1978. "Invariant cues for place of articulation in stop consonants." *Journal of the Acoustical Society of America* 64: 1358-1368.

Breen, J. Gavan. 1977. "Andegerebenha vowel phonology." *Phonetica* 34(5): 371–391.

Breen, J. Gavan. 1990. *The syllable in Arrernte Phonology (manuscript.)* School of Australian Linguistics and Institute for Aboriginal Development, Alice Springs.

Breen, J. Gavan. 1997. "Taps, stops & trills." In *Boundary Rider: Essays in Honour of Geoffrey O'Grady,* ed. by Darrel Tryon and Michael Walsh. Pacific Linguistics (C-136), Canberra: 71-93.

Breen, J. Gavan. In progress. *Western Arrernte Wordlist.*

Butcher, Andrew. 1995. "Phonetics of Neutralization." In *General and English Phonetics: Essays in Honour of Professor J. D. O'Connor,* ed. by Jack Windsor Lewis. Routledge, London.

Butcher, Andrew. To appear. *The phonetics of Australian languages.* Oxford University Press, Oxford.

Byrd, Dani. 1993. "54,000 American Stops." *UCLA Working Papers in Phonetics* 83: 97-116.

Catford, J. C. 1977. *Fundamental Problems in Phonetics.* Indiana University Press, Bloomington.

Cho, Taehong. 1998a. "Intergestural timing and overlap in Korean palatalization: An Optimality-Theoretic Approach." *Japanese/Korean Linguistics* 8, ed. by David Silva. CLSI, Stanford University, Palo Alto.

Cho, Taehong. 1998b. "Specification of intergestural timing and overlap: EMA and EPG studies. *Linguistics and Phonetics Conference 98*, Ohio State University, Columbus.

Crystal, T. and Arthur S. House. 1988. "Segmental durations in connected speech signals: current results." *Journal of the Acoustical Society of America* 83(4), 1553-1573.

Dart, Sarah. 1991. *Articulatory and Acoustic Properties of Apical and Laminal Articulations. (UCLA Working Papers in Phonetics* 79.) Ph.D. Thesis. University of California, Los Angeles.

Dart, Sarah. 1998. "Comparing French and English coronal consonant articulation." *Journal of Phonetics* 26: 71-94.

Deckert, J. 1991. *MacDonnell Ranges*. Westprint, Australia.

Dixit, R. Prakash. 1990. "Linguotectal contact patterns in the dental and retroflex stops of Hindi." *Journal of Phonetics* 18: 189-201.

Dixon, Robert M. W. 1970. "Proto-Australian Laminals." *Oceanic Linguistics* 9: 79-103.

Dixon, Robert M.W. 1980. *The Languages of Australia.* Cambridge University Press, Cambridge.

Dixon, Robert M.W. and Barry J. Blake, eds. 1991. *The Handbook of Australian Languages,* vol.4. Oxford University Press Australia, Melbourne

Evans, Nick. 1995. "Current issues in the Phonology of Australian languages." In *Handbook of Phonological Theory,* ed. by J. Goldsmith. Blackwell, Oxford.

Fant, Gunnar. 1960. *Acoustic Theory of Speech Production.* Mouton, The Hague.

Fischer-Jørgensen, Eli. 1954. "Acoustic analysis of stop consonants." *Miscellanea Phonetica* 2: 42-59.

Fischer-Jørgensen, Eli. 1964. "Sound duration and place of articulation in Danish." *Zeitschrift für Sprachwissenschaft und Kommunikationsforschung* 17: 175-207.

Flemming, Edward. 1997. "Phonetic Optimization: Compromise in Speech Production." *University of Maryland Working Papers in Linguistics 5: Selected Phonology Papers from H-OT (97).*

Flemming, Edward. To appear. "Phonetic Detail in phonology: Towards a unified account of assimilation and coarticulation." In *Southwest Workshop in Optimality Theory: Features in OT (SWOT I),* ed. by K. Suzuki and D. Elzinga. Coyote Papers.

Fougeron, Cécile and Patricia A. Keating. 1997. "Articulatory strengthening at edges of prosodic domains." *J. Acoust. Soc. Am.* 101: 3728-3740

Goldstein, Louis M. and Catherine P. Browman. 1986. "Representation of voicing contrasts using articulatory gestures." *Journal of Phonetics* 14(2): 339-342.

