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TOPICS IN THE PHONOLOGY AND PHONETICS
OF COATZOSPAN MIXTEC

by

Henry James Gerfen, Jr.

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF LINGUISTICS

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Henry James Gerfen, Jr.

entitled Topics in the Phonology and Phonetics of Coatzospan Mixtec

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

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SIGNED:

Acknowledgments

First, I thank my committee. They have been magnificent. To my advisor, Diana Archangeli, I am deeply indebted professionally and personally. She has pushed me to my limits in all the right ways. She has supported me personally, academically, and financially. She has encouraged me to learn to ask my own questions and to pursue them with rigor. I am proud to have her as a teacher and a friend. I thank Dick Demers for sparking my interest in phonetics, for his kindness, for securing funding that allowed me go to the field when things looked their bleakest, and for his house and Tortie and Cato. I thank Terry Langendoen for returning to his phonological roots, for his close reading, and above all, for his interest in indigenous America. A special thanks also to Mike Hammond, who, though not on this committee, has contributed immeasurably to my development as a phonologist and whose feedback has never failed to improve my work.

Thanks also to other faculty who enriched my graduate life: Merrill Garrett, Kerry Green, Jane Hill, Eloise Jelinek, Simin Karimi, Adrienne Lehrer, Dick Oehrle, Sue Steele, and Ofelia Zepeda. Special thanks to Andy Barss and Molly Diesing for great classes and personal support. I also thank Mary Beckman for her lab-phon class and for opening her lab to me at the 1993 Institute. Also Janet Pierrehumbert and Donca Steriade whose classes at the Institute were instrumental to my thinking. I gained much from Keith Johnson's phonetics class and Ian Maddieson's seminar. I thank Peter and Jennie Ladefoged for their support and generosity. And thanks to Bob Hausmann and Kemp Williams, who first got me interested in linguistics.

I thank my fellow students and friends, especially J. Ann, D. Basilico, T. Bourgeois, A. Ciszewska, T. Craig, C. Fitzgerald, A. Fountain, R. García, A. Heiberg, S.H. Hong, J. Lemus, J. Meyers, D. Meador, R. Mejía, J. Mohammad, A. Moina, J. Mugane, S. O'Connor, D. Ohala, L. Peng, P. Pérez, M. Sanz, C. K. Suh, K. Suzuki, J. Tsay, W. Wiswall, and, most of all, Pilar Piñar for all the shop talk and for knowing how to leave shop talk behind. Thanks also to E. Dyckman and especially Rosemary Emery for the wonderful work she does for UA grad students. Thanks to my friends and colleagues Megan Crowhurst and Yetunde Laniran at UNC for feedback and support--and to Yetunde for formatting help and for breaking and repairing my computer many times. Thanks to Heidi Fleischhacker for her help with the appendix.

I am deeply grateful to Pris Small for her help with Mixtec and for introducing me to the Mixtec community. Thanks to the Grumkas for giving us a family in Tucson, especially John and Elaine for their love and generosity. Thanks also to Rosa Morillas and Inés Antón and Geert Geesink for their unconditional friendship and too many good times. Finally, a very special thanks to all my parents, Henry and Maggie Gerfen and Connie Manson, for their love and for always supporting my academic addiction, and also to my Spanish family, especially Pepe and Ana.

Dedication

This dissertation is dedicated to the people of San Juan Coatzospan, whom I have the priviledge of knowing and with whom I have had the honor of working. I especially acknowledge a number of friends in the Coatzospan community: Ndʒau Piña, Mari Piña, Liʔⁱta Piña, Jaime Acosta, Gabriela Acosta, María Acosta, Efraín Campanela, Alejo Cayetano, Juan Ramírez, and, of course, Manuel. Their kindness, generosity, and help have contributed immeasurably to my knowledge of their language, deepened my appreciation for their culture, and enriched the quality of my life. I hope that this dissertation can begin to give back some of what they gave to me.

Finally, this dissertation is also dedicated to my wife, Pilar, for her strength and support in a very tough year, and to the memory of my mother-in-law, Ana Larrubia.

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ABSTRACT

This dissertation examines the phonology and phonetics/phonology interface in Coatzospan Mixtec (CM). I focus on two major prosodies, glottalization and nasalization, in CM. First, I provide detailed phonological analyses of both within the context of Optimality Theory, OT (Prince and Smolensky 1993). This is important because often the treatment of a subset of data obscures more problematic aspects of a system. For example, the analysis of nasalization extends our understanding of how constraints can combine in a grammar. I motivate the conditional union of two Alignment (McCarthy and Prince 1993a) constraints to characterize attested patterns of root nasality, while ruling out impossible forms. The treatment of glottalization explores the implications of freedom of input in OT. I show that we cannot equate *input* with *underlying*; encoding the traditional sense of underlying representation requires viewing UR's as sets of optimal inputs lexical items.

Regarding the phonetics/phonology interface, I pursue dual goals. Chapter 3 extends Grounding (Archangeli and Pulleyblank 1994a) to the *opportunistically grounded* relation between glottalization and stress. Although not inherently sympathetic to stress, glottalization is optimally realized under stress in the phonology of CM. Chapter 4 extends grounding by using sequential grounding (Smolensky 1993) to characterize the behavior of opaque consonants.

Second, building on research in phonetic implementation (Pierrehumbert 1980, Keating 1990b), I show that a phonologically specified [+constricted glottis] must be implemented for only a part of the duration of the specified vowel. Similarly, orality targets in CM fricatives are also implemented at segment edges. The data support a view where targets are temporally located within segments (Huffman 1989). However, the location of targets may vary from edge to edge. Voiced fricatives implement orality upon release; voiceless fricatives do so at the onset of closure. The data also argue for a more complex notion of the relationship between phonetic data and phonological information than that of Cohn (1990). Partial implementation of a feature in a segment does not entail the phonetic rather than phonological presence of that feature. Phonetic data must be interpreted in the context of the phonological system from which they derive.

CHAPTER 1 INTRODUCTION*

1. Overview

This dissertation focuses on two major issues--vowel glottalization and nasalization--in the phonology and phonetics of Coatzospan Mixtec (henceforth CM). CM is an Otomanguean language currently spoken by roughly 2000 people (Small 1990in the village of San Juan Coatzospan, which is located in the Sierra Mazateca of northern Oaxaca, Mexico.[1] Though Mixtec constitutes a major branch of the Otomanguean family, the so-called dialects are most appropriately viewed as distinct languages. According to Josserand (1982), there are at least 22 mutually unintelligible varieties of Mixtec. For its part, CM is among the most isolated.

The village of San Juan is located high in the mountains and is surrounded entirely by Mazatec speaking communities. Only two other Mixtec languages exhibit over a 25% rate of mutual intelligibility with CM (Josserand 1982). Though it is not entirely clear how this group of Mixtecs came to settle in what is a Mazatec speaking area, their isolation has given rise to special properties not shared by other varieties of the language. Major

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* This research was funded in part by NSF-FAW grant #BNS9023323 to Diana Archangeli as well as by graduate student grant support from the College of Social and Behavioral Sciences (1995) and additional support from the Office of the Dean of Research at the University of Arizona (1994).

[1] Some village residents have settled semi-permanently in Puebla and in Mexico City, though almost all of these people retain strong ties to the village, coming and going at regular intervals, depending on the season.

elements of both the phonology of vowel glottalization and nasalization under focus in this study are, to my knowledge, unique to CM among the Mixtec languages.

The data used in the study derive from my field research, conducted in Mexico in the Summer of 1994, with brief follow up work in November, 1994 and in Tucson with one speaker in the Spring of 1995. As is true of many Native American languages, both the phonology and phonetics of CM phonology are largely undocumented. With the exception of one short paper (Pike and Small 1974), there exist no primary data on the phonology of the language. One of the goals of the dissertation is thus to help remedy this situation. Consequently, besides the studies of glottalization and nasalization that comprise the bulk of the text, I also include a chapter offering a general overview of the segmental phonology and phonetics of the language, including inventories of consonant and vowel contrasts, spectrograms, and palatograms made in the field.

I take the position that such basic investigation of underdescribed languages is necessary if we are to test putative phonetic and phonological universal claims across a range of linguistic data. One of the central concerns of contemporary linguistic research is the search for universal principles and properties common to all human languages. As Hale (1992) notes, language diversity is critical to linguistic investigation in that it provides researchers with a fertile testing ground for putatively universal hypotheses, given the multitude of ways in which individual languages can vary. In a very direct sense, then, linguistic diversity constitutes the fundamental wealth of the field. At the same time, we live in a world of ever decreasing linguistic diversity. Indigenous languages are disappearing at an alarming rate (see Krauss 1992), while the lack of documentation and explicit description render their loss irrevocable for linguistic investigation. For the moment, it appears that CM is not threatened with immediate extinction. Families use the language almost entirely for home life. Announcements are made over the village public address system in CM. Public life in the small village shops proceeds in CM. And all of the young children that I encountered acquire CM as their first language. Nevertheless, Spanish/CM bilingualism is almost universal among people under forty, and there is neither an accepted standard orthography nor a body of written texts in the language.[2] At the same time, technological advances have recently brought electricity (and thus Spanish language television) and telephone service to the village.[3] As with any isolated, minority language that is spoken by relatively few people, I suspect that the long term prospects for CM are not entirely bright.

As I note above, my hope is that this research can serve both descriptive and theoretical ends. First, I attempt to provide explicit and

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[2] Priscilla Small has developed a reading primer, but this is not used in the school.

[3] While I was there, the first satellite dish arrived, and within six months, the Mexican government completed the first paved road to reach the village.

detailed descriptions of much of the phonology and phonetics of CM, in order to bring new language data to the field in general that will be of use and interest independently of the particular theoretical issues that I address and conclusions that I draw. At the same time, I argue that the phonetics and phonology of CM nasalization and glottalization raise significant theoretical questions for a number of domains within phonological theory and for the relationship between phonology and phonetics. I pursue two goals in this area. First, I explore the phonological properties of both glottalization nasalization in the context of an Optimality Theoretic view of phonology (cf. Prince and Smolensky 1993, McCarthy and Prince 1993b), attempting to provide an explicit account of a large part of the phonology of a single language. Secondly, I explore implications of the CM data for the interface of phonetics and phonology. A particular goal in this area is to relate quantitative phonetic data to the traditionally categorical domain of phonology, a project that has been taken up in recent years by researchers such as Pierrehumbert (1980), Pierrehumbert and Beckman (1988), Keating (1988, 1990a,b), Huffman (1989, 1993), and Cohn (1990, 1993a) .

As an example of the nature of this research, if we consider the issue of nasalization alone, we see that CM is remarkable from a cross-linguistic perspective. The language contains contrastively nasalized vowels, which, nevertheless, exhibit a regular pattern of distribution within morphemes. Additionally, vowels are predictably nasalized following (though not preceding) nasal consonants. Full nasal stops and prenasalized stops are contrastive. And finally, CM exhibits a morpho-phonological harmonic process of regressive vowel nasalization which marks the second person familiar--a process which skips over some but not all intervening consonants. The richness of the use of nasality in CM becomes particularly salient when we consider, for example, Cohn's (1990) cross-linguistic investigation of phonological and phonetic processes of nasalization. Cohn examines languages with phonemically nasalized vowels (French), contextually nasalized vowels (English), and trans-segmental nasal harmony (Sundanese). In Coatzospan Mixtec, all of these phenomena are exhibited in a single language.

Despite the fact that CM nasalization has received some attention in the theoretical literature (see Poser 1980, Cole 1987, Trigo 1988, Piggott 1992), as I note above, the only original source of CM nasal data is a short sketch of CM phonology, the primary focus of which is tonal downstep (Pike and Small 1974). Yet no previous analysis has attempted to integrate the full range of nasalization facts in the language. All have focused primarily on the treatment of second-person familiar nasalization. In the discussion of nasalization in Chapter 4, I incorporate nasal airflow data collected in the field. From a descriptive perspective, these data allow me to provide the first detailed, phonetic description of nasalization in the language. By contrast to data collected via transcription or even audio recording, flow data provide a more precise indication of velum activity both in terms of the degree of nasalization and in terms of its temporal extent. Working within Optimality Theory, I show that a constraint-based analysis affords a unified account of both the distribution of nasality within CM morphemes and of the unexpected (and previously not discussed) absence of a number of expected patterns. At the same time, the nasal flow data yield surprising evidence of phonetically nasalized voiceless fricatives, and raise significant questions regarding the division of labor between the phonological and phonetic components of the linguistic grammar and the assignment of phonetic targets for phonological features.

The remainder of this introduction is structured in the following manner. In §1.1, I preview the overall structure of the dissertation, summarizing the main points of each chapter. In §1.2, I lay out my phonological assumptions and those ragarding the relationship between phonology and phonetics, as they pertain to the ensuing chapters. In §1.3, I provide information regarding the language consultants used in the study and discuss the particulars of the experimental set-up by which I was able to collect nasal airflow data in the field.

1.1 Overview of chapters

The body of this study consists of three chapters. Chapter 2 provides an overview of the phonology of Coatzospan Mixtec. This serves two purposes.

First, it supplies the reader with an understanding of the morpheme structure and of the segmental contrasts of the language. Secondly, it provides the necessary context for the more detailed treatments of the two prosodies--glottalization and nasalization--in Chapters 3 and 4, respectively. In Chapter 2, I describe the canonical shape of CM roots, motivating the traditional notion of the so-called Mixtec *couplet*, a term I will use interchangeably with *root* throughout this study. I then provide data illustrating the respective consonant and vowel contrasts of the language. I end Chapter 2 with a discussion of palatalization, an important element of the segmental phonology of CM. Though a more detailed treatment of palatalization lies outside of the scope of the studies of glottalization and nasalization under focus here, its inherent interest merits an explicit description.

Chapter 3 focuses on vowel glottalization (i.e. laryngealization), a long-standing issue in pan-Mixtec work (see MacCaulay and Salmons 1995). This chapter provides a detailed examination of both the phonetics and phonology of the phenomenon. I divide the chapter into three major areas of discussion. First, I address the basic question of whether glottalization reflects the phonetic implementation of a vowel feature, or whether the presence of glottalization might more appropriately be characterized by including a glottal stop in the consonant inventory of the language. Here, I provide both phonetic, phonological, and external evidence in support of the former view. The second issue regards the behavior of glottalization in the phonological system. Glottalization surfaces both contrastively and predictably (a property unique to CM among the Mixtec languages), while at the same time both predictable and contrastive glottalization are licensed only under stress. Within the context of Optimality Theory, I argue that the dual constrastive and predictable role of glottalization can be shown to follow from the interaction of three constraints. I also argue that the system provides a vivid illustration the way in which Optimality challenges notions of underlying representations in standard phonological theory, In particular, I focus on the distinction between the Optimality Theoretic notion of input and the tradional concept of UR, motivating a view of URs as sets of optimal input forms.

I conclude Chapter 3 with a discussion of the interface of the phonology and phonetics of glottalization. In this section, I address the role of grounded path conditions (Archangeli and Pulleyblank 1994a), i.e. feature cooccurrence constraints, in characterizing the location of glottalization. Secondly, I examine the relevance of the CM glottalization facts to claims about how phonological features are interpreted phonetically. In particular, I focus on Cohn's (1990, 1993a) claim that phonologically specified features are implemented throughout the entirety of the segment for which they are specified. I argue that the CM glottalization data show this position to be overly restricted in that the CM facts require that phonologically specified [+constricted glottis] be implemented throughout only a part of the vowel for which it is specified. In turn, I suggest that the implications of such a view are such that the claim that certain patterns of phonetic implementation are indicative of the difference between phonological specification or underspecification is not tenable (cf. Cohn 1990, 1993a). Rather, I argue that phonetic data must be interpreted in the context of the phonological system of the language at hand.

Chapter 4 examines the complicated distribution of nasality both within CM roots and under the morphological process of second person familiar nasalization. As in the discussion of glottalization in Chapter 3, I provide a detailed description of both the phonetics and phonology of nasalization in the language, using nasal airflow traces in order to provide a clear picture of the facts that must be accounted for. I then argue for an Optimality Theoretic phonological analysis of the range of CM nasalization facts, unifying the treatment of both lexical vowel nasalization and the expression of phonotactic constraints on the distribution of root nasal consonants in a single hierarchy of constraints. In so doing, I argue that the language motivates a conditional interaction between two constraints in the hierarchy, a move which expands the use of Boolean operations on constraints, adding conditional constraints to local conjunction (Smolensky 1995, Crowhurst and Hewitt 1995, Suzuki 1995, Archangeli and Suzuki 1995) and disjunction (Kirchner 1995a) as mechanisms by which constraints may be combined in a grammar.

In the final section of the Chapter 4, I return to the issue of phonetic implementation. Here, I examine the implementation of [nasal], paying special attention to the phonetics of opacity and transparency to regressive nasal harmony. This section provides further support for the view of phonetic implementation taken in Chapter 3. In particular, I provide surprising evidence for coarticulatory overlap of velum lowering during both voiced and voiceless fricatives in the context of nasalized vowels, contrary to the claims of Ohala and Ohala (1993) and Cohn (1993b). I argue that the data are accounted for in a relatively straightforward fashion if we assume that the orality targets for these segments are located at the end of voiced fricatives but at the onset of voiceless fricatives. Finally, I return to the issue of the complexity of extracting phonological information patterns of phonetic implementation. In Chapter 5, I briefly summarize the results of the study.

1.2 Phonology and phonetics: background assumptions

This section details the guiding assumptions regarding phonetics, phonology, and the relationship between the two that I take as a point of departure. In §1.2.1, I focus on the distinction between phonology and phonetics in the grammar and outline the broad characteristics of each. In §1.2.2, I state my phonological assumptions, providing a brief description of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993b) and of the expression of Faithfulness in terms of Correspondence relations

(McCarthy and Prince 1995, Orgun 1995, McCarthy 1996) between input and output. In §1.2.3, I lay out the model of phonetic implementation that I will assume in the discussions of both glottalization and nasalization in the chapters which follow, focussing on the windows model of Keating (1990b) and on the predictions of Cohn (1990, 1993a) regarding the phonetic implementation of phonological features.

1.2.1 On the relationship of phonology and phonetics

Traditionally, although both have concerned themselves with the study of human language sounds, the natures of phonological and phonetic research have differed considerably. One fundamental methodological difference lies in the quantitative domain. Phonology has traditionally been viewed as the study of the abstract system or linguistic grammar that characterizes our knowledge of the language we speak (as a system of "rules") and that underlies regularities in the types of rule systems found across languages. By contrast, phonetic studies focus on phenomena such as lip, jaw and tongue movement during speech, the aerodynamics of stop voicing, or muscle activity during speech production. Phonological data are more abstract, and phonological features are categorical symbols such as [+voice] and [-voice]. Phonetic data are gradient, quantifiable and measurable in highly precise ways. What a phonologist encodes as a binary contrast between [+voice] and [-voice] stops might be instantiated phonetically via the presence or absence of vocal cord vibration during closure. But it might also (or alternatively) be implemented in terms of voice onset time (VOT) distinctions, F0 excursions on following vowels, lengthening effects on preceding vowels, and closure duration in intervocalic position (cf. Keating, Linker and Huffman 1983, Keating 1984, Kingston and Diehl 1995).

As Cohn (1990) notes, there is an implicit derivational relationship between phonology and phonetics. For example, we can view the expression of contrast in terms of categorical feature distinctions as a part of the phonology, while taking the position that the phonetics implements such categorical information in time and space. I adopt this basic position in this study. However, this is not to suggest that phonetics must be viewed as automatic or universal (Chomsky and Halle 1968) and consequently not a part of the linguistic grammar. Recent research has shown that phonetic implementation rules can be language particular. For example, Van Reenan (1982) discusses systematic differences in the timing of velum lowering for constrastively nasalized vowels in European and Canadian French. If phonetic implementation were automatic and universal, such findings are unexpected. Similarly, Lubker and Gay (1982) show that patterns of anticipatory lip rounding vary systematically for adult speakers of English and Swedish, with the onset of coarticulatory rounding initiating roughyl 100 milliseconds before the round vowel /u/ for English speakers and up to 500 milliseconds before /u/ for Swedish speakers. Such data argue strongly for a view in which at least some aspects of phonetic implementation must be taken to lie within the context of the linguistic grammar. Anticipating the discussion in §1.2.3 below, I further assume that the process of phonetic implementation involves a level of phonetic representation in which static phonological representations are implemented in time and space.

A second important aspect of the relationship between phonetics and phonology that is explored in this study involves the role of phonetically motivated or grounded (Archangeli and Pulleyblank 1994a) constraints in determining the well-formedness of surface phonological strings. Just as the phonetics interprets phonological specifications, I assume that phonologies respond to sympathetic and antagonist relations between the phonetic correlates of phonological features. That is, we can think of the phonetics as circumscribing a range of possible constraints on feature interactions that might be utilized by a phonological system. As I argue in Chapter 3, I extend the notion of grounding proposed by Archangeli and Pulleyblank, suggesting that constraints may interact with features in ways that are not ungrounded but are not obviously grounded either.

1.2.2 Phonological assumptions

This section focuses on two principle issues. First, I lay out my view of the architecture of the phonological grammar, adopting a correspondence based version of Optimality Theory. Secondly, I make explicit my assumptions regarding phonological features and their representation.

1.2.2.1 Optimality

In the ensuing chapters, I adopt an Optimality Theoretic (Prince and Smolensky 1993, McCarthy and Prince 1993b) view of phonology. As is now well known, Optimality Theory differs from both linear (i.e. SPE) and non-linear generative phonology in its use of ranked and violable constraints as a means of characterizing what have traditionally been treated as rule-based phonological phenomena. Constraints are organized in hierarchies of strict dominance, and optimal (i.e. attested) surface forms are evaluated in comparison with other candidate forms and selected on the basis of the degree to which they best satisfy the ranked constraints. Importantly, since all constraints are in principle violable, no single candidate will necessarily satisfy all the constraints of a hierarchy. Thus, that a grammar determines a candidate to be optimal for a given set of constraints does not mean that the candidate must be perfect, but rather, that it must be better than its competitors. For their part, constraints are assumed to be strictly ranked such that multiple violations of a lowly ranked constraint (or constraints) will always be less penalized by the grammar than a single violation of a more highly ranked constraint. This is illustrated schematically in (1) for a hypothetical set of constraints {A, B, C} ranked in descending order A >> B >> C.

(1) **Schematic tableau**

INPUT	Constraint A	Constraint B	Constraint C
☞candidate 1			*****
candidate 2		*!	▨
candidate 3	*!	▨	▨

In (1), I adopt the standard convention of comparing candidates in a tableau format. The rightmost column contains an input form and the candidate output forms with which it is paired. The constraints are ordered from left to right across the top of the tableau. Constraint violations are marked by the presence of asterisks, with one asterisk assigned each time a particular constraint is violated. Exclamation points signal fatal constraint violations--the point at which a candidate is eliminated as non-optimal. For ease of interpretation, the pointing finger indicates the optimal candidate selected under the grammar, while shaded cells indicate that a higher, fatal violation has eliminated a candidate from consideration. Here, note that candidate 1 is optimal, despite having incurred five violations of Constraint C. Under the assumption of strict dominance, the fact that candidate 2 violates the more highly valued Constraint B, while candidate 3 violates Constraint A, rules these candidates out as non-optimal.

I assume a two-level Optimality Theory in which a function GEN generates a potentially infinite set of paired input-output strings. Following Prince and Smolensky (1993), I adopt the basic Optimality Theoretic assumption of richness of the base (see also discussion in McCarthy 1996), i.e. the assumption that there are no restrictions on possible input forms and thus on possible pairings of input/output candidates. A grammar is comprised of two broad types of ranked constraints: 1) constraints holding of surface representations and 2) so-called faithfulness constraints holding of relations between input and output pairings. The function of surface constraints is to define the set of well-formed surface phonological strings in a given language (and exclude impossible surface forms). An example of one such constraint, which I employ in Chapter 3, is CG/STR, the function of which is to limit the association of [+constricted glottis] to stressed vowels only. By contrast, the function of faithfulness constraints is to discourage change between input and output forms.[4]

Within Optimality Theory, faithfulness constraints were first proposed in terms of the Parse/Fill family of constraints of Prince and Smolensky (1993) and extended and refined along these lines by various other researchers (cf. Archangeli and Pulleyblank 1994b, Pulleyblank 1994, Itô, Mester, and Padgett 1995). In this study, I adopt a view in which faithfulness is expressed in terms

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[4] Following Orgun (1995), I assume that only faithfulness constraints can hold of input-output relations, thus circumventing the problem of constraints

of Correspondence relations between input and output forms (McCarthy and Prince 1995, McCarthy 1996, Orgun 1995). Following McCarthy and Prince (1995), I assume the definition of correspondence in (2).

(2) **Correspondence** (McCarthy and Prince 1995)

> Given two strings S_1 and S_2, **correspondence** is a relation $\Re$ from the elements of S_1 to those of S_2. Elements $\alpha \in S_1$ and $\beta \in S_2$ are referred to as **correspondents** of one another when $\alpha \Re \beta$.

Faithfulness to correspondence relations can be expressed along a number of dimensions. For our purposes, I will make use of two particular constraints on correspondence relations, as they pertain to input-output fidelity between features.[5] The first of these involves the adoption of McCarthy and Prince's (1995) Identity constraint family (Ident). Identity constraints enforce input-output feature identity between corresponding segments. The general schema for expressing Identity relations is provided in (3).

(3) **Ident(F)** McCarthy and Prince (1995)

> Let α be a segment in S_1 and β be a segment in S_2.
> If α is $[\gamma F]$, then β is $[\gamma F]$.

The second involves extending the so-called MAX family of constraints to obtain of features as well as segments. For McCarthy and Prince, MAX

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requiring arbitrary input-output mappings.

[5] See McCarthy and Prince (1995) for a more complete exposition of correspondence constraints. See also Orgun (1995) for a slighly different approach to feature correspondence.

constraints enforce a one-way correspondence relation between input and output segments, as seen in (4).

(4) **MAX** (McCarthy and Prince 1995)

Every segment of S_1 has a correspondent in S_2.

As I discuss in Chapter 4, I assume that feature faithfulness can be expressed directly in terms of MAX constraints for features, as well as via identity constraints mediated by segmental correspondence. Under this view, I assume the extension of MAX to features as follows.

(5) **MAX[F]:** Every feature [F] in S_1 has a correspondent in S_2.

In traditional terms, MAX constraints can be viewed as pressures in the grammar that penalize the "deletion" or removal of information. Though they will not become relevant to the discussion below, their counterparts, DEP constraints, enforce correspondence in the mapping from output to input, thus penalizing the "addition" of information to output forms that is not present at input.

Though I return in detail to this issue in Chapter 3, the adoption of a correspondence based view has significant consequences for the traditional concept of underlying representations in phonology. Specifically, if faithfulness constraints militate for input-output identity, then the basic tenent of removing predictable information from underlying representations (only to restore it in the phonology) comes under direct attack in a correspondence based grammar. All else being equal, the best input for any optimal output form will be an input that is identical with the attested output form. That is, faithfulness actively rewards the incorporation of predictable information, such as predictable feature specification, at input (cf. Steriade 1995, Inkelas 1994, Kirchner 1995b), a move in direct conflict with the traditional ban of such information at the level of underlying representation.

1.2.2.2 Features and representations

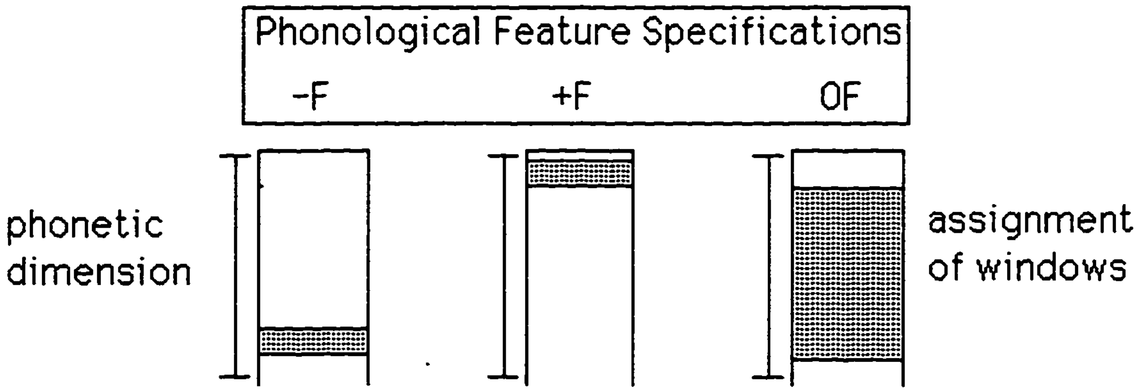
Optimality Theory provides a means of selecting optimal input-output pairs in terms of ranked and violable constraints. It does not, however, specify the nature of the representations that are compared. In the analyses that follow, I assume an autosegmental (Goldsmith 1976) view of phonological features. I further assume that features are organized hierarchically along the lines of feature geometric representations (cf. Clements 1985, 1989, Sagey 1986, McCarthy 1988, Hume 1992, Clements and Hume 1995), though none of my claims will rest crucially on the adoption of a particular geometry. I also assume along traditional lines that phonological features are either monovalent or binary. In particular, I formalize the analyses in Chapters 3 and 4, respectively, in terms of a binary [+/- constricted glottis] feature as the phonological encoding of glottalization (i.e. laryngealization or creaky voicing) for vowels, and in terms of a monovalent [nasal] feature encoding the contrast between phonological nasality and orality.

Given the Optimality Theoretic notion of richness of the base, i.e. the absence of restrictions on the possible set of input forms generated by GEN, I do not assume that redundant phonological information must be unspecified at input (cf. Kiparsky 1982, Archangeli 1984, Archangeli 1988, Steriade 1987). Recent work in constraint based systems has, in fact, openly challenged the the obligatory removal of predictable information from underlying representations (cf. Steriade 1995, Inkelas 1994, Kirchner 1995b, Itô, Mester and Padgett 1995). It is important to note, however, that there are two ways in which we can view the incorporation of predictable information in input strings. One involves making the assumption that traditionally predictable features such as the [+voice] quality of sonorants need not be eliminated by fiat from input representations, such that the possible presence or absence of such information will emerge from the constraint hierarchy. A second position is that all predictable information, including for example, non-categorical phonetic values such as ranges of duration expressed in milliseconds, may be formally encoded at input (cf. Kirchner 1995b). Without a doubt, the question is significant in that it raises questions for the traditional distinction between the domains of phonology and phonetics. For the purposes of this study, however, I assume the more traditional position, i.e. that predictable phonological information in the form of categorical binary and monovalent features need not be underspecified at input. For its part, as I note above, phonetics can be reflected in the constraint hierarchy to the extent that phonetically sympathetic and antagonistic relations can be encoded in terms of constraints on feature combinations (see Archangeli and Pulleyblank 1989, 1994a).

1.2.3 Phonetic implementation

Building on the ground-breaking work of Pierrehumbert (1980), I assume a level of phonetics in which phonological features are assigned phonetic targets and in which targets are linked up via a process of interpolation (see also Keating 1988, 1990a,b, Shih 1988, Pierrehumbert and Beckman 1988, Huffman 1989, Cohn 1990, Laniran 1993, among others). This process entails a mapping from the static and timeless representations of phonology to a level of phonetic representation which allows for the implementation of these features in time and space. In particular, I adopt the Windows model of Keating (1990b), in which phonetic targets are expressed in terms of ranges of possible values along a given articulatory or acoustic dimension. In broad strokes, under Keating's model, positive and negative feature specifications are implemented as narrow windows for a given phonetic dimension, while unspecified values are implemented in terms of wide windows, thus allowing for segmental context to determine the phonetic value of the unspecified segment via interpolation from adjacent windows. This assignment of windows, assuming a binary feature, is sketched in (6). For convenience, shaded areas represent the range of the window.

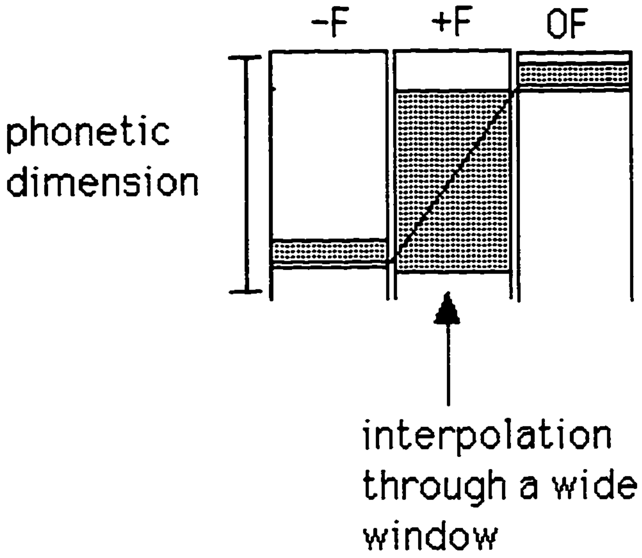
(6) **Assigning windows**



Note that positive and negative values for a feature implement narrow windows at the extremes of a given dimension, while the lack of a feature specification implements a wide window in which a broad range of values is possible.

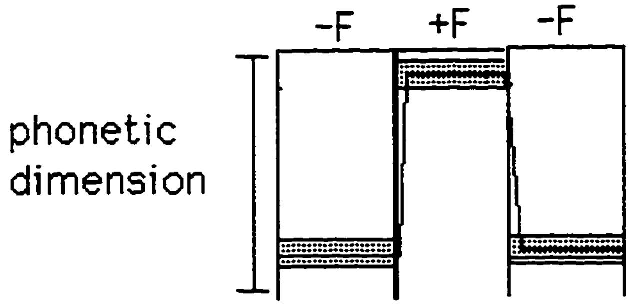
Phonetic coarticulation is modeled under the assumption that target windows are linked up via interpolation. This is shown schematically in (7), in which an unspecified segment surfaces between positive and negative specifications.

(7) Schematic view of interpolation



Here, note that the width of the window allows for a gradual change along the phonetic dimension in question. By contrast, narrow windows are predicted to trigger rapid changes along an articulatory dimension and to implement phonologically specified features in a constant or plateau-like fashion (see, especially Cohn 1990, 1993a for discussion of this issue).

(8) **Rapid transitions between narrow windows**



In broad strokes, the windows model provides criteria for distinguishing between the phonetic versus phonological presence of a feature. Phonological features are predicted to implement highly specific targets which would appear to remain constant throughout the duration of a segment. By contrast, phonetic coarticulation, as expressed by interpolation through wide windows, is predicted to be gradient. That is, wide windows should show no signs of implementing specific target values for a given phonetic dimension.

The model sketched above makes particular assumptions that will become relevant in a number of ways to the discussion of both the implementation of glottalization and nasalization below. In particular, binary features inherently permit a three way contrast in window types, with narrowness along two extremes of a phonetic dimension implementing positive and negative specifications and wide windows implementing the lack of specification.[6] This would seem to suggest that monovalent features should implement only a narrow window along one phonetic dimension--say velum lowering for [nasal]--and a wide window for absence of the feature. I do not adopt this position, however. Rather, as I discuss in both Chapters 3 and 4, phonetic implementation is best viewed in terms of the whole of the phonological system in which a feature is implemented. Thus, for a language such as English in which nasality is non-contrastive for vowels, the semantics of lacking a monovalent [nasal] specification are such that the phonetics implements the absence of [nasal] by constructing a broad window that permits coarticulatory overlap. By contrast, in a language such as Coatzospan Mixtec or French in which [nasal] plays a contrastive role for vowels, the absence of [nasal] is predicted to be implemented via the construction of a narrow window for a raised velum, i.e. as a target for orality.

A second implicit assumption in the sketches above is that windows extend throughout the duration of a segment. This is a prediction explicitly adopted by Cohn (1990, 1993a) in her cross-linguistic study of vowel nasalization (but see Huffman 1989, 1993). I take this position as a starting point for the discussion of the implementation of [constricted glottis] and [nasal] in CM. However, I will argue for a more finely grained approach under which phonological features may implement windows throughout only part

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[6] See Cohn (1990, 1993a) for extensive disucssion of this issue. See, also, Huffman (1989, 1993).

of the segment for which they are specified, a finding in line with, although not identical to, Huffman's (1989, 1993) model of landmarks for target assignment.

1.3 Speakers and data collection

In this section, I focus on the speakers who participated in this study and, in particular, on the collection and interpretation of the nasal airflow data employed in Chapter 4.

Acoustic, palatographic, and aerodynamic data were collected from seven CM speakers, labeled S1-S7. Four of these (S1, S2, S3, and S7) are female speakers ranging in age from 21 to approximately 45 years old. The three male speakers range in age from 23 to approximately 30 years old. Though all speak Spanish with varying degrees of proficiency, CM is the dominant and first language for each speaker, and is used in daily life both in and out of the home. The three female speakers S1, S2, and S3 were used in the nasal airflow study. I gathered acoustic data from all of the speakers, and the palatographic data were produced by S5 and S7 (male and female speakers, respectively).

Recordings in the field were made with a Shure, close talking unidirectional dynamic microphone on a Marantz PMD 222 portable cassette recorder. Palatographs were made in the following manner. Following the methodolgy described in Ladefoged (1993b), I made a mixture of equal parts of pharmaceutical charcoal powder and extra virgin olive oil. Using a small paint brush, I brushed the mixture onto the speaker's tongue. The speaker then pronounced a target word once and subsequently placed a small mirror in his or her mouth. Using a hand held Sony 8 millimeter video camera, I filmed the image of the hard palate as reflected in the mirror held by the speaker. The region of contact between the tongue and the palate is indicated by the black marks made via the transfer of the charcoal powder solution from the tongue. I then digitized the video image in a Macintosh computer at the University of Arizona.[7]

1.3.1 Nasal airflow

I chose nasal airflow as an indirect means of studying velum activity during speech in CM for three reasons. First, as noted by Cohn (1990), airflow studies allow for a non-invasive means of monitoring velum movement. Secondly, with the exception of work by Ladefoged and Maddieson (1996), little work of this type has been carried out in a field rather than a laboratory context. Third, although Pike and Small's (1974) original description of nasalization in CM has given rise to various proposals in the theoretical literature, no one had previously gathered detailed phonetic data regarding the actual implementation of nasalization in the language. This section discusses the means by which the data was collected and addresses the issue of the interpretation of nasal flow traces.

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[7] I thank Kerry Green for the use of his lab facilities, without which I would

1.3.1 Set up

I collected the data by using the MACQUIRER system, developed at the UCLA phonetics lab. The choice of this system, as compared with using a Rothenberg-type split flow mask (cf. Cohn 1990, Huffman 1989) was based on availability. The MACQUIRER system was designed for portability in order to be able to be used in field settings.[8] The system consists of a small metal box containing a pressure transducer that is connected to an 8-bit external A/D converter. Speakers place a small foam plug or nasal olive in their nostril (an E-A-R plug of the type used in audiology research), while wearing a close talking microphone connected to a tape recorder from which the signal is also fed to the A/D converter. The nasal olive is connected to the pressure transducer via a small, flexible tygon tube. As the speaker talks, the system samples and aligns the transducer's response to the nasal airflow (sampled at 480 Hz) with the audio signal (sampled at 11 kHz) and stores them on a Macintosh computer. Figure (9) provides a view of the set-up.

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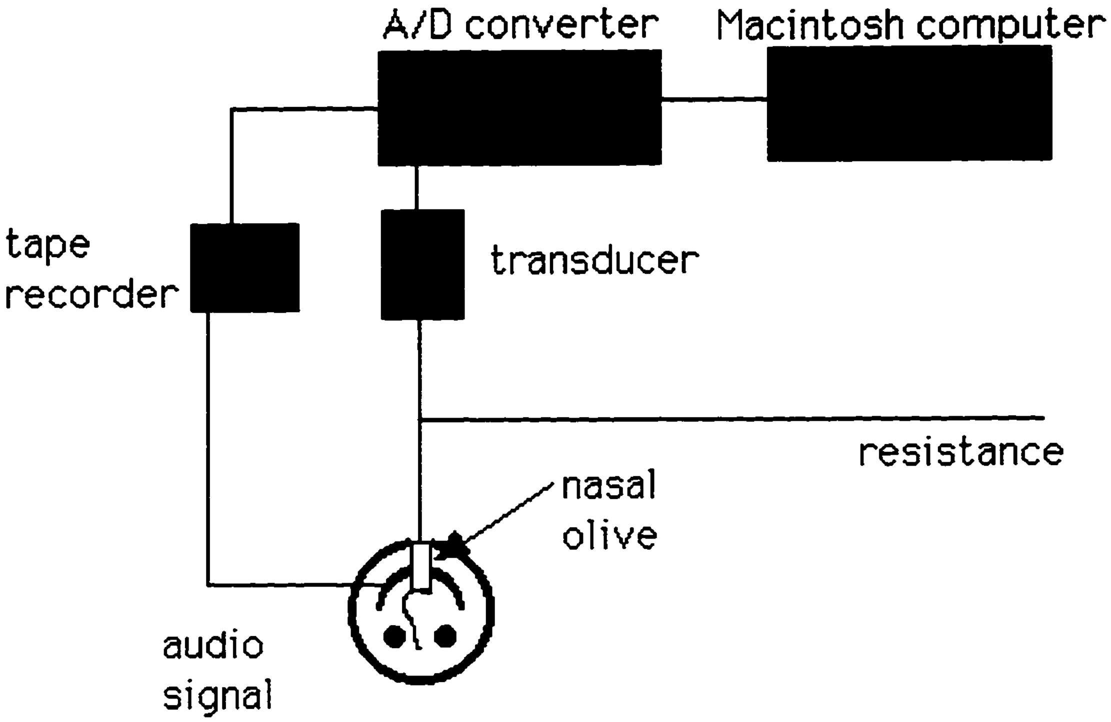
not have been able to digitize these images.

[8] See Ladefoged and Maddieson (1996) for more airflow and pressure data collected with this system.

(9) **Data collection set-up**



In order to avoid the problem of uncalibratable flow due to the lack of resistance at the open nostril, speakers closed off the unplugged nostril with a finger while speaking. As can be seen in (9), I provided a fixed resistance to flow by inserting a T in the tube between the olive and the transducer. The T was connected to a long, thin plastic tube (about three feet). Though I did not have a pump and was thus unable to calibrate the system in the field, I did have access to a pump at the the UCLA phonetics lab[9] and calibrated the system at 250 ml/sec of flow. Despite the fact that the response of the

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[9] I give special thanks to Peter Ladefoged for help with this task.

transducers can vary slightly with different weather conditions, I have provided a scale reflecting the UCLA calibration in order to give the reader a rough approximation of flow rate.

1.3.2 The Data

Following Cohn (1990, 1993a), the data were collected by having speakers repeat a target word in a non-nasal carrier phrase, ***KAʔU-U WORD TE-VAA*** 'I write WORD tomorrow'. Since CM has no standard orthography, each word was carefully reviewed with each speaker in order to guarantee that there was no misunderstanding as to what lexical item the speaker was being asked to produce. I presented the words to the speakers by using a modified version of Spanish orthographic conventions, with which the speakers were familiar. Given that the second person familiar is expressed by a process of nasalization, most of the forms that I selected are predicates (verbs and adjectives) that can be conjugated in the second person familiar so as to provide minimally contrastive pairs of nasalized and non-nasalized forms to aid in the interpretation of the data. I also selected some forms that contain lexically nasalized vowels in order to show that lexical nasalization is implemented in the same fashion of morphological nasalization. The list is provided in the Appendix. Though the data were not randomized, I did not present speakers with oral forms immediately preceded or followed by their nasal counterparts. Finally, speakers were somewhat uncomfortable with reading through the word list without making errors. To solve this problem, I recorded multiple tokens of a single item at one time before moving on to another word. As can be seen in the data presented in Chapter 4 and the Appendix, this did not seem to cause speakers to adopt a uniform strategy in their production of the multiple tokens.

1.3.3 Interpreting the data

Following the work of Cohn (1990, 1993a) and Huffman (1989, 1993), I use nasal airflow data as an indirect means of monitoring velum activity, under the assumption that the articulatory dimension of velum height and the phonological feature [nasal] stand in a fairly direct relationship. In simple terms, a lowered velum implements nasality, while a raised velum implements a phonological instruction for orality. All else being equal, we expect that the rate of air flow will increase as the velum is lowered and decrease as the velum is raised. Numerous factors complicate the situation, however. As noted by both Huffman (1989) and Cohn (1990), both glottal aperture and oral impedance will affect the overall rate of nasal airflow.[10] This means that a higher tongue body position, such as that of the vowels /i/ and /u/, will create more oral impedance than will the lower tongue body position of the vowel /a/ and, as a consequence, will trigger greater flow

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[10] See also Krakow and Huffman (1993) for a detailed discussion of these issues.

through the velo-pharyngeal port. To control for this potential confound, I have limited the data almost exclusively to tokens involving the three high vowels /i/, /u/, and /ɨ/.

As Huffman and Krakow note, changes in nasal airflow can also result from variations in glottal aperture rather than from adjustments of velo-pharyngeal port size. For example, voiceless sounds are realized with greater glottal width than are voiced sounds. Thus, a sudden shift in the pattern of flow may result entirely from a change in glottal aperture from a voiced to a voiceless state or vice versa. In order to control for this problem, especially as it pertains to the discussion of nasal flow present during the production of CM fricatives, I have been careful to provide minimal non-nasal contexts as a basis for comparison, in order to show that the observed nasal flow results from a different velopharyngeal port opening--i.e. a different velum position--for fricatives in the nasal context than in the oral context.

In this study, I use raw nasal flow data as a basis for analysis. This is different from the strategy of Cohn (1990) and Huffman (1989) who use filtered data. Cohn (1990), for example, filters her data by means of a root means squared (RMS) amplifier in order to smooth the flow trace and remove voicing energy from the nasal signal. A consequence of this approach is that any sudden pressure drops below baseline are reflected in the smoothed trace as positive flow, giving a smoother overall appearance to the data. A second consequence is that evidence of voicing is removed from the signal. In my data, we see both sudden pressure drops, corresponding in general to the release of oral closure, and voicing energy, due to the 480 Hz sampling rate of the nasal channel. The use of female voices, however, affords a clear view of the trajectory of nasal flow, despite the presence of voicing energy.[11] At the same time, the presence of voicing allows us to compare the relative presence or absence of voicing energy during the flow that appears on CM fricatives.

Though the technology made establishing a constant baseline a somewhat difficult task, as I have noted, I have pursued a strategy of providing minimally distinct nasal-oral forms. This task is made simpler by the fact that second person familiar nasalization allowed me to take non-derived items and nasalize them. I present the data in pairs of nasal and oral forms for each speaker, and in this manner am able to establish a non-nasal basis for comparison. As an example, consider the figure in (10) for S1.

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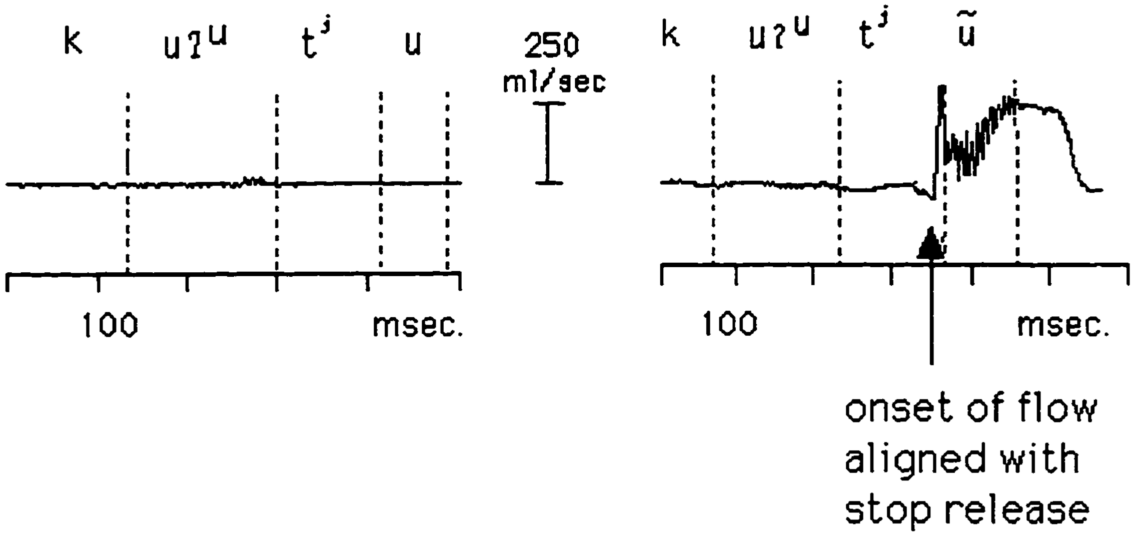
[11] I attribute this both to the higher fundamental frequency and the generally lower amplitude of the female voice, when compared to male voices. Note that the degree to which voicing is visible in the signal varies across the three speakers. For S1 and S3, voicing is clearly visible. For S2, voicing is less visible in many tokens.

(10) S1: comparison of oral and nasalized word



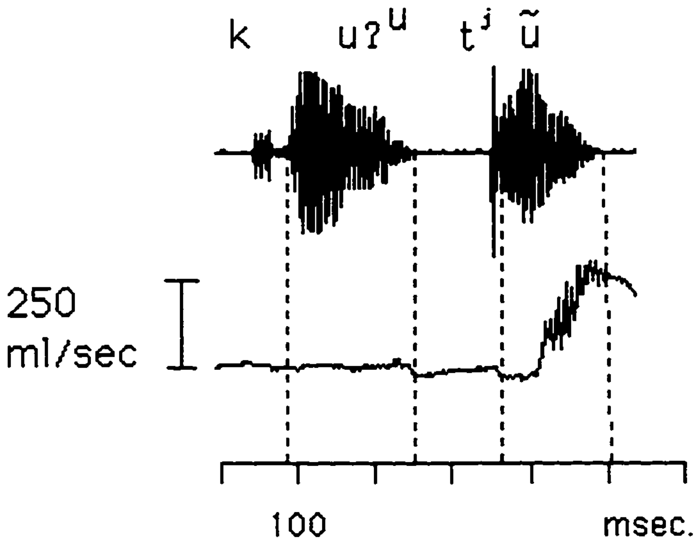
a) oral form

b) nasalized form

The figure provides an example of the contrast between an oral and a nasalized word: k*u*ʔ^{u}*t*^{j}*u* 'to plow, hoe' vs. *ku*ʔ^{u}*t*^{j}ũ 'you (fam) will hoe'. The form in (a) provides an oral form as a basis for comparison. Note the lack of change, i.e. the flatness, of the nasal airflow trace. By contrast, (b) provides an example of the second person familiar form of the same morpheme. Note that the onset of nasal flow appears as a sharp spike coincident with the release of the medial voiceless stop. We can attribute this spike to the wider glottal aperture of the release of the stop. Note also that voicing energy appears and flow drops slightly at the onset of the vowel; however, the rising trajectory of nasal airflow throughout the vowel is clear. That is, the vowel is nasalized throughout its entire duration.

Finally, the data were segmented by hand, using the waveform and, in more difficult cases, spectrograms to aid in the decision making process. An example is provided in (11).

(11) **Example of segmentation**



With this background, I begin in Chapter 2 with an overview of CM phonology.

CHAPTER 2 A PHONOLOGICAL SKETCH

2 Introduction

In this chapter I provide an overview of the basic phonological structure of Coatzospan Mixtec. This serves two purposes. First, it provides the reader with an understanding of the morpheme structure and of the segmental contrasts of the language. Secondly, it supplies the necessary context for the analyses of the two prosodies--glottalization and nasalization--in chapters 3 and 4, respectively. With this in mind, the chapter is structured as follows. In §2.1, I characterize the canonical shape of CM morphemes. In §2.2 and §2.3, I motivate the respective consonant and vowel contrasts of the language. §2.4 contains a detailed discussion of palatalization, an important element of the segmental phonology of CM. And in §2.5 I conclude with a summary.

2.1 Morpheme shape: the basic couplet

In CM, as with other Mixtec languages (see, for example, Josserand 1982, Longacre 1957), the concept of the *couplet* is central to understanding the canonical shapes of morphemes. The term *tonemic couplet* was first used by Pike (1948) in discussing the distribution of contrastive tones in the San Miguel el Grande variety of Mixtec. Pike argued that almost all distinctive tone bearing morphemes in San Miguel Mixtec are disyllabic (hence the term *couplet*), while monosyllabic morphemes (clitics and affixes) generally lack distinctive tone and are phonologically dependent on disyllabic forms. Pike and Small (1974) draw from Pike (1948) in their description of Coatzospan Mixtec. Besides noting that the couplet is crucial to the characterization of the distribution of contrastive tones, they also point out that the couplet provides a basis for understanding the distribution of both nasalized and glottalized vowels.

Given its apparent descriptive usefulness, it is necessary make the notion of *couplet* more precise. More concretely, it is necessary to address the question: just what is the couplet? For CM, the answer is that, with few exceptions, couplets comprise the set of open class morphemes. That they are viewed as *couplets* derives from the fact that these morphemes conform to a highly restricted set of canonical shapes: CVV and (C)VCV. Examples are provided in (1).

(1) **basic couplet shapes**

[CV_iV_i]		[CV_iV_j]	
a) laa	'flower'	f) teu	'stool'
b) tsɨɨ	'snail'	g) ndeu	'gravy'
c) ðoo	'cloth, clothing'	h) kʷia	'year'
d) tee	'straight'	i) ʃio	'griddle'
e) kii	'go out'	j) ðeɨ	'noose'

[CVCV]		[VCV]	
k) βiðe	'wet'	p) iði	'hair'
l) tinã	'dog'	q) unĩ	'three'
m) kuʃu	'diligent'	r) eðɨ	'closed, covered'
n) kuβi	'die'	s) oʃo	'smell of blood'
o) ndaðɨ	'closed (part.)'	t) amã	'when'

Descriptively, the data in (1) reveal couplets to be divocalic structures. That is, regardless of whether they contain a medial consonant (k-t) or a VV sequence (a-j), couplets have two vowels. Additionally, we see that in couplets containing VV sequences, these can either be identical (a-e) or disinct (f-j).[1]

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[1] It is interesting to note that for CVV morphemes in which V1 and V2 are distinct, all of the synchronic forms for which I have found corresponding Proto-Mixtec reconstructions in Josserand (1982) are diachronically derived from couplets containing a medial glide, e.g:

teu 'stool' < **teyu* *kʷia* 'year' < **kʷiya*

ndeu 'gravy' < **ndeyu,* *ʃio* 'griddle' < **ʃiyoʔ*

Josserand's reconstructions show that some CVV couplets containing

This generalization underlies Pike's (1948) original characterization of the couplet as *disyllabic* in that each vowel position is taken to constitute a syllable peak. Interestingly, Pike's analysis has persevered unchallenged as a general assumption in the Mixtec literature. For example, in their original description of the Coatzospan variety of Mixtec, Pike and Small (1974) simply assert that the vowels in CVV couplets are heterosyllabic, with no arguments to support this analysis. Small (p.c) has suggested that because CVV couplets exhibit the same variety of underlying tonal patterns as CVCV couplets, they should be viewed as disyllabic. This view resides, however, in the assumption that the syllable and not the mora is the tone bearing unit. If the mora is taken to be the tone bearing unit (TBU), the similarities between CVV and CVCV morphemes with respect to underlying tone patterns can be accounted for by viewing both CVV and CVCV couplets as bimoraic.[2] This leaves open the possibility that CVV couplets may be monosyllabic.

Anecdotal evidence suggests that the disyllabic view is possible, though not necessary. For example, while attempting to establish the syllable count of CVV forms, I asked one consultant to play a game in which she reversed the

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identical vowels are also diachronically derived from proto forms containing medial consonants, as in *kii* 'go out' < **keyi* above. They need not be so derived, however, as can be seen by *ndoo* 'sugar cane'< **ndooʔ*.

[2] Following Hyman (1993), I assume that the TBU is the mora. Clements (1984) argues that the syllable is the TBU in Kikuyu. However, as Hyman points out, one can also interpret such data as an indication that only the head mora of a syllable can bear tone, i.e. that there can be non-tonal moras. See also Steriade (1991) for related discussion of non-nuclear moras.

syllables of clearly disyllabic couplets. I provided simple forms such as *βiðe* 'wet' and indicated that the proper way to play the game involved returning the reversed form *ðeβi*. When she became comfortable with reversing the syllables of CVCV couplets, I provided CVV couplets such as *laa* 'bird', for which she returned the form *ala*. One possible interpretation is that such responses support treating forms such as *laa* as disyllabic: *la.a* → *a.la*. Another possibility, however, is that the speaker took the unit manipulated by the game to be the mora, as in Katada's (1990) analysis of the Japanese language game *shiritori*. This type of analysis is sketched in (2).

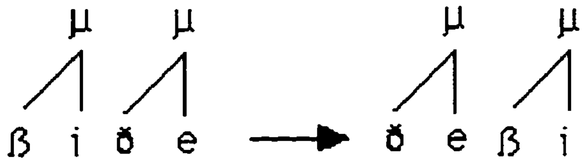
(2) **CM Game forms**

[laa] 'bird' → game form: [ala]

However, compelling arguments in favor of either position are difficult to come by. Assuming, as Katada argues for Japanese (see also Itô 1989, Ishihara 1991), that onset consonants dock to the mora and not directly to the syllable, the apparent circumscription of the second syllable in forms such as *βi.ðe* → *ðe.βi* can be equally well analyzed as the fronting of the second mora, as in (3).

(3) **CM Game forms**

[βi.ðe] 'wet' → game form: [ðe.βi]



This thus leaves open the question open of whether CV_iV_i couplets are best viewed as mono- or disyllabic. CV_iV_j forms, by contrast, are more obviously disyllabic in that both vowels exhibit clear steady states in their formant structures; stress (see chapter 3) systematically falls on the first vowel; and each is more distinctly perceived as a separate syllable nucleus.

Independent of the question of syllable count, however, it is imperative that we recognize an essential "two-ness" in the structure of CM morphemes. For the purposes of this study, I make the minimal assumption that CM couplets are necessarily bimoraic, and potentially disyllabic.[3] Adopting the moraic representations of Hyman (1985), I posit representations such as those in (4) for the range of canonical couplet shapes.

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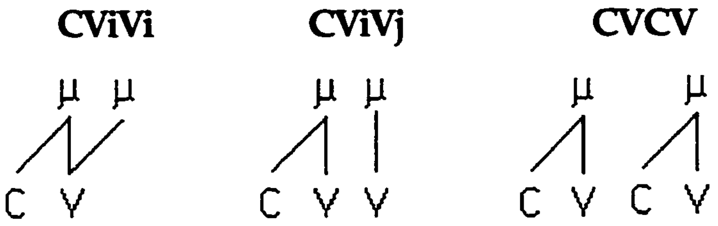
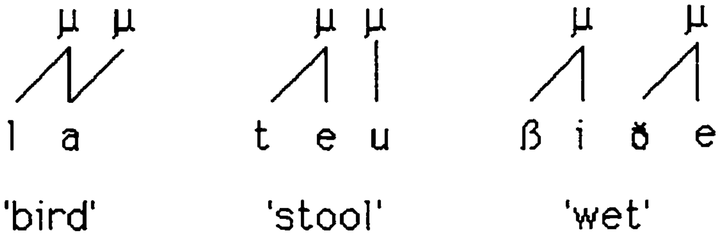
[3] None of the analyses in subsequent chapters will rest crucially on this point.

(4) **Canonical couplet shapes**

a)



b) **Examples**



Given this picture of the global structure of the couplet, I turn in the following section to the consonantal contrasts instantiated therein.[4]

2.2 The CM consonants

This section provides an overview of the CM consonant inventory. As a point of departure, consider the chart in (5), which reflects the consonantal contrasts originally posited by Pike and Small (1974).

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[4] Macaulay and Salmons (1995) independently reach a similar conclusion regarding the status of couplets in Mixtec in general. For them, couplets across the Mixtec language are viewed as being comprised of two vocalic timing slots, though they take no position on whether these are best viewed as skeletal positions, moras, or syllables.

(5) **CM consonant inventory (Pike and Small 1974)**

	labial	**interdental**	**alveolar**	**palato-alveolar**	**velar**
stops:	p		t		k, k^{W}
	mb		nd		ŋg, ŋg^{W}
affricates:			ts	tʃ	
			ndz	ndʒ	
fricatives:	s			ʃ	
	β	ð, ð^{j}			
liquids:	l,r				
nasals:	m		n	ɲ	

Two aspects of this inventory are immediately obvious. First, conspicuous by their absence are the glides, though Pike and Small do posit the phonemes /k^{w}/, /ŋg^{w}/, /ð^{j}/ with off-glide releases. Second, among plosives, there is no voiced/voiceless contrast in the expected sense; instead, the voicing contrast in non-continuants is manifested by a contrast between voicelessness and prenasalization.

A third point that the reader will not immediately note is the absence of a glottal stop phoneme /ʔ/. This absence becomes apparent, however, in that many of the examples in this chapter are transcribed with a glottal stop symbol (examples such as β*iʔi* 'house' or *taʔ*^{a}*ta* 'race, ethnicity'). In chapter 3, I argue in detail that this glottal gesture is best analyzed as a vowel feature and not as a consonantal segment in its own right. For the moment, it is important to note that all instances of transcribed /ʔ/ indicate that the vowel preceding the /ʔ/ symbol is glottalized. Further, superscripted vowels such as the one in *taʔ*^{a}*ta* 'race, ethnicity' also constitute part of this same glottalized vowel. This transcription reflects the phonetic realization of glottalized vowels in [CVCV] couplets in that glottalization involves an interruption of modal phonation followed by a short echo vowel, i.e. a brief resumption of modal phonation.

With these transcription notes in mind, the remainder of this section focusses on the status of each of the phonemic consonants posited by Pike and Small, providing minimal and near minimal pairs wherever possible.[5] The picture that emerges is one in which a smaller set of consonants than those posited by Pike and Small can be said to constitute a core or non-marginal set of constrasts. I begin in §2.2.1 with a discussion of the labial consonants.

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[5] The reader will doubtless notice that in most of the forms used in the chapter, consonant contrasts are exhibited in initial position of CV(ʔ)V morphemes. There are two reasons for this. First, as Pike and Small (1974) note, initial position in the couplet is where all of the consonantal contrasts in the language are exhibited. Many of the less common consonants either rarely or never surface as the second consonant of a CVCV couplet. Secondly, in searching for minimal pairs, I have attempted to use the simplest structures possible, i.e. CVV or CVʔV couplets, to probe for minimally distinct forms by varying the vowel quality. If there were a complete dictionary of CM morphemes, a more finely grained look at contrast in both possible consonant positions of couplets would have been possible. At this point, however, I view the lists here as contributing towards the building of a larger list of CM couplets.

2.2.1 The labials: /p/, /β/, /m/

Though Pike and Small posit four labial consonant phonemes, I have found no native CM couplets containing the prenasalized stop /mb/. It is also important to note that there are vanishingly few forms containing the voiceless stop /p/. By contrast, both the voiced fricative /β/ and the full nasal stop/m/ are more robustly attested, though these consonants are not as prevalent across morphemes as are, for example, the coronal consonants. Examples of couplets containing initial labial stops are provided in (6).

(6) **/p,β,m/_a**

a) pa?a	'baby, infant'
b) βa?a	'good, well'
c) mã?$^{\tilde{a}}$nã	'sleepiness, tiredness'

Near minimal pairs attesting to the contrast between /β/ and /m/ are provided in (7). These are not segmentally minimally distinct, due to the difference in vowel nasalization, which is itself predictable after a nasal consonant (see Chapter 4 for detailed discussion).

(7) **/β,m/ _i**

a)	βinĩ	'mean'	b)	βiʔi	'house'	c)	βii	'heavy'
	mĩnĩ	'lake'		mĩʔĩ	'where'		mĩĩ	'alone'

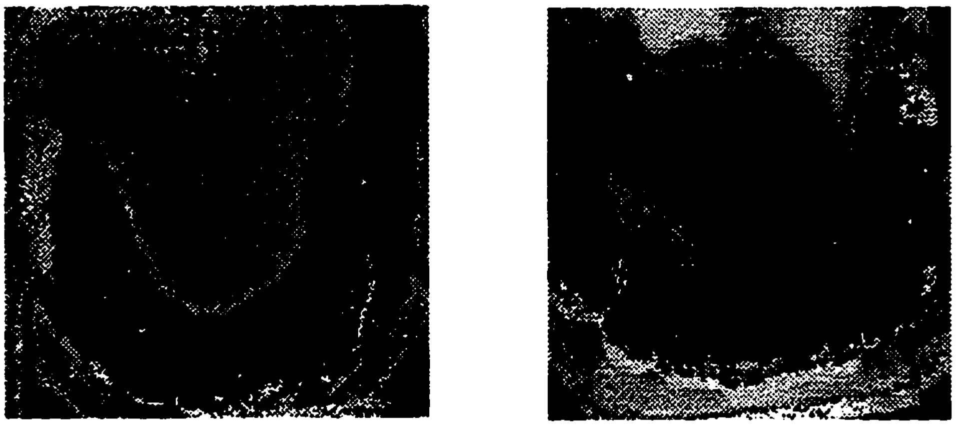
2.2.2 The alveolars

Consonants produced with an alveolar constriction are by far the most frequently occurring consonants in CM. Again, however, only a subset of these are found in a large number of forms. It is particularly interesting to note that neither /s/ nor the liquids /l/ and /r/ occur in many forms. Additionally, the alveolar affricate /ndz/ is scarce, although its voiceless counterpart /ts/ is robustly attested. Bearing these observations in mind, I begin with the stops: /t/, /nd/, and /n/.

2.2.2.1 /t/, /nd/ and /n/

These are among the most robustly attested consonants of the language. Generally, speakers produce the alveolar stops /t/, /nd/ and /n/ with clear contact between the tongue tip and the upper front teeth, so they are best characterized phonetically as alveodental stops. This is evident in the palatograms for two different CM speakers in (8). In (8 a) we see a palatogram of a female CM speaker (S7) producing the form *taʔa* 'pimple', while (b) provides an example of a male speaker (S5) producing the form nãã 'altar'. Note that the dark area indicates the point of contact between the tongue and the roof of the mouth.[6] Here, we see the clear alveodental articulation of each stop.

(8) **a) ta?a 'pimple'** **b) nãã 'altar'**



There are many examples illustrating the contrastive status of these stops in the language. This can be seen in the following data.

(9) **/nd/ contrasts with /t/**

a)	ndaβa	'hard, stiff'	b)	ndii	'force'
	taβa	'to take out'		tii	'many'
c)	nda?u	'to scream (donkey)'	d)	ndoo	'clean'
	ta?u	'tight, squeezed'		too	'to drip'

---

[6] See Chapter 1 for a discussion of the technique used for making the palatograms.

(10) **/n/ contrasts with /nd/**[7]

a)	nãã	'altar'	b)	nãʔã	'boy'
	ndaa	'be certain'		ndaʔa	'leaf'
c)	kanda	'to skip, jump'	d)	nẽẽ	'indefinite pronoun'
	kanã	'overgrown with weeds'		ndee	'black'

(11) **/n/ contrasts with /t/**

a)	nãnã	'aunt'	b)	nãʔ$^{\tilde{a}}$nũ	'big'
	tanã	'collapse'		taʔ^{a} nũ	'girl, woman'
c)	nẽnĩ	'be surprised'	d)	nĩʔĩ	'with'
	tenĩ	'to drown'		tĩĩ	'chat, talk'

2.2.2.2 /ts/, /ndz/, and /s/

Besides the three stops, Pike and Small posit two alveolar affricates and the fricative /s/. Of these, only the voiceless alveolar affricate /ts/ is common. These three are produced with slightly more retraction of the tongue tip than are /t/, /nd/, and /n/, and as a result, there is little if any contact between the tongue tip and the upper front teeth. These are true alveolars, rather than alveo-dentals. This can be seen for the fricative /s/ in the palatogram in (12), in which the same male speaker as above produced the form *saʔa* 'this'.[8]

---

[7] Recall that vowels are predictably nasalized after, but not before, nasal consonants (cf. (10c), (11a-c). This phenomenon is addressed in detail in chapter 4.

[8] This picture of contact for /s/ is representative of all three speakers (two

(12) **sa?a 'this'**

Below, I provide minimal and near minimal pairs for these sounds.

(13) **/ts/ contrasts with /s/**

a)	tsa?a	'large jug'
	sa?a	'this, these'

(14) **/ts/ contrasts with /ndz/**

a)	tso?o	'flea'	b)	tsɨ?^{ɨ}kɨ	'nail'
	ndzo?o	'hummingbird'		ndzɨ?^{ɨ}kɨ	'emaciated'

(15) **/s/ contrasts with/ndz/**

a)	so?o ndo nda?	'salutation among men (vocative)'
	ndzo?o	'hummingbird'

---

male and one female) from whom I gathered palatographic data.

There are numerous couplets containing /ts/, and thus many pairs of couplets exhibit the contrast between /ts/ and the stops /t/, /nd/, and /n/. Examples are provided in (16-18).

(16) **/ts/ contrasts with /n/**

a)	tsaʔa	'big jug'	b)	tsiʔi	'uncombed'
	nãʔã	'boy'		nĩʔĩ	'with'
c)	tsũʔũ	'chicken'			
	nũʔũ	'tooth'			

(17) **/ts/ contrasts with /t/**

a)	tsaʔ^{a}ta	'mediator (for marriage)'	b)	tsii	'to get wet'
	taʔ^{a}ta	'race, ethnicity'		tii	'man'

(18) **/ts/ contrasts with /nd/**

a)	tsii	'to get wet'	b)	tsiʔi	'uncombed'
	ndii	'force'		ndiʔi	'fine'
c)	tsaʔa	'big jug'			
	ndaʔa	'leaf'			

2.2.2.3 The liquids /l/ and /r/

Though Pike and Small (1974) list both /l/ and /r/ as CM phonemes, the status of /r/ is more marginal than that of /l/. While /l/ is found in a number of cognates (and is reconstructed by Josserand (1982) as a member of the Proto-Mixtec consonant inventory), the sound that Pike and Small transcribe as /r/ surfaces almost exclusively in two contexts: 1) in forms borrowed from Spanish, and 2) as a voiceless trill that constitutes the initial member of an /rk/cluster (that is itself historically derived from the fusion of two morphemes). In fact, Pike and Small's use of a single /r/ symbol is insufficient, since, in the borrowed cases, /r/ is realized either as a tap (ɾ) or a trill (r), depending on the Spanish source. Here, I focus first on the lateral approximant /l/ and then turn to the question of the status of /r/.

Though less common than the stops, there are couplets exhibiting the contrast between /l/ and the other phonetically voiced alveolar consonants. Examples are provided in (19-21).

(19) **/l/ contrasts with /nd/**

a)	loʔo	'deaf'	b)	laʔa	'knot of tree'
	ndoʔo	'adobe'		ndaʔa	'leaf'
c)	laa	'bird'			
	ndaa	'be certain'			

(20) **/l/ contrasts with /n/**

a)	laa	'bird'	b)	le?e	'circle'
	nãã	'altar'		nẽ?ẽ	'crippled'
c)	lũ?ũ	'road runner'			
	nũ?ũ	'tooth'			

(21) **/l/ contrasts with /ndz/**

a)	lo?o	'deaf'
	ndzo?o	'hummingbird'

As I note above, the status of /r/ is less clear. Generally, /r/ surfaces in forms borrowed from Spanish, and, if the /r/ of the Spanish source is trilled, it is generally trilled in CM. Similarly, if the /r/ is tapped, it surfaces as a tap in the CM form. Two examples are provided in (22).

(22) **trilled vs. tapped /r/ in Spanish borrowings**

a)	βuɾu	'burro'	< Sp. [βurro]
b)	tʲuɾu	'bull'	< Sp. [toro]

When it occurs initially, /r/ is trilled. In this position, /r/ is almost always the first member of a consonant cluster, the second member of which is a voiceless velar stop. In this context, /r/ is devoiced. Examples are provided in (23) (see §2.2.6 for more on the status of consonant clusters).

(23) **initial voiceless trill /r/ in /rk/ cluster**

a) r̥kuʔu	'deer'	b) r̥kaʔ^{a}ka	'crow'	c) r̥kii	'quail'

I also find three morphemes with an initial /r/ that does not surface in a cluster. In two of these, there is no clear Spanish source,[9] while in the third, the /r/ is obviously borrowed from Spanish.

(24) **initial trilled /r/**

a) raʔ^{a}βa	'pot bellied'
b) raʔ^{a}ŋg^{w}a	'turkey's wattle'
c) raʃa	'line' (< Sp. raya)

In short, by contrast with /l/, the status of /r/ in the consonant system is uncertain. First, historical evidence (see Josserand 1982) indicates that /r/ was not a member of the Proto-Mixtec consonant system, and as Josserand's synchronic Pan-Mixtec word lists show, /r/ is universally marginal across the present day Mixtec languages. Secondly, many of the tokens of /r/ in CM either derive from Spanish borrowings or surface in morphemes that begin with an initial /rk/ cluster--itself an oddity--suggesting that they have evolved diachronically from the fusion of more than one couplet.

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[9] Unfortunately, Josserand's (1982) list of Mixtec cognates does not include either of these morphemes. Thus, we cannot compare them with corresponding forms in other varieties of Mixtec to see if they have been either borrowed or are the result of a diachronic process of morpheme fusion.

2.2.3. Palatoalveolar consonants

CM has a palatoalveolar fricative /ʃ/ and two palatoalveolar affricates, the prenasalized /ndʒ/ and its voiceless counterpart /tʃ/. Though both affricates do surface in many forms as the predictable result of a palatalization process limited to women's speech, they surface contrastively in a highly limited number of forms. By contrast, /ʃ/ appears in many CM morphemes. And the palatal nasal /ɲ/, though not as common as its alveolar counterpart /n/, also surfaces contrastively. In this section, I first discuss the status of the palatoalveolar affricates and the palatal nasal. I finish with a brief discussion of /ʃ/, though I return in more detail to the status and phonological behavior of this sound in both chapters 3 and 5.

2.2.3.1 The palatoalveolar affricates: /ndʒ/ and /tʃ/

As I note above, both [ndʒ] and [tʃ] surface as palatalized variants of the alveolar stops /nd/ and /t/, respectively, when they precede a front vowel. This phenomenon is found exclusively in women's speech.[10] Some examples of the contrast between men's and women's forms are shown in (25).

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[10] I have also heard examples of this palatalization in the speech of a couple of young, male children--presumably due to the influence of the mother's speech. I asked one consultant if this was unusual, and she informed me that many young boys often use some women's speech forms but that they soon "learn" that this is not the correct way for them to speak.

(25)	Men's speech	Gloss	Women's speech
a) /ndii/	[ndii]	'force'	[ndʒii]
b) /ndee/	[ndee]	'black'	[ndʒee]
c) /ndaa/	[ndaa]	'certain'	[ndaa]
d) /tii/	[tii]	'man'	[tʃii]
e) /tee/	[tee]	'leaf used for roofing'	[tʃee]
f) /taʔa/	[taʔa]	'pimple'	[taʔa]

There are, nevertheless, a few couplets in which /ndʒ/ and /tʃ/ surface in both men's and women's speech, showing that the appearance of these palatoalveolar affricates is not altogether predictable. Examples containing unpredictable instances of /tʃ/ are given in (26):

(26) **couplets containing unpredictable instances of /tʃ/**

a) tʃaa	'oak'	d) tʃɨʔ^{ɨ}kɨ	'beam'
b) tʃoʔo	'medicine'	e) tʃeʔe	'post'
c) tʃũʔũ	'charcoal'	f) tʃii	'rifle'

In the couplets in (a-d), /tʃ/ appears before non-front vowels, while (e-f) provide examples in which /tʃ/ surfaces before front vowels in both men's and in women's speech. Note, for example, the contrast between the CM words for 'man' (25d) and 'rifle' (26f). For both men and women, 'rifle' is realized as *tʃii*, while the morpheme for 'man' is realized as *tii* in men's speech but predictably undergoes palatalization as *tʃii* in women's speech. In traditional terms, this suggests that in the form [tʃii] 'rifle', the affricate /tʃ/ is underlyingly present, while in /tii/ 'man' it is derived. Some instances of /tʃ/ can be shown to contrast minimally with /t/ and /ts/, as seen in (27):

(27) **/tʃ/ contrasts with /t/ and /ts/**

a)	tʃii	'rifle'	b)	tʃoʔo	'medicine'
	tii	'man' (men's speech)		toʔo	'owner'
	tsii	'to get wet'		tsoʔo	'flea'

c)	tʃaʔa	'gourd'
	taʔa	'pimple'
	tsaʔa	'big jug, big gourd'

The situation is similar for the voiced affricate /ndʒ/, though it surfaces unpredictably before a narrower set of vowels than does /tʃ/. In particular, I have found no cases in which /ndʒ/ appears before front vowels in men's speech; i.e., couplets analogous to forms such as /tʃii/ 'rifle'. Nevertheless, there are at least four forms in which /ndʒ/ surfaces unpredictably before non-front vowels, as seen in (28).

(28) **couplets containing unpredictable instances of /ndʒ/**

a)	ndʒaʔ^{a}βi	'iguana'
b)	ndʒoʔ^{o}ko	'heat'
c)	ndʒũʔũ	'fire'
d)	ndʒaʔa	'broth, soup'

I have also found two minimal pairs in which /ndʒ/ contrasts with the alveolar stop /nd/. These are shown in (29):

(29) /ndʒ/ **contrasts with /nd/**

a)	ndʒaʔa	'broth, soup'	b)	ndʒaʔ^{a}βi	'iguana'
	ndaʔa	'to stain'		ndaʔ^{a}βi	'poor'

I find no minimal pairs in which /ndʒ/ contrasts with the alveolar affricate /ndz/. This is not surprising, however, given that neither is common. One near minimal pair is provided in (27).

(30) **/ndʒ/ vs. /ndz/**

a)	ndʒoʔ^{o}ko	'heat'
	ndzoʔo	'hummingbird'

In short, the evidence indicates that both /tʃ/ and /ndʒ/ are synchronically contrastive, although neither is unpredictably attested in a large number of morphemes. This, in turn, suggests that their status as phonemes is somewhat marginal. However, both surface very frequently as allophones of /t/ and /nd/, respectively, in women's speech palatalization.

2.2.3.2 The nasal /ɲ/

In addition to /n/ and /m/, CM has a third contrastive nasal stop: /ɲ/. This sound is produced with significant tongue body contact along both the diagonal and the roof of the hard palate. As can be seen in the data in (31-32), it contrasts with the other two nasal stops. Note, however, that there are far more forms containing /n/ than /m/. As a consequence, minimal pairs exhibiting a contrast with /n/ are found more readily.

(31) **/ɲ/ contrasts with /m/**

a)	ɲĩʔĩ	'to scratch'	b)	ɲẽʔ$^{\tilde{e}}$ɲũ	'cowlick'
	mĩʔĩ	'where'		mẽʔ$^{\tilde{e}}$ɲũ	'in front of'

(32) **/ɲ/ contrasts with /n/**

a)	ɲĩʔĩ	'to scratch'	b)	ɲẽʔẽ	'to smell (intransitive)'
	nĩʔĩ	'to be equal to'		nẽʔẽ	'little child, little one'
c)	ɲɨ̃ɨ̃	'hat'	d)	ɲũʔũ	'floor'
	nɨ̃ɨ̃	'completely, all'		nũʔũ	'tooth'
e)	ɲãɲã	'lion'			
	nãɲã	'squash'			

2.2.3.3 The alveopalatal fricative /ʃ/

As I discuss in detail in chapter 3, the phonological behavior of the alveopalatal fricative /ʃ/ with respect to both glottalization and nasal harmony makes it perhaps the most interesting of the CM consonants. I will argue, in fact, that the behavior of /ʃ/ motivates an analysis in which we are led to countenance the synchronic presence of two phonologically distinct (yet phonetically indistinguishable) /ʃ/'s in the language. For the purposes of this chapter, however, we will limit our attention to establishing the contrast between /ʃ/ and other alveolar and alveopalatal consonants, leaving the more intricate phonological data and arguments for chapter 3.

/ʃ/ occurs quite commonly, so there is no shortage of forms attesting to its contrastive status in the grammar. In (33-36), I provide examples exhibiting the contrast between /ʃ/ and /s/, /ts/, /tʃ/, and /t/, respectively. (Note that due to the general scarcity of /s/'s in the language, I find only one minimal pair exhibiting the /s/ vs. /ʃ/ contrast.)

(33) **/ʃ/ contrasts with /s/**

a)	ʃaʔa	'chile'
	saʔa	'this, these'

(34) /ʃ/ contrasts with /ts/

a)	ʃaʔa	'chile'	b)	ʃii	'taboo'
	tsaʔa	'big jug, big gourd'		tsii	'get wet'
c)	ʃoʔo	'rope, cord'			
	tsoʔo	'flea'			

(35) /ʃ/ contrasts with /tʃ/

a)	ʃaʔa	'chile'	b)	ʃii	'taboo'
	tʃaa	'oak'		tʃii	'rifle'
c)	ʃoʔo	'rope, cord'			
	tʃoʔo	'medicine'			

(36) /ʃ/ contrasts with /t/

a)	ʃamã	'leaf of the corn'	b)	ʃee	'arrive'
	tamã	'scarce'		tee	'to roof'
c)	ʃoʔo	'rope, cord'			
	toʔo	'owner'			

2.2.4 The velar consonants: /k/, /kʷ/, /ŋg/, /ŋgʷ/

CM has two velar and two labiovelar stops. As with the alveolar and palatoalveolar plosives, the voiced/voiceless contrast is phonetically implemented as a contrast between prenasalization and voicelessness, respectively. Of these four, /k/ is the most common, and /ŋgʷ/ is vanishingly rare. (I have found only two couplets containing /ŋgʷ/, both of which are included in the data below.) Minimal or near minimal pairs for all four are provided in (37-40). Note that no minimal pairs can be found for the contrast between /ŋg/and /ŋgʷ/, although in (38) I provide a pair of forms in which both precede the vowel /a/.

(37) **/k/ contrasts with /kʷ/**

a)	kii	'to get under'	b)	kiʔi	'to take, grab'
	kʷii	'slow, slowly'		kʷiʔi	'sickness'
c)	kaa	'metal'	d)	kaʔa	'clearing in forest'
	kʷaa	'afternoon'		kʷaʔa	'right (handed etc...)'

(38) **/ŋg/ and /ŋgʷ/**

a)	ŋgaβa	'to slip, slide'
	raŋgʷa	'enormous'

(39) **/k/ contrasts with /ŋg/**

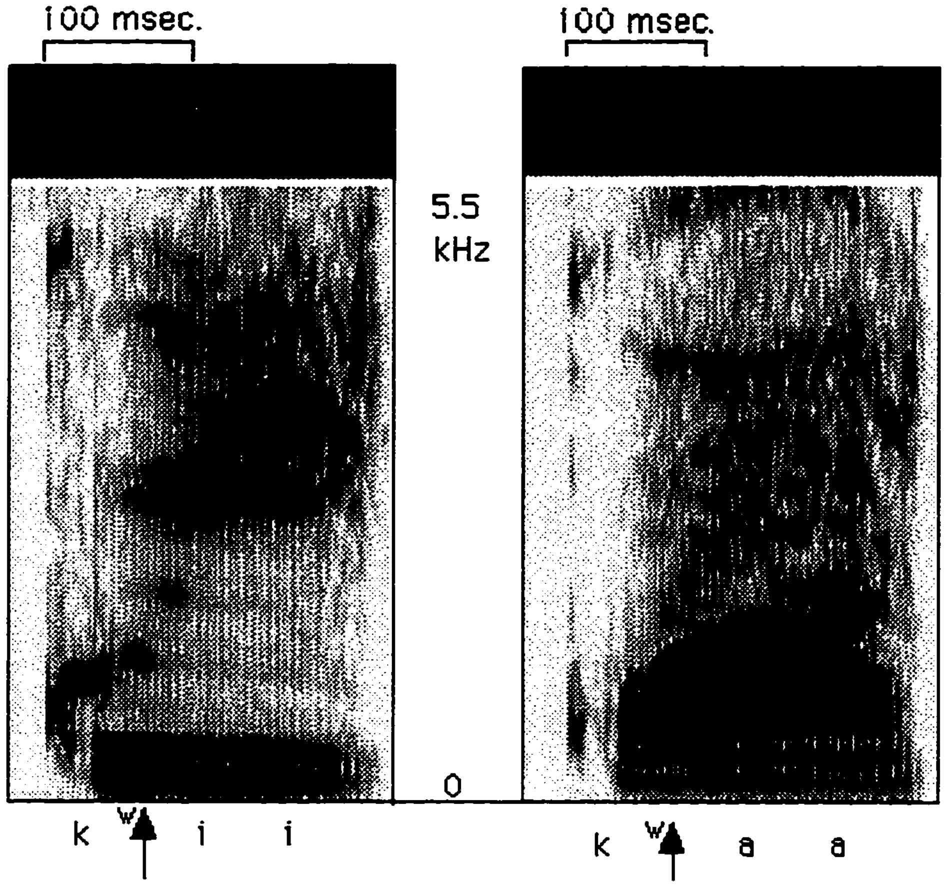
a)	kaʔᵃtsi	'cotton'	b)	kaβa	'mountain spring'
	ŋgaʔᵃtsi	'blanket, serape'		ŋgaβa	'to slip, slide'

(40) **/k/ contrasts with /ŋgʷ/**

a)	ŋgʷii	'the rest, the remainder'
	kʷii	'green'

One question that arises in positing the complex segments /k^w/ and/ŋg^w/ is why these are not treated as sequences of a velar stop followed by /u/. A look at the phonetic facts suggests at least that the sequential analysis is less felicitous than the complex segment approach. In particular, we see that the labiovelar approximant exhibits rapid transitions with no (even relatively brief) steady-state period in its formant structure. At the same time, we see in forms such as *k^wii* 'green' and *k^waa* 'afternoon' a long steady state in the formants for the /ii/ and /aa/ vowels, respectively. This can be seen clearly in the wide-band spectrograms in (41a-b), in which I have signalled the approximate onset of each of the steady states of the /aa/ and /ii/ sequences with an arrow.

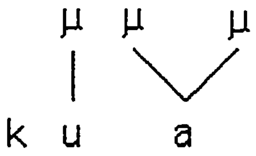
(41) a) **k^{w}aa 'afternoon'** b) **k^{w}ii 'green'**



This is not to suggest that we can trivially read phonological representations from spectrographic displays. However, it is important to note that viewing, say, surface [k^w] as an underlying /k + u/ sequence requires an explanation for why the /u/ surfaces as an off-glide upon the release of the preceding velar consonant, that is, for why it displays glide rather than vowel-like behavior. This is not a problem for an analysis in which /k^w/ is taken to be an underlyingly complex segment, consisting of a velar stop with an off-glide release.

Aside from the phonetic realization of these as off-glides, positing underlying velar stop plus /u/ sequences also needlessly complicates the description of the shape of the CM couplet. In the case of forms such as $k^{w}aa$ 'afternoon', for example, we might be forced to posit an underlying representation consisting of three moras—a representation that would undermine the simple characterization in §2.1 of couplets in CM as bimoraic. This type of representation is sketched in (42).

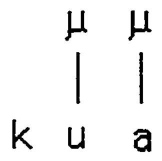
(42)



Nevertheless, if we adopt a view such as that of (42), we must still account for the original problem: why the initial /u/ surfaces as an off-glide release and not as a full vowel.

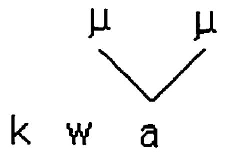
Alternatively, of course, we might posit an underlying representation containing two moras, as in (43).

(43)



Under this approach, the challenge would again be to account for why the /u/ fails to surface as a full vowel. Conceivably, the key to the problem lies in recognizing that these sequences should be treated not as velar stop plus /u/, but rather, as velar stop plus /w/ sequences. This approach circumvents the problem of positing trimoraic couplets or of trying to account for why underlying /kua/ surfaces as $k^{w}aa$, i.e. for why the [w] surfaces as an off glide and the [a] vowel is long. I sketch this possibility in (44):

(44)



Nevertheless, such an approach is not itself cost free in that it forces us to posit couplet-initial consonant clusters that are otherwise absent both in CM and across the Mixtec languages in general.

Finally, a compelling argument against treating labiovelar glide releases as separate /w/ phonemes is that this analysis affords no explanation for the absence of surface [w] elsewhere in the language, given that there are no native CM couplets in which a singleton [w] is either the initial or the medial consonant.[11] By contrast, a powerful reason for treating labiovelar stops (as well as for analyzing prenasalized segments and voiceless affricates) as single segments rather than as multi-segment sequences is that this allows for a highly simple characterization of CM as a CV language.[12]

2.2.5 The interdentals /ð/ and /ð^j/

Pike and Small (1974) posit two voiced interdental fricatives, /ð/ and /ð^j/, for which there are no voiceless counterparts. As with the velar stops, we appear to have another case of a complex segment with an off-glide

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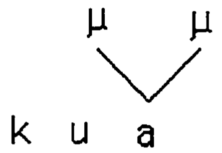
[11] Following Hayes (1989), an alternative to (44) could be a representation in which glides are represented underlyingly as a non-moraic vowels:



Nothing crucial rests on this difference for the purposes of the discussion here. For example, assuming that the glide [w] is underlyingly represented as a non-moraic /u/ would still leave the question of why we find no surface forms such as *[waa].

[12] It is interesting to note that same consultant from whom the spectrograms above are taken provided me with the following pair of forms which she claimed were minimally distinct: [k^{w}aa] 'afternoon' vs. [kua] 'to get bitter'. Her intuitions were that the distinction between these resided in a distinction between an off-glide release of the velar stop in the former and the presence of an /u/ vowel in the latter. Despite her intuitions, however, I hesitate to include this pair as evidence in favor of the complex segment approach, because I have thus far been unable to convince myself that spectrographic evidence from her speech clearly confirms her intuition. I thus leave further work with this pair and the hunt for other such possible minimal pairs for future work with CM speakers.

release. However, my work with consultants has led me to the conclusion that Pike and Small's claim is tenuous at best. I have found only one form unambiguously containing /ð^{j}/, here provided in (45) with a minimally contrastive couplet containing /ð/.

(45) /ð^{j}/ **contrasts with /ð/**

a) ð^{j}o?^{o}ko 'daughter'
   ðo?^{o}ko 'soon'

Pike and Small list an additional form ð^{j}ũ?ũ 'money', with which they contrast the palatal nasal /ɲ/ in the form ɲũ?ũ 'fire'. Closer scrutiny of the facts suggests that ð^{j}ũ?ũ should be treated instead as containing an initial /ð/ followed by an /i/vowel, i.e. as /ðĩ?ũ/.

This can be seen in the spectrogram in (46). Recall from the discussion above of the labiovelar glides that the off-glides in forms such as k^{w}ii 'green' are characterized by their short duration and rapid formant transitions. By contrast, here we see that in ðĩ?ũ 'money', the /i/ vowel is long in duration with clear steady state formants prior to the onset of glottalization (at roughly 160 msec in the spectrogram).[13]

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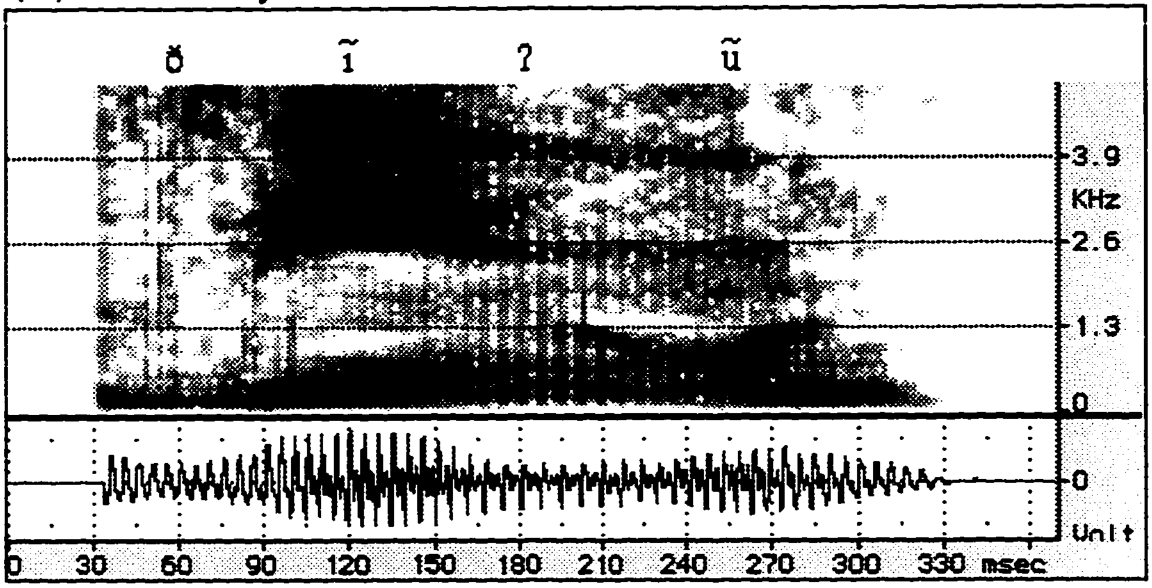
[13] Although it might be, I do not feel that this is simply a case of interspeaker variation. Though the recording above was not taken from one of the consultants who worked with Small and Pike on their original paper, I have checked her pronunciation of this form with one of Pike and Small's (1974)

(46) [ðĩ?ũ] **'money'**



As for the interdental /ð/, there are numerous forms exhibiting the contrast between /ð/ and the commonly appearing voiced coronals. These are shown in (47-50) below.

(47) **/ð/ contrasts with /nd/**

a)	ða?a	'ahead'	b)	ða?^{a}βi	'to toss over'
	nda?a	'leaf'		nda?^{a}βi	'poor'
c)	ði?^{i}ko	'flavor, taste'			
	ndi?^{i}ko	'sharp edged'			

---

consultants (Dolores Acosta Campos), and, to my ear, she pronounced it in the same manner as I have transcribed it here.

(48) **/ð/ contrasts with /l/**

a)	ðaʔ^{a}ka	'be mixed'	b)	ðaʔa	'ahead'
	laʔ^{a}ka	'scare crow'		laʔa	'knot of a tree'

(49) **/ð/ contrasts with /n/**

a)	kiði	'to sleep'	b)	ðaʔa	'ahead'
	kinĩ	'listen'		nãʔã	'clearing in the forest'

(50) **/ð/ contrasts with /ɲ/**

a)	ðĩʔĩ	'lower leg'	b)	ðiʔi	'ring'
	ɲĩʔĩ	'mute'		ɲĩʔĩ	'to scratch'

In sum, of the interdentals, /ð/ is robustly attested across morphemes, while /ð^{j}/'s status in the system is highly marginal.

2.2.6 Consonant clusters

In §2.1 I describe the basic shape of the CM couplet as CVV or (C)VCV. There are, however, a number of forms containing consonant clusters. These derive from one of two sources: either 1) they are diachronically derived via the fusion of two (or more) morphemes which themselves conformed to the canonical couplet shape, or 2) they surface in Spanish loan words.

In clusters surfacing in the native vocabulary, Pike and Small (1974) note that initial clusters almost always begin with one of the coronal consonants: /t, s, ʃ, r/. Examples are provided in (51).

(51) **examples of initial clusters in native Mixtec vocabulary**

a) tranã	'tomato'	c) ʃteʔᵉnũ	'tom turkey'
b) smĩĩ	'bumble bee'	d) r̥kʷaʔᵃndi	'rainbow'

The claim that such clusters are diachronically derived from more than one couplet is based on two factors. First, as Josserand's (1982) study indicates, clusters have a marginal status across all of the present-day Mixtec languages and are not reconstructed for any Proto-Mixtec forms. Secondly, and more specifically, the CM forms containing initial clusters that appear in Josserand's Pan-Mixtec list of cognates all clearly derive from the fusion of more than one morpheme. For example, Josserand's reconstructions of both (a) and (c) above indicate that these present day CM forms are not derived historically from single couplets. This is shown in (52).

(52)	**CM form**	**Gloss**		**Proto-form**	**Gloss**
a)	tranã	'tomato'	<	*tɨ lana	'tomato'
b)	r̥kʷaʔᵃndi	'rainbow'	<	*koo yeʔndiʔ	'rainbow'

In the same vein, Pike and Small (1974) suggest that *ʃteʔᵉnu* 'tom turkey' most likely derives from the fusion (of possible earlier incarnations) of what are now the CM monomorphemic couplets *tsũũ* 'turkey' and *teʔᵉnũ* 'male' and that similarly, *r̥kuʔu* 'deer' may come from *iðu* 'horse' and *kuʔu* 'wild'.

Though the historical relationship for these forms is not as immediately and intuitively obvious as it is for the forms in (52), one thing that is interesting about *r̥kuʔu* 'deer' and *ʃteʔ^{e}nu* 'tom turkey' is that they, like many other forms beginning with consonant clusters, are both terms which refer to animals. Obviously, forms such as r̥k^{w}aʔ^{a}ndi 'rainbow' indicate that not all such forms are animal terms; however many do seem to refer to animals or insects, as can be seen in (53).

(53) **animal or insect terms**

a) ʃteʔ^{e}nu 'tom turkey'
b) smĩĩ 'bumble bee'
c) r̥kuʔu 'deer'
d) ʃnũnũ 'frog'
e) ʃndoʔo 'spider'
f) skundi 'cricket'
g) triʔ^{i}ta 'woodpecker'

Priscilla Small (p.c.) has suggested that one of the reasons behind the abundance of animal or insect terms among cluster-initial forms may be a diachronic reduction of the pronoun *kɨʔ^{ɨ}t^{j}ɨ* 'animal'. Specifically, the short form of this morpheme, *t^{j}ɨ* , functions as a determiner which can precede an animal term in a sentence. This form is unstressed and is often devoiced. Small's suggestion is that the devoicing of the determiner before particular animal or insect terms may have given rise to the lexicalization of a number of the clusters above. Though not implausible as at least a partial explanation, such a hypothesis must remain speculative. One particular problem is that we must ask why we find a range of coronal consonants constituting the first member of a compound, i.e. , why t^{j}ɨ should reduce in such a variety of ways. Secondly, this offers little explanation for the development of clusters in non-animal or insect terms.