Hayes, Bruce. 1999. "Phonetically-Driven Phonology: The Role of Optimality Theory and Inductive Grounding." In *Functionalism and Formalism in Linguistics, Volume I: General Papers,* ed. by Michael Darnell, Edith Moravscik, Michael

Noonan, Frederick Newmeyer, and Kathleen Wheatly. John Benjamins, Amsterdam: 243-285.

Hayes, Bruce and Tanya Stivers. In progress. "The Phonetics of Post-Nasal Voicing."

Henderson, John, and Veronica Dobson. 1994. *Eastern and Central Arrernte to English Dictionary*. Institute for Aboriginal Development Press, Alice Springs.

Hobson, J. 1990. *Current Distribution of Australian Languages*. Institute for Aboriginal Development Press, Alice Springs.

Hockett, Charles F. 1963. "The problem of universals in language." In *Universals in Language*, ed. by J.H. Greenberg. MIT Press, Cambridge, MA.

House, Arthur S. 1957. "Analog studies of nasal consonants." *Journal of Speech and Hearing Disorders* 2: 190-204.

Hsu, Chai-Shune K. 1998. "Voicing underspecification in Taiwanese word-final consonants." *UCLA Working Papers in Phonetics* 96: 90-105.

Hsu, Chai-Shune K. and Sun-Ah Jun. 1998. "Prosodic Strengthening in Taiwanese: Syntagmatic or Paradigmatic?" *UCLA Working Papers in Phonetics* 96: 69-89.

Jakobson, Roman, Gunnar Fant, and Morris Halle. 1952. *Preliminaries to speech analysis*. MIT Press, Cambridge, MA.

Jernudd, Bjørn. 1974. "Articulating Gunwinjgu Laminals." *Papers in Australian Aboriginal Languages, Linguistic Communications #14,* ed. by Barry J. Blake. Monash University, Melbourne.

Johnson, Keith, Peter Ladefoged, and Mona Lindau. 1993. "Individual differences in vowel production." *Journal of the Acoustical Society of America* 94 (2): 701-714.

Jongman, Allard, Sheila E. Blumstein, and Aditi Lahiri. 1985. "Acoustic properties for dental and apical alveolar stop consonants: a cross-language study." *Journal of Phonetics* 13: 235-251.

Jun, Jongho. 1995. *Perceptual and Articulatory factors in Place assimilation: An Optimality-Theoretic Approach (UCLA dissertations in Linguistics #2.)* Ph.D. thesis. University of California, Los Angeles.

Keating, Patricia A. 1984a. "Phonetic and phonological representations of consonant voicing." *Language* 60: 286-319.

Keating, Patricia A. 1984b. "Aerodynamic modeling at UCLA." *UCLA Working Papers in Phonetics* 59: 18-28.

Keating, Patricia A. 1984c. "Physiological effects on stop consonant voicing." *UCLA Working Papers in Phonetics* 59: 29-34.

Keating, Patricia A. 1988. "The phonology-phonetics interface." In *Linguistics: The Cambridge Survey* (1): 281-302. Cambridge University Press, Cambridge.

Keating, Patricia A. 1990. "Phonetic representations in a generative grammar." *Journal of Phonetics* 18: 321-334.

Keating, Patricia A. 1991. "Coronal Places of Articulation." In *The Special Status of Coronals, Phonetics and Phonology* 2, ed. by C. Paradis and J.-F. Prunet. Academic Press, San Diego.

Keating, Patricia A. 1996. "The Phonology-Phonetics Interface." *UCLA Working Papers in Phonetics* 92: 45-60.

Keating, Patricia A., Barbara Blankenship, Dani Byrd, Edward Flemming, and Yuichi Todaka. 1992. "Phonetic Analysis of the TIMIT corpus of American English at UCLA." *UCLA Working Papers in Phonetics* 81: 1-16.

Keating, Patricia A., Taehong Cho, Cécile Fougeron, and Chai-Shune Hsu. 1999. Domain-initial articulatory strengthening in four languages. *UCLA Working Papers in Phonetics* 97: 139-151.