Pike and Small's original description also lists a number of forms containing medial clusters. In these, the initial member is always /ʃ/, and the cluster arises from the loss of a couplet final /i/. Examples are shown in (54). Note that the polymorphemic roots of these clusters are highly visible in that the surface forms are exceptions to the canonical bimoraic couplet shape. Additionally, it is interesting to note that the first member of the heteromorphemic sequence need not originally contain an /ʃ/ in C2 position, as seen in (b).

(54) **medial clusters**

a) uʃkɨmĩ	'fourteen'	<	uʔ^{u}ʃi 'ten' + kɨmĩ 'four'
b) ðuʃnũũ	'eye'	<	ðuʔ^{u}tsi 'bean' + nũũ 'face'

Other clusters arise from Spanish borrowings. Some examples of these are provided in (55).

(55) **clusters arising from Spanish borrowings**

a) skʷela	'school' < Sp. 'escuela'	c) oβiʔⁱsku	'bishop' < Sp. 'obispo'
b) puʔᵘstru	'apostle' < Sp. 'apostol'	d) speʔᵉʃu	'mirror' < Sp. 'espejo'

In sum, modern day CM does contain some consonant clusters, which must be listed as exceptions to the generalization that morphemes in CM lack such clusters. Their presence derives from two sources. Within the native Mixtec vocabulary, they are historically derived from morphemic fusion, although it is also important to note that the teasing out of the original polymorphemic sequence is not always a trivial matter. Otherwise, they arise via the incorporation of Spanish loan words into the CM lexicon.

2.3 Vowels

In this section, I briefly lay out the vowel contrasts in the language in order to provide an overview of the vowel system. I do not provide a description either of vowel allophony or of cooccurrence constraints on the distribution of vowels within couplets. The reader is referred to Pike and Small (1974) for some (albeit little) discussion of both of these.

Under a traditional analysis, CM has eleven contrastive vowels. These are the six oral vowels /i, e, a, o, u, ɨ/ together their nasal counterparts /ĩ, ẽ, ã, ũ, ɨ̃/. There is a gap in that the inventory lacks contrastive /õ/, though surface [õ] does arise as a result of second person familiar nasalization (see Chapter

4).[14] Both /o/ and /e/ appear less commonly than the peripheral vowels /i/ /a/, /u/, and /ɨ/.

As I first noted in §2.2, in addition to nasalization, vowels are contrastively glottalized (see Chapter 3 for discussion). Minimal pairs exhibiting the full range of both glottalized and non-glottalized oral vowel contrasts are provided in (56).

(56) **oral vowel contrasts**

a)	ʃii	'taboo'	b)	ʃee	'new'
	ʃiʔi	'door'		ʃeʔe	'hit'
c)	ʃaa	'ash'	d)	ʃoo	'moon'
	ʃaʔa	'chile'		ʃoʔo	'rope, cord'
e)	ʃuu	'stone'	f)	ʃɨɨ	'husband'
	ʃuʔu	'mouth'		ʃɨʔɨ	'raw'

Minimal and near minimal pairs can also be found for all of the contrastive nasal vowels, as seen in (57).

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[14] Though it is not incorrect to characterize CM as containing five contrastively nasal vowels, such a characterization fails to capture the whole story. Specifically, although it is not possible to predict a priori which morphemes will contain an underlyingly nasal vowel, the distribution of contrastively nasal vowels within a morpheme is predictable. In this sense, contrastive vowel nasalization is best seen as a lexical property of individual morphemes. This issue is discussed in more detail in Chapter 4.

(57) **nasal vowel contrasts**

a)	tĩĩ	'sweat'	e)	tsẽʔẽ	'mold'
b)	tãã	'earthquake'	f)	tsɨ̃ʔɨ̃	'fox'
c)	tũũ	'coal'	g)	tsũʔũ	'chicken'
d)	t^{j}ɨ̃ɨ̃	'grab'	h)	tsĩĩ	'nail, claw'
i)	ðãã	'weave'			
j)	ðẽʔẽ	'grease'			

Finally, minimal pairs of contrastive oral vowels and their nasal counterparts are provided in (58).

(58) **oral versus nasal vowel contrasts**

a)	tsii	'to get wet'	b)	k^{w}eʔe	'red'
	tsĩĩ	'nail, claw'		k^{w}ẽʔẽ	'went'
c)	kaʔ^{a}ka	'to walk'	d)	t^{j}uʔ^{u}t^{j}u	'paper'
	kaʔ^{a}kã	'to beg'		t^{j}uʔ^{u}tu˜	'firewood'
e)	kɨʔɨ	'to put on, put in'			
	kɨ̃ʔɨ̃	'to go'			

The picture that emerges is that the CM vowel system consists of six contrastive vowel qualities /i, e, a, o, u, ɨ/ to which we can add nasalization and glottalization to multiply the number of possible contrasts for each vowel quality (with the exception of /o/, for which there is no contrasting nasal vowel). Looking ahead, I will treat both the glottalization (Chapter 3) and nasalization (Chapter 4) contrasts as features whose presence or absence is contrastive at the morpheme level but whose realization can be predictably encoded in terms of ranked Optimality Theoretic constraints (Prince and Smolensky 1993, McCarthy and Prince 1993b).

2.4 Palatalization

Before concluding this chapter, I address one more aspect of the segmental phonology of CM. As noted in §2.2.3.1, women's speech is characterized by the palatalization of /t/ and /nd/ before front vowels. There is, however, an additional process of palatalization that obtains of both women's and men's speech. To avoid terminological confusion, I will refer to this phenomenon as *general palatalization*. As with women's speech palatalization, general palatalization also targets /t/ and /nd/. In the case of general palatalization, however, both the nature of the change and the triggering context are distinct.

Recall that women's speech palatalization involves a change in primary point of articulation and stricture type: alveolar stops become palatoalveolar affricates. By contrast, general palatalization involves the addition of a secondary palatal off-glide release.[15] As for the triggering

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[15] Hume (1992) distinguishes between these two types of palatalization cross-linguistically by calling the affrication process *coronalization*, while reserving

contexts, women's speech palatalization is conditioned by the front vowels /i/ and /e/, while general palatalization is triggered by the high back vowels /ɨ/ and /u/. (See §2.4.1 for an additional refinement of this context.)

The data in (59-61) provide examples of both. (59) shows the contrast between men's and women's speech when /t/ and /nd/ precede a front vowel; (60) provides examples of generalized palatalization in which /t/ and /nd/ surface with a palatal off-glide release before high, back vowels in both men's and women's speech; (61) provides examples of non-palatalized /t/ and /nd/.

(59) **women's speech palatalization**

	men's	**gloss**	**women's**
a) /ndii/	[ndii]	'force'	[ndʒii]
b) /ndee/	[ndee]	'black'	[ndʒee]
c) /tii/	[tii]	'man'	[tʃii]
d) /tee/	[tee]	'leaf used for roofing'	[tʃee]

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the term *palatalization* for the addition of a secondary [ʲ] articulation.

(60) **general palatalization**

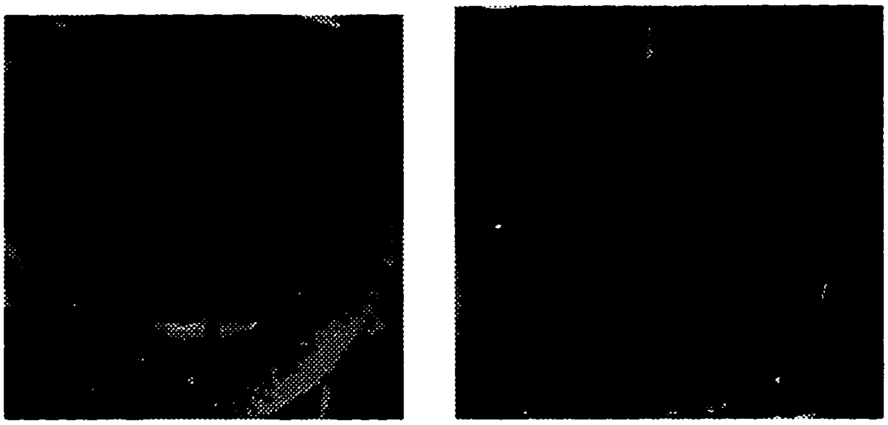
	gloss	**general palatalization**
a) /nduʔu/	'tree trunk'	[ndʲuʔu]
b) /ndɨɨ/	'flat, smooth'	[ndʲɨɨ]
c) /tuʔu/	'cutting off of water'	[tʲuʔu]
d) /tɨʔɨ/	'twisted'	[tʲɨʔɨ]

(61) **non-palatalized forms**

	gloss	**non-palatalized forms**
a) /ndaa/	'certain'	[ndaa]
b) /ndoo/	'sugar cane'	[ndoo]
c) /taʔa/	'pimple'	[taʔa]
d) /toʔo/	'mayor'	[toʔo]

In (62) I provide two palatograms illustrating the effects of general palatalization. Produced by a female CM speaker, these clearly illustrate the contrast between phonetically palatalized and non-palatalized /t/. Note the extensive degree of linguo-palatal contact in (62a) *tʲuʔu* 'cutting off of water' as compared to the lack of post-alveolar contact in the non-palatalized *taʔa* 'pimple' in (62b).

(62)



a) **palatalization: t-> t^j** t^juʔu 'cutting off of water'

b) **no palatalization** taʔa 'pimple'

Palatograms exhibiting the distinction between men's and women's speech are provided in (63) for the word *uʔ*^{u}*tẽ* 'tomorrow'. Here we see a sharp difference between a male speaker's production in (63a) and that of female speaker producing the same word in (63b). In (63a) note the alveodental contact typical of non-palatalized, plain alveolar stops. By contrast, the palatogram in (63b) reflects the articulatory effect of the affrication found in women's speech. Here, the tongue tip has been retracted, so that there is no evidence of contact between the front teeth and the tip or blade of the tongue. Instead, we see evidence of contact between the tongue blade or tip at and just behind the corner of the alveolar ridge.[16]

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[16] I take the term *corner* from Keating (1991), who treats the alveolar ridge as the whole area from the upper teeth to the point where the hard palate begins to angle sharply upwards. The corner is this turning point. See also Catford (1988) for discussion of this issue and Recasens (1990) for a slightly different descriptive perspective.

(63) a) **/utẽ/** b) **/utẽ/ → [uʔ^{u}tʃẽ]**

'men's speech' **'women's speech'**

It is also important to note the contrast between (63b) and the same speaker's production of *t^{j}uʔu* 'cutting off of water' in (62a). In the former case, there is far more tongue contact behind the corner of the alveolar ridge and along the roof of the hard palate. This is just what we expect to see when contrasting palatalization as the addition of a secondary high, front tongue body position to a primary alveolar point of articulation with palatalization as a shift in primary point of articulation from an alveodental to a post-alveolar or non-anterior coronal primary point of articulation (see discussion in Keating 1991, also Bhat 1978).

It is interesting to note as well that both processes target only /t/ and /nd/. Other alveolar consonants are unaffected.

(64)	a) nĩ	'with'	b) sule	'jar'	c) tsiʔi	'distribute'
	nɨ̃ɨ̃	'completely'	sia	'chair (Sp.)'	tsɨɨ	'snail'
	nũũ	'in front of, on'			tsuʔu	'mole'

Though a detailed phonological analysis of the CM palatalization facts is beyond the scope of this chapter, the data are of general theoretical significance.[17] This is because the two phenomena are triggered by different sets of vowels. As noted in Gerfen (1995), this presents a serious challenge to analyses of palatalization which argue for coronal (front) vowels as the sole triggers of palatalization (see, for example, Clements 1976, Hume 1992) and for feature geometries such as those of Hume (1992) and Clements and Hume (1995) in which the difference between secondary palatalization and affrication resides not in potentially distinct assimilating features but in the tier affiliation of the palatalizing feature. Thus, Hume (1992) provides the following technical approach to treating palatalization: secondary palatalization is assumed to involve the spreading of a vocalic coronal feature to the vocalic place node of the target consonant. By contrast, affrication (Hume's "coronalization") is assumed to involve the spreading of a vocalic coronal node to the primary consonantal place node of the target consonant, triggering the concommitant delinking of the primary place feature of the consonant. This is sketched in (65).[18]

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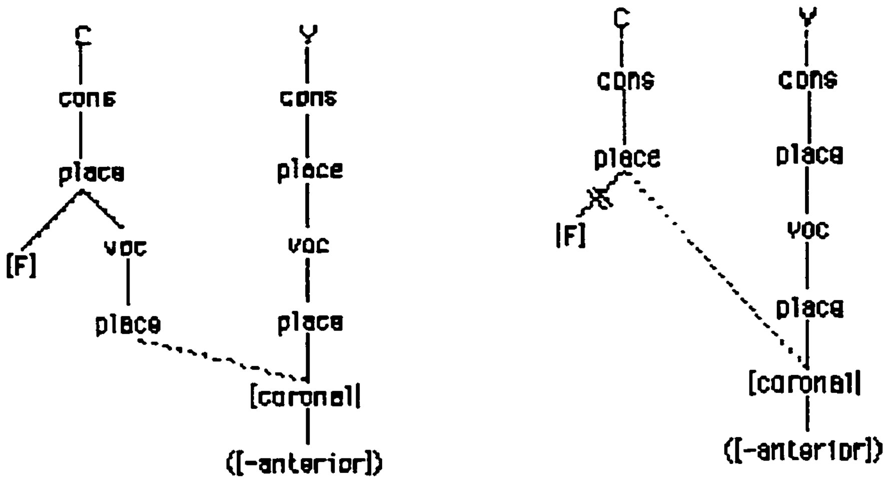
[17] A more detailed autosegmental analysis is presented in Gerfen (1995).

[18] The geometry of Clements and Hume (1995) is somewhat distinct from that of Hume (1992), but these differences do not affect this discussion.



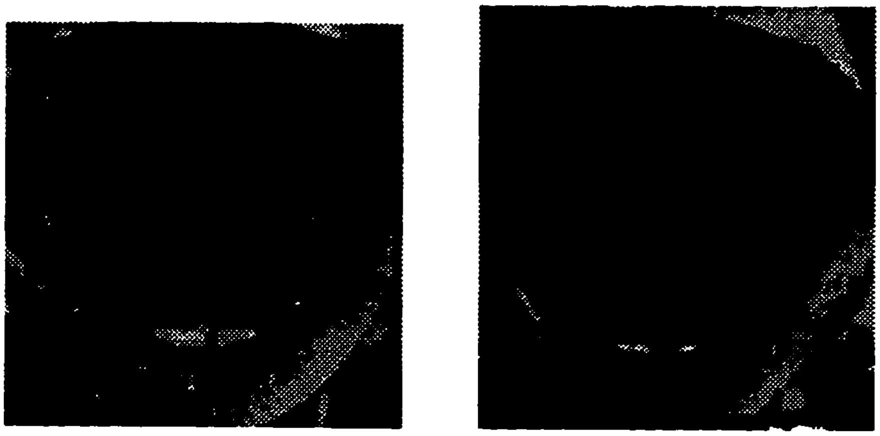
(65) **a) palatalization** **b) coronalization**

What casts doubt on the validity of this view, of course, is that while women's speech affrication can be modeled as the assimilation of a vocalic coronal node to the primary place of articulation of the target consonant, general palatalization is clearly not triggered by front (coronal) vowels. Instead, it would appear that the vowel feature [+high] must also be countenanced as a possible trigger for palatalization. (cf. Lahiri and Evers 1991, Crowhurst 1986, also Hill and Zepeda 1992 for evidence of high vowels as triggers for palatalization in Tohono O'odham.)

2.4.1 Palatalization and nasality

Another interesting aspect of CM palatalization is its surprising interaction with vowel nasality. In particular, general palatalization fails to obtain just in case the vowel following the alveolar stop is a contrastively nasalized /ũ/. If, however, the vowel is an underlyingly nasal /ɨ̃/,palatalization surfaces predictably.[19] This is shown in the palatograms in (66-67) for the same female speaker whose palatograms are shown above. Note first in (66) the minimally contrastive *tʲuʔu* 'cutting off of water' and *tũʔũ* 'word'. In the former, the couplet contains underlyingly oral vowels and /t/ surfaces as palatalized. In the latter, however, the vowels are contrastively nasal, and there is no palatalization.

(66) a) ***tʲuʔu* 'cutting off of water'** b) ***tũʔũ* 'word'**



Now note the contrast in (67a-b). In (67a), the high, central vowel following /t/ is underlyingly oral, while in (67b) it is nasal. However, in both cases, the /t/ surfaces as palatalized. That is, we can clearly discern the

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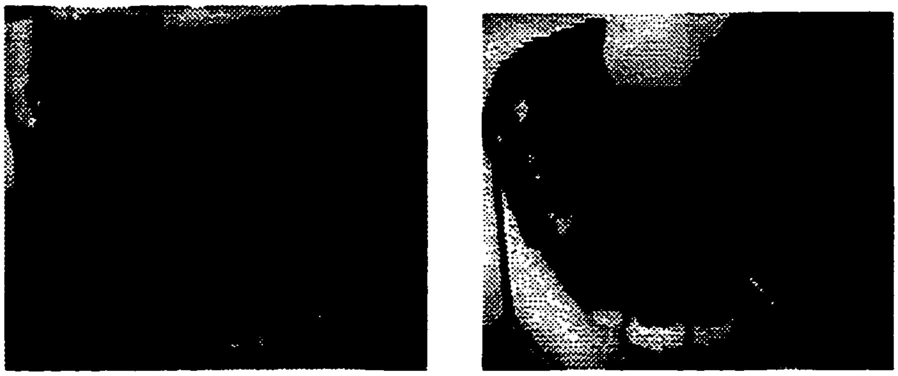
[19] Women's speech palatalization is unaffected by vowel nasality.

extensive area of contact that is diagnostic of the presence of secondary palatalization.[20]

67) a)tʲɨʔɨ **'twisted'** b) tʲɨ̃ɨ̃ **'grab'**



The situation is complicated by the fact that the lack of palatalization before nasalized /ũ/ is not surface true. Thus, if an underlyingly oral [ũ] is nasalized via the morphophonological process of second-person familiar nasalization, a preceding /t/ will surface as palatalized. This is shown in the palatogram in (68). Here, kuʔᵘtʲu 'hoe' is nasalized to form the second person familiar kuʔᵘtʲũ 'you will hoe'. In contrast to (66b), produced by the same

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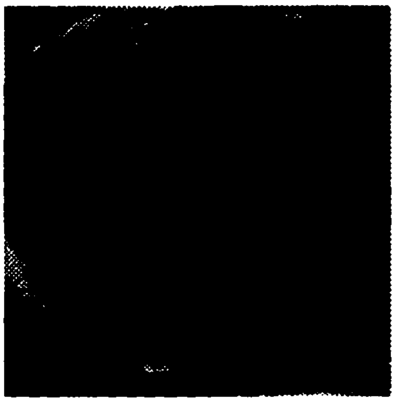
[20] The effect of contrastive/ũ/ on a preceding /nd/ is more difficult to discern due to the fact that the language generally prohibits the cooccurrence of prenasalized stops and contrastively nasalized vowels within morphemes (see Chapter 4). In one form, *ndʲ*ũðĩ 'honey' the prenasalized stop surfaces as palatalized before a lexically nasalized /ũ/. This suggests that the effect might be limited to underlying /t/. However, the presence of palatalization in *ndʲ*ũðĩ may receive a diachronic explanation in that this form may have arisen from the fusion of /ndute/ 'water' and /βĩðĩ/ 'sweet'. Thus, one might argue that the presence of palatalization on the stop constitutes a fossilized remnant of its realization before the non-nasal /u/ of /ndute/.

speaker, the /t/ here exhibits evidence of the large area of contact between the tongue and the hard palate found in our other cases of secondary palatalization.

(68) **kuʔ^{u}t^{j}ũ 'you will hoe'**



As with the issue of triggers for palatalization above, the interaction of of palatalization and nasalization raises theoretical questions. In particular, the failure of palatalization before /ũ/ raises interesting questions for theories of feature interaction that predict that feature cooccurrence constraints must be phonetically motivated (cf. Archangeli and Pulleyblank 1989, 1994a). At the least, the CM data suggest that the grammar contains some--potentially arbitrary--constraint prohibiting the assimilation of [+high] from a lexically nasal /ũ/, while not ruling out the assimilation of [+high] from a lexically nasal /ĩ/.[21] At the same time, there is clearly no global phonetic prohibition

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[21] One might claim that the data motivate an analysis in which lexically nasal /ũ/ is unspecified for [+high]. As Diana Archangeli has pointed out, this may be attributable to the lack of a constrastively nasalized /õ/. However, such

against the palatalization of /t/ before [ũ], given the common occurrence of forms such as kuʔᵘtʲũ 'you will hoe' in (68). Data such as these thus provide a basis for fruitful discussion of claims of the phonetic naturalness of phonological phenomena.[22]

2.5 Conclusions

This chapter provides a basic picture of the shape of CM morphemes and of the segments of which they are comprised. The picture that I have begun to articulate and on which I will build in the ensuing chapters is one in which CM morphemes, so-called couplets, can be viewed as canonically bimoraic structures of two shapes: CVV and CVCV. The schematic representations (with exemplifications) that I will assume throughout are repeated here in (69).

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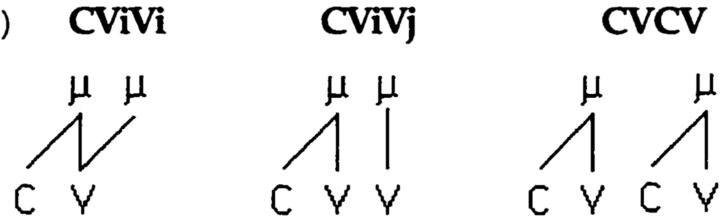
underspecification may constitute simply a strategy of shifting the location of arbitrariness in the treatment of the phenomenon. Assuming, say, that [+high] is the assimilating feature, why is /ũ/ unspecified for [high], while /ĩ/ is not? See Steriade (1995) for a discussion of general problems of this type for underspecification; also Inkelas (1994) for criticism of underspecification within Optimality Theory.

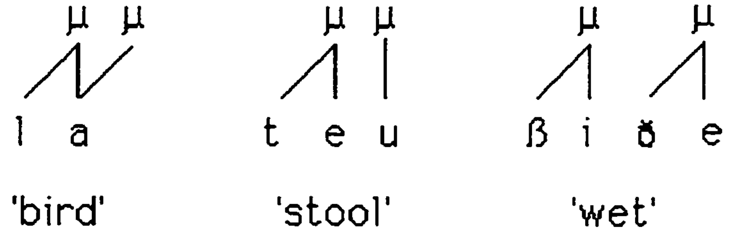
[22] Forms such as kuʔᵘtʲũ 'you will hoe' clearly suggest that level-ordering within lexical phonology plays an important role here (cf. Kiparsky 1982, 1985, Mohanan 1982, Pulleyblank 1986, Kaisse and Shaw 1985, among others). I cite such forms merely to show that there is no absolute prohibition against the surfacing of palatalized stops before nasal [ũ].

(69) **Canonical couplet shapes**

a)



b) **Examples**



Regarding the segmental contrasts of the language, I have attempted to provide the reader with a sense of which segments appear to play a central role in the segmental inventory and which appear to be marginal, despite the presence of a minimal pair that might be used to argue for the phonemic status of the sound in question. With this goal in mind, I provide here a modification of Pike and Small's (1974) original consonant inventory. In this case, however, I enclose marginal contrasts in square brackets.

(70) CM consonant inventory (Pike and Small 1974)

stops:	[p]		t		k	kʷ
	[mb]		nd		[ŋg]	[ŋgʷ]
affricates:			ts	[tʃ]		
			[ndz]	[ndʒ]		
fricatives:			[s]	ʃ		
	β	ð, [ðʲ]				
liquids:			l,[r]			
nasals:	m		n	ɲ		

This leaves a picture of roughly 11 contrastive consonants which appear with regularity across morphemes in the language. And it is from morphemes containing these that I have generally chosen, for example, for use in the nasal airflow study of Chapter 4. Similarly, in choosing forms for airflow study, I have chosen to focus on forms containing a single medial consonant, rather than on the non-canonical forms containing medial clusters.

As a final transcription note, throughout the remainder of the dissertation I have chosen to transcribe the data relatively narrowly. This means that I consistently mark palatalization, nasalization, and glottalization, even when predictably present. The choice results from my own dissatisfaction with grammars which state phonological generalizations and then pursue a policy of broad transcription thereafter. Though one is led to assume that such generalizations are accurate, I prefer to be certain that a phonological process has applied in every case in which it should.[23]

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[23] The one exception to this is the transcription of tone. The tone sandhi of the language is highly complex and I have chosen not to transcribe the tones of most forms, given that further fieldwork is needed before I feel that I will be able to do so with confidence. Chapter 3 makes some mention of tone within the context of the discussion of glottalization. However, the reader is referred to the transcriptions in Pike and Small (1974) for an overview of the tone system.

CHAPTER 3 GLOTTALIZATION

3 Introduction

This chapter provides a detailed examination of both the phonetics and phonology of CM glottalization. Like many other varieties of Mixtec, CM contains what have alternately been called *glottalized* or *checked* or *echo* vowels, as in the form *ku*ʔ^{u}*t*^{j}*u* 'to plow, to hoe'.[1] The treatment of glottalization in CM raises a number of significant issues, which I have broken down in this chapter into three general areas of discussion. The first basic question arises over whether glottalization should best be treated as a vowel feature or whether the presence of glottalization might more appropriately be characterized by including a glottal stop in the consonant inventory of the language. The second issue regards the behavior of glottalization in the phonological system. As I will show, glottalization plays a dual role in that it surfaces both contrastively and predictably, while at the same time both predictable and contrastive glottalization are licensed only under stress. The third issue focuses on the relevance of glottalization to the interface of phonology and phonetics. Here, I discuss two points of interest. First, I address the role of grounded path conditions (Archangeli and Pulleyblank 1994a) (i.e. feature cooccurrence constraints) in characterizing the

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[1] See MacCaulay and Salmons (1995) for a general overview across the Mixtec languages. In Spanish the term *saltillo* 'little skip or hop' has been used to describe this effect. See, for example, Pesinger (1974).

location of glottalization. Secondly, I examine the relevance of glottalization to claims about how phonologically specified features are implemented by the phonetic component of the grammar. In particular, I focus on Cohn's (1990, 1993a) claim that phonologically specified features are implemented throughout the entirety of the segment for which they are specified. I argue that the CM glottalization data show this position to be overly restricted in that the CM facts require that phonologically specified [+constricted glottis] be implemented throughout only part of a vowel for which it is specified.

The chapter is organized in the following manner. §3.1 provides a description of the basic distributional facts relating to CM glottalization. At the same time, it lays out the implications of treating glottalization as either a vowel feature or as a consonant in its own right. §3.2 and §3.3 provide phonetic and phonological arguments, respectively, for treating glottalization as a feature of vowels in CM. With this established, in §3.4 I provide an explicit phonological treatment of glottalization within the context of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993b). Here, I show that a complex array of facts pertaining to the distribution and to the dual status of glottalization as both contrastive and predictable can be made to follow from the interaction of three constraints. In §3.5, I provide an explicit characterization of the stress system, given that the phonological characterization of glottalization in §3.4 requires that glottalization be licensed only under stress. §3.6 provides a discussion of the interface of phonology and phonetics, with a focus on the issues of grounding (Archangeli and Pulleyblank 1994a) and phonetic implementation as assumed by Cohn (1990, 1993a). Finally, in §3.7 I summarize the primary claims of the chapter and present my conclusions.

3.1 Glottalization and the shape of the CM couplet

As MacCaulay and Salmons (1995) note, a long-standing issue among Mixtec scholars regards the determination of whether glottalization is a vowel feature or whether it constitutes a separate glottal stop consonant. This issue, in turn, raises possible challenges to the descriptive characterization in chapter 2 of the CM couplet as a canonically bimoraic structure. In this section, I describe the nature of the problem. I begin with a description of the distribution of glottalization in the CM couplet. I then provide a range of specific representational possibilities for glottalization within the grammar.

In CM, the distribution of glottalized vowels is narrowly restricted; they surface only as the initial vowel (mora) of the couplet, as seen in (1).[2]

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[2] Note that in the CV?V column, I have not transcribed the second vowel as a superscripted "echo" vowel. This choice reflects an analysis in which glottalization is limited to the first (stressed) mora of a couplet (see §3.4 below) and by evidence from the CM tone system (see chapter 4). As I note in chapter 2, a couplet is comprised of two moras. In CVV couplets, I have not superscripted the vowel following the glottal symbol to indicates that this vowel is a full mora; i.e. the second mora of the CVV form. This view receives support from Pike and Small (1974)'s report that heterovocalic CVV couplets such as *te?u* 'rotten' are sometimes realized as [te?^{e}u], i.e. with glottalization on the *first* mora.

(1) **Glottalized couplets**

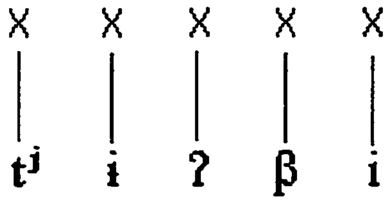
CVʔCV		**CV$_{i}$ʔV$_{i/j}$**	
a) t^{j}ɨʔ^{ɨ}βi	'to push'	e) βaʔa	'well, good'
b) kaʔ^{a}nde	'to cut'	f) ndaʔa	'be spread on'
c) kuʔ^{u}t^{j}u	'to plow, to hoe'	g) ðuʔu	'to steal, rob'
d) t^{j}uʔ^{u}ʃi	'to peel'	h) teʔu	'rotten'

Glottalization raises the most serious challenge to the bimoraic characterization of glottalized [CVCV] couplets such as those in (a-d). Concretely, we are led to ask whether forms such as *kaʔ^{a}nde* 'to cut' should be treated as bimoraic or as trimoraic structures containing a glottal stop consonant. These alternatives are shown in (2).

(2) a) bimoraic: **kaʔ^{a}.nde** vs. b) trimoraic: **ka.ʔa.nde**

Of course, the description *glottalized vowel* itself entails an analysis of the data which accords with the representation in (a). However, other researchers have adopted representations in line with the spirit of (b). For example, Piggott's (1992) treatment of CM nasal harmony assumes a glottal stop segment which is assigned a full timing slot (following Levin 1985, an X-slot on the skeletal tier) so that the segmental representation of a couplet such as *tʲɨʔᶤβi* ' 'to push' contains five timing units, as in (3).[3]

(3) **Glottalization as a segment** (from Piggott 1992)



A closer examination of the facts, however, suggests that this view is inadequate. In the following two sections, I argue that glottalization is best viewed as a vowel feature. I begin in §3.2 with a consideration of the phonetic manifestation of glottalized vowels. Here, I provide a basic description of the acoustic manifestation of glottalization and show that the phonetic data are consistent with viewing glottalization as a vowel feature and not as an independent segment in its own right. In §3.3, I complement the phonetic discussion with three phonological arguments and one external argument in support of the claim that glottalization is a vocalic feature, i.e. that there is no phonological motivation for assuming the presence of a glottal stop segment in the language.

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[3] Piggott has little to say about the status of the echo vowel. Important here is simply his attribution of segmental status to the glottal stop.

3.2 The phonetics of vowel glottalization

Typically, the realization of glottalized vowels involves the interruption of modal vowel production by a brief period of laryngealization or creaky voicing. By *modal vowel* production, I refer to normal voiced phonation, i.e. vowel production in which the vocal folds are drawn together and set into vibration in a quasi-periodic manner. Though the precise articulatory mechanism used to produce creaky voicing is a matter of some debate, acoustically, creaky voicing is characterized by both very low frequency glottal pulsing and by the absence of the quasi-periodicity found in normal or modal voicing (cf. Catford 1964, 1977; Ladefoged 1993a; Laver 1980, 1994; Henton and Bladon 1988; Ladefoged and Maddieson 1996 for discussion).

As Kirk et. al. (1984) show in a study of phonation types in Jalapa Mazatec, creaky voicing can be measured as a function of jitter in the acoustic waveform, where *jitter* refers to the temporal variation in the interval between adjacent glottal pulse peaks.[4] Due to the relative aperiodicity of the glottal pulses involved in creaky voicing, creaky voiced vowels will exhibit greater variation (i.e. will be realized with more jitter) than their modal counterparts. Bearing this in mind, I provide here a comparison of the jitter in the initial vowel of the minimal pair ʃɨʃɨ 'coati' ʃɨʔᶤʃɨ 'mushroom' for three CM speakers: S3, S6, and S5.[5] To avoid any possible effects of distinct

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[4] Like Mixtec, Mazatec is best viewed as a family of languages (see Kirk 1970).

[5] S5 and S6 are 24 year old and 29 year old male speakers, respectively. S3 is a

lexical tones, the target words are controlled for tone in that both are uniformly low toned forms: ʃɨʃɨ 'coati' ʃɨʔ^{ɨ}ʃɨ 'mushroom'. Each speaker produced multiple tokens of the target word in the frame */kaʔu-u WORD te-βaa/* 'I write WORD tomorrow'. For S3, five tokens were recorded, while three tokens of the target word were recorded for S6 and S5 in separate recording sessions using a Shure SM-512 unidirectional, close-talking dynamic microphone and a Marantz PMD222 cassette recorder. The data were digitized and analyzed with the use of the C-Speech speech analysis software at the University of Arizona. Following the methodology of Kirk, Ladefoged, and Ladefoged (1984), the distance in milliseconds between each glottal pulse peak was hand measured for each of the tokens of the target vowel (V1) of both words. The mean standard deviation in milliseconds between successive peaks for each speaker's production of each of the target vowels was then calculated. The results are shown in the table in (4).

(4) **Table of average standard deviations in msec. for V1 in ʃɨʃɨ versus ʃɨʔ^{ɨ}ʃɨ**

	S3	S5	S6	Mean	s.d.
modal ʃɨʃɨ	.265	.268	.428	.320	0.093
glottalized ʃɨʔ^{ɨ}ʃɨ	5.537	2.969	2.310	3.605	1.705

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21 year old female speaker.

The table can be interpreted as follows: the greater the mean standard deviation between adjacent peaks, the greater the measure of jitter in the signal. For S3, the average standard deviation in milliseconds between adjacent glottal pulse peaks in V1 across the five tokens of ʃɨʃɨ 'coati' was .265 milliseconds, while the average standard deviation in V1 across the five tokens of ʃɨʔ^{ɨ}ʃɨ 'mushroom' was 5.537 milliseconds. For S6, V1 of ʃɨʃɨ 'coati' exhibited an average standard deviation of .428 milliseconds, as compared to 2.31 milliseconds for the V1 of ʃɨʔ^{ɨ}ʃɨ 'mushroom'. Similarly, for S5, V1 of ʃɨʃɨ 'coati' exhibited an average standard deviation of .268 milliseconds, as compared to 2.969 milliseconds for the V1 of ʃɨʔ^{ɨ}ʃɨ 'mushroom'. In short, for each speaker, V1 of ʃɨʔ^{ɨ}ʃɨ 'mushroom' clearly shows a greater amount of jitter than does V1 of ʃɨʃɨ 'coati'.

It is also important to note that there is no crossover between speakers for these forms. Despite the fact that speakers vary in the degree of jitter with which the target vowels in both forms are realized, there is no case in which the modal vowel for one speaker exhibits more jitter than the glottalized vowel of another speaker. The final two columns of the chart provide a mean of the average standard deviations for the three speakers for each target vowel, along with a measure of the standard deviation from that mean. The net result of the data is straightforward: V1 of ʃɨʔ^{ɨ}ʃɨ 'mushroom' exhibits the acoustic behavior we would expect of a creaky voiced vowel for all of the speakers.

One aspect of the production of glottalized vowels that is not highlighted by the global calculation of relative jitter above is the ordering of modal and creaky voicing. As I have noted, the phonetic implementation of glottalized vowels most typically involves an interruption of modal phonation by creaky voicing--that is, a sequencing of the two phonation types within the glottalized vowel. In the case of glottalized [CVCV] couplets, this creaky voicing is often followed by a brief resumption of modal vowel production, thus producing the echo effect: the glottal gesture is followed by a rearticulated, short vowel of identical quality as the vowel which precedes the interruption. Nevertheless, it is interesting to note that there is a considerable amount of variation across speakers in the production of these vowels, especially with respect to the resumption of modal phonation following creaky voicing. Consider, for example, the distinct realizations of the form *kuʔᵘtʲu* 'to plow, to hoe' for the three speakers S2, S1, and S4 in (5-7) below.[6] Five tokens of *kuʔᵘtʲu* were recorded in the frame /*kaʔu-u WORD te-βaa*/ 'I write WORD tomorrow' for each speaker. A representative token for each speaker is provided below.

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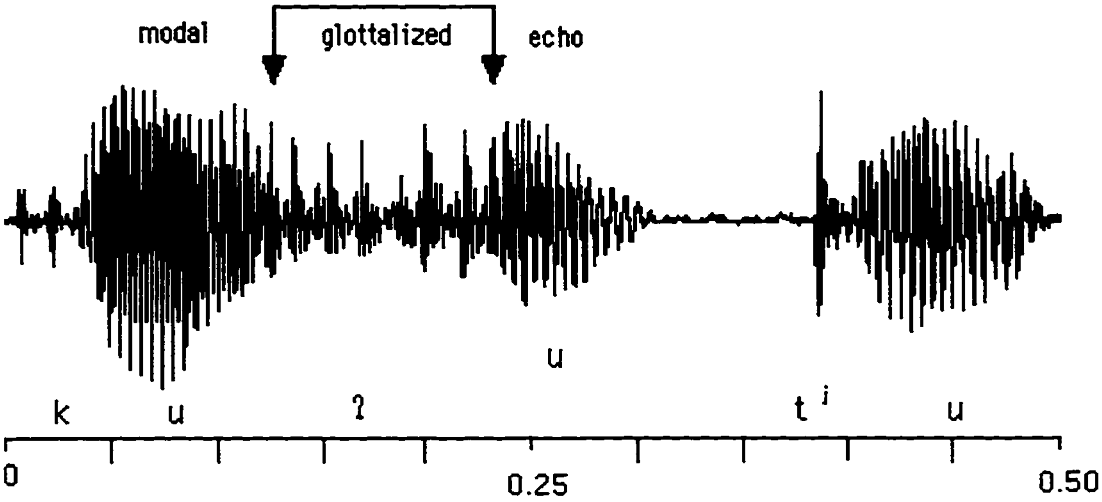
[6] S2 and S1 are female speakers approximately 42 and 30 years old, respectively. S4 is a 23 year old male speaker.

The form in (5) produced by S2 corresponds generally to what I have called the typical realization of a glottalized [CVʔCV] couplet.[7]

(5) **S2: echo vowel clear in the waveform**



We clearly see the sequencing of modal and creaky voicing in the waveform. As is indicated in the figure, V1 initiates just prior to the 50 millisecond point on the time scale. At close to 125 milliseconds we see the onset of creaky voicing (i.e. glottalization), characterized by a loss of quasi-periodicity and a sharp F0 drop. Finally, at approximately 240 milliseconds, we observe the resumption of modal phonation, resulting in the presence of an echo vowel.

By contrast, in the token in (6) produced by S1 there is no obvious manifestation of the echo vowel in the waveform:

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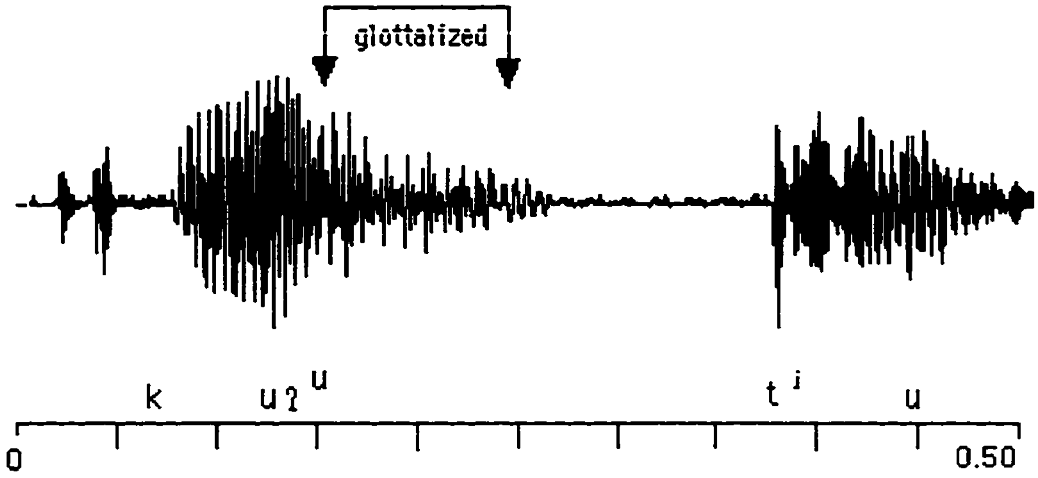
[7] It is worth noting that this speaker regularly produced tokens with the longest resumption of modal phonation, perhaps due to the fact that she was more careful than others in attempting to produce citation forms.

(6) **S1: no clear echo vowel**



As with S2, S1's production of *kuʔ^{u}t^{j}u* exhibits a clear sequencing of modal and creaky phonation; the onset of the latter is marked in the figure with an arrow. However, there is no obvious resumption of modal phonation in the vowel prior to the onset of closure for the medial stop.[8]

As a third case of variation, the token from speaker S4 provides an example in which the glottalized vowel appears to exhibit creaky voicing throughout its duration:

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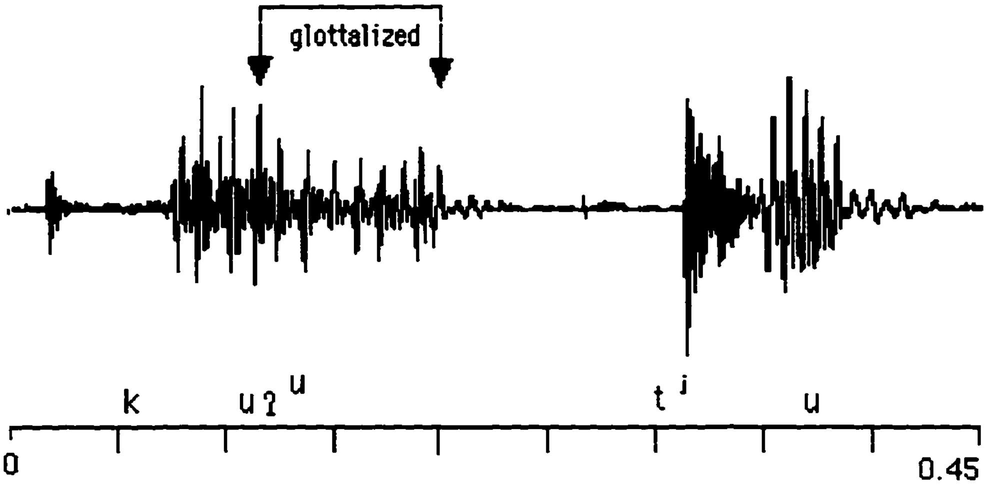
[8] Interestingly, this does not prevent me from *hearing* an echo vowel in this form and in other similar forms for this speaker.

(7) S4: no clear sequencing

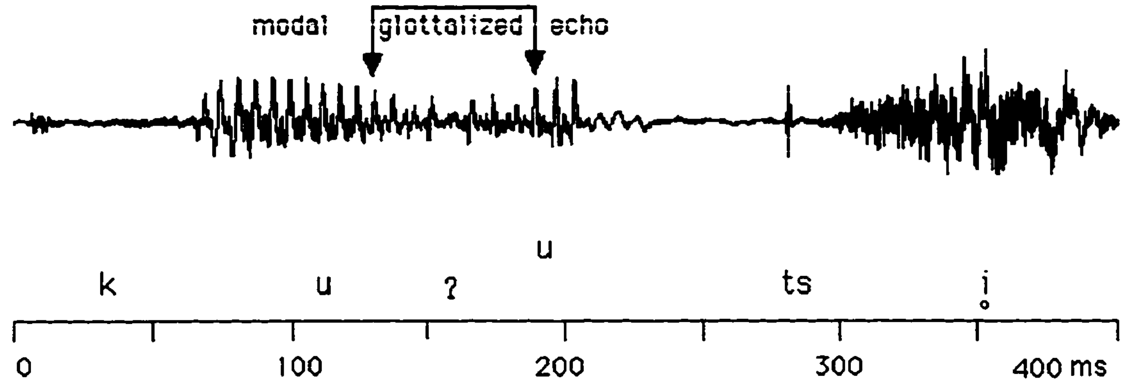


Though I have marked a point at roughly 110 milliseconds at which there is a decrease in the amplitude of the glottal pulses, the reader can see that this vowel appears to be glottalized throughout most if not all of its duration.[9] Nevertheless, it is important to note that the variation exhibited in (5-7) is not limited to cross-speaker data. Consider, for example, the token of *kuʔ*^{u}*tsi* 'bathe' in (8) below, also produced by S4. Here, we find the canonical sequencing pattern to which I refer above; that is, V1 is not realized with creaky voicing throughout its entirety:

---

[9] Note that S4 is a male speaker. Thus, we expect a lower F0 in general than for S1 and S2 above, who are both female. In any event, a transition from modal to creaky phonation is more difficult to discern in the token in (7).

(8) **S4: visible sequencing**



Rather, we can count ten glottal pulse peaks corresponding to modal vowel production. These are followed by the onset of creaky voicing, as is indicated by the presence of the arrow at approximately 125 milliseconds along the time scale. Finally, we see that the resumption of modal voicing (i.e., the echo vowel) can be extremely short--in this case, two glottal pulses.[10]

The phonetic implementation of glottalized vowels in biconsonantal couplets sheds light on the proper treatment of glottalized CVV couplets. Above, I note briefly (see fn. 2) my decision to transcribe glottalized CVV couplets as CVʔV and not as CVʔ^{V}. That is, I do not treat the vowel following the glottal gesture as an echo vowel, but rather as a full vowel in its own right. To put matters in terms more formal terms, I have argued that couplets

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[10] Note also that the final vowel of *kuʔ^{u}tsi* 'bathe' is voiceless in 8. CM speakers optionally devoice the second (unstressed) vowel of CVCV couplets, especially if the medial consonant is voiceless (more on stress in §3.5 below). As can be seen in (5-7), however, devoicing does not always obtain. For the purposes of this study, I assume that this is either an optional post-lexical or

in CM are bimoraic structures, and this transcription reflects a phonological analysis (to which I turn in detail below) according to which glottalization is a feature of the vowel dominated by the initial mora of the couplet. The full (non-superscripted) vowel transcribed after the glottal symbol in a form such as β*aʔa* 'good/well' signals that the couplet is bimoraic; superscripted vowels are reserved for indicating the presence of the non-moraic echo vowel found almost always in CVCV couplets.

Despite the kind of variation in the phonetic implementation of glottalization that we have just seen above, the phonetic data on glottalized CVV couplets support this approach. Consider, for example, the waveform and wide band spectrogram in (9) of the form *kaʔu* 'write'. Again, this form was produced in the carrier phrase */kaʔu-u WORD te-*β*aa*e/ 'I write WORD tomorrow', in this instance by speaker S3.[11]

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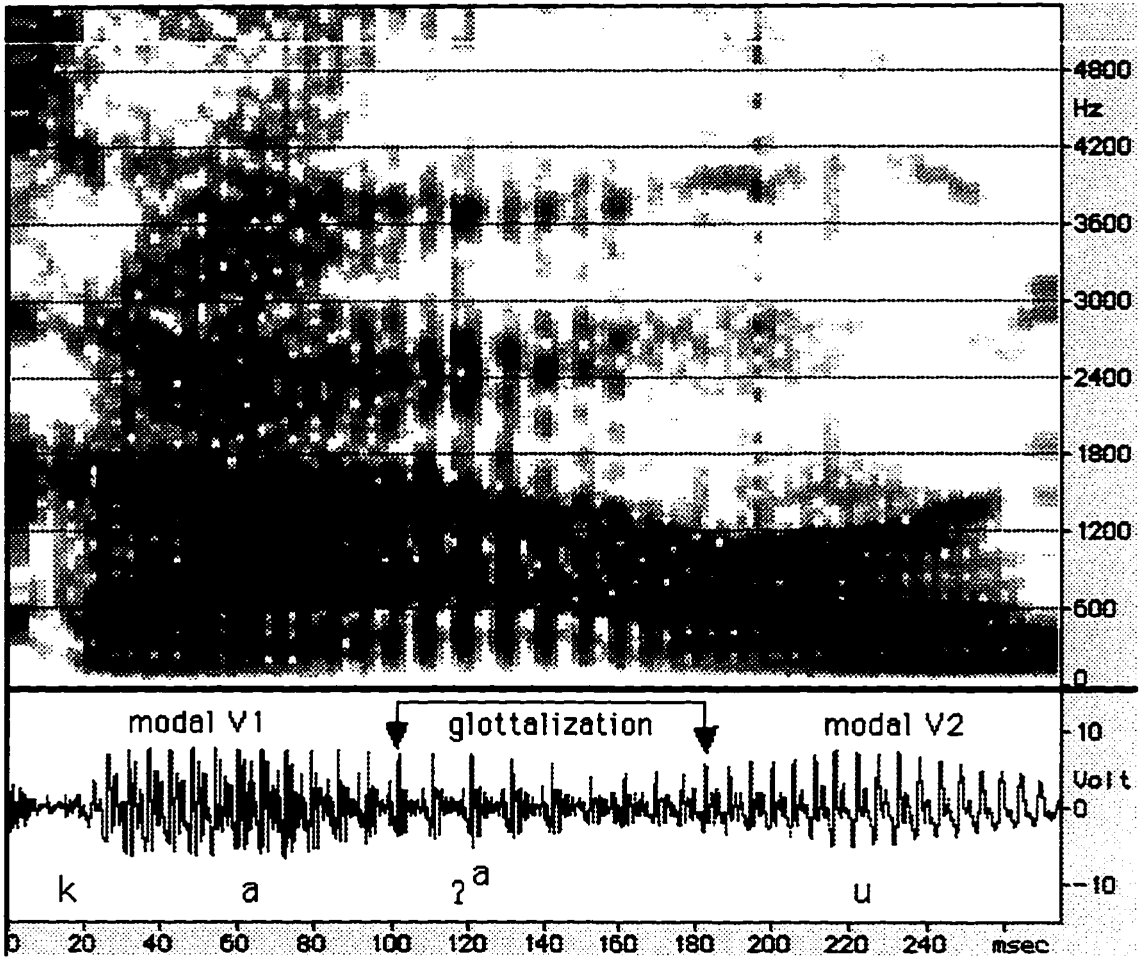
phonetic phenomenon and leave the issue for future investigation.

[11] This signal was digitized into a Power Macintosh 7500 computer and analyzed via the use of SoundScope at the UNC-Chapel Hill.

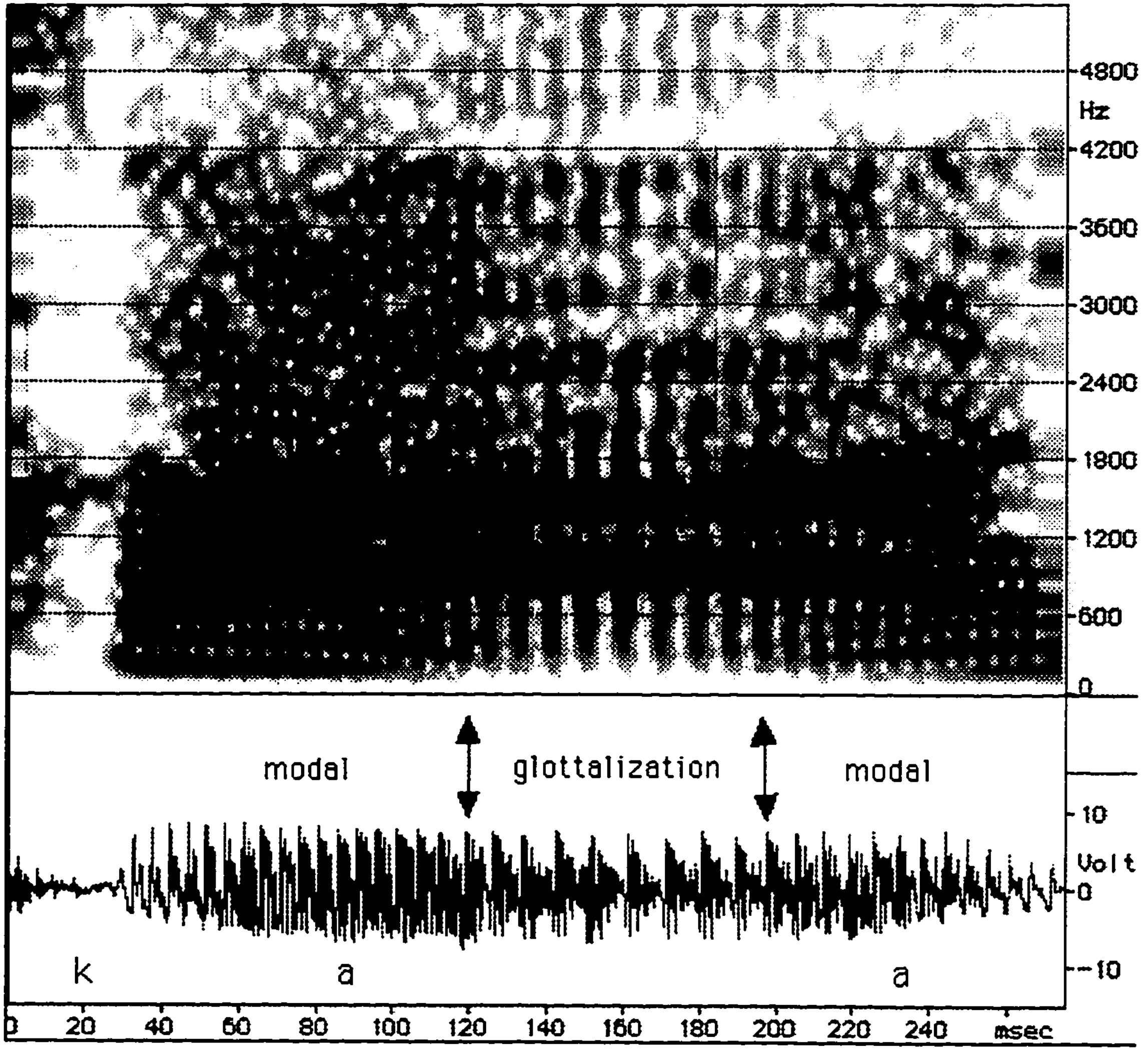
(9) **S3: vowel glottalization in ka?u 'to write'**



What the spectrogram allows us to see clearly is that the onset of glottalization occurs after approximately 90 milliseconds of modal phonation for the initial /a/ vowel of the couplet. The period of creaky voicing itself lasts for another 90 milliseconds, corresponding to the end of the steady state realization of /a/ and the transition from /a/ to the final /u/. Finally, from roughly 180-250 milliseconds, we see a fully modal /u/.

For glottalized couplets such as *kaʔa* 'clearing in forest', the situation is more complicated, as there is no change in vowel quality within the couplet and thus no distinct vowel root that can be correlated with each underlying mora. Nevertheless, as (10) shows, the implementation of creaky voicing in such forms is similar to that of couplets such as *kaʔu* 'to write'.

(10) S3: vowel glottalization in *kaʔa* 'clearing in forest'



Note the relatively long period of modal phonation for /a/ from approximately 30-120 milliseconds. This is followed by a period of creaky voicing--marked with arrows and most clearly visible in the widening space between the vertical striations in the spectrogram (the F0 drop)--from 120-195 milliseconds. Finally, we see that modal phonation is resumed for the /a/ during the final 55 milliseconds of the token.

To summarize, the transcription of such forms as, for example, *kaʔa* 'clearing in forest' rather than *kaʔ*^{a} thus reflects the affiliation of glottalization with the vowel affiliated with the first mora of the couplet, regardless of whether the couplet is of the shape CVV or CVCV.[12] One point needs to be kept clear, however. Recall from chapter 2 that I assume that couplets such as *kaʔa* 'clearing in forest' have one vowel root associated to two moras. This leaves two phonological representations for surface CVV couplets--one in which a single vowel root is associated to two moras and another in which each of two heterorganic vowel roots is associated to a distinct mora. (C's and V's are used here as a convenient short hand for root notes and their dependent features.)

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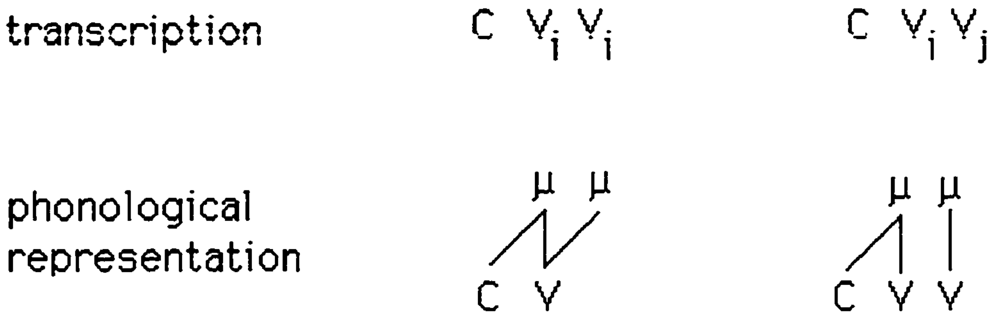
[12] Another possible transcription might be *kaʔ*^{a}*a*.

(11) Phonological representations for CVV couplets



Though this will not prove crucial to the phonological analysis below, transcriptions such as *kaʔa* 'clearing in forest' should nevertheless not be taken to indicate the presence of two vowel root nodes (cf. Selkirk 1990) or skeletal slots (cf. Clements and Keyser 1983, Levin 1985, Broselow 1995). Length in such forms is expressed on the moraic tier.

3.3 Phonological arguments for treating glottalization as a vowel feature

In this section, I provide three phonological arguments, together with an external argument, which support the conclusion that glottalization in CM is best viewed as a vowel feature. Although the phonetic data are compatible with this view, it is important to note that phonetic data alone cannot establish the phonological or systemic role played by glottalization in the grammar of CM. For example, it is possible to argue that the presence of creaky phonation constitutes the phonetic implementation of a glottal stop.[13]

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[13] I am grateful to Mary Beckman (p.c.) for first pointing this issue out to me and for discussion of the problems involved. For an example, see Cohn's (1993a) discussion of so-called glottalized /t/ in English, the phonetic implementation of which looks like creaky phonation on preceding vowel.

Nevertheless, there is strong phonological motivation to believe that creaky phonation in CM constitutes the phonetic implementation of vowel glottalization. The first argument in support of this position is that the assumption of a glottal stop segment leaves a strange gap in the basic phonotactic pattern of the language in that /ʔ/ never surfaces morpheme-initially. By contrast, as I point out in chapter 2, all of the other consonantal contrasts (even the most marginal cases) are attested in this position. If glottal stop is segmental, there is no explanation for this gap; if glottalization is treated as a vowel feature, the gap evaporates.

The second argument is similarly phonotactic in nature. In this case, if we assume that glottalization is consonantal, we must explain why CM contains no other CVCVCV *monomorphemic* forms in which the medial consonant is other than a glottal stop--that is, why we find monomorphemic forms such as *t*^{j}ɨʔ^{ɨ}β*i* 'to push' but never **t*^{j}ɨð^{ɨ}β*i*. Additionally, we must explain why only V1 exhibits echo effects. Thus, not only do we lack an explanation for the absence of forms such as **t*^{j}ɨð^{ɨ}β*i*, but we also lack an explanation for why there are no monomorphemic forms in which the final vowel surfaces as an echo vowel, as in the hypothetical but impossible **kuʔuʔ*^{u} or **kuʔaʔ*^{u}. As I show below, these problems disappear in an

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See also Pierrehumbert and Talkin (1992).

analysis in which glottalization is taken to be a vowel feature, the distribution of which is conditioned by the stress system of the language.

A third argument resides in the lack of an explanation for the "echo vowel" effect. In addition to addressing the phonotactic problems above, we must also ask why, in glottalized CVCV couplets, we should find a short copy vowel surfacing regularly after a glottal stop consonant and not after any other consonant? One might hypothesize that this is the result of a translaryngeal vowel harmony process that is blocked by supralaryngeal consonants. However, such an analysis fails to explain the lack of obligatory harmony in CV_iV_j forms such as *kau* 'to cough' in which no supralaryngeal consonant intervenes between the two vowels. Nor does such an analysis provide any explanation for the marked shortness of echo vowels. Anticipating further discussion of the phonetics of vowel glottalization in §3.6 below, I show that the echo vowel effect is best understood not in terms of vowel harmony, but rather, through a consideration of the phonetic implementation of the glottalizing feature that results in partial vowel glottalization, with echo vowels arising from the sequencing of the modal and creaky voicing described above.

Finally, interesting support for this position derives from the way in which speakers whistle the tone patterns of CVCV and CVʔ^{V}CV forms.[14]

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[14] Communicating at a distance by whistling the tone patterns of a set number of words or phrases is common, especially among young male speakers. This

Specifically, speakers whistle the tone of each mora separately in CVCV forms. This might lead us to suspect that in CV?^{V}CV forms, speakers should whistle three times (once for each mora or, perhaps, CV syllable). However, this is not the case. Instead, speakers ignore the presence of glottalization, simply whistling through it. Once again, if we take glottalization to be a property of vowels, its inertness with respect to whistle speech is understandable: the echo vowel phenomenon does not arise from a segmental [?V] string but rather constitutes the implementation of a [+constricted glottis] feature on a single vocalic segment.[15]

Taken together, then the phonetic and phonological facts strongly support a featural treatment of glottalization. In the ensuing discussion, I will assume that this position is correct and will also assume that glottalization is phonologically represented via the association of the feature [+constricted glottis] ([+cg]) (see, for example, Keating 1987) to a vowel anchor, yielding the representation in (12) (irrelevant geometry omitted):

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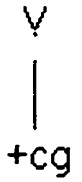
whistle speech phenomenon is also found in the neighboring Mazatec communities (see, for example, Cowan 1948, 1952).

[15] See also Kenstowicz and Kisseberth (1979), Bagemihl (1988) on the value of language games and the phonological utility of external evidence.

(12) Glottalization represented as the association of [+cg] to a vowel



This established, we are now in a position to understand the complex phonological behavior of glottalized vowels in CM. It is to this issue that I turn in §3.4.

3.4 The phonology of glottalized vowels

The arguments in §3.3 accord with MacCaulay and Salmons' (1995) recent proposal that glottalization be treated as a prosodic feature across the Mixtec languages in general. Taking a Pan-Mixtec perspective, MacCaulay and Salmons claim that couplets containing glottalized vowels are lexically specified for a floating [+cg] feature, which associates (in most varieties of Mixtec) to the leftmost (first) vowel of the couplet.[16]

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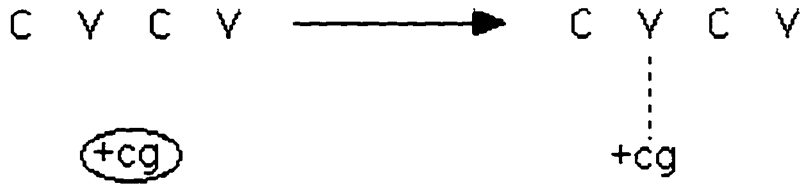
[16] MacCaulay and Salmons are the first to propose a floating feature analysis of the phenomenon, rather than positing a set of underlyingly contrastive glottalized vowels. Note, however, that they are not the first to claim that glottalization is a feature of vowels. They cite Bradley's (1970) discussion of Jicaltepec Mixtec as the earliest such analysis. Another example is Gittlen and Marlett's (1985) analysis of Ñumi Mixtec. Josserand (1982) treats glottalization as a vowel feature in her discussion of the synchronic status of glottalization across the different varieties of Mixtec (pp. 178-179). Also, Pike and Small (1974) in their original discussion of CM anticipate the concept of floating features in autosegmental phonology by identifying glottalization as a property of the entire couplet, though they do not posit a floating feature or provide a formal account of the phenomenon under discussion here.

(13) **MacCaulay and Salmons' (1995)**



At first glance, this appears feasible for CM. Upon closer examination, however, it becomes clear that characterizing the appearance of glottalized vowels in CM requires more than a rule of left-edge association of a floating [+cg] feature. In particular, there are two aspects of CM glottalization that motivate a distinct analysis. The first regards the predictability of vowel glottalization, and the second involves the dependency of glottalization on stress. I address each of these issues in §3.4.1 and §3.4.2, respectively.

3.4.1 Glottalization as both contrastive and predictable in CM

To my knowledge, CM is unique among the Mixtec languages in that glottalized vowels surface both predictably *and* contrastively, i.e. unpredictably. In most varieties of Mixtec, glottalized vowels are contrastive. For example, in (14) we see pairs from Ñumi Mixtec (Gittlen and Marlett 1985), where [V?] indicates a glottalized vowel:

(14) Contrastively glottalized vowels in Ñumi

a) ndeʔ.yu	'mud'
nde.yu	'food'
b) iʔ.ni	'heat'
i.ni	'inside'
c) yuʔ.ma	'smoke'
yu.ma	'wax'

As the data in (15) reveal, CM glottalization is similarly contrastive:

(15) Contrastively glottalized vowels in CM

a) ɲĩĩ	'buy'	d) tɨβi	'blow'
ɲĩʔĩ	'scratch'	tɨʔᶤβi	'push'
b) teu	'bench, stool'	e) kinĩ	'listen'
teʔu	'rotten'	kiʔⁱnĩ	'tie down'
c) uʔβi	'pain'	f) lendʲu	'dirty'
uβi	'two'	leʔᵉndʲu	'uncombed, tangled'

Crucially, however, all of these minimal pairs share one of two properties. Either they are CVV couplets such as (a-b) (i.e. couplets lacking a medial consonant) or they are (C)VCV couplets whose medial consonant is phonetically voiced (c-f). If the medial consonant of a (C)VCV couplet is voiceless, there is no contrast: V1 is *always* glottalized.[17]

(16) No glottalized vowel contrast before a voiceless consonant

a) kuʔᵘtʲu	'to hoe, plow'	g) aʔᵃsu	'garlic'
b) *kutʲu		h) *asu	
c) kuʔᵘtsĩ	'pig'	e) kaʔᵃka	'walk'
d) *kutsĩ		f) *kaka	

In sum, for other varieties of Mixtec, the lack of contrast before voiceless medial consonants is manifested by the *absence* of glottalization. In CM the lack of contrast in this context is instantiated by the *presence* of glottalization. Any analysis of the CM facts must thus go beyond simply associating a floating [+constricted glottis] feature to the first vowel of a couplet in that it must also explicitly characterize the contrastive and predictable role of the [+constricted glottis] feature in the grammar.

3.4.2 Glottalization is dependent on stress

The second important point that must be addressed is that vowel glottalization in CM is conditioned by stress. Descriptively, stress falls predictably on the first mora of a couplet. This raises the possibility that the

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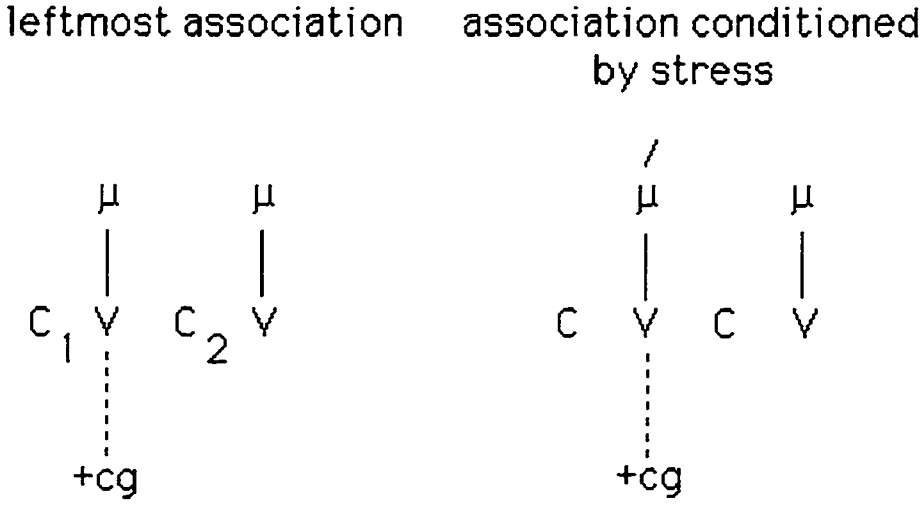
[17] One surface exception is that glottalized vowels do not always surface before the alveo-palatal fricative [ʃ]. I address this issue in detail in §3.4.4.2 below.

important generalization is not that glottalization targets the initial vowel of a couplet (as per MacCaulay and Salmons 1995), but rather, that glottalization is licensed under stress:

(17) **Two views**



Interestingly, Pike and Small's (1974) original description of CM adopts the latter position. The reason is that although stress is predictable within couplets, Pike and Small note that the couplet itself does not always constitute the *nucleus* of the *phonological word-phrase.* In more contemporary terms, the crux of their position consists of two main points: 1) the couplet is a possible prosodic word, though the prosodic word can also be larger than a single couplet; and 2) there is only one main stress per prosodic word. For Pike and Small, then, the *nucleus* of the phonological word-phrase is the couplet that contains the stressed syllable. Pike and Small note that word-phrases that are larger than the couplet "...may include a noun plus one or two modifiers." (122) This characterization is actually incomplete, given that the phonological word-phrase can also consist of a verb plus adverbial elements, of two or more nouns in a compound, or of a noun plus adjective sequence.[18] An example is provided in (18). For expository clarity, stress is marked for each couplet on the left (input) side of the arrow as it would be realized were that couplet to constitute its own prosodic word. The actual surface form on the right side of the arrow indicates that there is only one primary stress per phonological word and that this falls on the penultimate mora of the *final* couplet.

(18) **verb + adverb**

Input	→	*Surface form*
'ku.nu + 'ndiʔ^{i}.ʃe		ku.nu 'ndiʔ^{i}.ʃe 'really run'
'run' 'really'		

These facts are central to characterizing the appearance (and non-appearance) of glottalized vowels. Since glottalized vowels surface *only* under primary stress and since there is only one primary stress per prosodic word, only one glottalized vowel can surface in a word, regardless of whether the couplets comprising the word would surface as glottalized--either predictably or contrastively--when uttered in isolation. Thus, given a sequence of

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[18] These are termed post-verbal elements in Small's (1990) syntactic sketch.

glottalized couplets CVʔCV + CVʔCV comprising a single prosodic word, the only possible location for a glottalized vowel is the penultimate mora:

(19) **Glottalized vowels surface only under primary stress**

a) 'kuʔᵘtʲu 'to hoe' + 'βaʔa 'well' → kutʲu 'βaʔa 'to hoe well'

b) 'tʲɨʔᶤβi 'to push' + 'βaʔa 'well' → tʲɨβi 'βaʔa 'to push well'

c) 'tʲɨβi 'to blow' + 'βaʔa 'well' → tʲɨβi 'βaʔa 'to blow well'

In (a), *'kuʔᵘtʲu* contains a vowel that is predictably glottalized before the medial voiceless consonant /k/ in isolation. But glottalization fails to surface in the larger prosodic word *kutʲu 'βaʔa*. The forms in (b-c) contain initial vowels which contrast for glottalization. In (b) glottalization fails to surface when the couplet containing the glottalized vowel does not host stress. As a result, the contrast in glottalization between (b-c) is neutralized: the phrases are homophonous.

MacCaulay and Salmons (1995) do take note of this phenomenon, suggesting that Pike and Small's (1974) original description fails to adequately distinguish between phonemics and phonetics in its claim that glottalization is limited to only the stressed syllable of the word-phrase.[19] For their part, MacCaulay and Salmons assert that the absence of expected glottalization at the phrase level is "merely" a function of a rapid speech rule--a rule which is

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[19] MacCaulay and Salmons do not address the dual status of glottalization in CM as both predictable and contrastive.

assumed to be phonetic and which, they imply, is epiphenomenal. In this way, the proper phonological generalization is simply that glottalization targets the initial vowel of a couplet.

Unfortunately, this claim appears to be based on a misunderstanding of Pike and Small's observation that in slow, emphatic speech, a word-phrase containing more than one couplet may be realized with more than one glottalized syllable. My own work with speakers leads me to believe that Pike and Small's observation does not refer to normal speech. Rather, it reflects the potential for glottalization to surface in highly slowed down speech in which each couplet of a string is pronounced in isolation, with its own stress pattern, for the benefit of the non-native speaking listener. In fact, glottalized vowels systematically fail to appear when unstressed, even when speakers are producing citation forms in careful, non-accelerated speech.[20] The problem, then, is not one of vowel glottalization which fails to surface due to a non-phonological, fast speech effect, but rather, one in which the presence of glottalization is conditioned by stress.

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[20] A useful comparison can be made to the stress in English compounds. If an English speaker carefully and slowly pronounces a compound such as *White House*, each member of the compound may well be realized with its own primary stress. Nevertheless, we would not want to dismiss compound stress in English as an epiphenomenonal, phonetic reflex of fast speech.

3.4.3 A formal account of vowel glottalization

A satisfactory analysis of the data must thus account for two apparently distinct yet, as I will show, ultimately closely related problems. The first of these is that we must formalize the descriptive generalization that glottalization is conditioned by the location of stress within the phonological word. The second is that our analysis must offer a coherent explanation of how glottalization simultaneously plays both a contrastive and an entirely predictable role within the phonology of CM.

I pursue both goals within the context of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993b and many others). The core of the analysis revolves the interaction of potentially conflicting pressures within the grammar 1) for glottalization to be limited to stressed vowels and 2) for contrastive glottalization to be respected (i.e. not neutralized). The formal treatment of the problem involves the interplay of three constraints: 1) a constraint requiring that glottalized vowels be stressed; 2) a constraint requiring the presence of glottalization in a definable class of roots; and 3) a constraint requiring input-output correspondence (cf. McCarthy and Prince 1995, McCarthy 1996, Orgun 1995). In §3.4.3.1, I motivate the first and third of these. In §3.4.3.2, I motivate the second, Force(cg), the effect of which is to require the presence of glottalization in a subset of roots in the language. In §3.4.3.3, I show that the analysis extends in straightforward fashion to glottalization in prosodic words consisting of more than one couplet. Finally, throughout the discussion, I argue that optimality theoretic approaches to problems of contrast and predictability challenge standard notions of underlying representations in standard phonological theory.

3.4.3.1 Contrastive glottalization, CG/STR, and Ident

I begin with the licensing of contrastive glottalization in couplets such as *tʲɨʔᶤβi* 'to push' (cf. *tʲɨβi* 'to blow') or *teʔu* 'rotten' (cf. *teu* 'bench'). Building on the observations above, I take a direct approach to the problem, proposing that the presence of glottalization in such forms is best characterized via the Path Condition (Archangeli and Pulleyblank 1994a) CONSTRICTED GLOTTIS/STRESS in (20).

(20) **Constricted Glottis/Stress (CG/STR)**
If [+cg], then stressed;
If [+cg], then not unstressed

The effect of this condition is to prohibit the association of [+cg] to any vowel that is unstressed, thus restricting [+cg] to association under stress. Evaluating the relative satisfaction or violation of CG/STR requires a definition of Path. I adopt here the formulation of Archangeli and Pulleyblank (1994a):

(21) **Path** (Archangeli and Pulleyblank 1994a)
There is a path between α and β iff
a) α and β belong to a linked set Σ of nodes or features or prosodic categories, and
b) in the set Σ, there is no more than one instance of each node or feature or prosodic category.[21]

In this particular case, satisfaction of CG/STR requires that [+cg] enter into a path relation with a stressed vowel. I assume that a stressed vowel is a vowel dominated by the mora that constitutes the head of a stress foot. As I discuss in §3.5 below, CM stress assignment involves the alignment of a moraic trochee with the right edge of the prosodic word (here, a single couplet). Of importance for now, however, is simply that we take a stressed vowel to be a vowel associated to the head mora. This is illustrated in (22), where I adopt the notation of Halle and Vergnaud (1987) to signal headship of

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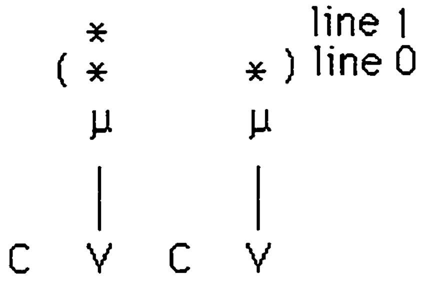
[21] One potential problem with this definition regards the use of the term *set*. Assume two sets of linked nodes Σ_1={1,2,1} and Σ_2={1,2,3}. Archangeli and Pulleyblank's definition intends to distinguish between these sets in the following manner. In Σ_1, there does not exist a path between all three nodes {1,2,1} , since, by definition, no instance of a node can be repeated in a single path. Hence, no path can contain two moras, two syllables, two root nodes, two place nodes, two tokens of [coronal], etc... By contrast, all three nodes in Σ_2 can be said to be in a path relation, since they are a) linked and b) no member is repeated in the set. The potential problem with the formal statement of path, however, derives from the use of the use of the term *set*. In particular, classical set theory does not distinguish between the following two sets: {1,2} and {1,2,1}; i.e. it does not treat repeated elements as distinct elements in the way necessary for Archangeli and Pulleyblank's calculation of path. This problem can be trivially circumvented without affecting the spirit of Archangeli and Pulleyblank's use of the concept, however, if a term such as *group* is substituted for *set* in the formal definition of *path*.

the trochee by means of the presence of a line 1 asterisk over the leftmost mora of the foot:

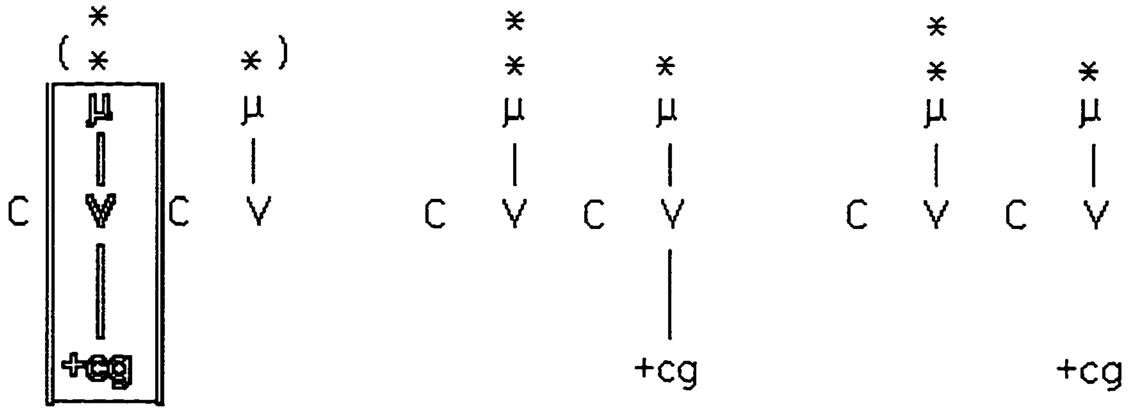
(22)



Given this picture, by transitivity, CG/STR is satisfied if a path relation obtains between [+cg] and a vowel root node and if that same vowel root is dominated by the head mora of the stress foot. This is illustrated by the examples in (23). Note that in (a), CG/STR is satisfied; [+cg] is associated to the vowel dominated by the head mora. However, in both (b) and (c), CG/STR is violated.

(23) **Evaluating CG/STR**

a) *CG/STR Satisfied* b) *CG/STR Violated* c) *CG/STR Violated*



In (b), [+cg] enters into a path relation with an unstressed vowel, while in (c), a token of [+cg] is present in the representation and fails to enter into a path relation with a stressed vowel.[22] In short, either association to an unstressed vowel or the failure to associate (i.e. a floating [+cg]) will equally violate CG/STR. Finally, following Archangeli and Pulleyblank (1994a), I assume that the constraint is trivially satisfied if [+cg] is absent from a representation.

With this in mind, let us first consider how CG/STR functions for *teʔu* 'rotten', a couplet in which glottalization surfaces contrastively.[23]

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[22] This differs from the standard interpretation in Archangeli and Pulleyblank (1994a), in which path relations hold of associated elements only and thus are trivially satisfied by floating features. Nothing in this analysis will crucially rest on this difference, however. See, also, footnote 25.

[23] For typographic simplicity, I follow Archangeli and Pulleyblank (1994a) and Crowhurst (1996), indicating headship in the tableau by enclosing the vowel linked to the head mora in square brackets. Also for simplicity, I consider only candidates in which stress is correctly located, under the assumption that the stress constraints are inviolate.

(24) **Evaluating CG/STR**

Input: teʔu		**CG/STR**
a)☞	t [e] u | +cg	
b)	t [e] u | +cg	*!
c)	t [e] u +cg	*!
d)	t [e] u | / +cg	*!

As (24) shows, (a) is the optimal output candidate, given that (b), (c), and (d) fatally violate CG/STR. An interesting issue arises, however, concerning the possibility of a fifth candidate in which [+cg] is altogether absent from the output representation, as seen in (25):

(25) **Evaluating CG/STR**

Input: teʔu		**CG/STR**
a)☞	t [e] u | +cg	
b)	t [e] u | +cg	*!
c)	t [e] u +cg	*!
d)	t [e] u | / +cg	*!
e) ??	t [e] u	

Note that both candidates (a) and (e) equally satisfy CG/STR. That is, given an input /teʔu/containing a glottalized first vowel, CG/STR yields two distinct yet equally acceptable outputs: [teʔu] and [teu].

This issue motivates the incorporation of a second constraint, IDENT, in the constraint hierarchy. Crucially, we see that although the output [teu] in (e) respects CG/STR, it necessarily incurs a faithfulness violation in the mapping from the glottalized input form to the non-glottalized candidate. Originally proposed in terms of the Parse/Fill system of Prince and Smolensky (1993)[24] and more recently recast within Correspondence Theory (cf. among others McCarthy and Prince 1995, McCarthy 1996, Orgun 1995), the global function of

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[24] See Archangeli and Pulleyblank (1994b), Pulleyblank (1994), Itô, Mester, and Padgett (1995) for variations of the original Parse/Fill type constraint system

faithfulness constraints is to discourage change, i.e. difference and thus lack of correspondence, between input and output forms. In this study, I adopt a view in which faithfulness constraints are expressed in terms of correspondence relations between input and output forms (cf. McCarthy and Prince 1995, McCarthy 1996, Orgun 1995). Following McCarthy and Prince (1995), I assume that featural identity relations are evaluated in terms of a constraint Ident[F], enforcing input-output identity between features. McCarthy and Prince's formulation is provided in (26).

(26) **Ident(F):** Correspondents are identical in their specification for F.

Under this view, correspondence is evaluated at the segmental level. That is, Ident[F] requires corresponding segments to be identical in their respective input and output values for a given feature [F]–in this case, [cg].

(27) **Ident(cg):** Correspondents are identical in their specification for [cg].

The incorporation of Ident(cg) in the constraint hierarchy, independently of the issue of its ranking with respect to CG/STR, renders (25e) above non-optimal and selects (25a) as the optimal output form. This is shown in (26), where the non-glottalized output form (e) fatally violates Ident(cg).

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of Prince and Smolensky (1993).

(28) **The effect of Ident[cg]**

Input: teʔu		**CG/STR**	**Ident(cg)**
a)☞	t [e] u | +cg		
b)	t [e] u | +cg	*!	**
c)	t [e] u +cg	*!	*
d)	t [e] u | / +cg	*!	*
e)	t [e] u		*!

For its part, a ranked order of the two constraints can be deduced from the tableau in (29). Note that, given an input in which the final vowel is glottalized, a ranking of Ident(cg) >> CG/STR incorrectly predicts the that we should find unattested surface forms such as **teuʔ*.

(29) **Ident(cg) >> CG/STR**

Input: teu | **+cg**	**Ident(cg)**	**CG/STR**
a) t [e] u | +cg	*!	
*b) ☞ t [e] u | +cg		*
c) t [e] u +cg	*!	*
d) t [e] u | / +cg	*!	*
e) t [e] u	*!	

However, given the same input as in (29), the ranking CG/STR >> Ident does not yield an unattested class of surface forms. This is illustrated in (30).

(30) **CG/STR >> Ident(cg)**

Input: teu | **+cg**	**CG/STR**	**Ident(cg)**
a) t [e] u | +cg		**!
b) t [e] u | +cg	*!	
c) t [e] u +cg	*!	*
d) t [e] u | / +cg	*!	*
e) ☞ t [e] u		*

What makes (30) intriguing is that the optimal surface form is (e), the non-glottalized output candidate. In satisfying CG/STR, (a) necessarily incurs two violations of Ident(cg)--one corresponding to the change in the value of [cg] in V2, and the other corresponding to the lack of input-output correspondence for V1. By contrast, (e) satisfies CG/STR trivially by eliminating [+cg] from the output representation altogether and, as a consequence, violates Ident only once. The same result obtains of an input containing a floating token of [+cg], as seen in (31).

(31) **CG/STR >> Ident(cg)**

Input: teu **+cg**	**CG/STR**	**Ident(cg)**
a) t [e] u | +cg		*!
b) t [e] u | +cg	*!	*
c) t [e] u +cg	*!	
d) t [e] u | / +cg	*!	**
e) ☞ t [e] u		

Again, the crucial contrast lies between candidates (e) and (a). Both satisfy CG/STR and thus the burden of distinguishing between the two falls on Ident(cg).

This result may appear odd, given traditional approaches to the representation of underlying representation in phonological theory. In particular, within autosegmental theory, a lexically contrastive feature whose surface distribution is predictable is standardly assumed to be underlyingly represented as floating feature, and association of the feature proceeds by convention or rule (cf. Goldsmith 1976, Pulleyblank 1986, Archangeli and Pulleyblank 1989, 1994a). Here, however, a floating [+cg] at input maps optimally to a non-glottalized output form.[25] It is important to note, however, that non-glottalized output forms such as *teu* are attested in the language. That is, the hierarchy CG/STR >> Ident(cg) does not define as optimal a set of unattested surface forms. Rather, it calls attention to the distinct status of inputs in an Optimality Theoretic grammar, when compared to traditional assumptions of underlying representation in generative phonological theory. I return to this issue in more detail below. For the moment, however, it is important to bear in mind that regardless of the input, our constraints describe a possible surface form. That is, they do not predict the optimality of a class of unattested surface forms such as **teuʔ*, in which the final vowel is glottalized.

With this in mind, the generation of non-glottalized surface forms such as *teu* 'bench' proceeds as in (32).

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[25] Technically, this follows from the fact that Ident(cg) is evaluated in terms of segmental correspondence. Alternatively, we might view feature correspondence on a feature by feature basis, positing a correspondence constraint Parse(F) requiring all input features to be parsed at output. In this case, a floating input [+cg] would associate to V1 and the optimal output would be glottalized. However, nothing in this analysis will crucially rest on the choice between these two conceptions of feature correspondence.

(32) **Contrastively non-glottalized couplets**

Input: teu		**CG/STR**	**Ident(cg)**
a)	t [e] u | +cg		*!
b)	t [e] u | +cg	*!	*
c)	t [e] u +cg	*!	
d)	t [e] u | / +cg	*!	**
e) ☞	t [e] u		

Here, (e) is selected as optimal in that all other output candidates incur fatal violations of either CG/STR or Ident(cg).

In (32) I provide an input that is identical with the output form. Again, inputs containing a floating [+cg] or a token of [+cg] that is singly linked to V2 will also map to the surface form (e). Note, however, that within an optimality theoretic grammar, faithfulness constraints have the function of discouraging correspondence discrepancies between input and output forms. That is, all other things being equal, an optimal output candidate will be identical to the input. Given this phenomenon of so-called LEXICON OPTIMIZATION (see Prince and Smolensky 1993, Itô, Mester, and Padgett 1995), some input-output pairing will be more optimal than others, even if distinct inputs converge under the grammar of constraints on the same output form. Following Itô, Mester, and Padgett (1995), this can be illustrated in a tableau des tableaux or meta-tableau, as in (33). Here, the optimality of various input candidates is evaluated with respect to the attested or optimal surface candidate. Though all three possible inputs map to the surface form *teu* 'bench, stool', the input in (c) does so in the most optimal fashion.

(33) **Contrastively non-glottalized couplets**

Output: t[e]u **Inputs: ↓**	**CG/STR**	**Ident(cg)**
a) t [e] u | +cg		*!
b) t [e] u +cg	*!	
c) ☞ t [e] u		

An interesting question does emerge, however, when we consider the comparison between an optimal output unspecified for [cg] and one in which [-cg] encodes the non-glottalized status of the input.

(34) Contrastively non-glottalized couplets: unspecified input

Output: t[e]u Inputs: ↓	CG/STR	Ident(cg)
a) t [e] u | -cg		*!
b) ☞ t [e] u		

In (34), lexicon optimization selects (b) as the optimal input, since the addition of [-cg] in (a) violates Ident(cg). By contrast, if we choose to represent the optimal output form in vowel docked to [-cg], then (a) would be the optimal input form.

(35) Contrastively non-glottalized couplets: [-cg] input

Output: t[e]u | -cg Inputs: ↓	CG/STR	Ident(cg)
a) ☞ t [e] u | -cg		
b) t [e] u		*!

This distinction calls our attention to the role of underspecification in an optimality theoretic grammar. That is, it raises the interesting question of just what distinction is actually described by such variably optimal input-output pairings. I suggest that there are a number of plausible means of addressing the situation. One obvious possibility is to assume that an unspecified output legitimately characterizes the surface form *teu* 'bench, stool'. Such an approach must assume that the phonetics implements a vowel phonologically unspecified for [constricted glottis] as a modal vowel; i.e. as if it were specified for [-cg]. This is not altogether unreasonable in that the motivation behind such a move is the assumption that modal voicing is the default or unmarked register of phonation, a generalization that receives clear cross-linguistic support.[26]

Another possibility is to assume that output forms are fully specified, or at least fully specified for contrastive features--a kind of Optimality Theoretic twist on the notion of Contrastive Underspecification (Steriade 1987).[27] In this sense, though, rather than imposing the contrastive specification of features at the level of underlying representation, we instead posit a highly ranked constraint such as Spec-Con, requiring that if a feature is contrastive in a grammar, that feature must be specified for all output contexts in which the contrast is manifested. In this case, Spec-Con would force stressed vowels to be specified for some value, either [+constricted glottis] or [-constricted glottis]. If Spec-Con were placed above Ident in the

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[26] I know of no language, for example, in which the set of contrastive vowels are all creaky voiced vowels.

[27] Yet another possibility is to posit a constraint or constraint family pressuring for full specification (see Steriade 1995 for arguments in favor of full specification, though in the context of an advocacy of a greater proportion of monovalent features).

constraint hierarchy, unspecified inputs would be ruled out as optimal input candidates, since the lack of a constricted glottis specification in the output would fatally violate Spec-Con.

Under either approach, the possibilities can be accommodated within the grammar, and neither possibility makes incorrect predictions about the phonetic qualities of the optimal surface forms. As I have noted, what this does call to our attention, however, is the more general issue of the status of underspecification in an Optimality Theoretic grammar. Given the freedom of Gen to generate an infinite set of input-output pairs, we cannot a priori assume that a feature is either absent or present at *input*. Instead, if there is to be underspecification, it appears either that it must result from the constraints allowing it, or underspecification must be barred via the introduction of a mechanism such as a Spec-Con constraint requiring the output specification of a contrastive feature.[28]

In short, the pressure of CG/STR guarantees that any token of [+cg] present at output must be associated to a stressed vowel, while it simultaneously bans the association of [+cg] to any unstressed vowel. For its part, Ident[F] preserves the underlying value of [cg] for vowels, unless it

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[28] Another tack might be to assume feature monovalence. Underspecification would thus be the only alternative to specification. However, many features do appear to show evidence of binarity. (See Archangeli and Pulleyblank 1994a on evidence for [+ATR] and [-ATR], for example. See also Steriade 1995 for a discussion of the difficulty of motivating a purely monovalent feature system, especially as regards the feature [voice].) For further discussion of

conflicts with the higher ranked CG/STR. The combination of the two constraints creates a situation in which input forms containing a token of [+cg] that is associated to the initial vowel of a couplet will optimally map to a licit glottalized output form. All other input forms will map to a non-glottalized form under this grammar. As I will discuss further in §3.4.3.3, this captures the distinction between couplets that are contrastively glottalized and non-glottalized in terms of distinct sets of possible input forms and thus encodes the observation that [+cg] is contrastive in the grammar. Additionally, no output forms are generated in which V2 is incorrectly predicted to be glottalized.

3.4.3.2 Predictable glottalization and Force(cg)

Recall from above that couplets such as *kuʔ*^{u}*t*^{j}*u* 'to hoe, plow', which contain a medial voiceless consonant, are predictably glottalized. That is, there is no glottalization contrast in such forms. In traditional models of generative phonology--both linear and non-linear--and, in particular, under the assumption of lexical minimality (see Steriade 1995 and references therein), the behavior of glottalization would require two distinct treatments. Assuming, for example, an autosegmental analysis, cases involving contrastive glottalization would require the postulation of an underlyingly specified [+cg] feature that would be associated by rule (or convention) to a

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underspecification here, see §3.4.4.2 regarding the treatment of /ʃ/.

target vowel, while in the case of predictable glottalization, an underlyingly absent [+cg] feature would have to be added to the representation first and subsequently associated to the target vowel. As we have just seen, however, in an Optimality Theoretic grammar, multiple inputs may converge on an optimal output form. And, in fact, the optimal input-output pairing for contrastively glottalized surface forms such as *teʔu* 'rotten' contains an input form in which [+cg] is associated to the first vowel of the couplet.

By the same logic, we cannot assume that in the case of predictable glottalization, [+cg] must be absent from the input form. In fact, the freedom of Gen to provide a potentially infinite set of input-output pairings causes problems for the treatment of predictable glottalization. To explore this issue, let us consider first the tableau for *kaʔ^{a}ka* 'to walk' in (36).

(36) **Tableau for kaʔ^{a}ka 'to walk'**

Input: kaʔ^{a}ka	**CG/STR**	**Ident(cg)**
a) ☞ kaka | +cg		
b) kaka +cg	*!	*
c) kaka | +cg	*!	**
d) kaka \ | +cg	*!	*
e) kaka		*!

As with the cases of contrastive glottalization above, the output form in (a) is selected as optimal, given that in the mapping from input to output, both CG/STR and Ident(cg) are respected, while the other candidates (b-e) all incur at least one violation of one of the two constraints. The problem arises, however, when we consider possible tableaux such as that in (37), in which [+cg] is not present at input.

(37) **No [+cg] at input**

Input: kaka	**CG/STR**	**Ident(cg)**
a) kaka | +cg		*!
b) kaka +cg	*!	
c) kaka | +cg	*!	*
d) kaka \ | +cg	*!	**
e) ?? ☞ kaka		

Here, (e) is selected as optimal, since the lack of [+cg] at output satisfies CG/STR, while the non-glottalized status of both vowels at input and output satisfies the correspondence constraint Ident(cg). Its closest competitor, candidate (a), incurs a fatal Ident(cg) violation by satisfying CG/STR via the association of [+cg] to the initial, stressed vowel of the couplet. The problem is that output forms such as *'*kaka* are systematically absent from the language. That is, in stressed couplets containing a medial voiceless consonant, V1 always surfaces as glottalized; candidate (a) should be the optimal output form.

Just as our constraints must characterize the contrastive role played by [cg] for some couplets, they must also encode its entirely predictable behavior in others. Specifically, the hierarchy must guarantee that regardless of the input presence or absence of [+cg], stressed couplets containing a medial voiceless consonant must be glottalized at output. Again, I approach the situation in a direct fashion. Since CVCV couplets with a voiceless medial consonant comprise the class of non-contrastive roots for the feature [+constricted glottis], I assume that a fundamental aspect of the phonological system of CM involves a constraint, FORCE(cg), that is sensitive to the presence of a medial voiceless consonant in a root.[29] Force(cg) is informally defined in (38):

(38) **Force(cg)**: If a couplet contains a medial voiceless consonant, it must also contain a glottalized vowel.

In simple terms, Force(cg) requires the presence of [+cg] in a couplet containing a medial voiceless consonant. Note that specifying the location of glottalization is not necessary, given that CG/STR will limit the association of

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[29] [-voice] medial consonants also play a key role in blocking nasal harmony in CM (see Chapter). As for why only CVCV couplets with a voiceless medial consonant should be of the non-contrastive class for [constricted glottis], I have no simple explanation. As I have noted, however, the lack of contrastive glottalization in this context is found across the Mixtec languages in general. In fact, this lack of contrast is reconstructed back to Proto-Mixtec by Josserand (1982). See §3.4.4 for more discussion of the diachronic facts.

[+cg] to stressed vowels only. More formally, Force(cg) can be expressed as in (39).

(39) **Force(cg)**: For all roots R, if R contains a [-voice] consonant on a path with the rightmost mora of R, then R also contains a vowel associated to [+cg]:[30]

Let R be a root;
let P be a path;
let μ-rt be the rightmost mora of a root;
let V be a vowel;
$\forall$ R, if $\exists$ P(μ-rt, [-voi]), then $\exists$ V in R that is associated to [+cg].