Keating, Patricia A. and Aditi Lahiri. 1993. “Fronted velars, palatalized velars, and palatals.” *Phonetica* 50: 73-101.

Keating, Patricia A., John R. Westbury, and Kenneth N. 1980. “Mechanisms of stop consonant release for different places of articulation.” *Journal of the Acoustical Society of America* 67, Supp. 1: S93.

Kewley-Port, D. 1983. “Time-varying features as correlates of place of articulation in the articulation of stop consonants.” *Journal of the Acoustical Society of America*, 73: 322-335.

Kirchner, Robert. 1998. *An Effort-Based Approach to Consonant Lenition.* Ph.D. dissertation. University of California, Los Angeles.

Klatt, Dennis H. 1975. “Vowel lengthening is syntactically determined in a connected discourse.” *Journal of Phonetics* 3: 129-140.

Kohler, Klaus J. 1990. “Segmental Reduction in Connected Speech in German: Phonological Facts and Phonetic Explanations.” In *Speech Production and Speech Modelling*, ed. by W.J. Hardcastle and A Marchal. Kluwer, Netherlands: 69-92.

Kohler, Klaus J. 1991. “The Phonetics/Phonology Issue in the Study of Articulatory Reduction.” *Phonetica* 48: 180-92.

Kohler, Klaus J. 1992. “Gestural Reorganization in Connected Speech: A Functional Viewpoint on ‘Articulatory Phonology’.” *Phonetica* 49: 205-211.

Kurowski, Kathleen M. and Sheila E. Blumstein. 1984. “Perceptual integration of the murmur and formant transitions for place of articulation in nasal consonants.” *Journal of the Acoustical Society of America* 76 (2): 383-390.

Kurowski, Kathleen M. and Sheila E. Blumstein. 1987. "Acoustic properties for place of articulation in nasals." *Journal of the Acoustical Society of America* 81: 1917-1927.

Ladefoged, Peter. 1990. "What do we symbolize? Thoughts prompted by bilabial and labiodental fricatives." *Journal of the International Phonetic Association* 20: 33-36.

Ladefoged, Peter. 1991. "Instrumental phonetic fieldwork: techniques and results." In *XII International Congress of Phonetic Sciences 4*. Université de Provence, Aix-en-Provence: 126-129.

Ladefoged, Peter. 1993a. *A Course in Phonetics.* (3rd edition.) Harcourt Brace Jovanovich, New York.

Ladefoged, Peter. 1993b. "Linguistic Phonetic Fieldwork: a Practical Guide." *UCLA Working Papers in Phonetics* 84: 1-24.

Ladefoged, Peter. 1996. "The sounds of languages." *UCLA Working Papers in Phonetics* 94: 52-65.

Ladefoged, Peter. 1997a. "Instrumental techniques for linguistic phonetic fieldwork." In *The Handbook of Phonetic Sciences*, ed. by W. Hardcastle and J. Laver. Blackwell, Oxford: 137-166.

Ladefoged, Peter. 1997b. "Linguistic Phonetic Descriptions." In *The Handbook of Phonetic Sciences*, ed. by W. Hardcastle and J. Laver. Blackwell, Oxford: 589-618.

Ladefoged, Peter and Peri Bhaskararao. 1983. "Non-quantal aspects of consonant production: a study of retroflex consonants." *Journal of Phonetics* 11: 291-302.

Ladefoged, Peter, J. DeClerk, Mona Lindau, and G. Papcun. 1972. "An auditory-motor theory of speech production." *UCLA Working Papers in Phonetics* 22: 48-75.

Lahiri, Aditi, L. Gewirth and Sheila E. Blumstein. 1984. "A reconsideration of acoustic invariance for place of articulation in diffuse stop consonants: Evidence from a cross-language study." *Journal of the Acoustical Society of America* 76: 391-404.

Ladefoged, Peter and Ian Maddieson. 1996. The Sounds of the World's Languages." Blackwell, Oxford.

Laver, John. 1994. *Principles of Phonetics.* Cambridge Textbooks in Linguistics, Cambridge.

Lee, Jenny. 1987. *Tiwi Today: a study of language change in a contact situation.* Department of Linguistics, Research School of Pacific Studies, Australian National University, Canberra.

Lehiste, Ilse. 1970. *Suprasegmentals.* MIT Press, Cambridge, MA.

Lindblom, Bjørn. 1983. "Economy of Speech Gestures." In *The Production of Speech*, ed. by P.F. MacNeilage. Springer-Verlag, New York.

Lindblom, Bjørn. 1986. "Phonetic universals in vowel systems." In *Experimental Phonology*, ed. by J. Ohala and J. Jaeger. Academic Press, Orlando.

Lindblom, Bjørn. 1990. "Phonetic content in phonology." *PERILUS (Phonetic Experimental Research, Institute of Linguistics, University of Stockholm)* 11.

Lindblom, Bjørn and Ian Maddieson. 1988. "Phonetic universals in consonant systems." In *Language, speech and mind: Studies in honor of Victoria A. Fromkin*, ed. by L. Hyman and C. Li. Routledge, London.

Lisker, Leigh and Arthur S. Abramson. 1964. "A cross language study of voicing in initial stops: Acoustical measurements." *Word* 20: 384-422

Maddieson, Ian. 1984. *Patterns of Sounds.* Cambridge University Press, Cambridge.

Maddieson, Ian. 1991. "Tone spacing." In *Festschrift for Jack Carnochan*, ed. by John Kelly and John Local. Working Papers in Linguistics, University of York, York.

Maddieson, Ian. 1993. "Investigating Ewe articulations with electromagnetic articulography." *Forschungberichte des Instituts für Phonetik und Sprachliche Kommunikation der Universität München* 31: 181-214.

Maddieson, Ian. 1996. "Gestural economy." *UCLA Working Papers in Phonetics* 94: 1-6.

Maddieson, Ian. 1997. "Phonetic Universals." In *The Handbook of Phonetic Sciences*, ed. by W. J. Hardcastle and J. Laver. Blackwell, Oxford: 619-639.

Maddieson, Ian and Kristin Precoda. 1992. *UCLA Phonological Segment Inventory Database*. University of California, Los Angeles.

Maddieson, Ian, Siniša Spajić, Bonny Sands and Peter Ladefoged. 1993. "The phonetic structures of Dahalo." *Afrikanistische Arbeitspapiere* 36: 5-53.

Malécot, André. 1956. "Acoustic cues for nasal consonants: an experimental study involving tape-splicing techniques." *Language* 32: 274-284.

Manuel, S.Y. 1990. "The role of contrast in limiting vowel-to-vowel coarticulation in different languages." *Journal of the Acoustical Society of America* 88, 1286-98.

Martinet, André. 1952. "Function, structure and sound change." *Word* 8:1.

Martinet, André. 1955. "Économie des changements phonétiques." Francke, Berne.

Oates, W. J. 1967. "Syllable patterning and phonetically complex consonants in some Australian languages." *Papers in Australian Linguistics* 1. Pacific Linguistics, series A, no. 10: 29-52.

Ohala, John J. 1976. "A model of speech aerodynamics." *Report of the Phonology Laboratory* (Berkeley) 1: 93-107.

Ohala, John J. 1980. “Moderator’s Introduction to Symposium on Phonetic Universals in Phonological Systems and their Explanation.” In *Proceedings of the Ninth International Congress of Phonetic Sciences* 3. Institute of Phonetics, Copenhagen: 181-185.

Ohala, John J. 1990. “The Phonetics and phonology of aspects of assimilation.” In *Papers in Laboratory Phonology I: Between the grammar and the physics of speech*, ed. by J. Kingston & M. Beckman. Cambridge University Press, Cambridge: 258-275.

Osborne, C. R. 1974. *The Tiwi Language: Grammar, myths and dictionary of the Tiwi Language spoken on Melville and Bathurst Islands, Northern Australia.* Australian Institute of Aboriginal Studies, Canberra.

Perkell, Joseph S., Suzanne Boyce and Kenneth N. Stevens. 1979. “Articulatory and acoustic correlates of the [s-š] distinction.” In *Speech Communication Papers Presented at the 97th Meeting of the Acoustical Society of America*, ed. by J.J. Wolf and D.K. Klatt. Acoustical Society of America, New York: 109-113.