I assume that the evaluation of Force(cg) checks for two conditions. First, as stated in the definition, a voiceless medial couplet is formally expressed as a path condition that obtains between a token of [-voi] and the rightmost mora of a root.[31] Returning then to the canonical structures posited for couplets in Chapter 2, I illustrate the relevant logical possibilities for establishing whether Force(cg) will hold of a root.[32]

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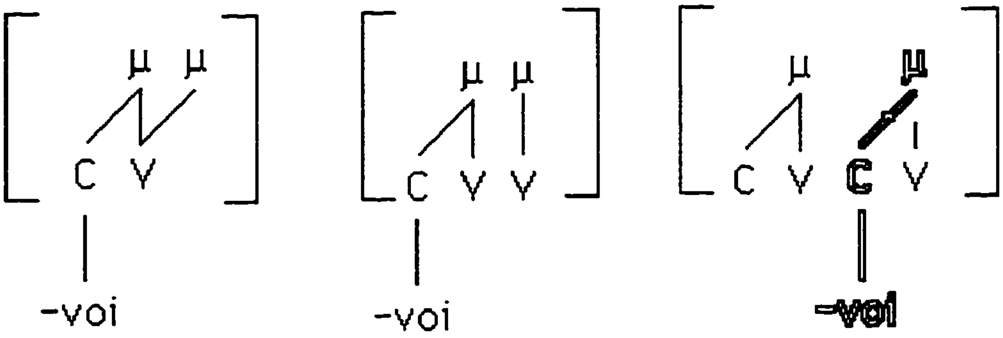
[30] See also Peng (1993) and Gerfen (1994) for path relations involving subsegmental features and moraic structure.

[31] The rightmostness of the mora can be derived by principles of Alignment (McCarthy and Prince 1993). For example, we can establish a more explicit statement of contrastiveness for [+cg] whose conditions are satisfied conjunctively: i) there exists a mora(μ) such that [-voice] is on a path with (μ) AND the right edge of (μ) is aligned with the right edge of the root. For simplicity, however, I simply refer above to rightmost mora.

[32] I do not consider representations with [+voice] consonants or consonants unspecified for [voice], given that Force(cg) is sensitive to the presence of a path relation between the rightmost mora and a [-voice] specification.

(40) **Cases in which Force(cg) will obtain**



a) NO b) NO c) YES

In (40 a-b), there is no path relation between [-voice] and the rightmost mora of the couplet, given that the group of associated nodes would contain two moras and, by the definition in (21), would thus not constitute a path. By contrast, in (c) there is a path between the rightmost mora of the couplet and [-voice]. The couplet in (c) is thus of the type that must contain a glottalized vowel at output; that is, it is of the non-contrastive class of couplets for vowel glottalization.

I assume that Force(cg) is ranked above Ident(cg). Thus, regardless of the input value for [+cg] in couplets with a medial voiceless consonant, the optimal output candidate will contain a glottalized vowel. This is illustrated in (41).[33]

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[33] To simplify discussion, I do not consider candidates in which glottalization is placed on the final vowel, since CG/STR will rule out these forms.

(41) **Forcing glottalization in couplets with a medial voiceless consonant**

	Input-Output pairs ↓	CG/STR	Force(cg)	Ident(cg)
☞	a) kaka → kaka | | -cg +cg			* *
	b) kaka → kaka | -cg		*!	*
	c) kaka → kaka | -cg +cg	*!	*	*
	d) kaka → kaka | | -cg -cg		*!	
☞	e) kaka → kaka | +cg			*
	f) kaka → kaka		*!	
	g) kaka → kaka +cg	*!	*	
	h) kaka → kaka | -cg		*!	*

Note that the candidate pairs in (a-d) provide cases in which the input contains an initial [-cg] specification on V1, while (e-h) provide an input unspecified for [cg]. In both cases, the optimal output form converges on the same candidate: *kaʔ*^{a}*ka* 'to walk'. In (a-d), the need to satisfy Force(cg) while respecting the inviolable CG/STR renders the input-output pair in (a) optimal, despite the violation of Ident(cg). Similarly, in (e-h), since Force(cg) outranks, Ident(cg), (e) is correctly selected as the optimal output candidate. And CG/STR requires that [+cg] be associated to the stressed vowel. Of course, if the input contains an initial glottalized vowel, it, too, maps to the correct output form--in this case without violating any of the constraints. Again, regardless of the input, Force(cg) requires the presence of an associated token of [+cg] at output.[34]

(42) **Glottalized input form**

	Input-Output pairs ↓	**CG/STR**	**Force(cg)**	**Ident(cg)**
☞	kaka → kaka a) | | +cg +cg			
	kaka → kaka b) | +cg		*!	*
	kaka → kaka c) | +cg +cg	*!	*	*
	kaka → kaka d) | | +cg -cg		*!	*

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[34] Again, I assume that lexicon optimization will render non-optimal those input forms in which correspondence fails with respect to the [constricted glottis] feature on vowels. But it is still important to bear in mind that the substantive constraints CG/STR and Force(cg) determine the optimal output forms and that the grammar will derive the correct output regardless of the input specification for [constricted glottis].

As in the discussion of contrastive glottalization above, we see that under an Optimality Theoretic grammar, input structures do not play the same role that underlying representations have played in traditional generative phonology. In this case, a completely predictable feature can be present or absent at input; either way, the constraint system correctly chooses the optimal output form. Interestingly, much recent work in constraint based systems has, in fact, challenged the traditional assumptions of lexical minimality and its obligatory elimination of predictable information from underlying representations (cf. Steriade 1995, Inkelas 1994, Kirchner 1995b, Itô, Mester and Padgett 1995). As I have discussed here, the general consequence of faithfulness is to militate for the maximization of predictable information at the level of input in order to minimize correspondence failure between input-output pairs.

In simple terms, then, my analysis of the glottalization facts breaks the glottalization problem into two parts: 1) we must be able to characterize the predictable location of glottalization; and 2) we must identify which morphemes are and which are not contrastive for glottalization. The constraint CG/STR correctly limits glottalization to stressed contexts, addressing the first problem. The combined effects of CG/STR and Ident(cg) capture the contrastive behavior of glottalization, while the interaction of CG/STR and Force(cg) characterize the predictable surfacing of glottalization in couplets with a voiceless medial consonant. With this basic analysis in mind, we turn now to the treatment of glottalization in words larger than a single couplet.

3.4.3.3 Glottalization in words larger than the single couplet

In this section, I show that the above analysis extends directly to phonological words comprised by more than one couplet. Recall that one of the primary motives for rejecting the strategy of simply docking [+cg] to, say, the first vowel of a couplet (MacCaulay and Salmons' 1995) is the demonstrable dependency of glottalization on stress in prosodic words that are larger than a single couplet. Thus we find pairs such as (43-44). Note in (43) that lexically contrastive [+cg] fails to surface because *t*^{j}ɨʔ^{ɨ}β*i* 'to push' is unstressed in the prosodic word *t*^{j}ɨβ*i* 'β*a*ʔ*a* 'to push well', though it would surface if *t*^{j}ɨʔ^{ɨ}β*i* were uttered in isolation or if *t*^{j}ɨʔ^{ɨ}β*i* were the final (rightmost) couplet of a word. Similarly, in (45), we see that predictable glottalization fails to surface in the couplet *ka*ʔ^{a}*ka* 'to walk' when it is not stressed.

(43) 't^{j}ɨʔ^{ɨ}βi 'to push' + 'βaʔa 'well' → t^{j}ɨβi 'βaʔa 'to push well'

(44) 't^{j}ɨβi 'to blow' + 'βaʔa 'well' → t^{j}ɨβi 'βaʔa 'to blow well'

(45) 'kaʔ^{a}ka 'to walk' + 'βaʔa 'well' → kaka 'βaʔa 'to blow well'

Though the descriptive facts are straightforward, surface forms such these are significant for two, ultimately related reasons. First, they provide evidence regarding the nature of the putative ranking of our three constraints: CG/STR >> Force(cg) >> Ident(cg). Secondly, they provide further insight into the distinction between input forms in an Optimality Theoretic grammar and the traditional notion of underlying representation.

Regarding the order of the constraints, the failure of contrastive glottalization in '*tʲɨʔᶤβi* 'to push' to surface in tʲɨβi 'βaʔa 'to push well' would appear to motivate the ranking of CG/STR over Ident(cg). This as illustrated in (46), where, for simplicity I assume full specification; i.e., a vowel marked as glottalized is associated to [+cg], all other vowels are associated to [-cg]. (Stressed vowels are indicated by the presence of a single quotation mark before the stressed syllable.)

(46) **CG/STR >> Ident(cg)**

Input: tʲɨʔᶤβi + βaʔa **'to push' 'well'**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ tʲɨβi 'βaʔa			*
b) tʲɨʔᶤβi 'βaʔa	*!		

The candidate in (a) is optimal, incurring a single violation of Ident(cg) in order to guarantee satisfaction of the more highly ranked CG/STR. Note, however, that Gen affords an alternative input in which [+cg] is absent.

(47) **An alternative input**

Input: t^{j}ɨβi + βaʔa 'to push' 'well'	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ t^{j}ɨβi 'βaʔa			
b) t^{j}ɨʔ^{ɨ}βi 'βaʔa	*!		

Here, the attested output form is again selected, but in this case, none of the constraints is violated. Under the logic of lexicon optimization, the input-output pairing in (47) is more optimal than that of (46) above. What is interesting, however, is that we saw above (in the treatment of contrastive glottalization in words containing a single couplet) that generating the surface form 't^{j}ɨʔ^{ɨ}βi 'to push' required the presence of an input in which [+cg] was associated to the initial vowel, as in (48).

(48)

Input: t^{j}ɨʔ^{ɨ}βi **'to push'**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) t^{j}ɨβi			*!
b) ☞ t^{j}ɨʔ^{ɨ}βi			

What does this mean for both the particular phonological question at hand and for phonological theory in general? I argue that this issue again calls attention to the fact that under an Optimality Theoretic grammar in which Gen is free to generate input/output pairs, there is no notion of a unique representation which underlies surface alternation. Rather, the logic of correspondence is such that alternating surface forms would appear to motivate a set of best possible or optimal inputs. So, a morpheme such as '*tʲɨʔᶤβi* 'to push' that in traditional terms might be underlyingly represented as /tʲɨβi [+cg]/ with surface variants [tʲɨʔᶤβi] ~ [tʲɨβi] can now be represented as a set of attested surface forms sharing the same meaning and a corresponding set of optimal inputs: {tʲɨʔᶤβi, tʲɨβi}.

As for morphemes such as *tʲ*ɨβi 'to blow', the grammar still distinguishes these from forms such as '*tʲɨʔᶤβi* 'to push'. Consider, for example, the tableau in (49) for the surface form *tʲ*ɨβi '*βaʔa* 'to blow well':

(49) **Tableau for tʲɨβi 'βaʔa 'to blow well'**

Input: tʲɨβi + βaʔa	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ tʲɨβi 'βaʔa			
b) tʲɨʔᶤβi 'βaʔa	*!	*	

Note that although an input in which [+cg] is associated (i.e. an input string /tʲɨʔᶤβi + βaʔa/) would also map to the attested surface form in (a), such an input would be less optimal than the non-glottalized [tʲɨβi] in (49) above. This is shown in the meta-tableau in (50).

(50) **Lexicon optimization tableau**

Output: tʲɨβi 'βaʔa **Inputs: ↓**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ tʲɨβi + βaʔa			
b) tʲɨʔᶤβi + βaʔa	*!		*

What we see is that the couplet *tʲɨβi* 'to blow' is thus distinguished in the grammar from *tʲɨʔᶤβi* 'to push' by virtue of having a single, non-alternating surface form *tʲɨβi* with the same optimal input *tʲɨβi*.

(51) **Representation of contrast**

Surface alternants	**Set of optimal inputs**	**G loss**
tʲɨβi, tʲɨʔᶤβi	{tʲɨβi, tʲɨʔᶤβi}	'to push'
tʲɨβi	{tʲɨβi}	'to blow'

In this way, the system still captures the distinction between such forms, without the need to posit a single, unique UR for each. I assume that if the set of surface alternants and inputs were identical in both rows, the grammar would not distinguish between these couplets as phonologically distinct. As things stand in CM, however, the picture in (51) accurately characterizes the fact that glottalization is contextually neutralized or, as it were, contextually licensed; lexically distinct couplets may share some but not all optimal input/output pairs.

This leads us to our final case. In surface forms such as *kaka 'βaʔa* 'walk', the lack of glottalization in the initial couplet follows straightforwardly from a conflict between Force(cg) and CG/STR. When such couplets surface as prosodic words themselves, these two constraints do not interact. Force(cg) requires the presence of [+cg] and CG/STR requires that [+cg] be associated under stress. In this case, however, we see that the ranking CG/STR >> Force(cg) prohibits glottalization in the unstressed context.

(52) **Effect of CG/STR >> Force(cg)**

Input: **kaka + βaʔa**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ kaka 'βaʔa		*	
b) kaʔ^{a}ka 'βaʔa	*!		*

Again, this is true regardless of the input, as shown in (53), where the initial vowel of the input form is [+cg].

(53)

Input: **kaʔ^{a}ka + βaʔa**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ kaka 'βaʔa		*	*
b) kaʔ^{a}ka 'βaʔa	*!		

Given the discussion above, however, the pressure of correspondence constraints is such that the non-glottalized input will be evaluated as preferred under lexicon optimization.

(54) **Lexicon optimization tableau**

Output: kaka 'βaʔa **Inputs:** ↓	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ kaka + βaʔa		*	
b) kaʔ^{a}ka + βaʔa	*!		*

Returning to a chart such as (51), then, we see that CM lacks lexically distinct forms in which glottalization plays a contrastive role.

(55)

Surface alternants	Set of inputs	G loss
kaʔ^{a}ka, kaka	kaʔ^{a}ka, kaka	'to walk'
*kaka	*kaka	NO SUCH FORM

That is, our grammar correctly characterizes the fact that such forms are never lexically distinguished by glottalization differences. Instead, they are forced to surface as glottalized when stressed (modulo Force(cg) and CG/STR) and prohibited from surfacing as glottalized when not stressed (modulo CG/STR). Given our constraints, their behavior is entirely predictable.

Finally, returning to the overall ordering of the three constraints governing the distribution of glottalization in the language, we see that CG/STR must outrank Force(cg) in order to account for glottalization's failure to surface in forms containing medial voiceless consonants in unstressed contexts. By contrast, I have argued that the potentially infinite set of input-output pairings generated by GEN for contrastively glottalized forms does not allow us to establish a direct ordering between CG/STR and Ident(cg). In the case of predictable glottalization, however, we can motivate an ordering of Force(cg) over Ident(cg). In this way, regardless of the input, forms containing a voiceless medial consonant will surface as glottalized (modulo CG/STR). Since CG/STR outranks Force(cg), by transitivity, we can establish the total ordering CG/STR >> Force(cg) >> Ident(cg).

3.4.4 Residuals: two diachronic anomalies

There are two CM consonants, /ð/ and /ʃ/, whose behavior with respect to glottalization appears to be anomalous. In this section I review the facts, showing 1) that the behavior of both receives a straightforward diachronic explanation and 2) that both are accounted for in terms of the synchronic analysis above. I begin in §3.4.4.1 with the case of /ð/. I then discuss the more complicated case of /ʃ/ in §3.4.4.2.

3.4.4.1 /ð/ and contrastive [+cg]

The oddity of /ð/ is not apparent from forms such as β*iðe* 'wet' or *kiði* 'sleep'. Glottalization fails to surface in each, given that so doing would constitute a violation of Ident(cg), as per the discussion in §3.4.3.1. That is, since the medial /ð/ is not [-voice], both couplets pertain to the class of morphemes that can exhibit a lexical contrast for [constricted glottis], and in this sense, each behaves normally. What is interesting, however, is that the language lacks glottalized couplets in which the medial consonant is /ð/, as in the hypothetically possible but unattested *βiʔ^{i}ðe or *kiʔ^{i}ði.

Synchronically, this gap is unexpected. But, when viewed from a diachronic perspective, the gap emerges as the residue of historical change. To understand the situation, consider the following proto-Mixtec consonant inventory, which does not contain /ð/:

(56) **Proto-Mixtec consonant inventory** (from Josserand 1982)

t	k	k^{w}
nd		
s	x	
l	y	w

In (56), we see that /ð/ does not belong to the set of proto-consonants. What is important for our purposes is that Josserand shows that present-day CM /ð/ is historically derived from the voiceless alveolar fricative */s/.[35] Thus, we find forms such as those in (57) (taken from Josserand 1982).

(57) **Diachronic correspondence: *s > ð**

Proto-form	**CM form**	**Gloss**
a) *siko	ðiʔ^{i}ko	'odor, smell'
b) *sawa	ðaβa	'half'
c) *kɨsɨ	kɨðɨ	'clay pot'
d) *ndɨsi	ndɨði	'liquor'

This historical change provides the key to understanding the present day gap. Josserand's dialect maps indicate that the */s/ > /ð/ change is an old phenomenon in that it is not limited to CM but rather attested throughout

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[35] Recall from the discussion in chapter 2 of consonant phonemes that I pointed out the noticeable lack of forms containing /s/. This gap also now receives a diachronic explanation.

almost the entire eastern half of the Mixteca, as well as in the northernmost varieties of the language (Josserand 1982: 468). Josserand's work traces this general lack of contrast back to Proto-Mixtec. Not surprisingly, she reconstructs no forms in which the proto-phoneme */ʔ/ appears before a couplet-medial voiceless consonant.[36] By contrast, I have noted in §3.4 above that CM is unique among the present day varieties of Mixtec in that the lack of contrast before couplet-medial voiceless consonants is instantiated by the *presence* rather than the *absence* of glottalized vowels. Taken together, these facts provide strong support for a diachronic analysis in which predictable glottalization in CM is viewed as a more recent innovation than the */s/ > /ð/ change.

When these observations are considered together, what emerges is a clear picture of a synchronic gap that has emerged from the chronology of change. The reason there are no glottalized couplets containing medial /ð/ is that at the time that */s/ became /ð/, these couplets contained a medial voiceless consonant and thus were never preceded by a glottal stop. And by the time predictable glottalization arose in its present incarnation in CM, the

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[36] Josserand reconstructs a glottal stop phoneme for Proto-Mixtec. Whether this was a consonant or a vowel feature in *PM is orthogonal to its synchronic status in CM. What is important is that of 188 Proto-Mixtec reconstructions, 28 contain a medial consonant preceded by a glottal stop. And of these, none contains a medial voiceless consonant. Some examples are: */leʔyi/ 'armpit, */xeʔnde/ 'to cut', */sɨʔwa/ 'cacao', */k^{w}iʔna/ 'devil'.

voiceless */s/ which would have conditioned it was no longer present, having become the voiced fricative /ð/.

How, then, are the historical facts reflected in the synchronic grammar? My claim is simple. The historical change from proto- */s/ to current day /ð/ involved a change in voicing from [-voice] to [+voice]. This explains two things. First, as I have just noted, the synchronic lack of contrastively glottalized forms such as *kiʔ^{i}ði is a residue of a time when such forms contained medial /s/ and thus did not exhibit a contrast for glottalization. At the same time, the constraint Ident(cg) provides a synchronic account for why CM forms such as *βiðe* 'wet' fail to exhibit vowel glottalization.

The facts thus fall out from the above analysis in which synchronic glottalization in CM is driven by the satisfaction of CG/STR in output forms in which there is no token of [+cg] and an Ident(cg) constraint that bans featural correspondence discrepancies between input and output. That is, /ð/ behaves normally with respect to the constraint hierarchy.

(58)

Input: βiðe 'wet'	CG/STR	Force(cg)	Ident(cg)
a) ☞ βiðe			
b) βiʔ^{i}ðe		▨	*

One lingering question, however, is that Gen can generate inputs such as that of (58), predicting the potentially optimal but unattested output form in (b):

(59)

Input: βiʔ^{i}ðe 'wet'	CG/STR	Force(cg)	Ident(cg)
a) βiðe			*
b) ☞ ?? βiʔ^{i}ðe			

My claim is that this is not, in fact, a problem for the analysis. By predicting such forms, the grammar is encoding the regularity of the phonological behavior of glottalization. I thus treat this as an accidental, rather than a systematic, gap. All languages can be said to license possible though not attested forms. In this case, the lack of forms such as βiʔ^{i}ðe is the synchronic reflex of historical change, despite their being allowed by the synchronic grammar.[37]

3.4.4.2 The case of CM /ʃ/

A more complicated case involves the fricative /ʃ/. As I note in §3.4.1, /ʃ/ is exceptional in that it appears to constitute the only case of a medial voiceless consonant before which contrastive glottalization surfaces. Thus we find minimal pairs such as ʃɨʔ^{ɨ}ʃɨ 'mushroom' and ʃɨʃɨ 'coati'. The particular problem here resides in the existence of ʃɨʃɨ 'coati' and other like forms, since they contain a medial voiceless consonant and should (but do not) condition the predictable glottalization of the preceding vowel. At first blush, we might take the existence of such minimal pairs as motivation for assigning /ʃ/ to the class of [+voice] consonants, despite its phonetic voicelessness. While such a strategy would have the drawback of assigning phonological voicing to a phonetically voiceless sound, it would nevertheless appear to capture the fact that /ʃ/ acts like a voiced consonant with respect to glottalization. Let us call this the *voiced-/ʃ/ hypothesis*.

The issue is more complex, however. An insurmountable problem for the voiced-/ʃ/ hypothesis is that treating all tokens of /ʃ/ as [+voice] makes

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[37] If a form of the surface shape in (59b) were borrowed into CM, for example, from neighboring Mazatec, which also has creaky voiced vowels, my

incorrect predictions regarding the behavior of /ʃ/ with respect to regressive nasal harmony (see Chapter 4 for further discussion). Briefly, voiced consonants are transparent to--while voiceless consonants block--the regressive nasal harmony system by which CM marks the second person familiar. This is seen in (60). In (a-b), both vowels of the root are nasalized, while in (c-d), the voiceless medial consonant restricts nasalization to the final vowel of the couplet:

(60) **Root**	**2nd fam.**	**Gloss**	**Root**	**2nd fam.**	**Gloss**
a) kiði	kĩðĩ	'sleep!'	c) kuʔ^{u}t^{j}u	kuʔ^{u}t^{j}ũ	'plow!'
b) tɨʔ^{ɨ}βi	tɨ̃ʔ$^{\tilde{ɨ}}$βĩ	'push!'	d) kuʔ^{u}tsi	kuʔ^{u}tsĩ	'bathe!'

If /ʃ/ is phonologically [+voice], we should expect it to pattern with voiced consonants with respect to nasal harmony. But this is not the case. Instead, there appear to be two distinct /ʃ/'s in the grammar. One patterns with voiced consonants, i.e. it is transparent to nasal harmony, while the other /ʃ/ is opaque, thus acting like a voiceless consonant.[38] More specifically, the /ʃ/ which conditions the appearance of a preceding glottalized vowel, as in ʃɨʔ^{ɨ}ʃɨ 'mushroom', behaves as though it were voiceless. By contrast, the

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prediction is that it would simply pattern with other contrastively glottalized couplets.

[38] This is similar to the case of Barrow Inupiaq (Kaplan 1981) in which there are two phonetically identical yet phonologically distinct /i/ vowels (see discussion in Bourgeois 1988, Archangeli and Pulleyblank 1994a).

/ʃ/ which fails to condition vowel glottalization, as in *ʃɨʃɨ* 'coati', patterns with voiced consonants. Two more such examples are provided in (61):

(61) **Opaque /ʃ/**	**Transparent /ʃ/**
a) ki?^{i}ʃi → ki?^{i}ʃĩ 'come!'	b) kuʃu → kũʃũ 'you (fam) are diligent'

Couplets like *ki?^{i}ʃi* present no difficulty for our analysis of glottalization if we assume that the medial /ʃ/ in these forms is phonologically [-voice] and thus conditions the predictable glottalization of the preceding vowel under pressure from Force(cg). But what are we to make of the /ʃ/ in *kuʃu* 'diligent'?

Here again, I argue that an understanding of the synchronic picture requires a consideration of the diachronic facts. The root of the problem is that present day CM /ʃ/derives from two diachronic sources. Josserand (1982) shows that some instances of /ʃ/ are derived from the Proto-Mixtec voiceless velar fricative */x/, while others come from the glide (and hence phonetically voiced) */y/.[39] Examples taken from Josserand (1982) are provided in (62).

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[39] Note in the chart the proto-form */yuyu?/ containing a morpheme-final glottal stop. Josserand posits a number of such forms, though in CM, as in most other present day Mixtec languages, glottalization does not surface couplet finally. Additionally, there is no evidence in CM, as can be seen in the example here, that the final /?/ of proto-forms has been preserved by migrating to the first vowel of synchronic CM couplets. By contrast, couplet medial glottalization in proto-forms is almost always preserved, as in the CM form *nda?^{a}βi* 'poor' from Proto-Mixtec */nda?wi/.

(62)	correspondence	Proto-form	CM	gloss
	a) *x > ʃ	*kixi	kiʔ^{i}ʃi	'come'
		*ndixe	ndiʔ^{i}ʃe	'true, really'
		*ndixī	ndiʔ^{i}ʃī	'wing'
	b) *y > ʃ	*yawi	ʃaβi	'hole'
		*yɨyɨ	ʃɨʃɨ	'coati'
		*yuyuʔ	ʃuʃu	'dawn'

In the forms in (a), /ʃ/ is historically derived from the */x/, and, as expected, the current CM forms all contain predictably glottalized vowels. The forms in (b), which are surprising in that vowel glottalization is expected but not attested, all contain tokens of /ʃ/ that are derived from the proto-glide */y/. Descriptively, then, we see that not all /ʃ/'s are patterning with voiced consonants, but rather, only those /ʃ/'s derived from */y/ are. In terms of the analysis above, these forms appear to be unexpectedly violating Force(cg) by not conditioning glottalization of the vowel preceding /ʃ/.[40]

There is, in fact, one more piece to the puzzle. What the data above suggest is that the lack of glottalization in forms such as ʃɨʃɨ 'coati' can be viewed as the residue of the historically voiced medial consonant--the type of consonant before which glottalization was (and still does) surface

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[40] Readers consulting Josserand's synchronic word lists should be warned about one important problem, however. Her transcription of CM forms never marks glottalization before voiceless consonants. This is not problematic for voiceless consonants other than /ʃ/, before which glottalization is completely predictable. But it has dire consequences for medial /ʃ/. In these cases, her transcriptions fail to reflect the fact that some forms have glottalized vowels

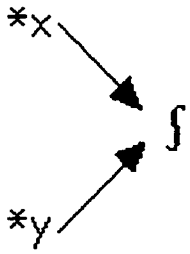
contrastively. If this is so, the prediction is that we should find synchronic CM forms containing medial /ʃ/'s that are 1) diachronically derived from */y/, and 2) preceded by a glottalized vowel. This is, indeed, the case. Two examples (proto-forms taken from Josserand) are provided in (63):

(63) ***y > ʃ with glottalization arising from historical residue**

Proto-form	**CM**	**gloss**
* nde?yu	ndo?^{o}ʃo	'mud, muddy'
* ndɨ?yɨ	ndɨ?^{ɨ}ʃɨ	'pimple'

Historically, the evolution of CM /ʃ/ thus involved the partial merging of two proto- consonants:

(64) ***/x/ and */y/ merge to /ʃ/**



For glottalization, this merger has three synchronic consequences. First, some couplets such as ʃɨʃɨ 'coati' and ʃ*u*ʃ*u* 'dawn' contain medial tokens of /ʃ/ derived from */y/ and fail to condition predictable glottalization of the initial vowel of the couplet. Secondly, a number of couplets contain medial /ʃ/'s

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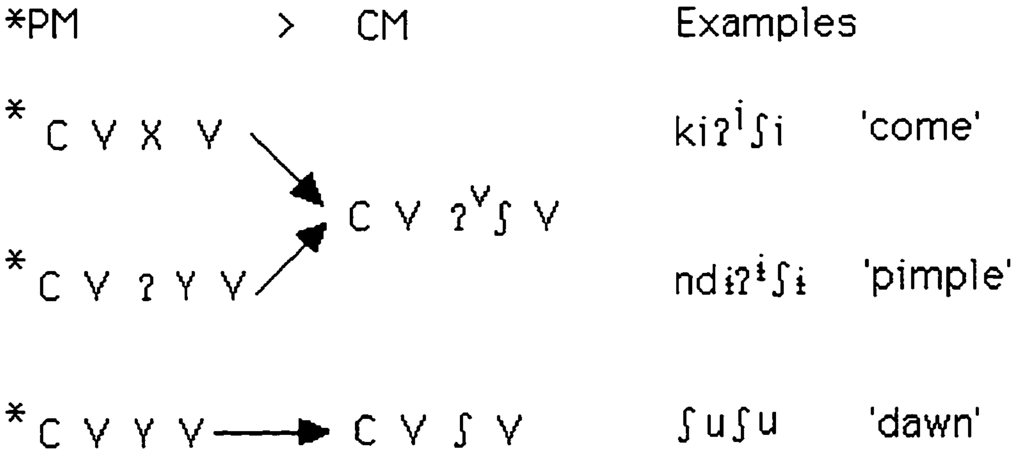
before medial/ʃ/ (e.g., ki?^{i}ʃi 'come') while others do not (e.g., ʃɨʃɨ 'coati').

derived from */y/ and appear to condition predictable vowel glottalization. In these cases, however, glottalization can also be traced back to the proto-forms for which it was lexically contrastive, as in *ndɨʔyɨ* > *ndɨʔ^{ɨ}ʃɨ* 'pimple'. Finally, other CM forms contain medial /ʃ/'s that are historically derived from */x/. These systematically condition predictable vowel glottalization, as in *kiʔ^{i}ʃi* 'come'. A schematic view is provided in (65).

(65) **Glottalization and historical merger**



How is the legacy of historical change to be formally encoded in the synchronic phonology? My claim is that the current situation reflects a partial (and perhaps not yet completed) merger of */x/ and */y/ in couplet-medial position. In the case of contemporary CM forms such as *ndɨʔ^{ɨ}ʃɨ* 'pimple', I see no reason to assume that the medial /ʃ/ is anything other than a [-voice] consonant, despite its historical derivation from the glide */y/.[41] Thus, like any other couplet with a voiceless medial consonant, glottalization of the preceding vowel will proceed under pressure from Force(cg). This is the simplest approach to the treatment of these consonants. Phonetically, they are voiceless. Phonologically, they pattern with voiceless consonants. Therefore, I take them to be phonologically [-voice].[42]

For the cases of /ʃ/ that fail to condition vowel glottalization, it is clear that something more must be said. Despite historical explanations for how they have come to be, their synchronic behavior is unpredictable, and this must be encoded in the grammar. One possibility is to adopt a modified version of the voiced-/ʃ/ hypothesis and simply assume that these /ʃ/'s are [+voice] segments. Piggott (1992) takes this position, for example, transcribing *kuʃu* 'diligent' as [kuʒu] and assuming the existence of a /ʒ/ phoneme. To assume (without argument) the existence of /ʒ/ is troubling, however, especially since neither of the sources (Pike and Small (1974) or Pankratz and

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[41] Unfortunately, I have not found couplets such as *ndɨ*ʔ^{ɨ}ʃɨ 'pimple' that speakers freely nasalize in the second person familiar; i.e. couplets whose medial /ʃ/ is both historically derived from /*y/ and preceded by a glottalized vowel. If these were to be synchronically (albeit abstractly) voiced, we would expect /ʃ/ to be transparent to nasal harmony. When asked to provide the familiar form of *ndɨ*ʔ^{ɨ}ʃɨ 'you (fam) are a pimple', speakers respond that they can't say that. (They also reject *ndoʔ*^{o}*ʃo* 'mud, muddy' as an adjective to describe a person.) My prediction is that such /ʃ/'s will block regressive nasalization, but more detailed investigation of the issue is necessary.

[42] Of course, I also assume that instances of /ʃ/ historically derived from /*x/

Pike (1967)) on either of the varieties of Mixtec cited by Piggott posits an underlying /ʒ/. As a consequence, Piggott's assumption is an oversimplification that provides a less than accurate rendering of the original sources.

Perhaps some evidence for this position can be adduced from Pike and Small's (1974) observation that /ʃ/ alternates with [ʒ] intervocalically in non-glottalized couplets, i.e. in couplets such as *kuʃu* 'diligent'. I have not found this to be the case, however.[43] In any case, Pike and Small's original observation refers to the optional appearance of intervocalic allophony. Even if this constitutes evidence for a voiced palato-alveolar phoneme, there is clearly no evidence to indicate that a /ʒ/ appears couplet-initially in CM. And this is odd, given our observation in chapter 2 that couplet-initial position is where all other consonantal contrasts *are* exhibited in CM. What the problem comes down to is this: these medial /ʃ/'s sound voiceless but don't act voiceless.

Positing a /ʒ/ phoneme, then, can be viewed as one way of responding to the fact that phonetically we are inclined to view them as /ʃ/'s, while phonologically, we might be inclined to view them as voiced. Another means of encoding their special status in the grammar, i.e. of recognizing two

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are [-voice].

[43] Priscilla Small (p.c.) has also told me that she has always harbored doubts

phonologically distinct /ʃ/ sounds in the language, is to treat one of them as unspecified for voicing. I argue that this option more successfully reconciles the discrepancy between their phonological behavior and phonetic voicelessness.

First, the assumption of a subset of couplet-medial /ʃ/'s that are phonologically unspecified for voicing poses no threat to the formal analysis of vowel glottalization above. This is because Force(cg), as I have formally expressed it, determines a couplet's constrastiveness for the feature [cg] on the basis of whether the medial consonant is a [-voice] segment. As a consequence, there will be no empirical difference with respect to glottalization between whether we specify this class of /ʃ/'s as [+voice] or [0 voice]. In both cases, all that is necessary is that they do not have a [-voice] specification. As (66) shows, if they surface with a glottalized vowel, they will be ruled out by violating Ident(cg)[44].

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about that description in the original Pike and Small (1974) paper.

[44] I assume that the candidate in (a) reflects no change in the input specification for [cg]. If the input is the unspecified form, the output vowel is unspecified. If input V1 is [-cg] so is output V1. In this way, two tableaux have been compressed into one.

(66)

Input: ʃɨʃɨ **'coati'** | **0 voi/+voi**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ ʃɨʃɨ			
b) ʃɨʔ$^{\text{ɨ}}$ʃɨ			*!

Phonetically, however, I argue that the underspecified approach is preferable. If we assume that these /ʃ/'s are [+voice], it is justifiable to ask why they are phonetically realized as voiceless, especially since the language has two other voiced fricatives: /ð/ and /β/, which do surface as voiced. On the other hand, the lack of any voicing specification allows for a straightforward and phonetically plausible explanation of their surface voicelessness.

As is well known, fricatives are characterized by the presence of turbulent airflow at the point of vocal tract constriction. Ohala (1983) points out that the aerodynamic requirements of fricatives are such that they must be realized with high oral air pressure in order to guarantee high velocity flow through the oral tract constriction (see also Catford 1977, Ladefoged and Maddieson 1996). At the same time, sustained voicing requires low oral pressure; i.e. the avoidance of supraglottal pressure build up. This, Ohala argues, suggests that to the extent that fricatives are voiced, they may not be very good fricatives. And in this sense, there are good aerodynamic reasons to take fricatives to be optimally voiceless from a phonetic perspective. For the case at hand, I assume that a phonologically unspecified /ʃ/, all other things being equal, would have no reason to be phonetically implemented as voiced, since voicing, though not entirely incompatible with frication, is antagonistic to the aerodynamic requirements of frication.

A final issue thus involves the formal phonological consequences of the claim that these segments are unspecified for voicing. As I have shown in (66), for the formal analysis of glottalization, it does not matter whether these /ʃ/'s are underlyingly specified as [+voice] or [0 voice]. Either specification maps identically to the optimal output under the grammar here, as seen again in (67) for *kuʃu* 'diligent'.[45]

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[45] As Diana Archangeli points out to me, the analysis in (67a) may also require a constraint guaranteeing that [+voice] /ʒ/ be realized as phonetic [ʃ].

(67)

a) Input: **k u ʃ u** | **+voi**	**CG/STR**	**Force(cg)**	**Ident(cg)**
☞ 'kuʃu | +voi			
'kuʔ^{u}ʃu | +voi			*!
b) Input: **k u ʃ u**			
☞ 'kuʃu			
'kuʔ^{u}ʃu		*!	

As I note earlier, the issue revolves around the fact that within Optimality Theory, Gen freely generates input-output pairs. In this case, under this grammar, the winning pair of both (a) and (b) correctly describes the optimal surface form. What does it mean, then, to say that the /ʃ/ in *kuʃu* is unspecified for voicing? The problem is that in traditional generative phonology, we assume the existence of a unique underlying representation, whereas OT tableaux such as those in (a) and (b) show that distinct URs can map to the same surface form under a given grammar (cf. McCarthy and Prince 1995, McCarthy 1996, Kirchner 1995b for more examples). One legitimate solution is to simply allow this situation, i.e. to assume that surface *kuʃu* 'diligent' may be represented at input either with a [+voi] or with a [0voi] /ʃ/.

Another solution is to introduce additional constraints into the grammar that would mediate in favor of the optimal input-output pair in (67b) over that of (67a). One such constraint, for example, would be to introduce a Path Condition (Archangeli and Pulleyblank 1994a) into the hierarchy which prohibits the feature cooccurrence of [+strident] and [+voice].

(68) **STRIDENT/VOICE (STRI/VOI)**
If [+strident] then [-voice]
If [+strident] then not [+voice]

Such a constraint would prohibit the occurrence of voiced strident fricatives, while not affecting the non-strident voiced fricatives /ð/ and /β/. The effect of STRI/VOI is to guarantee that /ʃ/ will not be specified for [+voice] at output. (Note that I assume a high ranking for illustration purposes in the tableau, though we have no evidence here that STRI/VOI need be crucially ranked with respect to the glottalization constraints.[46]

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[46] For the purposes of this tableau, I also assume that correspondence must value faithfulness to [strident] over faithfulness to [voice], given that an input containing both could satisfy STRI/VOI by failing to be faithful to either in its corresponding output form. Thanks to Diana Archangeli for bringing this to my attention.

(69) **STRIDENT/VOICE**

a) Input: **k u ʃ u**	**STRI/VOI**	**CG/STR**	**Force(cg)**	**Ident(cg)**
a) ☞ 'kuʃu				
b) 'kuʒu	*!			*
c) 'kuʔ^{u}ʃu				*
d) 'kuʔ^{u}ʒu	*!			

An interesting consequence of this approach is that the traditional notion of underlying underspecification can be translated in Optimality Theoretic terms to a constraint indirectly demanding surface underspecification. That is, the grammar selects the output candidate containing the underspecified /ʃ/, even if we posit an input in which /ʃ/ is [+voice]. Again, lexicon optimization (Prince and Smolensky 1993, Itô, Mester, and Padgett 1995) will select the underspecified /ʃ/ as the optimal input form. Assuming a Correspondence based model of Optimality Theory (McCarthy and Prince 1995, Orgun 1995, McCarthy 1996), the presence of an input [+voice] specification paired with an unspecified /ʃ/ at output will constitute a faithfulness violation; i.e. a lack of feature correspondence between input and output. Nevertheless, it is important to note that the impetus behind the violation is the STRI/VOI constraint, which forces the absence of voicing in the optimal output, rather than in the input candidate.

3.5 Stress

Throughout the discussion in §3.4 above, I have assumed the correct placement of stress. Since CG/STR refers to stress, an explicit characterization of CM stress is in order. This section provides a formal treatment of the facts. In §3.5.1, I account for the basic stress pattern of the language, focusing on stress at the level of the individual couplet and in prosodic words that are larger than the single couplet. In §3.5.2 I refine the analysis, extending the discussion to include a consideration of prosodic words containing enclitics.

3.5.1 Stress: the basic pattern

In descriptive terms, the basic CM stress pattern is most simply accounted for by building a single moraic trochee at the right edge of the prosodic word. In this way, we capture the fact that there is one stress per word and that stress is located on the penultimate mora.

Formally in OT, stress placement involves the interaction of the following familiar constraints (not yet ranked):

(70) **CM stress** (spirit of McCarthy and Prince 1993b)

a) $\text{FootBin}_{\text{mora}}$: all feet are binary at the moraic level

b) Align(Ft, R, PrWd, R): *"Every Ft is final in PrWd"*

c) Foot Type: Trochee

d) Parse-Mora: *"Every mora belongs to a foot"*

The first constraint, $\text{FOOTBIN}_{\text{MORA}}$ parses feet as obligatorily binary structures consisting of two moras. FOOT TYPE: TROCHEE locates prominence on the leftmost mora of the foot. Satisfaction of ALIGN(Ft, R, PrWd, R) requires that all feet be aligned with the right edge of the prosodic word, and PARSE-MORA requires that all moras be parsed into feet.

In the simplest case, that of prosodic words consisting of a single couplet, all four constraints can be satisfied and thus no ranked order is established. This is shown in (71) for the single couplet *'kunũ* 'to run'.[47]

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[47] For consistency, I again use the notation of Halle and Vergnaud, marking headship via the presence of a line one asterisk. Each mora is indicated by the presence of a line 0 asterisk. Nothing crucial hinges on this particular notation, however. I do not consider stressless candidates under the assumption of an inviolable constraint in the grammar requiring that all words be stressed.

(71)

Input: **kunũ 'to run'**	**Align**	**FootBin**	**Trochee**	**Parse-Mora**
* (* *) a) ☞ k u n ũ				
* * (*) b) k u n ũ		*!	*	*
* (*) * c) k u n ũ	*!	*	*	*
(* *) d) k u n ũ			*!	
* (* *) e) k u n ũ			*!	

In the optimal candidate, (a), no constraint is violated. Candidate (b) violates constraints on foot size and type, as well as the Parse-Mora constraint. The form in (c) violates all of the constraints, and the forms in (d) and (e) are both non-optimal because they incur violations of the Trochee constraint.

That a partial ordering of the stress constraints is necessary becomes evident when the prosodic word consists of more than one couplet, as in the string /kunũ/+/βaʔa/ 'to run well'. In particular, Align and Parse-Mora conflict: Align forces all feet to be aligned with the right edge of the prosodic word, while Parse-Mora requires that all moras be parsed into feet. Of course, if a string of four moras is parsed into two binary feet under pressure from Parse-Mora, one of these feet will violate Align. On the other hand, if Align is ranked above Parse-Mora, only one foot will be parsed, incurring Parse-Mora violations. For CM, I argue that Align is ranked above Parse-Mora, as in (72).

(72) **Trochee, FootBin, Align >> Parse-Mora**

This ordering, together with the assumption of undominated Trochee and FootBin constraints, guarantees that only one trochaic foot will be built on the right edge of the prosodic word and thus captures the generalization that there is only one stress per prosodic word. This is shown in (73)

(73)

Input: kunũ+ βa?a	**Align Trochee FootBin**	**Parse-Mora**
* (* *) a)☞ k u n ũ β a ʔ a		* *
* * (* *)(* *) b) k u n ũ β a ʔ a	*!*	

The candidate in (b) is representative of any candidate in which a foot fails to align with the right edge of the prosodic word. The ranking Align >> Parse-Mora thus rules such forms out, even though the correct form in (a) violates

Parse-Mora twice as a result.[48] In this way, regardless of whether the prosodic word consists of a single couplet or a string of couplets, stress will be limited to the penultimate mora of the final couplet of the string.

3.5.2 Stress and enclitics

One question that arises from the discussion in §3.5.1 is whether footing is at all necessary to characterize the stress system. Alternatively, we might say that stress involves two constraints: an edgemost constraint assigning prominence (via, say, the presence of a line 1 asterisk) to the rightmost mora of a word, and another, more highly ranked constraint enforcing non-finality (see, for example, McCarthy and Prince 1993b for discussion of Edgemost and Rightmostness). Thus, the penultimate mora of the prosodic word will be the rightmost and hence most optimal location for stress, given the inviolable nature of non-finality.

There do, however, exist surface exceptions to stress falling on the penultimate mora of the word. These involve cases in which enclitics follow

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[48] Two Parse-Mora violations are assigned, since two moras separate the right edge of the leftmost foot from the right edge of the word. Note also that this type of ranking within Optimality Theory renders concepts such as obligatorily exhaustive footing (for example, Hayes 1980, Hammond 1984, Halle and Vergnaud 1987, Halle 1990) as a by-product of a highly ranked Parse-Mora constraint and not as universal primitives of stress theory. Additionally, this type of approach provides a mechanism for avoiding the building and subsequent conflating of metrical feet, resulting in the construction of a single foot, exactly the CM case. See also Crowhurst (1996) for alternatives to conflation within Optimality Theory.

the final couplet of the word. One such example is the question marker *ndʲu*, as seen in (74).[49]

(74) Enclitics and stress

a) [kutʲu 'βaʔa ndʲu] ['βuru]	'is the burro going to work/plow well?'
b) [kutʲu 'βãʔã ndʲũ]	'are you (fam) going to work/plow well?'
c) ['kuʔᵘtʲũ ndʲũ]	'are you (fam) going to work/plow?'

The string in (a) contains two prosodic words: one consisting of the questioned verb phrase *kutʲu 'βaʔa ndʲu* lit: 'work + well + Q' and the other consisting of the subject NP *'βuru* 'burro', which receives stress independently. Both (b) and (c) each contain one prosodic word, comprising the whole sentence. In all three cases, the prosodic word containing the enclitic *ndʲu* constitutes a surface exception to the generalization that stress falls on the antepenultimate rather than the penultimate mora of the prosodic word. Specifically, stress does not appear to count the mora of the clitic.

Of course, it is not atypical cross-linguistically for clitics to be inert to stress, but their behavior requires an explicit analysis.[50] Consider, for example,

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[49] The nasalization in (b-c) reflects the result of second person familiar nasalization. This phenomenon is discussed in detail in Chapter 4. Note that the examples in (b-c) serve to illustrate that the question marker is phonologically affiliated with the preceding verb phrase and not the following subject, given that (b-c) contain no overt subject.

[50] See, for example, discussion of the inertness of clitics to Spanish stress in Harris (1995).

the placement of stress in *kũnũ ndʲũ* 'are you (fam) running' in (69). If stress feet include clitics, we might expect stress to fall on the incorrect form in (a). As with the forms above, however, the correct surface form is (b), in which stress falls on the penultimate mora of the final couplet of the prosodic word; i.e. on the antepenult.

(75) a) **incorrect stress placement** b) **correct stress placement**

```
            *                           *
     *      *         *              (  *        * )       *
     ~      ~         ~                 ~        ~         ~
  k  u   n  u   ndʲ   u           k     u   n    u   ndʲ   u
```

I conclude from the data that proper footing requires that the trochee not include the mora of the clitic. This can be accomplished in a straightforward fashion by introducing an additional alignment constraint into the stress hierarchy--a constraint by which all feet must be aligned with the right edge of a root (i.e., a couplet):

(76) **Align Foot:** *"Every Ft is aligned with the right edge of a root"*
Align(Ft, R, Root, R)

This move creates a situation in which AlignPrWd forces rightmost stress by locating the stress foot at the right edge of the prosodic word, while AlignRoot requires that feet be aligned with the right edge of a root. If the prosodic word ends with a clitic, one of these constraints must be violated.

For CM, ordering AlignRoot above AlignPrWd (AlignRoot >> AlignPrWd) effectively bans the presence of a foot at the rightmost edge of a prosodic word containing enclitics. Consequently, stress will surface on the antepenultimate mora. The crucial candidates illustrating this are seen in (77). (Candidates violating Trochee and FootBin are excluded from consideration.)

(77) The effect of AlignRoot >> AlignPrWd

Input: kutʲũ + ndʲũ	AlignRoot	AlignPrWd (Trochee) (FootBin)	Parse-Mora
* (* *) * a)☞ [k ũ n ũ]ndʲũ		*	*
* * (* *) b) [k ũ n ũ]ndʲũ	*!		*

That this approach is on the right track is further supported by the fact that prosodic words can end in more than one enclitic, with stress thus surfacing on the preantepenultimate mora of the word. This is shown in (78), where the question marker is followed by an additional clitic subject marker.

(78) a) ['ka?ᵃnũ ndʲu tũ] 'is she big?' (lit: big + Q + she)

b) ['ku?ᵘtʲu ndʲu nã] 'is he going to plow/ work?' (lit: plow + Q + he)

In both cases, stress surfaces on the initial mora of the couplet, which is the preantepenultimate mora of the word. (And, as we expect, stress is accompanied by glottalization--contrastively in the case of (a) and predictably in (b)). Under the analysis here, such cases are unproblematic: the preantepenultimate mora is the head of the foot in both cases, due to the need to satisfy AlignRoot:

(79) **The effect of AlignRoot >> AlignPrWd**

Input: ku?ᵘtʲu + ndʲũ	**AlignRoot**	**AlignPrWd (Trochee) (FootBin)**	**Parse-Mora**
* (* *) * * [k u tʲu] ndʲu nã | a)☞ +cg		* *	**
* * * (* *) [k u tʲu] ndʲu nã | b) +cg	*!*		**
* * (* *) (* *) [k u tʲu] ndʲu nã | c) +cg	*!*	**	

The candidates in (a) and (b) once again exhibit the crucial ordering between the two alignment constraints, with the optimal candidate in (a) preferring to violate AlignPrWd twice in order to assure satisfaction of AlignRoot. The form in (c) provides an example of exhaustive footing in which all moras are parsed. Here, the rightmost foot twice violates AlignRoot (thus ruling the form out), while the leftmost foot twice violates AlignPrWd. The optimal candidate is thus (a).

Incorporating AlignRoot into the analysis works equally well for the characterization of stress in words consisting of more than one couplet.

(80) **Tableau: *kunũ 'k^{w}ii* 'run slowly'**

Input: kunũ + k^{w}ii **'run' 'slowly'**	**AlignRoot**	**AlignPrWd (Trochee) (FootBin)**	**Parse-Mora**
* * * (* *) a)☞ [k u n ũ] [k^{w}i i]			**
* (* *) * * b) [k u n ũ] [k^{w}i i]		*!*	**
* * (* *) (* *) c) [k u n ũ] [k^{w}i i]		*!*	
* (* *) * * d) [k u n ũ] [k^{w}i i]		*!**	**
* * * * * e) [k u n ũ] [k^{w}i i]			**!**

A glance at the tableau reveals that of candidates in (a-e), none violates AlignRoot, since in all three each foot present in the representation is right edge aligned with the right edge of a root. Nevertheless, in (b-d), AlignPrWd is twice violated by the leftmost foot of the representation and all three candidates are thus ruled out. (Candidate (d) also violates Foot Type, hence the third asterisk.) Finally, candidate (e) is eliminated from consideration due to a complete absence of footing. Although stress in (e) is located on the proper mora, candidate (a) also places stress correctly, while incurring fewer violations of the otherwise lowly ranked Parse-Mora. Thus (a) is correctly selected as the optimal candidate.[51]

In sum, CM stress can be straightforwardly accounted for in terms of the following partially ordered constraint hierarchy.

(81) **CM Stress:**

Align(Ft, R, Root, R): *"The right edge of every foot is aligned with the right edge of a root."*
>>

Align(Ft, R, PrWd, R): *"The right edge of every foot is aligned with the right edge of a prosodic word."*
FootBin$_{mora}$: *"All feet are binary at the moraic level."*
Foot Type: Trochee
>>
Parse-Mora: *"Every mora belongs to a foot."*

From a cross-linguistic perspective, these constraints are of an ordinary variety. FootBin$_{mora}$ encodes the fact that stress employs binary feet consisting of two moras. FootType encodes the fact that the system is of the common

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[51] Note also that Parse-Mora is equally important for ruling out hypothetically unfooted candidates such as *'kunũ k*^{w}*ii* in which stress is incorrectly located on the first mora of the initial couplet, since the lack of foot structure on such forms will trivially satisfy constraints on alignment, foot size, and foot type. Another general approach to this problem might be to add a highly ranked constraint requiring stress to have a foot. That is, if we take stress to mean head (see McCarthy and Prince 1994b), then we can motivate a constraint (e.g. STRESS→FOOT) barring the presence of any head that does not dominate a foot. In the notation used here, such a constraint would bar the presence of line one asterisks that do not dominate a footed mora. At any rate, the motivation for such a constraint would be to formally encode the traditional notion that headship is a property of feet, or, in more simple terms, that heads need feet. I have not adopted such a constraint here, however, because the formal analysis proceeds correctly without its incorporation into the

trochaic type. Parse-Mora simply expresses the traditional notion of the prosodic hierarchy (cf. Selkirk 1984, Nespor and Vogel 1986) in that feet are built from lower level prosodic structure. The two Alignment constraints are also unremarkable. AlignPrWd locates prominence at the right edge of the word (cf. Hayes's (1995) End Rule), while AlignRoot formally encodes the exclusion of clitics from the foot, i.e. the close affinity between foot and root boundaries in the language. These constraints thus systematically locate stress on the penultimate mora of the final root of a prosodic word. If we take the stress constraints to be inviolable in CM, the predictable location (under stress) of glottalization follows straightforwardly from our constraint CG/STR, which limits glottalization to stressed contexts only.[52]

3.6 Glottalization and the relationship between phonetics and phonology

This section addresses two issues pertaining to the interface of phonetics and phonology. The first regards the use of the path condition CG/STR in the above analysis. The second regards the phonetic

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constraint hierarchy.

[52] As Diana Archangeli has pointed out, for those inclined to dispense with foot structure, an alternative analysis exists in which stress can be viewed as obligatorily non-final in both the prosodic word and the root (NonFin(PrWd) >> NonFin(Root)). To these, we can add two lower ranked alignment constraints forcing the rightmost alignment of stress in both a root and a prosodic word: (Al-Rt(stress,Root) >> Al-Rt(stress-PrWd). These four ordered constraints would also appear to locate stress predictably on the penultimate mora of the final couplet of a prosodic word. Nothing in my analysis of glottalization, however, rests on evaluating these competing views, so long as the predictability of stress placement is explicitly characterized.

implementation of the phonologically specified [+cg] feature. Both constitute distinct yet important aspects of the relationship between these two modules of the grammar. In the case of path conditions, we explore the way in which phonetics constrains phonological processes (cf. Archangeli and Pulleyblank 1989, 1994a, Cohn 1989, 1990). In the case of implementation, we address the complex issue of how static, symbolic phonological representations are ultimately to be interpreted in the dynamic process of speech (cf. Pierrehumbert 1980, Keating 1988, 1990b, Shih 1988, Pierrehumbert and Beckman 1988, Huffman 1989, 1993, Cohn 1990, 1993a, Laniran 1993).

3.6.1 On the path condition CG/STR

A central claim of Archangeli and Pulleyblank (1994a) is that path conditions must be phonetically motivated or *grounded*. As seen in §3.4.3.1 above, the formal expression of a path condition has two components: 1) a positive implication involving sympathetic gestures and 2) a negative implication banning the cooccurrence of antagonistic gestures. A simple example of the former is IF [NASAL] THEN [+VOICE], i.e., an implication which is satisfied if [+voice] is present on a path with [+nasal]. Its negative counterpart is IF [NASAL] THEN NOT [-VOICE], i.e., a prohibition against paths containing [nasal] and [-voice].[53] By contrast, ungrounded implications such as IF [NASAL] THEN [-VOICE]; IF [NASAL] THEN NOT [+VOICE] are

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[53] See also Pulleyblank (1989), Gerfen (1993), and chapter 5 for discussion of

universally proscribed for natural language phonologies. In this way, the formal power of the model to invoke constraints over the cooccurrence of features is itself constrained by the hypothesis that these conditions must be phonetically motivated or natural.[54]

Archangeli and Pulleyblank's (1994a) claim is an important one insofar as it explicitly advances a view of the phonology/phonetics interface in which phonological phenomena are governed at least in part by a principle of phonetic naturalness. Given the formal treatment of glottalization above, it is thus legitimate to ask whether or not a constraint such as CG/STR is, in fact, phonetically grounded. Such cases provide fertile territory for exploring general claims of naturalness. Ultimately, I argue CG/STR is phonetically motivated, but that the nature of the motivation leads us to a more finely grained extension of grounding than the view adopted in the particular cases addressed by Archangeli and Pulleyblank.

Why is this the case? In their research, Archangeli and Pulleyblank (1994a) focus on path conditions involving combinations of vowel features such as [+/- round], [+/-high], [+/-low], and, in particular, [+/-ATR]. These features have fairly direct articulatory correlates, and their phonological

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NASAL/VOICE.

[54] Archangeli and Pulleyblank's position is not that all phonological phenomena must be "natural", but rather, that feature cooccurence conditions, when invoked by a phonological system, will be phonetically motivated. See Stampe (1972) and Donegan and Stampe (1979) on the issue of naturalness in phonology, as well as Anderson (1981). See also Fowler (1983)

interaction can thus be grounded in terms of articulatorily sympathetic and/or antagonistic relationships.[55] For [+/-ATR], for example, Archangeli and Pulleyblank offer solid physiological evidence for viewing tongue root retraction as antagonistic with tongue body raising, thereby providing a phonetic basis for phonological constraints such as the following.[56]

(82) a) RTR/HI: If [-ATR] then [-high]; If [-ATR] then not [+high]
b) HI/RTR: If [+high] then [+ATR]; If [+high] then not [-ATR]

By contrast, no straightforward correlation exists between [+constricted glottis] and stress. The former refers to a particular laryngeal state, while the latter refers to the more abstract notion of prominence and lacks any single acoustic, articulatory or aerodynamic correlate (cf. Lehiste 1970, Hayes 1995). Additionally, the incorporation of stress into a grounded path condition extends the notion of grounding by relating a subsegmental feature to a metrical property. In short, there is no direct or obvious sense in which the implementation of [+constricted glottis] should prefer the presence of stress or vice versa.

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for a pyscholinguistic perspective.

[55] Though Ladefoged (1993a) notes, for example, that vowel height is best correlated with the frequency of F1 while frontness and backness seem best characterized via F1-F2 differences rather than any particular tongue position.

[56] See Perkell (1971), Ladefoged et. al. (1972), and Jacobson (1980), all cited in Archangeli and Pulleyblank (1994a) regarding the interaction of tongue root advancement and tongue body height. See also Stevens and Keyser (1989) on the notion of phonetic enhancement between sympathetic features.

Nevertheless, there are good reasons to view CG/STR as phonetically motivated within the context of CM phonology, a motivation to which I refer as *opportunistic grounding*. The crux of my claim is that the predictably longer duration of stressed vowels provides a phonetically optimal context for the realization of the [+constricted glottis] feature, while at the same time the presence of glottalization serves as an additional acoustic cue for stress. In this sense, each benefits from the other, despite the lack of an obvious sympathy between them.

Recall the formal expression of CG/STR, repeated here for convenience.

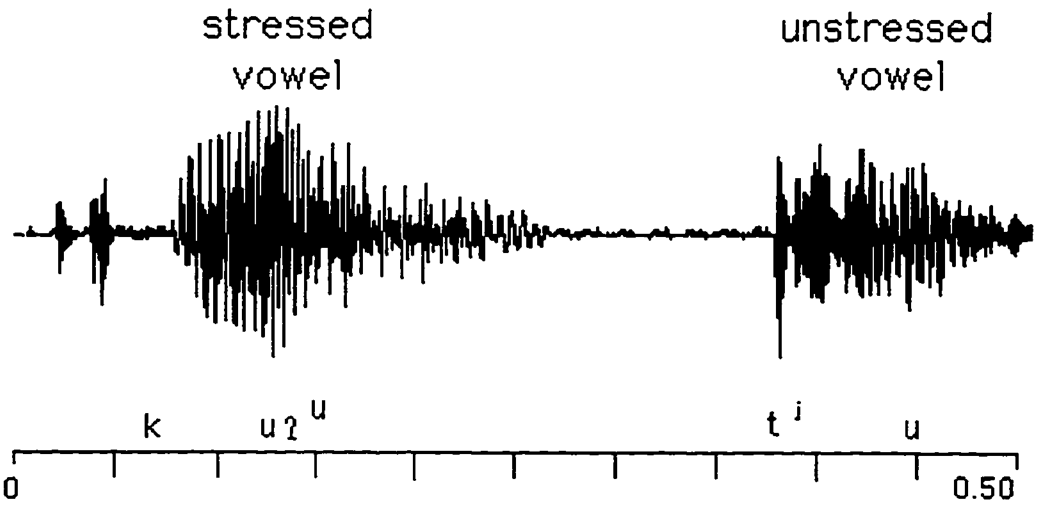
(83) **CG/STR**: If [+constricted glottis] then stressed
If [+constricted glottis] then not unstressed

Given that the claim is that the extra length of stressed vowels affords an optimal context for glottalization, two points must be addressed. First, we must establish that there is a predictable relationship between stress and length, since this provides the putative phonetic underpinning for the constraint. Secondly, we must still answer the question of why glottalization should profit from extra length. I turn in §3.6.1.1 to the first of these issues. As for the second, in §3.6.1.2 I build on the work of Silverman (1995) by discussing the complex interplay of stress, lexical tone and glottalization in CM.

3.6.1.1 Stress and length

Together with amplitude, length constitutes an important acoustic correlate of stress in CM. This can be seen in the token of *kuʔ*^{u}*t*^{j}*u* produced by S1 in (84).

(84) **S1: stressed 'kuʔ^{u}t^{j}u**



Note that the stressed V1 is longer than the unstressed V2. Two points are of interest. First, this general durational distinction under stress is found independently of the presence of glottalization. Secondly, since there is only one stress per phonological word, the V1 vs. V2 length distinction exhibited under stress disappears in unstressed contexts.

To determine these two points, I measured the respective durations of V1 and V2 for two different couplets in both stressed and unstressed contexts.

One couplet *tʲɨβi* 'to blow' is non-glottalized, while the other *kuʔᵘtʲu* 'to hoe, to plow' contains a glottalized vowel when stressed. The experimental sentences are provided in (85), with phonological words enclosed by brackets.

(85) **Frame sentences:**[57]

a) [kutʲu 'kʷii] ['βuru] 'the burro is going to work slowly'
b) ['kʷii] ['kuʔᵘtʲu] ['βuru] 'the burro is going to work SLOWLY'
c) [tʲɨβi 'kʷii] ['βuru] 'the burro is going to blow slowly'
d) ['kʷii] ['tʲɨβi] ['βuru] 'the burro is going to blow SLOWLY'

In (a) and (c), stress does not fall on either *kutʲu* or *tʲɨβi*. But by syntactically fronting and thus semantically focusing [kʷii] in (b) and (d), the stress pattern is varied such that stress does fall on each of *kuʔᵘtʲu* and *tʲɨβi*. That is, in (b) and (d) each verb constitutes its own phonological word, while in (a) and (c), the respective verb phrases [kuʔᵘtʲu kʷii] and [tʲɨβi kʷii] constitute single phonological words, with stress falling predictably on *kʷii* in both. The subject *βuru* 'burro' provides a uniform, sentence-final context which protects the target couplets from any final lengthening effects.[58]

Five repetitions of each sentence were recorded for speakers S1, S2, S3, S4, and S5, and mean durations for V1 and V2 in the target words were

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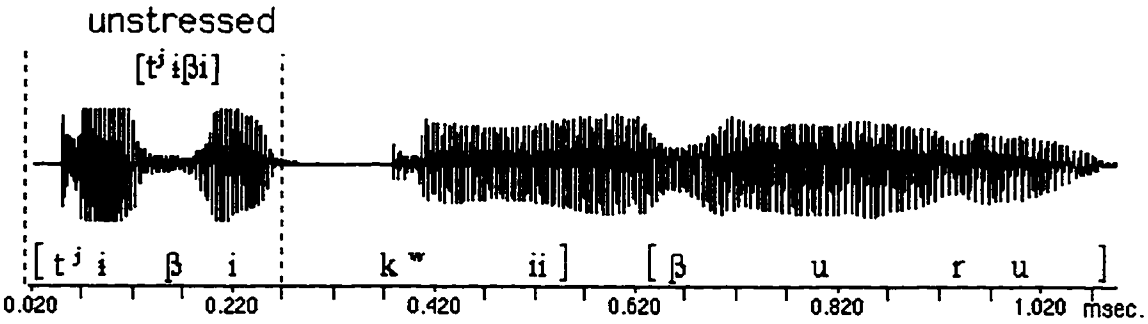
[57] Note that *kuʔᵘtʲu* is literally translated as 'to hoe, to plow'. However, in this context it is more loosely translatable as 'to work (in the field)'.

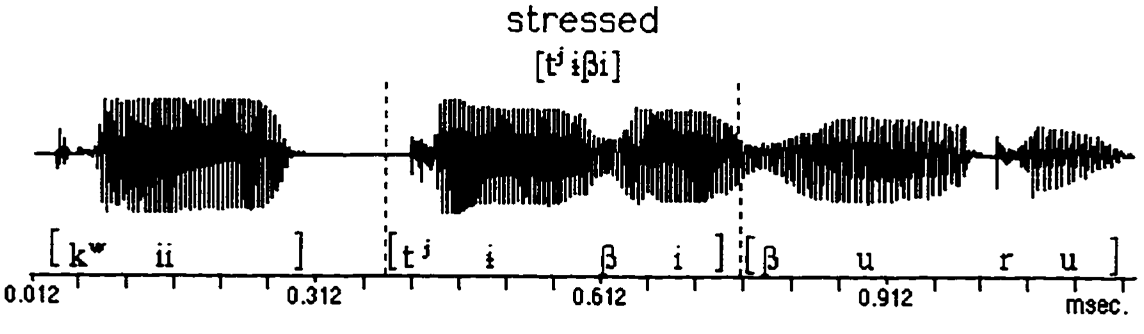
[58] Also, as the subject NP and independent prosodic word, *βuru* receives its own main stress. See Small (1990) for a general syntactic description of CM.

calculated. What the data clearly show is a regular correlation across speakers between length and stress. Specifically, in comparing V1 and V2 within a couplet, we see that durational distinctions between these are reduced in unstressed contexts, or, to put it another way, sharp durational distinctions surface under stress. In (86) and (87), I provide representative tokens of *tʲɨβi* 'to blow' for S3:

(86) **S3: unstressed *tʲɨβi* 'to blow'**

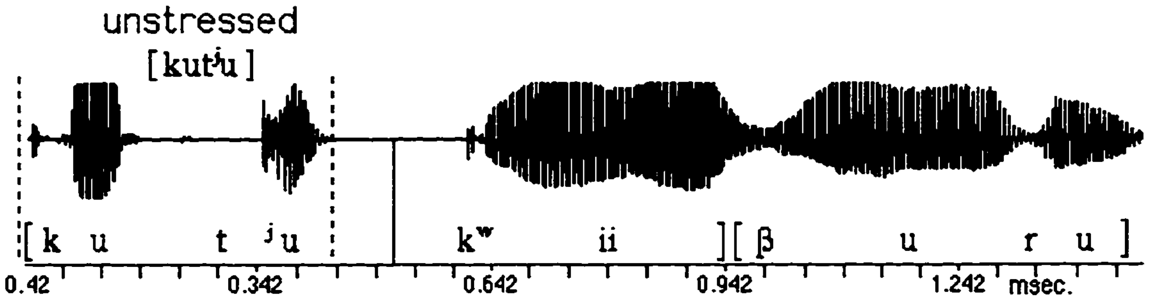


(87) **S3: stressed *tʲɨβi* 'to blow'**



Note in (86) that V1 and V2 in *t*^{j}*ɨβi* are similar in length. By contrast, in (87) V1 is visibly longer than V2. This same general pattern is found for *kuʔ*^{u}*t*^{j}*u* 'to hoe, to plow', as seen in the examples in (88) and (89) for S1.

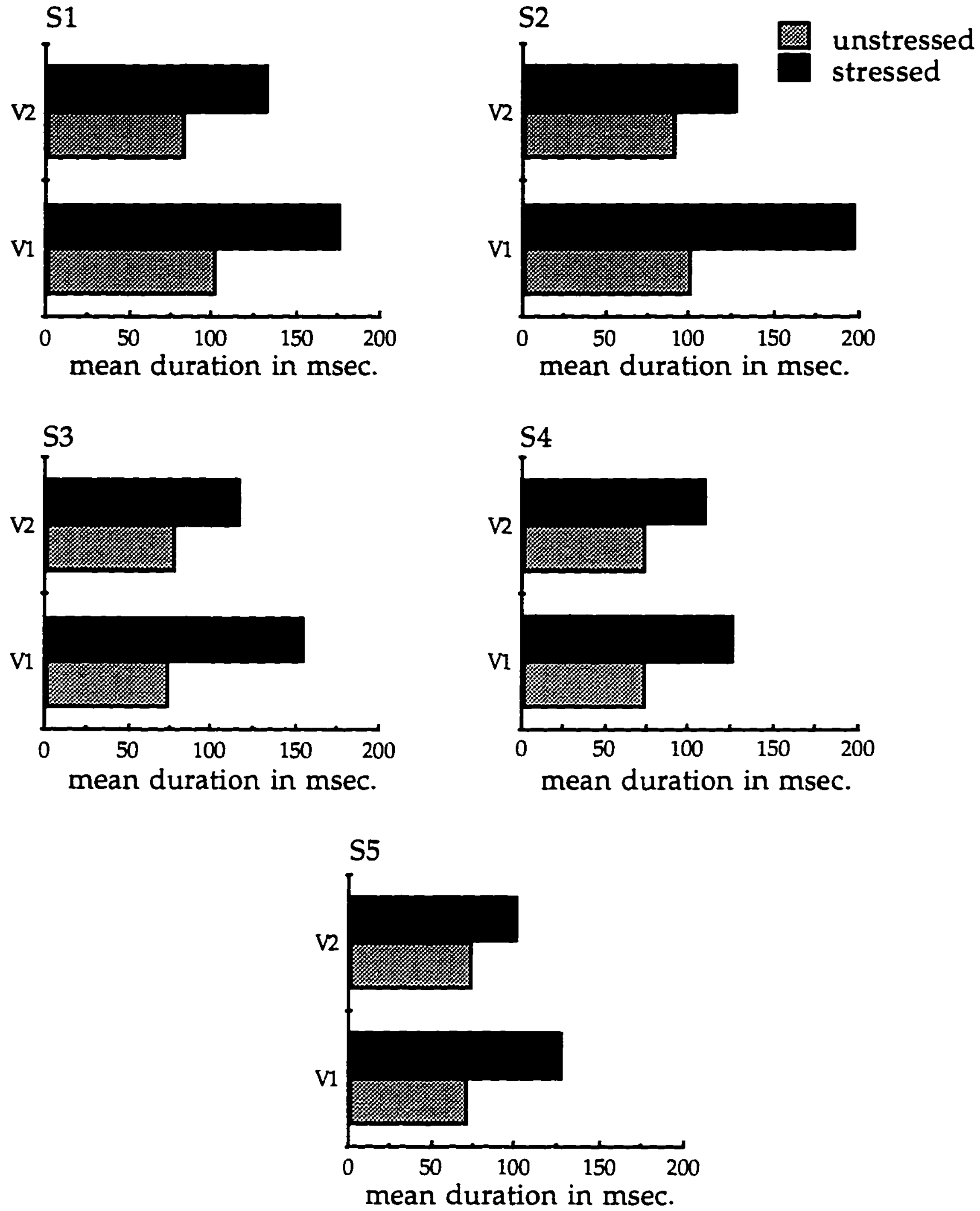
(88) **S1: unstressed *kuʔ*^{u}*t*^{j}*u* 'to hoe, to plow'**



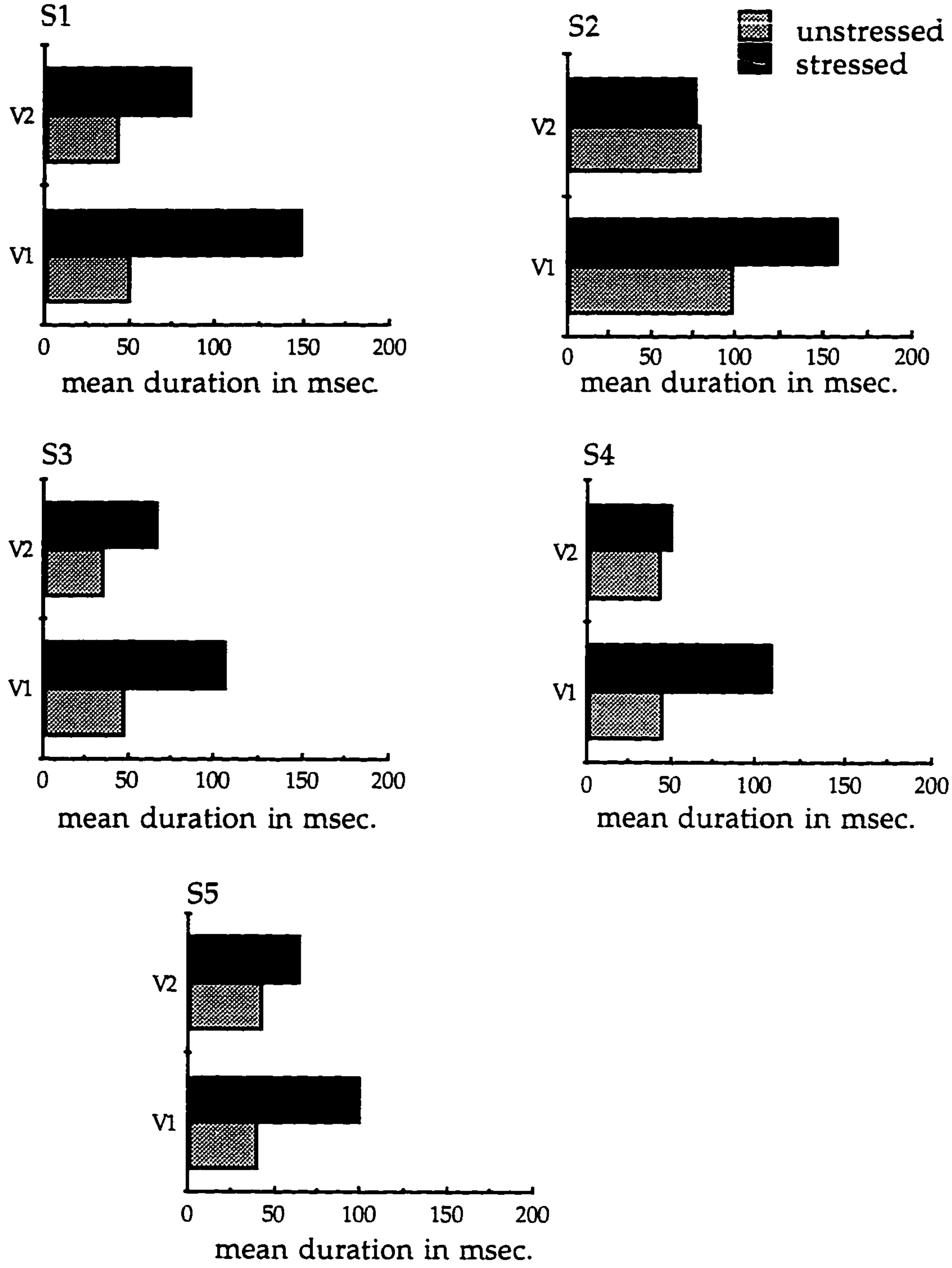
(89) **S1: stressed *kuʔ*^{u}*t*^{j}*u* 'to hoe, to plow'**

Bargraphs showing respective mean V1 and V2 durations in both contexts for all speakers are provided in (90) and (91). By comparing the dark bars representing V1 and V2 in a stressed couplet with the shaded bars representing V1 and V2 in an unstressed couplet, we see the correlation between length and stress; that is, under stress V1 is notably longer than V2.

(90) tʲɨβi graphs



(91) **kuʔᵘtʲu/kutʲu graphs**



Pooling the data and using an alpha-value of .01 for statistical rigor, a 2-tail paired t-test reveals the durational contrast between V1 and V2 to be significant under stress across all speakers (ρ = .0001):

(92) **Mean durations and t-test results in stressed context**

Couplet	V1	V2	Speaker
kuʔᵘʈʲu	150.2	87.2	S1
	159	77.4	S2
	107	68.6	S3
	110.2	52.6	S4
	100.6	64.6	S5
ʈʲɨβi	176.8	133.4	S1
	199.2	129	S2
	155.8	118	S3
	127.2	110.8	S4
	128.8	101.8	S5

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
9	47.14	7.32	.0001

By contrast, durational distinctions between V1 and V2 are not significant in the unstressed context (ρ = .0639):

(93) **Mean durations and t-test results in unstressed context**

Couplet	V1	V2	Speaker
kutʲu	52.4	45	S1
	99.8	80.6	S2
	49.6	37.2	S3
	46.4	44.2	S4
	40.6	43.2	S5
tʲɨβi	102.6	84.8	S1
	101	92	S2
	73.8	78.8	S3
	74.2	74.8	S4
	72.4	74.2	S5

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
9	5.8	2.112	.0639

The statistical results confirm the descriptive observation: relative length is an important acoustic correlate of stress in CM.[59] Returning to the

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[59] Not surprisingly, V1 is significantly longer in the stressed context than it is in the unstressed context (p = .0001). V2 is also longer when in a stressed couplet than in an unstressed couplet ((p = .0003). This is evident in the bargraphs above and is arguably attributable to the well known lengthening effect of voiced consonants on preceding vowels (see, for example, House and Fairbanks 1953, Peterson and Lehiste 1960, Delattre 1962, Keating 1984). Here the [β] of *βuru* follows V2 in the stressed context, while the voiceless [kʷ] of kʷ*ii* does so in the unstressed condition. Note also that in both stressed and unstressed contexts, V1 and V2 in *tʲɨβi* are generally longer than corresponding V1 and V2 in *kuʔᵘtʲu/kutʲu* in like contexts. This may be due to at least two factors. Specifically, the medial consonant of *tʲɨβi* is voiced and thus likely triggers a lengthening of the preceding vowel. Secondly, the medial consonant may also affect the length of the following vowel. As Fowler (1983) notes for English CV syllables, the duration of the vowel varies inversely with that of the preceding consonant. If this is the case for CM, the cross-linguistic tendency for voiced obstruents to be shorter than voiceless obstruents (Lisker 1957) may account for the generally longer duration of V2

relationship between glottalization and stress, this distinction under stress provides, I claim, an optimal context for the phonetic implementation of glottalization within the couplet. I now turn to the issue of why this should be the case.

3.6.1.2 Grounding stress and glottalization

Typologically, CM is what Silverman (1995) characterizes as a laryngeally complex language, i.e., a language in which non-modal phonation and contrastive tone cross-classify. The examples in (94) are taken from Pike and Small (1974).[60]

(94) **Cooccurrence of glottalization and lexical tone**

a) ndùʔ^{u}tsì	'beans'
b) kúʔ^{u}tsí	'pig'
c) ndàʔ^{a}βí	'poor'
d) kúʔ^{u}ʃì	'to bury'

---

in *tʲɨβi* as compared to V2 in *kuʔ^{u}tʲu/kutʲu*. However, potential confounds for this view are that labials tend to be of greater duration than alveolars and that we are comparing across manners of articulation, i.e. between a voiced fricative and a voiceless stop. I leave this last question open to further investigation. In any case, these facts do not obscure the highly regular and salient distinction within couplets between V1 and V2 duration under stress.

[60] I cite these forms with tone marked from Pike and Small because I have not yet systematically described the complex CM tone system from a phonetic perspective. I thus prefer to follow Pike and Small's transcription of tone. It is important to note, however, that tone is contrastive in CM, so all glottalized couplets also bear distinctive tone. The examples above provide cases in which glottalization surfaces with both the H and L tones. The reader is refered to Pike and Small (1974) for a description of the tone system.

Though the discussion of the issues is complex, one of Silverman's fundamental insights is that non-modal phonation (breathy and creaky voicing) can be acoustically and articulatorily antagonistic with distinctive tone. His claim is that languages with both lexical tone and non-modal phonation frequently sequence the phonetic implementation of these gestures so as to assure that the tone contrasts will be both best perceived and produced.[61] In looking at a variety of laryngeally complex languages, Silverman shows that one of the attested strategies is that of interrupted modal phonation, i.e. a modal-creaky-modal sequencing like that which we encounter in CM. Bearing this in mind, we can now better understand how the extra length of stressed vowels phonetically grounds glottalization: the relatively longer duration of stressed vowels provides a temporal window that is sufficiently and predictably wide enough to easily accommodate both the period of modal phonation used in implementing distinctive tone and the subsequent implementation of glottalization on the same vowel.

For its part, I claim that glottalization itself provides an additional and highly salient acoustic cue for stress. A conceivable argument against this hypothesis is that not all stressed vowels are glottalized (due, as I have shown above, to the effect of Ident(cg)). My position is not, however, that

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[61] Siverman's work is also interesting in light of the phonological discussion above in that the constraint Force(cg) has the effect of preserving contrastive glottalization. His work is similarly motivated by the desire to protect

glottalization is a necessary condition for stress. Rather, what is important is that it is a sufficient condition. That is, the presence of glottalization unambiguously indicates that the vowel is stressed. By contrast, the same cannot be said for length. For example, in considering the data in (92-93) above, we see that for S1 and S2, the mean durations of the unstressed /ɨ/ of *tʲ*ɨβ*i* are as long as the mean duration of the stressed /u/ of *kuʔᵘtʲu* for S5 and just slightly shorter than those of S3 and S4. This calls attention to the difficulty of assigning something like a minimum threshold duration (say, 100 msec.) for stressed vowels across different consonantal contexts and/or speakers and bolsters the observation above that relative length—-i.e. the relative durational difference between V1 and V2--is the more important cue for stress.[62] In this context, then, glottalization provides an additional acoustic cue for stress, even if it is the case that not all stressed vowels are glottalized. And in this sense, we can even view what appears to be a fairly arbitrary constraint, Force(cg), as means of utilizing glottalization as an additional means of signaling prominence, i.e. as a constraint which has the effect of guaranteeing that all stressed vowels will be glottalized, except if such glottalization would neutralize a lexical contrast.

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contrast, though in this case in the phonetics.

[62] See, for example, Nakatani et. al. (1981) for relative length in English as an acoustic property of stress, with word and phrase-final lengthening effects also contributing to vowel duration independent of stress.

Returning to the broader issue of the nature of the grounding of the constraint CG/STR, it seems clear that stress and glottalization have no *inherent* affinity. Rather, the particulars of the phonological system conspire to render stressed vowels an optimal location for the realization of [+cg], while concomitantly allowing [+cg] to contribute to the arsenal of acoustic cues available for marking prominence. At the same time, it is important to note that CG/STR is by no means ungrounded in the sense of Archangeli and Pulleyblank (1994a). That is, to invoke it as a constraints in the grammar is not equivalent to postulating phonetically antagonistic conditions such as IF [+HIGH] THEN [+LOW]; IF [+HIGH] THEN NOT [-LOW]. Rather, CM glottalization is interesting in that it extends the notion of grounding to a grayer area in which constraints may arise that, if not grounded in a direct articulatory or acoustic sense, are not ungrounded either--a situation which I have termed *opportunistic grounding.*

3.6.2 On the phonetic implementation of glottalized vowels

The final issue under examination in this chapter concerns the phonetic implementation of vowel glottalization. As I note in chapter 1, I assume that phonetic implementation involves a mapping between static phonological representations and their interpretation in time and space. I further assume that a part of this process can be characterized via the postulation of an abstract level of phonetic representation in which phonological features are assigned phonetic targets (cf. Pierrehumbert 1980, Keating 1988, 1990a,b, Shih 1988, Pierrehumbert and Beckman 1988, Huffman 1989, Cohn 1990, Laniran 1993, among others).[63] What makes CM glottalization most interesting in this regard is that the phenomenon is clearly phonological in nature[64] but nevertheless results in only the partial glottalization of target vowels. This adds to a growing body of evidence pointing to the complexity of evaluating what phonetic data tell us about phonological feature specification and, conversely, of predicting how phonological features will be realized in the phonetics.

3.6.2.1 Features and targets

The CM glottalization data raise particular problems for Cohn's (1990, 1993a) view of phonetic implementation. Working within a target and interpolation model (cf. Pierrehumbert 1980, Keating 1988), Cohn contends that phonetic data will reflect the ternary possibilities of binary feature specification. Positively and negatively specified features will be implemented throughout the entirety of the segment for which they are specified, while unspecified features receive their phonetic value from their segmental context; i.e. they will be assigned no phonetic target. Cohn argues that

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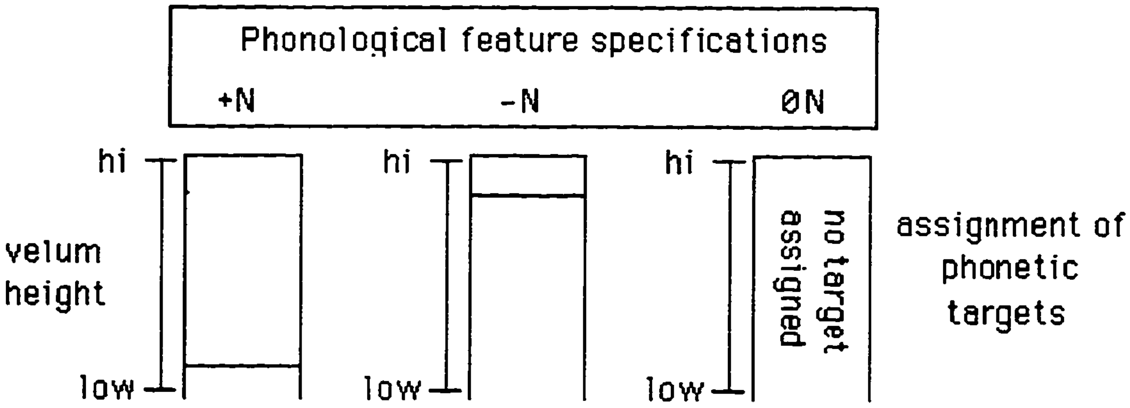
[63] See Ohala (1990) for an opposing view. See also Browman and Goldstein's articulatory phonology (1986, 1989) for an alternative, task dynamics approach to phonetic implementation.

[64] I make the assumption that contrastiveness, at least, is a property of phonology.

phonetic data can thus provide a diagnostic for determining whether or not a feature is phonologically specified. Taking Cohn's example of [+/-nasal], these three possibilities are exemplified in (95). Here, a [+nasal] specification is interpreted as an instruction for a low velum target, a [-nasal] feature makes for a raised velum target, and unspecified [nasal] is characterized by the absence of a target for velum position.[65]

(95) **Targets** (Cohn 1990, 1993a)



A similar view emerges from Keating's (1990b) windows model. Rather than assigning precise acoustic or articulatory targets, however,

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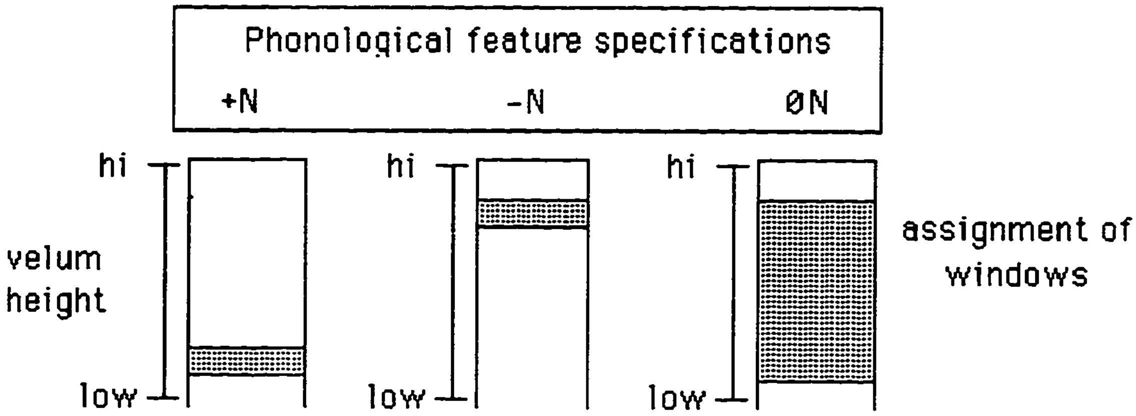
[65] Cohn (1990, 1993a) does countenance some partial implementation as phonological, but only by allowing for nasality or orality to be expressed on the closure or release phases of plosives (cf. Keating 1990a, Steriade 1993). In this way, the decomposition of these segments into aperture phases allows for the full implementation of the feature throughout the entirety of the duration of the aperture phase. However, no such phases are available for vowels. Note also that the logical possibilities are reduced for monovalent features, though Cohn limits her discussion to nasality and assumes a binary [+/- nasal] feature.

Keating views targets as ranges of possible values along a given phonetic dimension.[66] In simple terms, a narrow window corresponds to a specified feature/value pair, while a broad window corresponds to a lack of phonological specification. This is schematized in (96) for [+/-nasal], in which windows are shaded for easy identification:

(96) **Windows** (Keating 1990b)



An advantage of this model over Cohn's is that variation is hard-wired into the assignment of targets, at least in the spatial domain. More importantly for our purposes here, it is also different in that Keating explicitly leaves open the question of whether windows have variable durations, though in the cases she discusses, windows are invariably constructed throughout entire segments. In the discussion which follows, I address the issue of timing. Adopting a windows-based approach, I propose that glottalization is

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[66] The width of a window is derived empirically by observing the range of phonetic values that a feature exhibits for a segment or class of segments in all contexts.

implemented by locating a window for glottal constriction whose onset lies at the midpoint of vowels that are phonologically specified for [+cg].

3.6.2.2 Implementing [+cg] in CM: the basic analysis

There are at least two obvious ways in which time can be introduced into the construction of windows. One of these involves the incorporation of real time into the phonetic representation, while the other involves the incorporation of the relative timing of particular windows. My comments here will be limited to the latter issue. This is due in large measure to practical concerns. At this point, the addition of real time would introduce an extraordinarily complex variable into what is still only incipient knowledge of how phonological features are interpreted phonetically.[67] As I note above, I thus follow Pierrehumbert (1980), Keating (1988, 1990a,b), Shih (1988), Pierrehumbert and Beckman (1988), Huffman (1989, 1993), Cohn (1990, 1993a), and Laniran (1993), among others, in assuming a level of phonetic representation in which phonological features are interpreted via the assignment of targets at an abstract level of phonetic representation.

Building on the analysis in §3.4, I assume that glottalized vowels are specified for [+cg] at the output of the phonology as in (97):

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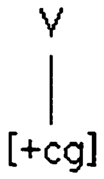
[67] Note, for example, that even Browman and Goldstein's (1986, 1989) task dynamics based gestural scores abstract away from real time. See, however, van Gelder and Port (1994a,b) for arguments against abstracting away from from time.

(97)



Following the model of Keating (1990b), a window for glottal constriction is constructed for the vowel. The narrowness of the window reflects the phonological [+cg] specification, and, importantly here, its temporal placement captures the phasing of creaky phonation.[68]

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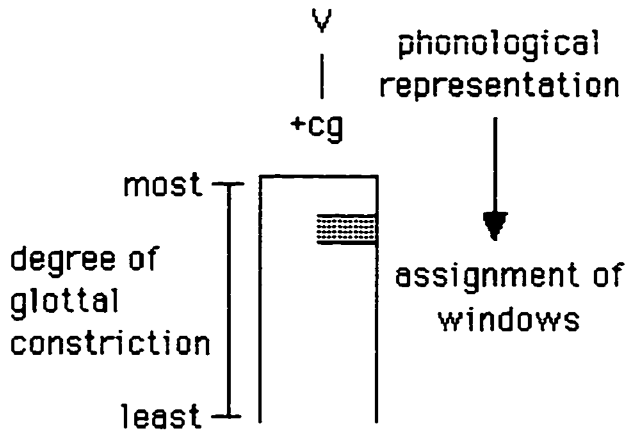
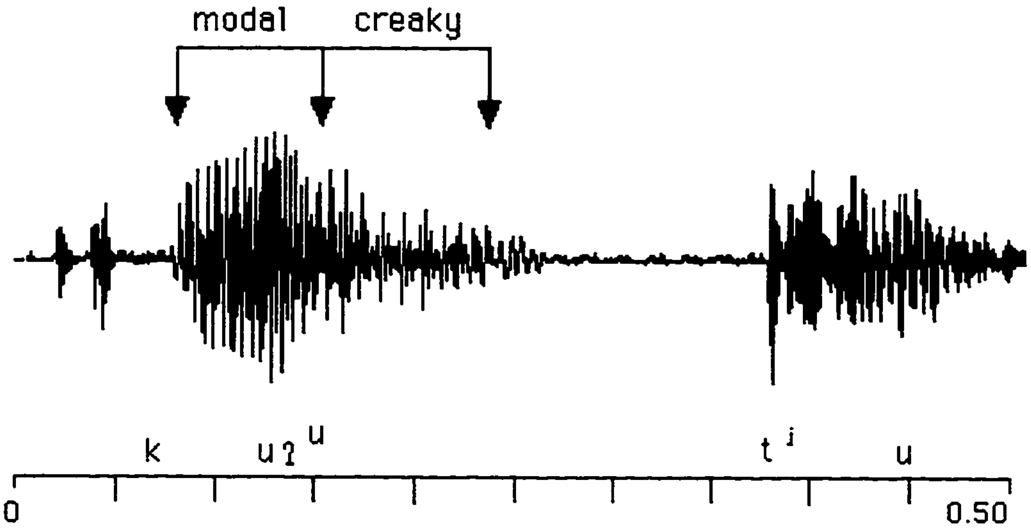
[68] As I note in §3.2 above, the determination of the precise articulatory mechanism or mechanisms behind creaky phonation is a matter of debate (cf. Catford 1964, 1977, Ladefoged 1993a, Laver 1980, 1994, Henton and Bladon 1988, Ladefoged and Maddieson 1996 for discussion). I adopt a continuum of degree of glottal stricture here as a convenient and direct phonetic translation of the articulatory feature [constricted glottis] adopted in the phonological analysis. The location of the narrow window within this continuum is somewhat arbitrary, though intuitively clear. More precision must derive from further phyisological investigation of creaky phonation.

(98)



This representation, I claim, provides the first step in arriving at the abstract phonetic input for the sequencing of modal and creaky phonation that we find under glottalization, as seen in (99).

(99) **S1: kuʔ^{u}t^{j}u 'to hoe, to plow'**



With this basic view in mind, I turn in §3.6.3 to questions raised by and implications of the analysis.

3.6.3 Remaining questions and broader implications

The approach in §3.6.2.2 raises a number of non-trivial questions regarding phonetic implementation. In this section, I consider four separable though related issues. First, in §3.6.3.1 I address both the assumptions behind and the consequences of constructing windows throughout half of a segment. In §3.6.3.2, I examine why I have chosen to represent the phonetic sequencing of glottalization in terms of a phonetic and not a phonological representation. In §3.6.3.3, I discuss the problem of variability in the actual sequencing of glottalization, particularly with respect to whether or not modal phonation is resumed after the period of creaky voicing. Finally, in §3.6.3.4, I explore the implications of my analysis for the question of how (or whether) phonetic data serve as a diagnostic for phonological feature specification.

3.6.3.1 On window construction and segmenthood

One basic assumption, shared with the researchers cited above, is that some notion of the segment perseveres in a useful fashion into phonetic representation, despite the well known encoded nature of speech (Liberman et. al. 1967).[69] Though an idealization, this captures the intuition that, despite

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[69] Even less segmental feature geometric representations have an organizing tier corresponding roughly to the notion of segment or timing slot, whether it

encoding, there persists nevertheless an acoustic integrity for sounds[70] and, for the case at hand, concomitantly provides reference points for the temporal alignment of glottalization within the affected vowel. A remaining question, though, is how we are able to temporally locate a window segment-internally; i.e. how window construction accesses the internal structure of a segment.

At the same time, a related question is how modal phonation is encoded in the phonetic representation in (99). Although the representation provides a clear view of where glottalization is initiated, it says nothing about the phonetic instruction for voicing during the first half of the vowel. In fact, following the logic of Keating (1990b), the lack of a window for modal voicing suggests that phonetic targets for voicing should be interpolated throughout this unspecified span. It seems clear, however, that voicing is more precisely sequenced between periods of modal and creaky voicing (i.e. glottalization), in a manner corresponding more closely to the representation in (100).

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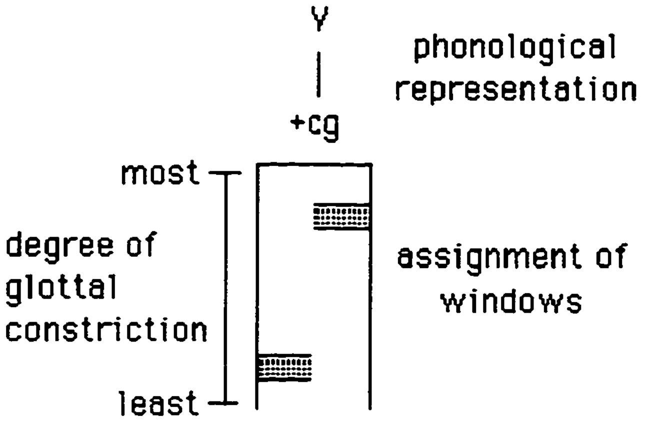
be a C/V (McCarthy 1979, Halle and Vergnaud 1980, Clements and Keyser 1983), X (Levin 1985) or root node (Archangeli and Pulleyblank 1994a).

[70] See Ohala (1992) for a defense of the segment. See, also, Bell-Berti and Harris (1981) who argue for separate acoustic and articulatory periods in their model of co-production. Though they view phonetic representation from a distinct perspective, their assumption of an acoustic period constitutes an implicit recognition of segmental integrity.