Prince, Alan and Paul Smolensky. 1993. *Optimality theory: constraint interaction in generative grammar.* To appear, MIT Press, Cambridge, MA.

Rose, Philip. 1993. “A linguistic-phonetic acoustic analysis of Shanghai Tones.” *Australian Journal of Linguistics* 13: 185-220.

Rothenberg, M. 1968. “The breath-stream dynamics of simple-released-plosive production.” *Bibliotheca Phonetica* 6.

Sands, Bonny. 1991. “Evidence for click features: Acoustic characteristics of Xhosa clicks.” *UCLA Working Papers in Phonetics* 80: 6-37.

Shalev, Michael, Peter Ladefoged and Peri Bhaskararao. 1994. “Phonetics of Toda.” *PILC Journal of Dravidian Studies* 4(1): 19-56.

Spajić, Sinĭša, Peter Ladefoged and Peri Bhaskararao. 1994. "The rhotics of Toda." *UCLA Working Papers in Phonetics* 87: 35-66.

Steever, S. B., ed. 1998 *The Dravidian Languages.* Routledge. London.

Steriade, Donca. 1993. "Closure, release and nasal contours." In *Nasals, nasalization, and the velum*, ed. by M. Huffman and R. Krakow. Academic Press, San Diego: 401-470.

Steriade, Donca. 1995. "Underspecification and markedness in phonology." In *Handbook of Phonology*, ed. by J. Goldsmith. Blackwell, Oxford.

Steriade, Donca. 1999. "Phonetics in Phonology: the case of laryngeal neutralization." In *Working Papers in Phonology 2*, ed. by M. Gordon. University of California, Los Angeles.

Steriade, Donca. To appear. "Directional asymmetries in place assimilation: a perceptual account." In *Perception in Phonology*, ed. by Elizabeth Hume and Keith Johnson. Academic Press, San Diego.

Stevens, Kenneth N. 1989. "On the quantal nature of speech." *Journal of Phonetics* 17: 3-45.

Stevens, Kenneth N. 1998. *Acoustic Phonetics.* MIT Press, Cambridge, MA.

Stevens, Kenneth N. and Sheila E. Blumstein. 1975. "Quantal aspects of consonant production and perception: A study of retroflex consonants." *Journal of Phonetics* 3: 215-233.

Stevens, Kenneth N., S. Jay Keyser and Haruko Kawasaki. 1986. "Toward a phonetic and phonological theory of redundant features." In *Invariance and Variability in Speech Processes*, ed. by J.S. Perkell and D. Klatt. Lawrence Erlbaum Associates, New Jersey: 426-463.

Stevens, Kenneth N. and S. Jay Keyser. 1989. "Primary features and their enhancement in consonants." *Language* 65: 81-106.

Stone, Maureen. 1991. “Towards a model of three-dimensional tongue movement.” *Journal of Phonetics* 19: 309-320.

Thomas, Kimberly. 1997. “EPG and aerodynamic evidence for the coproduction and coarticulation of clicks in IsiZulu.” In *Proceedings of the 5th European Conference on Speech Communication and Technology,* ed. by G. Kokkinakis et al. University of Patras, Greece: 1: 379-382.

Turner, Margaret Mary and J. Gavan Breen. 1984. “Akarre Rabbit Talk.” *Language in Central Australia* 1: 10-13.

Weismer, G. 1980. “Control of the voicing distinction for intervocalic stops and fricatives: Some data and theoretical considerations.” *Journal of Phonetics* 8: 427-438.

Wilkins, David L. 1989. *Mparntwe Arrernte (Aranda): Studies in the structure and semantics of grammar.* Ph.D. dissertation. Australian National University, Canberra.

Wright, Richard. 1996. *Consonant Clusters and Cue Preservation in Tsou*. Ph.D. dissertation. University of California, Los Angeles.

Zipf, G.K. 1949. *Human Behavior and the Principle of Least Effort.* Addison-Wesley, Cambridge, MA.

Zue, Victor W. 1976. *Acoustic Characteristics of Stop Consonants: A Controlled Study*. Ph.D. dissertation. MIT, Cambridge, MA.

Zue, Victor W., S. Seneff and J. Glass. 1990. “Speech database development at MIT: TIMIT and beyond.” *Speech Communication* 9: *351-356.*