(100) **Two windows for degree of glottal constriction**

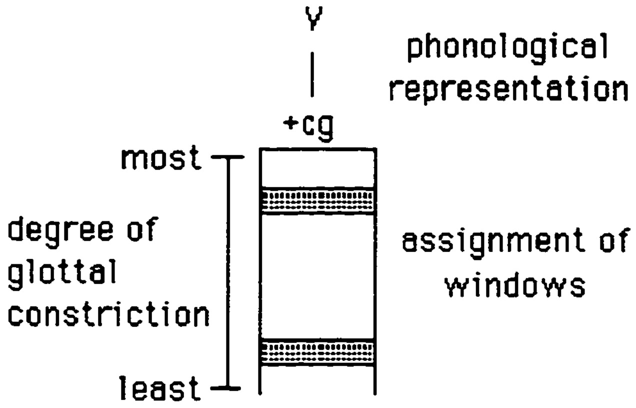


Taken together, these two issues raise the question of how a single [+constricted glottis] specification should trigger the phonetic construction of temporally sequenced windows, one for modal and the other for creaky phonation. I claim that an answer, as Keating (1990b) points out, lies in the fact that the relationship between phonological feature specification and window assignment is complex. First, windows do not stand in a one-to-one relationship with phonological features. Rather, single phonological features may contribute to the shape of various windows. This is clear when we consider, for example, the multiple phonetic correlates of a feature such as [+/- voice], which include F0 excursions in following vowels, length distinctions on preceding vowels, VOT differences, and the presence or absence of acoustic energy during closure (see, for example, discussion in Keating 1984, Kingston and Diehl 1994). In this case, one phonological feature value is simultaneously interpreted along multiple phonetic dimensions; i.e. it contributes to the shape of a number of different windows.

Likewise, more than one phonological feature may contribute to the shape of a window along a single phonetic dimension. For CM glottal constriction, I claim that this is exactly what happens. In particular, recall from above that CM is a language with distinctive tone. As I have noted, Silverman (1995) provides solid acoustic motivation for why such laryngeally complex languages often resort to sequencing strategies: they seek to optimally implement both lexical tone contrasts and non-modal phonation. Relevant here is the assumption that the production of lexical tone exploits a fundamental frequency range whose floor and ceiling fall within the scope of modal voicing. More to the point, lexical tone, whether high or low, contributes a window for a relative lack of glottal constriction.

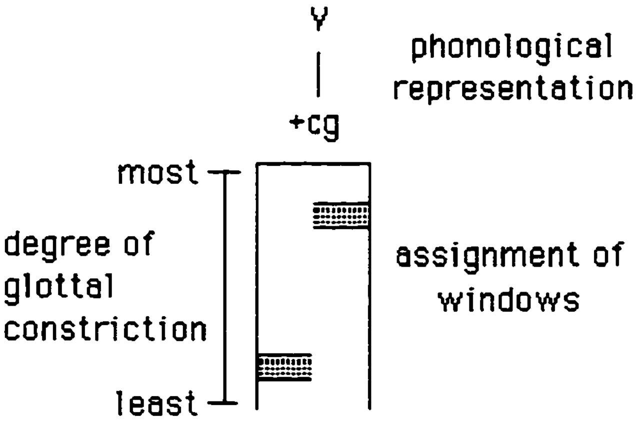
Let us assume, then, that both [+cg] and lexical tone were to contribute windows for glottal constriction throughout the duration of a vowel. What emerges is a phonetic representation, such as the one in (101).

(101) **Conflicting windows**



What we see is that the two windows stand in conflict: at any point in time the phonetic representation will provide contradictory instructions with respect to glottal constriction. By contrast, if the phonetics can split the vowel into temporally ordered windows for glottal constriction, both the phonetic requirements of tone and glottalization can be satisfied in a kind of phonetic trade-off: neither feature is implemented throughout the duration of the vowel, but at the same time, neither is sacrificed. This yields a representation such as the one in (100) above, here repeated for convenience.

(102)



Again, as I have argued above, the phonological relationship between glottalization and stress provides a phonetically optimal context for sequencing. Under stress, the sequencing of modal and creaky phonation can be systematically realized with the least precision, given that stressed vowels are systematically longer than their unstressed counterparts.[71]

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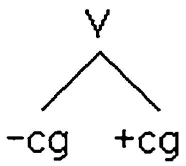
[71] Note that the general approach here bears more than a passing resemblance to Huffman's (1989, 1993) notion of landmarks for window construction. Focusing on nasalization data, Huffman proposes that for [+continuant] sounds such as fricatives and vowels, there is one landmark corresponding roughly to the acoustic peak of the segment notion of landmarks for window construction. For vowels, landmarks are assumed to be located at the center. Such landmarks could be incorporated in this analysis as offset and onset points for modal and creaky phonation, respectively. However, this approach differs from Huffman's in that it shares with Cohn the use of the segment edge as a boundary for window construction. For Huffman, windows are constructed from landmark to landmark.

3.6.3.2 Sequencing: phonology or phonetics?

An alternative approach to the one above is to assume that sequencing is phonological rather than phonetic, i.e., the result of a phonologically specified sequence of [-cg] and [+cg], as in (103):

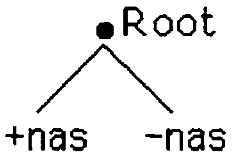
(103)



In this way, the phonology itself would provide instructions for the sequencing of the two phonation types. This possibility actually raises two closely related issues. The first and more immediate, of course, regards the specific issue of how the phonetic implementation of glottalization is better encoded in the grammar of CM. The second involves the broader issue of the division of labor between phonetics and phonology, especially as regards the segment internal sequencing of distinctive features.

Much depends here upon how we view the role of phonology and phonological representations. Implicit in the adoption of a representation such as the one in (103) is the view that the surface sequencing of modal and creaky phonation should be derived from a phonological instruction. This is essentially the view in which contour segments, such as prenasalized stops, are treated as sequences of [+nasal]-[-nasal] (cf. Sagey 1986), as in (104).

(104)



Nevertheless, there is no evidence that such representations are phonologically necessary or that phonological theory has ever explicitly articulated a clear vision of how much intrasegmental sequencing is to be encoded by phonological representations. For the case of nasal contour segments, for example, Steriade (1993) forcefully rejects representations such as (104) and provides arguments for limiting the phonological encoding of segmental contours to the number of aperture positions that a segment has. Steriade's claim is that the phonological representation of contours should be limited to segments containing closure and release phases, each of which can be associated (or not associated) to a feature such as [nasal].[72] Vowels and continuant consonants, she argues, have only one aperture phase; i.e., unlike

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[72] See also Keating (1990a), who adopts this view, citing an earlier version of work on this matter by Steriade.

non-continuants they are not characterized by distinct closure and release phases and thus do not structurally encode contours.

The particulars of Steriade's claims notwithstanding, it is clear from the phonological literature that there exists no consensus as to whether the overall characterization of intrasegmental sequencing need emerge from phonological representations themselves. Thus, Piggott (1992) proposes a representation in which prenasalized stops are represented by locating [+nasal] as a dependent of a single [SV] (sonorant) node, with no reference in the phonological representation to the fact that nasality is to be phonetically realized on the closure phase of the stop.[73] Similarly, geometries such as those of Hume (1992) and Clements and Hume (1995) represent secondary features such as palatalization via the presence of a V-place feature on a segment whose primary place is a dependent of a C-place node. Yet, the temporal ordering of the gestures does not emerge from the representation itself.[74] Even Steriade's own more phonetically-based decomposition of root nodes into aperture positions leaves no direct phonetic encoding of sequencing in segments such as palatalized liquids or fricatives, since such segments, by definition, have only one aperture position to which features are anchored.

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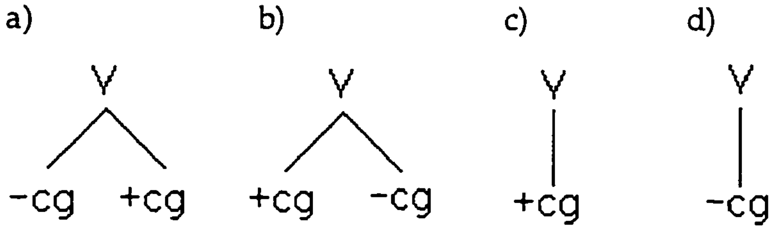
[73] In fact, for Piggott, this same representation in another language can represent a full nasal stop, and a bare SV node can represent a prenasalized stop, thus providing an extreme case of phonological representations that do not directly or unambiguously encode sequencing information.

[74] Sagey (1986) also makes this point in her treatment of complex segments.

For both the particular case of sequencing in CM and the broader issue of sequencing, I suggest that a good place to begin to articulate an argument against representations such as (103) lies in the predictions they make, especially as regards the possibility of contrast.[75] In particular, the availability of representations such as (103) predicts that we might expect to find at least four logical possibilities, all potentially contrastive in a given language, as in (105).

(105) **Potential contrasts**



What Silverman (1995) notes in his cross-linguistic typology, however, is a different situation. In languages that are not laryngeally complex (i.e., in which contrastive tone and non-modal phonation do not cross-classify), non-modal phonation is not sequenced within vowels. Yet, given the logical possibilities in (105) there is no a priori reason to exclude contrasts such as (a) and (b) in such languages. In fact, sequencing possibilities such as (a) and (b) appear to emerge only in languages with cross-classification of tone and non-

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[75] As I have noted above, I assume that the expression of contrast lies within the purview of phonology.

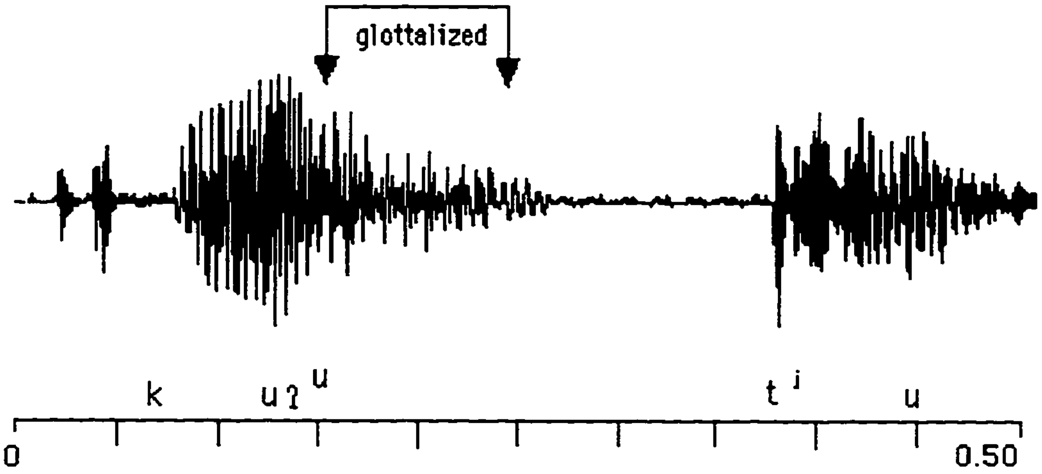
modal phonation. Nevertheless, I know of no cases in which sequencing contrasts such as those in (a) and (b) are distinctive within even a laryngeally complex language. This makes sense, given the phonetic discussion above for CM, in which the contribution of contrastive tone to the window for glottal constriction conflicts with that of the specified [+cg] feature and in which phonetic window assignment, not phonological representation, sequences the gestures so as to optimally express both tone contrasts and vowel glottalization.

This view entails a "smart" phonetics. I suggest that there are, in fact, good reasons to believe that this is the case. From a phonological perspective, I have just shown above that in many models of phonological representation, phonetic implementation must involve intrasegmental sequencing that is not explicitly encoded by the phonology. From a phonetic perspective, however, there is also evidence that phonetics is sensitive to phonology in a systemic way; i.e. that phonetic implementation involves complex, language particular knowledge. To cite a clear example, Manuel and Krakow (1984) and Manuel (1987) show that vowel to vowel coarticulation is more pronounced in a language with a sparse vowel system than in one with more vowel contrasts. That is, coarticulation is constrained to some degree by the inventory of systemic phonological contrasts. For the CM case, and for such phonetic sequencing in general, a smart phonetics means a phonetics capable of sequencing gestures so as to respond to phonological pressures such as the expression of both contrastive tone and glottalization, while at the same time avoiding the phonetic antagonism between them.

3.6.3.3 Variability

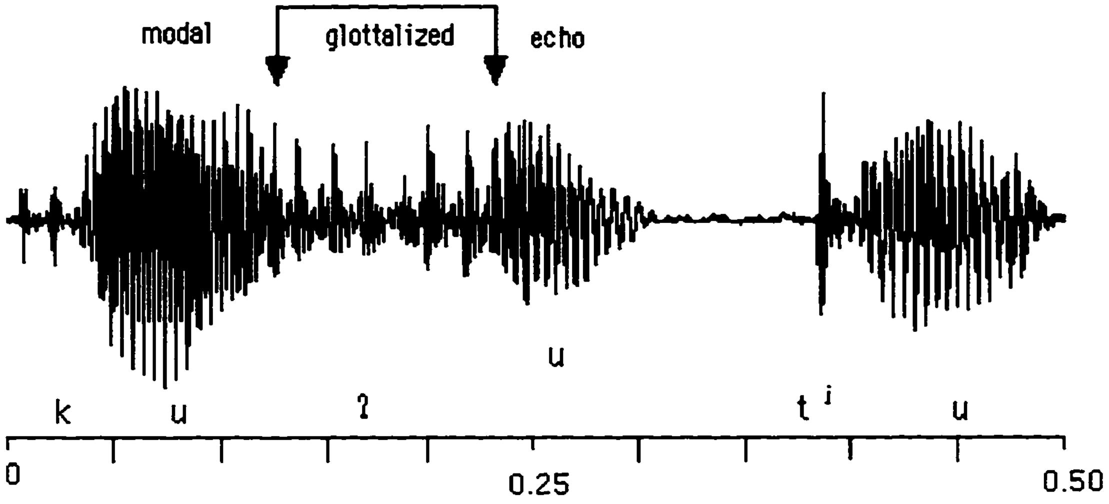
One more issue regarding the implementation of [+cg] merits consideration. As I note in §3.2 above, there is some variability with respect to the resumption of modal phonation after the period of glottalization in forms with a medial consonant. Thus, we find cases such as (6) above, here repeated as (106) for convenience, in which there is no clear resumption of modal activity.

(106) **S1: no clear echo vowel**



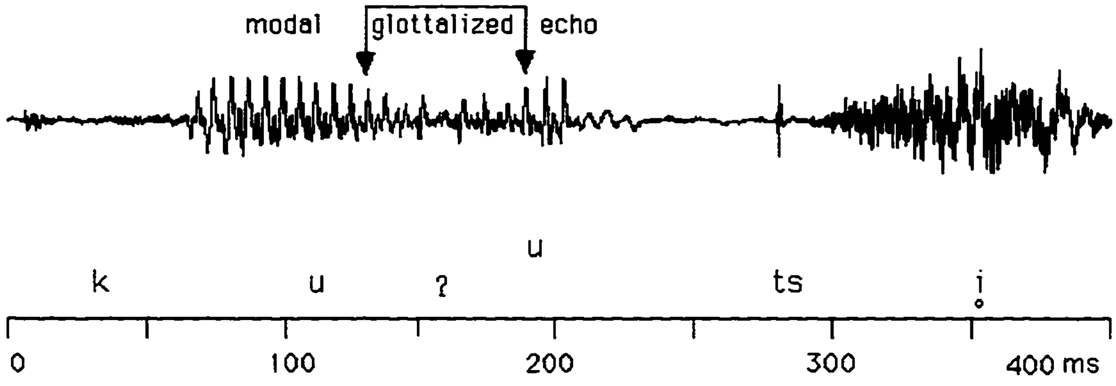
We find cases such as (5) above, in which there is a pronounced period of resumed modal phonation, here repeated as (107).

(107) **S2: echo vowel clear in the waveform**



And we find cases such as (8) above, here repeated as (108), in which the resumption of modal phonation is minimal in duration, comprising two or three glottal pulses.

(108) **S4: visible sequencing**



Clearly, the gross collocation of sequenced windows for glottal constriction within a vowel is an idealization that does not directly encode this finely grained range of variation.

In a broad sense, this is not altogether unexpected in that the analysis here assumes an idealized level of phonetic window assignment that does not constitute a representation of any particular acoustic/articulatory event. I suggest, however, that at least part of this variability is attributable to the transition between the vowel and the following consonant. Since neither voiced nor voiceless consonants are glottalized in CM, I assume, following Keating (1990a), that their phonetic implementation entails the construction of a window for little glottal constriction, thus creating a segmental context such as that in (109), in which the constricted glottis gesture is located between two non-constricted windows.[76]

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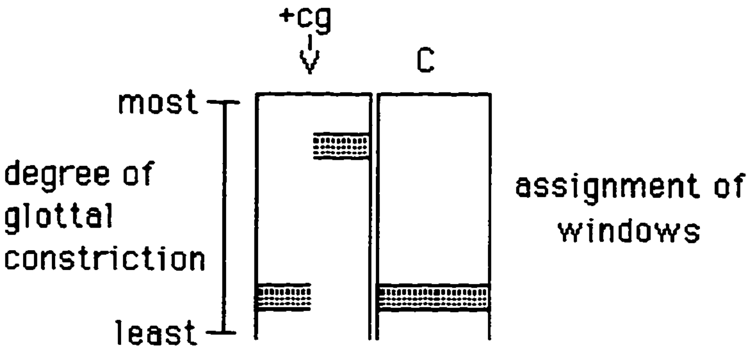
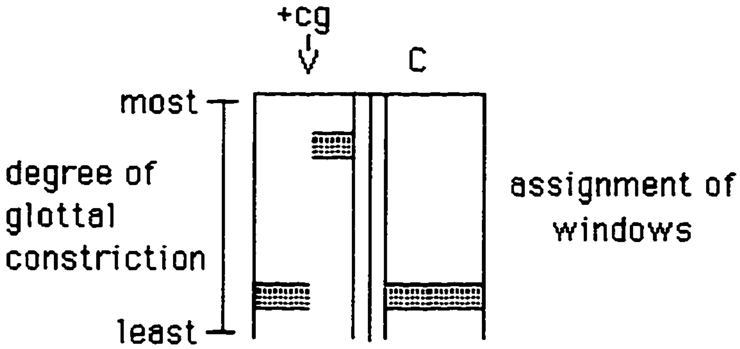
[76] Keating takes [-constricted glottis] to be the neutral or unmarked specification for consonants.

(109)



As the representation indicates, speakers must rapidly achieve different phonetic targets for glottal constriction both within and across segments. One way of encoding this is in terms of transitions and priority statements (Cohn 1990). Under this approach, transitions between segments are characterized in terms of brief 20-30 millisecond periods at segment edges, to account for periods of articulatory change and overlap. This is as pictured in (110), where transitions are supplied for the right edge of the vowel and the left edge of the following consonant.

(110) **Transitions**



Additionally, priority statements are invoked to account for the dominance of one segment edge over the other along a particular phonetic dimension.[77] If, for glottal constriction, we hypothesize that C takes priority over V, we produce a situation such as that in (111), in which part of the glottalized vowel may be realized with a brief period of resumed modal phonation, corresponding to the rapid interpolation between the two target windows (cf. Pierrehumbert 1980, Keating 1988, 1990b, Cohn 1990, 1993a, Huffman 1989, 1993).

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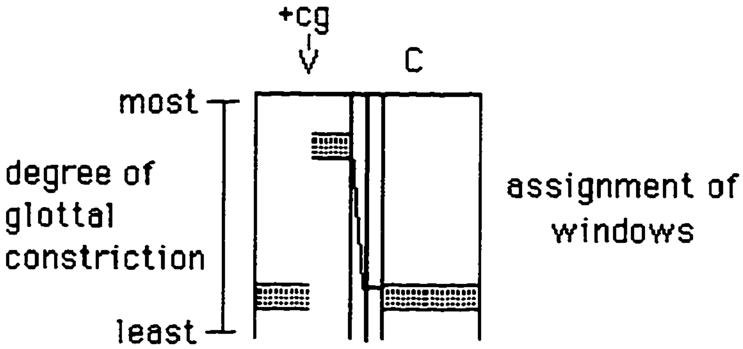
[77] That is, there is no evidence that the edge of one segment will dominate that of the other across the range of phonetic targets it implements.

(111) **priority: C > V for glottal constriction**



This general approach brings us closer to the type of variability that we find, with two caveats. First, the notion of priority must be weaker than the simple statement in (111) indicates, allowing for cases such as (106) in which there is no visible resumption of modal phonation. Secondly, we must recognize that exaggeratedly precise articulation may underlie the long period of resumed modal phonation in examples such as (107); i.e., in such cases speakers may be exaggerating the effect of the priority statement, perhaps by extending the duration of the transitional domain.[78]

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[78] There are, of course, many other variables that we are not considering here, including speaking rate, register, speaker specific priority statements, etc. Also, I assume that there must be a similar transition between the modal and creaky sequences internal to the vowel. Variation in this case will result in a relatively earlier or later onset of glottalization.

3.6.3.4 Phonetic data and their relation to phonological information

In this section, I briefly turn to the question of what the CM facts tell us about the relationship between phonetic data and phonological feature specification. I began in §3.6.2.1 by suggesting that the data are problematic for Cohn's (1990, 1993a) claims that the phonetic target for a phonological feature will be implemented throughout the duration of the segment. Cohn's claim is attractive in that it provides a fairly straightforward means of interpreting phonetic data--as they reflect phonological specification. Yet, in CM we find a phonologically contrastive feature ([+cg]) that is systematically realized throughout only a *part* of the vowel for which it is specified, corresponding to what Cohn might term a gradient, phonetic effect.[79]

Put simply, what this means is that the relationship between phonetic data and phonological specification is a more complex affair. This finding is in line with a diverse range of researchers, such as Boyce, Krakow, and Bell-Berti (1991), Huffman (1989, 1993), and Fowler (1990), who call attention in various ways to the non-triviality of intuiting phonological information from phonetic data. In particular, for CM I claim that knowledge of the phonological system of the language is necessary for understanding how and why glottalization is sequenced. At the same time, a smart phonetics is required, i.e. a phonetics that is capable of resolving phonetic conflicts via the

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[79] Note that this problem is independent of the particular approach to windows assignment that I adopt in the above analysis.

segment internal sequencing of distinct phonetic windows along a single dimension. In this sense, it seems clear that phonetic data alone will not always suffice to unambiguously reflect phonological feature specification.

3.7 Conclusions

In this chapter, I have taken a long, detailed look at the phonology and phonetics of glottalization in CM. I have provided a basic phonetic description of the phenomena and advanced both phonetic and phonological arguments in favor of viewing glottalization as a feature of vowels, rather than as a consonant in its own right. I then provide an Optimality Theoretic treatment of the issue, arguing that elegant and unified account of both predictable and contrastive glottalization emerges when the problem is viewed in terms of the interaction of three constraints. One of these, CG/STR, limits glottalization to stressed syllables only. Another, Force(cg), requires the class of couplets in the language for which glottalization is non-contrastive to surface with a glottalized vowel. The third, Ident(cg), militates for the preservation of input values for the feature [constricted glottis], thus allowing us to encode the lexically contrastive status of glottalization in the grammar. In the discussion of the phonology, I also argue that a correspondence based approach to phonological systems motivates a radically different approach to the notion of underlying representation. I focus on two points: 1) that the optimality theoretic notion of input is not the equivalent of a traditional underlying representation, and 2) that the uniqueness of the traditional UR can be expressed in terms of sets of optimal inputs.

In the last part of the chapter, I discuss the interface of phonology and phonetics as it pertains to glottalization. Here, I focus on two issues. First, I discuss the concept of the phonetic grounding (Archangeli and Pulleyblank 1994a) of phonological feature cooccurrence constraints. I motivate what I have termed the *opportunistic grounding* of CG/STR, showing that phonetic motivation need not involve only implicational relations favoring the cooccurrence of articulatorily sympathetic features. As the same time, I adhere to Archangeli and Pulleyblank's claim that such implicational relations will not require the cooccurrence of articulatorily antagonistic features.

Finally, I discuss the complex issue of how [+constricted glottis] is phonetically implemented in CM. Here, I adopt the Windows model of Keating (1990b), but I argue that the implementation of CM glottalization requires the temporal alignment of conflicting windows for degree of glottal constriction within target vowels. Additionally, I argue that data such as these obscure the more straightforward relation that Cohn (1990, 1993a) attempts to establish between phonetic data and phonological feature specification, concluding that phonetic data must be interpreted in conjunction with a knowledge of the phonological system at hand.

CHAPTER 4 NASALIZATION

4 Introduction

Coatzospan Mixtec is best known in the phonological literature for the regressive nasal harmony system by which it marks the second person familiar, a problem which has given rise to a number of analyses that have focused on how to best characterize the blocking effect of some but not all consonants (cf. Poser 1980, Cole 1987, Trigo 1988, Piggott 1989,1992, Gerfen 1992, 1994, Homer 1995). In addition to morphological harmony, however, CM contains two other sources of vowel nasalization: 1) there are contrastively nasal vowels, and 2) vowels are predictably nasalized following nasal consonants. To this point, no one has offered a comprehensive account of the entire range of nasalization facts in CM.

This chapter seeks to remedy the situation. As with glottalization in Chapter 3, I provide a detailed consideration of both the phonetics and phonology of nasalization in the language. In so doing, my goals are threefold. First, I provide phonetic data in the form of nasal airflow traces in order to offer for the first time a degree of descriptive precision unavailable to impressionistic transcription. Secondly, these data serve as the concrete underpinnings of a single, unified Optimality Theoretic (Prince and Smolensky 1993, McCarthy and Prince 1993b) phonological analysis of the range of CM nasalization facts. Finally, the data inform the discussion of the phonetics/phonology interface, especially as it regards the relationship between physiological data and phonological feature specification.

The chapter is organized in the following manner. In §4.1, I provide a basic description of the nasalization facts, presenting data sets and illustrative nasal flow data. §4.2 offers a phonological analysis in which the three varieties of nasalization are accounted for within the context of a partially ranked set of Optimality Theoretic constraints. In §4.3, I discuss the implications of CM nasalization for the interface of phonetics and phonology. Specifically, I discuss the role of phonetic grounding (Archangeli and Pulleyblank 1994a) in the phonological analysis, and, as I have noted, the relevance of the CM flow data to claims regarding the relationship between phonetic implementation and phonological feature specification (cf. Keating 1990b, Huffman 1989, 1993, Cohn 1990, 1993a). In §4.5, I present my conclusions.

4.1 The basic facts: 3 varieties of nasalization

As I mention briefly in the phonological sketch in Chapter 2, there are three distinct sources of vowel nasalization in CM: 1) the contextual nasalization of vowels following (but not preceding) a full nasal stop; 2) lexical vowel nasalization, i.e. vowels whose nasal quality cannot be attributed to assimilation from an adjacent nasal consonant; and 3) the morphologically conditioned phenomenon of regressive vowel nasalization that marks the second person familiar. In this section, I provide an explicit characterization of the properties of each that will serve as a basis for the subsequent phonological analysis and for later consideration of the interface of the phonetics and phonology of nasalization. I begin in §4.1.1 with contextual nasalization. In §4.1.2, I describe the realization and distribution of contrastively nasalized vowels, and in §4.1.3 I characterize the process of regressive nasal harmony that marks the second person familiar (2-FAM).

4.1.1 Contextual nasalization

Pike and Small (1974) first reported that CM vowels are predictably nasalized following, but not preceding, full nasal stops, as in the form *kun*ũ 'to run'. (In contexts in which both consonants of a couplet are nasal stops, both vowels are nasalized.) Data illustrating the phenomenon are presented in (1-3) below.

(1) **Perseveratory nasalization in NV(ʔ)V couplets**

a) nãã	'altar'	e) nãʔã	'boy'
b) ɲɨ̃ɨ̃	'hat'	f) nũʔũ	'tooth'
c) nɨ̃ɨ̃	'completely, all'	g) nẽʔẽ	'crippled'
d) nũũ	'in front of'	h) ɲĩʔĩ	'to scratch'

(2) **Asymmetry: no anticipatory nasalization in (C)V(ʔ)NV couplets**

a) βinĩ	'mean, petty'	f) kaʔ$^{\tilde{a}}$mĩ	'to burn'
b) kinĩ	'to listen'	g) kiʔ^{i}nĩ	'to tie down'
c) tanã	'to collapse'	h) taʔ^{a}nũ	'girl, woman'
d)kunũ	'to run'	i) taʔ^{a}nĩ	'to smell'
e) inĩ	'in'	j) iʔ^{i}nĩ	'hot'

(3) **Both vowels are nasalized in NV(ʔ)NV couplets**

a)mĩnĩ	'lake'	e) mẽʔ$^{\tilde{e}}$ɲũ	'in front of'
b) nĩɲũ	'night'	f) nãʔ$^{\tilde{a}}$nũ	'big'
c) nãnã	'aunt'	g) ɲẽʔ$^{\tilde{e}}$ɲũ	'cowlick'
d) nĩnũ	'up'	h) nĩʔ$^{\tilde{\imath}}$nĩ	'be inside of'

The asymmetry in (2) is striking in light of commonly held assumptions regarding the coarticulatory effects of nasality on vowels when adjacent to nasal consonants. Note, for example, Beddor's (1993) observation that vowels are almost universally allophonically nasalized in the context of a nasal consonant. Additionally, it has often been assumed (cf. Moll 1962, Ohala 1971) that anticipatory effects of coarticulation are stronger than perseveratory effects. However, Pike and Small's original description suggests that there is a clear lack of anticipatory vowel nasalization in CM, especially as compared to the perseveratory context.[1]

One question that thus arises is whether the perceived asymmetry is actually corroborated by phonetic data. As Cohn (1990, 1993a) points out in her study of contextual vowel nasalization in American English (AE), impressionistic claims about perceived degrees of nasalization may not hold up under close scrutiny. Cohn addresses the claim that AE anticipatory vowel nasalization is stronger than perseveratory nasalization and that only the former constitutes a phonological rule of the language. In some conditions, at least, Cohn's English data exhibit the same pattern of vowel nasalization both preceding and following a nasal consonant and, thus, do not support the claim that the effects of anticipatory nasalization are systematically greater than those of perseveratory nasalization.

As I discuss in chapter 1, like Cohn (1990, 1993a) and Huffman (1989, 1993), I use nasal airflow data as an indirect means of monitoring velum activity, under the assumption that the articulatory dimension of velum height and the phonological feature [nasal] stand in a fairly direct relationship. In simple terms, a lowered velum implements nasality, while a raised velum implements a phonological instruction for orality. All else being equal, we thus expect to find increased airflow as the velum is lowered

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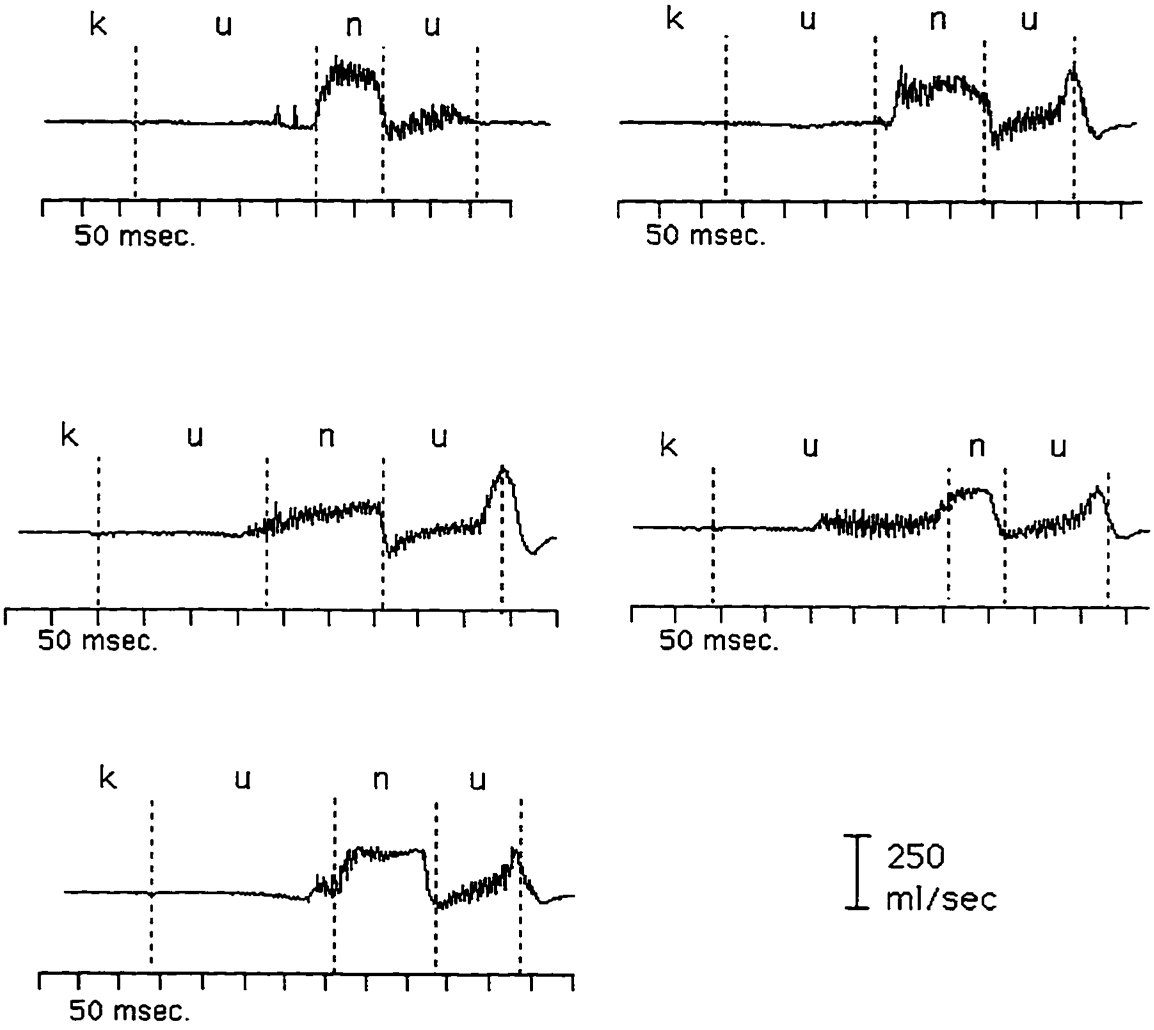
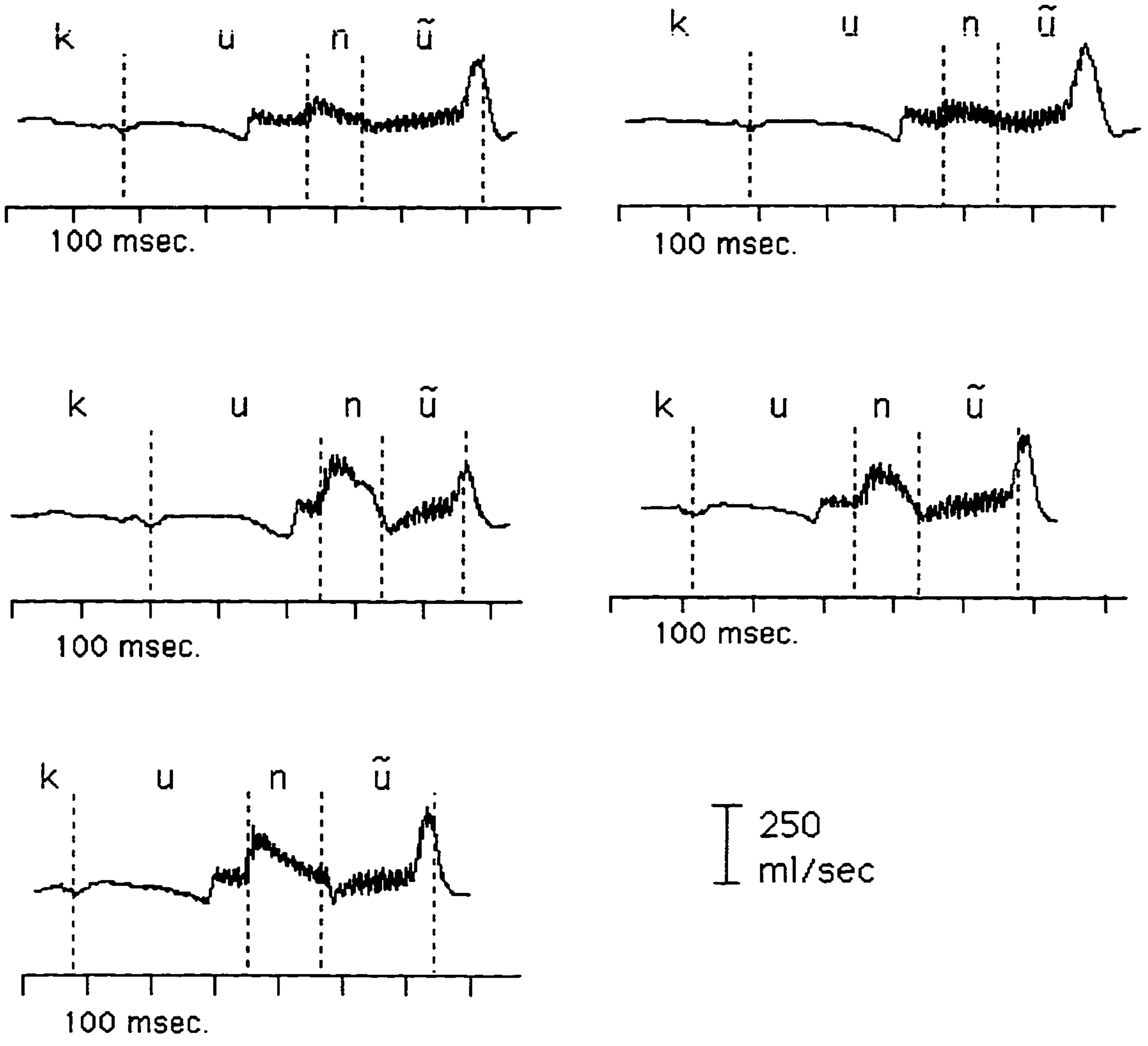
[1] The nasalization of the initial vowels in data in (3) can be attributed to the perseveration of nasality from the preceding nasal consonant.

and decreased flow as the velum is raised. Interestingly, the flow data corroborate Pike and Small's original claim, as can be seen, for example, in the tokens in (4-6) for S1, S2, and S3, respectively.

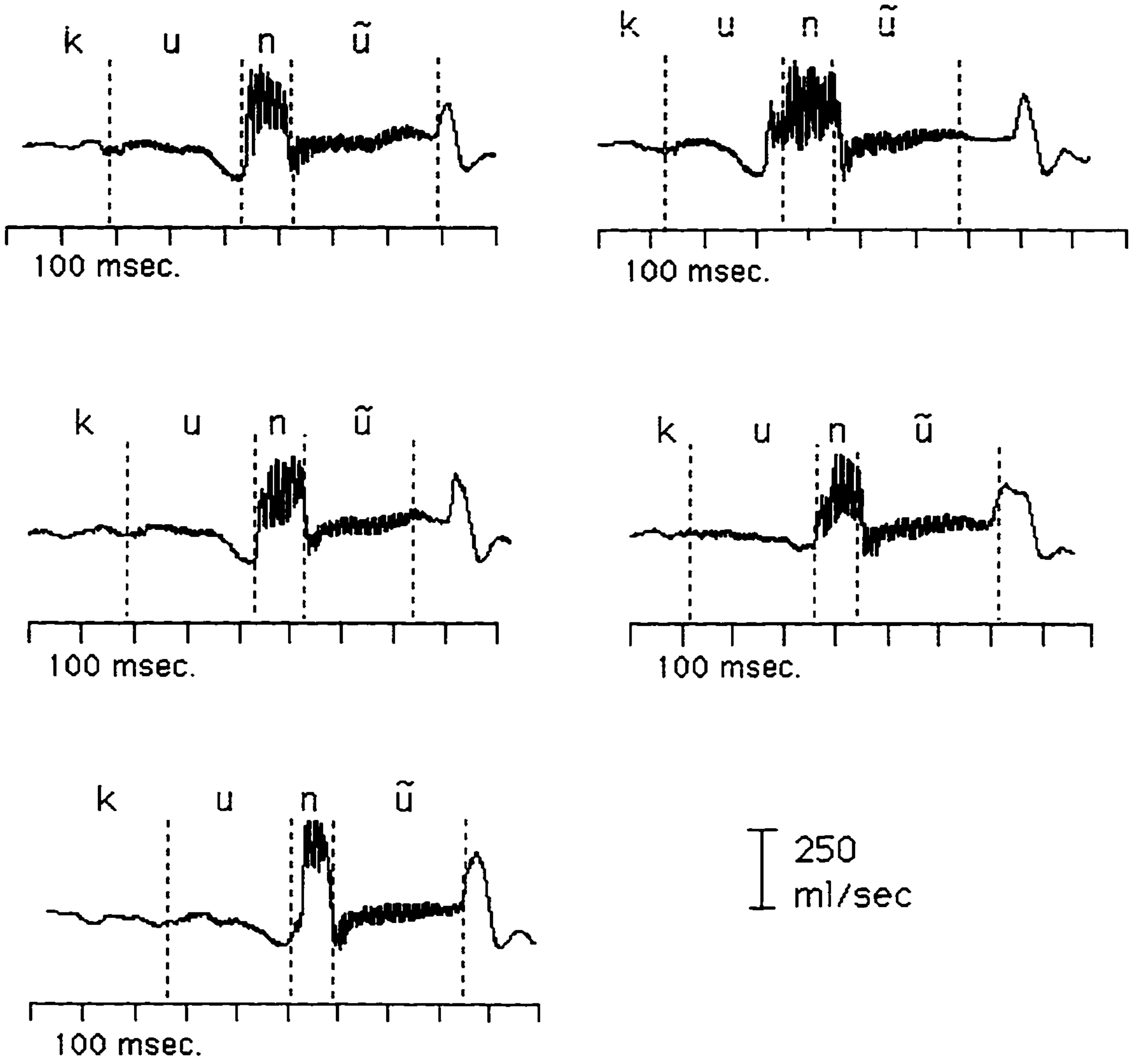
(4) **S1 flow data: kunũ 'to run'**



(5) S2 flow data: kunũ 'to run'



(6) **S3 flow data: kunũ 'to run'**



Though the details of timing differ across the three speakers, two clear generalizations emerge. First, the onset of activity on the nasal flow channel (visible both in terms of a rise in the flow trace and in the presence of the increased energy reflecting nasal resonance) is closely correlated with the onset of closure for the medial nasal stop. Overall then, there is little evidence that speakers lower the velum during a large portion of the vowel prior to the onset of stop closure. S1 and S3 appear to take pains to avoid anticipatory velum lowering, while S2 exhibits a fairly regular pattern of approximately 30 milliseconds of transitional lowering prior to the onset of the consonant.[2] Secondly, we see that for all three speakers, following a drop in flow corresponding to the release of the oral constriction for the stop, nasal flow rises steadily throughout the entire duration of the following vowel. Taken together these two generalizations corroborate Pike and Small's (1974) original claim: vowels are nasalized after, but not before a nasal consonant.

4.1.2 Contrastive nasalization

As discussed in Chapter 2, CM also contains lexically (i.e. unpredictably) nasalized vowels. Examples of nasal/oral vowel contrasts are repeated here for convenience in (7).

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[2] Note that there is one token for S1 in which the velum is lowered significantly before the onset of the nasal consonant.

(7) oral versus nasal vowel contrasts

a)	tsii	'to get wet'	b)	kʷeʔe	'red'
	tsĩĩ	'nail, claw'		kʷẽʔẽ	'went'
c)	kaʔᵃka	'to walk'	d)	tʲuʔᵘtʲu	'paper'
	kaʔᵃkã	'to beg'		tʲuʔᵘtũ	'firewood'
e)	kɨʔɨ	'to put on, put in'			
	kɨ̃ʔɨ̃	'to go'			

In CV(ʔ)V couplets, the entire vocalic sequence is nasalized.[3] That is, there are no adjacent oral-nasal or nasal-oral vowel sequences.

(8) Lexical nasalization in CV(ʔ)V couplets

a)	tĩĩ	'sweat'	g)	tsẽʔẽ	'mold'
b)	tãã	'earthquake'	h)	tsɨ̃ʔɨ̃	'fox'
c)	tũũ	'coal'	i)	tsũʔũ	'chicken'
d)	tʲɨ̃ɨ̃	'grab'	j)	kʷãã	'yellow'
e)	ðãã	'weave'	k)	ðĩʔũ	'money'
f)	ðẽʔẽ	'grease'	l)	*tiĩ, *tĩi, *tıʔi, etc...	

Interestingly, however, in biconsonantal couplets the distribution of lexically nasalized vowels is predictable from the voicing status of the medial

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[3] Recall from Chapter 3 that glottal stop does not constitute a segment in CM. Rather, glottalization, when present, is a property of the initial vowel of a couplet. There is thus no issue of glottal stop "transparency" here.

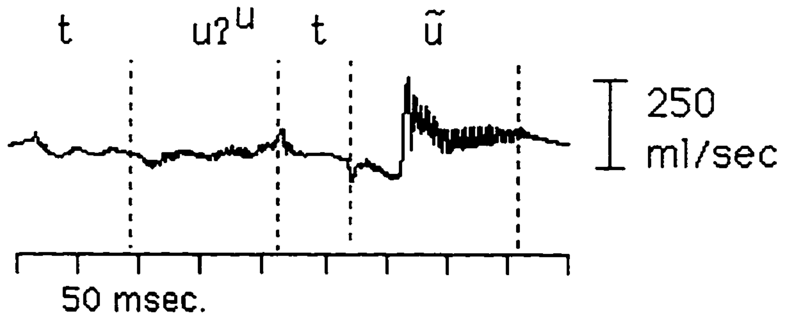
consonant. If the medial consonant is phonetically voiceless, only the final vowel of the couplet can be nasalized, as in (9).

(9) **CV(ʔ)CV couplets with a voiceless medial consonant**

a) ðuʔᵘkũ	'tall'	d) kaʔᵃkɨ̃	'be hungry'
b) tʲuʔᵘtũ	'firewood'	e) *kãʔã̃kã, *kãʔᵃka, etc...	
c) βiʔⁱʃĩ	'cold'		

This is exemplified in (10) with flow data for a token of *tʲuʔᵘt*ũ 'firewood', produced by S3.

(10) S3 **flow data: tʲuʔᵘtũ 'firewood'**



Note that flow spikes upward roughly 40-50 milliseconds after the release of the stop. Though there is some variation both within and across speakers with respect to timing in these cases, for our purposes here, what is important is that nasalization is limited to the final vowel.

By contrast, if the medial consonant is voiced, both vowels of the couplet are nasalized.[4]

(11) **CVCV couplets with a voiced medial consonant**[5]

a) ndʲũðĩ	'honey'	c) kĩðĩ 'sticky'
b) βĩðĩ	'sweet'	d) *kĩði, *kiðĩ, etc...

Another flow trace from S3 for βĩðĩ 'sweet' provides a concrete example of the nasalization of both vowels of such couplets. Note the heavy flow throughout each of the vowels flanking the medial fricative.[6]

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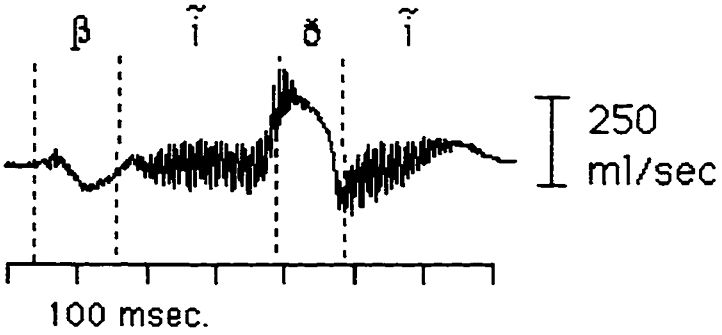
[4] Poser (1980) was the first to observe that within an autosegmental framework, there was no need to establish a separate set of contrastive nasal vowels, given that the *distribution* of lexically nasal vowels is predictable and can be accounted for by the postulation of a lexically floating nasal autosegment that spreads from right to left in the word.

[5] Note that all of the forms in (11) contain the voiced interdental fricative [ð]. Neither the voiced fricative [β] nor prenasalized stops appear in medial position in couplets with contrastively nasalized vowels, though they do surface medially in the context of second person familiar nasalization (see figure 17, this chapter). This issue is addressed in §4.2.2 below.

[6] The increase in flow at the onset of the fricative can be attributed to a combination of sustained velum lowering during the transition from vocalic to fricative stricture. That is, as the stricture is formed for the fricative, less air will escape through the oral channel of the vocal tract. Again, see §4.3 for discussion of phonetic implementation.

(12) **S3 flow data: β̃ĩð̃ĩ 'sweet'**



This general pattern is important, since the same basic facts obtain of the regressive nasal harmony phenomenon that marks the second person familiar. We turn to these data in §4.1.3.

4.1.3 Second person familiar nasalization

As with contrastively nasal vowels, when CV(ʔ)V couplets undergo nasalization to form the second person familiar, both vowels are nasalized.

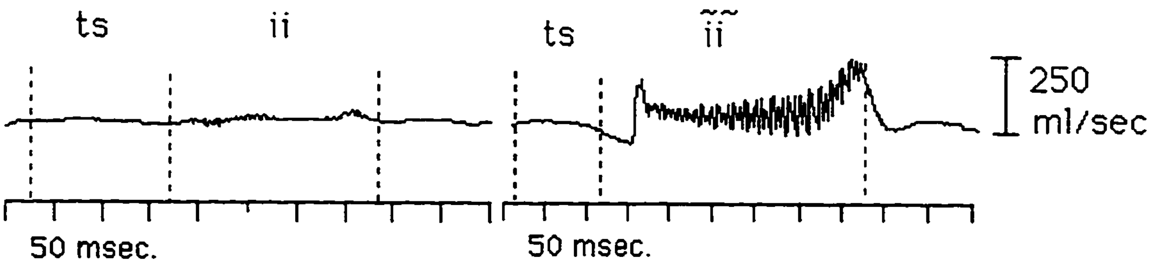
(13) **Second person familiar nasalization: CV(ʔ)V couplets**

a) kau	'cough'	→	kãũ	'you (fam) will cough'
b) ndii	'to go down'	→	ndĩĩ	'you (fam) will go down'
c) ʃee	'arrive'	→	ʃẽẽ	'you (fam) will arrive'
d) tsii	'to get wet'	→	tsĩĩ	'you (fam) will get wet'
e) kaʔu	'to write'	→	kãʔũ	'you (fam) will write'
f) kiʔi	'to take'	→	kĩʔĩ	'you (fam) will take'
g) ndoʔo	'to suffer'	→	ndõʔõ	'you (fam) will suffer'
h) ðuʔu	'to steal'	→	ðũʔũ	'you (fam) will steal'

Figure (14) provides a representative example of the contrast between the non-nasalized CVV couplet *tsii* 'to get wet' in (a) and its 2-FAM counterpart, *tsĩĩ* 'you will get wet' in (b).

(14) **S1 flow data: tsii 'to get wet' vs. tsĩĩ 'you (fam) will get wet'**

a) non-nasalized b) nasalized



As with lexical nasalization above, the presence of a couplet-medial voiceless consonant restricts 2-FAM nasalization to the rightmost vowel of a couplet. That is, voiceless consonants block leftward nasal spread.

(15) **Blocking effect of voiceless consonants**

a) ku?^{u}t^{j}u 'to hoe' → ku?^{u}t^{j}ũ 'you (fam) will hoe'

b) ku?^{u}tsi 'to bathe' → ku?^{u}tsĩ 'you (fam) will bathe'

c) nde?^{e}ku 'to be on' → nde?^{e}kũ 'you (fam) are on'

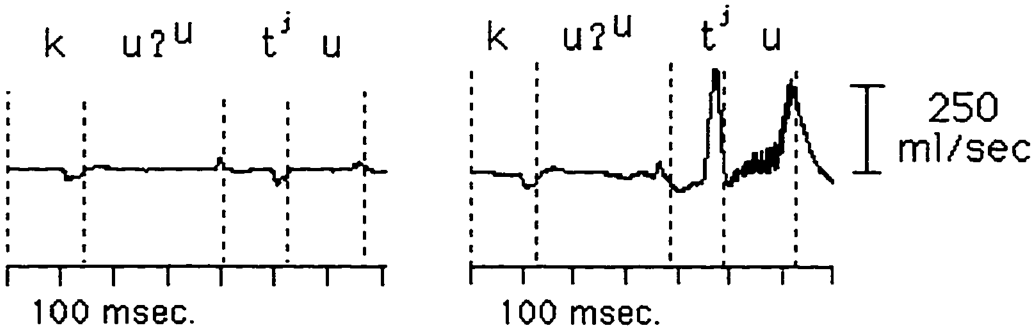
d) ki?^{i}ʃi 'to come' → ki?^{i}ʃĩ 'you (fam) will come'

e) ka?^{a}ka 'to walk' → ka?^{a}kã 'you will walk'

f) *kã?^{ã}kã, *kã?^{ã}ka, etc...

The pair of traces in (16) illustrate this by showing the contrast between the oral *ku?^{u}t^{j}u* 'to hoe, to plow' and its nasalized counterpart *ku?^{u}t^{j}*ũ.

(16) **S2 flow data: ku?^{u}t^{j}u 'to hoe' → ku?^{u}t^{j}ũ' you (fam) will hoe'**



a) non-nasalized b) nasalized

Note in (a) that there is no nasal flow throughout the form. In (b), however, a sharp spike in nasal flow indicates the onset of velum lowering coincident with the palatalized release of the medial stop. This is followed by a period of steadily increasing flow throughout the duration of the final vowel. Importantly, there is no flow on the initial vowel. Rather, the medial voiceless stop impedes the leftward propagation of nasality.

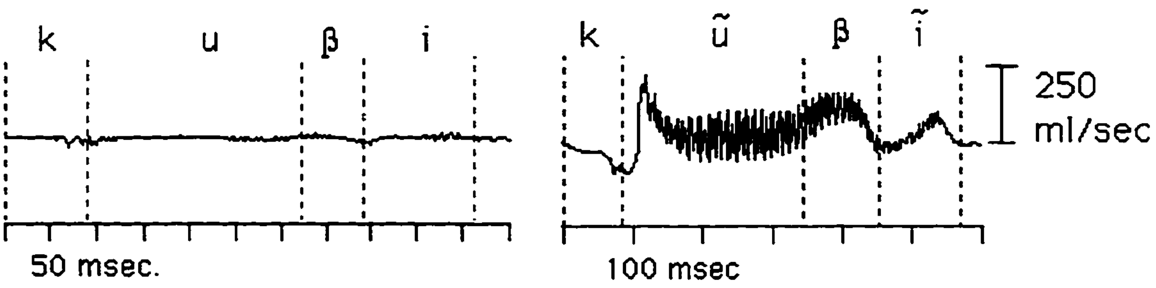
By contrast, if the medial consonant of a couplet is phonetically voiced, nasalization surfaces on both vowels of the form. Descriptively, voiced consonants are thus transparent to the harmonic process.

(17) **voiced medial consonants are transparent**

a) βiðe	'wet'	→	βĩðẽ	'you (fam) are wet'
b) kuβi	'to die'	→	kũβĩ	'you (fam) will die'
c) tʲɨβi	'to blow'	→	tɨ̃βĩ	'you (fam) will blow'
d) tʲɨʔᶤβi	'to push'	→	tɨ̃ʔᶤ̃βĩ	'you (fam) will push'
e) luʔᵘndi	'small'	→	lũʔᵘ̃ndĩ	'you (fam) are small'
f) lendʲu	'dirty'	→	lẽndʲũ	'you (fam) are dirty'
g) *kũβi, *kuβĩ, etc...				

This is seen in the tokens of *kuβi* 'to die' and *k*ũβĩ 'you (fam) will die' in (18).

(18) **S1 flow data: kuβi 'to die' → kũβĩ'you (fam) will die'**

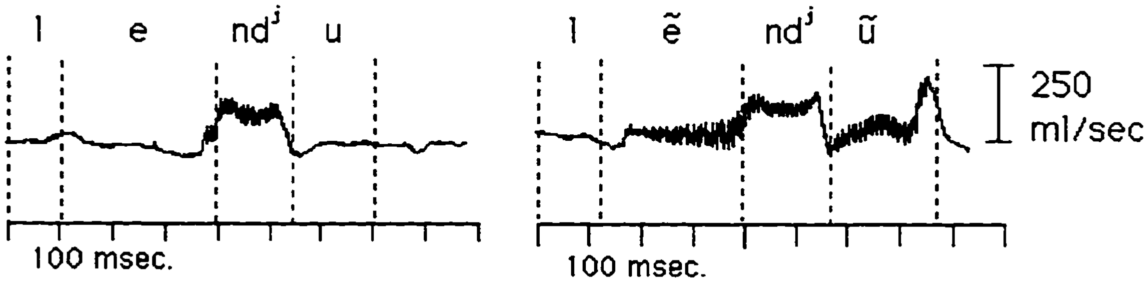


a) non-nasalized b) nasalized

Again, the form in (a) provides an oral base form. In this case, the form in (b) shows heavy flow throughout the duration of both vowels, reflecting the transparency of the medial voiced fricative to harmony. (Furthermore, flow is present and even increasing throughout much of the voiced medial fricative, an issue to which I return in in §4.3 below.)

Figure (19) provides an example of the transparency of medial prenasalized stops. Note in (a) that in non-morphologically nasalized contexts, prenasalized stops are similar to medial full nasal stops in that they do not induce anticipatory nasalization on the preceding vowel. Unlike full nasal stops, however, they do not trigger perseveratory nasalization. This is not surprising, of course, given their oral release. In (b) we see the same morpheme in the second person familiar. Here again, both vowels of the couplet are nasalized, while the medial stop maintains its oral release, i.e. it does not become an [n].[7]

(19) **S2 flow data: lendʲu 'dirty' → lẽndʲũ 'you (fam) are dirty'**



Finally, it is interesting to note that the prohibition against nasalized vowels surfacing before medial nasal stops in CV(ʔ)NV roots does not hold here. Rather, both vowels of these couplets will surface as nasalized in the second familiar. Thus, these pattern with other phonetically voiced consonants from a descriptive perspective in that they can be characterized as transparent to harmony.

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[7] As I note in Chapter 1, since flow drops rapidly at the release of oral closure for all stops from what appears to be a consequence of the experimental setup, the distinction between the oral release of prenasals flanked by nasal vowels and the nasal release of full nasal stops in the same context is hard to discern from the flow traces. In forms such as (19), however, it is clearly audible.

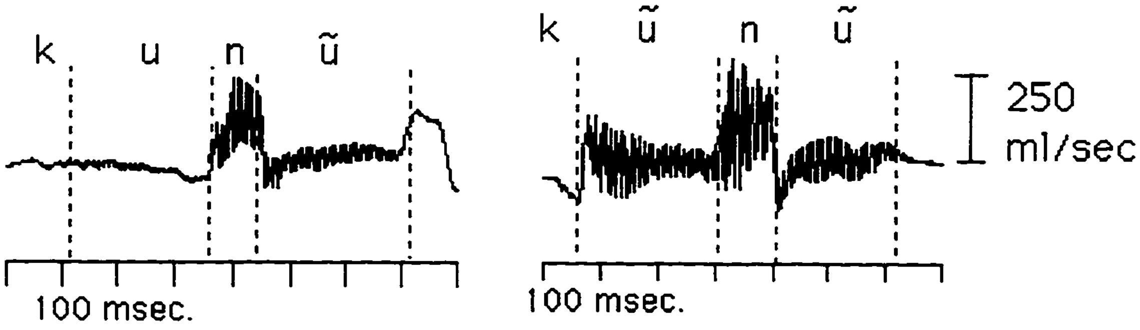
(20) **medial nasal consonants are transparent to harmony**

a) kunũ	'to run'	→	kũnũ	'you (fam) will run'
b) βinĩ	'mean, petty'	→	βĩnĩ	'you (fam) are mean, petty'
c) kinĩ	'to listen'	→	kĩnĩ	'you (fam) will listen'
d) ki?^{i}nĩ	'to tie down'	→	kĩ?$^{\tilde{i}}$nĩ	'you (fam) will tie (it) down'
e) ka?^{a}mĩ	'to burn'	→	kã?$^{\tilde{a}}$mĩ	'you (fam) will burn'
f) ta?^{a}nũ	'to break'	→	tã?$^{\tilde{a}}$nũ	'you (fam) will break'
g) ta?^{a}nũ	'to break'	→	*tanũ, etc...	

Illustrative flow data for S3 is provided for the morphologically minimal pair *kunũ* 'to run' and *kũnũ* 'you (fam) will run'.

(21) **S3 flow data: kunũ 'to run'→ kũnũ 'you (fam) will run'**

a) non-nasalized (non-2-FAM) b) nasalized (2-FAM)



Note the contrast between the underived base form in (a) and the 2-FAM form in (b). S3 clearly times the onset of nasalization with the onset of the medial nasal stop in the underived form. By contrast, the velum is lowered and nasal flow is heavy from the outset of the initial vowel in (b).

Bearing this range of nasal data in mind, I turn in §4.2 to the phonology of CM nasalization.

4.2 The phonology of nasalization

This section provides a formal analysis of the array of CM nasalization facts. As in Chapter 3, I carry out my analysis within the context of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993b, and many others), under the assumption of a Correspondence based model (cf. McCarthy and Prince 1995, Orgun 1995, McCarthy 1996) in which Faithfulness is evaluated in terms of input-output correspondence relations. Additionally, I assume the formal Optimality Theoretic mechanism of Alignment (McCarthy and Prince 1993a) as one means of characterizing the surface distribution of [nasal] in an output string (Kirchner 1993, Archangeli and Pulleyblank 1994b, Pulleyblank 1994; Archangeli and Suzuki 1995, Cole and Kisseberth 1995, Jiang-King et. al. 1995, Ola 1995, Zoll 1995).

Given that the data are complex in their interaction, I break the discussion down into three main sections. I begin in §4.2.1 with a discussion of the distribution of lexically contrastive, i.e. unpredictable, vowel nasalization, which I analyze in terms of the interaction of three constraints. Two are alignment constraints pressuring for the right and left-edge moraic alignment of [nasal] within roots, and the third is an additional constraint banning the occurrence of [nasal] before a voiceless consonant. In §4.2.2, I incorporate contextual vowel nasalization into the analysis. Here, I address the thorny issue of accounting for the observed patterns of nasal distribution in vowels as well as consonants, while simultaneously ruling out unattested patterns of [nasal] distribution within CM couplets. In particular, I argue that an adequate characterization of both attested and unattested patterns of nasalization requires the introduction of conditionally conjoined alignment constraints; that is, conditions such as IF LEFT ALIGNED, THEN RIGHT ALIGNED. Given that such constraints, like constraint conjunction (Smolensky 1995, Suzuki 1995, Archangeli and Suzuki 1995) and disjunction (Kirchner 1995a) introduce powerful mechanisms in the grammar, I slowly build up my argument, making my assumptions explicit and beginning with the simplest patterns before proceeding for the need for the added power of the conditional union of simpler constraints. Finally, §4.2.3 provides an analysis of vowel nasalization in the second person familiar--a phenomenon whose treatment largely parallels that of lexical nasalization, but which 1) requires that we distinguish between the alignment of [nasal] within roots and the alignment of morphological categories and 2) provides additional support for recent claims that distinct correspondence relations can be subject to distinct faithfulness constraints (cf. McCarthy and Prince 1995, Benua 1995, McCarthy 1996).

In broad strokes, the core of my argument is the following: the best way to understand the full range of nasalization facts is to view the system as simultaneously comprised of two intertwined varieties of nasalization: 1) prosodic or vowel-to-vowel nasalization typical of vowel harmony systems and 2) root-to-root nasalization, typical of segment-to-segment assimilation. I begin, then, in §4.2.1 with the characterization of the first of these, contrastive vowel nasalization.

4.2.1 Contrastive vowel nasalization

As seen in §4.1 above, CM couplets contain vowels whose nasality cannot be attributed to contextual assimilation from a nasal consonant. Nevertheless, although the presence or absence of these vowels is unpredictable, their distribution within morphemes is highly systematic. In a CV(ʔ)V couplet, both vowels are nasalized, as in (a). In couplets containing a medial consonant, nasalization is either restricted to the final vowel if the consonant is phonetically voiceless, as in (b), or realized on both vowels if the consonant is phonetically voiced, as in (c).

(22)	a) ðĩʔũ	'money'
	b) tʲuʔᵘtũ	'firewood'
	c) kĩðĩ	'sticky'

Employing the language of a traditional, rule-based framework, the data suggest a three part analysis. First, the presence of lexical nasalization can be accounted for by positing an underlying floating token of the feature [nasal]. Secondly, a rule will associate [nasal] to the rightmost vowel of a couplet, while another will subsequently spread [nasal] to the left. Thirdly, some mechanism is required to account both for the opacity of voiceless consonants and the transparency of voiced consonants to the process.[8] This is schematically illustrated in (23), in which a floating [nasal] is associated and either spreads (left arrow) or fails to spread (right arrow) to the left.

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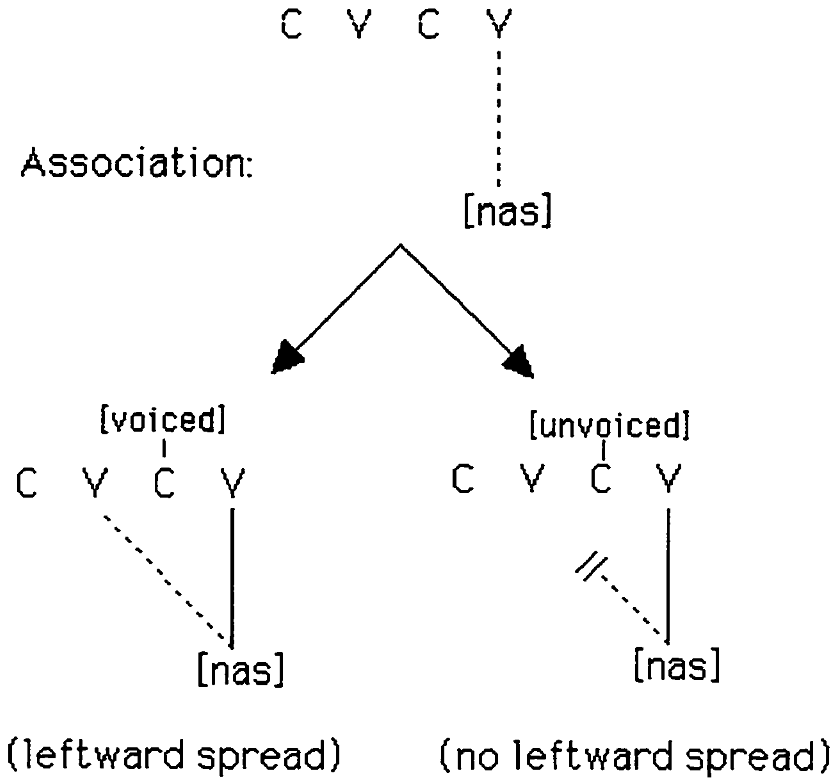
[8] Specific proposals within a rule-based framework include Poser (1980), Cole (1987), Trigo (1988), Piggott (1989,1992), Gerfen (1992, 1994).

(23) **Association and subsequent spread**



As I discuss in Chapter 3, in Optimality Theory, there are neither rules in the traditional sense nor assumptions of Lexical Minimality (cf. Steriade 1995) to govern the notion of underlying representation. For the case at hand, we cannot simply stipulate the existence of a unique underlying representation consisting of a segmental string and a floating token of [nasal]. Rather, the burden of explanation falls to the constraint hierarchy.

I argue that attending to the problem involves building on two descriptive generalizations that emerge from above. First, lexical nasalization appears to exhibit right-to-left association and spread. Secondly, in so doing, it exhibits the behavior of a canonical vowel-to-vowel harmony process, with the added complication that non-target or so-called *neutral* (see Archangeli and Pulleyblank 1994a) consonants interact with it.[9] In the ensuing discussion, I show that the distribution of lexically (i.e. contrastively) nasal vowels follows in a straightforward manner from the interaction of three constraints. Two of these involve the alignment (McCarthy and Prince 1993a) of [nasal] with the rightmost and leftmost moras of root. The third, an extension of Pater's (1995) analysis of NC consonantal clusters, constrains the distribution of [nasal], banning sequences of nasal vowels followed by voiceless consonants. I begin in §4.2.1.1 with the question of of alignment. In §4.2.1.2, I motivate *NC as a means of accounting for the opacity of voiceless consonants to lexical vowel nasalization.

4.2.1.1 Alignment and transparency

To express both the association and spreading relations of canonical harmony, I adopt the now common extension of Alignment (McCarthy and Prince 1993a) to the featural domain. As first proposed by Kirchner (1993) and subsequently developed and refined in a number of analyses (see, among others, Archangeli and Pulleyblank 1994b, Pulleyblank 1994; Archangeli and Suzuki 1995, Cole and Kisseberth 1995, Jiang-King et. al. 1995, Ola 1995, Zoll

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[9] Pending further discussion of phonetic implementation in §4.3 below, I assume that intervening voiced fricatives are not *phonological* targets for

1995), I assume that features can be formally treated as possessing alignable edges. McCarthy and Prince's (1993a) original statement of Alignment is provided in (24).

(24) **Alignment** (McCarthy and Prince 1993a)
Align (Cat1,Edge1; Cat2,Edge2) = def
$\forall$ Cat1 $\exists$ Cat2 such that Edge1 of Cat1 and Edge2 of Cat2 are shared

For CM, I propose that the appearance of rightmost vowel association and subsequent leftward spread can be characterized in terms of two rankable constraints. One of these will align [nasal] with the rightmost mora of the root, while the other aligns [nasal] with the leftmost root mora.[10]

(25) **Align [nasal] Right: (AL-R)**
Align ([nasal],Right; Rightmost-μ,Right)

(26) **Align [nasal] Left (AL-L)**
Align ([nasal],Left; Leftmost-μ,Left)

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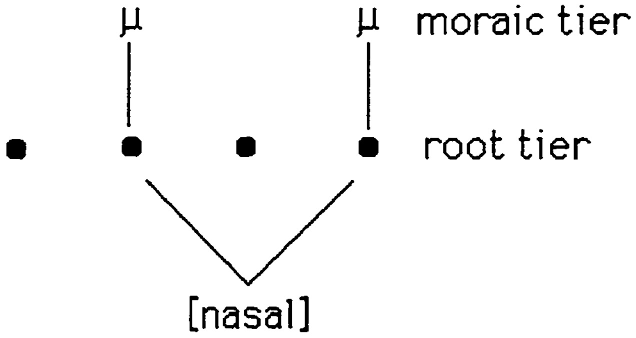
nasalization.

[10] Note that the notion of edgemost mora is itself derivable from precedence relations (see Archangeli and Pulleyblank 1994a). For example, we can define the leftmost mora of a root as a μ that is 1) associated to a vowel in the root and 2) not preceded by any other μ' in the root. Likewise, we can define the rightmost mora as a mora in the root that is not followed by another mora in the root. For convenience, I will simply refer to rightmost and leftmost.

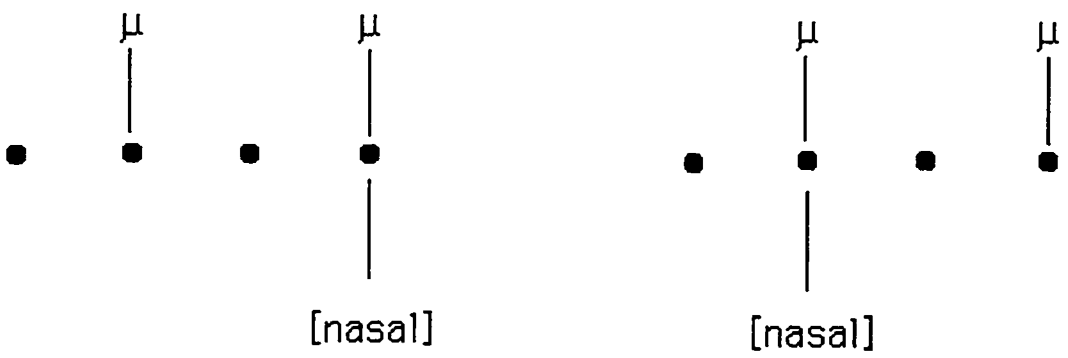
Following Archangeli and Pulleyblank (1994a), I assume that vowel features are prosodically anchored at the moraic level. Thus, both rightmost and leftmost moraic alignment are satisfied in the representation in (27).

(27) **Satisfaction of both AL-R and AL-L**



By way of contrast, the representations in (28) provide examples in which each constraint is violated. In (a), [nasal] is correctly aligned with the rightmost mora of the form, but the lack of association to the initial vowel incurs a violation of AL-LEFT. The opposite is the case in (b).

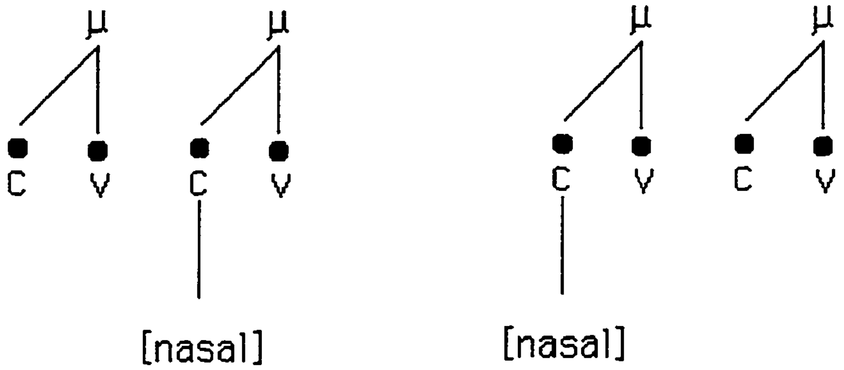
(28) **Respective alignment violations**


a) AL-L violated

b) AL-R violated

Finally, under the assumption that the satisfaction of moraic alignment is mediated through features associated to vowels, alignment is also violated in structures such as (29), in which I have marked C's and V's as a convenient shorthand to indicate consonantal and vocalic roots.[11]

(29) **Respective alignment violations**



a) both AL-L & AL-R violated b) both AL-L & AL-R violated

Let us consider first the simplest cases--forms in which both constraints are satisfied, as illustrated in the tableau in (30) for ðĩ?ũ 'money'.

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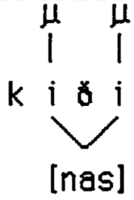
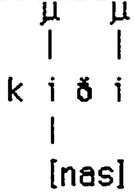
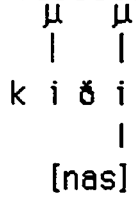
[11] Another means of looking at this issue is to say that satisfaction of moraic alignment is mediated by the head or most sonorous element of the mora. In CM, in which there are no codas, this will always be a vowel.

(30) **Tableau for** ðĩ?ũ **'money'**

Input: ðĩ?ũ	**AL-R**	**AL-L**
a) ☞ ðĩ?ũ		
b) ði?ũ		*!
c) ðĩ?u	*!	

Here, the output candidate in (a) satisfies both constraints, while the forms in (b) and (c) violate AL-L and AL-R, respectively. The analysis extends directly to the treatment of the transparency of phonetically voiced medial consonants, as in the form *kĩðĩ* 'sticky'. This is shown in (31).

(31) **Tableau for** kĩðĩ **'sticky'**

Input: kĩðĩ	**AL-R**	**AL-L**
a) ☞ 		
b) 		*!
c) 	*!	

The optimal candidate, (31a), provides a canonical example of vowel-to-vowel feature assimilation, here encoded by the two constraints aligning [nasal] to the rightmost and leftmost moras of the form. In fact, were it not for the blocking effect of medial voiceless consonants, the transparency of intervening voiced consonants would be fairly unremarkable, given that consonants are often transparent to vowel harmony processes.

Why, then, do voiceless consonants prevent nasalization from reaching the initial vowel of a couplet? I argue that the first key to solving the problem lies in the observation that lexical nasalization always surfaces on the final vowel of a couplet. In Optimality Theoretic terms, this suggests that rightward alignment is highly ranked in the language. On the other hand, when a couplet contains a lexically nasal vowel and a voiceless medial consonant, vowel nasalization is predictably absent from the initial vowel. This in turn suggests that AL-L is ranked below AL-R, i.e. that leftward alignment is violated under some conditions. Since permissible violations of a constraint are driven by the need to satisfy some other more highly ranked constraint in an Optimality Theoretic grammar, accounting for the opacity of voiceless consonants requires a constraint ranking such as that in (32).

(32) **AL-R, ?? >> AL-L**

The interesting question, of course, lies in specifying the nature of "??", such that we correctly account for the presence of forms such as *tʲuʔᵘt*ũ 'firewood' (as well as the absence of couplets such as **tʲ*ũʔᵘ̃*t*ũ) in the language.

4.2.1.2 Opacity and *NC

In recent years, one of the central areas of investigation in phonology has been the proper characterization of opacity in harmonic systems, where *opacity* refers to the arresting of a feature-spreading process. Within autosegmental theory, opacity effects are typically accounted for in one of two ways: 1) by constructing analyses in which the spreading of a harmonic feature will violate the *No Crossing Constraint* (NCC) (Goldsmith 1976, Clements and Sezer 1982, Sagey 1986, Hammond 1988, Rice and Avery 1990, etc.) or 2) by the use of feature cooccurrence constraints (FCC's) which, in conjunction with some theory of locality, arrest feature spreading by filtering out representations comprised of illicit feature combinations (cf. Archangeli and Pulleyblank 1989, 1994a,b, Cole 1987, Cohn 1989, 1990, Davis 1995, Gerfen 1993, 1994, Pulleyblank (1989).[12] These two types of approaches are sketched in (33) and (34), respectively.

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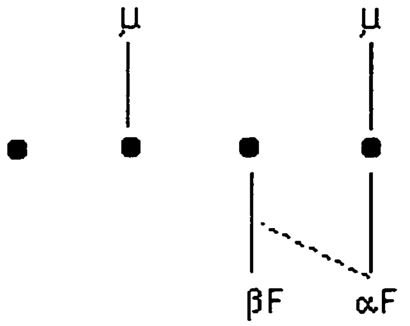
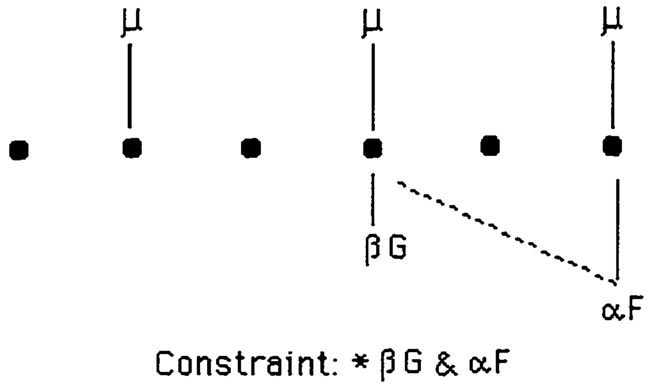
[12] See also Myers (1991) for a general discussion of the role of constraints, and Calabrese (1995) for an alternative view from the one taken here.

(33) **Opacity via the No Crossing Constraint**

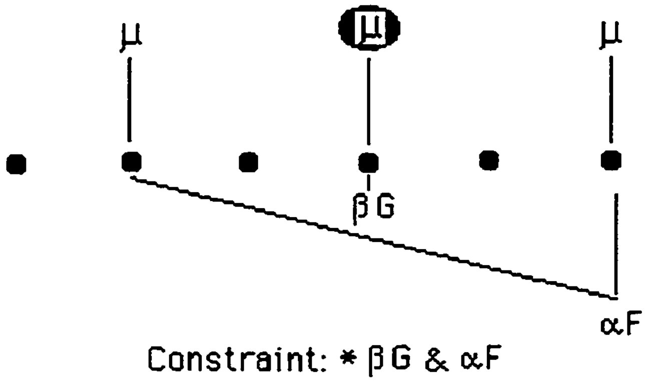


(34) **Opacity via feature cooccurrence constraints**



In (33), opacity is derived by a prohibition against line crossing on the same featural tier. In (34), opacity follows from the inability of [αF] to cooccur in a segment with some other feature [βG], together with the assumption that potential targets for association cannot be skipped over, i.e. a prohibition against gapping (see, for example, Archangeli and Pulleyblank 1994a), as in (35), where the skipped mora is highlighted.

(35) **No gapping**



Generally speaking, we see that NCC-based approaches to opacity bar spreading across an association line on the same tier, while feature cooccurrence-based approaches prevent features from targeting a segment that is already specified for some other, antagonistic feature.[13]

At first blush, this would appear to make the NCC a strong candidate for deriving the opacity of CM voiceless consonants, given that the targets for nasalization are vocalic. In traditional autosegmental terms, such an analysis would require that opaque consonants be specified for [-nasal], thus blocking regressive spread as in (36a), while transparent consonants are unspecified for nasality, thus deriving transparency, as in (36b).

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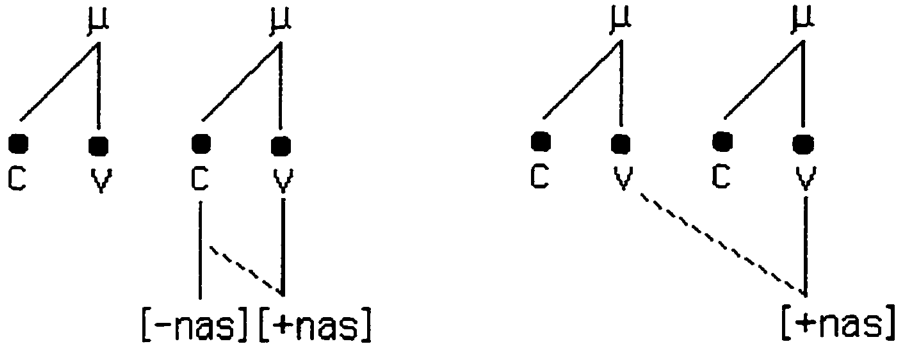
[13] As Diana Archangeli has reminded me, another type of FCC based opacity is one in which a feature [F] targets only anchors specified for a feature [G]. In this case, [F] may spread to an adjacent anchor that is associated to [G] and subsequent spread will be licit only if the next adjacent anchor is specified for [G]. Important for our purposes is that FCC based approaches halt spreading not by banning crossed association lines, but by feature cooccurence constraints, together with a ban on the skipping of possible targets.

(36) **NCC sketch of CM lexical nasalization**


a) opacity

b) transparency

While intuitively attractive, this strategy is not without major drawbacks, both conceptual and technical.[14] On a general conceptual level, it is important to note that it hinges on the assumption of a binary [nasal] feature. However, recent work by Steriade (1993, 1995) casts serious doubt over the validity of viewing nasality as phonologically binary. Steriade points out, for example, that [-nasal] does not trigger long distance or unbounded harmony in any language. That is, we do not find languages in which orality spreads iteratively through an unbounded domain, triggering alternations in which full nasals become fully oral. Secondly, she notes that if [-nasal] exists, it is surprising that we never find cases of OCP-like dissimilation for it. She cites Mazateco (Pike and Pike 1947) as a case in which we do, however, find local [nasal] dissimilation. In Mazateco, sequences such as *[nã] are prohibited,

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[14] For a general critical perspective on the NCC, see Coleman and Local (1991).

while [ta], [tã], and [na] are all possible. In contrast, Steriade notes that no known language prohibits both *[nã] and *[ta] sequences while allowing [tã] and [na]. Given a phonological [-nasal] feature, we expect to find such a case. In short, such arguments reduce the cross-linguistic usefulness of [-nasal] to its function as a blocker of assimilation--a purely diacritic role in phonological systems.[15]

Even if we assume the existence of a binary [nasal], it is not clear that the opacity of the class of voiceless consonants is best characterized by assigning to them a [-nasal] specification. In particular, given the lack of input constraints inherent in OT, we cannot assume a priori that all voiceless consonants must be specified at input for [-nasal], while at the same time assuming that non-nasal voiced (i.e. transparent) fricatives are unspecified for [nasal] at input. Thus, we might expect to find both opaque and transparent /t/'s, with the former corresponding to [-nasal] input /t/'s and the latter corresponding to [0 nasal] /t/'s at input. Moreover, we might equally expect to find [-nasal] tokens of /ð/ that block harmony.

In short, there is no clear evidence that [-nasal] plays an active phonological role cross-linguistically. There is no need for a [-nasal] specification to capture the orality of non-nasal sounds, since the presence or

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[15] Cohn (1990, 1993a) offers phonetic arguments in favor of [-nasal]. I return to this issue in §4.3 below. See also Trigo (1993) for a kind of middle ground position in which [nasal] is sometimes binary and sometimes equipollent.

absence of a monovalent [nasal] can accomplish the same goal. And finally, it is not clear that forcing opaque and only opaque segments in CM to be [-nasal] is itself a trivial task.[16] At the same time, a feature cooccurrence approach to opacity in CM is not without its own difficulties. The heart of the problem lies in the fact that such approaches function formally by limiting the cooccurrence of features on a particular target rather than prohibiting the spread of a feature across a given context. In simple terms, if intervening consonants are not targets for lexical vowel nasalization, how can feature cooccurrence bar the spread of nasal across them?

I argue that Optimality Theory affords the opportunity to characterize the opacity of voiceless consonants in a phonetically motivated fashion, while at the same time circumventing the above technical problems. In particular, I extend the work of Pater (1995), arguing that opacity results from the pressure of a constraint *NC which bans the presence of a nasal vowel-oral consonant sequence. Pater focuses on the phonology of NC effects such as

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[16] Even in pre-OT terms, there is no evidence that the specification of [-nasal] for opaque consonants derives from any principled theory of specification (cf. Kiparsky 1982, Archangeli 1984, 1988, Steriade 1987, Clements 1988, Archangeli and Pulleyblank 1994a). The best motivation appears to come from Contrastive Underspecification (Steriade 1987), with voiceless stops specified as [-nasal] in order to encode the contrast with nasal stops. However, this fails to account for the opacity of /ʃ/ in forms such as *ndiʔ*^{i}ʃẽ 'shoe'. Since nasality is non-contrastive for fricatives, there is no motivation for specifying /ʃ/ as [-nasal]; the only motivation is that /ʃ/ blocks harmony. See Steriade (1995) for a critique of the logic of Contrastive Underspecification and Mohanan (1991) for arguments against Radical Underspecification.

nasal substitution, post-nasal voicing, nasal deletion and denasalization in sequences involving adjacent nasal stops and following voiceless consonants in a range of languages. The basic typological motivation for a *NC constraint, Pater notes, is that cross-linguistically, NC sequences involving nasal stops and voiceless consonants are often banned while NC sequences involving nasal stops and following voiced consonants are not proscribed. The CM case is interesting because, by extending the use of *NC to ban ṽC sequences, the opacity of voiceless stops to harmony can be viewed in terms of the same type of constraint whose effects are manifested in apparently unrelated phenemona involving nasal-oral sequences.[17]

(37) ***NC: No nasalized vowels before voiceless consonants.**

From a phonetic perspective, such a constraint is grounded (Archangeli and Pulleyblank 1994a) in the relationship between nasality and voicing. The primary acoustic cues for nasality involve the complex effects of nasal resonance on the overall spectrum.[18] At the same time, the aerodynamic requirements of voiceless obstruents are such that velum lowering is antithetical to their production. As Ohala and Ohala (1993) discuss, obstruents whose primary point of stricture is in front of the velum require a pressure

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[17] See also Smolensky (1993) and Suzuki (1995) for sequential constraints.
[18] See House and Stevens 1956, Fujimura and Linqvist 1971, Maeda 1982, 1993 for the acoustics of nasal vowels. See also Fujimura 1962, Fant 1970, Kurowski

build up behind the constriction in order to supply either burst energy (for plosives) or sufficient flow to generate turbulence at the point of constriction, as is the case for fricatives. Velum lowering, by providing an additional escape channel for flow, is antithetical to both of these goals. This is especially true of voiceless obstruents, given that velic aperture will either subvert the build up of supraglottal pressure or impair their voicelessness, or both. Thus, just as voicing is necessary to the realization of nasality, the articulatory gesture of velum lowering is antithetical to the production of intervening voiceless obstruents, especially if nasalization is present during the onset of closure.[19] This is precisely the sequencing of velic gestures against which *NC militates.

By ranking *NC over AL-LEFT, we derive the opacity of voiceless consonants as a consequence of the need to satisfy *NC, even at the cost of violating the alignment of [nasal] with the leftmost mora of a couplet. This is seen in (38).

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and Blumstein 1993 on nasal consonants.

[19] Departing from the rule-based analysis deriving opacity from the voicing status the opaque consonants of Gerfen (1992, 1994), Homer (1995) treats opacity in terms of nasality and voiclessness within the Optimal Domains model of Cole and Kisseberth (1995). My proposal is distinct in that I do not adopt Cole and Kisseberth's specialized theoretical machinery of domain construction, nor do I assume, as does Homer, that regressive vowel harmony targets the intervening consonants themselves. Additionally, Homer's analysis does not attempt to account for the entire range of nasalization facts in the language.

(38) **Tableau for ðuʔ^{u}kũ 'tall' illustrating *NC >> AL-L**

Input: ðuʔ^{u}kũ	AL-R	*NC	AL-L
a) ☞ ðuʔ^{u}kũ			*
b) ðũʔ$^{\tilde{u}}$kũ		*!	▨
c) ðũʔ$^{\tilde{u}}$ku	*!		▨

With the analysis of lexically nasalized vowels in mind, we turn in §4.2.2 to the issue of contextual nasalization.

4.2.2 Contextually nasalized vowels

As I have noted, CM contains vowels that are predictably nasalized following a nasal consonant. The basic pattern is exhibited again for convenience in (39).

(39)		
a)	mẽũ	'cat noise'
b)	inĩ	'in'
c)	nĩɲũ	'night'

These data reflect four important generalizations. First, in couplets such as (a) that do not contain a medial consonant, both vowels will surface as nasalized, even when the vowels differ in quality. Secondly, in couplets containing a medial nasal stop and no initial nasal stop, as in (b), the vowel following the stop surfaces as nasalized, while the vowel preceding the stop surfaces as predictably oral. Thirdly, if both consonants of a couplet are nasal stops, as in (c), both vowels will surface as nasalized. Finally, there is an asymmetry in the distribution of nasal stops within morphemes. While CV(ʔ)NV forms such as βinĩ 'mean, petty' and *kiʔ*^{i}*nĩ* 'to tie down' are common, NV(ʔ)CV forms such as **nĩβi* or **nãta* are so vanishingly rare as to appear to be best viewed as prohibited by the grammar.[20] An adequate analysis must thus account for both the pattern of contextual assimilation and for the distributional properties of nasal stops within morphemes. As I will argue below, this task is non-trivial and motivates the employment of conditional constraints on moraic alignment. I begin the discussion here, however, with a treatment of the attested patterns.

In rule-based, autosegmental terms (Goldsmith 1976) contextual vowel nasalization in forms such as *kunũ* 'to run' or *nĩɲũ* 'night' would be accounted for by positing a rule spreading [nasal] from a nasal stop to a following vowel, as in (40).

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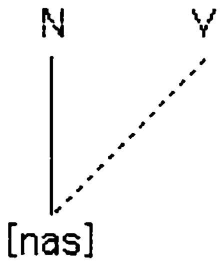
[20] I have found two exceptions: ɲũʔt^{j}ɨ 'sand', which may reflect the fusion of the morpheme ɲũũ meaning 'earth' and some other morpheme, and *mĩʔ*$^{\tilde{\imath}}$*nde* 'prickly pear'.

(40) **Autosegmental spread**



To account for the nasalization of the distinct vowels of a form such as mẽũ 'cat noise', the rule must be iterative. The lack of anticipatory nasalization follows from the left-to-right directionality of the assimilation rule; i.e. from the absence of a rule of leftward [nasal] spread. Finally, it is unclear exactly how the lack of NV(?)CV (but the presence of NV(?)NV) couplets is to be accounted for.[21] That is, there is nothing inherent to the left-to-right spread rule that bars the presence of such forms. Presumably, there must be an independent phonotactic statement in the grammar.

I argue that these three apparently distinct issues receive a unified explanation within the context of an Optimality Theoretic analysis. As I show, this derives from the fact that an Optimality based account must necessarily diverge from the approach sketched above by explicitly ruling out anticipatory nasalization in VN contexts, while at the same time characterizing

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[21] See Archangeli and Pulleyblank (1994a) for extensive discussion of rule parameters within an autosegmental framework. Note that iterativity would not be motivated for forms such as ɲɨ̃ɨ̃ 'hat', under the assumption that these

perseveratory nasalization. Thus, for example, by contrast to an autosegmental analysis, the lack of anticipatory nasalization cannot be attributed to the absence of a rule, but rather, must be explained by the effect of a constraint (or of multiple, ranked constraints) holding of surface representations.

Below, I develop an analysis in which the pressure to assimilate nasality rightwards crucially conflicts with a need to satisfy rightward alignment. As I will show, characterizing the attested patterns follows relatively straighforwardly from alignment and an additional constraint forcing the orality of vowels preceding nasal consonants in forms such as *kun*ũ 'to run'. Ruling out the unacceptable configurations becomes a more complex task. I begin in §4.2.2.1 with a discussion of the simplest cases--those involving attested surface forms such as *kun*ũ 'to run' and *n*ĩɲũ 'night'. In subsequent sections, I provide a detailed, step-by-step discussion of the means by which unacceptable forms must be proscribed.

4.2.2.1 *ṽN

Couplets such as *kun*ũ 'to run' are interesting in that the grammar must explicitly prohibit the presence of nasality on the vowel preceding the nasal stop. To account for this phenomenon, I propose a constraint, *ṽN,

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contain a single vowel root associated to two moras.

which bans a sequence comprised of a nasal vowel followed by a nasal consonant. Similarly, the absence of nasalized vowels before prenasalized stops can also be attributed to the effect of *ṽN.[22] Adopting the representations of Steriade (1993), I formulate the constraint as in (41), where [nasal] vowels are prohibited before any stop whose closure phase (Ao) is specified for [nasal].

(41) ***ṽN: No [nasal] vowels immediately preceding a [nasal] Ao node.**

In essence, *ṽN can be viewed as a constraint banning anticipatory coarticulation. As Ladefoged (1983) notes, speech involves a number of potential conflicts and trade offs between the ease of articulation and auditory distinctiveness. Assimiliatory coarticulation can be viewed as a desire to minimize change along an acoustic or articulatory dimension (cf. Lindblom 1983, also Kirchner 1995b for applications of Lindblom's notions of economy in OT), while a prohibition against coarticulation can be viewed as a means of enforcing phonetic distinctions between segments.[23] In this case, we can view *ṽN as a means of preserving the orality of V1 in CVNV couplets.[24]

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[22] For more on the behavior of prenasalized stops see §4.2.2.2 below.

[23] More broadly, we might profitably think of the phonologization of coarticulation as falling under the rubric of constraint families such as PERSEVERE and ANTICIPATE for contextual assimilation and *PERSEVERE and *ANTICIPATE for forced distinctiveness along a phonetic dimension.

[24] I return to the issue of the possible motivation for this constraint in the grammar in §4.3.

By ordering *ṽN above AL-LEFT in our constraint hierarchy, we can characterize the orality of vowels before nasal consonants, as in (42).

(42) **Tableau for kunũ 'to run'**

Input: kunũ	**AL-R**	***NC**	***ṽN**	**AL-L**
a) ☞ kunũ				*
b) kũnũ			*!	
c) kũnu	*!		*	
d) kunu	*!			*

In (42), the optimal output candidate is (a), in which only AL-LEFT is violated in order to avoid incurring a violation of the more highly ranked *ṽN. The candidates in (b) and (c) both violate *ṽN, while (c) also violates AL-RIGHT. Finally, (d) violates both alignment constraints, since the [nasal] specification of the medial [n] is not associated to either vowel.

At the same time, the ranking AL-R >> *ṽN would appear to account for the nasality of both vowels in surface forms such as *nũnĩ* 'corn'.

(43) **Tableau for nũnĩ 'corn'**

	AL-R *NC	*ṽN	AL-L
a) nunĩ	*!		*
b) ☞ nũnĩ		*	
c) nũni	*!	*	
d) nuni	*!		*

Here, both rightmost and leftmost alignment are satisfied, at the cost of violating *ṽN, and (b) is selected as the optimal form. Note that I assume that (a) is ruled out, given that the token of [nasal] associated to the initial [n] of the couplet will violate AL-R.[25] In sum, by invoking *ṽN to prevent anticipatory nasalization, we account for the orality of vowels in VN sequences in forms such as *kunũ* 'to run'. For its part, the ranking AL-R >> *ṽN would appear to acocunt for the nasalization of both vowels in surface forms such as nũnĩ 'corn'. What we have not yet accounted for, however, is the absence of forms such as **nãta* , **nãða*, or **nãðã* in CM. We turn to this issue in §4.2.2.2.

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[25] Alternatively, we might assume that there is a single token of [nasal] in (a) whose association skips the initial vowel. As I discuss in §4.2.2.4 below, I assume that such a configuration would incur a fatal violation of *GAP.

4.2.2.2 The issue: how to ban NṽCV sequences

One type of couplet that is almost never attested in the language is that in which a full nasal stop is the initial consonant of a root, while a non-nasal consonant (i.e. a voiced fricative; a voiceless stop, affricate, or fricative; or a prenasalized stop) occupies the medial position, as in the following hypothetical but unattested pairs in (44).[26]

(44) **Non-occurring couplet shapes**

a) *nãta b) *nãða c) *nãnda
*nãtã *nãðã *nãndã

Given our constraints, the absence of such forms would appear to be straightforwardly explained in terms of assuming 1) that AL-R is inviolate and 2) that all of the forms in (a-c) in which [nasal] is realized on the final vowel constitute violations of a similarly inviolate prohibition against gapped configurations (*GAP).[27] Ignoring for the moment the issue of why a form such as *nãðã should constitute a violation of *GAP while attested forms such as *kĩðĩ* 'sticky' would not, ruling out the set of forms in (44) might

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[26] I have found two exceptions: ɲũʔt^{j}ɨ 'sand', which may reflect the fusion of the morpheme ɲũũ meaning 'earth' and some other morpheme, and *mĩʔ^{ĩ}nde* 'prickly pear'.

[27] I also assume an inviolate OCP for [nasal], thus barring the possibility of avoiding gapping by introducing multiple tokens of the OCP. I return in more detail to this issue below in the discussion of prenasalized stops.

proceed as in the following tableau.[28] In (45) the double line separates the four constraints that must be inviolable, though for the moment I provide no evidence that these must outrank *NC.

(45) **Tableau of unacceptable outputs**

Input: naða	**AL-R**	***GAP/ OCP**	***NC**	***ṽN**	**AL-L**
a) nãðã		*!			
b) nãða	*!				
c) naðã		*!			*
d) naða	*!*				*

Though it satisfies AL-R, (a) is ruled out as either a violation of *GAP (assuming that the medial fricative is skipped) or the OCP (assuming that a second token of [nasal] surfaces on the final vowel in order to satisfy alignment without incurring a *GAP violation). The candidate in (b) violates rightmost alignment, while (c) will violate either *GAP or the OCP. For its part, the candidate in (d) twice violates AL-R. Under the assumption that the doing nothing, i.e. the null parse, (cf. Prince and Smolensky 1993) is preferable to violating any of these undominated constraints, such forms might be

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[28] Note that my choice of *naða* as the input form is arbitrary. I make no assumptions about the value of [nasal] for the input vowels here. What is important is that the form contain an initial /n/ and a non-nasal medial consonant in order to illustrate the class of surface forms that our constraints will not generate.

eliminated as possible surface forms in CM. Alternatively, we might argue that the grammar generates an optimal candidate *taða*, given the input form in (45). That is, faithfulness to the [nasal] specification is sacrificed in order to trivially satisfy AL-R.

An approach along these lines is attractive in that it encodes the fact that candidates such as those in (a-d) are non-optimal, regardless of the input specification for [nasal]. That is, the grammar will not generate unattested surface forms, while it still characterizes attested outputs. Formally, the engine that drives this approach is the high ranking of AL-R, which is instrumental in ruling out candidates (b) and (d).[29] There is, however, a fundamental complication for this analysis. As I argue in §4.2.2.3, it fails to adequately account for the behavior of prenasalized stops.

4.2.2.3 Prenasalized stops

Curiously, prenasalized stops constitute an exception to the generalization that if there is [nasal] in a couplet, then rightmost alignment must be satisfied. That is, we find forms such as those in (46) and (47), which contain a prenasalized stop in either initial or medial position and in which both vowels of the couplet are oral.

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[29] Note that this analysis would also require a constraint banning the association of [nasal] to continuants (cf. Cohn 1989, 1993b) in order to rule out the association of [nasal] to the medial fricative and the final vowel, thus circumventing the gapping problem.

(46) **Couplets with initial prenasalized stops**

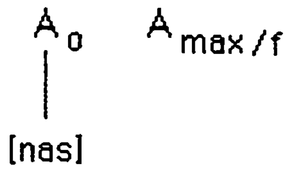
a) ndaðɨ 'closed' b) ntaʔ^{a}βa 'to put out' c) ndaʔ^{a}βi 'poor'

(47) **Couplets with medial prenasalized stops**

a) lend^{j}u 'dirty b) kaʔ^{a}nde 'cut' c) tsanda 'scar'

Any claim that such forms constitute violations of rightmost (and leftmost) [nasal] alignment depends crucially on the representation adopted for prenasalized stops. Here, I make explicit my assumptions, providing a treatment of prenasalization in terms of aperture geometry (Steriade 1993, also Keating 1990a). As I mention above in the formulation of *ṽN, I adopt Steriade's decomposition of plosive root nodes into phases corresponding to closure and release. Prenasalized plosives are represented via the association of [nasal] to the closure phase (Ao = Aperture zero) of the plosive, while nasality is absent from the release (max for stops, and f for affricates).

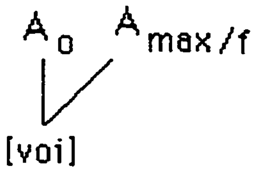
(48) **Representation of a prenasalized stop/affricate**



Under this view, the presence of the prenasalized stop in forms such as *ndee* 'black' violates AL-R twice. And, if the null parse (or violating faithfulness) is preferable to violating AL-RIGHT, such forms are predicted to be unattested in CM, together with unacceptable NVCV forms such as *naβa or *nãβa.

An alternative, of course, is to view prenasalization as the phonetic manifestation of phonological stop voicing, as in (49).[30]

(49) **Prenasalized stops phonological stop voicing**



Such a view is reasonable from a phonetic perspective, given that velum lowering during closure can serve as a mechanism for avoiding supraglottal pressure build up and thus sustaining voicing throughout the Ao phase. This view is additionally attractive in that it would allow us to maintain the analysis sketched above. That is, prenasalized stops would trivially satisfy our alignment constraints, because they would not be phonologically specified for [nasal].

The problem is that this choice leaves other facts regarding the distribution of prenasalized stops in CM morphemes without a clear explanation. Specifically, prenasalized stops appear to be subject to OCP effects as if their closure phase *were* phonologically associated to [nasal]. Three

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[30] This is the position taken by Iverson and Salmons (forthcoming) for prenasalization in the Mixtec languages in general.

distributional facts support this position. First, there are vanishingly few forms in which prenasalized stops surface with unpredictably nasal vowels: e.g. **ndãta, *ndatã.*[31] Secondly, I have found no monomorphemic forms in the language containing two prenasalized stops: e.g. **ndanda*. Thirdly, there are again vanishingly few cases in which prenasalized stops cooccur in a couplet with a nasal stop: e.g., **nãnda, *ndanã *nãndã, *ndãnã.*[32] As I show in §4.2.2.4, these three patterns are directly characterizable in terms of the OCP (cf. Leben 1973, McCarthy 1986, Yip 1988) and a constraint banning gapped configurations (see Archangeli and Pulleyblank 1994a), while a voicing hypothesis leaves the distributional properties of prenasalized stops without an explicit characterization.

4.2.2.4 *GAP, the OCP, and [nasal]

The generalization that emerges from the discussion of prenasalized stops is the following: in couplets containing a token of [nasal], rightmost alignment is always satisfied, unless [nasal] is associated to the closure phase of a prenasalized stop. In this section, I provide an account of the distribution

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[31] I have found two exceptions: nd^{j}ũðĩ 'honey' and *ndiʔ^{i}ʃẽ* 'shoe'. Though the former appears to derive from the fusion of *nduʔ^{u}te* 'water' and βĩðĩ 'sweet'. The latter may also be diachronically derived from two roots. The CM form for 'foot' is ʃeʔe, though the lack of nasalization in this form leaves the presence of the nasal vowel in *ndiʔ^{i}ʃẽ* 'shoe' unexplained.

[32] As I note above, there is one exception to this generalization: *mĩʔ$^{\tilde{\imath}}$nde*

of prenasalized stops in terms of two inviolable constraints: *GAP and the OCP. I argue that under pressure from these two constraints, rightmost alignment must be violated. I then return in §4.2.2.5 to the implications of ruling out couplets such as **nāta* and **nata* in the context of a violable AL-R.

The first piece of the argument involves the incorporation of a prohibition against gapped representations. Pending a more explicit characterization of what constitutes a gap in (51) below, *GAP is stated in (50).

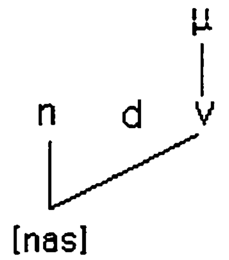
(50) ***GAP**: No gapped representations.

One consequence of *GAP is to rule out configurations such as the following, in which [nasal] is associated to the closure of a prenasalized stop and to a following vowel, while skipping over the release of the stop.[33]

'prickly pear'.

[33] That such configurations should constitute gapped structures is not surprising. As Steriade (1993) points out, there are no known cases of rightward nasal harmony triggered by prenasalized stops.

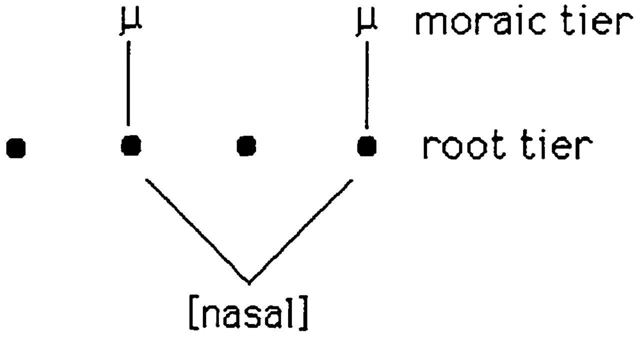
(51) **Gapped configuration**



n = nasal closure
d = oral release

At the same time, it is necessary that we not rule out configurations such as that in (52), corresponding to canonical vowel-to-vowel harmony in forms such as kĩð̃ĩ 'sticky'.

(52) **Non-gapped representation**



I argue that the crucial difference resides in Archangeli and Pulleyblank's (1994a) distinction between two classes of anchors for phonological features: root nodes and moras, or, in Archangeli and Pulleyblank's terms, *root* versus *prosodic anchors*. Features docked to consonants are anchored at the level of the root. By contrast, vowel features are anchored at the level of the mora. As Archangeli and Pulleyblank show, the general necessity of drawing such a distinction derives from the fact that locality in vowel harmony systems is straightforwardly characterized in terms of adjacent moraic anchors for harmonic features. That is, vowel harmony phenomena regularly skip over non-target consonants but not over vowels. This is straightforwardly explained if gapping in such cases is calculated on the moraic tier.

What makes the CM nasal data particularly intriguing is the intertwining of vowel harmony-like behavior for lexical (and, as we see below, second person familiar) nasalization with the segment-to-segment assimilatory behavior of contextual nasalization. In this sense, [nasal] simultaneously patterns as a harmonic feature on both the prosodic and root levels. My position is that the difference between (51) and (52) lies in the fact that the anchors for [nasal] association in (51) are comprised by a mixture of root and prosodic anchors, while (52) consists entirely of prosodic anchors. Bearing this in mind, a definition of GAP is provided in (53).[34]

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[34] See Archangeli and Pulleyblank (1994a) for a distinct view in which gaps in domains of association comprising both root and prosodic (part ii above) anchors are calculated separately for each type of anchor.

(53) **GAP**: For any multiply associated feature [F], the domain of association of [F] is gapped iff the set of associations:

i) consists of prosodic anchors only AND
contains a prosodic anchor not associated to [F]

OR

ii) consists of root anchors only or both root and prosodic anchors AND
contains any anchor not associated to [F].

By the definition in (53), any token of [nasal] that is associated exclusively to vowels that are adjacent at the moraic level is not gapped. By contrast, association to the closure phase of a prenasalized stop and a following vowel involves association to both root and prosodic anchors. By skipping over a the oral release of the stop, such a configuration is gapped. In simple terms, this conception of *GAP is a direct way of expressing the fact that gapping is calculated over the moraic tier when assimilation is exclusively prosodically anchored and over the root tier when assimilation consists entirely of consonantal anchors or of both root and prosodic anchors as we find for CM nasalization.[35]

Under this view, and assuming for the moment that faithfulness to the input nasality of prenasalized stops is inviolable, the ranking *GAP >> AL-R

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[35] In fact, this definition is probably too restrictive, given that any vowel-to-vowel harmony process that is triggered by a consonant will incur a *GAP violation. Within the context of OT, however, such a situation is analyzable in terms of a violable notion of gapping, under pressure from other, more highly ranked constraints.

accounts for the systematic failure of prenasalized stops to satisfy the moraic alignment of [nasal] in CM.

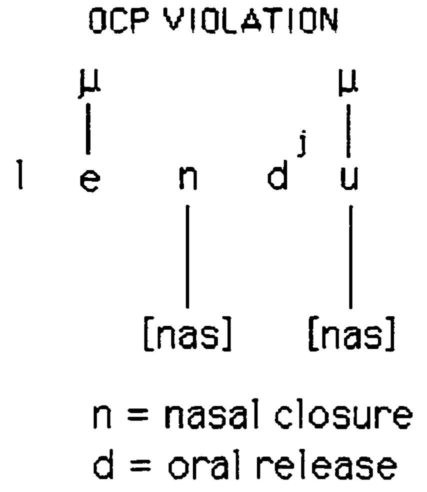
(54) **Tableau for lend^{j}u 'dirty': *GAP >> AL-R**

Input: lend^{j}u	*GAP	AL-R	*NC	*ṽN	AL-L
a) ☞ lend^{j}u		*			*
b) lẽnd^{j}u		*		*!	
c) lend^{j}ũ	*!				*
d) lẽnd^{j}ũ	*!			*	

Candidate (a), the optimal form, respects *GAP at the cost of violating both rightward and leftward moraic alignment. Candidate (b) violates AL-R and *ṽN, the prohibition against nasal vowels followed by nasal stop closure. Crucially, both (c) and (d) violate *GAP in that the association of [nasal] to V2 requires skipping the release of the stop.

One potential strategy for avoiding gapping is to introduce a second token of [nasal], as in (55).

(55) **An alternative representation**



To rule such candidates out, I assume that the OCP (cf. Leben 1973, McCarthy 1986, Myers 1991, 1995, Yip 1988) as it pertains to [nasal] is also inviolate within CM roots. Here, I adapt the formulation of McCarthy (1986).[36]

(56) **OCP**: Adjacent tokens of a feature are prohibited within a tier.

Under this view, representations such as (55) are also banned. Since both the OCP and *GAP must be respected, a surface form such as *lend^{j}ũ 'dirty' will either violate one or the other, as in (57), and thus be ruled out.

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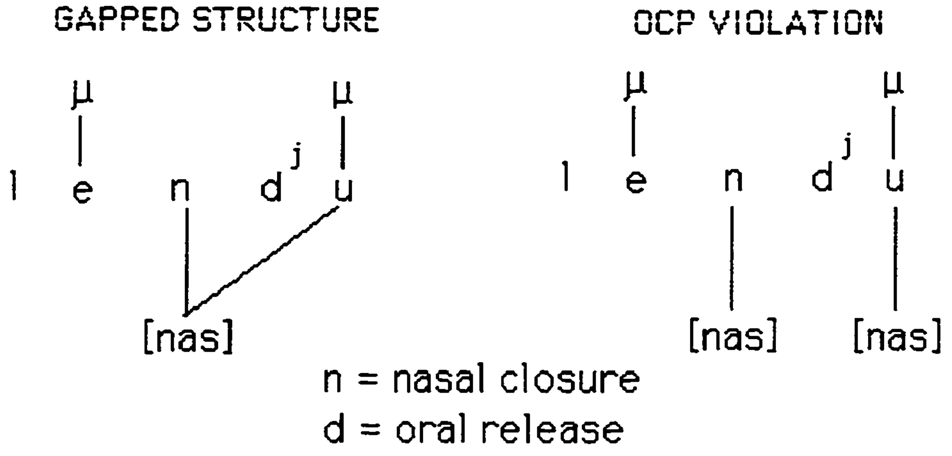
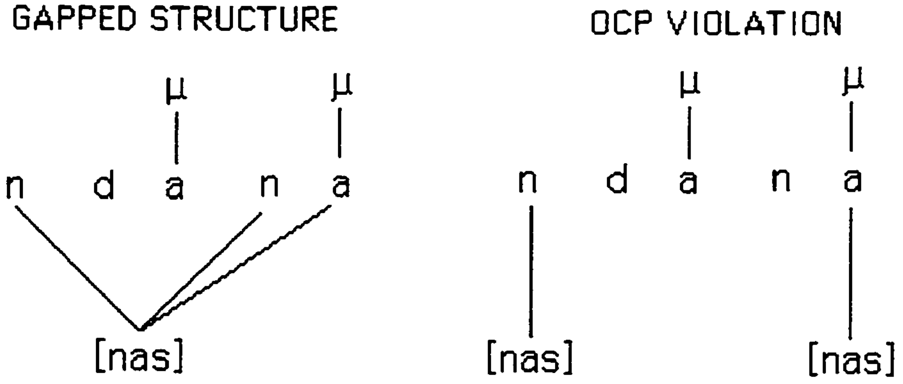
[36] The formulation and status of the OCP is subject to debate. See, for example, Archangeli and Pulleyblank (1994a), who provide a more complex calculation based on tier and anchor adjacency. See also Odden (1988) for arguments against the universality of the OCP and Pierrehumbert (1992) for arguments that calculation of the OCP is gradient and based on global notions of similarity rather than simple tier adjacency.

(57)



Note that the OCP also affords a straightforward account for the lack of couplets such as **ndanã*, given that either *GAP or the OCP must be violated for such forms to surface.

(58) **No ndvnṽ couplets**



In sum, the distributional properties of prenasalized stops support their being viewed as phonologically specified for [nasal] closure. And a formal treatment of their distribution motivates an analysis in which *GAP and the

OCP are inviolate, forcing violations of the rightward alignment of [nasal] in morphemes containing prenasalized stops. This leaves us, for the time being, with constraint ranking in (59).

(59) **OCP, *GAP >> AL-RIGHT, *NC >> *ṽN >> AL-LEFT**

Of these, I have motivated the ranked ordering of the OCP and *GAP over AL-RIGHT in order to account for the behavior of prenasalized stops. I have also motivated the ordering of AL-RIGHT and *NC over ALIGN-LEFT to account for the opacity of voiced stops and the ordering of *ṽN over ALIGN-LEFT to account for the orality of vowels in CVNV couplets such as _kunũ_ 'to run'. In the next section, I turn to the question of how to ban couplets such as *_nãta_ and *_nãnda_ given a violable AL-RIGHT.

4.2.2.5 *NV and If Left then Right

If AL-R is violable, what prevents the surfacing of generally unacceptable outputs such as *_nãta_ or *_nãβa_ or *_nãnda_? Arguably, all might be derived by respecting *GAP at the expense of rightward alignment.[37] I

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[37] Other possible candidates are *nãβ̃ã and nãt̃ã in which both AL-R and *GAP can be satisfied via the association of [nasal] to the medial consonant. I assume that such forms are ruled out by phonetically motivated constraints banning the phonological association of [nasal] to continuant consonants (cf. Cohn 1989, 1993b) and voiceless segments (see Pulleyblank 1989, Gerfen 1993, 1994). To simplify the discussion above, I ignore such candidates, though I return to these issues in the discussion of phonetic implementation below.

argue that alignment is, in fact, relevant to ruling out such forms. In particular, I return to the observation that the distribution of nasality in CM roots involves the interplay of two factors: prosodic or vowel-to-vowel nasalization that responds to alignment pressures and root-to-root nasalization driven by a constraint that I will call *NV, the effect of which will be to ban oral vowels from following an immediately preceding [nasal] specification.

The key to the solution lies in allowing violations of AL-R in roots containing prenasalized stops, while at the same time forcing all other instances of [nasal] to be aligned with the rightmost mora of the root. I argue that the first step involves postulating an undominated *NV such that an inevitable consequence of satisfying *NV for initial nasal stops is that Align-Left will be satisfied: e.g. **nãCa,* (where C is any non full nasal stop). Though I return in more detail to the formalization and motivation for *NV below, we can informally conceive of *NV as a constraint banning oral vowels following a full nasal stop.

Under pressure from *NV, any vowel following a full nasal stop must be nasalized. The second step involves the hypothesis that there is indeed an inviolable quality to rightmost alignment, but that what is inviolable is its relationship to leftmost alignment. That is, what is inviolable about rightmost moraic alignment in the language is that the satisfaction of leftmost alignment is always accompanied by the satisfaction of rightmost alignment. In logical terms, we can say that there is a one-way entailment relation between the two alignment constraints such that satisfaction of leftmost alignment entails satisfaction of rightmost alignment. This relationship is characterizable as a constraint expressed in terms of the logical conditional in (60).

(60) **ALIGN-LEFT → ALIGN RIGHT (L → R):**

> *"If leftmost moraic alignment is satisfied, then rightmost moraic alignment is satisfied."*

The use of such a constraint in an Optimality Theoretic grammar is in keeping with recent arguments for recognizing relations between constraints involving interactions beyond simple ranking, i.e. relations such as constraint conjunction (Smolensky 1995, Suzuki 1995, Archangeli and Suzuki 1995, Crowhurst and Hewitt 1996) and disjunction (Kirchner 1995a). For the data at hand, ordering L → R and *NV over AL-R in our constraint hierarchy rules out forms such as **nãnda*. This is shown in the tableau in (61). Though I return to the issue of what it means to be ruled out in §4.2.2.6, to simplify the discussion here, what is important is that we assume that the highest ranked constraints in the hierarchy are inviolate; i.e., no optimal output forms can surface if they incur violations of these constraints.

(61) **Tableau illustrating the unacceptability of *NVndV**

Input: nãnda	***NV**	***GAP /OCP**	**L → R**	**AL-R**	***NC**	***ṽN**	**AL-L**
a) nãndã		*!		*		*	
b) nãnda			*!	*		*	
c) nandã	*!	*					
d) nanda	*!	*		*			*

Note that all of the output candidates in (61) violate at least one of the set of inviolable constraints. Candidate (a) must either violate the OCP or *GAP, since [nasal] is associated to both vowels flanking the prenasalized stop. Crucially, the form in (b) violates the conditional L → R under pressure to satisfy *NV, and in similar fashion, (d) fails to satisfy *NV (and *GAP/OCP) by satisfying L → R. Finally, (c) also runs aground both by violating *NV and *GAP/OCP. In the same way, the grammar rules out possible output structures such as *nãβa, *nãβã, *naβã, and *naβa. If *NV is satisfied, either *GAP/OCP or L → R must be violated.

Note that *NV is crucial to ruling out potential but unattested surface forms such as *naβa or *nata* in that were it not for the pressure to nasalize a vowel following a nasal consonant, such surface forms might be expected to surface, as do forms such as *ndaðɨ* 'closed'. That is, we might restrict [nasal] to the first consonant only of *naβa*, thus trivially satisfying the conditional

L→R. In this sense, it would be desirable if there were independent motivation for a constraint forcing the perseveratory coarticulation of [nasal], independent of the problem of the alignment of root nasality. I argue that such evidence lies in the intra-morphemic spreading of [nasal] to vowels. Consider the data in (62), in which the verbal prefix [nã] is added to vowel-initial verb roots containing no root nasalization.

(62)	a) /nã + uʔ^{u}βi/	[nãũʔ$^{\tilde{u}}$βi]	'frighten, scare'
	b) /nã + uβi/	[nãũβi]	'lick'
	c) /nã+ iʔ^{i}tsi/	[nãĩʔ$^{\tilde{\imath}}$tsi]	'dry'

These data are indicative of a general pattern in the language. In traditional terms, the data in (62) and other similar forms would motivate an iterative, post-lexical rule of rightward nasal spread that is blocked by any supralaryngeal consonant. For our purposes here, the data are interesting in that they indicate that although couplets such as *ĩʔ$^{\tilde{\imath}}$*tsi* are banned from the language as possible roots, such strings can arise under pressure from segment-to-segment coarticulation, provided that the nasality of the vowel originates in another morpheme. Building on Steriade's (1993) observation that vowels and stop releases can both be characterized as Amax nodes--i.e. as having maximum aperture--I propose the *NV can be formalized to guarantee that any Amax immediately following an Amax specified for [nasal] must also be specified for [nasal]. In this way, we capture both the fact that full nasal stops will force the nasalization of a following vowel and that the language bans all *ṽv sequences as well, even across word and morpheme boundaries.[38]

(63) ***NV**: No oral Amax immediately following a [nasal] Amax

Of course, given that *NV forces the generation of surface forms such as *nãũβi* 'lick', we must address the question of whether L→R is violated in such strings. One possibility is to postulate that *NV is ordered above L→R, thus forcing the violation of the latter. This move, however, would appear to predict that we should find monomorphemic forms such as **nãβa*, but we do not. I propose that the answer to the puzzle is to limit the scope of our alignment constraints such that they govern the distribution of root [nasal] specifications only. In this way, attested poly-morphemic forms such as [nãũβi] (from /nã + uβi/) 'lick' will not incur L→R violations, while monomorphemic roots such as **nãβa* must fatally violate either *NV or L→R, neither of which is an acceptable alternative.

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[38] This is subject to some exceptions. For example, within a sentence, an oral vowel might follow a nasal vowel if a speaker makes a clear pause between a word ending in a nasal vowel and a following word is V-initial.

Now let us reconsider the generation of forms such as *lend^{j}u* 'dirty' and *ndaa* 'straight, direct'. Consider the tableau in (64):

(64) **Tableau for lend^{j}u 'dirty'**

Input: lend^{j}u	*NV	*GAP /OCP	L→R	AL-R	*NC	*$\tilde{v}$N	AL-L
a) ☞ lend^{j}u				*			*
b) lend^{j}ũ		*!					*
c) lẽnd^{j}u			*!			*	
d) lẽnd^{j}ũ		*!				*	

Only candidate (a) satisfies all of the inviolate constraints, though it violates AL-R in so doing. Nevertheless, we have not addressed the question of why the input *lend^{j}u* maps to the identical output *lend^{j}u*. That is, given an input [lend^{j}u], we might also consider an output candidate such as *_lenũ_ in which AL-RIGHT is satisfied and only the lowly AL-L is violated under pressure to satisfy *$\tilde{v}$N. In the context of correspondence theory, the answer to this question would appear to lie in the domain of input-output faithfulness. Yet, as I discuss in §4.2.2.6, this issue is less trivial than it might intuitively appear to be.

4.2.2.6 Inviolability, correspondence and input

In principle, a way of understanding the status of inviolate constraints (INVIOL) in a correspondence-based Grammar (G) is to view them as ranked above all correspondence constraints (FAITH) in the grammar. In this fashion, any input with an identical output that would violate a constraint INVIOL would be forced to incur at least one FAITH violation in the mapping to an acceptable surface form under G. At the same time, as I discuss in Chapter 3, since we cannot assume that inputs are unique in an Optimality Theoretic model, there will be multiple inputs that map to the same surface form. To take the example of glottalization in CM, an input [kauʔ^{u}] will map to an output form [kau] under pressure from the inviolable CG/STR constraint. Nevertheless, modulo lexicon optimization, we can show that there exists a more optimal input form [kau] that maps to the same output.

For surface forms containing prenasalized stops such as *lend*^{j}*u* 'dirty' or *ndaa* 'straight, direct' this suggests that some correspondence constraint (or constraints) must outrank AL-R in order to prevent *lend*^{j}*u* from mapping more optimally to a hypothetically acceptable output form such as [lenũ] or [leðu]. This is illustrated in simplified fashion in (65).

(65) **FAITH >> AL-R**

Input: lend^{j}u	***NV L → R *GAP/ OCP**	**FAITH**	**AL-R**	**AL-L**
a) ☞ lend^{j}u			*	*
b) lenũ		*!		

Candidate (a) is optimal because respecting faithfulness is more valued than rightward alignment. Intuitively, it seems clear that if this were not the case, we would never expect to find surface forms such as *ndaa* 'straight, direct' at all.

As in Chapter 3, I assume that the constraint Ident[F] (McCarthy and Prince 1995) governs input-output correspondence between features, as mediated at the segmental level. In this case, the relevant constraint requires input-output identity for the feature [nasal].

(66) **Ident(nasal):** Correspondents are identical in their specification for [nasal].

Thus, ranking Ident(nas) above AL-RIGHT would appear to provide the final piece of the puzzle in accounting for the distribution of nasality within CM roots.

(67) **Ident(nasal) >> AL-RIGHT**

Consider, for example, a possible input such as [ndaa]. If Ident outranks AL-R, then faithfulness to input [nasal] will generate the expected surface form. This is seen in the tableau in (67).[39]

(67) **Tableau for input [ndaa]**

Input: ndaa	***NV**	***GAP /OCP**	**L → R**	***ṽN**	***NC**	**Ident (nas)**	**AL-R**	**AL-L**
a) ndãã		*!				*		
b) ☞ ndaa							*	*
c) nãã						**!		
d) taa						*!		
e) tãã						**!		

Here, we see that the grammar correctly chooses candidate (b), *ndaa*, as the optimal output candidate. The form in (a) is ruled out by its violation of *GAP (or the OCP). Candidates (c-e) all incur at least one fatal Ident(nasal) violation.[40]

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[39] Given the high ranking of *NV in the hierarchy, I no longer assume the ranking AL-R >> *ṽN is motivated by forms such as nũnĩ 'corn' (see figure 43). Rather, the nasalization of V1 in such forms can be attributed both the need to satisfy *GAP/OCP and *NV. AL-R can thus be freely demoted in the hierarchy.

[40] Note that I assume that the loss of [nasal] for a prenasalized stop will result in a surface [t] in candidates (d-e). This is because the language contains no plain voiced stops. There is a tacit assumption here that voiced stops must be nasal, which could be encoded as a constraint on the representation of stop

For inputs such as [ndãã], consider the tableau in (68).

(68) Tableau for input [ndãã]

Input: ndãã	*NV	*GAP /OCP	L→R	*ṽN	*NC	Ident (nas)	AL-R	AL-L
a) ndãã		*!						
b) ☞ ndaa						*		
c) ☞ tãã						*		

Here, note that the grammar does not choose (a) as the optimal output. Rather, it will choose to violate either Ident(nas) for the vowel or for the initial consonant in mapping the input to a possible surface form. I do not assume that the grammar must unambiguously map all inputs to a distinct output. As we saw in Chapter 3, distinctiveness does not reside in the assumption of a unique UR but rather distinct sets of optimal inputs. A consequence of this is that multiple inputs may converge on a single output under a particular grammar. What is important for our purposes here is that we see that the grammar does not generate impossible forms.

Note that it appears that Ident(nasal) must be outranked by *ṽN and *NC in order to prevent faithfulness to possible input candidates such as *_lẽnd^{j}u_ or *_tãʔ^{ã}ta_. Note, however, that given our hierarchy, we cannot prove

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voicing. This issue is tangential to the point at hand, since both surface forms are more optimally paired with respectively identical inputs than with [ndaa] as in the tableau. Note also that under the assumption that [aa] is a single this ordering, as faithfulness to such forms would incur a violation of the even more highly ranked L → R.

A final problem is that our ranking of Ident(nas) over both AL-L and AL-R incorrectly predicts that we should find surface forms such as **kiðĩ*, given the possibility of the identical input form [kiðĩ]. This is shown in the tableau in (69).

(69) **Tableau for input [kiðĩ]**

Input: kiðĩ	***NV *GAP /OCP L → R**	***ṽN *NC Ident (nas)**	**AL-R**	**AL-L**
a) kiði		*		
b) kĩðĩ		*		
c) ☞ ?? kiðĩ				*
d) kĩði	*!		*	

In this case, faithfulness to input [nasal] only triggers a violation of the lowly ranked AL-L. Though either (a) or (b) should be preferable surface forms for this input, the ranking of Ident(nas) over both alignment constraints selects (c) as the optimal output form.

Again, we are left with the problem of the special nature of prenasalized stops. If the ranking Ident >> AL-R accounts for the ability of

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vowel root, only one violation of Ident(nas) is assessed in candidate (a).

prenasalized stops to circumvent alignment pressures, and AL-R outranks AL-L, then we should rule in impossible forms such as **kiðĩ*. Note, however, that with the incorporation of an undominated L → R into our hierarchy, we no longer require the original ranking AL-R >> AL-L. That is, we need not assume that Ident(nas) need dominate AL-L. Given the power of L → R, satisfaction of leftmost alignment mandates concomitant satisfaction of rightmost alignment. If we assume the ranking AL-L >> Ident(nas), then our input **kiðĩ* will not map to an identical (and illicit) output form.

(70) **Revised tableau for input [kiðĩ]: AL-L >> Ident(nasal)**

Input: kiðĩ	***NV *GAP /OCP L → R**	***ṽN *NC**	**AL-L**	**Ident (nas)**	**AL-R**
a) ☞ kiði				*	
b) ☞ kĩðĩ				*	
c) kiðĩ			*!		
d) kĩði	*!			**	*

Under this ranking, the grammar now maps the input to either (a) or (b), given that both forms incur a single violation of Ident(nas), but respect the more highly ranked constraints in the hierarchy. Importantly, both forms are possible surface forms under this grammar. Again, in each case, a more optimal input can be shown to exist (modulo lexicon optimization), but what is crucial here is that the ranking AL-L >> Ident(nas) provides a means of eliminating possible surface forms such as *kiðĩ, while at the same time affording an identity-based account of the distribution of [nasal] in couplets containing prenasalized stops.

A final, partial ranking of constraints governing the distribution of root nasality is provided in (71).

(71) ***NV, *GAP, OCP, L → R >>*ṽN, *NC >> AL-L >> Ident(nas) >> AL-R**

In §4.2.2.7, I address remaining questions and summarize the results.

4.2.2.7 Remaining issues and summary of root nasalization

In this section I explore an issue that remains from the discussion above. This concerns the status of /ð/. As in the case of glottalization, /ð/ displays special properties in the way in which it patterns with respect to root nasalization. One oddity concerning the distribution of contrastively nasalized vowels is that in those couplets with a transparent medial consonant, the consonant is always /ð/. (As we will see below, this is not the case for second person familiar nasalization.) Why, we are led to ask, is /ð/ the only phonetically voiced consonant to appear between contrastively nasalized vowels?

A large part of the answer resides in the phonology of nasal consonants and prenasalized stops. These are by far the most common of the phonetically voiced consonants, and, as I have shown above, the constraint hierarchy functions in such a way as to render lexical nasalization impossible to discern in both. In the case of CVNV forms, *ṽN enforces the orality of V1. In NVNV forms, satisfaction of *NV itself guarantees perseverative nasalization of both vowels. And in the case of prenasalized stops, the effect of the constraint hierarchy is such that it will block the cooccurrence of nasalized vowels in forms containing prenasalized stops.

In essence, this reduces the gap to the absence of /β/ between lexically nasalized vowels (since there are almost no medial /l/'s and, as we recall from Chapter 2, there are few /r/'s , and their status is marginal). Though /β/ is not vanishingly rare, neither is it found in a large number of forms. Furthermore, there appears to be no current day constraint on the appearance of /β/ in morphemes with nasalization.

(72)	βĩðĩ	'sweet'
	βiʔⁱtsĩ	'cat'
	βiʔⁱʃĩ	'cold'
	βẽðũ	'scrubbing pad'
	βinĩ	'mean, petty'

Synchronically, I thus take this absence to be a lexical gap. Nevertheless, an intriguing (though not immediately obvious) diachronic explanation may lie in Marlett's (1992) claim that across all current day Mixtec languages, both nasalized vowels and fully nasal consonants arise from the right-to-left, segment-to-segment spreading of a lexically contrastive [nasal] autosegment. Marlett maintains that prenasalized stops are simply the phonetic manifestation of non-nasal, sonorant stops. This is in-line with the possibility that I raised above that prenasalized stops might be thought of as the phonetic implementation of stop voicing. For Marlett, leftward spreading of floating [nasal] targets all segments until it is arrested by a voiceless sound. Thus, nasal stops are sonorant stops associated to [nasal]. Prenasalized segments are sonorant stops that are not associated to [nasal], i.e. sonorant stops in morphemes not lexically specified for floating [nasal].[41]

A major problem with Marlett's analysis, however, is that his analysis fails to make clear whether it provides a diachronic or synchronic account of the facts.[42] If it purports to account for the synchronic distribution of nasality in the Mixtec languages, it makes the wrong predictions for CM. In particular, it affords no account whatsoever of the predictable orality of vowels in all (C)VNV couplets such as *kun*ũ 'to run', i?ⁱnĩ 'hot', or β*in*ĩ 'mean, petty'. On the contrary, it predicts that the first vowel in all such forms should be nasalized, as in the incorrect **kũn*ũ 'to run', since nasalization spreads leftwards until arrested by a voiceless stop. Additionally, it provides no

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[41] This idea is similar to ideas advanced in Piggott (1992). Note that for CM, the bilabial sonorant "stop" would not be /mb/ but the fricative /β/.

[42] I thank Joseph Salmons for discussion of this point.

account for the prohibition against morphemes containing two prenasalized stops, e.g. **ndanda*. Rather, these should be commonly attested, given that they are the hypothetical non-nasalized counterparts of NVNV couplets such as *n*ãʔ$^{\tilde{a}}$*n*ũ 'big'.[43]

In another sense, there does seem to be insight in Marlett's analysis in the fact that modern day CM /ð/ is diachronically derived from the voiceless proto-consonant */s/ (see discussion in Chapter 3). If we assume some diachronic process along the lines Marlett suggests, and if the right-to-left nasalization of sonorant consonants and vowels were to have run its course prior to the */s/ to /ð/ sound change for CM, then we might have an explanation for the lack of other voiced, medial consonants in synchronic forms. That is, we could argue that the presence of medial /ð/ in couplets with contrastively nasal vowels is the residue of its earlier status as the voiceless, and thus opaque, */s/. Secondly, after its change to the voiced segment /ð/, we can assume that the constraints of the synchronic grammar would force the leftward moraic alignment of [nasal], thus aligning [nasal] with the leftmost vowel and flanking the now medial voiced fricative in the root. This is not entirely implausible. However, so much of the synchronic

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[43] In making claims for all of the Mixtec languages, it is not clear how well any particular variety of Mixtec is characterized when Marlett's account is subjected to close scrutiny.

data remains unexplained under Marlett's general analysis that such scenarios are best viewed as highly speculative.

In summary, the analysis of root nasalization presented above is both simple and complex. It is simple in that the attested patterns appear to follow rather directly from two interacting sub-types of nasalization: 1) lexical vowel nasalization, whose distribution corresponds to that of canonical vowel harmony and in which opacity is derived by a phonetically grounded (cf. Archangeli and Pulleyblank 1994a) constraint banning nasal vowel-oral consonant sequences; and 2) the imperative of perseverative nasalization following nasal consonants. The system is complex in that I have argued that the treatment of prenasalized stops and the concomitant need to rule out unattested (or vanishingly rare) patterns of [nasal] distribution in couplets motivates the use of a conditional constraint comprised of the simpler alignment conditions, AL-L and AL-R. Though such a strategy is in keeping with recent explorations of other Boolean combinations of constraints (cf. Smolensky 1995, Suzuki 1995, Kirchner 1995a), all such moves introduce powerful mechanisms into what began as a simpler notion of absolute domination and no trade-offs (cf. Prince and Smolensky 1993) in determining optimal outputs from constraint hierarchies.

A curious consequence of incorporating conditional alignment constraints into the analysis is that the effects of the simple alignment constraints themselves are not reflected directly in output forms--except to the extent that the ranking AL-L >> Ident(nas) prohibits faithfulness to an input such as *kĩðĩ*. Consider, for example, the case of any form containing a full nasal stop. Since *NV requires the nasalization of the following vowel, this vowel must be nasalized regardless of alignment pressures. If the nasal consonant is medial, there are two possibilities: 1) there is an initial nasal consonant, or 2) there is either no initial consonant or a non-full nasal stop in initial position. In the latter case, despite pressure from AL-L, the higher ranked *ṽN must be respected and the initial vowel will be oral. In the former case, the initial vowel will be nasalized under pressure from the inviolable *NV.

Finally, the treatment of the distribution of root nasality calls attention to the way in which an Optimality Theoretic grammar forces us to explicitly attempt not only to characterize what we find at the surface, but to eliminate unattested patterns in terms of the constraints that generate the attested surface forms in conjunction with correspondence-based faithfulness. For CM, I have attempted to provide a rigorously explicit account of how this might be achieved for the distribution of [nasal] in CM roots. In §4.2.3, I complete the discussion of the phonology of nasalization with an analysis of nasalization in the morphological context of the second person familiar.

4.2.3 The second person familiar

In this section, I characterize the distribution of [nasal] in the second person familiar (2-FAM). Generally speaking, the descriptive facts resemble those of lexical nasalization in §4.2.2. The second person familiar is formed by regressive vowel nasalization, and as with lexical nasalization, both vowels of a couplet will surface as nasalized (a-b), provided that the couplet does not contain a medial, voiceless consonant (c).

(73)	a) kaʔu	'to write'	→	kãʔũ	'you (fam) will write'
	b) kuβi	'to die'	→	kũβĩ	'you (fam) will die'
	c) kaʔᵃka	'to walk'	→	kaʔᵃkã	'you will walk'

At first glance, the transparency of phonetically voiced consonants appears to be directly accounted for via the satisfaction of the two alignment constraints, while *NC characterizes the opacity of voiceless consonants. This is illustrated in the simplified tableaux in (74) and (75), respectively.[44]

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[44] Note that (74c) and (75c) would also violate the even more highly ranked conditional constraint L → R.

(74) **Tableau for kuβi+ [N]2-FAM**

Input: **[kuβi] + 2-FAM**	***NC**	**AL-R**	**AL-L**
a) ☞ kũβĩ			
b) kuβĩ			*!
c) kũβi		*!	

(75) **Tableau for kuʔ^{u}tsi 'to bathe' + [N]2-FAM**

Input: **kuʔ^{u}tsi + 2-FAM**	***NC**	**AL-R**	**AL-L**
a) ☞ kuʔ^{u}tsĩ			*
b) kũʔ$^{\tilde{u}}$tsĩ		*!	
c) kũʔ$^{\tilde{u}}$tsi	*!	*	

The situation becomes slightly more complicated, however, when we consider the behavior of medial nasal stops. Recall that these pattern with other voiced consonants in that they are transparent to 2-FAM harmony.

(76) **Transparency of medial nasal stops**

a) kinĩ	'to listen'	→	kĩnĩ	'you (fam) will listen'
b) kiʔ^{i}nĩ	'to tie down'	→	kĩʔ$^{\tilde{\imath}}$nĩ	'you (fam) will tie (it) down'

The core of the problem is the following. The behavior of medial nasals in CV(ʔ)NV couplets in the second person familiar appears to reveal an ordering paradox in the constraint hierarchy. In non-derived forms, vowels are predictably oral before nasal consonants, a fact which can be accounted for above under the constraint ordering *ṽN >> AL-L. In the 2-FAM case, however, vowels are predictably nasalized in this context, suggesting the opposite ordering: A-LT >> *ṽN.

I argue that the problem resides in the conflation of two distinct issues: 1) the alignment within roots of lexical [nasal] and 2) the alignment of a morphological category--the [nasal] morpheme that expresses the second person familiar--with a word. A clear indication that the two issues are distinct is that the domain over which 2-FAM nasalization obtains is larger than the single root. In particular, the domain of nasalization, like that of glottalization in Chapter 3, is constituted by the phonological word. Consider, for example, the data in (77).[45]

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[45] This provides further evidence that the scope of AL-R and AL-L is root nasality, as argued in the discussion of *NV above.

(77) **Non-Nasal Forms**		**2-FAM Forms**	
a) tɨβi	'to blow'	tɨ̃βĩ	'you (fam) will blow'
b) tɨβi kʷii	'to blow + slowly'	tɨβi kʷĩĩ '	'you (fam) will blow slowly'
c) tɨβi βaʔa	'to blow + well'	tɨ̃βĩ βãʔã	'you (fam) will blow well'
d) kuʔᵘtʲu	'to plow, hoe'	kuʔᵘtʲũ	'you (fam) will plow'
e) kuʔᵘtʲu kʷii	'to plow + well'	kuʔᵘtʲu kʷĩĩ	'you (fam) will plow slowly'
f) kuʔᵘtʲu βaʔa	'to plow + slowly'	kuʔutʲũ βãʔã	'you (fam) will plow well'

In traditional, autosegmental terms, the data in (a-f) reveal that the target for association of the [nasal] morpheme that marks the second person familiar is the rightmost mora of the phonological word. Leftward spread then proceeds from vowel to vowel, provided that a voiceless consonant does not intervene. This is clearly shown in examples such as (b) and (e), in which the presence of the initial voiceless stop [kʷ] in the adverbial couplet /kʷii/ prevents nasalization from reaching either verb. In (f), since the adverb contains an initial voiced fricative, nasalization reaches the final vowel of /kuʔᵘtʲu/ before its further propagation is blocked by a voiceless consonant.

Once we recognize this distinction, we can force the violation of *ṽN under pressure to align the second person familiar morpheme with the leftmost mora of the prosodic word, as in (78).

(78) **Align [2-FAM] Left (2-LEFT)**

Align [2-FAM],Left; Leftmost-μ(P-WD),Left)

The transparency of nasal stops to 2-FAM harmony follows directly from the ordering 2-LEFT >> *ṽN, as seen in the tableau in (79) for *kũnũ* 'you (fam) will run'.[46]

(79) **2-LT >>* ṽN**

Input: **kunũ + 2-FAM**	**AL-R**	**2-LEFT**	***ṽN**
a) ☞ kũnũ			*!
b) kunũ		*!	

Returning to the treatment of the opacity of voiceless consonants, we must now ask why 2-LEFT fails to align the [nasal] feature marking the second person familiar with the leftmost mora of a root. To account for this, I first assume a counterpart alignment constraint, 2-RIGHT, which aligns the second familiar morpheme with the rightmost mora of a prosodic word.

(80) **Align [2-FAM] Right: (2-RIGHT)**

Align [2-FAM],Right; Rightmost-μ(P-WD),Right)

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[46] Alternatively, we might explore the hypothesis that *ṽN obtains only of root nasal specifications; either approach, however, must explicitly recognize the distinction between a root [nasal] specification and [nasal] corresponding to the 2-FAM morpheme. I return to this issue in more detail below regarding the status of *NC.

Secondly, I claim that just as *NC bans the presence of a [nasal] vowel before a voiceless consonant, it outranks 2-LEFT, yielding the partial hierarchy in (81).

(81) **2-RIGHT , *NC >> 2-LEFT**

Under this analysis, the treatment of nasalization in the second person familiar correlates closely with that of lexical vowel nasalization. Moraic alignment constraints account for what in autosegmental terms would be the spreading of [nasal] from vowel to vowel, while *NC derives the opaque behavior of voiceless consonants in both contexts. The only difference lies in making a familiar distinction between the alignment of a lexical [nasal] specification within a morpheme and the alignment of a morphological category, the 2-FAM morpheme, with the prosodic word. A revised tableau for *ku?^{u}tsī* 'you (fam) will bathe' is provided in (82).

(82) **Tableau for ku?^{u}tsi 'to bathe' + [N]2-fam**

Input: **ku?^{u}tsi +2-FAM**	**2-RIGHT**	***NC**	**2-LEFT**
a) ☞ ku?^{u}tsī			*
b) kũ?$^{\tilde{u}}$tsī		*!	
c) kũ?$^{\tilde{u}}$tsi	*!		

Under this ranking the output candidate (a) is optimal, given that satisfying leftward alignment would violate the more highly ranked *NC. Forms containing a lexically nasalized vowel that can also undergo 2-FAM nasalization, such as *ðu?^{u}kũ* 'tall' and its homophonous 2-FAM counterpart *ðu?^{u}kũ* 'tall' 'you (fam) are tall', can be accounted for in the following manner.

(83) **Tableau for ðu?^{u}kũ 'tall' + [N]2-fam**

Input: **ðu?^{u}kũ + 2-FAM**	**2-RIGHT**	***NC**	**2-LEFT**
a) ☞ ðu?^{u}kũ			*
b) ðũ?^{ũ}kũ		*!	
c) ðũ?^{ũ}ku	*!		

Under pressure from *NC, both root and 2-FAM [nasal] specifications are restricted to the final vowel of the couplet. For simplicity, I exclude root nasal alignment constraints from the tableau, but their inclusion would not affect the optimal output. Candidate (a) is selected as the optimal output form, under pressure to respect *NC.

The transparency of prenasalized stops can also be accounted for by distinguishing between the alignment of root [nasal] and that of the 2-FAM morpheme. This is shown in the tableau in (84) for the input [lu?^{u}ndi + 2-

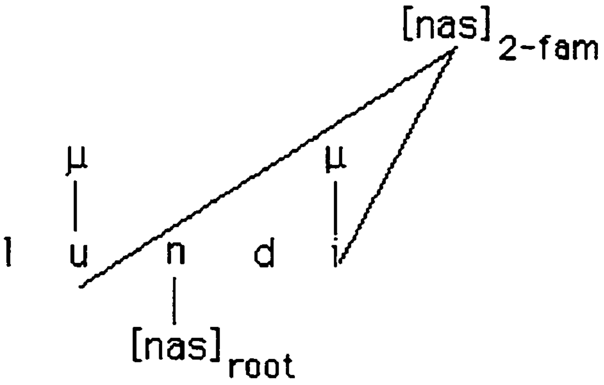
FAM] 'you (fam) are small'. Note that in interpreting the tableau, for simplicity I assume that all nasalized output vowels result from the association of the [nasal] morpheme that marks the 2-FAM. As per the earlier discussion of prenasalized stops, if the root [nasal] specification were associated to these vowels, either *GAP or the OCP would be fatally violated. As a consequence, AL-L and AL-R, constraints governing the distribution of root nasalization, are violated in all of the output forms.

(84) **Prenasalized stop transparency**

Input: luʔ^{u}ndi + 2FAM	**2-R**	**2-L**	***ṽN**	**AL-L**	**AL-R**
a) luʔ^{u}ndĩ		*!		*	*
b) ☞ lũʔ$^{\tilde{u}}$ndĩ				*	*
c) lũʔ$^{\tilde{u}}$ndi	*!			*	*

The optimal candidate in (b) satisfies both rightward and leftward alignment of the 2-FAM morpheme. An issue that arises, however, is whether such an output violates what I have claimed to be the inviolate constraints, *GAP and the OCP, given that 2-FAM nasalization appears to skip over the oral release of the medial prenasalized stop. I argue that it does not, under the assumption that the output representation of the optimal candidate (b) is that shown in (85).

(85) **Transparency of prenasalized stops: lũʔ$^{\tilde{u}}$ndĩ 'you (fam) are small'**



n = nasal closure
d = oral release

Such a representation neither violates *GAP nor the OCP for [nasal], if we bear in mind the distinction between [nasal] specifications pertaining to the root and the [nasal] feature that constitutes the second person familiar morpheme. Following McCarthy (1979) and Cole (1987), I assume that the token of [nasal] marking the second familiar here lies on a distinct plane from the lexical specification of [nasal] that is docked to the closure node of the stop.[47] In this sense, the familiar notion that OCP violations are calculated within rather than between morphemes is encoded in the analysis.

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[47] By contrast to McCarthy (1979) and Cole (1987), however, I assume within the context of an Optimality Theoretic grammar that there is no derivational ordering between association and subsequent plane conflation. Rather, I assume that (85) is the representation of the output candidate.

At the same time, as I have shown in the discussion of lexical vowel nasalization, since the only anchors for 2-FAM nasalization are moraic, I follow Archangeli and Pulleyblank (1994a) in calculating locality entirely on the moraic tier. Technically, this result follows from drawing a distinction between types and tokens. I assume that both lexical nasality and 2-FAM nasalization are expressed via the specification of a phonological [nasal] feature. However, as the representation in (85) above shows, these can cooccur in a 2-FAM word as two distinct tokens of [nasal], each on its own plane. Given the definition of GAP, *GAP is not violated in such cases.

(86) **GAP:** For any multiply associated feature [F], the domain of association of [F] is gapped iff the set of associations:

i) consists of prosodic anchors only AND
contains a prosodic anchor not associated to [F]

OR

ii) consists of root anchors only or both root and prosodic anchors AND
contains any anchor not associated to [F].

In short, in (85) the token of 2-FAM nasal is multiply linked, but since its domain of association consists entirely of prosodic anchors, *GAP is respected.

A more interesting problem arises concerning the interaction of *NC and 2-FAM harmony in words that are larger than a single couplet. Consider, for example, forms such as *kunũ kʷĩĩ* 'you (fam) will run slowly'. In the string [kunũ + kʷĩĩ], the ban against sequences consisting of a nasal vowel followed by a voiceless consonant must either be violated or defined in such a way such that it is irrelevant to this configuration. One simple hypothesis regarding this string is to assume that the inviolate *NV forces the violation of a lower *NC.

However, this argument itself is not sufficient. Note that surface exceptions to *NC arise independently of NV contexts, as in /kuʔᵘʃĩ + kʷii/ 'bury + slowly + 2-FAM', which surfaces as kuʔᵘʃĩ kʷĩĩ 'you (fam) will bury' in the second person familiar. That the nasality of the adverb derives from the second person familiar and not the final vowel of the verb root is evidenced by constructions such as *kuʔᵘʃĩ kʷii ta Liʔⁱta* 'Lita will bury slowly'. Descriptively speaking, the problem is that we find surface violations of *NC within the domain of the phonological word, but at the same time, the phenomenon of 2-FAM nasalization will not incur such violations. That is, violations only surface when such sequences occur across morpheme boundaries, i.e. when [nasal] is present on the final vowel of a root, either lexically or following a nasal consonant, but, to use the language of autosegmental spreading, 2-FAM nasalization will still not spread over a voiceless consonant in a string.

As a first approximation, we might take the following approach to this problem. Building again on the distinction between constraints governing the distribution of [nasal] within roots and those governing the alignment of one morpheme (the 2-FAM) with a host phonological word, we can subdivide

*NC into two constraints, one holding within roots and of root specifications for [nasal] and a second holding of the [nasal] feature that constitutes the 2-FAM morpheme.

(87) ***NC-root (*NC-r):**

> For any root R containing a root-[nasal] specification associated to a vowel V, ban the sequence VC, where C is a [-voice] consonant in R.

(88) ***NC-2-FAM (*NC-2):**

> For any phonological word PW containing a vowel V associated to 2-FAM-[nasal], ban the sequence VC, where C is a [-voice] consonant in PW.

If we assume that *NC-2 is inviolable, this guarantees the opacity of voiceless stops to 2-FAM harmony, while allowing them to be preceded by a nasalized vowel, as in the string *kun*ũ *kw*ĩĩ 'you (fam) will run slowly'.

Interestingly, this approach is in keeping with the spirit of McCarthy's (1996) treatment of Rotuman and, in particular, with the notion that distinct correspondence relations can be subject to distinct faithfulness constraints in a grammar (see also McCarthy and Prince 1995, Benua 1995). This is not immediately obvious given that *NC is not a faithfulness constraint, but rather, a constraint on the shape of possible output structures in the language. However, its bifurcation amounts to an explicit recognition that constraints can hold of particular morphological relations between input and output. What *is* undesirable about the above constraints is that it looks as though a single output constraint has been defined as two in order to avoid incurring *NC violations between roots, just in case such violations would be triggered by a root nasal specification.

An alternative is to explore the use of faithfulness in deriving the difference. Here, I argue that a plausible solution lies in the recognition of feature specific faithfulness constraints--the featural equivalent of the MAX and DEP constraints proposed by McCarthy and Prince (1995) for segmental correspondence. In particular, I show that a highly ranked MAX(nasal) provides a straightforward characterization of how *NC is both respected by 2-FAM nasalization and violated in strings such as *kunũ kwĩĩ* 'you (fam) will run slowly'. Adopting the MAX and DEP constraints of McCarthy and Prince (1995), suppose that correspondence relations can obtain between features directly--as well as through the segmentally mediated Ident(F) family of constraints[48]. These are adapted here to refer to features as follows.

(89) **Max[F]:** Every feature [F] in S_1 has a correspondent in S_2.

(90) **Dep[F]:** Every feature [F] in S_2 has a correspondent in S_1.

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[48] As McCarthy (1996) notes in pursuing this idea in Rotuman, it is reasonable on independent grounds to assume that features are subject to identity relations independent of their segments, since faithfulness to features is a viable means of understanding stability effects under segmental deletion. McCarthy also cites Lombardi (1995) for arguments in favor of the necessity of direct feature correspondence. See also Orgun (1995) on featural faithfulness in correspondence theory.

Most interesting to the discussion here is that the introduction of feature-specific faithfulness constraints affords a more finely grained approach to calculating relative input-output faithfulness than that available to a model in which feature correspondence is mediated through segments. Specifically, consider an input string (S_1) comprised of a segment α associated to nasal and another segment β that is not associated to [nasal]. Assuming a monovalent [nasal] feature, if β is associated to [nasal] in the output string S_2, then the input-output mapping for β necessarily incurs a violation of Ident(nasal). That is, the featural identity of β for [nasal] is distinct. However, if α is still associated to [nasal] at output, the constraint Max(nasal) is respected, given that the input [nasal] specification of α has a correspondent in the output form.

For 2-FAM nasalization, I argue that a highly ranked Max(nasal) in the mapping from strings of roots to 2-FAM forms provides a simple account for why *NC can be violated. In simple terms, my claim is that *NC is violated if and only if satisfaction of *NC would trigger a violation of MAX(nasal) in the relation holding between roots and the 2-FAM. At the same time, since MAX(nasal) enforces a one-way correspondence between input and output, we can add [nasal] to input strings under pressure to align the 2-FAM morpheme. The association of the 2-FAM morpheme will violate

Ident(nasal), but under the assumption that Ident(nasal) is outranked by the relevant alignment constraints for the second person familiar, this is inconsequential. Following McCarthy (1996), I formalize the statement of Max(nasal) in (91) to reflect its role in governing input-output relations involving the marking of the morphological category of the second-person familiar.

(91) **Max-2F(nasal):** Every feature [nasal] in S_1 has a correspondent in S_2.

Taking strings of roots comprising phonological words as the relevant input to 2-FAM tableaux, the effect of Max-2F is to guarantee that all input [nasal] specifications will be respected at output. Here, we consider the most interesting case--that of an input string consisting of a verb root, in which contrastive vowel nasalization is both present and limited to the final vowel of the verb. If this root is followed by a non-nasal adverb that begins with a voiceless consonant, as in /kuʔ^{u}ʃĩ + k^{w}ii + 2-FAM/ 'bury + slowly + 2-FAM', we see that ordering MAX(nas) over *NC generates the correct surface form.[49]

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[49] As I note above, this case is interesting in that the voiceless consonant will arrest the leftward extension of 2-FAM nasalization, while at the same time we cannot attribute the presence of the root [nasal] vowel to the inviolate nature of *NV.

(92) **Max-2F(nas) >> *NC, 2-R >> 2-L**

Input: **kuʔ^{u}ʃĩ + k^{w}ii + 2-F**	**MAX (nas)**	***NC**	**2-R**	**2-L**
a) ☞ kuʔ^{u}ʃĩ k^{w}ĩĩ		*		**
b) kũʔ^{ũ}ʃĩ k^{w}ii		**!	**	
c) kuʔ^{u}ʃi k^{w}ĩĩ	*!			**
d) kũʔ^{ũ}ʃĩ k^{w}ĩĩ		**!		
e) kuʔ^{u}ʃi k^{w}ii	**!			

In (92), I assume no ranking of *NC and 2-RIGHT, since all words are vowel final and the two will thus not conflict. As the tableau shows, the optimal candidate is (a), in which the input specification of [nasal] for the root *kuʔ^{u}ʃĩ* 'to bury' is respected under pressure from MAX(nas). This triggers a violation of *NC, but it is important to note that competing outputs are all less optimal. For its part, although (b) also satisfies MAX(nas), it violates *NC twice. The same is true of (d).[50] Both (c) and (e) are ruled out under the assumption that MAX(nas) is violated by the failure of correspondence for root nasal in the former and of both root [nasal] and the token of [nasal] constituting the 2-FAM morpheme in the latter.[51]

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[50] Recalling the discussion of transparency in prenasalized stops above, I assume that the nasalization of V1 in (b) results from the association of the 2-FAM morpheme. Association of the lexical [nasal] would constitute a fatal violation of the ranking *NC >> AL-LEFT for roots.

[51] Note that there is an alternative view of the optimal candidate in (a), in which the 2-FAM token of [nasal] is associated to both the final vowel of the verb and to the final vowel of the adverb. Given the constraints, I assume

Finally, it is important to make explicit a covert assumption in this analysis. Specifically, I have assumed that the [nasal] morpheme corresponding to the 2-FAM must be associated. Arguably, however, it might remain floating at output, satisfying MAX and trivially satisfying both alignment constraints. This possibility is a consequence of the formal properties of alignment in that alignment does not force association but rather imposes associative preferences if a feature happens to be associated in a given string. In a functionalist sense, it is clear why [nasal] must associate; it is the means by which the speaker expresses the intention to communicate in the second person familiar. More formally, we might express this as a constraint requiring that any token of 2-FAM-[nasal] must be associated at output, e.g. FORCE(2-FAM). The effect of FORCE(2-FAM) would be to ban any floating token of 2-FAM-[nasal]. Under this view, deletion from the representation would still violate the highly ranked MAX, while association would only result in a lowly ranked *Ident[F] violation.

In sum, the incorporation of the constraints pertaining to 2-FAM nasalization into the overall constraint hierarchy result in the ranking in (93):

(93): *NV, *GAP, OCP, L → R, >> MAX-2F(nasal) >>*NC >> AL-2R >> AL-2L
>> *ṽN >> AL-L >>Ident(nas) >> AL-R

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that such a form would be ruled out, as it would incur two violations of *NC, one corresponding to the *NC triggered by lexical nasalization, and the other

By transitivity, the transparency of nasal stops to 2-FAM nasalization and the concomitant blocking effect of voiceless consonants motivates the ordering of *NC >> ṽN. Recall that ṽN must outrank AL-L to prevent leftward alignment of [nasal] in CVNV roots. Finally, *NV, *GAP, OCP, L → R, MAX-2F(nasal) exhibit no clear evidence of ranking, either directly or by transitive relations between a partial ranking involving a subset of these constraints, though I rank MAX-2F under the other four in order to prevent faithfulness to unacceptable root input strings in the 2-FAM.

The treatment of 2-FAM nasalization is similar to that of lexical nasalization in that its prosodic (i.e. vowel to vowel) quality can be directly characterized in terms of moraic alignment. At the same time, it is different in that characterizing the distribution of 2-FAM nasalization requires a distinction between root [nasal] alignment and the alignment of roots (or strings of roots) and the 2-FAM morpheme. I capture this distinction in two ways. First, I posit particular alignment constraints to capture the larger domain of alignment for the 2-FAM morpheme. These are placed in the hierarchy such that by outranking *ṽN we can derive a distinction between the prohibition against *ṽN sequences within roots and the predictable appearance of such sequences in 2-FAM forms such as *kũnũ* 'you (fam) will

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triggered by the association of 2-FAM [nasal] to the final vowel of the verb.

run'. At the same time, they are outranked by *NC, deriving the opacity of voiceless consonants to both lexical and 2-FAM nasalization. Finally, I note that strings such as *kuʔᵘʃĩ kʷĩĩ* 'you (fam) will bury slowly' are interesting in that they motivate a view in which faithfulness to root [nasal], as expressed by MAX(nas), affords an explanation for why surface exceptions to *NC surface across morpheme boundaries within prosodic words.[52]

4.2.4 A final note on the status of /ʃ/

In this section, I briefly return to the issue the synchronic status of /ʃ/ in CM. As I discuss at length in Chapter 3, synchronic CM /ʃ/ derives from two historical sources (Josserand 1982): the proto-glide */y/ and the voiceless fricative */x/. As I have noted, this historical merger underlies the apparently anomalous behavior of some couplet-medial tokens of /ʃ/, which fail to condition the predictable glottalization of a preceding vowel under stress. These same /ʃ/ segments are equally anomalous in that they fail to pattern with voiceless stops in blocking the regressive [nasal] harmony that marks the second-person familiar. Figure (94) provides illustrative nasal flow data for the form *kuʃu* 'diligent' and its second familiar counterpart *kũʃũ* 'you (fam) are diligent'.

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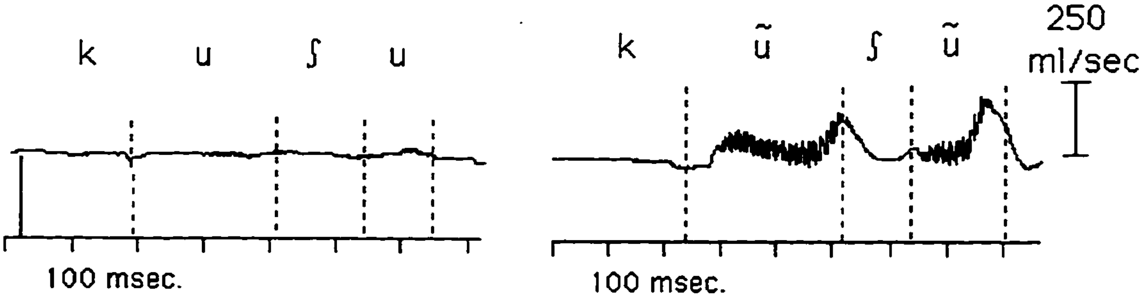
[52] Though I have focused on the issue of 2-FAM nasalization and *NC, note that MAX(nas) must hold in ṽ + C sequences independently of 2-FAM

(94) S2 flow data: kuʃu 'diligent' and kũʃũ 'you are diligent'



a) non-nasalized

b) 2-FAM form

The flat line in (a) shows that the base form *kuʃu* 'diligent' is non-nasal. By contrast, its 2-FAM counterpart exhibits nasalization throughout almost all of the first vowel of the couplet and, after a decline in nasal flow during the fricative, also registers increasing nasal flow throughout the entire duration of the second vowel. This is a clear case of transparent /ʃ/—a phonetically voiceless segment flanked by nasalized vowels.

By way of contrast, consider the two forms in (95) for the verb *kiʔ*^{i}*ʃi* 'to come' and its 2-FAM variant *kiʔ*^{i}*ʃĩ* 'you (fam) will come'.

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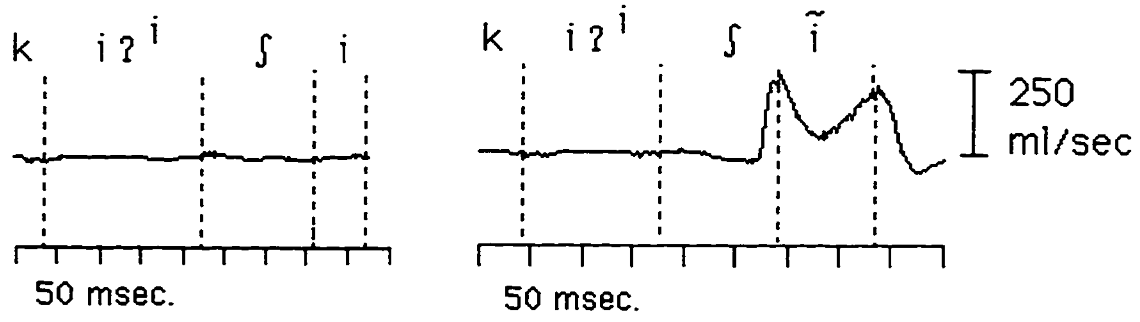
constructions, i.e. in syntactic sequences comprised of input strings of roots.

(95) **S2 flow data: kiʔ^{i}ʃi 'to come' and kiʔ^{i}ʃĩ 'you (fam) will come'**

a) non-nasalized b) 2-FAM form



Again, the form in (a) establishes the absence of nasality in the non-derived root. The form in (b) shows a marked rise in nasal flow coincident with the offset of the fricative and sustained, rising flow throughout the duration of the final vowel. Here, /ʃ/ patterns as we expect, blocking the leftward propagation of 2-FAM nasalization (and conditioning the glottalization of the preceding vowel). Though I return in detail to the implementation of [nasal] in §4.3, this provides a clear case of the expected opacity of medial voiceless consonants.

Returning to the question posed in Chapter 3 regarding the phonological specification of voicing in exceptional /ʃ/'s, does this mean that we have evidence for a phonological /ʒ/ phoneme that surfaces phonetically as /ʃ/? I do not think so. Rather, all that is necessary is that we recognize a limited number of medial /ʃ/'s that are 1) historically derived from the Proto-Mixtec */y/ and 2) lack a [-voice] specification in the synchronic grammar. In this way, their transparency to nasal harmony will not violate *NC and will simultaneously prevent them from triggering predictable glottalization--as per the analysis in Chapter 3. At the same time, we avoid having to provide an explanation for why, if they are phonologically [+voice], they should be systematically realized as phonetically voiceless.

4.3 Nasalization and the relationship between phonology and phonetics

In this section, I examine the interface between the phonology and phonetics of nasalization. As in Chapter 3, I address two general issues. In §4.3.1 I focus on the interaction of phonetics and phonology as it is reflected in the phonological constraints holding of CM nasalization. In §4.3.2 I provide a closer look at the phonetic implementation of [nasal] across the various nasalization phenomena in the language. Throughout this section, I consider two related issues. First, I explore the distinction between the phonetics versus the phonology of opacity and transparency. Secondly, I return to the complex relationship between phonetic data and phonological representation (cf. Pierrehumbert 1980, Keating 1988, 1990b, Shih 1988, Pierrehumbert and Beckman 1988, Huffman 1989, 1993, Cohn 1990, 1993a, Laniran 1993). Building on the analysis of glottalization in Chapter 3, I argue again for the necessity of assigning phonetic targets for particular phonetic dimensions throughout only part of a segment. At the same time, I show that the nasal data once again call our attention to the necessity of interpreting phonetic data in the context of knowledge of the phonological system as a whole.

4.3.1 *NV, *ṽN, and *NC

As I discuss in Chapter 3, grounded conditions (Archangeli and Pulleyblank 1994a) constitute an important aspect of the relationship between phonology and phonetics in that they encode a way in which phonetic relationships (between articulatory and/or acoustic properties) shape phonological systems. For CM glottalization, I argued that the constraint CG/STR is particularly interesting in that it extends the notion of phonetic grounding by relating two elements--creaky phonation and stress--that are not intrinsically phonetically sympathetic, but rather, *opportunistically* sympathetic within the context of the phonology of the language. For CM nasalization, I invoke three constraints involving the sequencing of nasality and orality within roots.

One of these, *NV is a straightforward encoding of the phonologization of perseveratory nasalization from a nasal stop to a following vowel. By contrast, *ṽN enforces the orality of a vowel preceding a nasal consonant--a clear case of maximizing acoustic distinctness along a particular phonetic dimension. I note above that both situations are attested across languages. However, their role in CM nasalization merits a bit more consideration. In particular, we are led to ask why speakers should rigorously maintain the orality of vowels in VN contexts, while at the same time they clearly nasalize vowels in their entirety following full nasal stops. I suspect that there are no simple answers to this question. However, I suggest that the functional load that nasality plays in the language may come into play in the following manner. First, nasal stops are among the most common consonants. If nasalization were to systematically spread to both of the vowels flanking medial nasal stops, massive morphological neutralization would occur. That is, we can view the prohibition against anticipatory nasalization as a means of helping to maintain a distinction between 2-FAM forms and non-2-FAM forms. At the same time, perseverative nasalization itself helps to enforce the auditory distinctness of nasal stops and prenasals. Specifically, perseverative velum lowering can be viewed as a mechanism for maximizing the salience of the oral release of contrastive prenasals in contrast with the nasal transient of full nasal stops. To the extent that these explanations are on the right track, they again point to the necessity of understanding phonetic constraints in the context of the particular language in which they are phonologized. In this case, we might profitably view both the lack of anticipatory nasalization and the presence of perseverative nasalization as respective ways of protecting morphological distinctiveness while maximizing segmental contrastiveness.

The relationship between nasality and voicing in the analysis of lexical and 2-FAM nasalization is interesting in its extension of the use of grounded conditions. In this case, however, the principal interest does not reside in the questionable phonetic motivation of the constraint, but in the fact that a phonetically grounded constraint, *NC, obtains of a sequence of segments rather than within a segment. That is, *NC derives the opacity of voiceless consonants by prohibiting the presence of a [nasal] vowel immediately before a voiceless segment. As I point out in §4.2.1.2, there are reasonable aerodynamic and acoustic arguments to support the view that nasalized vowels might be dispreferred before a voiceless consonant. Late velic closure is antagonistic to the pressure build-up necessary for the production of the obstruent, while nasalization itself is antagonistic to voicelessness.[53]

It is also important to note, however, that *NC derives opacity in the context of a system of constraints that generally militate for maximizing the extension of [nasal] throughout a root (or prosodic word, in the case of 2-FAM nasalization). I suggest that much of the motivation for the inviolability of *NC to both root-internal nasalization as well as 2-FAM nasalization resides in the assumption that the domain of assimilation of a harmonic feature optimally contains no articulatorily or acoustically antagonistic feature, i.e. the proposal that it is preferable to realize a feature in a gesturally uniform fashion throughout the extent of its phonological association. This in turn is predicated on the notion that a single autosegment that is multiply associated

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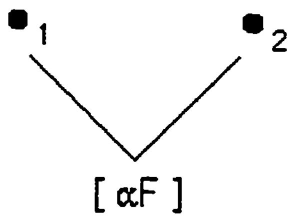
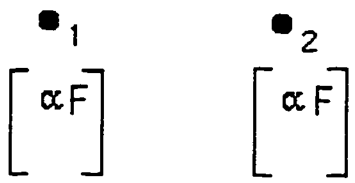
[53] But see §4.3.2.1 for evidence that voiceless fricatives can be produced with velum lowering.

has a different semantics than an SPE-style (Chomsky and Halle 1968) approach in which assimilation is represented by copying the features from one matrix into an adjacent matrix or matrices, a difference sketched in (96).

(96) **Autosegmental assimilation** **Output of SPE treatment**





This position is explicitly advanced, for example, by Hayes (1986: 467) who points out that a fundamental distinction between an autosegmental approach to assimilation and the traditional SPE view is that spreading rules "...expand the *temporal domain* of autosegments by adding association lines" (italics mine). It is also adopted by Keating (1990b), who notes that autosegmental representations allow for at least some gestural overlap to be represented phonologically. In this context, it is interesting to note that *NC, in consort with constraints on alignment, has the effect of always prohibiting a nasalized vowel-voiceless consonant sequence in which the consonant is flanked by the multiple association of a single token of [nasal].

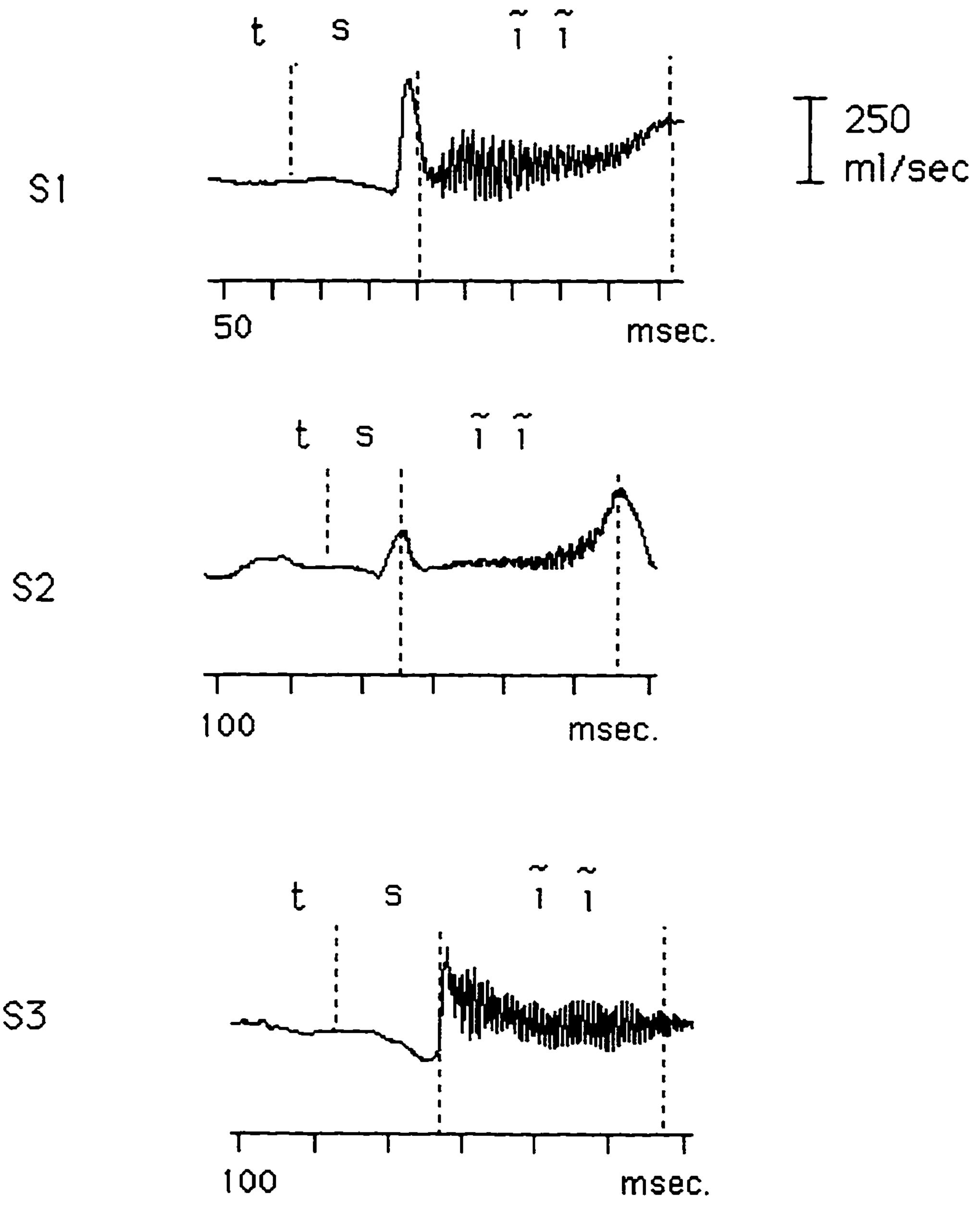
At the same time, *NC is equally interesting for what it does not do. That is, just as it derives opacity by banning voicelessness in the domain of nasal harmony, there are legitimate phonetic reasons to think it might equally render voiced non-nasal consonants in CM opaque to the process. This is the case in languages such as Sundanese (cf. Robins 1957, Cohn 1990), where both voiced and voiceless consonants block the rightward propagation of nasality. As Ohala and Ohala (1993) point out, not only voiceless consonants, but all buccal obstruents require a pressure build up in order to generate either burst energy or, in the case of fricatives, turbulent flow. In fact, Ohala (1975) argues that the aerodynamics of voiced fricatives make these particularly bad candidates for tolerating nasalization, given that the necessity of maintaining voicing already requires a lower supraglottal pressure than in voiceless sounds, and that velic opening would have the effect of channeling off enough air so as to render the presence of turbulent flow at the point of constriction highly unlikely.

Thus, if we assume that a sustained velum lowering gesture is the optimal phonetic interpretation of a multiply linked [nasal] autosegment, then intervening fricatives such as /ð/ and /β/ might equally well be expected to systematically block harmony. That they do not is interesting in that it provides a clear example of the way in which phonetically motivated constraints can but need not shape phonological systems (cf. Archangeli and Pulleyblank 1994a). That is, while phonetics circumscribes a range of constraints that might be invoked by natural language phonologies, phonetically motivated constraints are not merely a set of phonological imperatives. At the same time, it challenges what is essentially the null hypothesis above--the supposition that multiple association correlates phonetically with a lack of change along a particular articulatory or acoustic dimension throughout some temporal domain. We turn to this issue in §4.3.2, taking a closer look at the surprising facts of the phonetic implementation of nasality in CM.

4.3.2 A starting point: implementing [nasal] in vowels

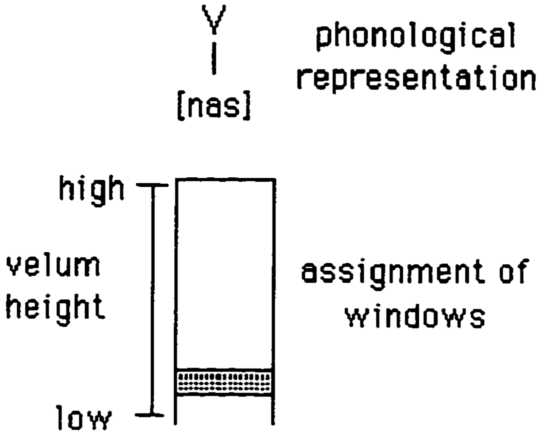
I begin with the implementation of lexical vowel nasalization in Cṽṽ couplets such as tsĩĩ 'fingernail'. Consider, for example, the data in (97) for S1, S2, and S3. Here, we see that the phonological specification of vowel nasalization is realized much as predicted by Cohn (1990, 1993a). For all three speakers, flow initiates at the transition of the fricated release of the affricate and is sustained in a steady fashion throughout the duration of the vowel.

(97) **Nasal flow data: tsĩĩ 'fingernail'**



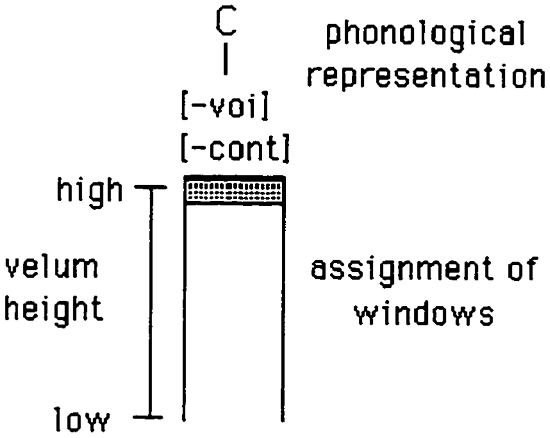
The implementation of vowel nasalization here can be accounted for by positing a window for a low velum position throughout the duration of the vowel, as in (98).

(98) **Constructing windows for [nasal] vowels**



Similarly, we can assume that a window for a raised velum is constructed for the voiceless affricate, as in (99).

(99) **Constructing windows for oral plosives**



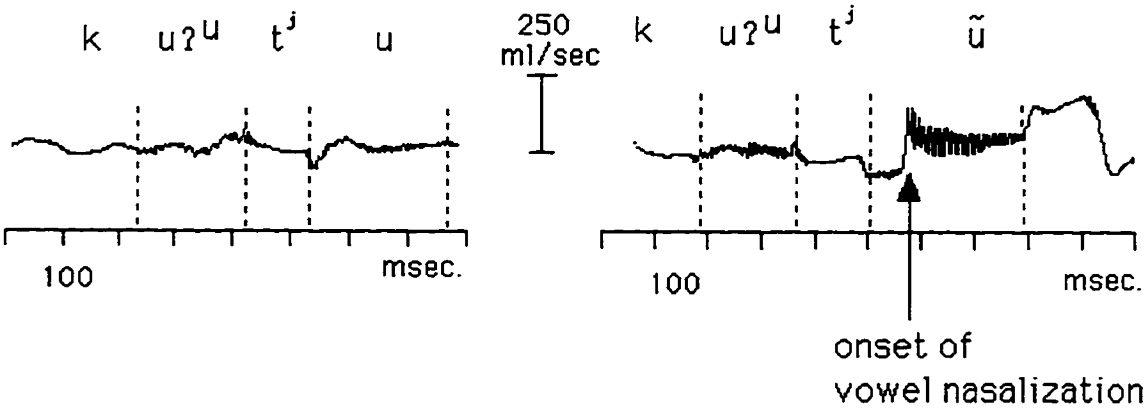
This view of the assignment of phonetic targets essentially follows Cohn (1990, 1993a), though in a windows-based framework. I differ from Cohn in that I do not assume that orality targets in non-continuants must derive from a [-nasal] specification. Rather, I assume that the aerodynamic requirements of these sounds, together with their voicelessness, contribute to the assignment of a phonetic target for velum height. This difference aside, these figures provide a starting point from which to view the data involving opacity and transparency to nasalization in the language. I turn first in §4.3.2.2 to a discussion of the phonetic nature of opacity.

4.3.2.1 Nasalization and the blocking effect of voiceless consonants

In the discussion of the phonology of nasalization, I have argued that voiceless consonants block the right to left pattern of vowel nasalization in both lexical and 2-FAM cases. This section provides a more detailed description of the nature of phonetic opacity, with a focus on the timing of the onset of nasalization, as reflected by nasal flow data. As we will see, there is some variability across the three speakers S1, S2, and S3, the nature of which lies in the degree to which the onset of nasal flow coincides with the release of the medial stop. There is also a striking discovery in that opaque fricatives and affricates exhibit anticipatory velum lowering, suggesting that these are not always phonetically oral throughout the duration of closure (cf. Ohala and Ohala 1993, Cohn 1993b).

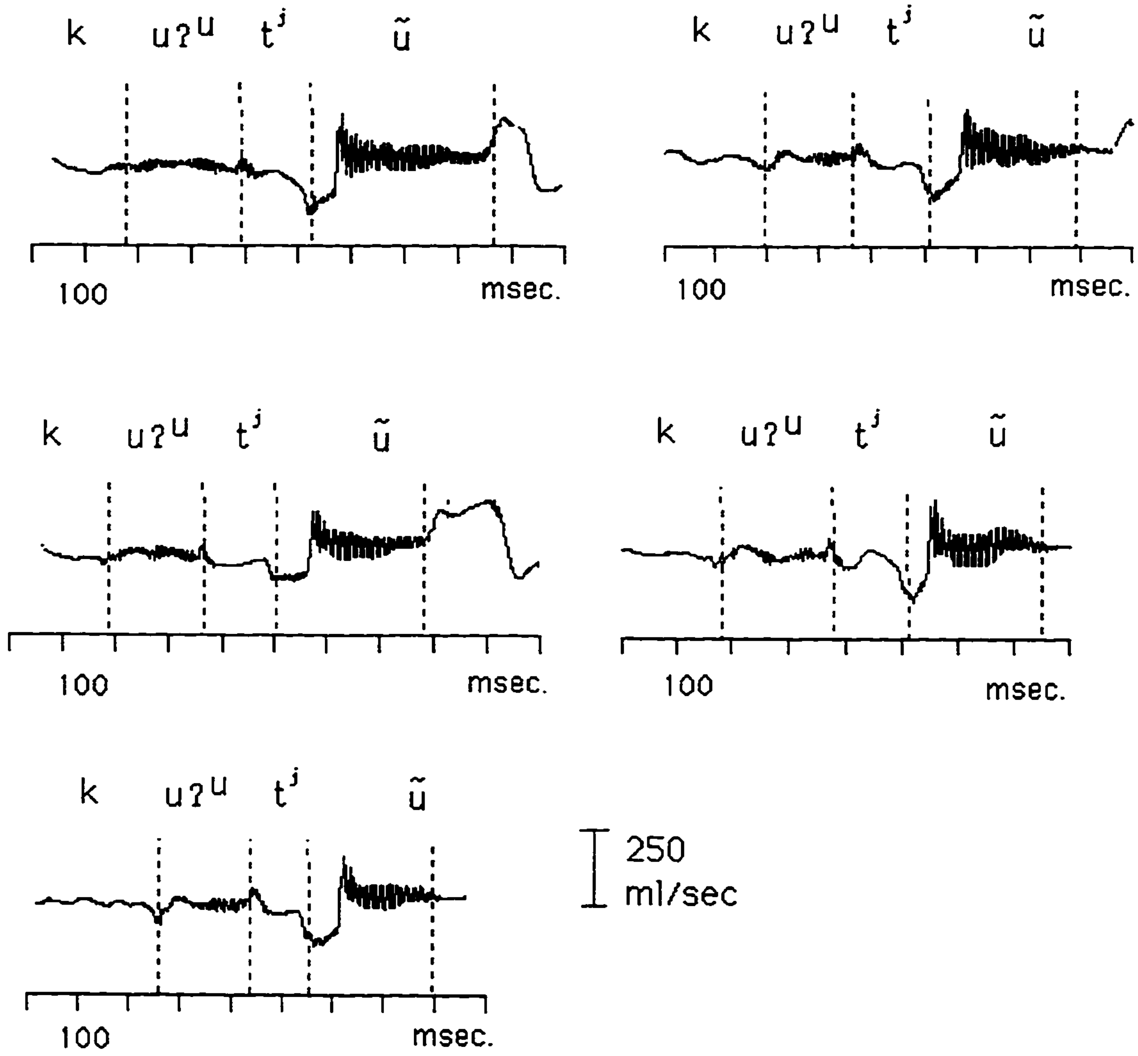
We begin with a consideration of the opacity of voiceless stops. Consider, for example, the data in (100) for the couplet *kuʔᵘtʲu* 'to plow, hoe' and its 2-FAM counterpart *kuʔᵘtʲ*ũ 'you (fam) will hoe', produced by S3:

(100) S3 flow data: kuʔᵘtʲu 'to plow, hoe' vs. kuʔᵘtʲũ 'you (fam) will hoe'


a) non-nasalized form
b) 2-FAM form

The form in (a) provides a non-nasalized token of *kuʔᵘtʲu* for purposes of comparison. Note that there is only minimal baseline fluctuation, with a general lack of activity on the nasal channel throughout the token and no indication from the nasal flow channel of sustained velum lowering or of a change in velum position. By contrast, (b) provides an example of the 2-FAM counterpart *kuʔᵘtʲ*ũ. Here, we see the clear onset of nasal flow roughly 100 milliseconds following the release of the medial stop, with flow sustained in a steady fashion throughout the duration of the vowel. This is representative of the implementation of nasal vowels in such forms for S3, as can be seen in the complete set of tokens for the 2-FAM form *ku?^{u}t^{j}ũ* in (101):

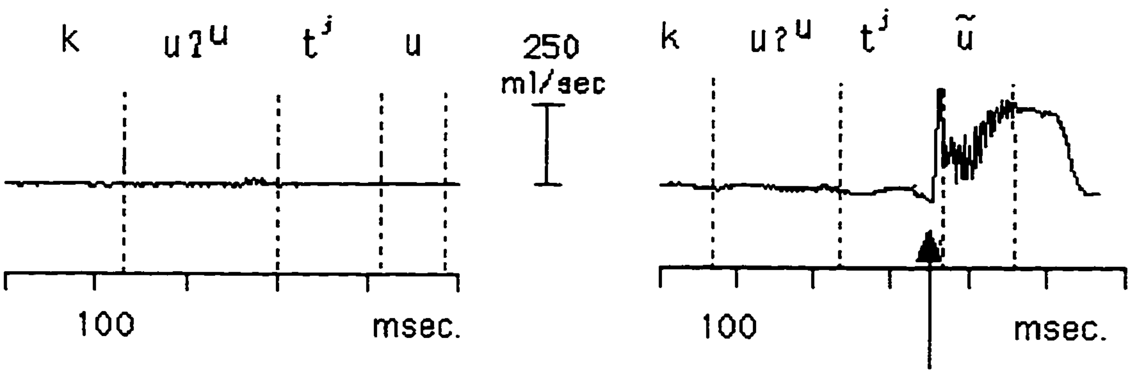
(101) **S3 flow data: ku?^{u}t^{j}ũ 'you (fam) will hoe'**



Note that in all cases, the onset of vowel nasalization lags behind the release of the stop. By contrast, S1 aligns the onset of nasalization at the stop release. This is seen in (102). Again, the form in (a) provides a non-nasal form as a basis for comparison. In (b), an arrow signals the presence of a sharp spike in nasal flow that is coincident with the release of the stop.

(102) **S1 flow data: ku?^{u}t^{j}u 'to plow, hoe' vs. ku?^{u}t^{j}ũ 'you (fam) will hoe'**

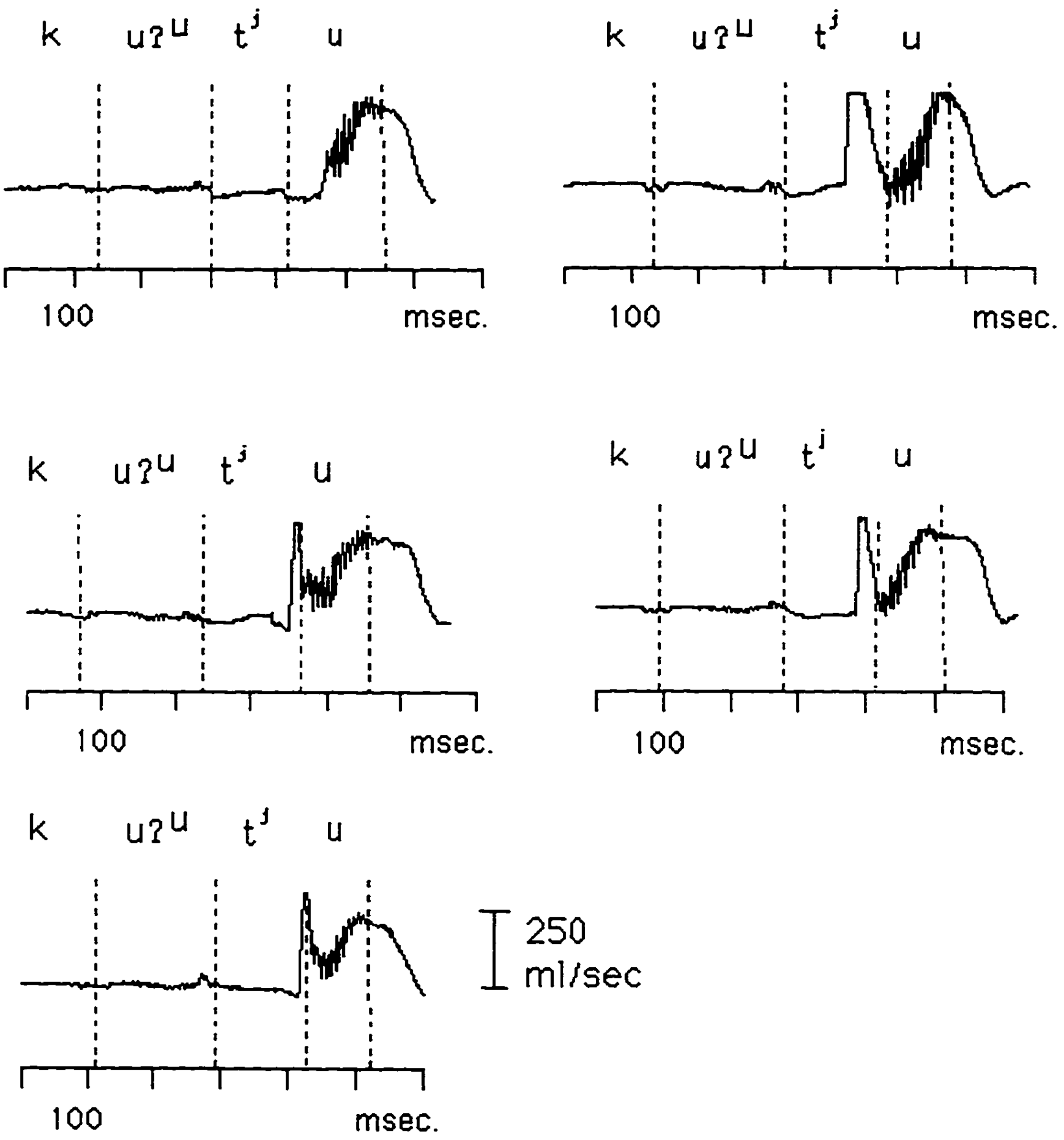
a) non-nasalized form b) 2-FAM form



onset of flow aligned with stop release

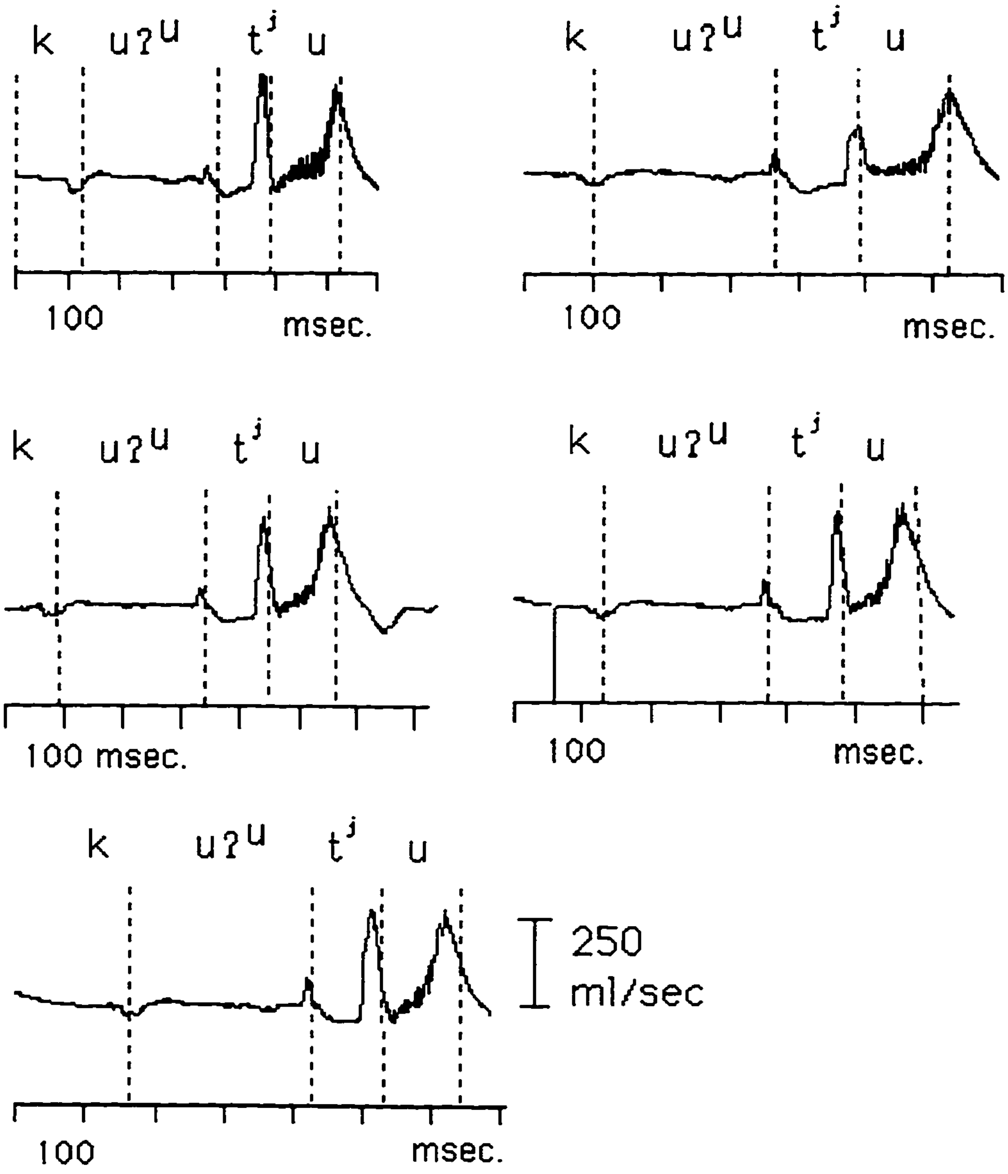
This is typical of S1's production of nasalized vowels in this context. Four of her five tokens exhibit the spiking indicative of anticipatory velum lowering prior to the onset of voicing in the following vowel; i.e. velum lowering prior to the release of the medial stop. This is seen in (103).

(103) **S1 flow data: kuʔ^{u}t^{j}ũ 'you (fam) will hoe'**



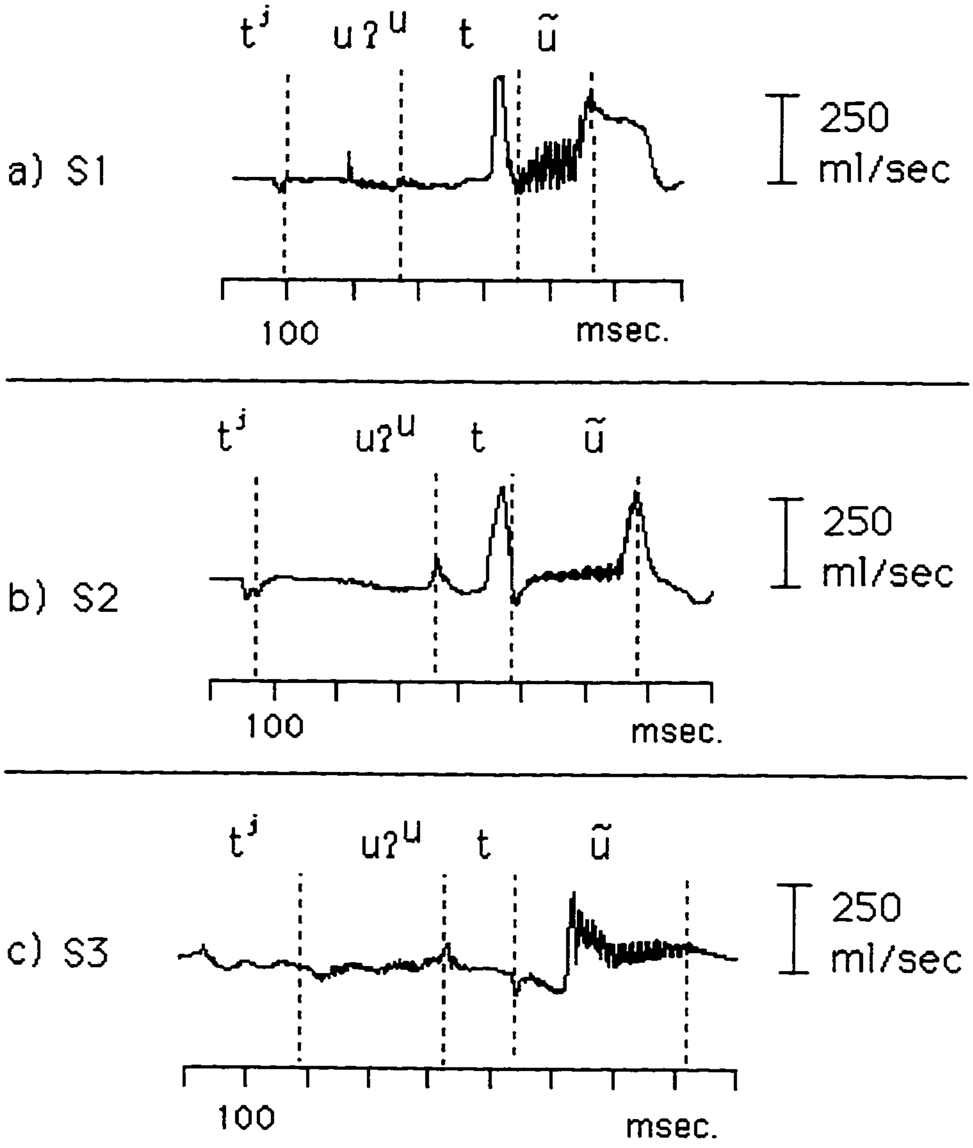
The forms in (104) reveal a similar pattern for S2. In this case, all five tokens are characterized by a spike in nasal flow that is coincident with the release of the medial stop. The following vowel exhibits steadily rising flow throughout its entirety.

(104) **S2 flow data: kuʔ^{u}t^{j}ũ 'you (fam) will hoe'**



The facts are much the same under lexical nasalization. That is, there is no evidence from these data that speakers vary the timing of velum lowering as a function of whether nasalization plays a morphological or lexically contrastive role. The data in (105) provide representative tokens of the form *t*^{j}*u*ʔ^{u}*tũ* 'firewood' with a final, contrastively nasal vowel for all three speakers.

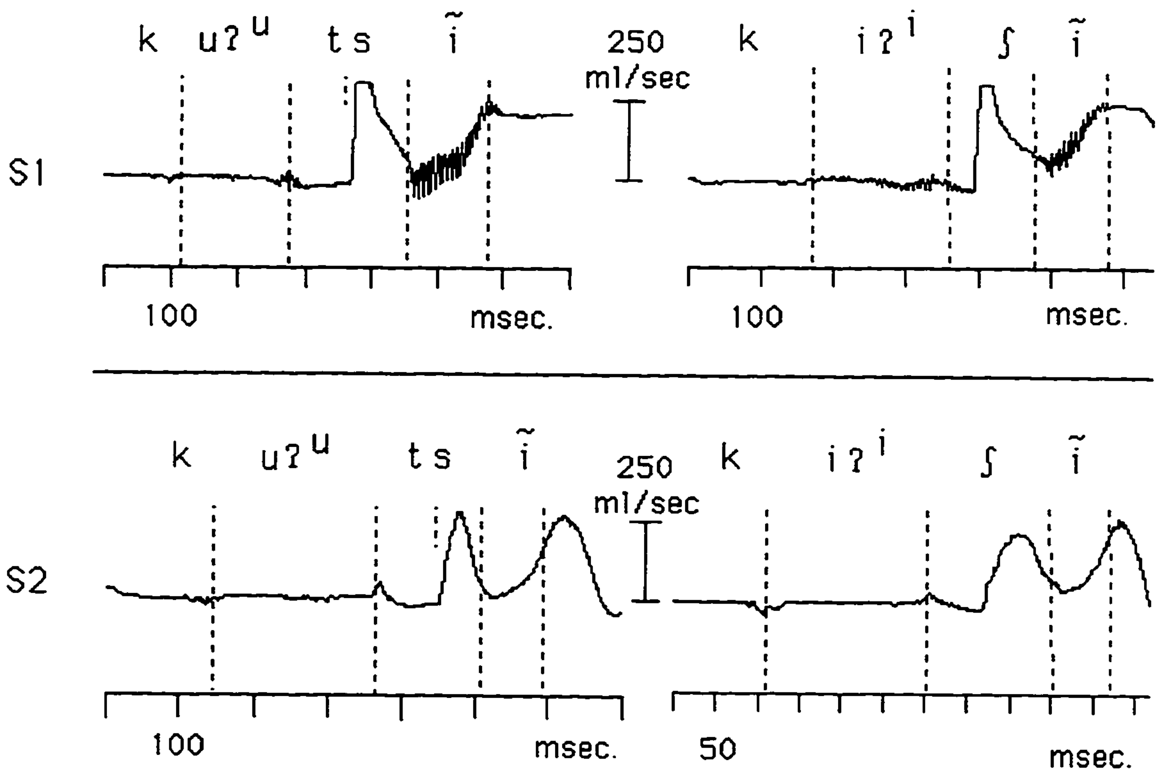
(105) **S1-S3 flow data: t^{j}uʔ^{u}tũ 'firewood'**



Here again, S1 and S2 align the onset of velum lowering with the release of the medial stop, while S3 lowers the velum after the onset of the vowel. In all three cases, however, the first vowel of the form is predictably oral.

What is particularly striking is that both S1 and S2 exhibit the same general pattern of anticipatory velum lowering in the context of the affricate /ts/ and the fricative /ʃ/, as well. Consider, for example, the data in (106) for *kuʔ^{u}tsĩ* 'you (fam) will bathe' and *kiʔ^{i}ʃĩ* 'you (fam) will come' for both speakers.

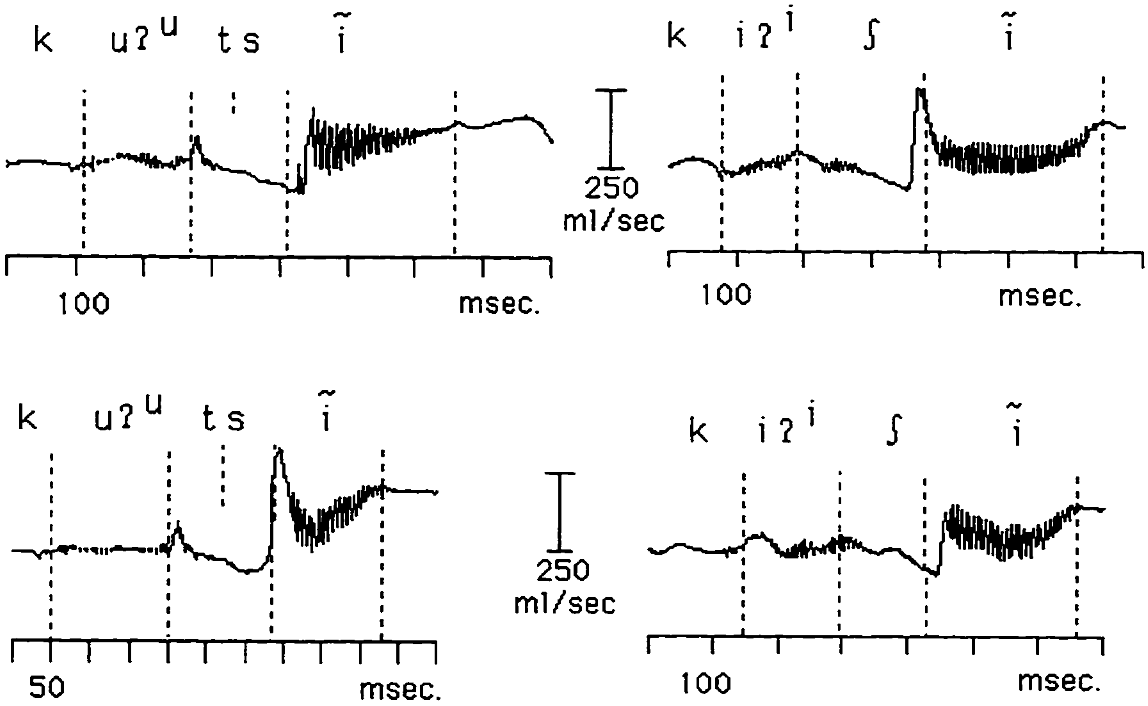
(106) a) **kuʔ^{u}tsĩ** b) **kiʔ^{i}ʃĩ**



Here, we again see that the onset of nasal flow begins prior to the onset of the vowel. Velum lowering is thus concomitant with the fricated release of the affricate in (a) and with at least part of the duration of closure for the fricative /ʃ/ in (b).

For her part, S3 is less likely to exhibit such anticipatory velum lowering. Rather, for this speaker, the onset of nasal flow is more closely correlated with the onset of voicing in the vowel. Two examples of each of *kuʔ^{u}tsĩ* and *kiʔ^{i}ʃĩ* for S3 are provided in (107).

(107) **S3:** a) **kuʔ^{u}tsĩ** b) **kiʔ^{i}ʃĩ**



In these tokens, we see that in both *kuʔᵘtsĩ* and *kiʔⁱʃĩ* the onset of nasal flow either aligns closely with the transition from the consonant to the following vowel or begins slightly after the release of the consonant.

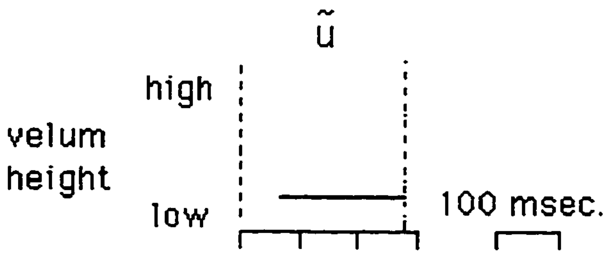
In looking at the phonetic data, two questions arise. First, why should the onset of nasalization be later for S3 than for S1 and S2? Secondly, in the cases of S1 and S2, what is the significance of the presence of flow upon the release of the medial stop? Specifically, is this a phonological or a phonetic phenomenon?

I suggest that these two questions may, in fact, be related. Regarding the former, it is interesting to note that V2 is unexpectedly long in all of the tokens produced by S3 in (101) above, with durations of 250 milliseconds and over. This is surprising, given that in normal speech, unstressed vowels (see Chapter 3) are systematically shorter than their stressed counterparts. For example, in the tokens produced by S1 in (103) and S2 in (104) V2 ranges in duration from 100 to no more than 150 milliseconds for both speakers, while V1 generally lasts for 200 or more milliseconds.

It is not altogether clear why S3 should lengthen the final vowel in this fashion, though I suspect that the effect may be due to the experimental setting. One suggestion is that, despite the presence of the carrier phrase, the target item undergoes something like phrase final lengthening for S3, while S1 and S2 produce the target form in a more natural fashion. Note, for example, that in the more natural sentences in §3.6.1.1 above, S3 does exhibit the length distinction under stress that corresponds to the expected pattern of the language. This again suggests that her lengthening of V2 here is a result of the experimental setting and is perhaps attributable to overly careful articulation.

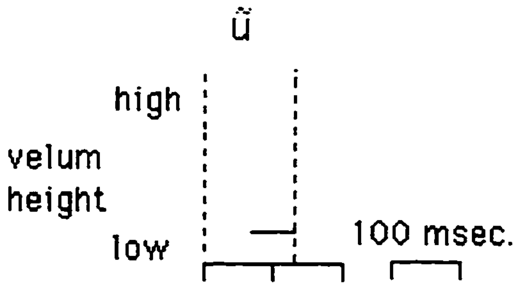
A consequence of lengthening, however, is that a later onset of velum lowering still allows for a relatively long period in which nasal flow is present on the vowel for S3. This is illustrated schematically in (108).

(108)



Note that even with a 75 millisecond lag between the onset of nasalization and the onset of the vowel (i.e. the release of the preceding stop), there remain more than 200 milliseconds in which nasalization is present on the vowel. By contrast, the cost of a 75 millisecond lag is more serious to S1 and S2, as illustrated schematically in (109).

(109)

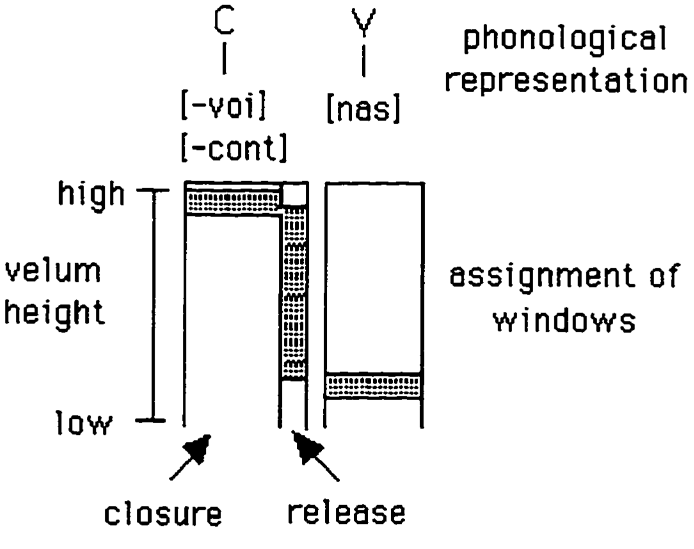


Here, a 75 millisecond lag in velum lowering will result in a vowel that is nasalized throughout less than half of its duration. To complicate matters, since the vowel in this position is unstressed, it is generally lower in amplitude and is even sometimes partially devoiced. It is thus reasonable to suspect that speakers will risk clearly implementing the nasal quality of the vowel if they are late in lowering the velum.

This bring us to the second issue, i.e. the question of whether the presence of nasal flow on the release of opaque consonants for S1 and S2 is a phonological or a phonetic phenomenon. My claim is that the data are best treated as a consequence of phonetic implementation, and, in particular, as an effect of the transition between the target for velum height of the oral obstruent and that of the following nasalized vowel. We begin with a discussion of the phonetic implementation of [nasal] in the context of a voiceless stop.

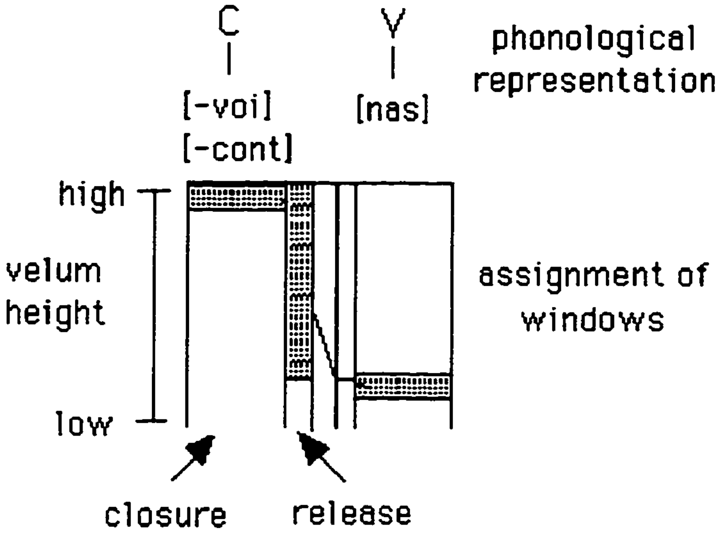
As in Chapter 3, I follow Keating (1990b) in assuming that phonologically specified features are interpreted phonetically via the construction of windows along particular articulatory and/or acoustic dimensions. In this case, the [nasal] specification of the final vowel results in the construction of a narrow window specifying a relatively low velum position, thus implementing nasality throughout the vowel. I assume that the aerodynamic requirements of the preceding voiceless non-continuant consonant are such that it is characterized by a narrow window for a high velum position, enforcing orality throughout its closure phase. By contrast, I assume a relatively wide window for velum height for the release of the plosive, as sketched in (110).

(110)



This requires a change from an oral articulatory configuration through a relatively phonetically unspecified release to a following nasal vowel. Following Cohn (1990), I again adopt priority statements to account for the transition. In particular, I assume that the left edge of the [nasal] vowel takes priority for S1 and S2 over the right edge of the non-continuant consonant, as in (111).

(111) **Priority for velum height: left edge [nasal] V > right edge [-voice]**



Under this approach, velum lowering precedes the onset of the vowel, i.e., it is temporally aligned with the release of the stop. That we find spiking is not surprising, under the assumption that the glottis is wide open upon the release of the stop. As the velum is lowered, air will rush through the nasal cavity. The wide window for velum height also allows for a degree of variation in the possible interpolative paths during the release; i.e. for slightly earlier and later velum lowering respective to the onset of the vowel. Alternatively, the data appear to indicate that for S3, in the experimental context, at least, the priority statement is reversed--perhaps due to the longer duration of the final vowel, as I have noted above.[54]

The presence of nasal flow on the fricatives and on the release of affricates poses distinct problems. As I note above, the data are striking in that, cross-linguistically, nasalized fricatives are rarely (if ever) constrastive (cf. Ohala 1975, Cohn 1993b, Ladefoged and Maddieson 1996). Ohala (1975) argues that velum lowering is antithetical to the generation of turbulent airflow necessary for fricative production. However, these sounds are fricatives, as seen in (112).

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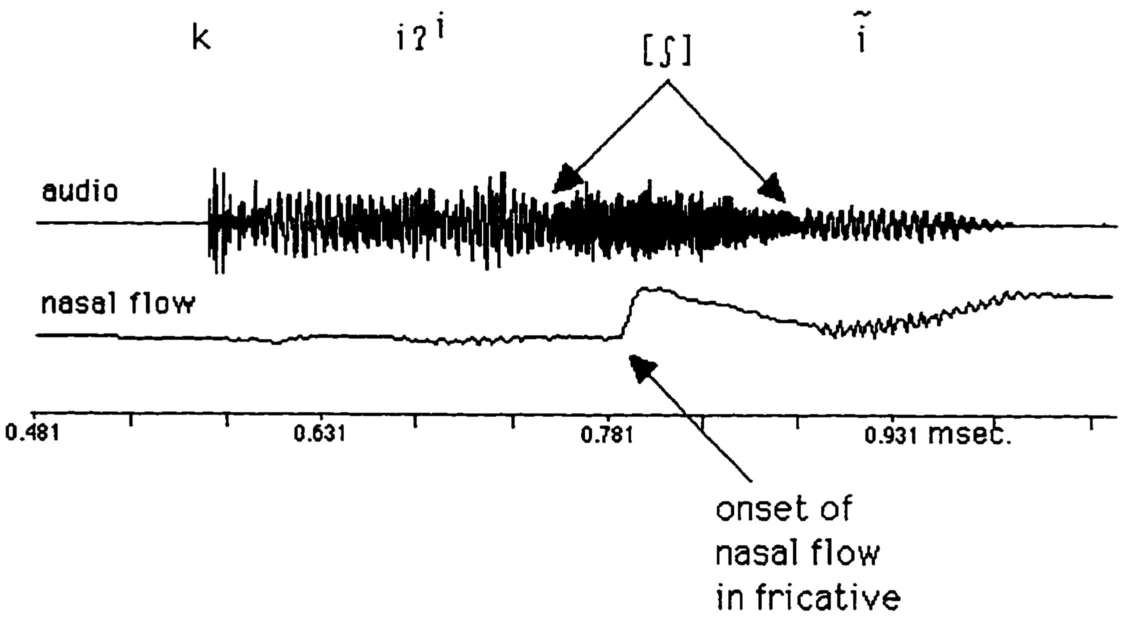
[54] We might also take the data from S3 to indicate that this speaker's phonetic implementation involves the construction of a narrow window for a raised velum in the release phase of the stop, thus forcing a later onset of nasalization.

(112) **S1: audio and nasal flow data for kiʔ^{i}ʃĩ 'you (fam) will come'**



Here, the waveform displays the random noise charcteristic of voiceless fricatives, while we see a rapid rise in nasal flow soon after the onset of frication. Additionally, the onset of voicing for the vowel is also visible on the nasal flow channel. Note, by contrast, the absence of comparable voicing energy on the nasal flow channel throughout the duration of the fricative.

Of course, such fricatives are not contrastive in CM. Nevertheless, the nasal flow data provide evidence of velum lowering that is coincident with closure in fricatives and with the fricated release of affricates. The data are thus significant in that they would appear to falsify both Ohala and Ohala's (1993) claim that all buccal obstruents must be realized with velic closure, and

Cohn's (1993b) claim that all phonetically nasalized continuants must, in reality, be approximants.

As to why speakers such as S1 and S2 should anticipatorily lower the velum in these contexts, I have no simple account, other than to suggest that anticipatory lowering here constitutes a means of guaranteeing that the following vowel will be realized as fully nasalized. This approach seems reasonable when we consider forms containing an initial voiceless consonant and a medial consonant which is transparent to regressive nasalization. In such cases, there seems to be less pressure to lower the velum prior to the release of the initial consonant, as seen in the four tokens of *kũnũ* 'you (fam) will run' for S1 below.[55]

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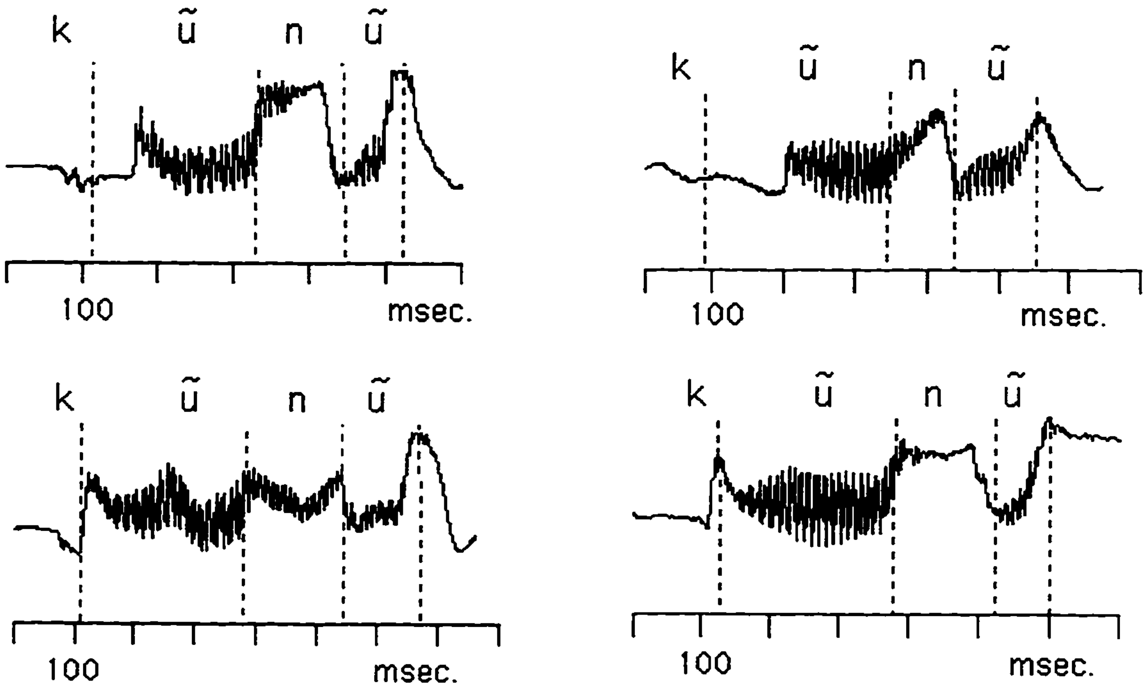
[55] Note that S1's fifth token of this form appears to be a speech error. That is, the form exhibits a pattern of nasal implementation that corresponds to the non-2-FAM form *kunũ* 'to run'. This form can be found in the Appendix.

(113) **S1 flow data: kũnũ 'you (fam) will run'**



Again, this may be attributable to the inherently longer duration of the stressed vowel and thus to the ability to delay the onset of velum lowering without adverse perceptual consequences.[56]

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[56] An interesting perceptual follow up study would involve delaying the onset of nasal acoustic cues to gauge the point at which speakers cease to perceive CM vowels as nasal. At the same time it is intriguing to note Ohala and Ohala's (1993) discussion of the fact that high airflow segments such as aspirated stops and voiceless fricatives--sounds realized with a greater than normal glottal opening--give rise both synchronically and historically to spontaneous nasalization. This is attributed to the spreading or overlap of the wider glottal position of the consonant and the beginning of the following vowel, which nevertheless remains completely voiced. This overlap creates acoustic effects which mimic those of nasalization, thus triggering the percept of a nasal vowel that is physiologically realized with a raised velum. That is, although velum lowering is articulatorily antagonistic to the production of

As in the case of voiceless medial stops, I take the presence of anticipatory velum lowering on preceding affricates and fricatives to be the result of phonetic coarticulation. That the phenomenon is phonetic is first supported the fact that not all speakers do it, while all speakers are, by contrast, careful to realize the final vowel as fully nasal. Additionally, the timing of anticipatory lowering appears to be quite variable. Consider, for example, the five tokens of *kiʔ*^{i}ʃĩ 'you (fam) will come' produced by S1 in (114). Here, we see that S1 times velum lowering irregularly. In some cases, nasal flow is present soon after the onset of closure, while in others the onset of nasal flow is more closely aligned with the release of the fricative.

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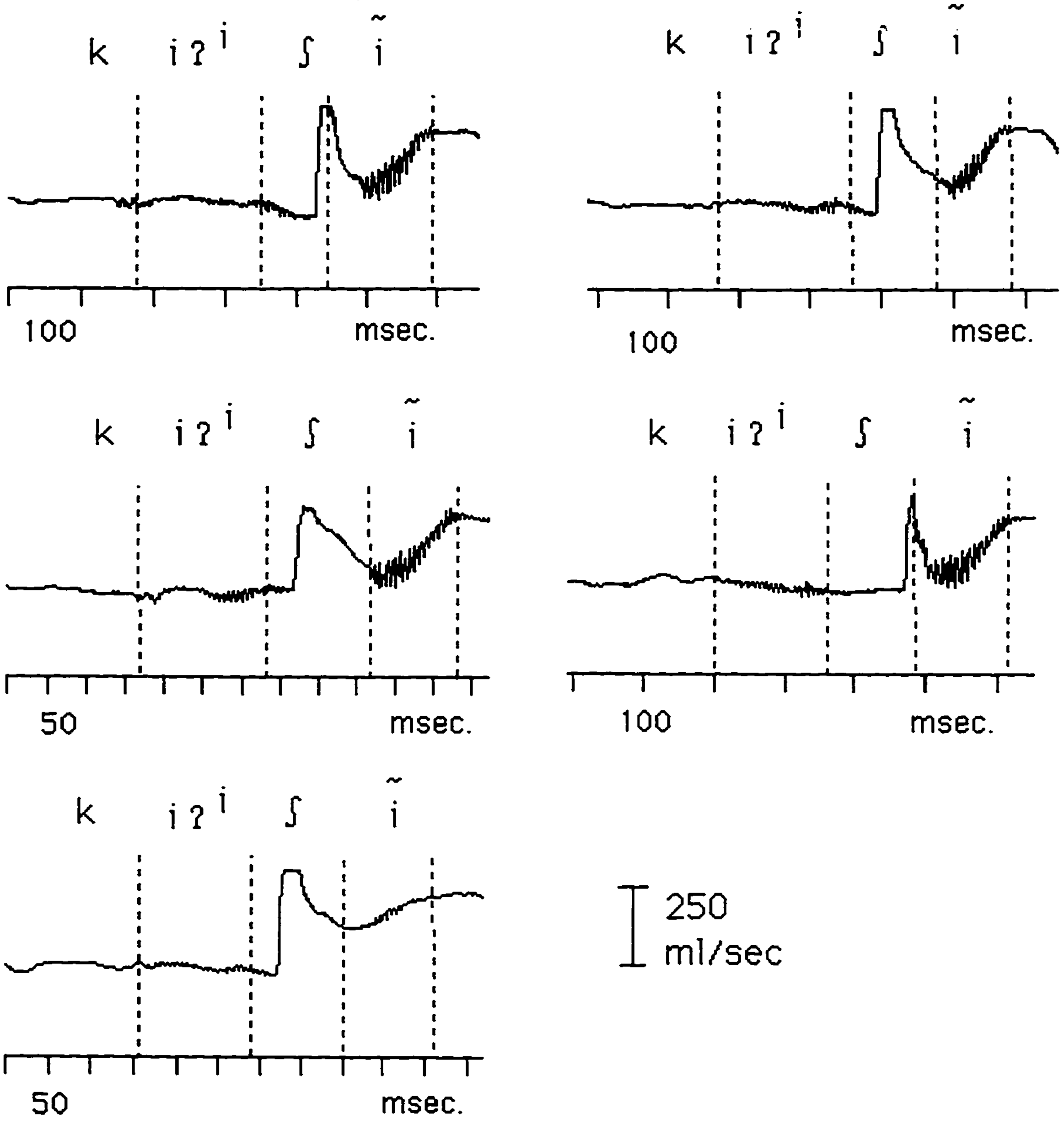
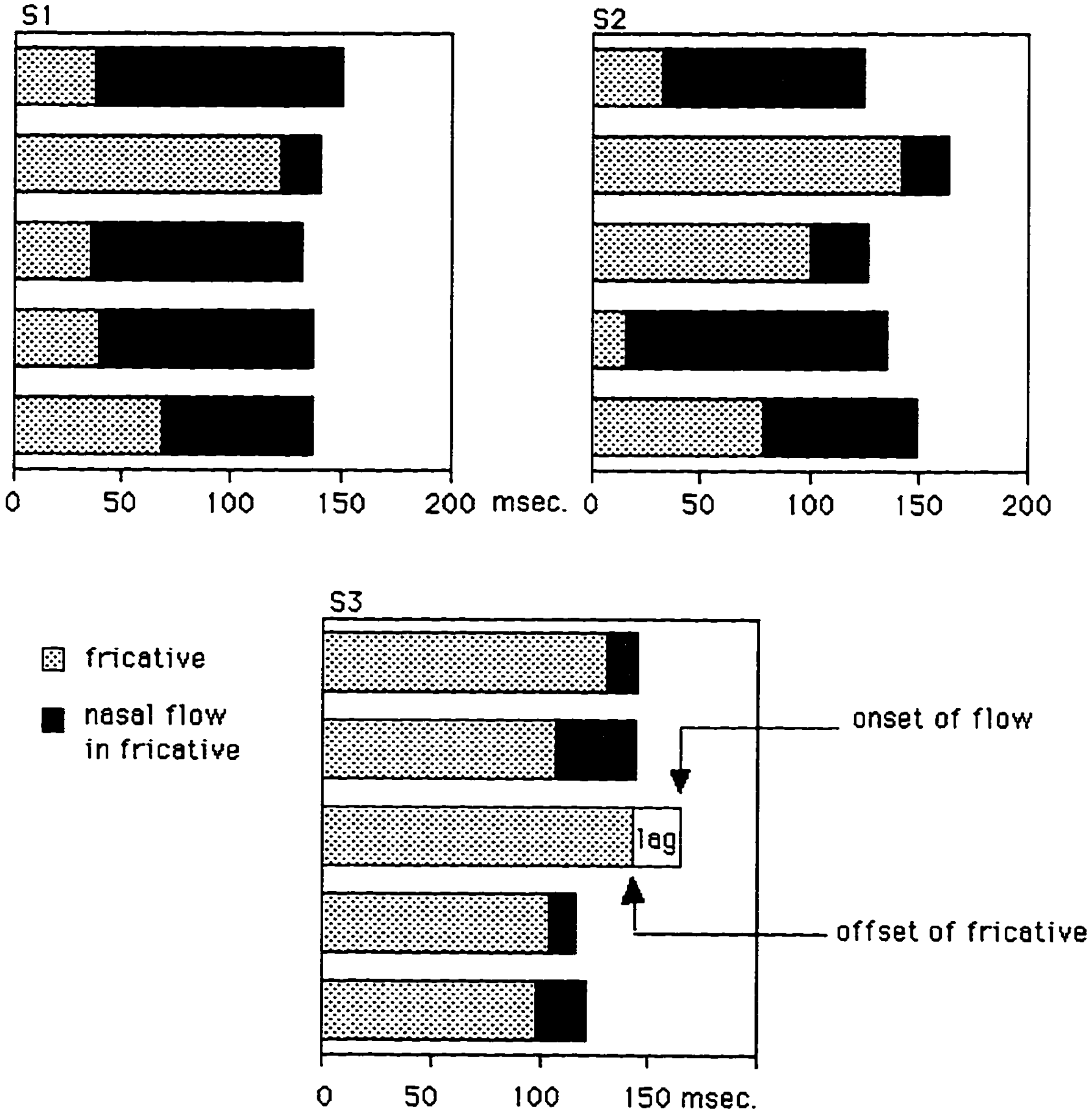
fricatives, the glottal configuration of fricatives can generate the percept of nasalization in a following vowel. Perhaps the anticipation of velum lowering here further enhances the nasal quality of the following vowel.

(114) S1 flow data: kiʔ^{i}ʃĩ 'you (fam) will come'



The stack bar graphs in (115) give a clear sense of the variability in alignment of the onset of nasal flow with respect to the medial /ʃ/ in *kiʔ^{i}ʃĩ* for all three speakers. Each shaded column reflects the duration of a token of the fricative. The darker shading represents the portion of the fricative that is realized after the onset of nasal flow.

(115) **Stack bar graphs showing portion of /ʃ/ realized with nasal flow**



Note that S1 and S2 both exhibit anticipatory flow in all tokens, though the timing of the onset of flow is quite variable. S3's production of *kiʔ*^{i}*ʃĩ* also shows anticipatory flow prior to the onset of voicing for the following vowel in four of the five tokens. However, in her case, velum lowering is more closely correlated with the release of the medial fricative.

This type of variability within and across speakers is not surprising if we bear in mind that the morphological information--here the phonetic implementation of the second person familiar--is crucially conveyed by vowel nasalization. That is, speakers are careful to realize the final vowel as nasalized, but they are less precise with respect to the onset of velum lowering, just so long as it precedes the onset of the vowel, and, in the case of voiceless affricates and stops, follows orality during stop closure[57].

Returning to the notion of windows, the empirical facts suggest that voiceless fricatives and the releases of voiceless affricates for CM speakers such as S1 and S2 are assigned a fairly wide window for velum height, i.e. that they tolerate a certain degree of velum lowering. This is sketched in (116):

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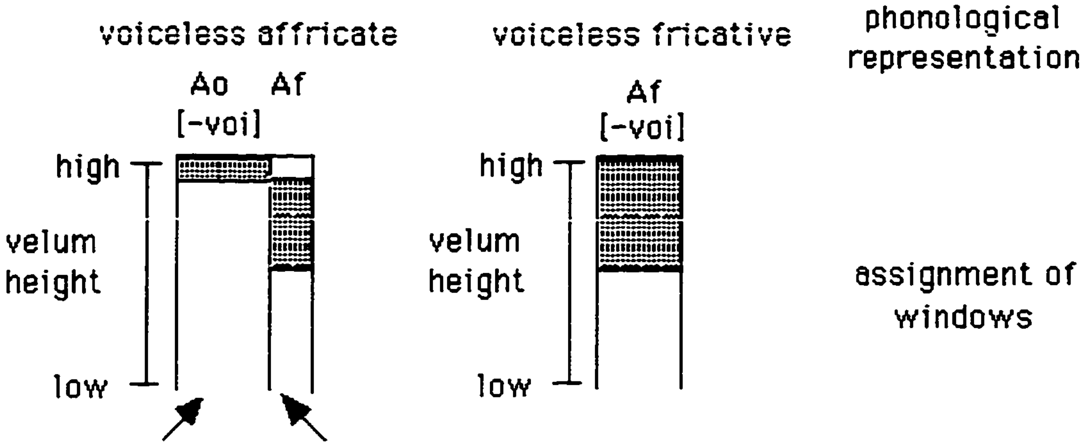
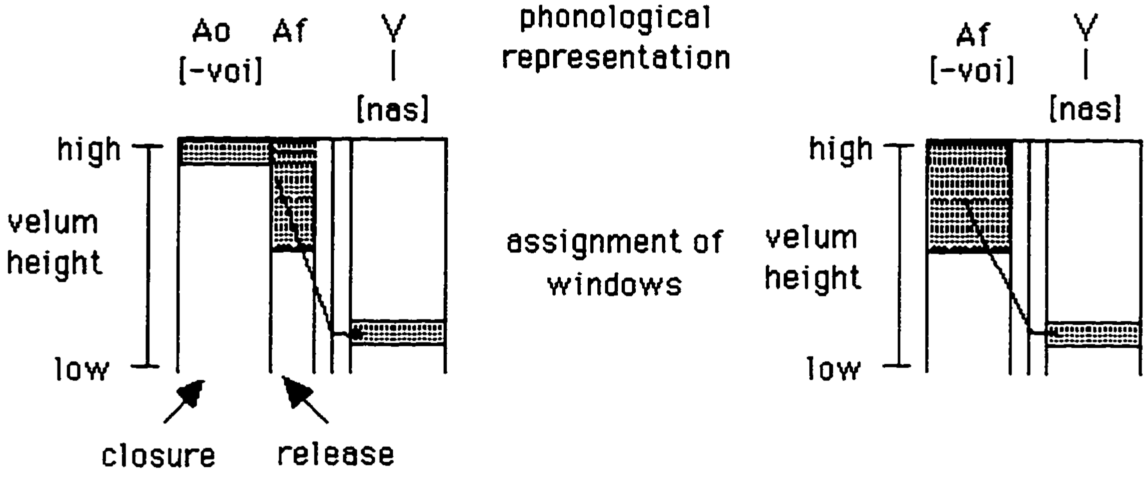
[57] Of course, the earlier that they lower the velum during the preceding fricative closure, the less phonetically felicitous the fricative. But, in these cases, speakers appear to be willing make this sacrifice.

(116)



Assuming again that the left edge of a nasal vowel takes precedence over the right edge of a voiceless consonant (at least in couplet medial position), I assume the following picture of interpolation in (117), where some degree of velum lowering is initiated prior to the onset of the phonologically [nasal] vowel.

(117)



Under this approach, we expect to find anticipatory flow prior to the onset of the vowel. Additionally, the relatively wide window for nasalization throughout the release of the affricate and throughout the duration of the fricative allows for a number of interpolative paths in the transition from orality to the nasality of the final vowel, i.e. for the variability in timing reflected in the bar graphs above[58]. By contrast, I assume that S3 assigns a narrow window specifying a high velum target in such contexts, limiting coarticulatory effects to the transitions between the segments.

Finally, the data are interesting in the light of similar data found by Cohn (1990) for English. Cohn notes that some English speakers optionally lower their velum upon the release of voiceless stops in English for words

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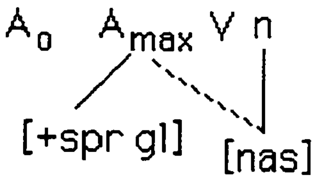
[58] Note that this model allows for a number of possible interpolative paths through a window. However, the development of an explicit model of interpolation is still an outstanding issue for the theory. (cf. Pierrehumbert

such as [pʰĩn] 'pin' and during the glottal fricative in forms such as [hẽnri] 'Henry'. Cohn notes that in such cases, the vowel is completely nasalized, a result which appears to contradict her claim that vowels in English are only partially nasalized in the context of a nasal consonant; i.e. that they receive their nasal quality via phonetic interpolation and not by phonological specification. In addressing this problem, Cohn attributes the phenomenon to an optional phonological rule spreading [nasal] from a nasal stop to the [+spread glottis] release of a preceding stop or to the root node of the [+spread glottis] fricative [h], as sketched in (118):

(118) **Sketch of Cohn's optional [nasal] spread rule**



By spreading [nasal] across the vowel, Cohn argues that the appearance of full nasalization on the vowel derives from the interpolation of nasality from between the following [+nasal] consonant and the preceding, phonologically specified [+nasal] stop release or [h].[59]

1980, Keating 1990b, Huffman 1989, Cohn 1990).

[59] Cohn's English data do not include words such as *seen*.It would be interesting to see if her speakers exhibit anticipatory velum lowering prior to

Cohn's argument is fundamentally driven by the desire to maintain two claims: 1) that vowels in VN contexts in English are not phonologically specified for [nasal] and 2) that phonetic nasal coarticulation in English is limited to a span of one segment. For our purposes here, however, it calls attention again to the difficulty of using phonetic data as a means of intuiting phonological specification. Cohn's claim is predicated on a particular view of the relatively inert role played by vowel nasalization in the phonological system of English. By contrast, in CM, the final vowel of couplets such as *kuʔ*^{u}*t*^{j}ũ 'you (fam) will hoe' must be specified for [nasal], since nasality here marks a morphological contrast. Once we know that [nasal] is phonologically present on the vowel, anticipatory lowering of the velum upon the release of the preceding, adjacent voiceless stops, affricates and fricatives can be viewed as a coarticulatory phenomenon and not necessarily as the result of a phonological specification. In short, the way in which we view the significance of phonetic data is tightly intertwined with the phonology of the system at hand.

Bearing in mind this view of the phonetics of vowel nasalization in the context of opaque consonants, we now turn in §4.3.2.2 to the phonetics of transparency.

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the release of the fricative in such cases.

4.3.2.2 Nasalization and Transparency

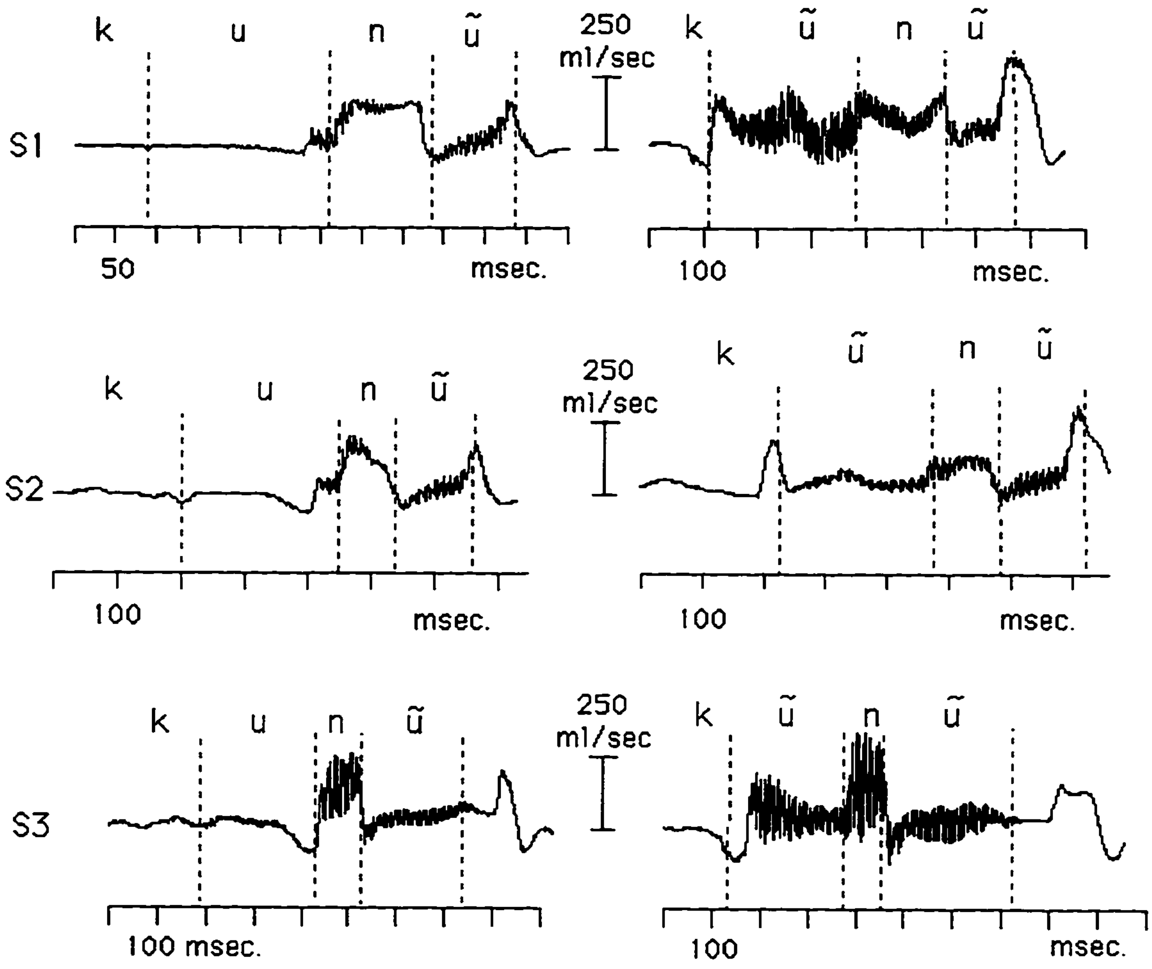
In this section, I address the implementation of nasality in what I have termed transparent contexts, i.e. contexts in which vowel nasalization propagates over intervening full nasal stops, voiced fricatives, and prenasalized stops. I begin in §4.3.2.2.1 with a discussion of the transparency of full nasal stops to vowel nasalization in the second person familiar. In §4.3.2.2.2 I discuss the implementation of nasalization in the context of the two voiced fricatives, [ð] and [β]. And in §4.3.2.2.3, I address the irregular behavior of both prenasalized stops and the special, transparent /ʃ/ under 2-FAM harmony.

4.3.2.2.1 Vowel nasalization and intervening full nasal stops

As we have seen above, in CVNV couplets that are not conjugated in the second person familiar, the vowel preceding the medial nasal stop is predictably oral throughout most or all of its duration. By contrast, full nasal stops are predictably transparent to 2-FAM harmony. That is, under 2-FAM nasalization, the first vowel of the couplet surfaces as predictably nasalized. Representative pairs of non-derived and 2-FAM forms *kunũ* 'to run' and *kũnũ* 'you (fam) will run' are provided in (119) for all three speakers.

(119) **Contrast between non-nasalized and 2-FAM CVNV couplets**

a) non-derived form b) 2-FAM form

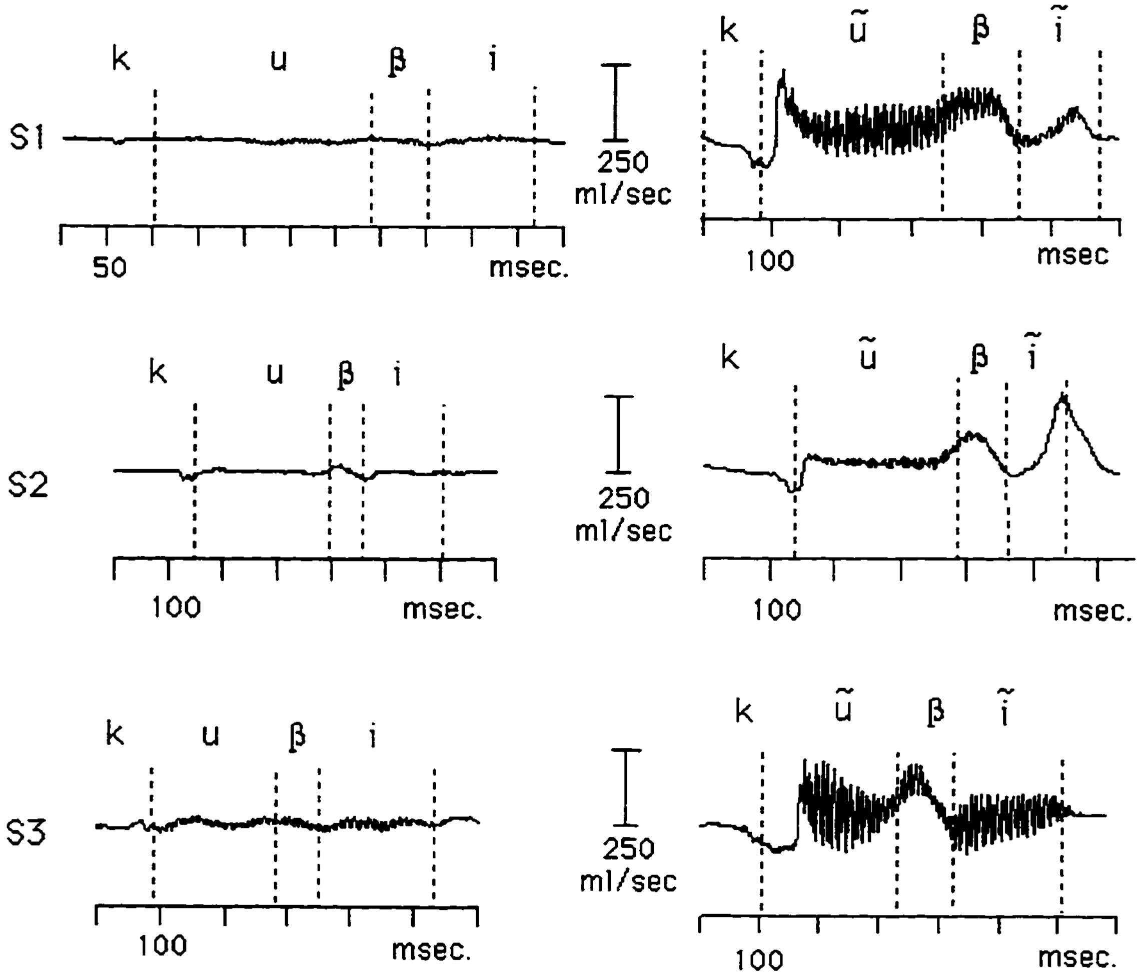


One question that arises from these data regards the means by which we are to account for the orality of the initial vowels in the underived context. That is, what is the phonological information that is interpreted by the phonetics as an assignment of a target for orality? Throughout the discussion in this chapter, I have assumed a monovalent [nasal] feature. I do not assume that orality targets for vowels must result from a [-nasal] specification. Rather, I take the position that the contrastive force of [nasal] in a phonological system; i.e. the role that [nasal] plays for vowels is sufficient to serve as a means for target assignment. For CM, a language in which vowel nasalization marks lexical contrasts, I assume that the lack of a [nasal] specification is implemented phonetically in terms of a high velum target. For a language such as English, in which nasality is not contrastive for vowels, the lack of a [nasal] specification can be implemented phonetically as a wide (i.e. relatively unspecified) window for [nasal]. In the case of nasal stop transparency, I assume that in non-2-FAM forms such as *kunũ* 'to run', the initial vowel lacks a [nasal] specification at the output of the phonology, which is interpreted phonetically as a target for orality. Under 2-FAM nasalization, the presence of a [nasal] specification on the initial vowel is interpreted phonetically via the construction of a narrow window for a low velum position.

4.3.2.2.2 Vowel nasalization and the fricatives /ð/ and /β/

Here again, the non-nasalized forms provide a basis for contrast when considering the implementation of [nasal] in the second person familiar.

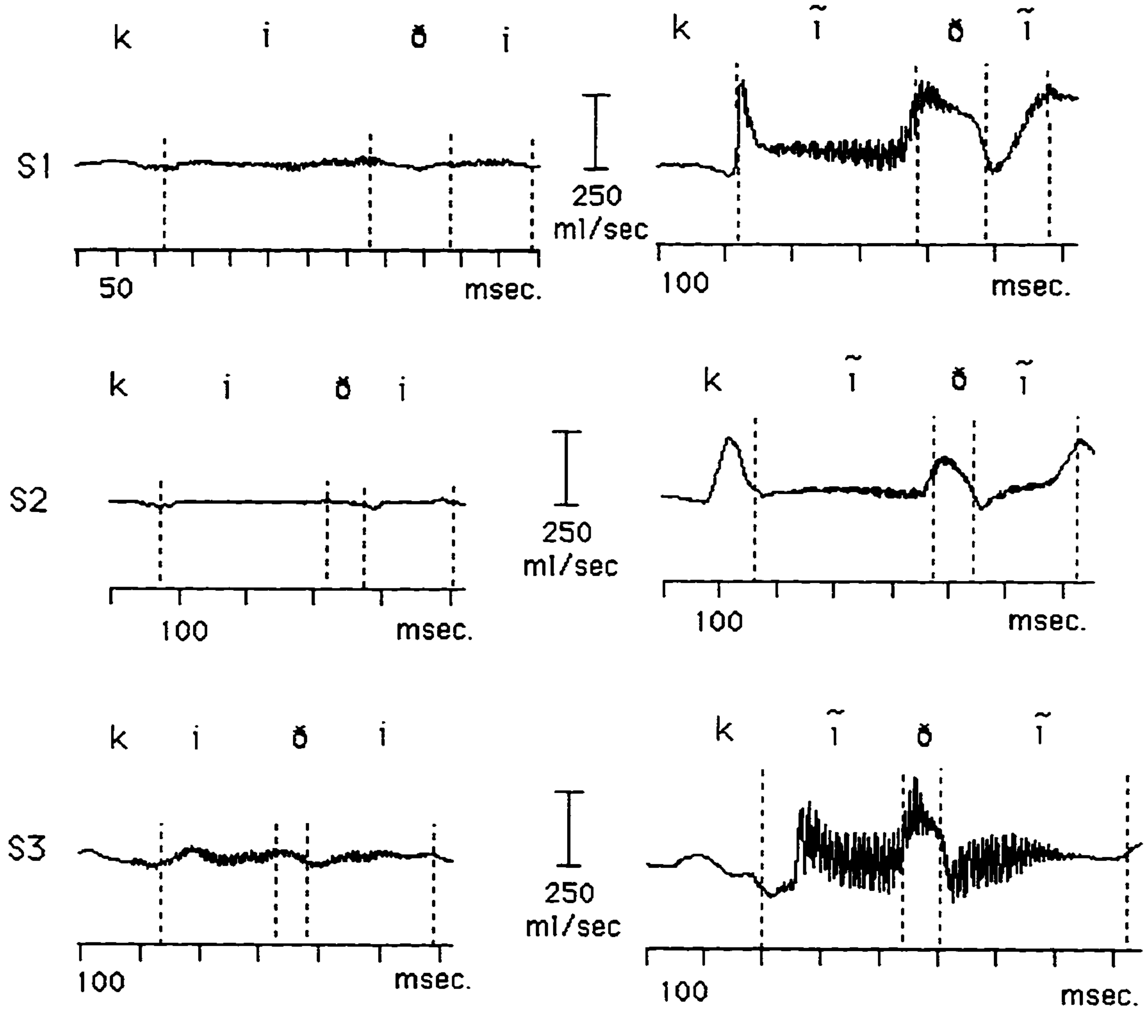
(120) Contrast between non-nasalized and 2-FAM CVβV couplets



a) non-nasal form

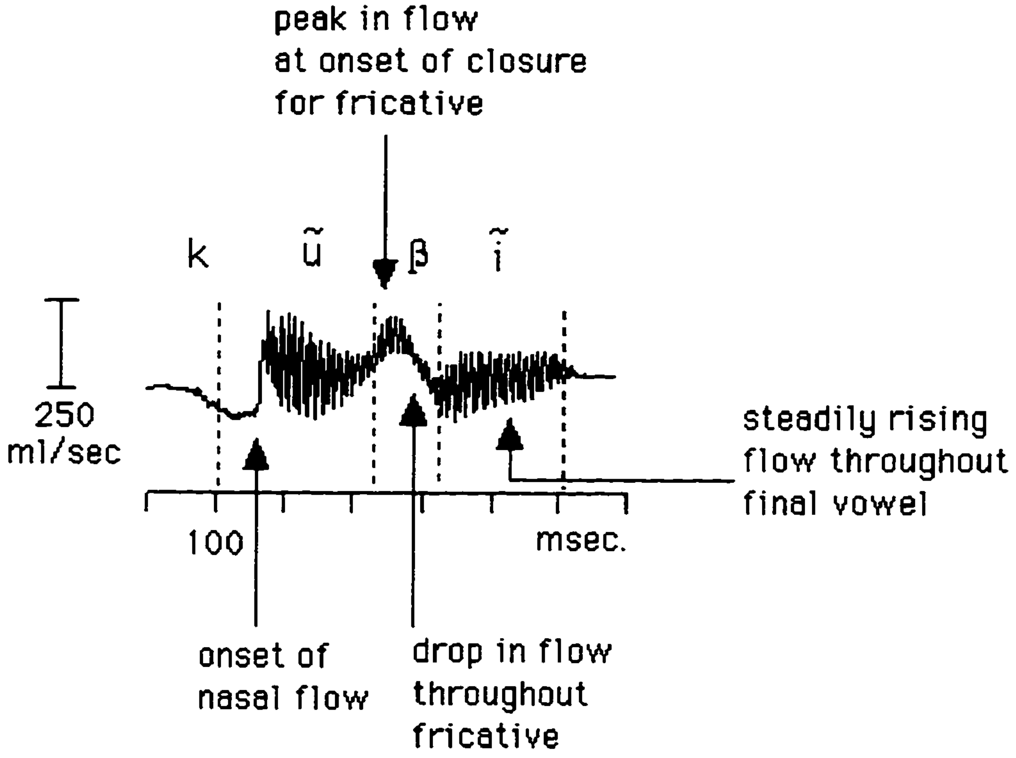
b) 2-FAM form

(121) Contrast between non-nasalized and 2-FAM CVðV couplets



The nature of transparency is interesting in that medial fricatives exhibit a target for orality. That is, the nasal flow data indicate that vowel-to-vowel nasal harmony is not implemented via a single, sustained velum lowering gesture, but rather involves a change in velum height throughout the production of the fricative, as shown in (122).

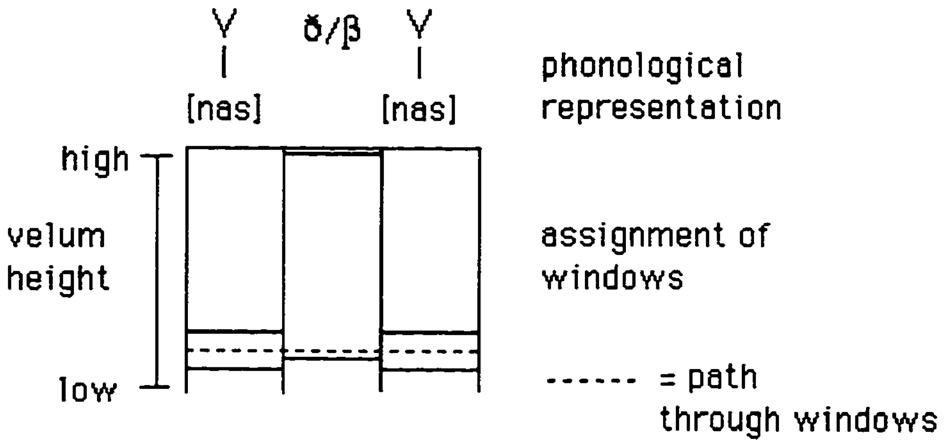
(122) **S3 nasal flow data: kũβĩ 'you (fam) will die'**



Here we see the onset of steady and (subsequently sustained) nasal flow early in the initial vowel of the couplet. Note that there is a rise in flow in the transition from V1 to the medial consonant [β]. I assume that this is a result of the formation of oral stricture and thus of an increased channeling of flow through the nasal cavity. That is, it does not necessarily indicate additional velum lowering. However, what is important is that flow decreases steadily during the fricative, indicating that the speaker is raising the velum throughout the duration of closure. At the onset of the final vowel, flow again increases, and the vowel is nasalized in its entirety.

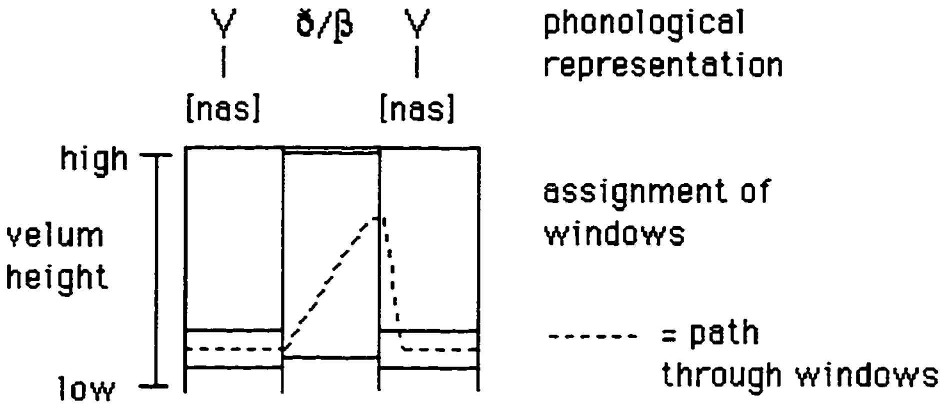
The data are interesting in that voiced fricatives that are flanked by nasalized vowels provide a fruitful testing ground for exploring the predicted nature of interpolation between two [nasal] targets. Following Keating (1990b) and Cohn (1990, 1993a), the general prediction is that interpolation through an unspecified domain (i.e. a domain with a wide window for a given articulatory or acoustic dimension) will proceed in a fairly linear fashion between the two [nasal] vowels, as sketched in (123):

(123) **Expected interpolation through an unspecified domain**



The CM nasal flow data indicate that the situation is more complicated, however, resulting in a picture corresponding more closely to (124).

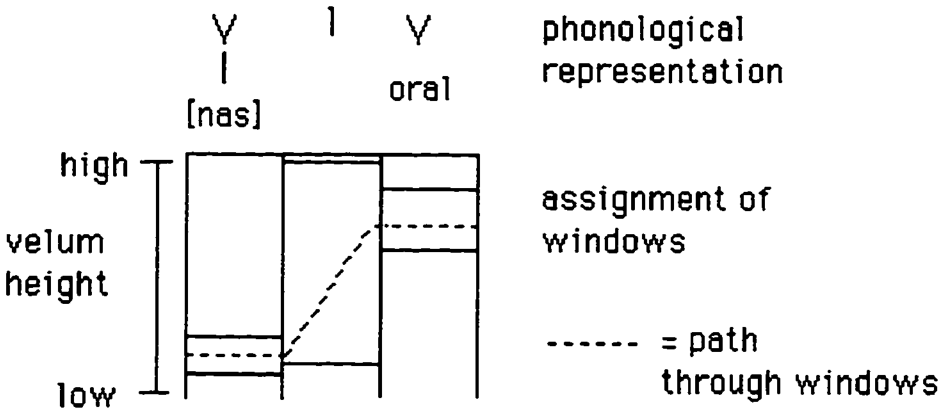
(124) **Pattern of attested interpolation through voiced fricatives**



That is, on the one hand, voiced fricatives appear to tolerate nasalization when flanked by nasal vowels, thus motivating a relatively wide window for velum height for these sounds. At the same time, they have a target for orality upon release, suggesting a narrow window for a relatively high velum position.

This pattern is surprising because it resembles the type of interpolation found by Cohn (1990), for example, for laterals that are *opaque* to progressive nasalization in Sundanese. Cohn argues that in forms such as ŋũliat 'stretch (active)' a phonological constraint banning the cooccurrence of [nasal] and [+continuant] blocks the phonological association of [+nasal] to the lateral and, because of a ban on skipping targets, the rightward propagation of [+nasal] is thus halted. The phonetics of opaque [l] exhibit a pattern of nasal flow similar to that in (124), in that the [l] is partially nasalized via interpolation from the preceding vowel, while the velum raises gradually throughout the duration of the consonant, as sketched in (125).

(125) **Opaque Sundanese /l/ (after Cohn 1990)**



In such cases, Cohn's nasal flow data appear to follow straightforwardly from the assignment of a relatively wide window for velum height for the lateral and the assumption of a gradual interpolation away from the low velum target of the preceding vowel.

Interestingly, the phonology of Sundanese is such that not all [l]'s are opaque to nasalization; infixed [l] surfaces in contexts in which it appears to be transparent to nasalization, as in [ɲ-ãl-ãũr] 'say (infixed form)'.[60] What is important to the discussion here is that such forms provide a contrast in

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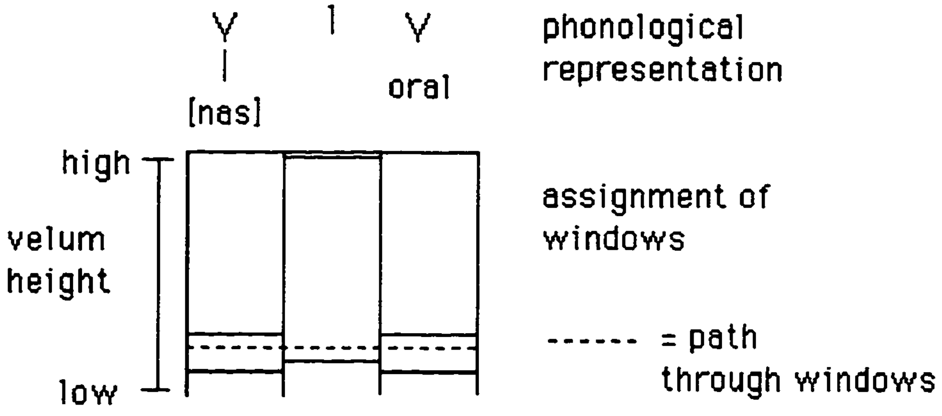
[60] The reader is referred to Cohn (1990) for the particulars of the phonological account of the facts.

Sundanese for [l] in two contexts. In the case of ŋũliat 'stretch (active)' above, [l] is preceded by a nasalized vowel but followed by an oral vowel. In the case of [ɲ-ãl-ãũr] 'say, infixed form', it is flanked by phonologically [nasal] vowels. In this latter case, [l] exhibits more of a straight line interpolation between nasal targets, as sketched in (126):

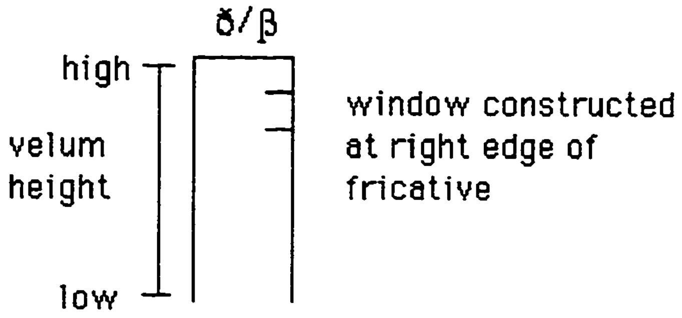
(126) **Phonetically transparent Sundanese /l/ (after Cohn 1990)**



Again, Cohn's data are compatible with the general prediction of the model. Interpolation in the case of opaque [l] results in a gradual raising of the velum throughout the duration of the lateral. By contrast, nasal flow throughout the duration of "transparent" [l] results in a more plateau-like pattern, which is itself expected as a function of interpolation from the phonologically specified targets for nasality on both sides of the consonant.

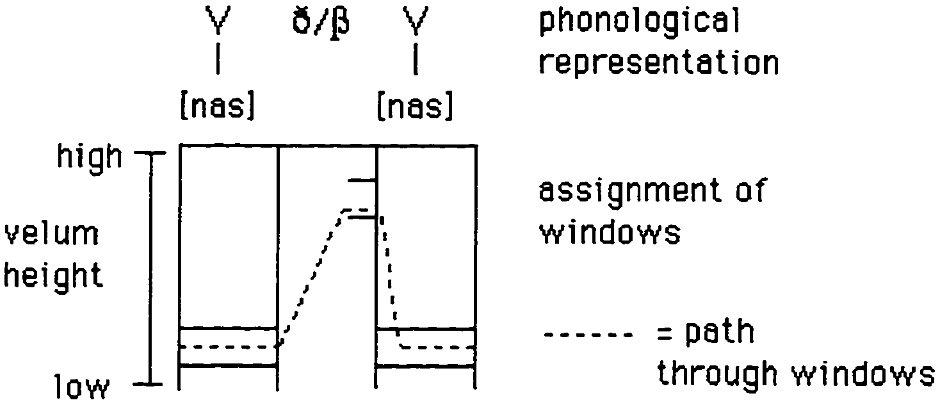
Importantly, the CM voiced fricative data are distinct in that they indicate that the width of the window for velum height appears to vary as a function of time within the voiced fricative. Where we might expect little change in velum height in a transparent fricative flanked by [nasal] vowel targets, we instead find a regular pattern of decreased flow throughout the fricative. As I have argued above in Chapter 3, this again suggests that window construction is a non-trivial affair. In this case, either we cannot assume that the temporal span of a window along a given phonetic dimension must correspond to the duration of the entire segment, or, we cannot assume that window width remains invariant throughout a segment. These findings support Huffman's (1989, 1993) claim that phonetic targets--in this case, relative nasality or orality--can be implemented with different durations. For CM voiced fricatives, I follow the spirit of Huffman (1989, 1993) in proposing that a relatively narrow window for a raised velum is located at the right edge of voiced fricatives, as in (127):

(127) **Window construction for velum height in voiced fricatives**



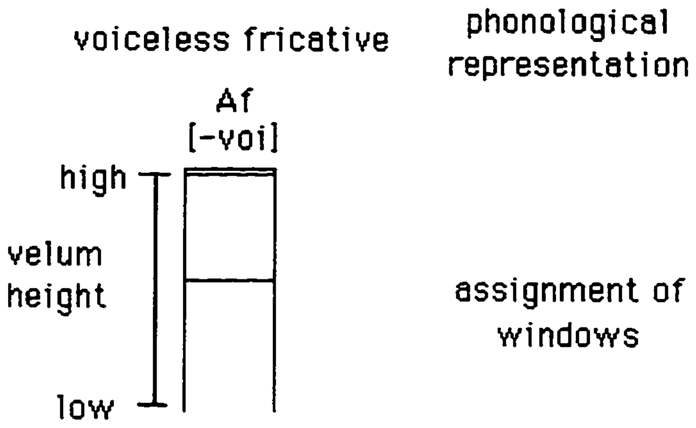
Under this approach, the observed pattern of flow is accounted for via interpolation from the low velum target of the preceding vowel to the target for orality at the right edge of the fricative. This is followed by a rapid lowering of the velum to achieve the [nasal] target of the following vowel, as seen in (128).

(128) **Interpolation of nasality through voiced fricatives**



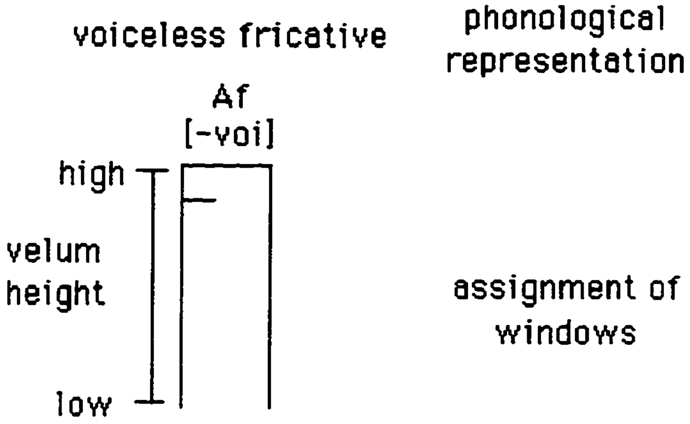
Finally, the behavior of voiced fricatives provides an interesting contrast to the phonetic behavior of the opaque fricative /ʃ/. As we have seen, /ʃ/ is remarkable not for its phonological opacity to nasal harmony, but rather, for its phonetic tolerance of velic aperture in the context of a following nasal vowel. I took such data to indicate that the phonetic implementation of /ʃ/ involves the construction of a relatively wide (i.e. unspecified) window for velum height throughout the duration of the fricative, thus allowing for a degree of anticipatory interpolation from the nasality of a following vowel. This is sketched for convenience in (129):

(129) **Window construction for velum height in /ʃ/**



Alternatively, we might view the behavior of /ʃ/ as best characterized via the collocation of a narrow window for a raised velum at the onset of the fricative, as in (130):

(130) **Window for velum position at left edge of voiceless fricative**



In short, the difference between the temporal location of targets for velum height in voiced versus voiceless fricatives can arguably be viewed as one in which the window is located at the offset of the former and the onset of the latter. Under this view, we can understand the opacity of voiceless consonants to both 2-FAM and contrastive nasalization as the phonological encoding of an avoidance of phonetic contexts that would require rapid velum raising[61]--i.e. an avoidance of rapid velum displacement between fully nasal and immediately following fully oral phonetic targets.[62] By the same token, we can understand the transparency of voiced consonants in terms of their ability to tolerate interpolative nasalization from a preceding [nasal] vowel, while gradually reaching a fairly high velum target at their offset.

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[61] I thank Patricia Keating (p.c.) for bringing this possibility to my attention.

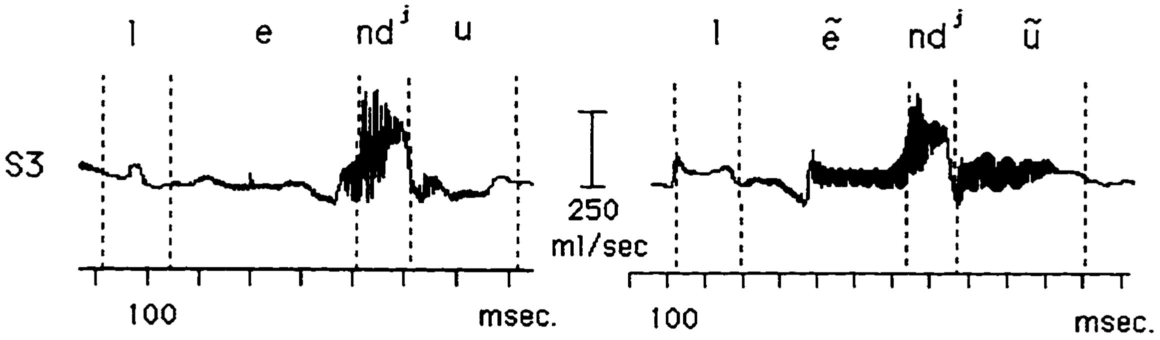
[62] For their part, I assume that voiceless stops have a raised velum target from the onset of closure that extends throughout the closure phase of the stop.

4.3.2.2.3 The behavior of prenasalized stops and transparent /ʃ/

As was the case for both the voiceless and voiced consonants discussed above, prenasalized stops and transparent /ʃ/ yield surprising data in the context of vowel nasalization. The general phonological treatment of these sounds is straightforward; they pattern with the voiced fricatives and full nasal stops in not blocking the right-to-left spread of nasality. However, the facts of implementation are a bit more complicated. This sections reviews the different ways in which speakers exhibit variation in forms in which these segments are medial. First, I describe the data that correspond to the expectations emerging from the phonological analysis, providing an account for the phonetic implementation of nasality in these cases. I then discuss the nature of the variation found in the data and propose possible accounts for variation from the expected norm.

We begin with a discussion of the behavior of medial prenasalized stops under 2-FAM nasalization. To establish a clear view of the expected behavior of prenasalized stops in this context, consider the data in (131) for the pair of couplets *lendʲu* 'dirty' and *len*dʲũ 'you (fam) are dirty' produced by S3.

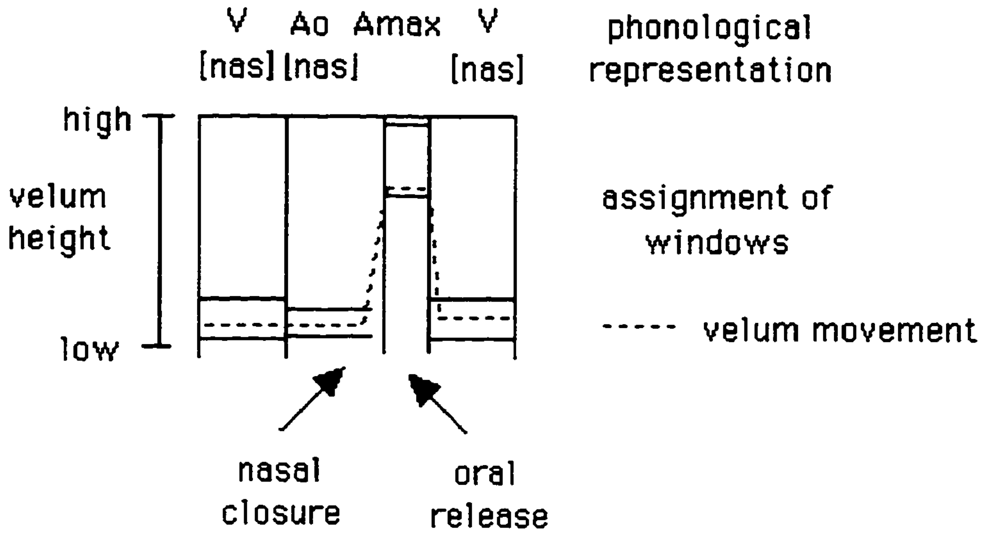
(131) **S3 nasal flow data: lendʲu versus lendʲũ**



a) non-2-FAM form b) 2-FAM form

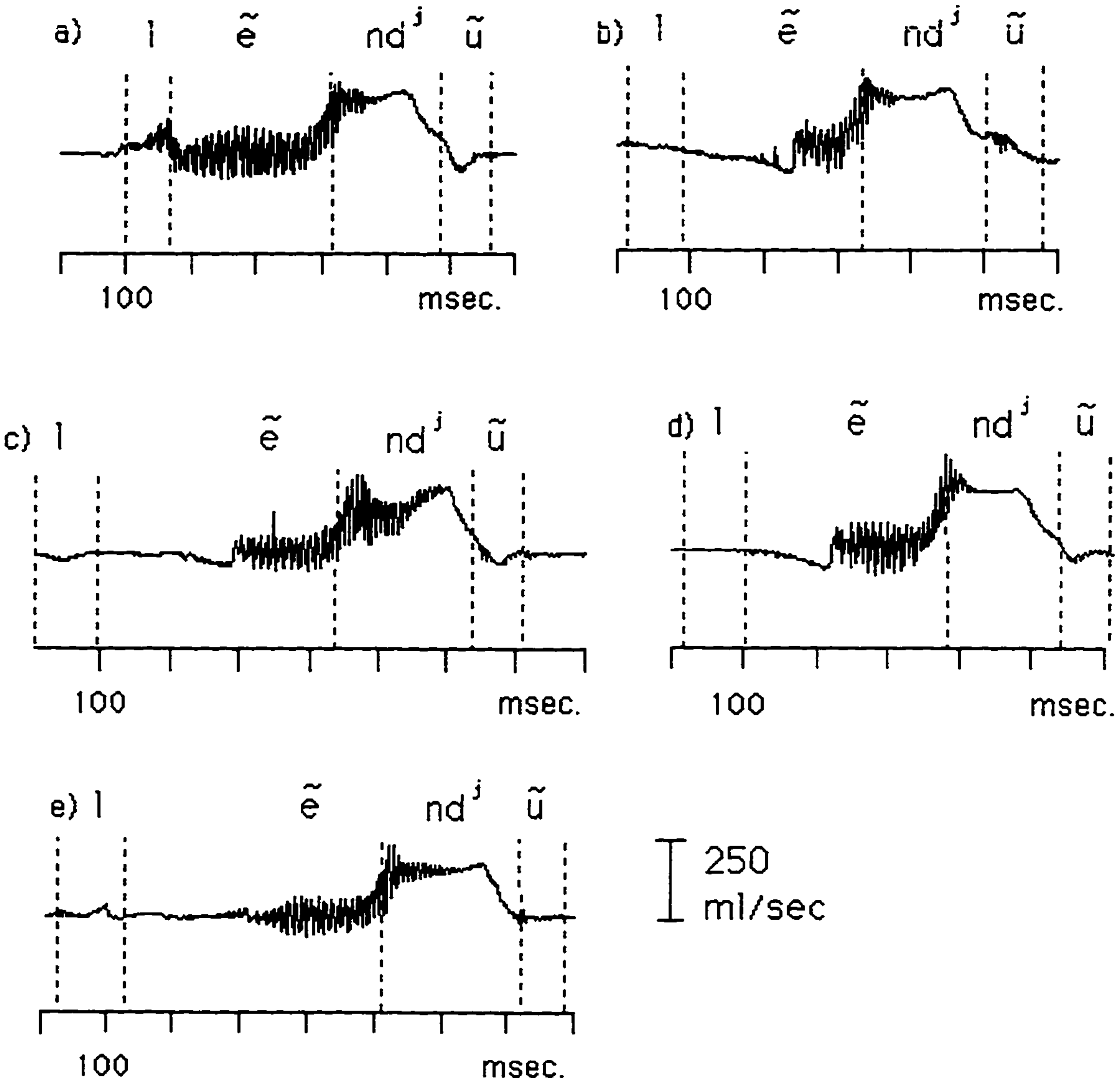
The form in (a) shows the implementation of a prenasalized stop flanked by oral vowels, i.e. in the non-2-FAM context. Here, [nasal] is implemented on the closure phase of the stop and limited to a brief period of transition between the onset of stop closure and the preceding vowel. This is consistent with an analysis in which both vowels are oral at the output of the phonological component of the grammar. By contrast, in the 2-FAM form in (b), the first vowel of the couplet exhibits roughly 250 milliseconds of sustained nasal flow prior to the onset of the stop. And, following the oral release of the stop, the final vowel is nasalized. In this case, the flow data are consistent with a phonological analysis in which both vowels of the couplet are specified for [nasal] at the output of the phonology, but in which the release of the medial stop is oral, as sketched in (132).

(132) Implementation: prenasalized stops in the context of 2-FAM harmony



S1, however, differs systematically from the other two speakers in that her data exhibit nasal flow throughout only the first vowel of the couplet in the second person familiar. All five tokens are presented in (133).

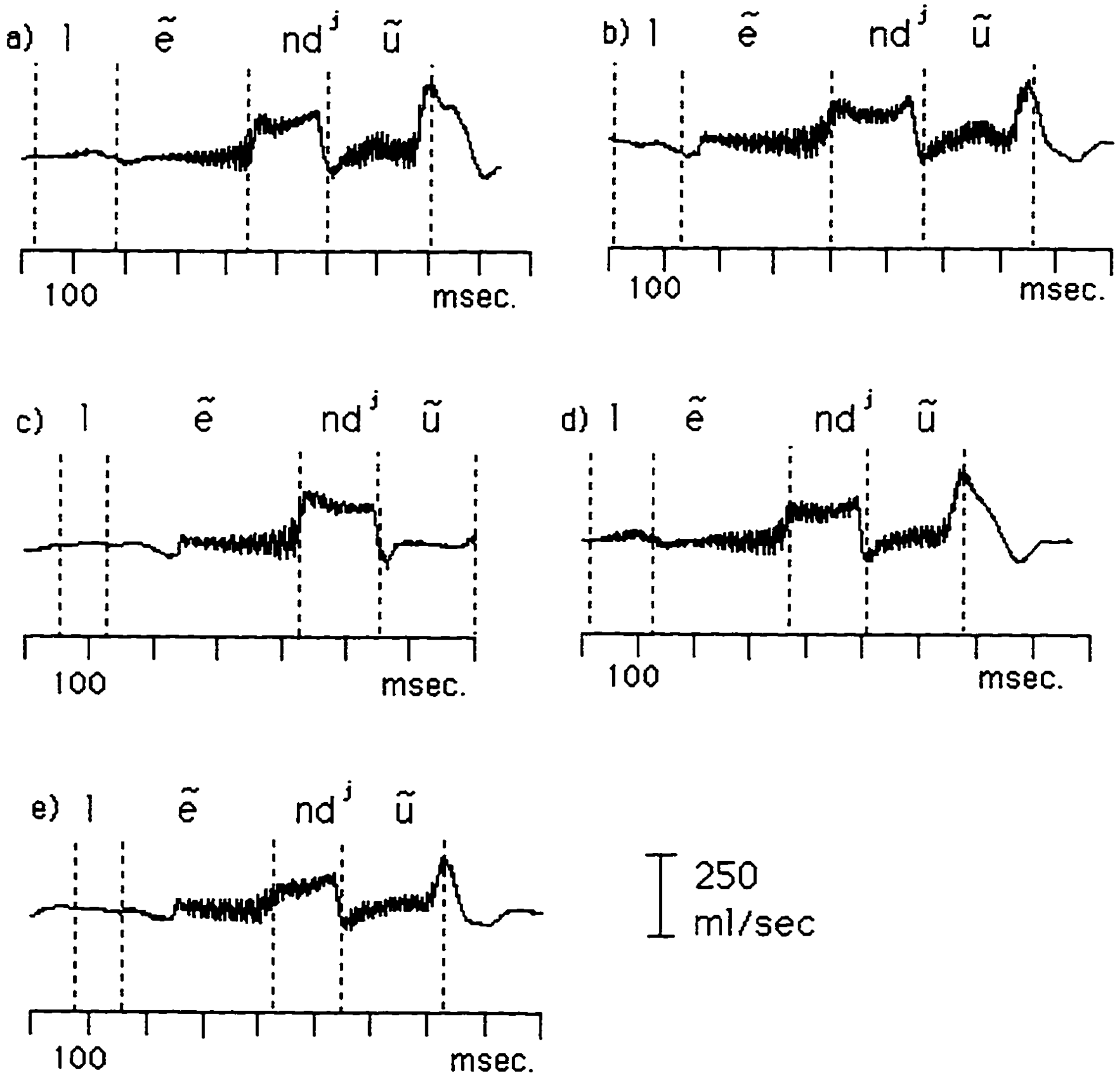
(133) **S1 nasal flow data: /lendʲu + 2-FAM/**



Note that, with the exception of (a), in which there appears to be flow present on part of the initial [l], despite a fairly late onset of nasalization, there is, nevertheless a fairly long period for the implementation of nasality. In fact, only (b) appears to exhibit less than 150 milliseconds of nasalization. By contrast, V2 does not exhibit a rise in nasal flow subsequent to the release of the stop. That is, the final vowel is phonetically oral.

As for S2, four of the five tokens exhibit the expected flow pattern, but one token, (c), also appears to be realized without resumed nasal flow on the final vowel:

(134) **S1 nasal flow data: /lend^{j}u + 2-FAM/**



What does this suggest about the status of prenasalized stops under 2-FAM harmony? On the basis of only the data at hand, it is impossible to provide a definitive analysis. However, I hypothesize that S1's data in particular reveal a tension between the phonological grammar and performance. A closer examination of the nasal flow from S1 above reconfirms the generalization that unstressed vowels in CM are normally short. Here, V2 ranges from roughly 50 to 75 milliseconds in duration. At the same time, the absence of energy visible on the nasal flow trace indicates that the speaker is most likely devoicing as early as the nasal closure of the onset of the prenasalized stop in the final, unstressed syllable.[63] This becomes clear when we consider the nasal flow in conjunction with the audio signal, as shown in (135).

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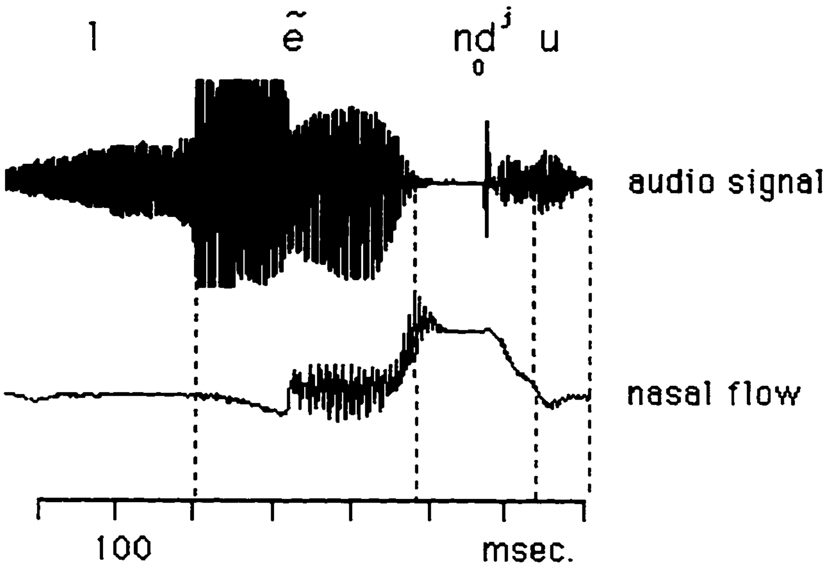
[63] See, for example, Ladefoged and Madiesson (1996:111) for similar looking data on voiceless nasal stops in Burmese.

(135) **S1: audio signal and nasal flow for /lendʲu + 2-FAM/**



Here, the onset of nasal flow is evident both in the sudden rise of flow at roughly 220 milliseconds and in the concomitant loss of amplitude in the acoustic waveform. Note that the prenasalized stop exhibits little if any acoustic energy, and the final vowel is weakly voiced at best.

The explanation for S1's failure to resume nasalization in V2 in these forms may be functional. That is, with little or no energy on the final vowel and a devoiced prenasalized stop preceding it, the acoustic consequences of lowering the velum during the articulation of the final vowel would be negligible: vowel nasalization is not simply a matter of lowering the velum, but rather, a matter of coupling the resonances of the nasal and oral cavities. Nevertheless, note that the 2-FAM is still clearly expressed by the long period of nasalization preceding the prenasalized stop, by contrast to the orality of this vowel in the underived context. In short, though S1's phonological grammar may specify both vowels as [nasal] in these forms, the prospect of little or no acoustic gain may prompt her to not fail to attempt to achieve a low velum target for devoiced unstressed vowels, following the oral release of the stop.[64]

The second issue under consideration in this section is the behavior of the transparent /ʃ/ of forms such as kũʃũ 'you (fam) are diligent'. Again, the phonological generalization presents a somewhat idealized picture of the data: such /ʃ/'s are transparent to regressive nasalization. The nasal flow facts reveal, however, reveal a more complex picture. Again, S1's data provide an interesting source of variation, though all three speakers produce tokens which fail to correspond to what we might take to be the expected pattern of velum movement.

Again, the data in (136) provide examples of the expected phonetic implementation of vowel nasalization in pairs of non-nasalized and 2-FAM forms for *kuʃu* 'diligent' and *kũʃũ* 'you (fam) are diligent' for all three speakers.

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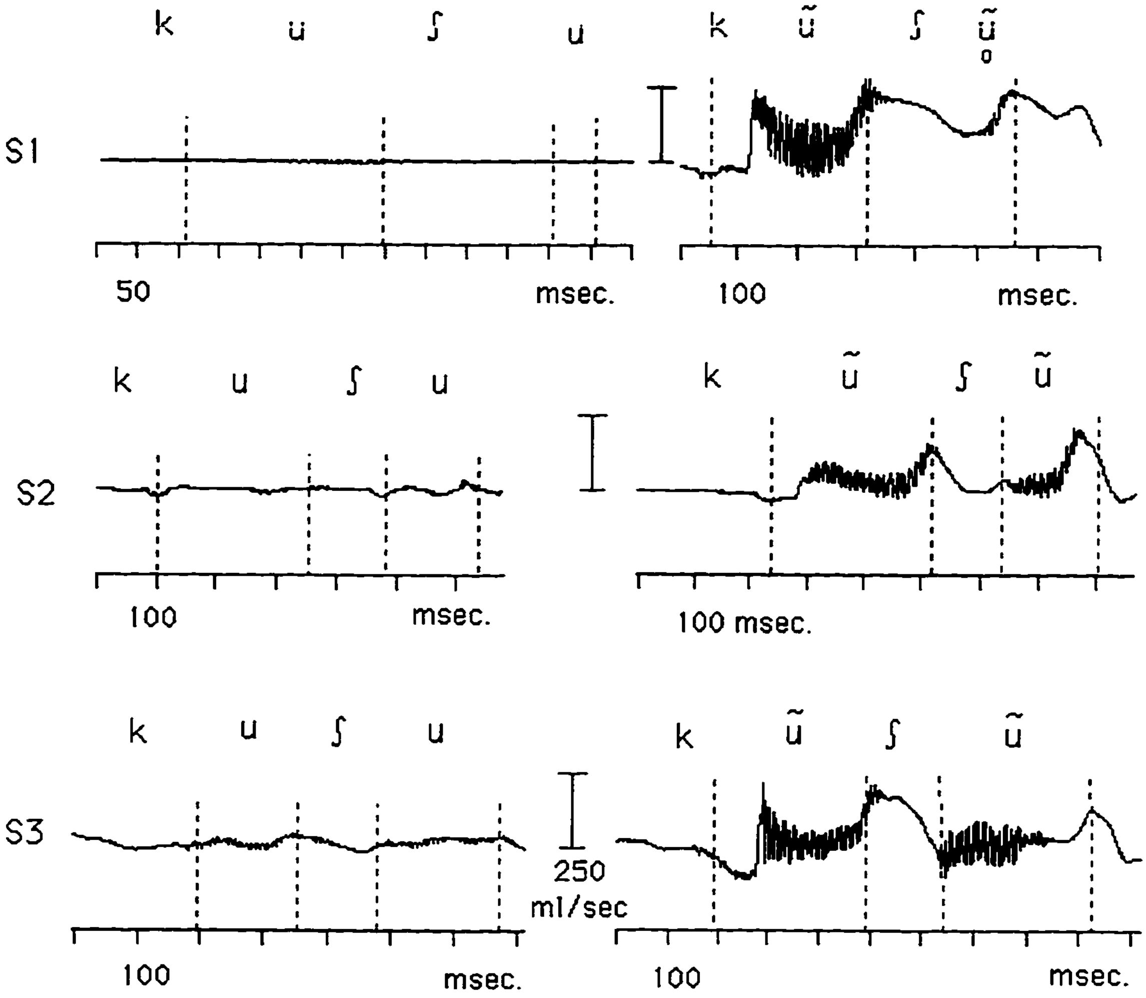
[64] Perhaps this can be related to the notion of LAZY recently exploited by Kirchner (1995b), building on the work of Lindblom (1983) on the economy of speech gestures.

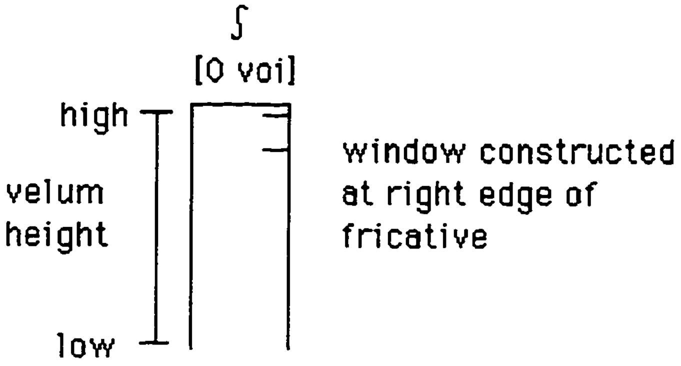
(136)



The forms in the left column provide oral forms as a basis of comparison. Note that in the 2-FAM context for all three speakers, the flow pattern resembles that found for medial voiced fricatives that are flanked by nasal vowels. That is, we see 1) steady, plateau-like nasal flow on the initial vowel of the couplet, 2) an upward slope corresponding to the onset of fricative closure, and 3) a subsequent decline in nasal flow throughout the duration of the fricative. At the end of the couplet, V2 is nasalized throughout its duration.

This suggests that the phonetic implementation of such /ʃ/'s involves the construction of a window for a high velum at their right edge, as I have claimed is the case for voiced fricatives.[65]

(137) **Window assignment for velum height in transparent /ʃ/**



Following the treatment of voiced fricative transparency above, the attested flow pattern can be characterized as in (138).

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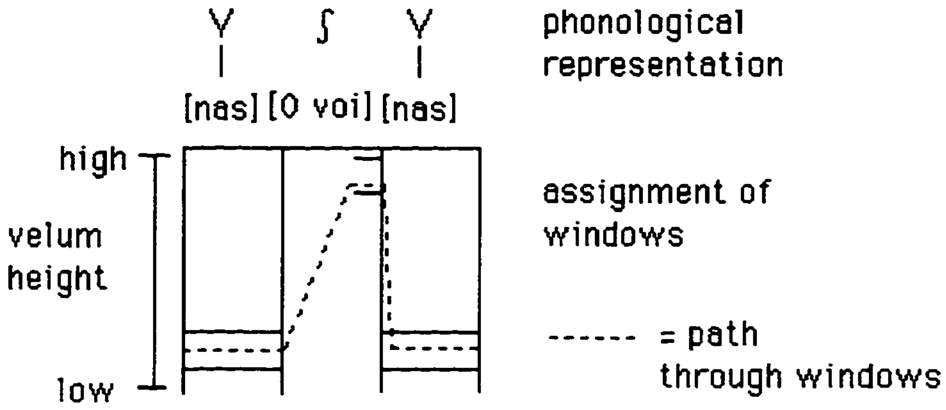
[65] Recall that I assume that this /ʃ/ has no voicing specification under the assumption that it is thus phonologically distinguished from the [-voice] opaque /ʃ/ (see discussion in Chapter 3).

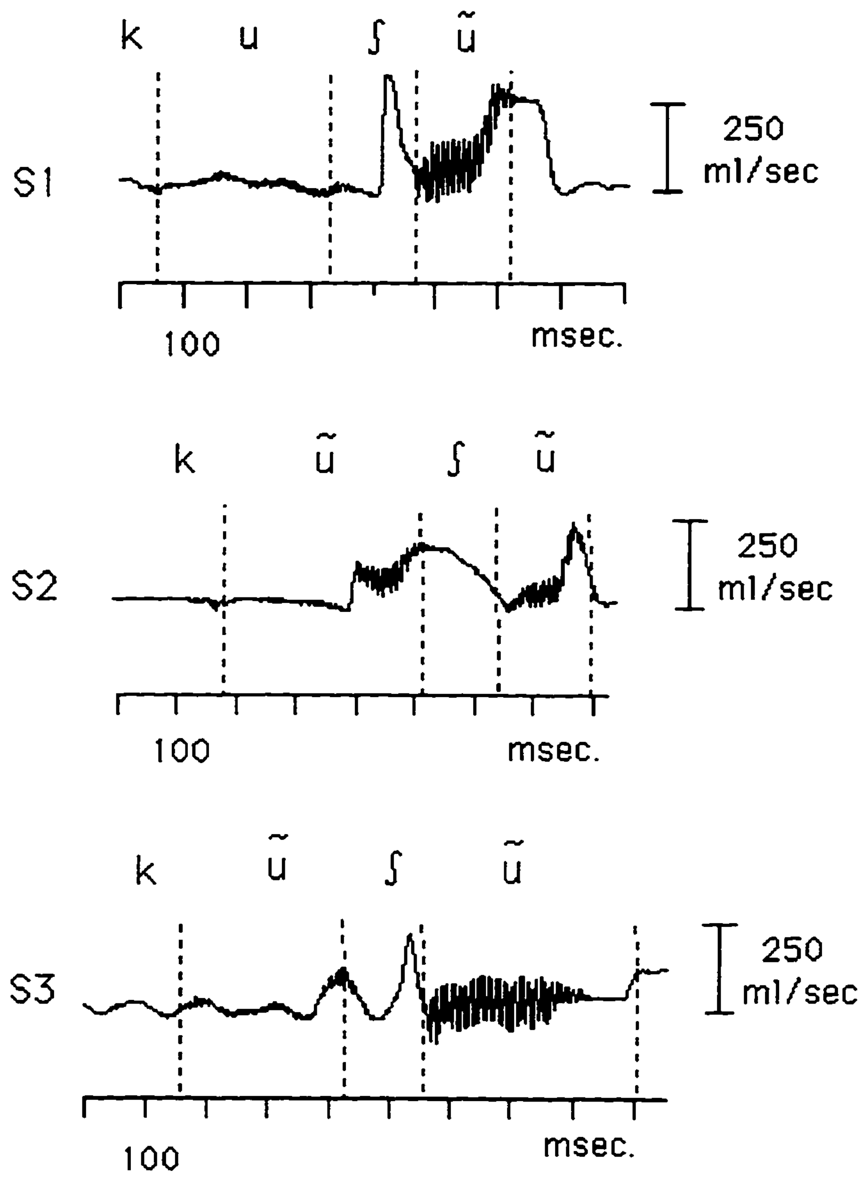
(138) Implementation of [nasal] in transparent ṽʃṽ sequences



Here, both vowels are phonologically specified for [nasal] at the output of the phonology. The fricative--flanked by low velum targets and characterized by having its own orality target at the right edge--allows for interpolative velum raising throughout its duration. Subsequently, the velum is lowered again to achieve the nasal target of the following vowel.

Again, however, the facts are somewhat more complicated. The data in (139) provide tokens that illustrate the variation in nasal implementation in this same pair of forms across all three speakers.

(139) Flow traces: kũʃũ 'you (fam) are diligent'



These data are interesting in that they call attention to two issues. First, in the token produced by S1, /ʃ/ unexpectedly blocks regressive nasalization. That is, it appears to pattern with phonologically voiceless consonants. Secondly, in the tokens produced by S2 and S3, though /ʃ/ does not block nasalization, the extent of nasalization on the initial vowel of the couplet is strikingly short. That is, the temporal duration of nasal implementation in the vowel is not what we would expect of the phonetic implementation of a vowel that is phonologically specified for [nasal] (see, for example, Cohn 1990, 1993a)[66].

The most striking source of variation is manifested in S1's speech. Consider the five tokens for /kuʃu + 2-FAM/ 'you (fam) are diligent' in (140).

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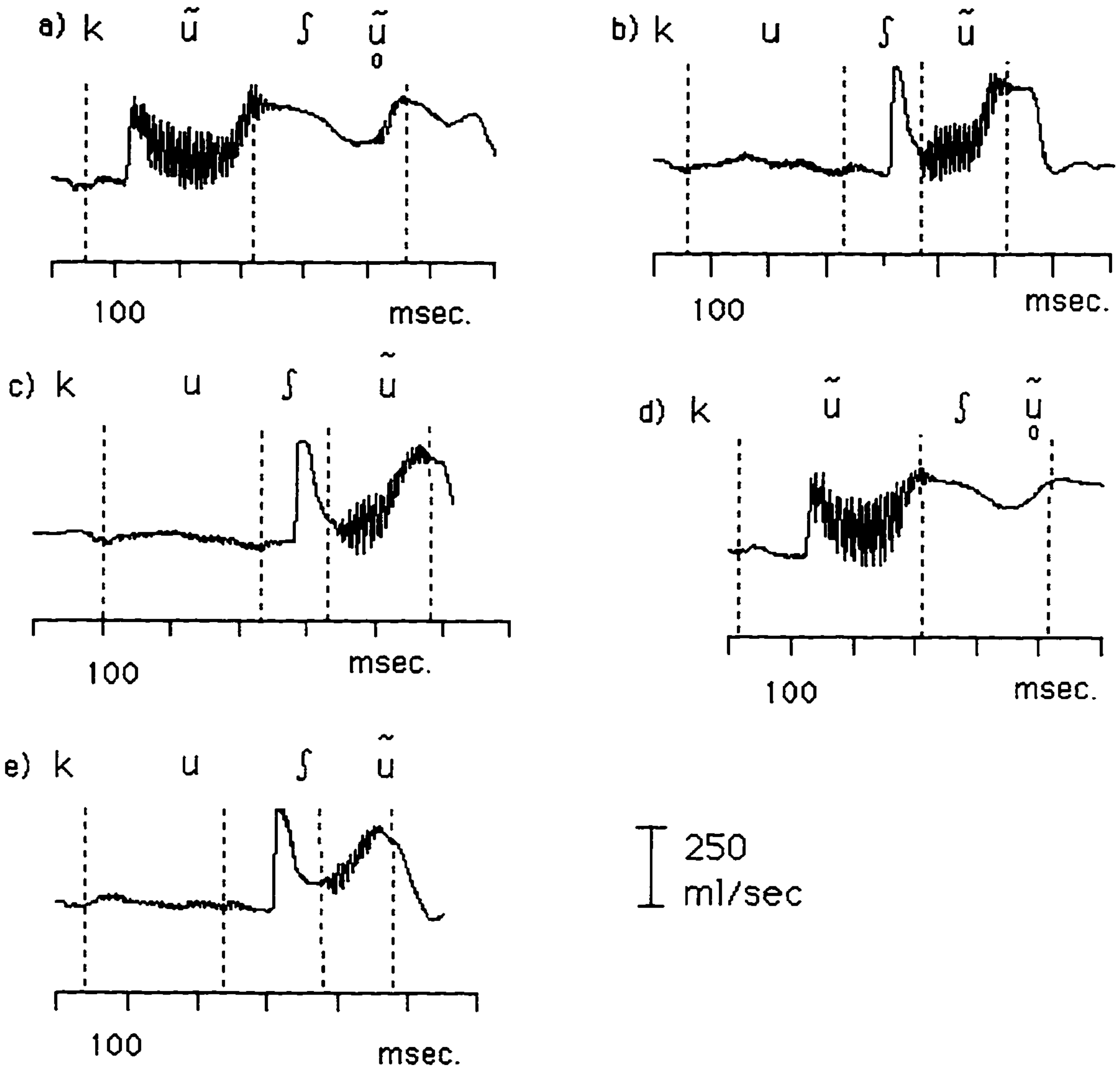
[66] Note as well that the flow pattern on the token produced by S3 in (139) is additionally odd in that it exhibits an increase in nasal flow at both the onset and offset of the fricative, suggesting that the orality target at the right edge is not reached in this form, i.e. that the velum lowering gesture for the final vowel overlaps with the release of the fricative.

(140) **S1 nasal flow data: /kuʃu + 2-FAM/ 'diligent + 2-FAM'**



In tokens (b,c,e), the leftward propagation of [nasal] is blocked by /ʃ/, while in (a) and (d), the fricative is transparent to harmony; i.e., both vowels are realized with a lowered velum. Interestingly, in the two tokens in which /ʃ/ is transparent to nasalization, the final, unstressed vowel of the couplet is devoiced. By contrast, in the three opaque cases, the final vowel is voiced and thus provides sufficient energy for the generation of nasal resonance. In all of the forms, S1 produces nasalized vowels that are sufficient to unambiguously distinguish the 2-FAM form from its oral, non-2-FAM counterpart.

What is intriguing is that the variable implementation of nasality on the first vowel of the couplet seems to be related to whether or not the final vowel is devoiced. Of course, on the basis of such a limited data set, it is difficult to draw more conclusive generalizations, but her performance calls to mind Jakobson, Fant, and Halle's (1952) observation that "...we speak to be heard in order to be understood". I tentatively conclude that, phonologically, the unspecified voicing status of /ʃ/ may be somewhat unstable, given its phonetic voicelessness. The variability exhibited by S1 may be a function of this instability, causing her to implement this /ʃ/in nasal contexts with an early phonetic target for orality that serves to suppress the implementation [nasal] on V1.[67]

The second type of variability involves the timing of the onset of nasalization in the first vowel of the couplet. In the tokens in (139) above for S2 and S3, we see that the timing of velum lowering is closely coordinated with the end of V1. One of the five tokens for S2 and two of S3's tokens

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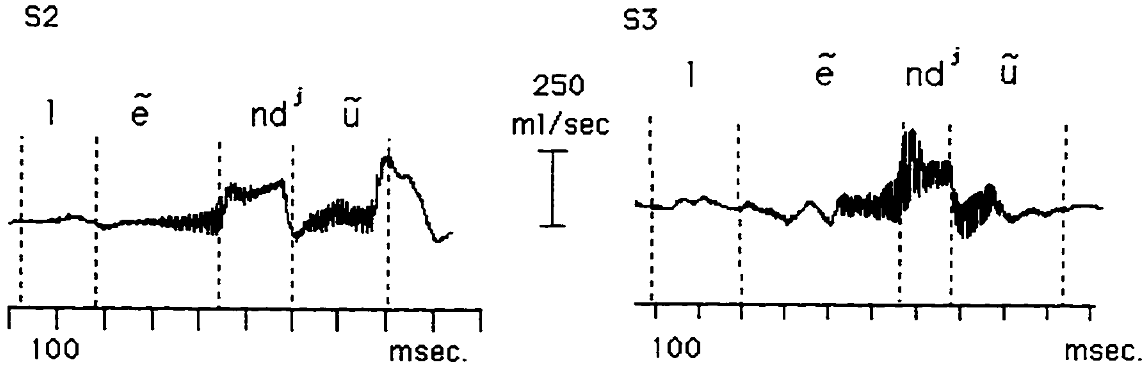
[67] Note, however, that matters are complicated by the fact that S1 does not glottalize the preceding vowel. That is, she sometimes treats /ʃ/ as voiceless with respect to nasalization, but not with respect to glottalization.

exhibit this type of short vowel nasalization prior to the onset of the medial fricative. More generally, we see in looking across the data involving transparent consonants (see Appendix) that there is often (though not always) a considerable lag between the release of the initial consonant and the onset of nasalization in V1. This is important in that it again calls attention to the difficulty of intuiting phonological information from phonetic data. Consider, for example, forms such as lẽndʲũ 'you (fam) are dirty' in (141), produced by S2 and S3:

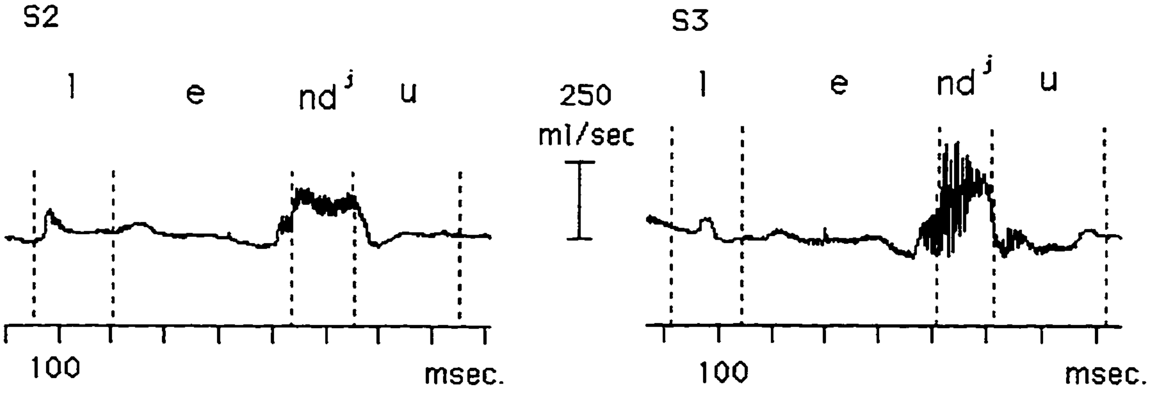
(141) **Nasal flow data: lẽndʲũ 'you (fam) are dirty'**



What in the phonetic data indicates that V1 in these contexts should be viewed as phonologically specified for [nasal]? Both vowels are partially nasalized, with the onset of nasalization at or following the midpoint of a vowel which precedes a medial prenasalized stop. Such a pattern would appear to follow straightforwardly from a notion of interpolation such as that advanced by Cohn (1990, 1993a) to account for similar looking English data. That is, the nasalization of the vowel can be attributed to phonetic coarticulation with the nasal closure of the following stop.

However, for CM speakers, even in such cases, nasalization would appear to contribute to the phonological marking of the morphological category of the second person familiar, i.e. to the distinction between such forms and their non-2-FAM counterparts such as lend^{j}u 'dirty'.

(142) **Nasal flow data: lend^{j}u 'dirty'**



These data call attention to two important points. First, they reinforce the claim that intuiting phonological information from phonetic data is a highly complex affair. Secondly, they remind us of Keating's (1990b) discussion of the fact that the level of phonetic implementation in which phonological categories are translated to phonetic targets is itself an abstraction away from the intricacies of the dynamic and variable process of--

to borrow Browman and Goldstein's (1986, 1989) terminology--orchestrating the articulatory gestures that result in speech.

4.3.3 Conclusions

In this chapter I have provided a detailed examination of both the phonology and phonetics of nasalization in CM. I begin with a basic description of the general patterns of the distribution of nasality within roots in the language. Then, within the context of Optimality Theory, I provide a formal phonological account of the entire range of facts that takes surface nasalization patterns to be the result of two interacting types of nasalization: 1) vowel-to-vowel or prosodic nasalization and 2) root-to-root nasalization triggered by nasal consonants. These patterns are characterized in terms of constraints pressuring for the alignment of [nasal] with the rightmost and leftmost moras of a couplet, together with segmental constraints, such as *NC, *NV, and *ṽN, and configurational constraints, such as *GAP and the OCP, which interact with the alignment constraints to generate the particular properties of the system. In the discussion of the phonology of [nasal] distribution, I argue that an explicit account of the facts, and, in particular, the need to ban faithful mappings from logically possible input candidates to illicit surface forms, motivates the use of a conditional constraint, L → R, which characterizes the entailment relation by which rightmost moraic alignment is always satisfied if it is the case that leftmost alignment is satisfied in a root.

In the last part of the chapter, I focus on the interface of phonology and phonetics as it pertains to nasalization. First, I discuss the use of the segmental constraints *NV, *ṽN, and *NC. I point out that the first two have the effect of phonologizing left-to-right or perseveratory nasal coarticulation, while banning right-to-left or anticipatory coarticulation, from nasal consonants to adjacent vowels. Though I note that there are no simple answers to the question of why the language should choose to enforce such a pattern, I suggest that *ṽN might profitably be viewed as a mechanism for preventing morphological neutralization, i.e. of maintaining a distinction between CVNV forms in the non-derived and second familiar contexts, while *NV can be viewed as a means of maximizing the auditory distinctiveness of nasal stop-vowel versus prenasalized stop-vowel sequences. Regarding the constraint *NC, I note that it is interesting in that it derives from a phonetically grounded relationship between voicing and nasality, but that it characterizes opacity by obtaining of sequences consisting of a nasal vowel followed by an oral consonant, rather than by banning the coocurrence of nasality and voicing within a single segment. I have also noted that it is interesting for what it does not do. In particular, I argue that there are good reasons to expect all obstruent consonants to block nasalization, both voiced and voiceless. This is not the case in CM, where voiced consonants are transparent to vowel-to-vowel nasal harmony. This, in turn, calls our attention to the fact that phonetically motivated constraints are not simply phonological imperatives (Archangeli and Pulleyblank 1994a). Possible phonetic motivation circumscribes a range of possibilities for constraints, which may or may not be exploited by a particular phonology.

Finally, I discuss the phonetic implementation of [nasal], using nasal airflow data as evidence of velum activity. This section reveals surprising data regarding the timing of velum lowering, especially with respect to the production of fricatives. First, I show that claims about the universal orality of fricatives (cf. Ohala and Ohala 1993, Cohn 1993b) appear to be falsified by the CM data. Specifically, both voiceless and voiced fricatives are realized with nasal flow throughout a large part or all of their durations. I argue that the data further motivate the position adopted in Chapter 3 in the treatment of glottalization, i.e., the position that phonetic targets for articulatory (and/or acoustic) dimensions can be constructed throughout only part of a segment (cf. Huffman 1989, 1993). In this case, I show that orality targets for voiceless fricatives are constructed at the left edge of the segment, with anticipatory velum lowering resulting from interpolation between the absence of a target for orality throughout the latter half of the fricative and the low velum target of a following vowel. By contrast, I argue that the target for orality in voiced fricatives is located at the right edge of the segment. Their transparency can thus be related to their ability to tolerate nasal during their closure while an orality target is gradually reached at the right edge of these segments. In this sense, we can better understand the way in which *NC derives the opacity of voiceless sounds to nasal harmony in the phonology: it bans nasal vowel-consonant sequences in contexts in which the consonant has an early or left-edge target for orality.

Finally, I return to the issue of intuiting phonological information from phonetic data. Using the case of the timing of the onset of nasalization in the initial vowel of 2-FAM forms such as [lẽndʲũ] 'you (fam) are dirty', I argue again that the interpretation of phonetic data requires a knowledge of the phonological system of the language in question. In this case, I provide tokens in which the pattern of nasal timing closely resembles what Cohn (1990, 1993a) has convincingly shown to be a pattern of interpolative nasalization in English VN sequences. However, I note that the CM cases are cases in which such partial nasalization serves to mark a morphological category. To the extent that we assume that phonetic interpolation does not mark morphological category distinctions, we are forced to conclude that we cannot determine the phonological specification of [nasal] for such vowels on the basis of phonetic data alone.

CHAPTER 5 CONCLUSIONS

In this dissertation, I have pursued two parallel theoretical goals. First, I have provided an explicit Optimality Theoretic (Prince and Smolensky 1993, McCarthy and Prince 1993b) account of two major aspects of the phonology of a single language. I argue that such accounts are important in that all too often the treatment of only a subset of data can obscure deeper and more problematic aspects of a phonological system. Regarding the issue of nasalization, for example, I show that accounting for the attested distribution of nasalized vowels can be relatively easily characterized in terms of alignment constraints interacting with sequential cooccurrence constraints on nasality and orality. However, a comprehensive account of the distribution of both nasal consonants and vowels within CM roots motivated a more complex view of constraint interaction involving the conditional combination of alignment constraints in the grammar. Similarly, the treatment of glottalization led to a detailed discussion of the implications of freely generated input structures for the concept of underlying representations in phonological theory. I argue that it is inaccurate to equate *input* with *underlying* and that if we are to encode the traditional notion of underlying representation, this is best achieved by viewing UR's as sets of optimal inputs for a given lexical item.

At the same time, I have taken a detailed look at the interface of phonetics and phonology as it pertains to nasalization and glottalization in CM. I develop two areas of discussion in this regard. First, I explore the way in which phonetic relations between features are phonologized via the introduction of phonetically grounded constraints (cf. Archangeli and Pulleyblank 1994a). In the discussion of glottalization, I argue for an extension of the notion of grounding to countenance what I have termed the *opportunistically grounded* relation between glottalization and stress. I show that although these are not inherently sympathetic, the overall nature of the phonology of the language is such that glottalization is optimally realized in on a stressed vowel. In the discussion of nasalization in Chapter 4, I extend the use of grounding by arguing for the relevance of grounding to the treatment of opaque consonants. In particular, I argue that prohibiting the presence of nasalized vowels before voiceless consonants has the effect of protecting orality at the point of closure, thus allowing for the build up of pressure necessary for burst energy or frication.

The second aspect of the relationship between phonology and phonetics under study here regards the implementation of both vowel glottalization and nasalization in consonants and vowels in CM. This builds on the work of many researchers in recent years, who have begun to address the complex issue of how static, categorical phonological features are implemented in time and space (cf. Pierrehumbert 1980, Keating 1988, 1990a,b, Shih 1988, Pierrehumbert and Beckman 1988, Huffman 1989, Cohn 1990, Laniran 1993, among others). Working within a windows framework (Keating 1990b), I provide arguments that phonologically specified features such as [+constricted glottis] must implement windows for only a part of the duration of the vowel for which they are specified. Similarly, I argue that orality targets in voiced and voiceless fricatives in CM are implemented at the edges rather than throughout these segments. In a broad sense, these findings support Huffman's (1989) model of articulatory landmarks to the extent that the data support a view in which targets are temporally located within segments. What make the data particularly interesting, however, is that the location of window targets may vary from segment edge to segment edge. Here, I claim argue voiced fricatives implement orality at their release, while voiceless fricatives implement a target for orality early in the segment. Turning back to the issue of the opacity of all voiceless segments to CM nasalization, I suggest that this distinction in target location can be seen as the driving phonetic force behind the banning of nasal vowel-voiceless consonant sequences in the language. Moreover, I use the implementation data to argue for a more complex notion of the relationship between phonetic data and phonological information than that advanced, for example, by Cohn (1990, 1993a). In particular, I show that we cannot assume that partial implementation of a feature in a segment entails the phonetic rather than phonological presence of that feature. This means that phonetic data must be interpreted in the context of the phonological system from which it is derived.

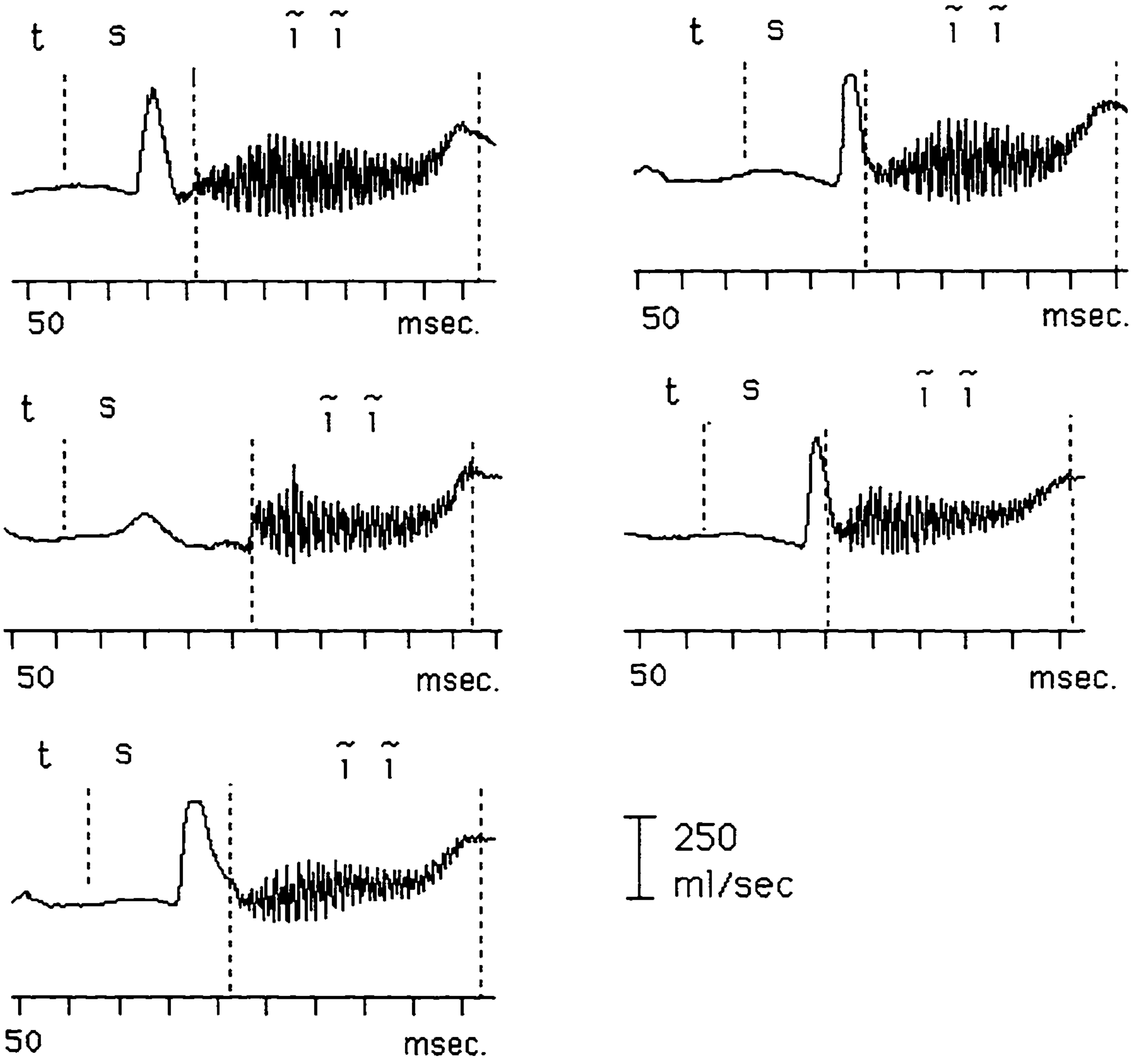
Such data here point to the need for more cross-linguistic studies of how phonetics implements phonological features. Discovering evidence of systematic nasal coarticulation during CM fricatives constitutes a major surprise of the study fricatives (contra the predictions of Ohala and Ohala 1993 and Cohn 1993b). At the same time, a language with such a degree and variety in its employment of [nasal] has never been subjected to this kind of study. The more languages we examine, the more we will learn about the range of possible patterns of coarticulation that we will find. Finally, my hope is that this dissertation will aid in the detailed and explicit documentation of one more endangered language in a landscape of increasingly vanishing linguistic and cultural diversity.

APPENDIX

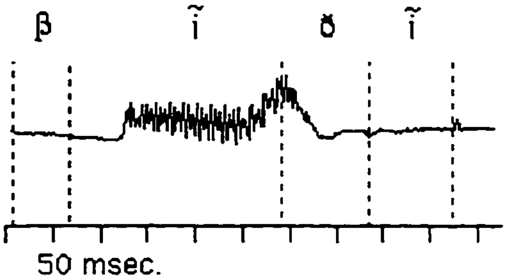
Word list

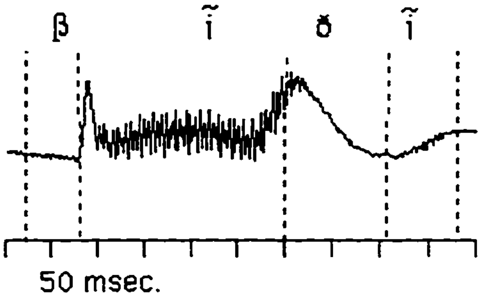
[tsĩĩ]	'nail (fingernail)'
[βĩðĩ]	'sweet'
[tʲuʔᵘtũ]	'firewood'
[tsii]	'to get wet'
[tsĩĩ]	'you (fam) will get yourself wet'
[ʃee]	'to arrive’
[ʃẽẽ]	'you (fam) arrived'
[ðuʔu]	'rob, steal’
[ðũʔũ]	'you (fam) will rob'
[ðuʔᵘkũ]	'tall'
[ðuʔᵘkũ]	'you (fam) are tall'
[kuʔᵘtʲu]	'to plow, hoe'
[kuʔᵘtʲũ]	'you (fam) will plow'
[kiʔⁱʃi]	'to come'
[kiʔⁱʃĩ]	'you (fam) will come'
[kuʔᵘtsi]	'to bathe'
[kuʔᵘtsĩ]	'you (fam) will bathe'
[kiði]	'to sleep'
[kĩðĩ]	'you (fam) will sleep'
[βiðe]	'wet’
[βĩðẽ]	' you (fam) are wet’
[kuβi]	'to die'
[kũβĩ]	'you (fam) died'
[tɨβi]	'to blow'
[tɨ̃βĩ]	'you (fam) will blow'
[tɨʔⁱβi]	'to push'
[tɨ̃ʔⁱ̃βĩ]	'you (fam) will push'
[kunũ]	'to run'
[kũnũ]	'you (fam) will run'
[lendʲu]	'dirty'
[lẽndʲu]	'you (fam) are dirty'
[luʔᵘndi]	'small'
[lũʔᵘ̃ndĩ]	'you (fam) are small'
[kuʃu]	'diligent'
[kũʃũ]	'you (fam) are diligent'

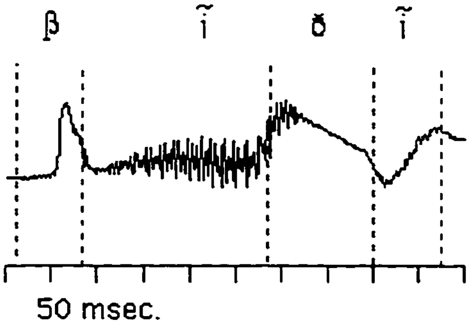
S1: [tsĩ] 'nail (fingernail)'

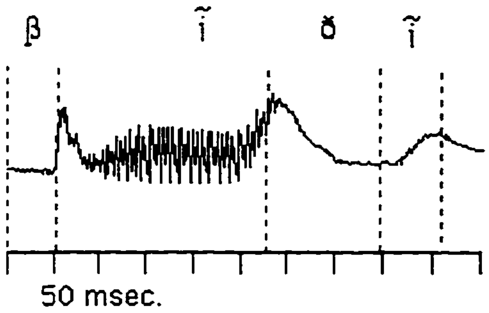


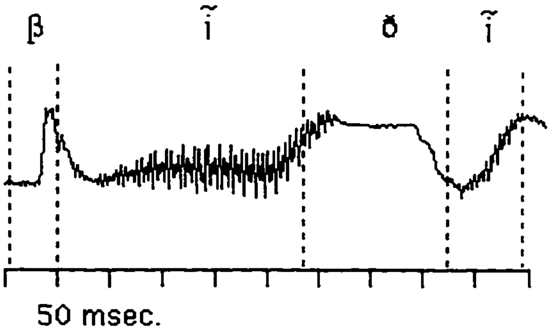
S1: [βĩðĩ] 'sweet'

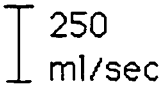




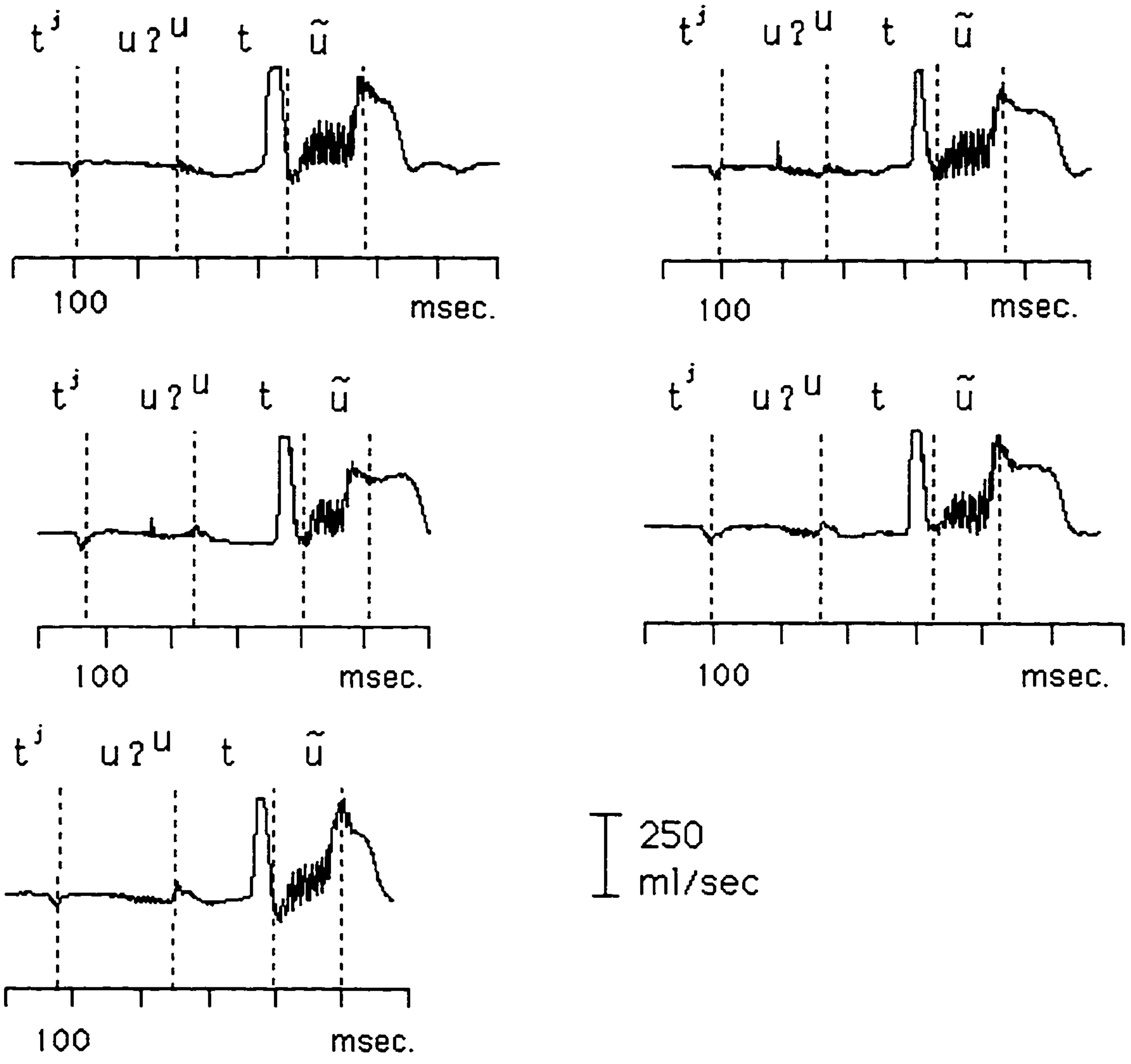




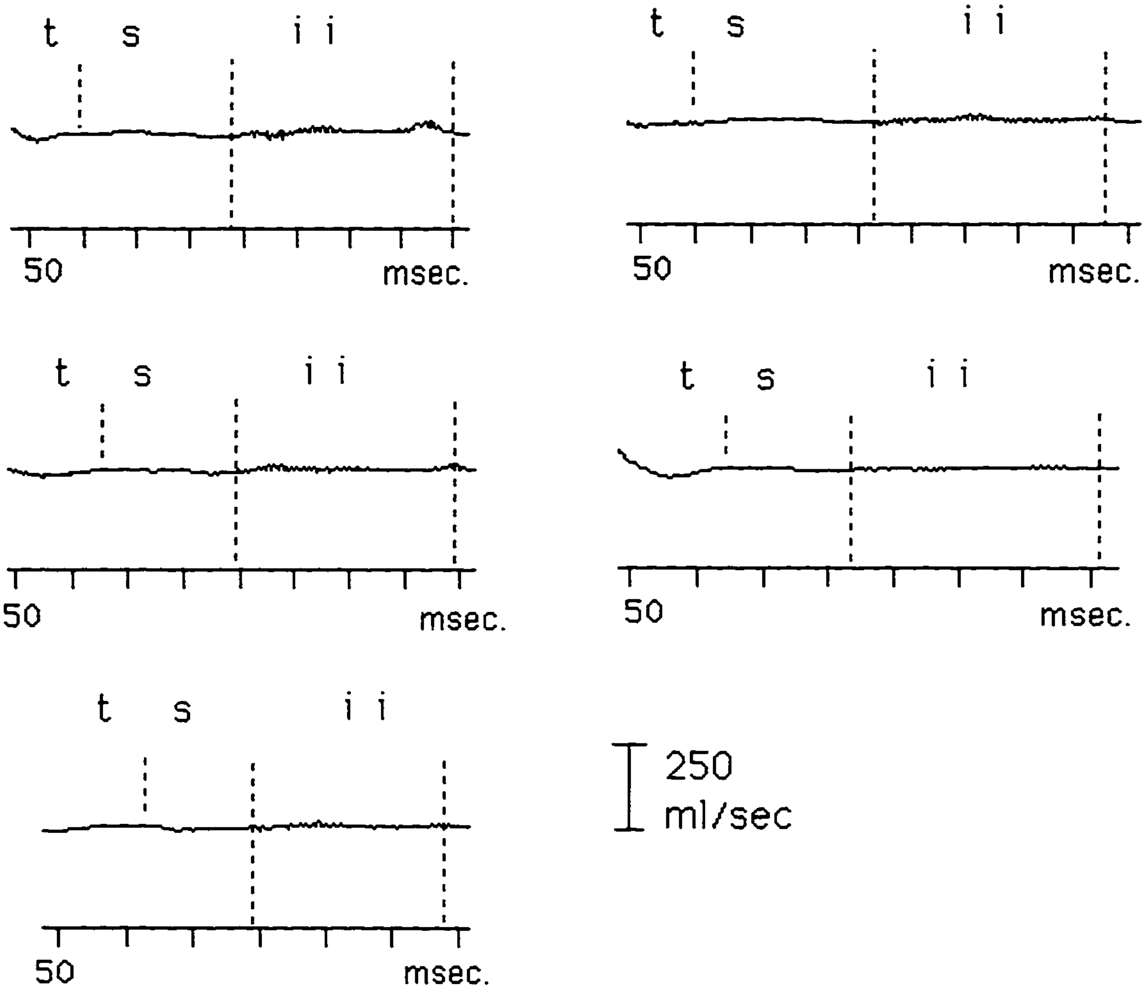




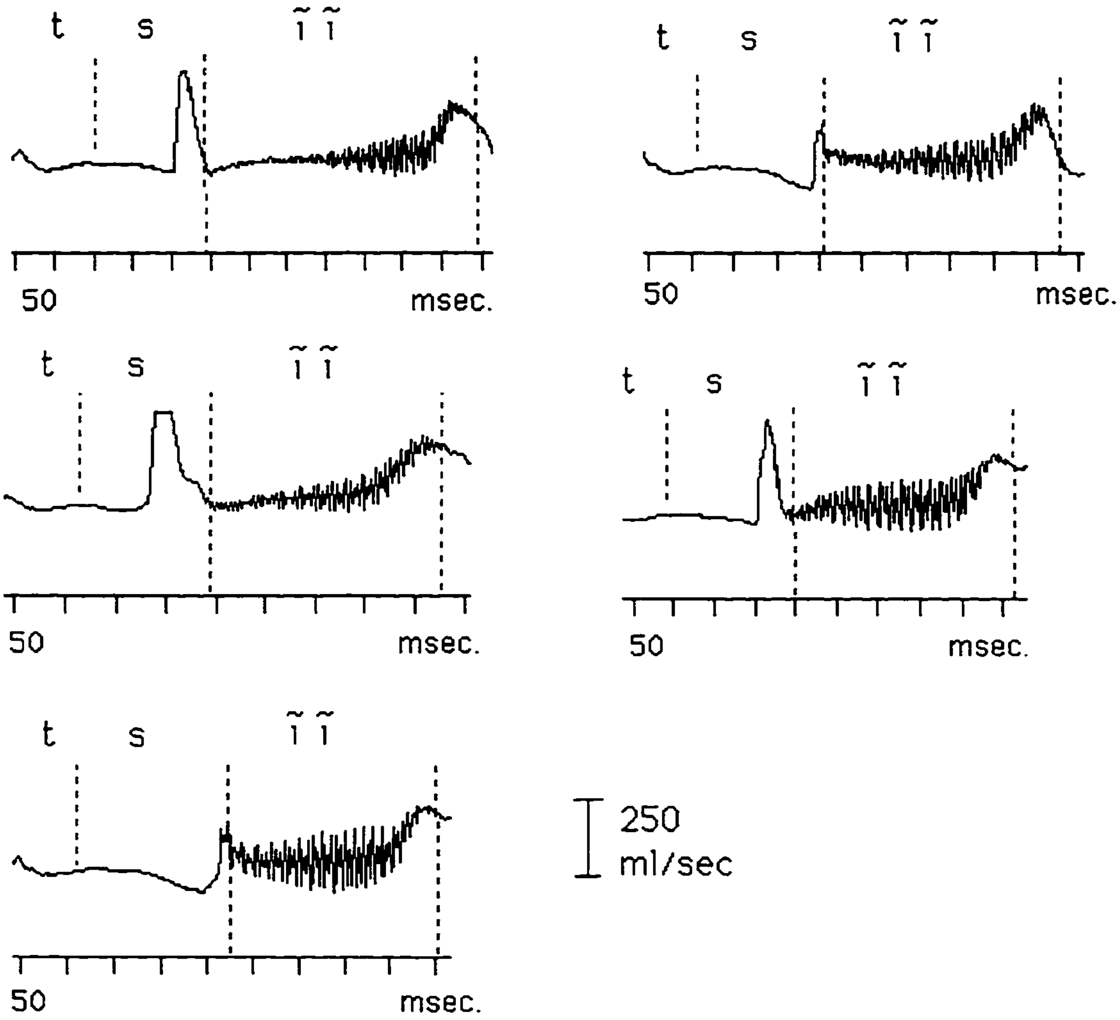
S1: [tʲuʔᵘtũ] 'firewood'



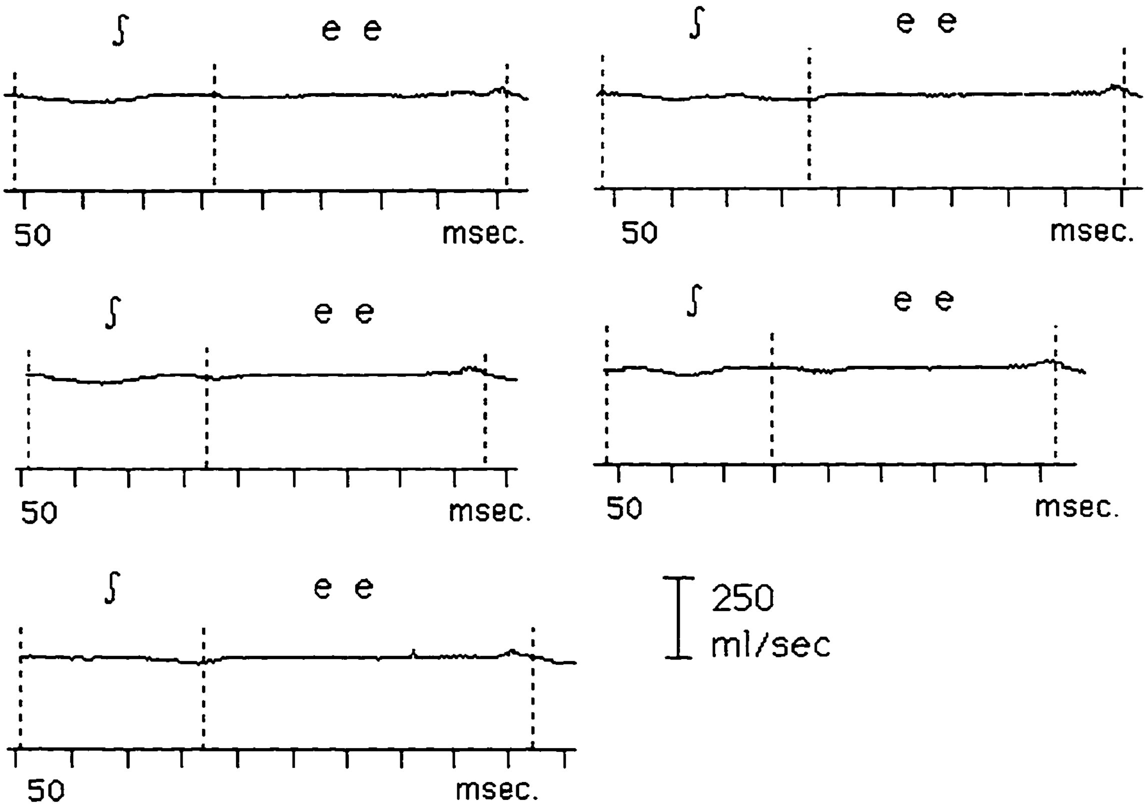
S1: [tsii] 'to get wet'



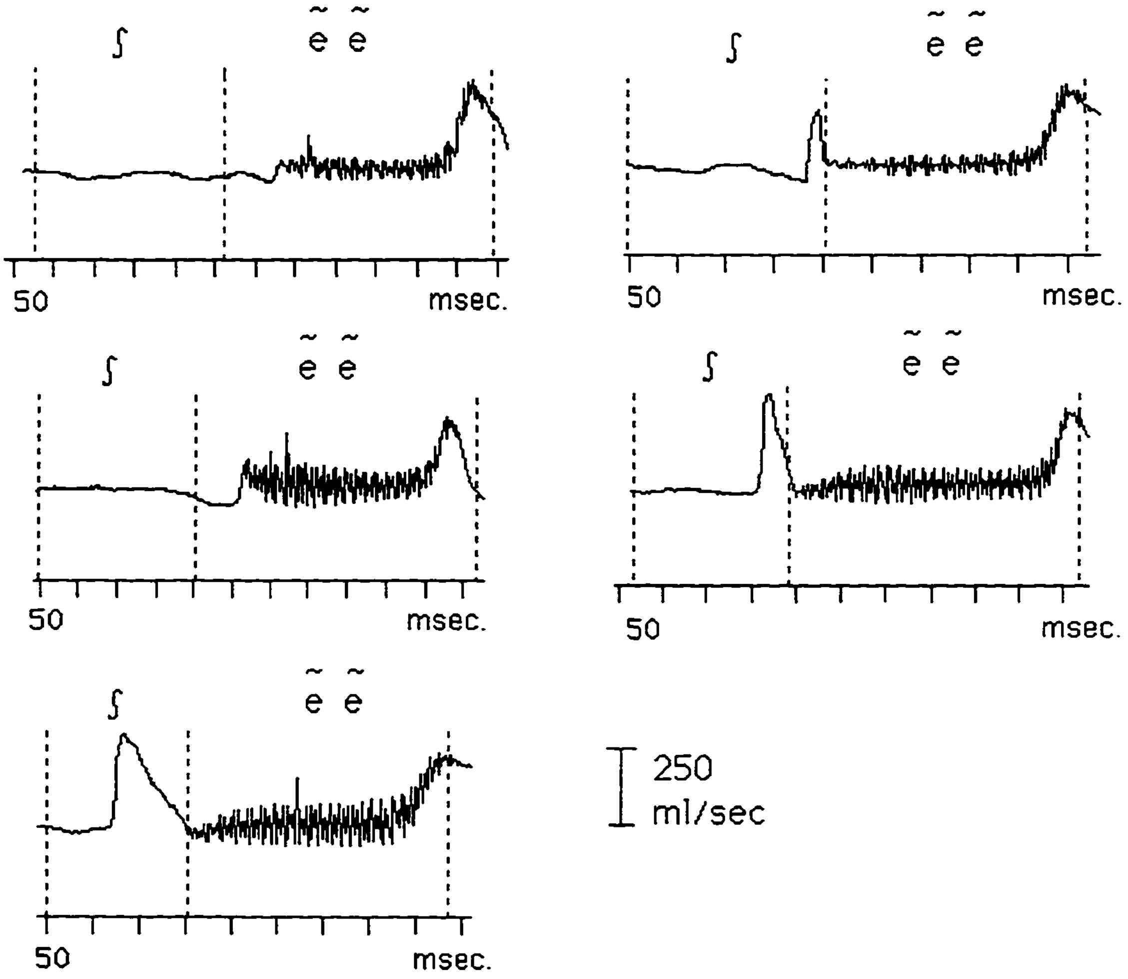
S1: [tsĩĩ] 'you (fam) will get yourself wet'



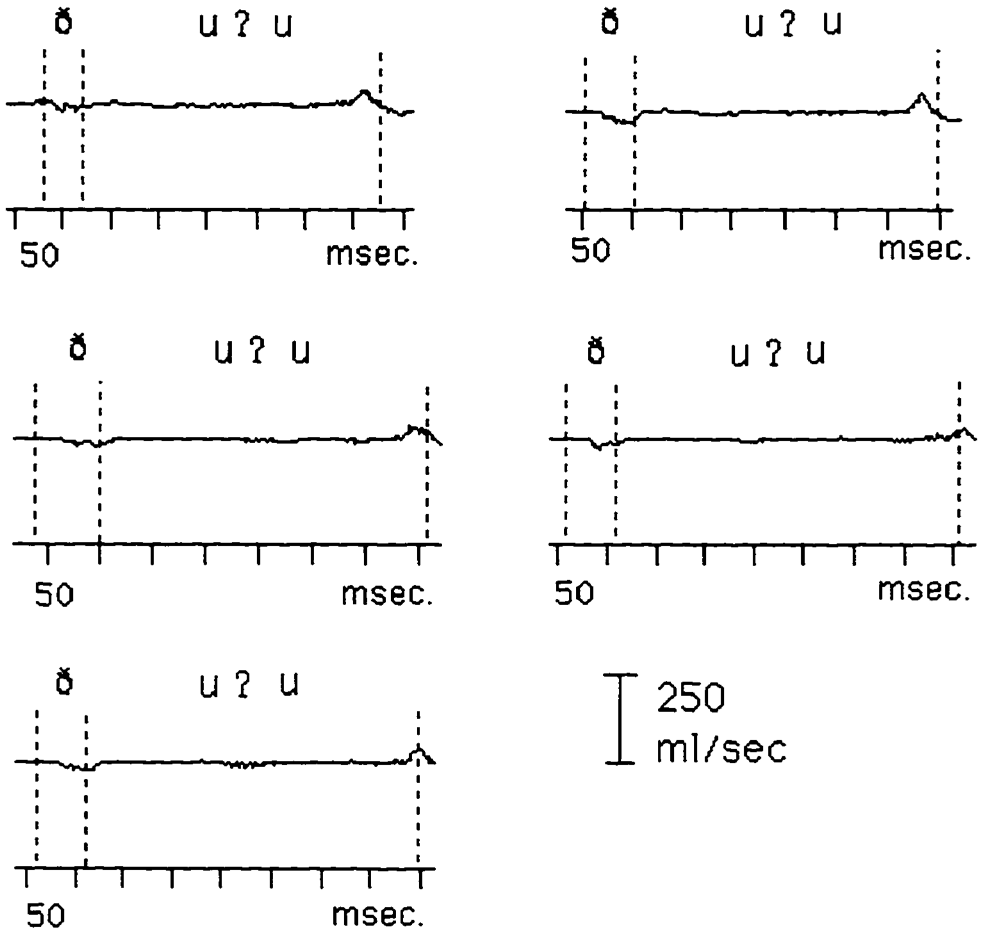
S1: [ʃee] 'to arrive'



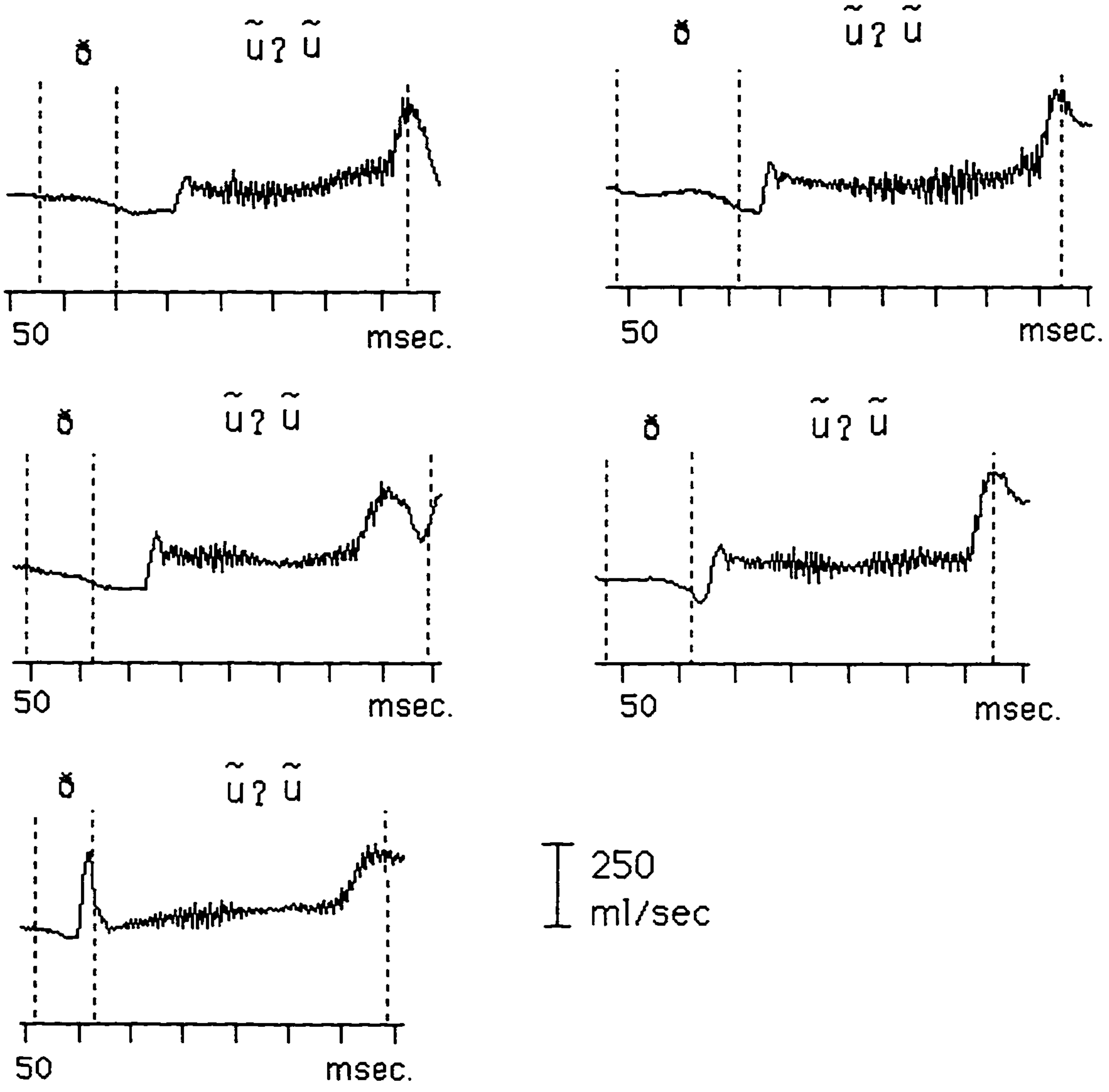
S1: [ʃẽẽ] ‘you (fam) arrived’



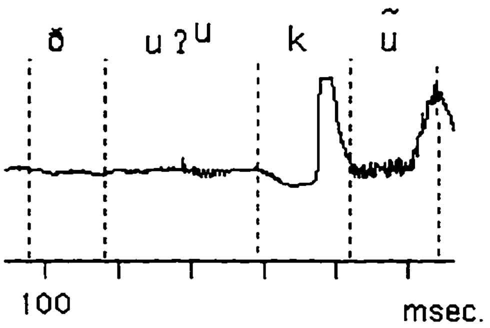
S1: [ðuʔu] 'rob, steal'

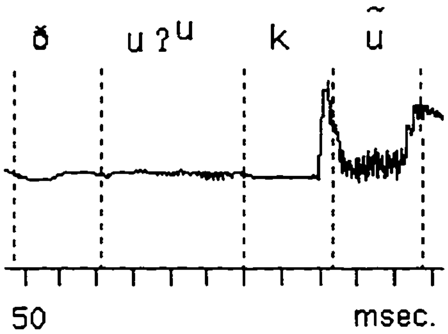


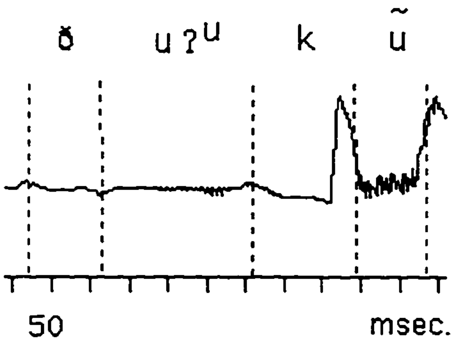
S1: [ðũʔũ] 'you (fam) will rob'

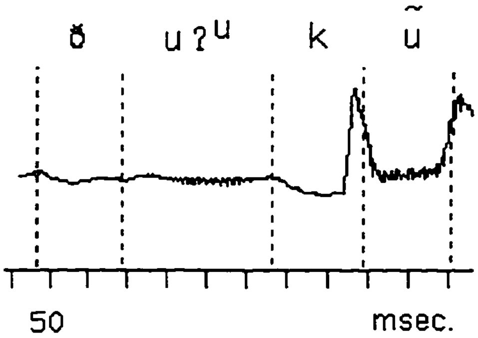


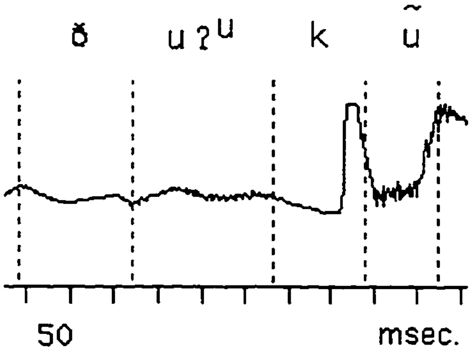
S1: [ðuʔ^{u}kũ] 'tall'

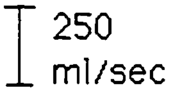




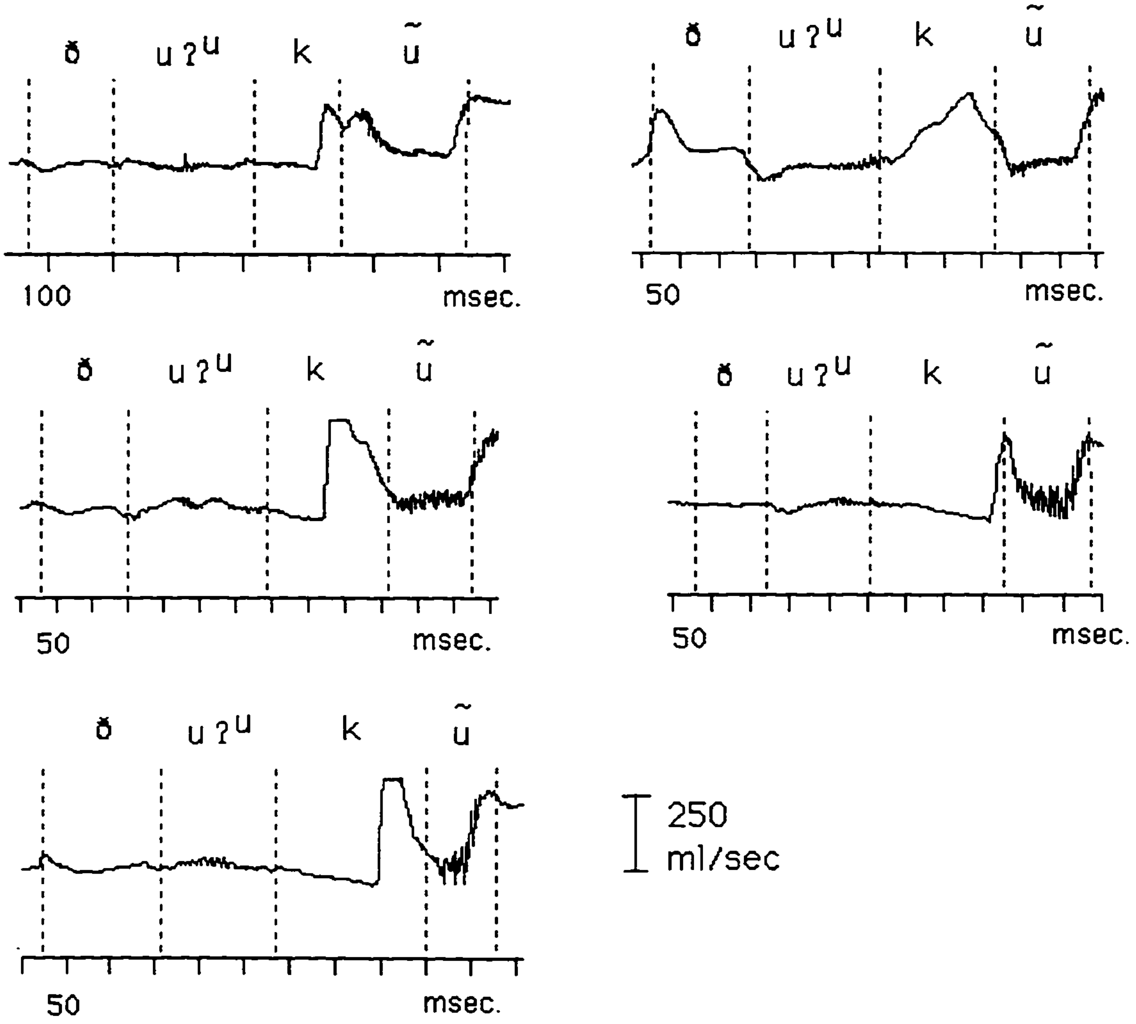




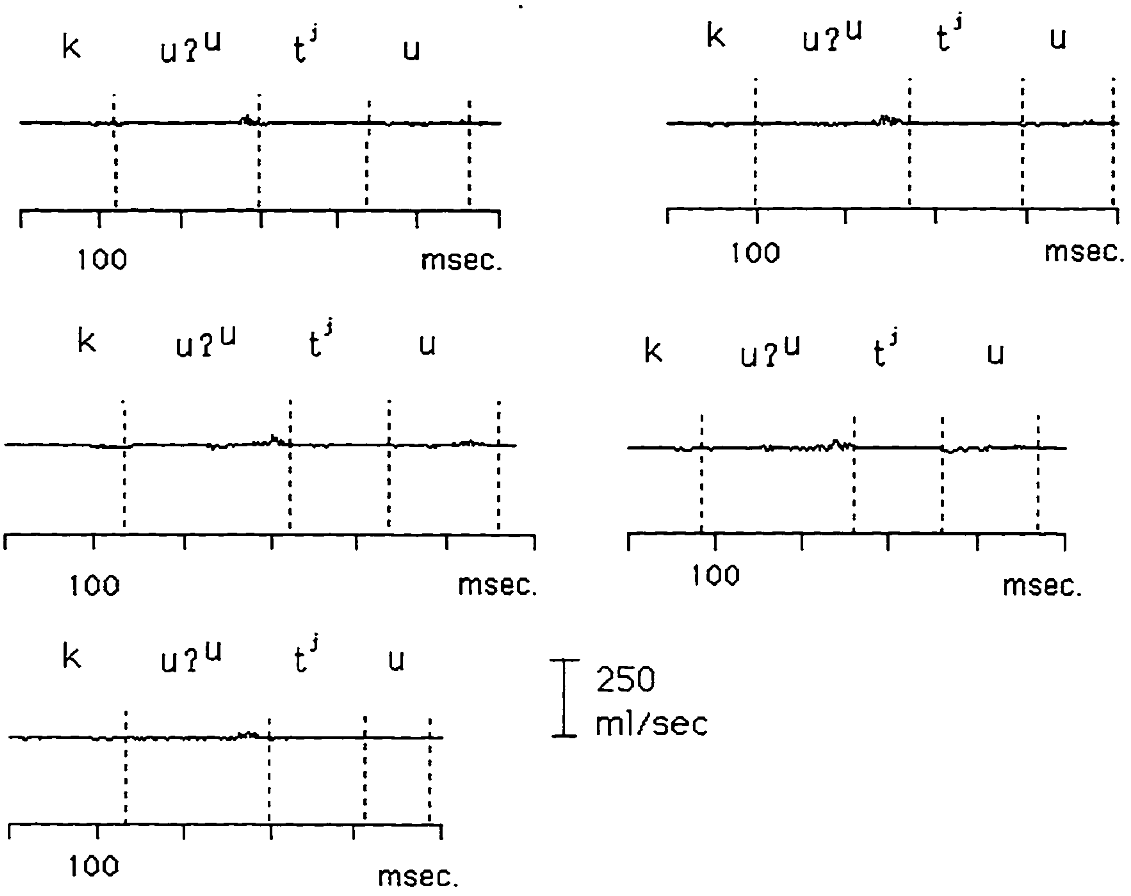




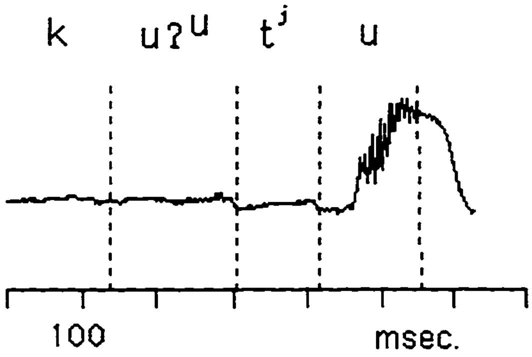
S1: [ðuʔᵘkũ] 'you (fam) are tall'

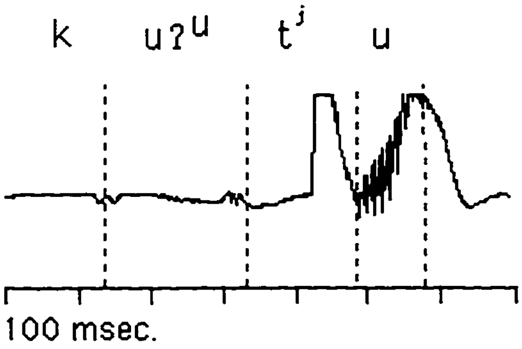


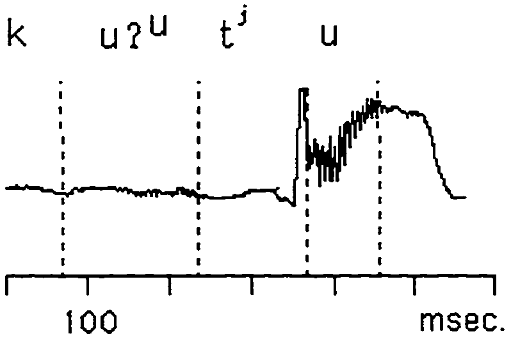
S1: [kuʔᵘtʲu] 'to plow, hoe'

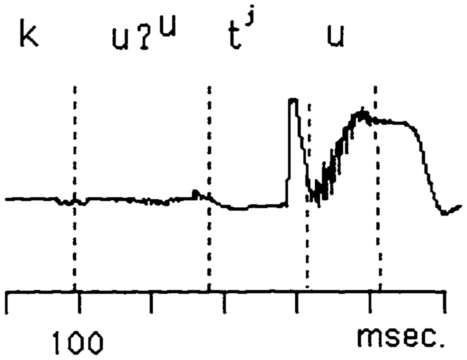


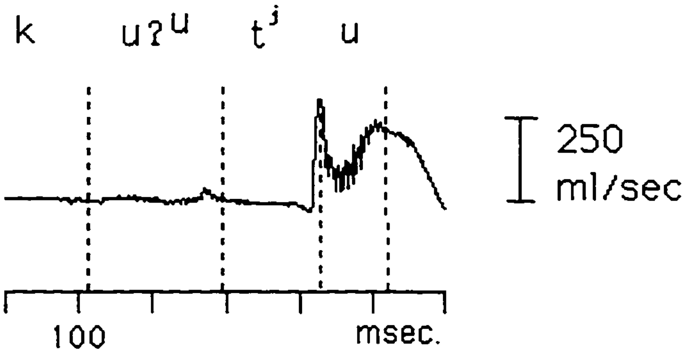
S1: [kuʔᵘtʲũ] 'you (fam) will plow'



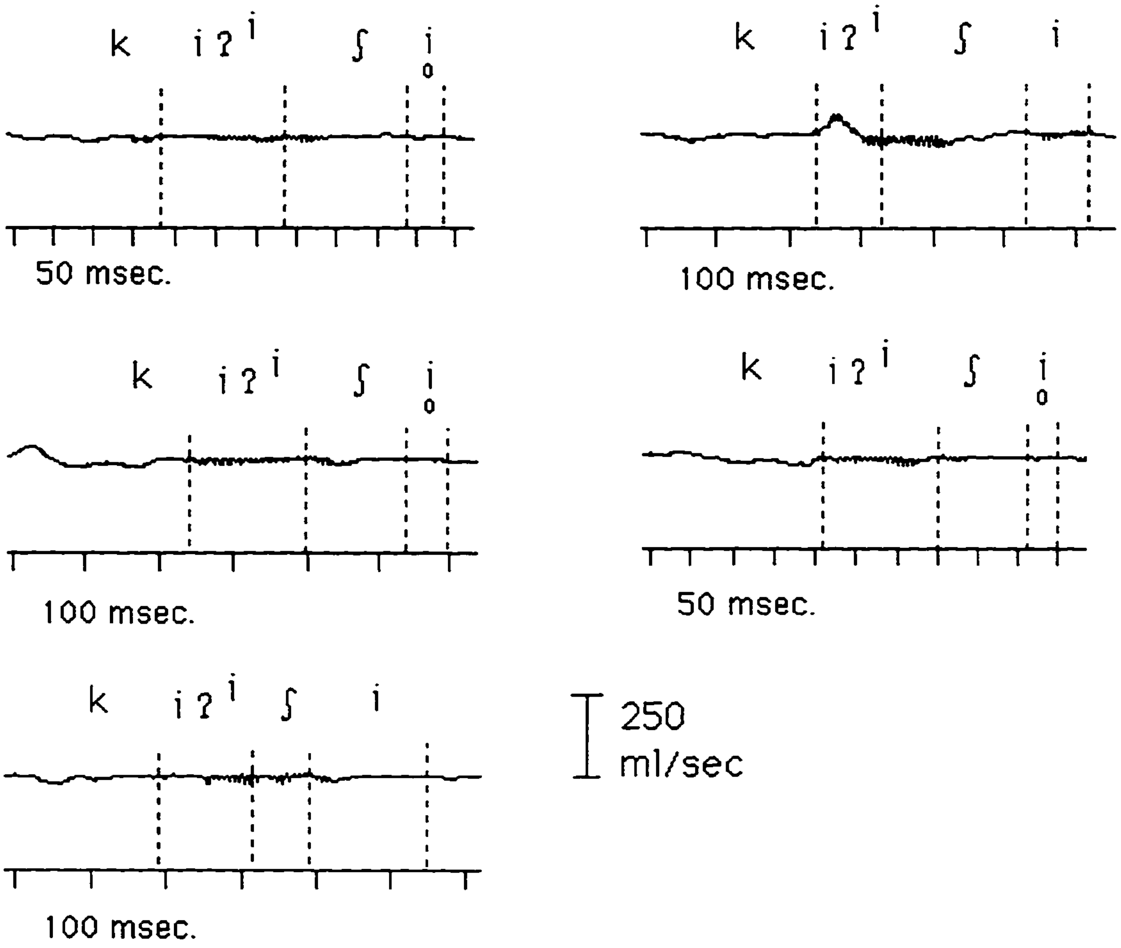




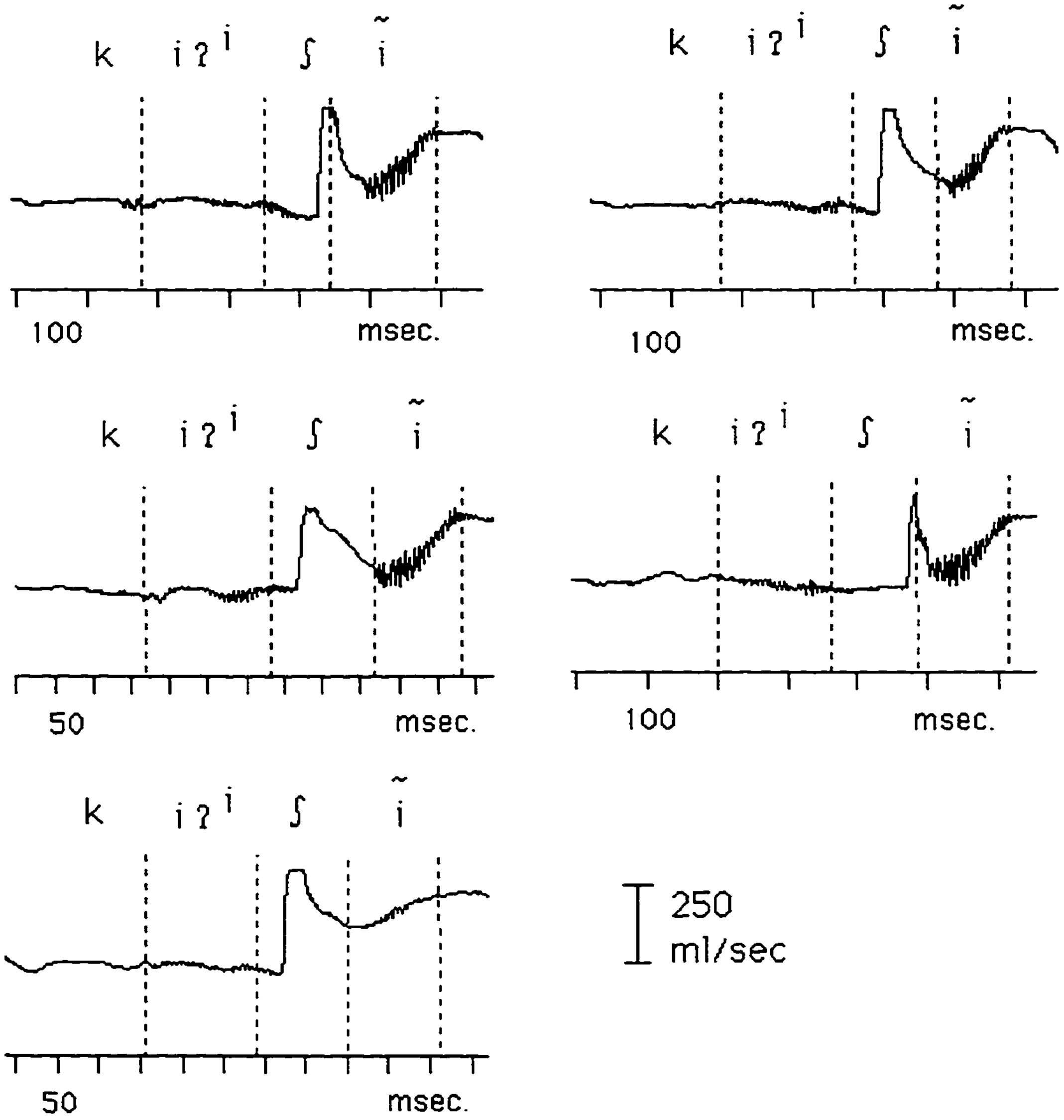




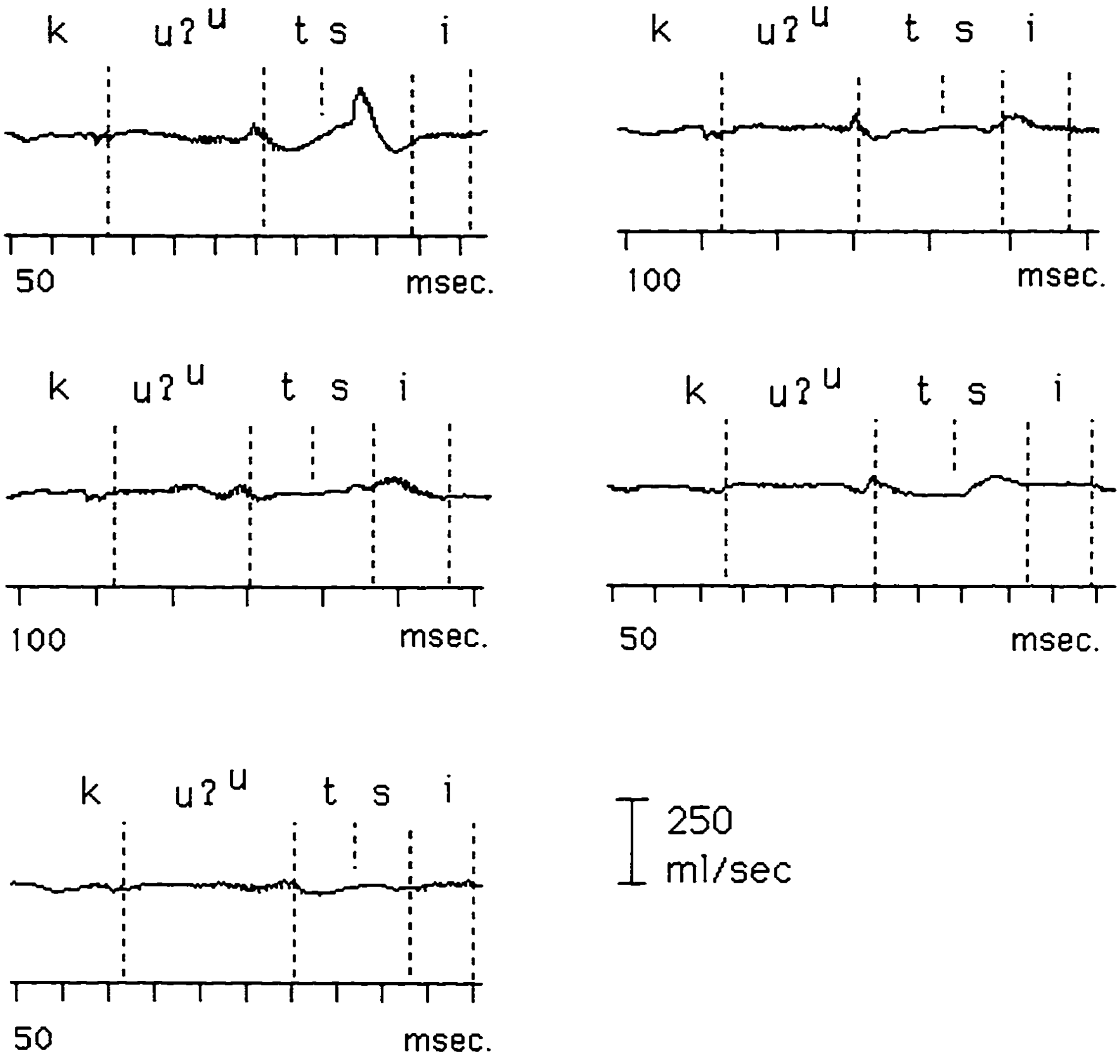
S1: [kiʔ^{i}ʃi] 'to come'



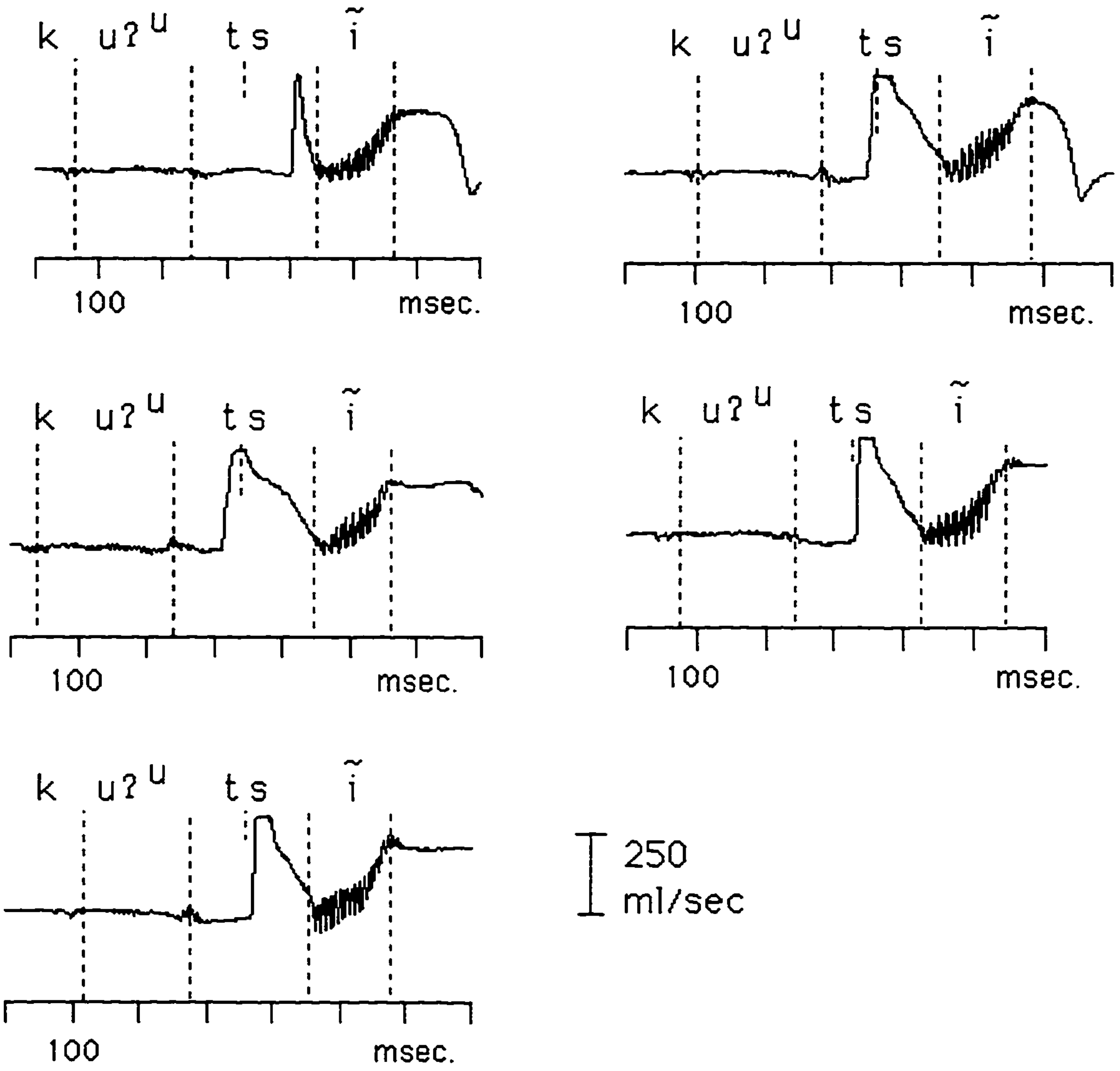
S1: [kiʔ^{i}ʃĩ] 'you (fam) will come'



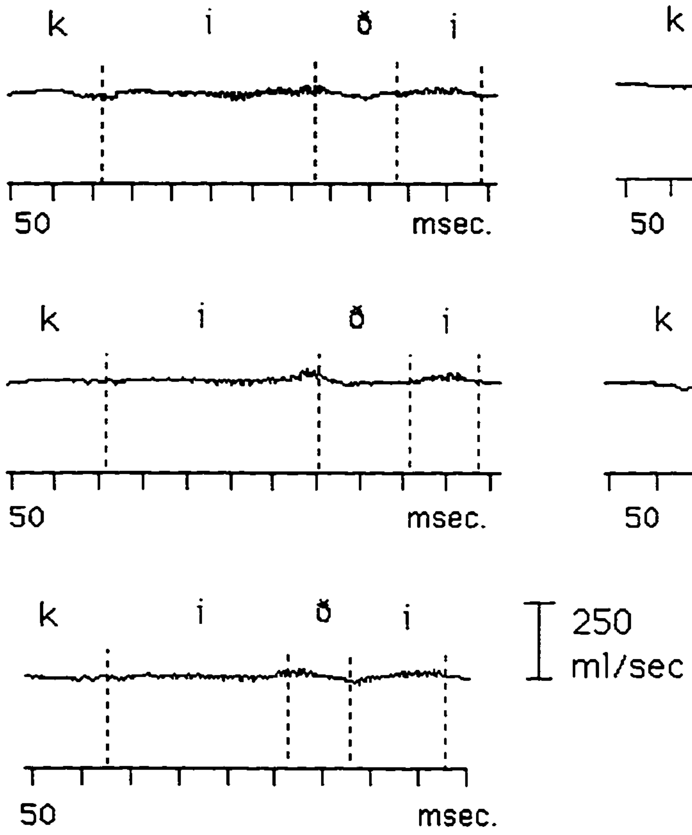
S1: [kuʔ^{u}tsi] 'to bathe'



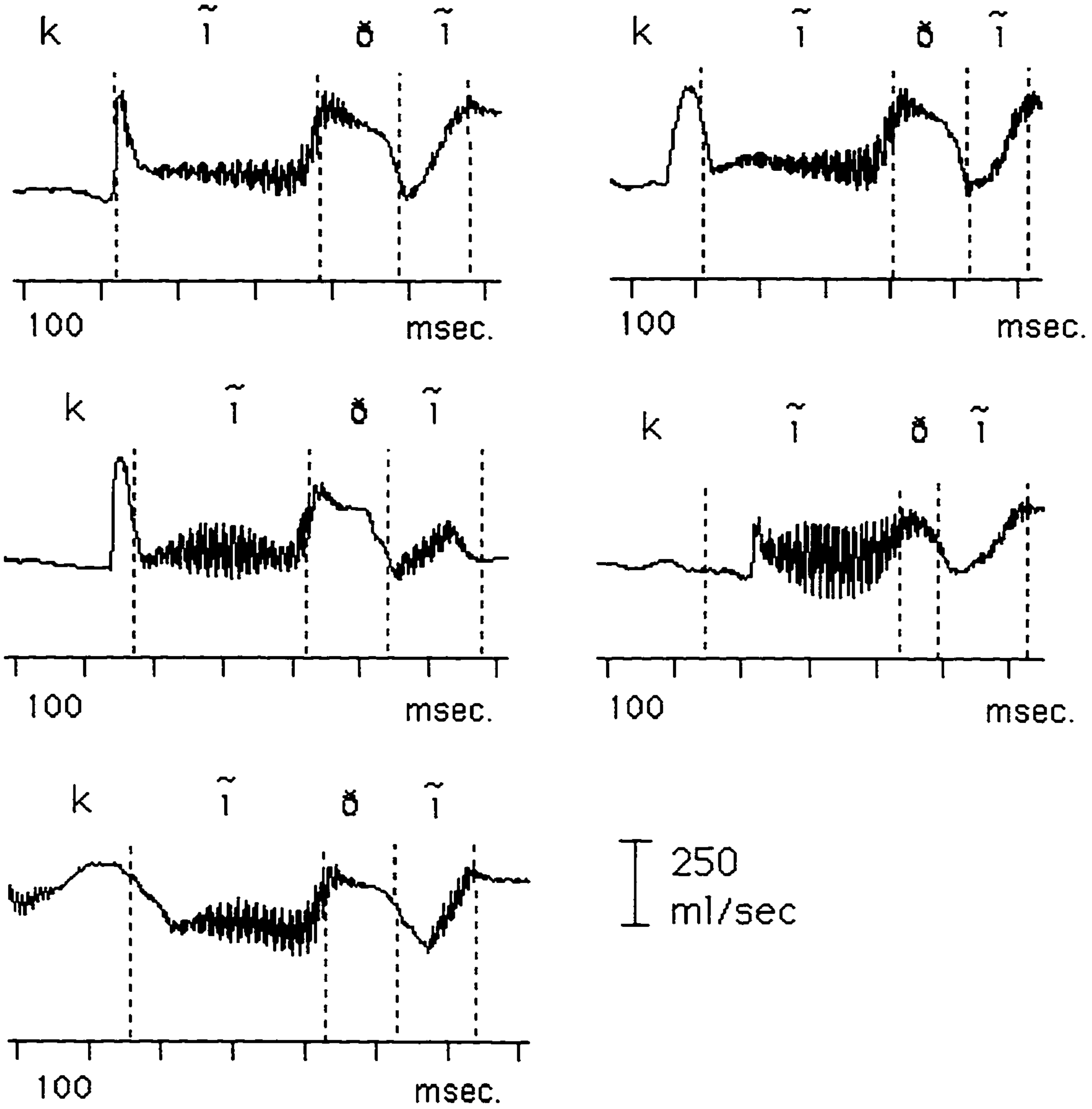
S1: [kuʔ^{u}tsī] 'you (fam) will bathe'



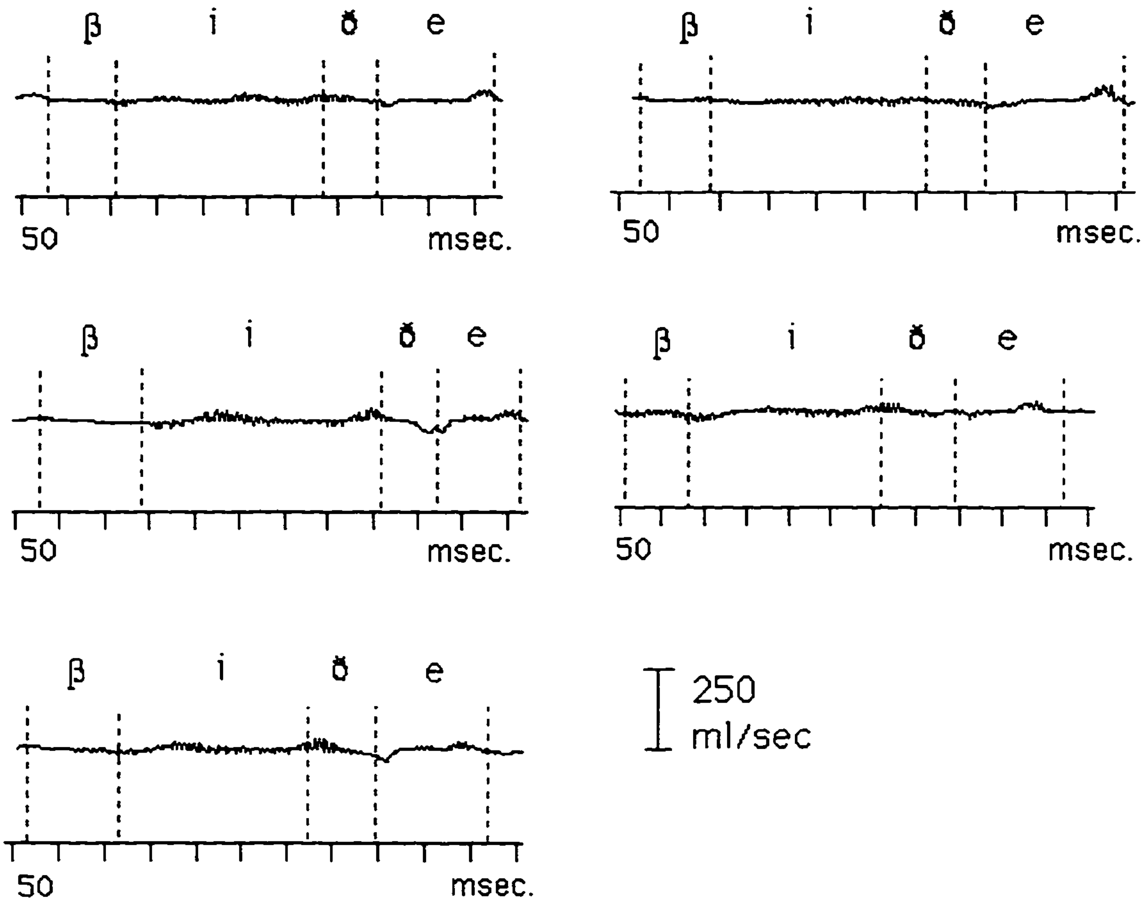
S1: [kiði] 'to sleep'



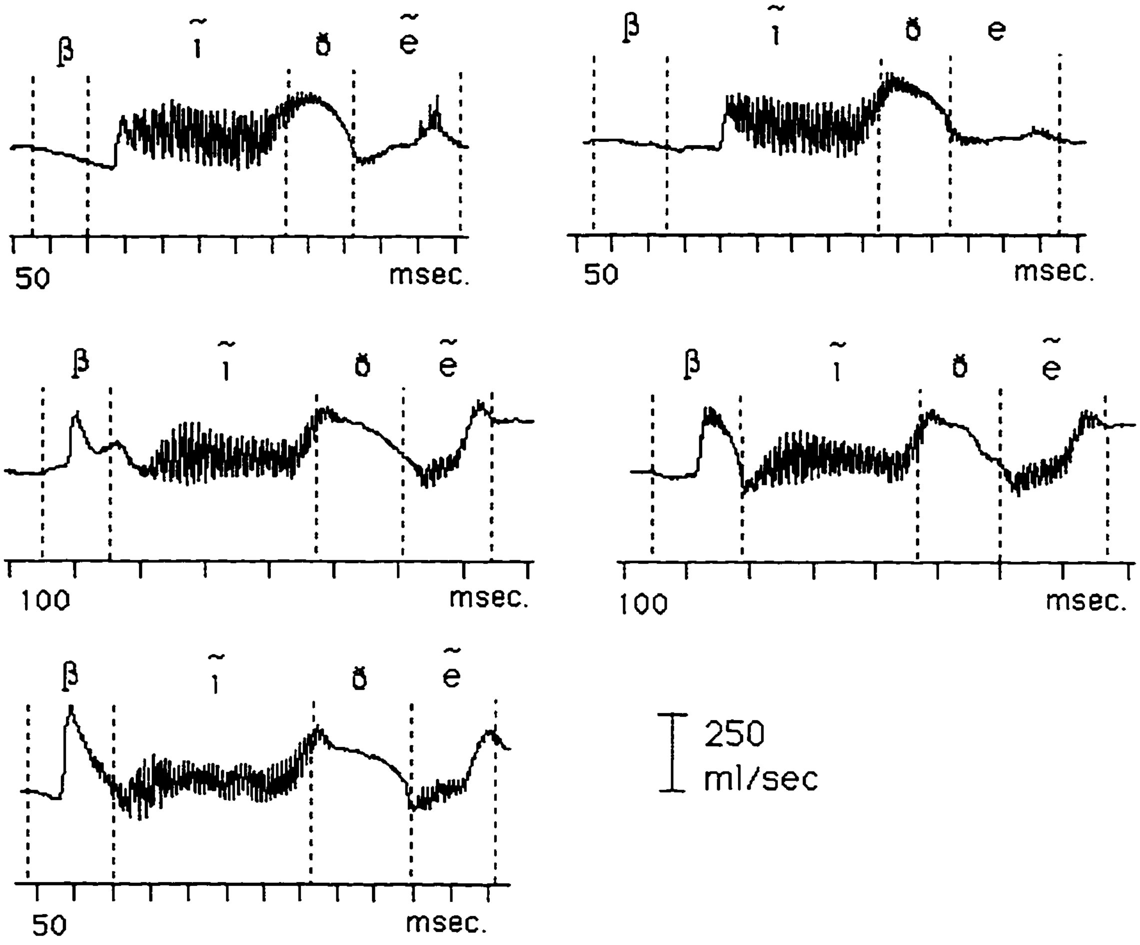
S1: [kĩðĩ] 'you (fam) will sleep'



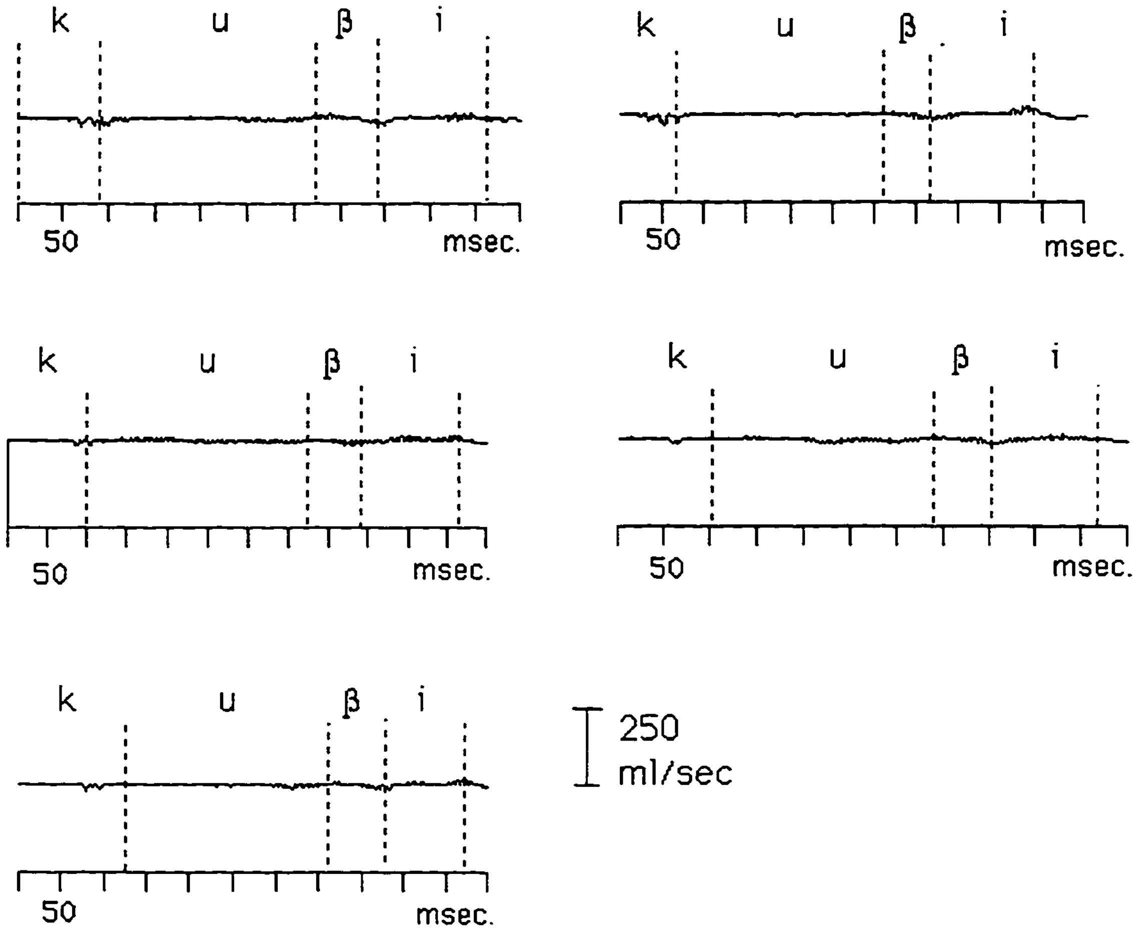
S1: [βiðe] 'wet'


β i ð e
50
msec.
β i ð e
50
msec.
β i ð e
50
msec.
β i ð e
50
msec.
β i ð e
50
msec.
250
ml/sec

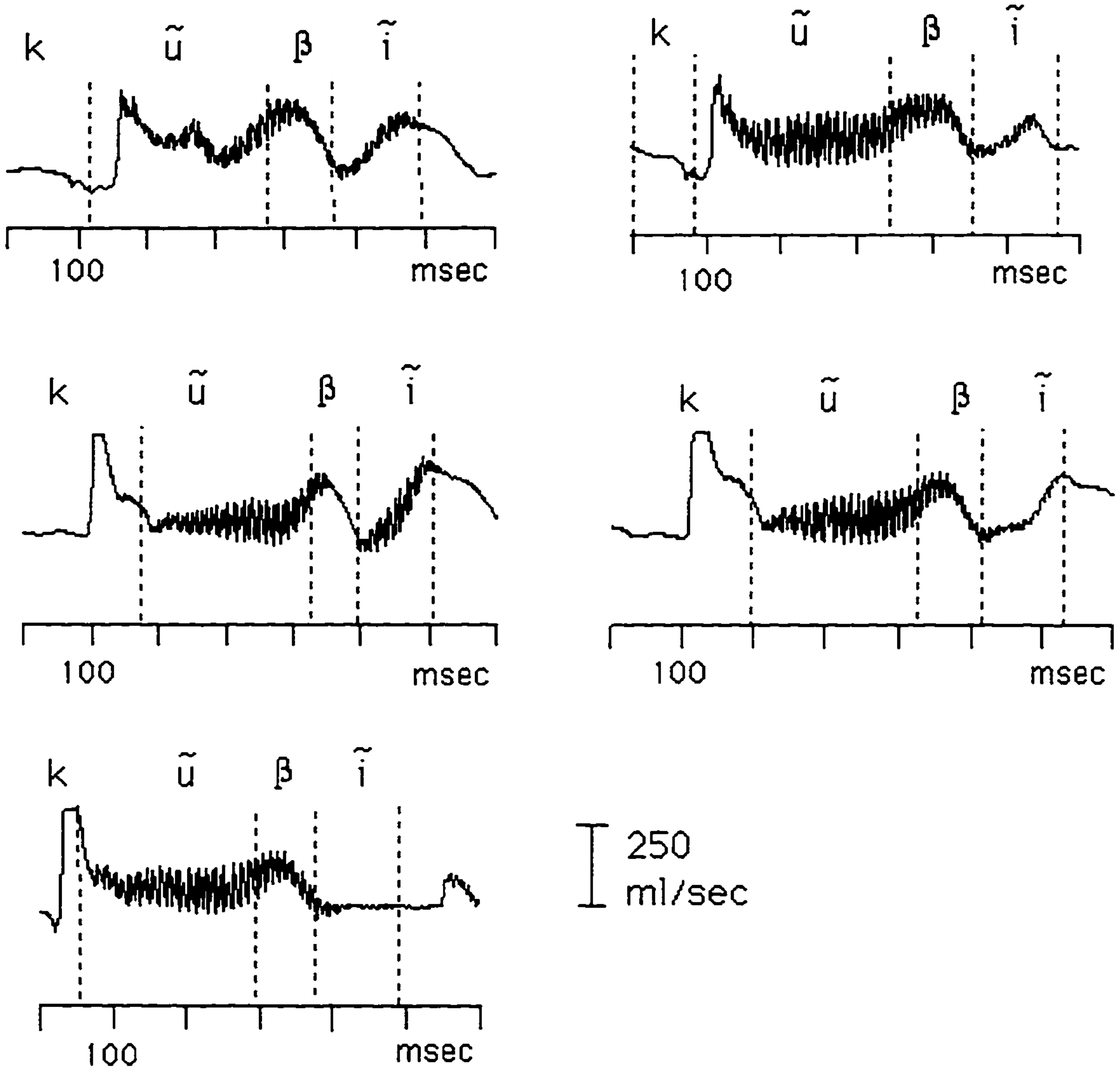
S1: [βĩðẽ] ' you (fam) are wet'



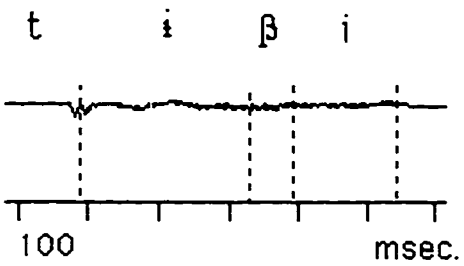
S1: [kuβi] 'to die'

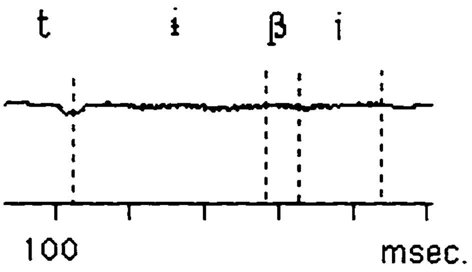


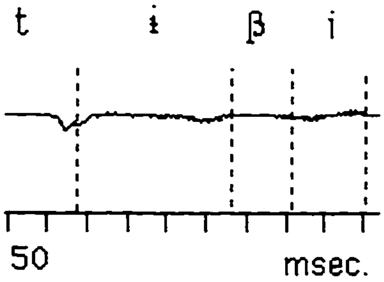
S1: [kũβĩ] 'you (fam) died'

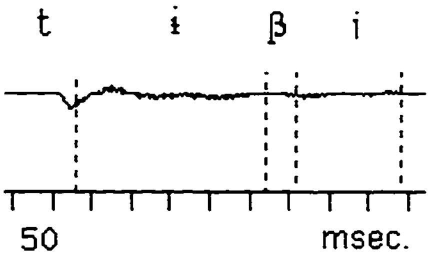


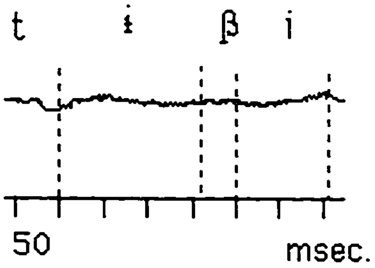
S1: [tɨβi] 'to blow'



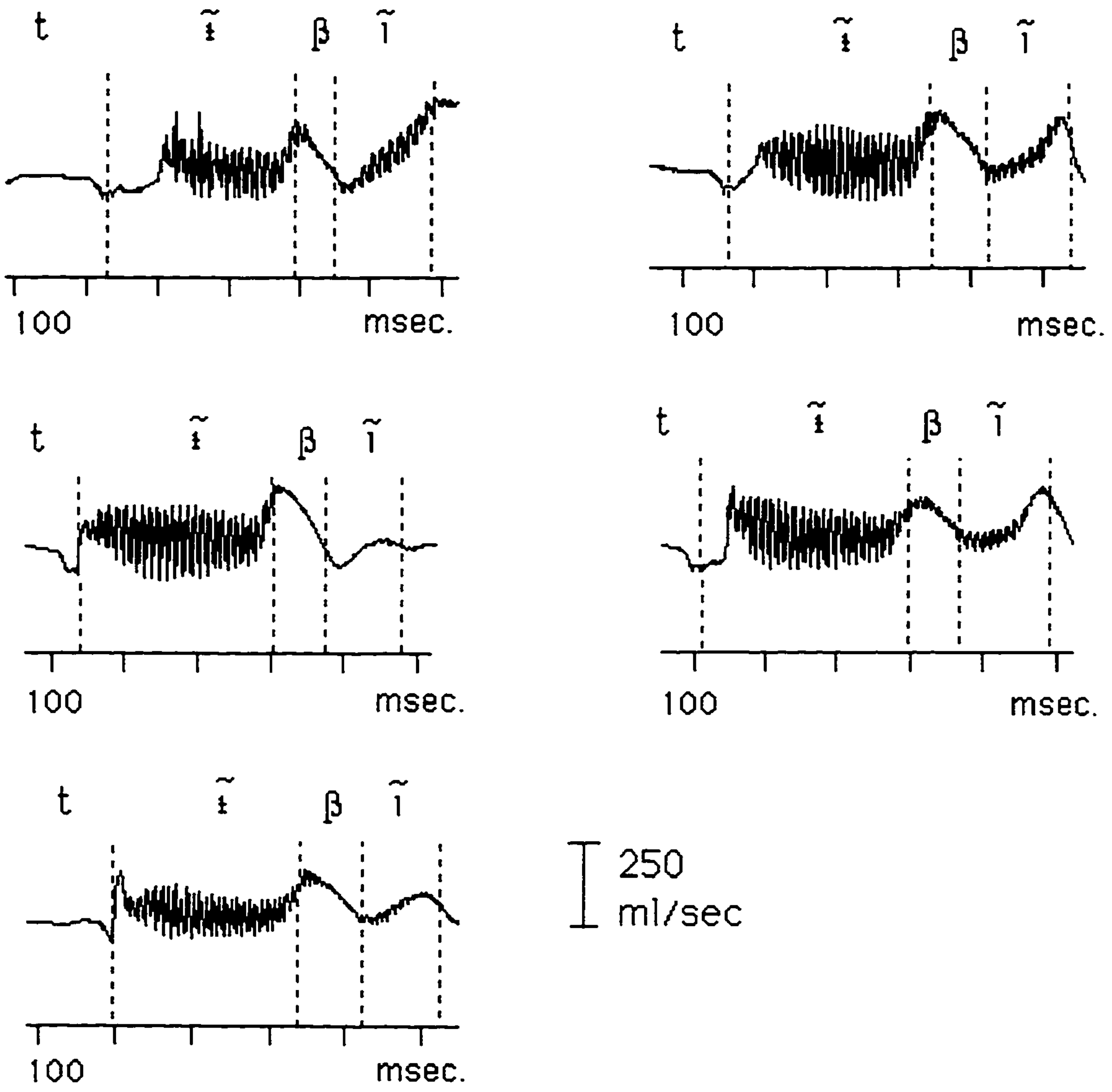




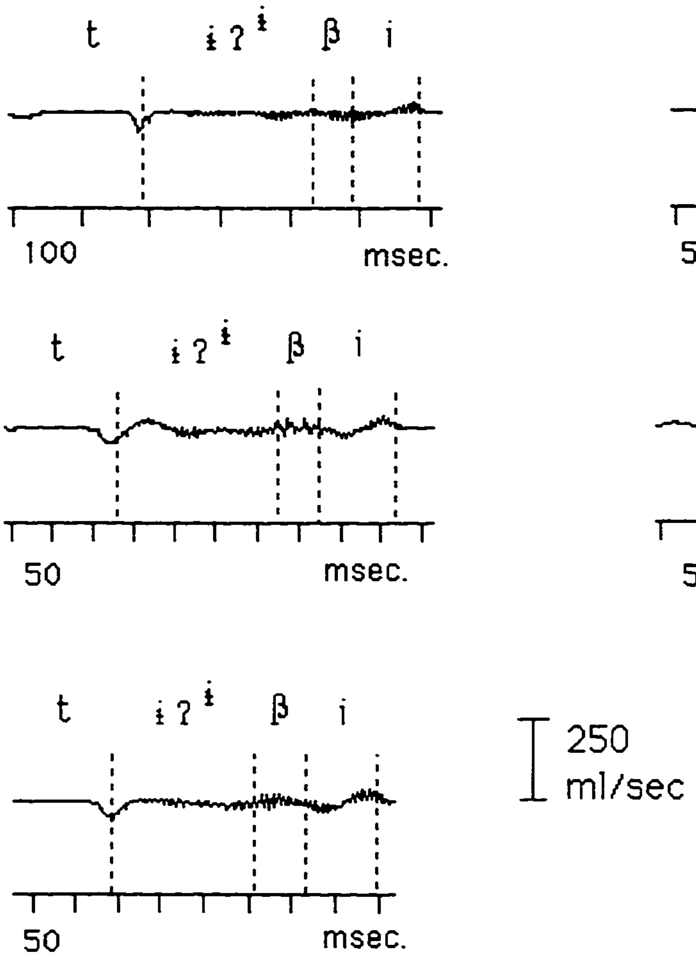




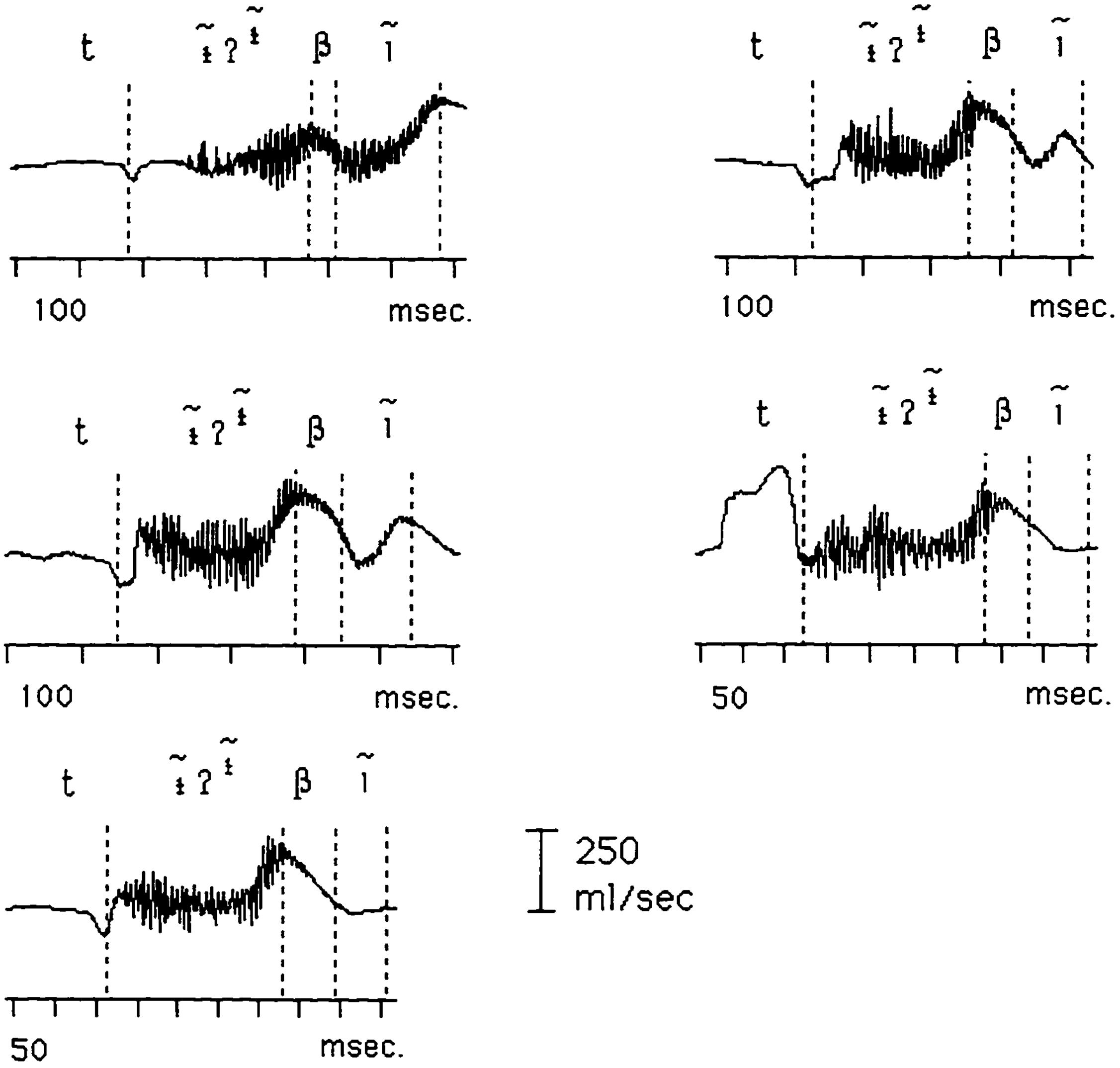
S1: [tɨ̃βĩ] 'you (fam) will blow'



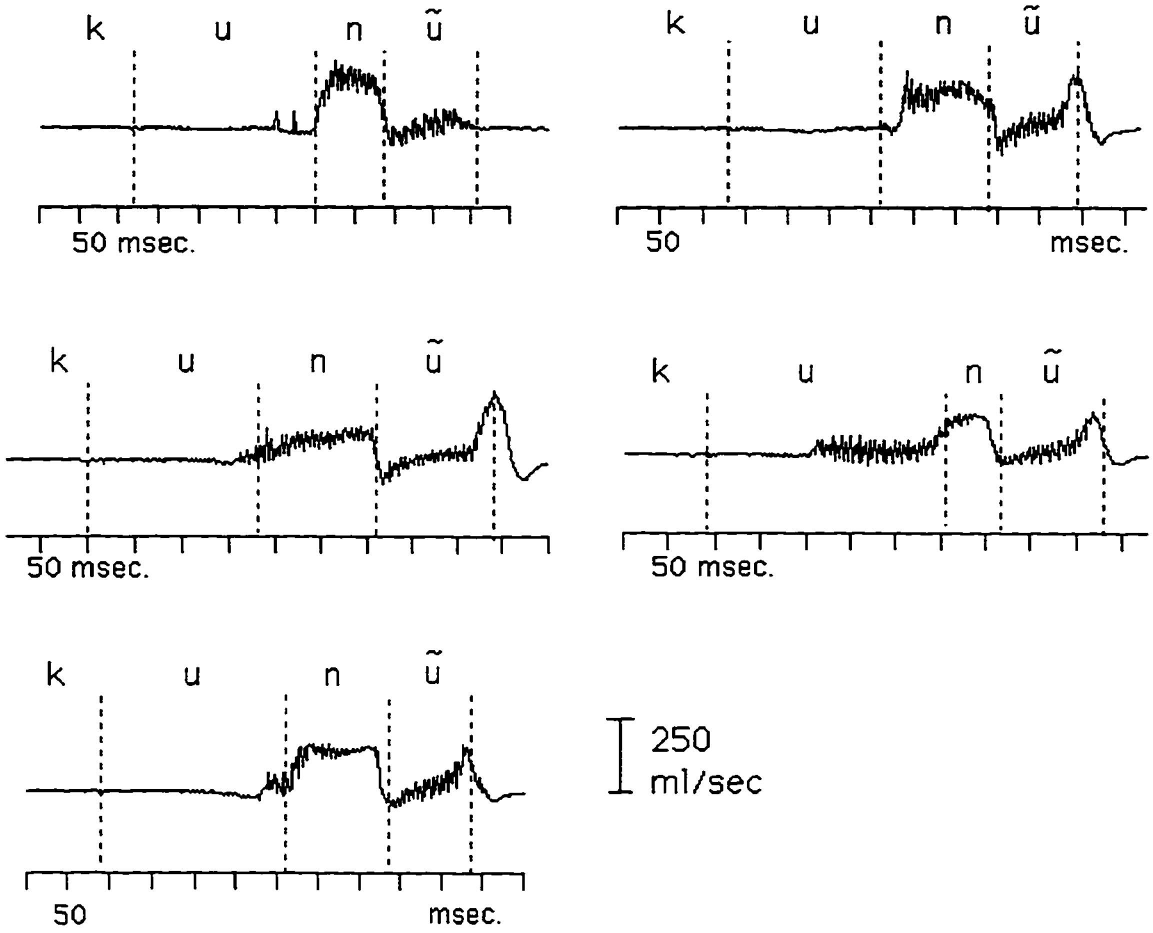
S1: [tɨʔ^{i}βi] 'to push'



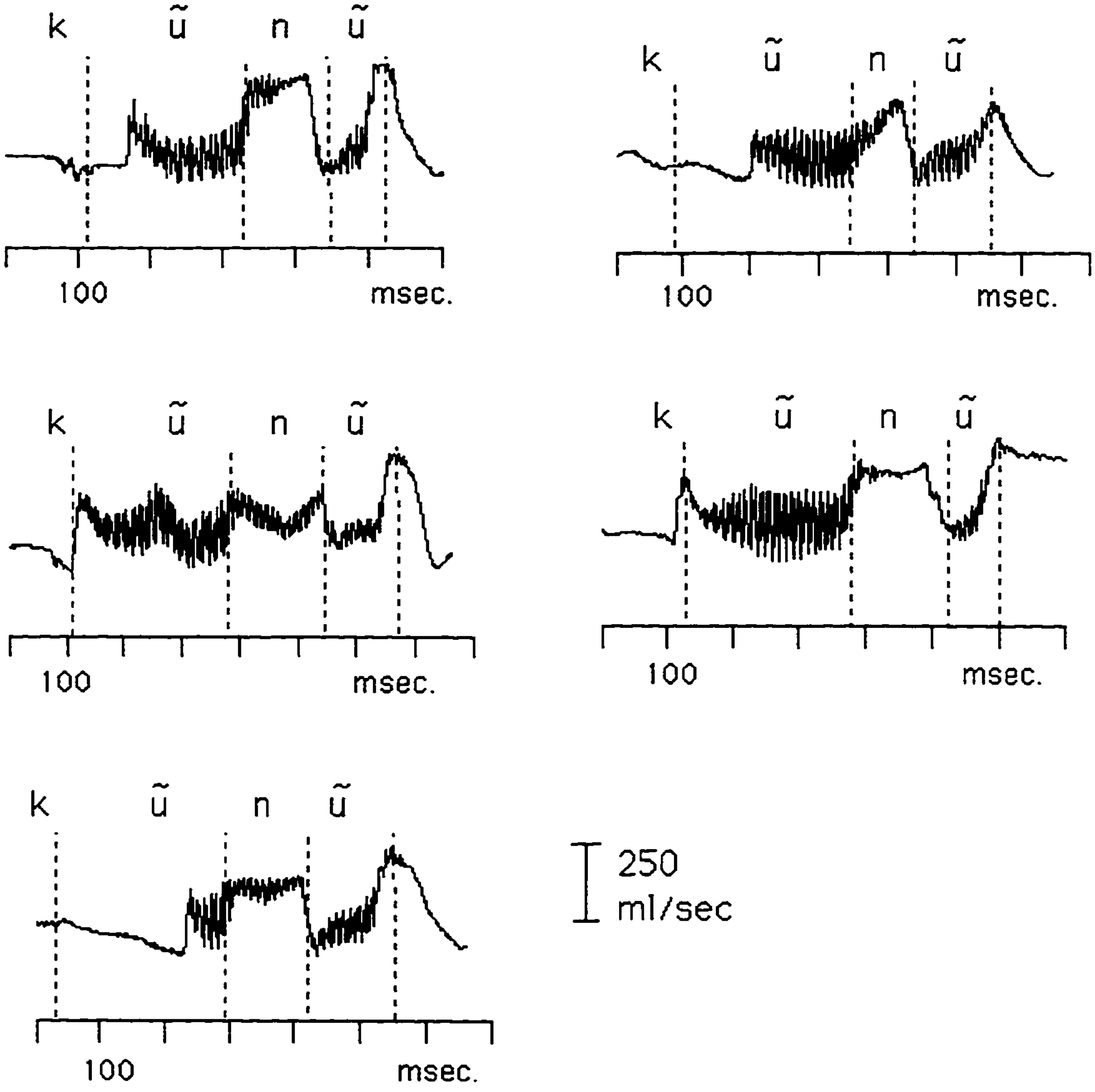
S1: [tĩʔⁱβĩ] 'you (fam) will push'



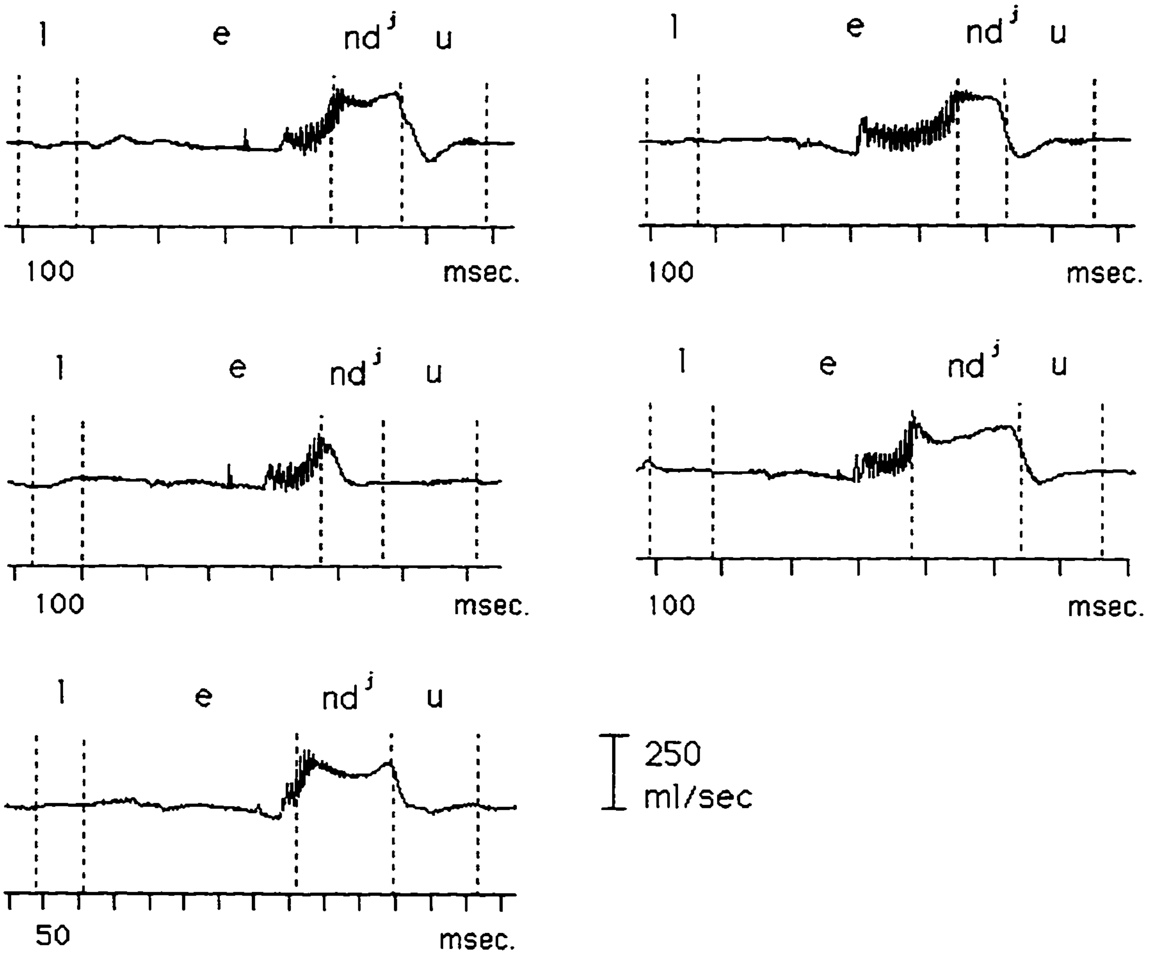
S1: [kunũ] 'to run'



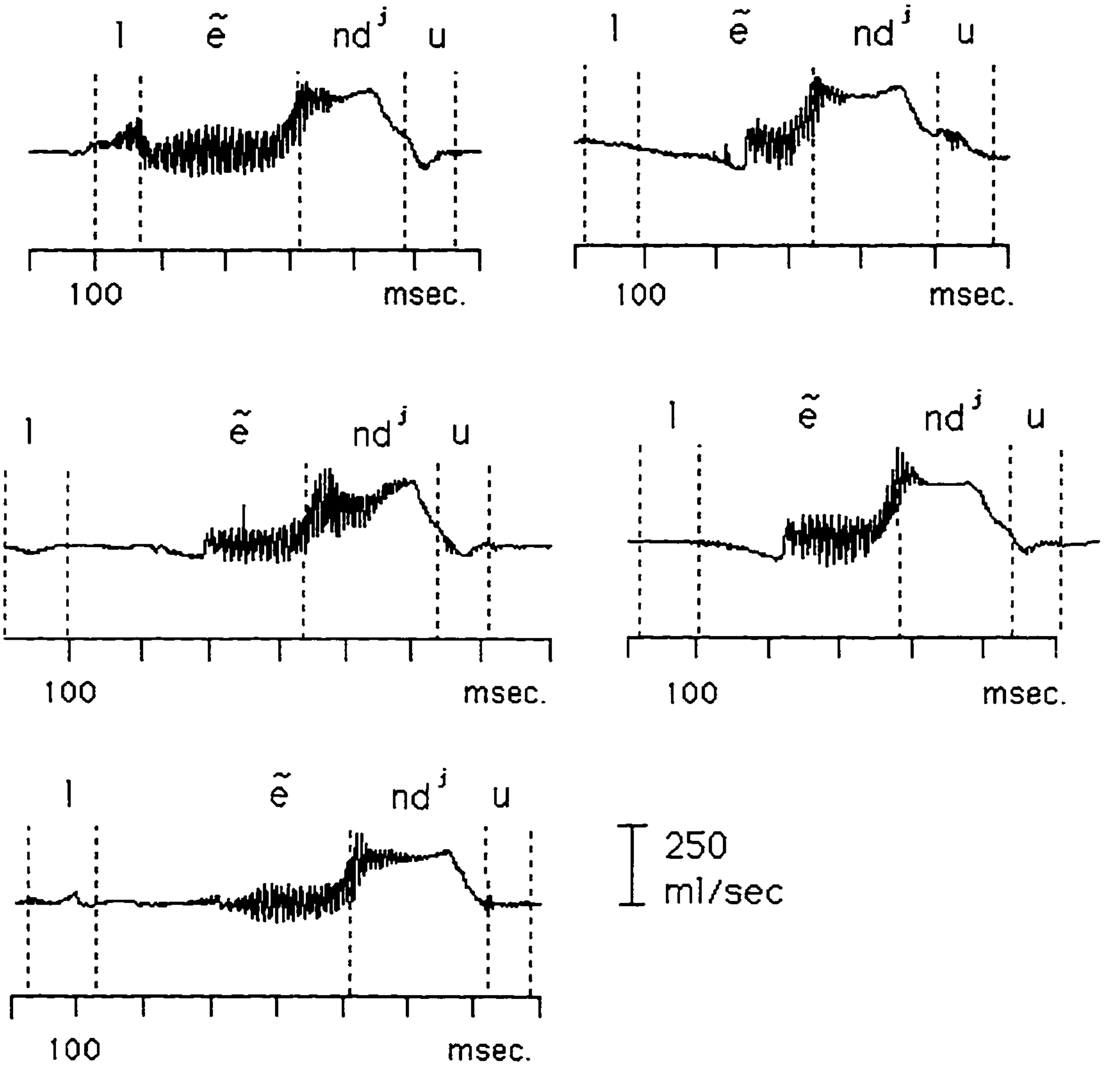
S1: [kũnũ] 'you (fam) will run'



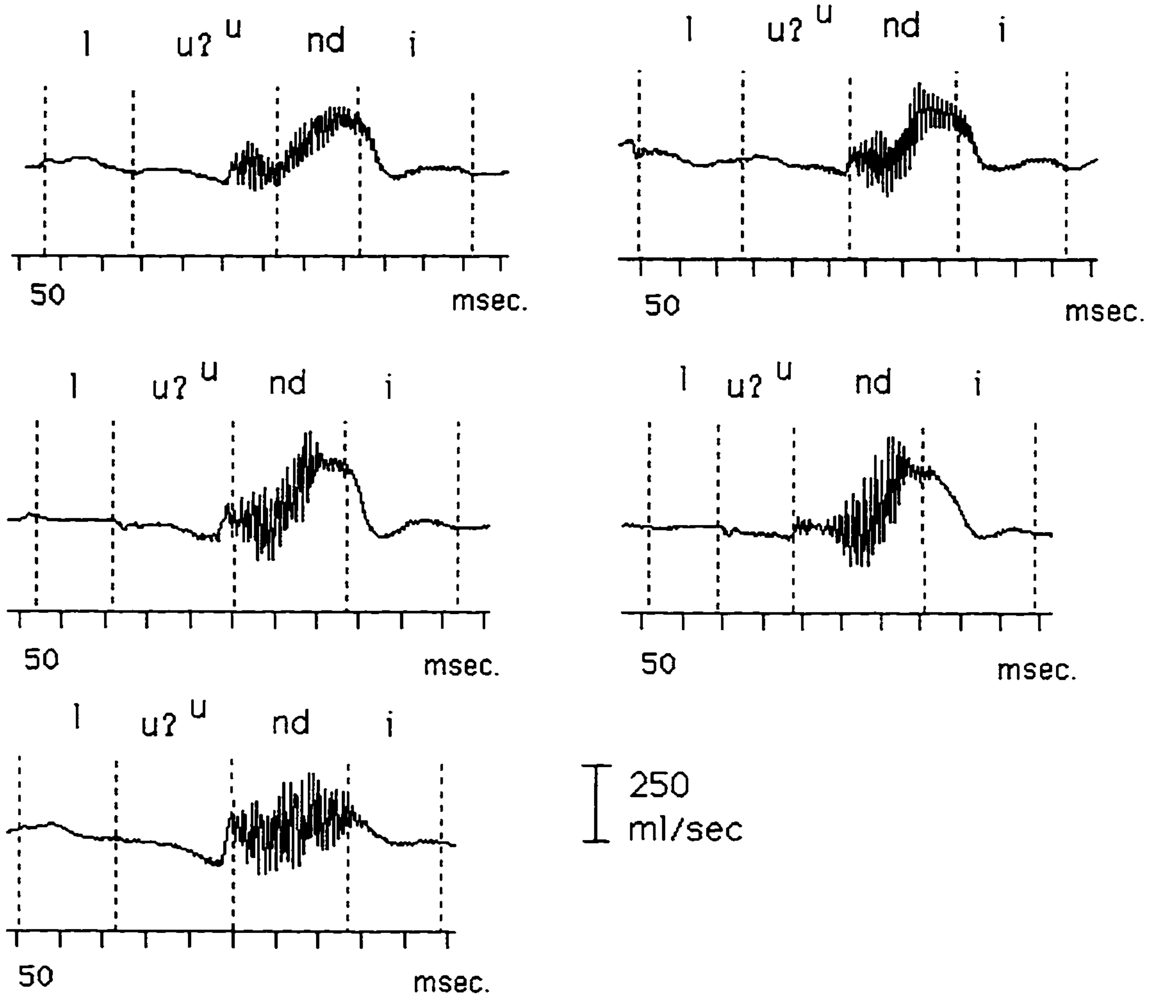
S1: [lend^{j}u] 'dirty'



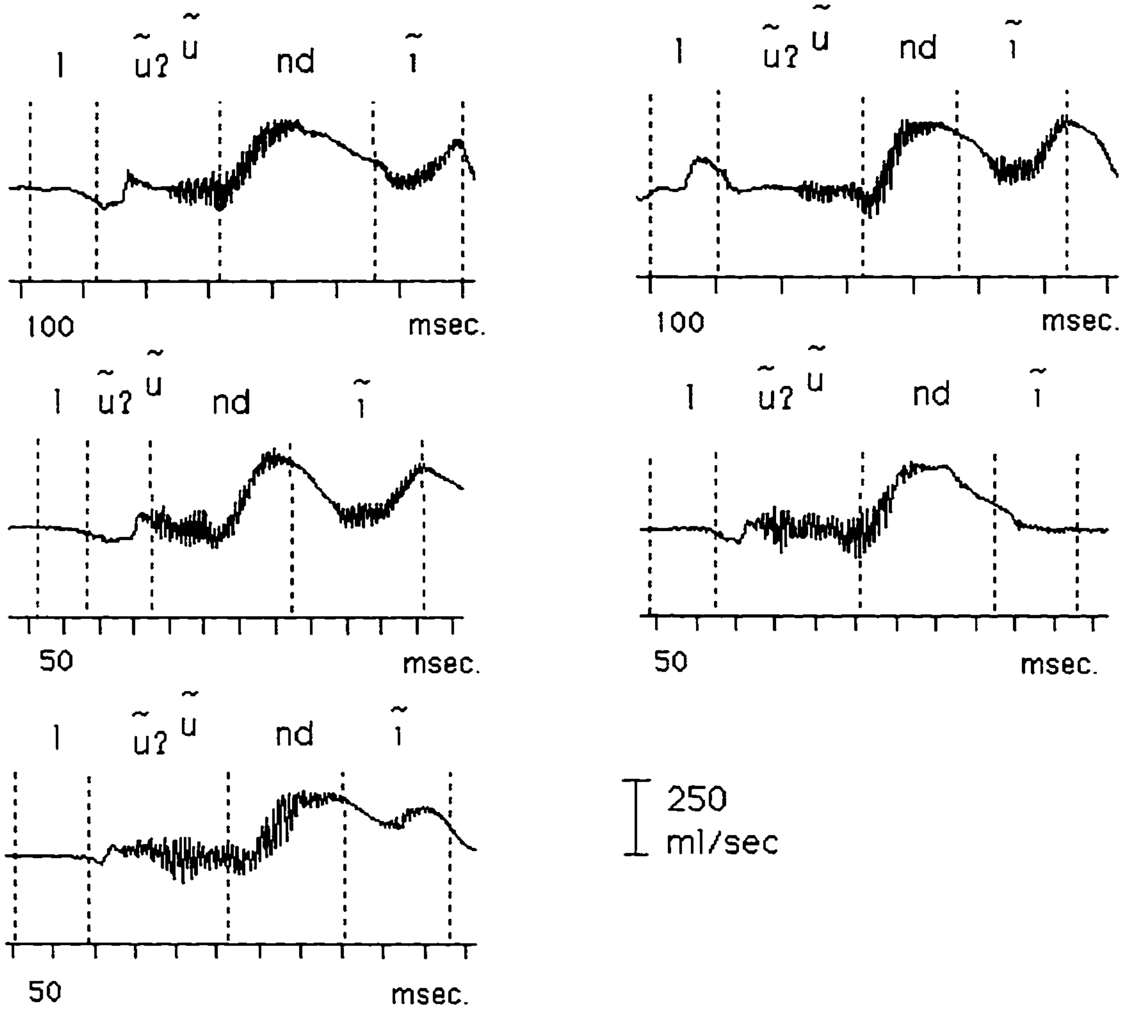
S1: [lẽndʲu] 'you (fam) are dirty'



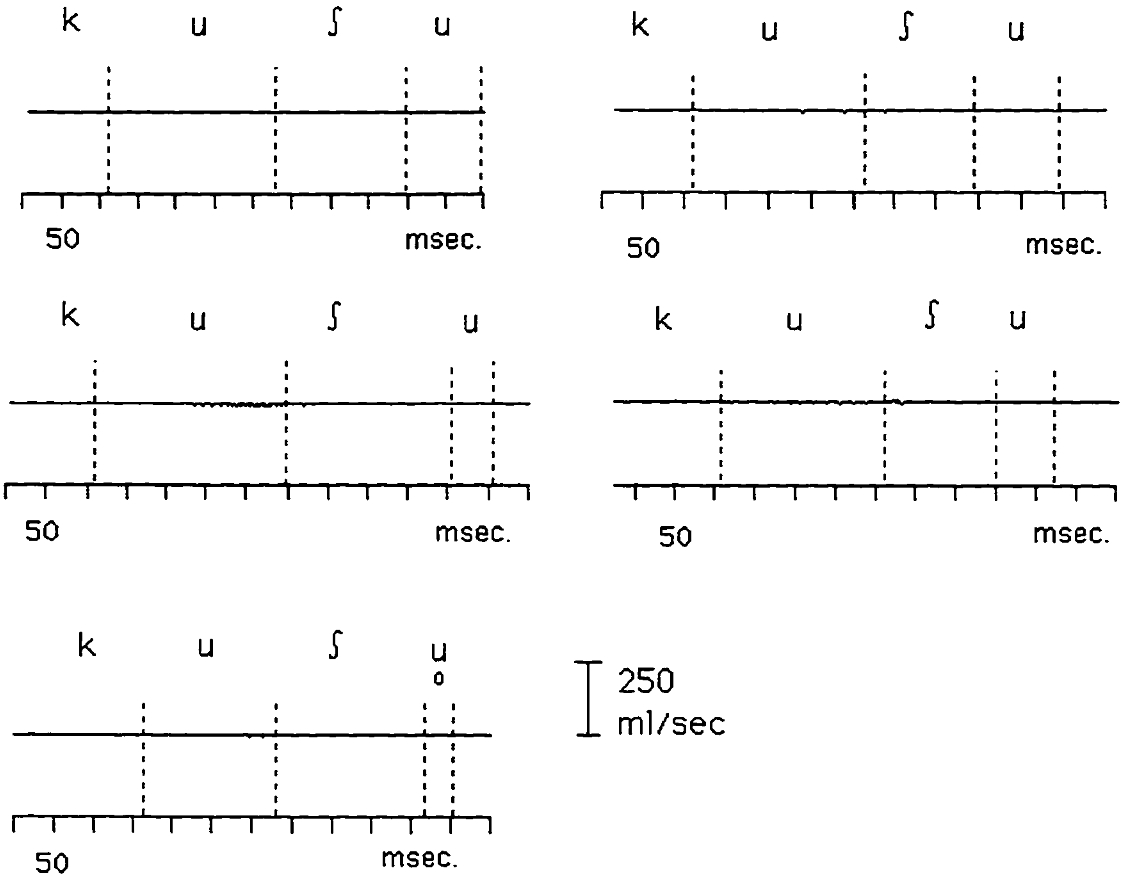
S1: [luʔ^{u}ndi] 'small'



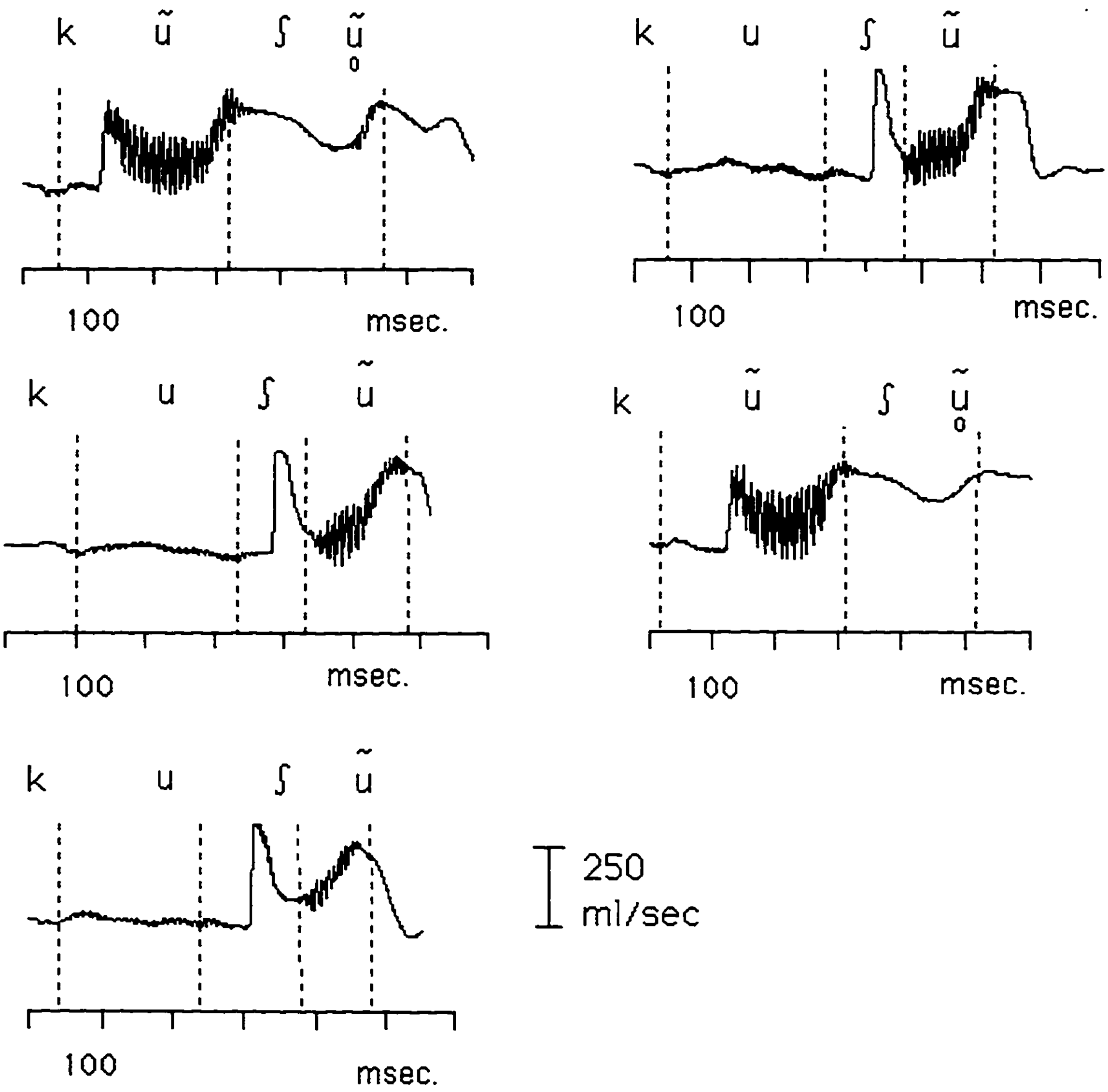
S1: [lũʔ$^{\tilde{u}}$ndĩ] 'you (fam) are small'



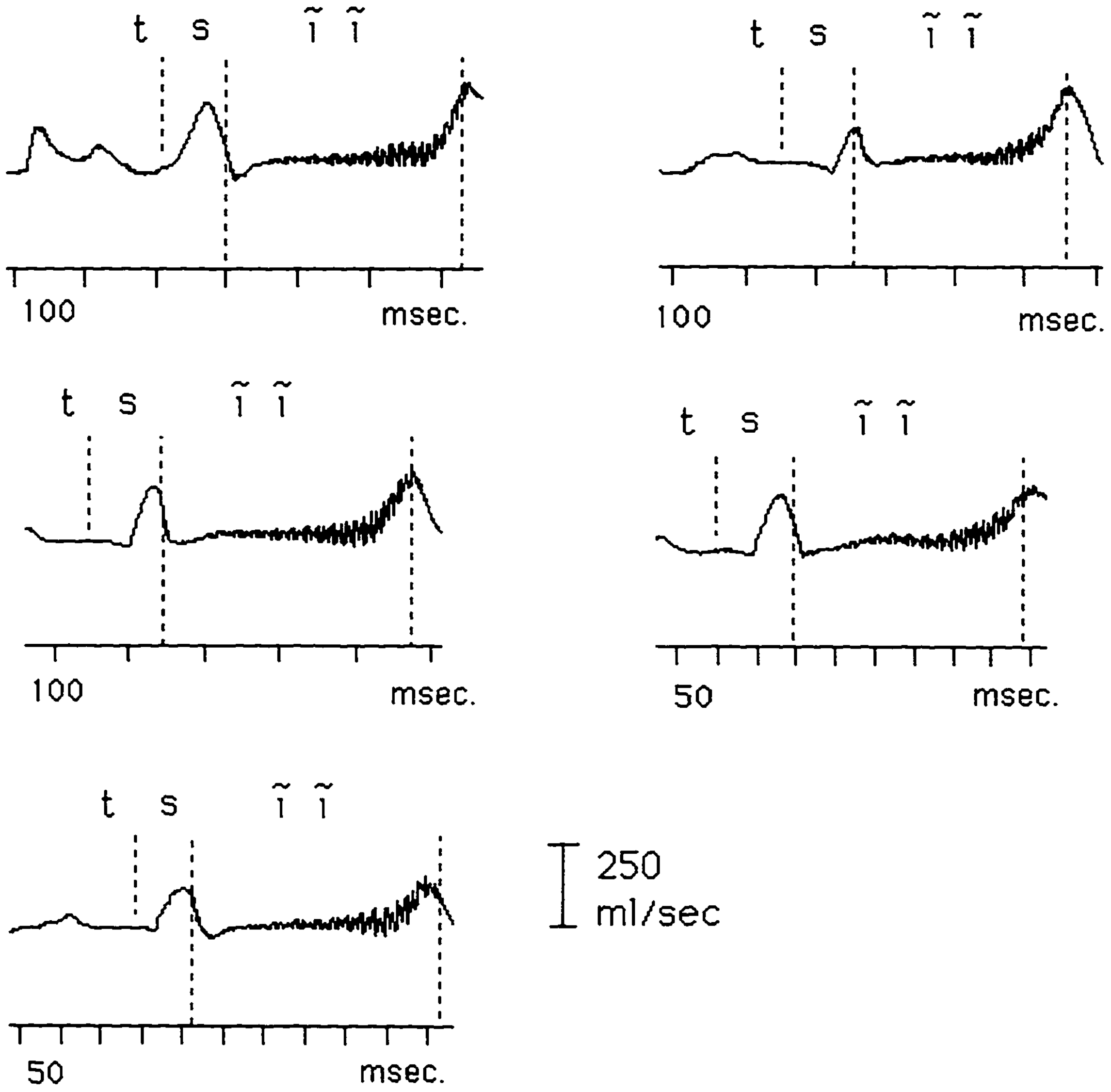
S1: [kuʃu] 'diligent'



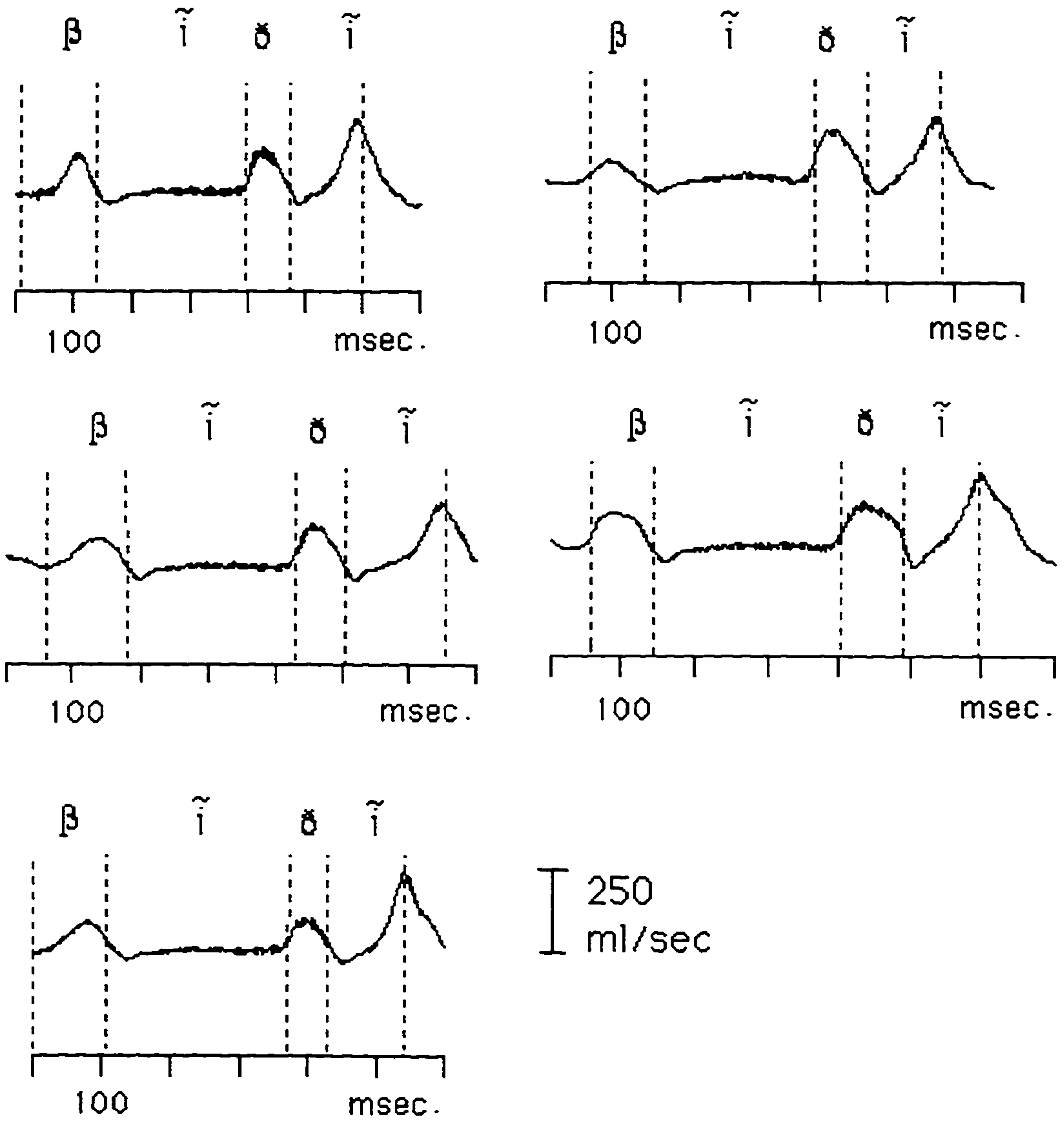
S1: [kũʃũ] 'you (fam) are diligent'



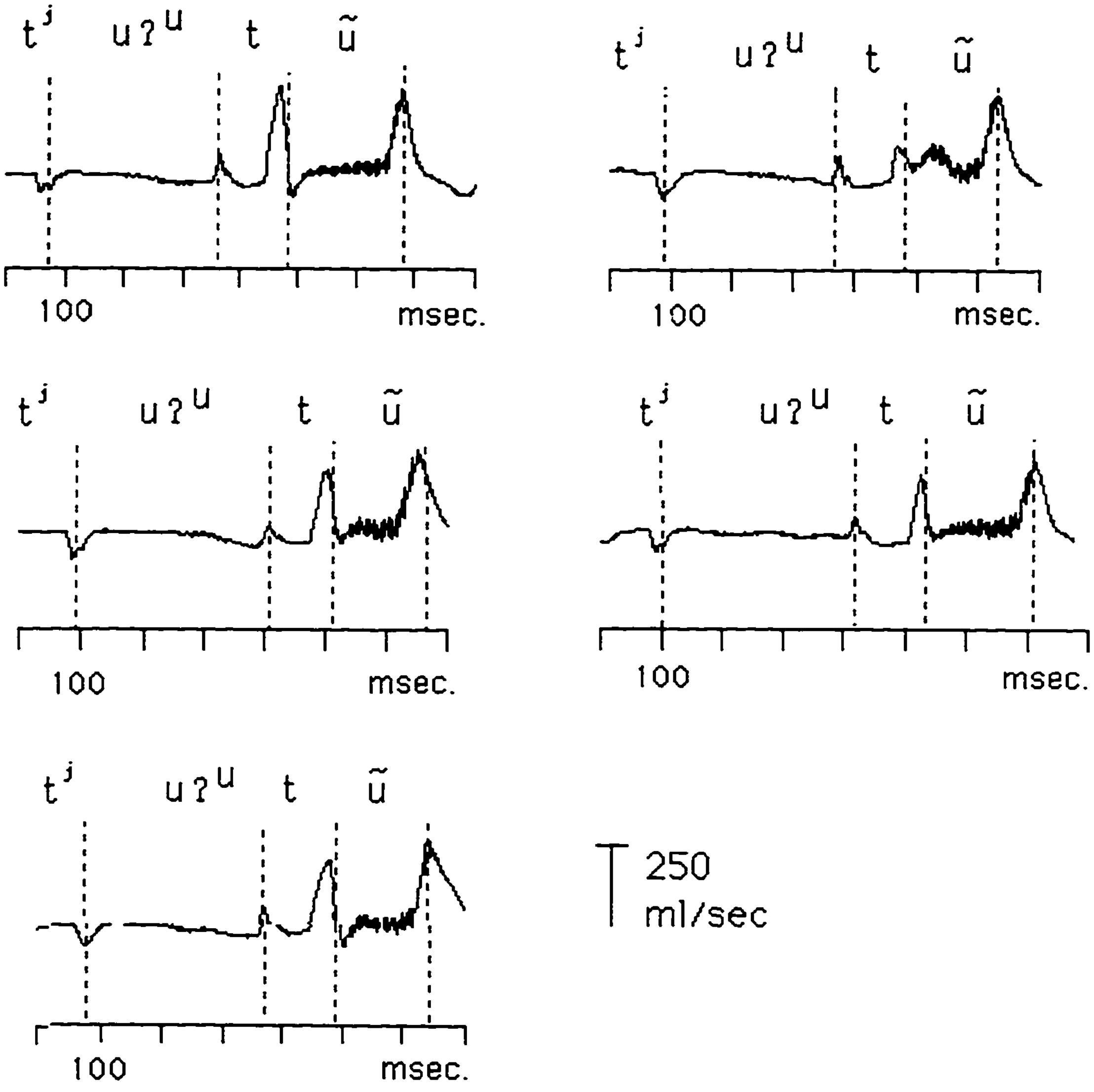
S2: [tsĩĩ] 'nail (fingernail)'



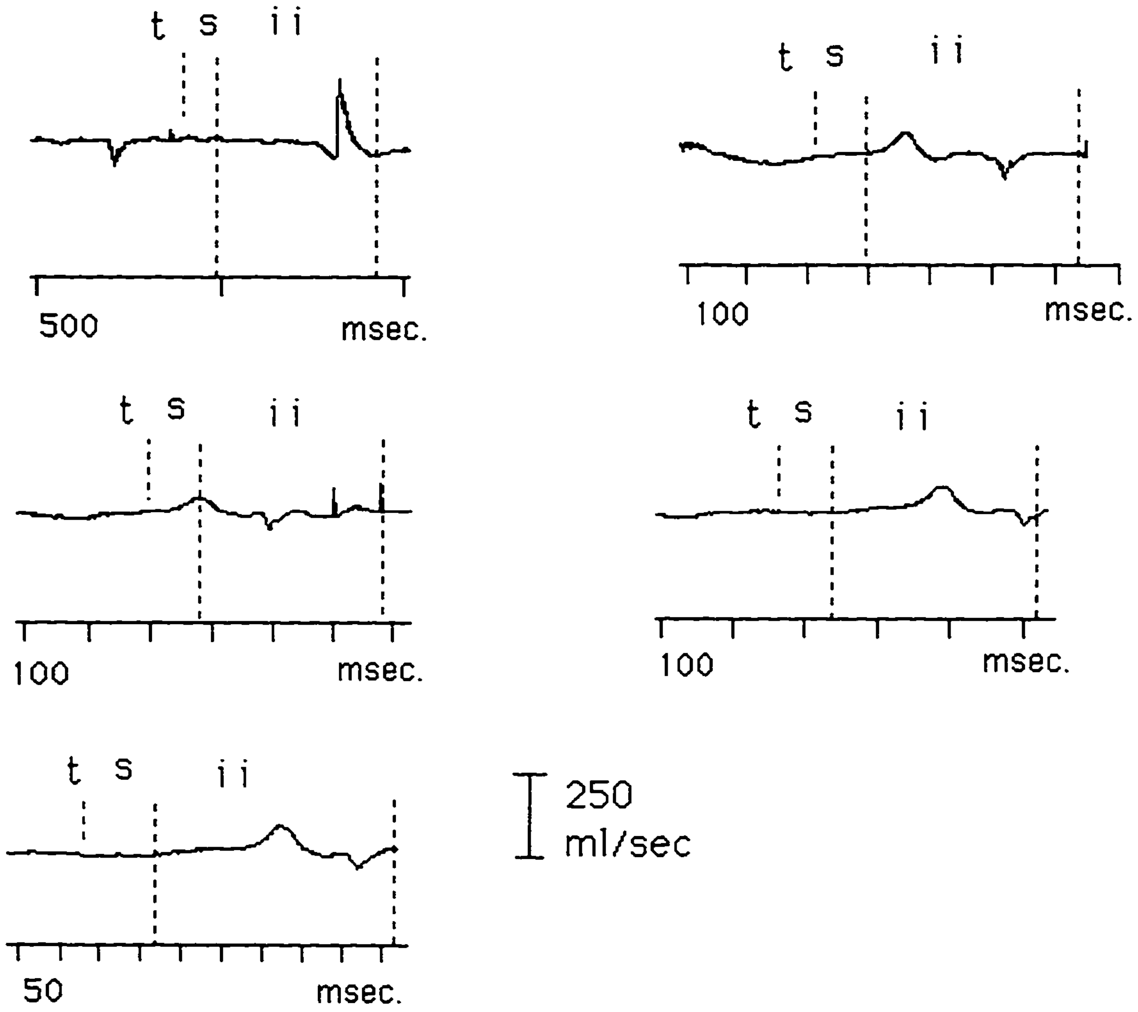
S2: [βĩðĩ] 'sweet'



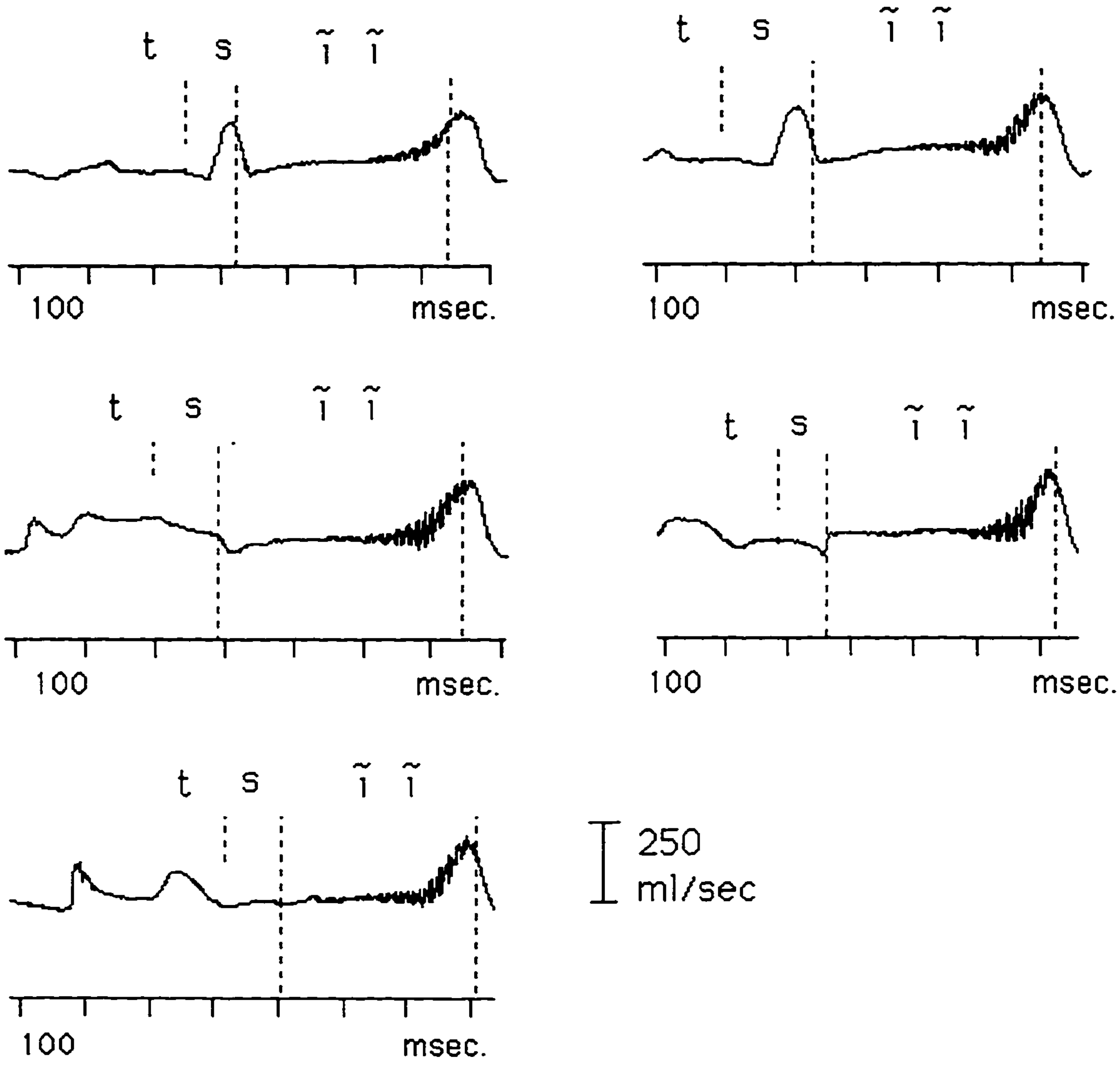
S2: [t^{j}uʔ^{u}tũ] 'firewood'



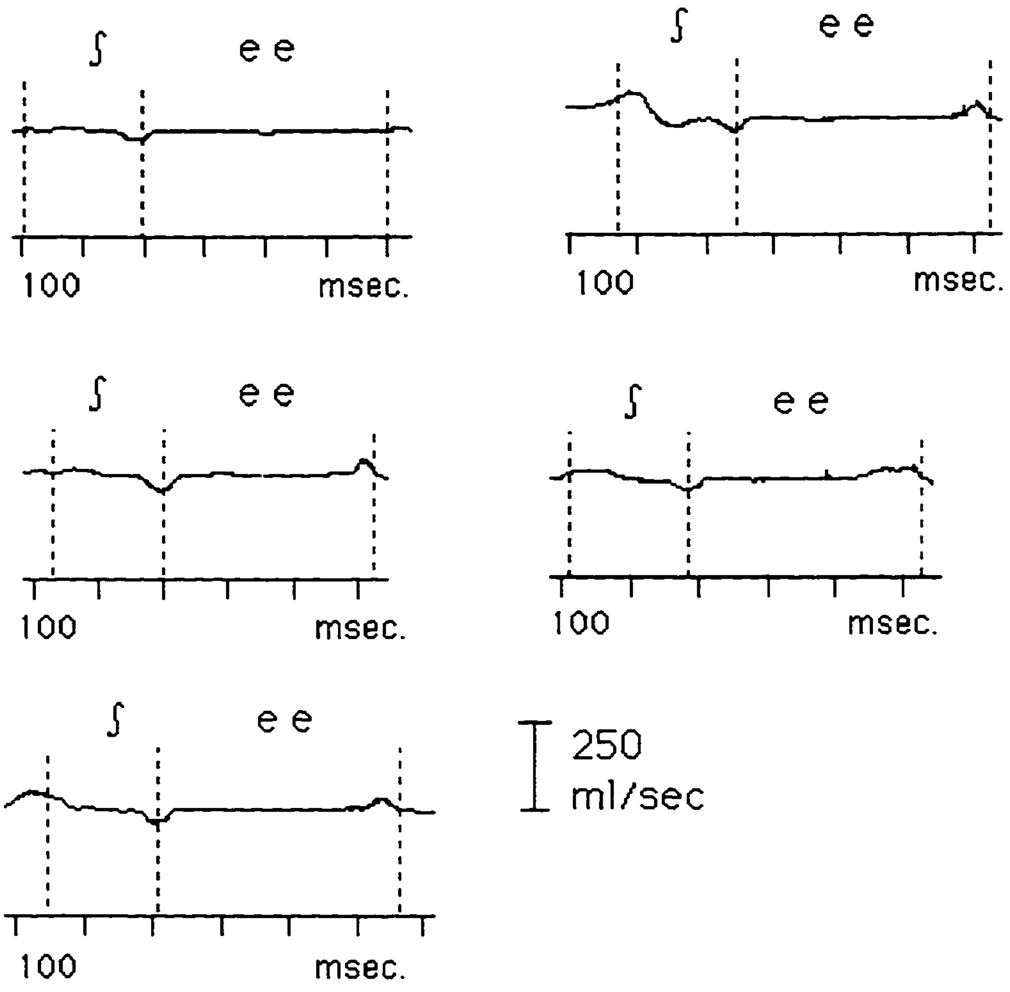
S2: [tsii] 'to get wet'



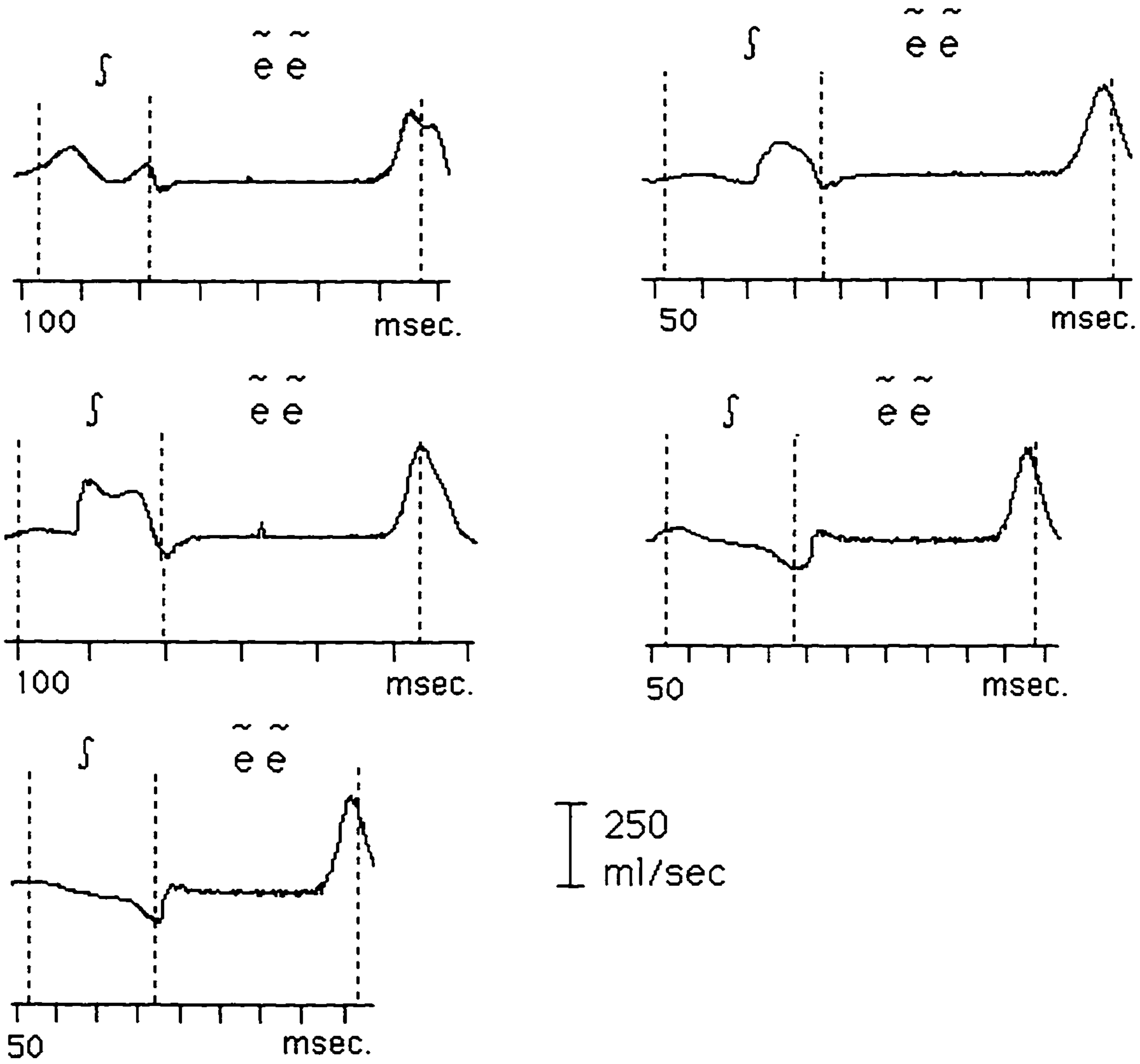
S2: [tsĩĩ] 'you (fam) will get yourself wet'



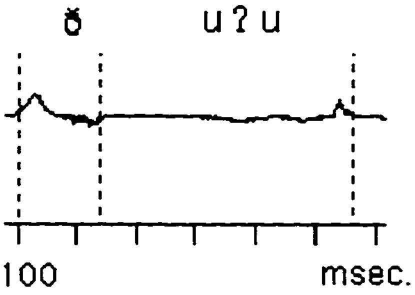
S2: [ʃee] 'to arrive'

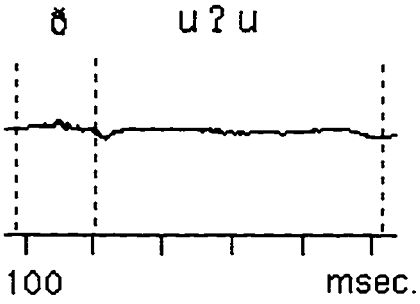


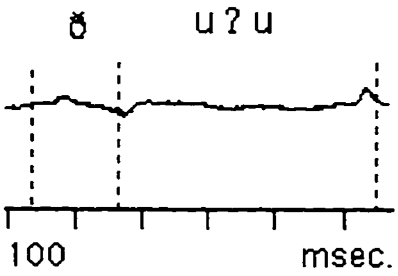
S2: [ʃẽẽ] 'you (fam) arrived'

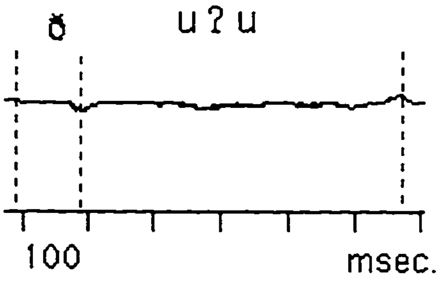


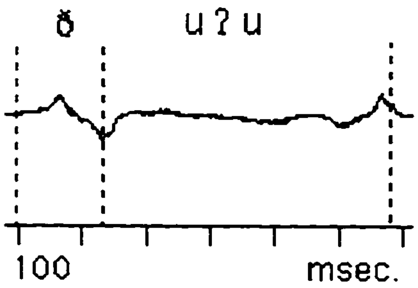
S2: [ðuʔu] 'to rob, steal'

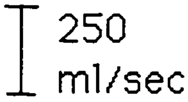




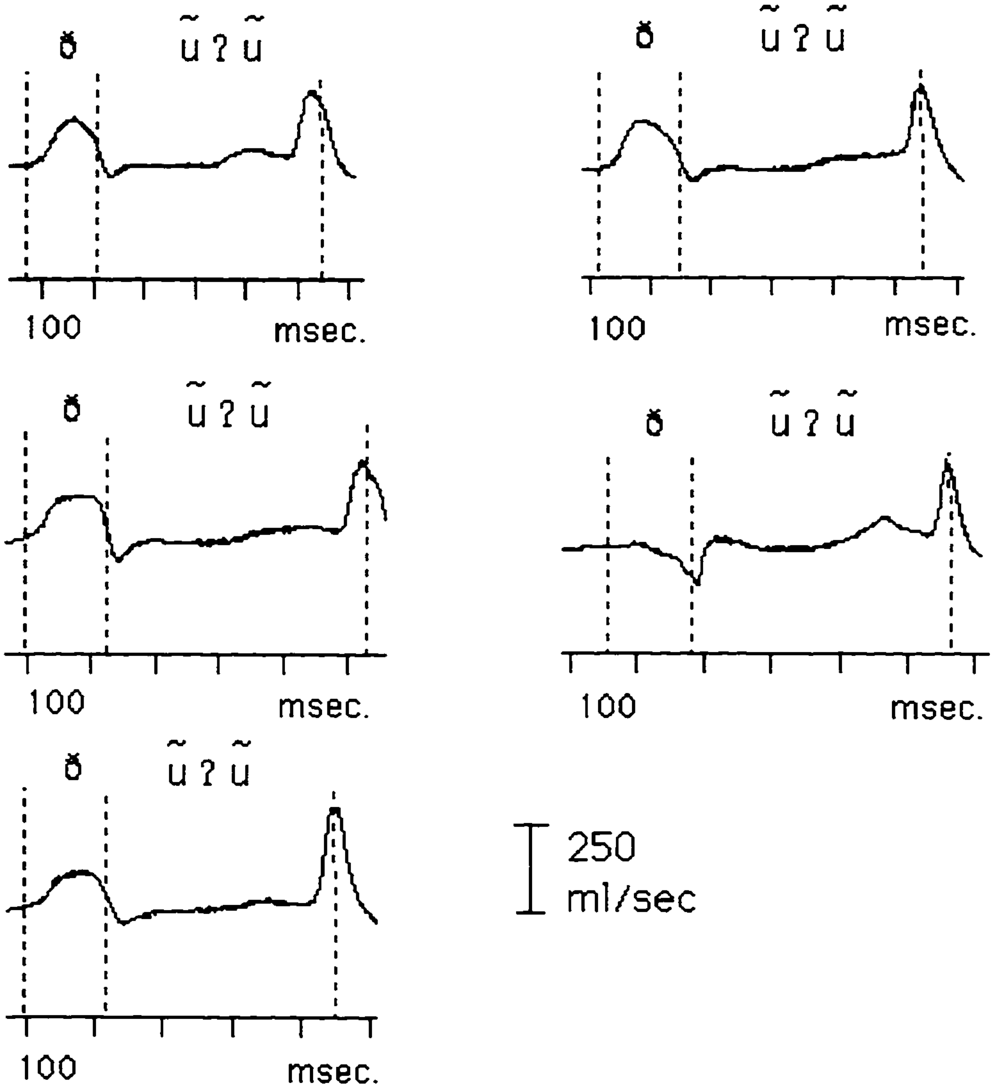




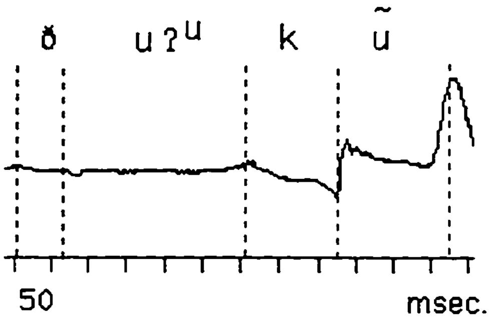


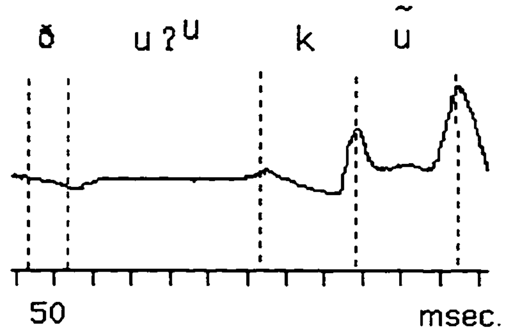


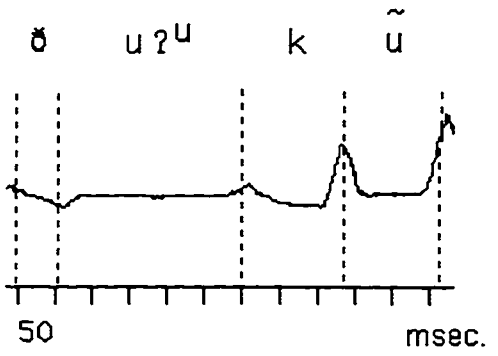
S2: [ðũʔũ] 'you (fam) will rob'

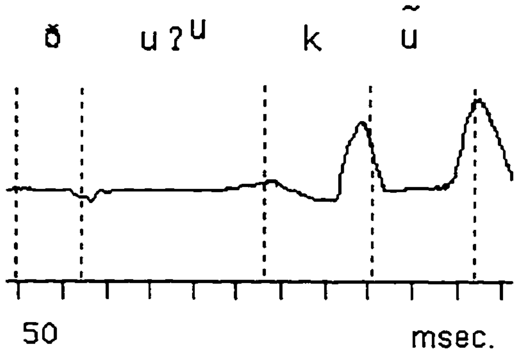


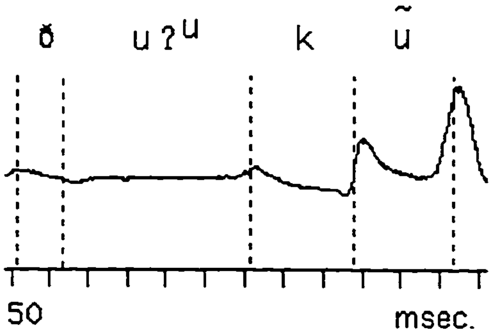
S2: [ðuʔ^{u}kũ] 'tall'

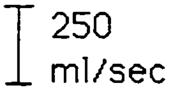




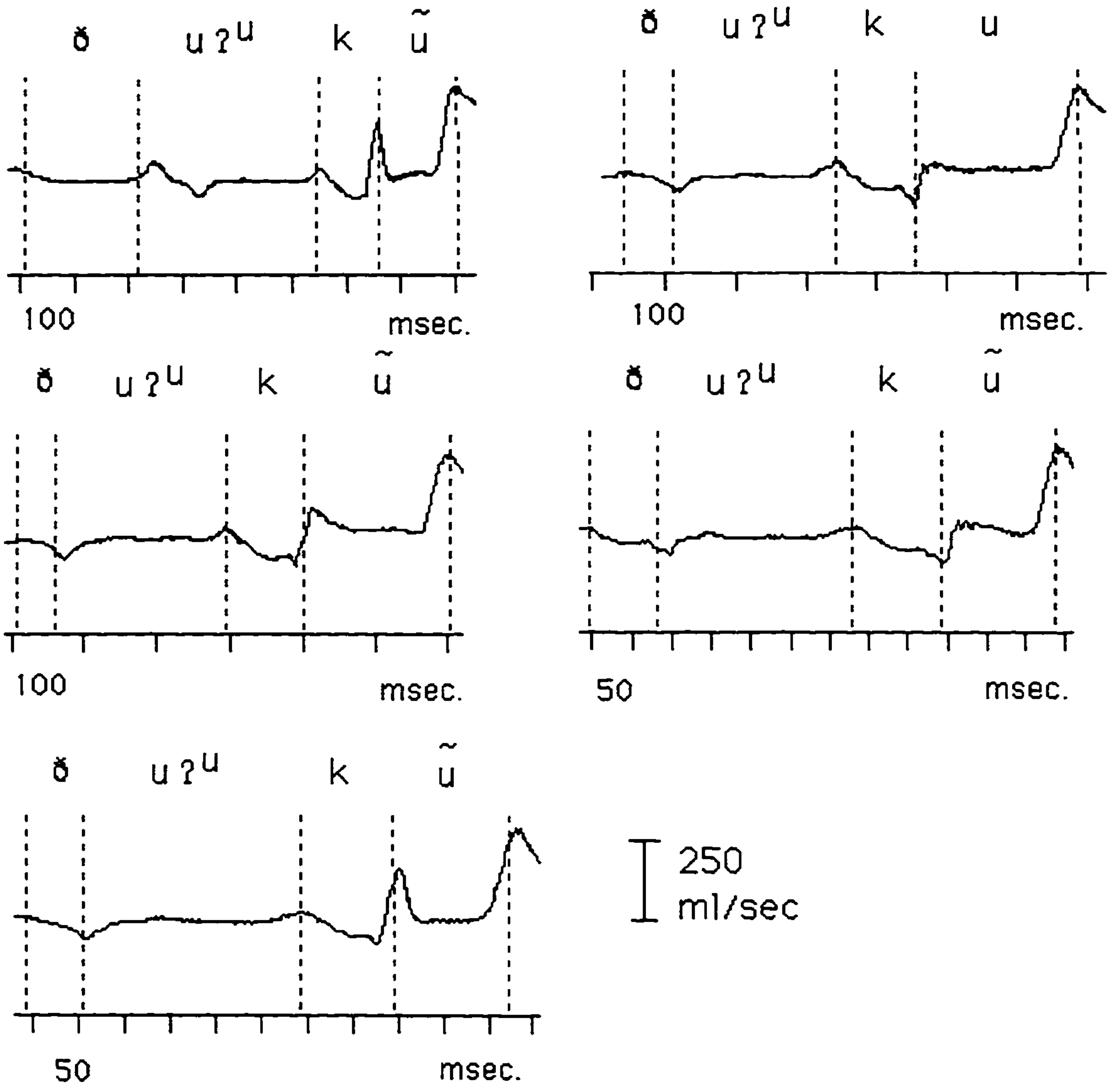




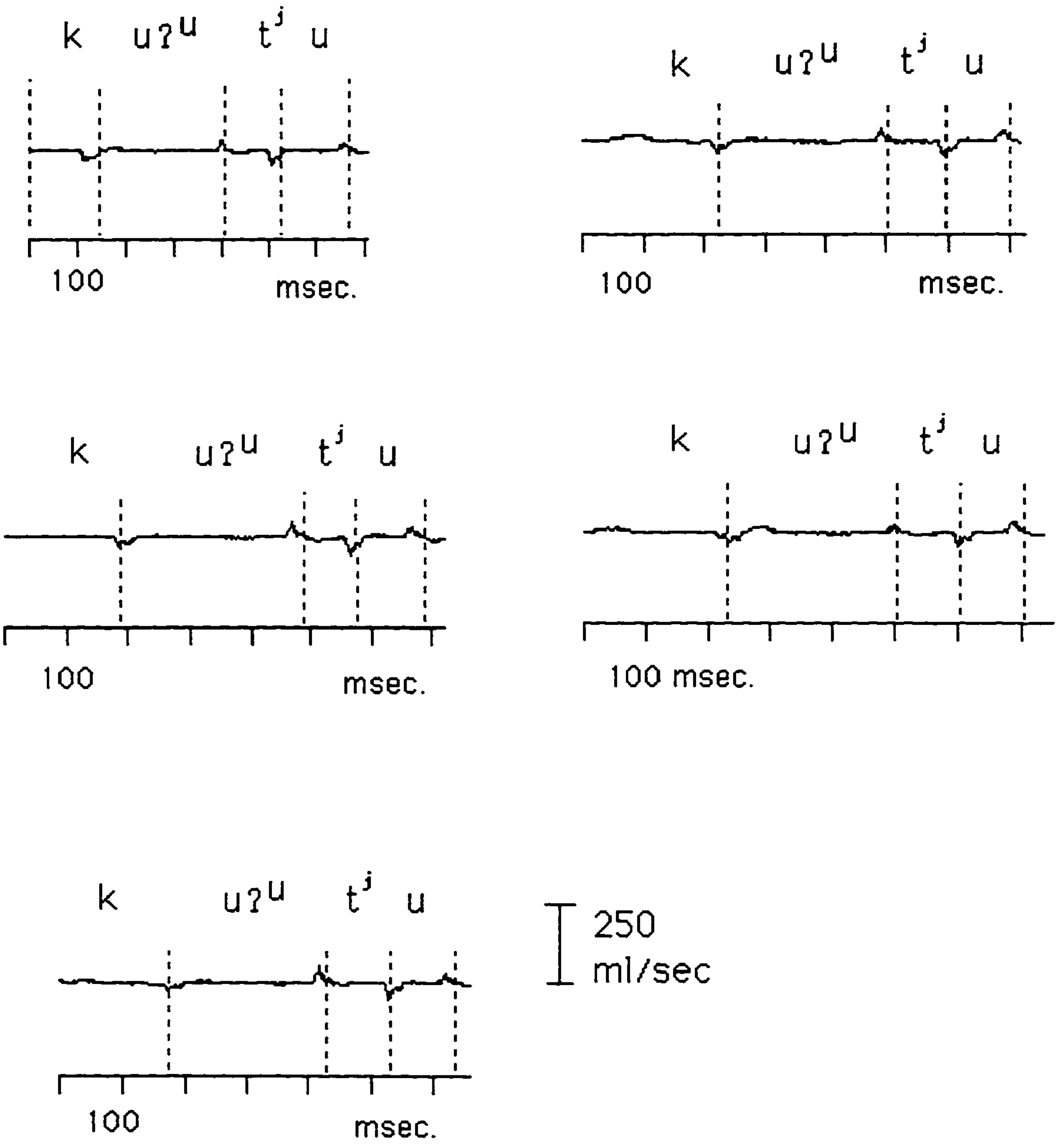




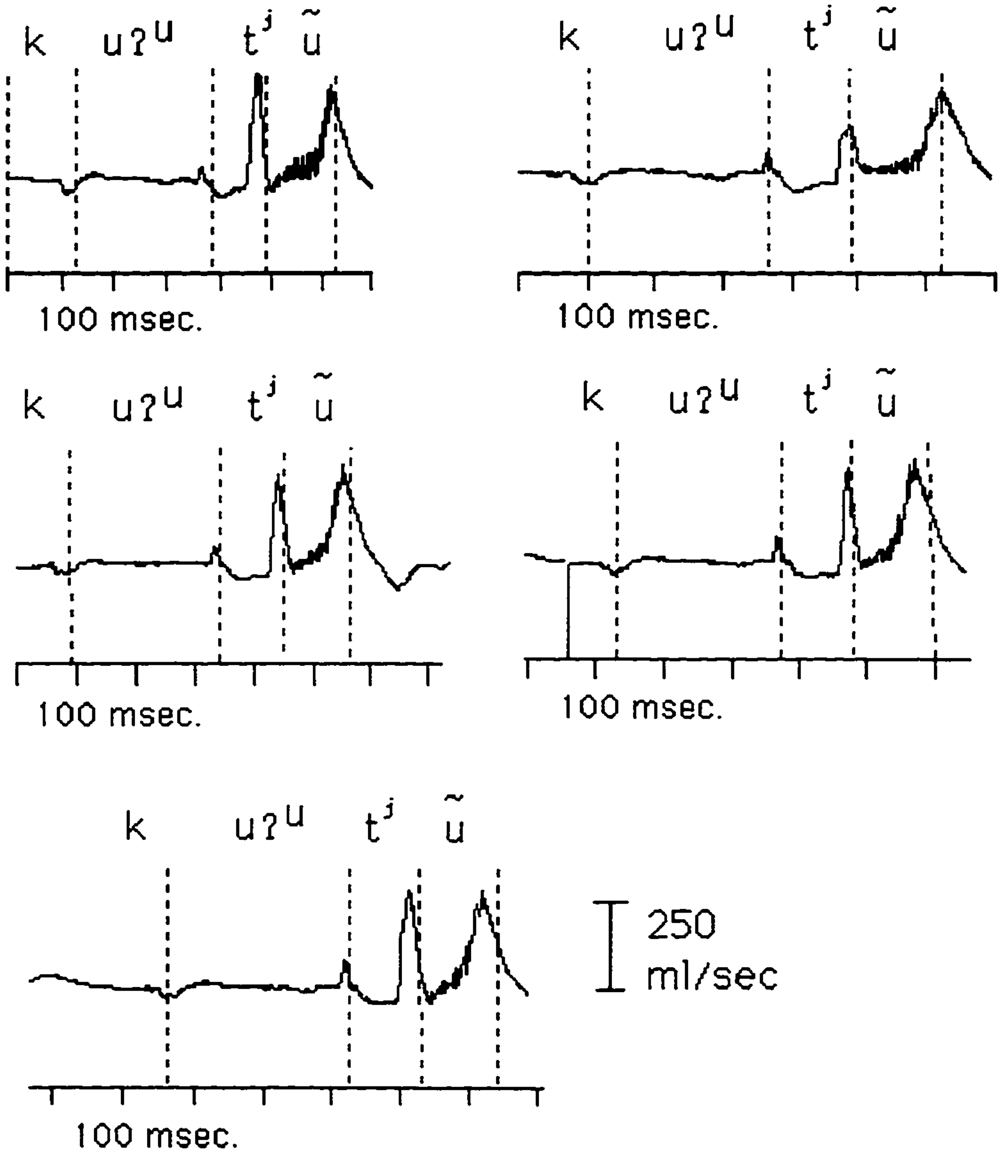
S2: [ðuʔ^{u}kũ] 'you (fam) are tall'



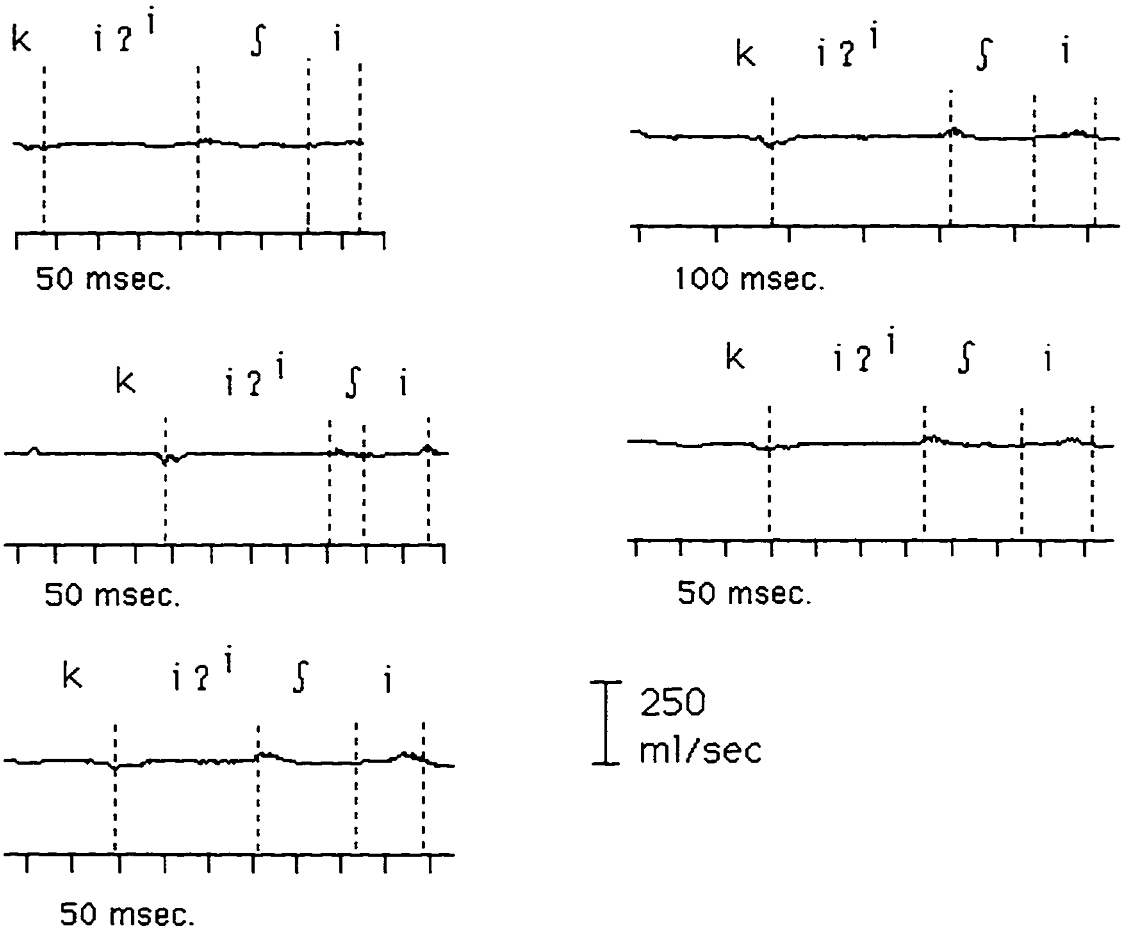
S2: [kuʔ^{u}t^{j}u] 'to plow, hoe'



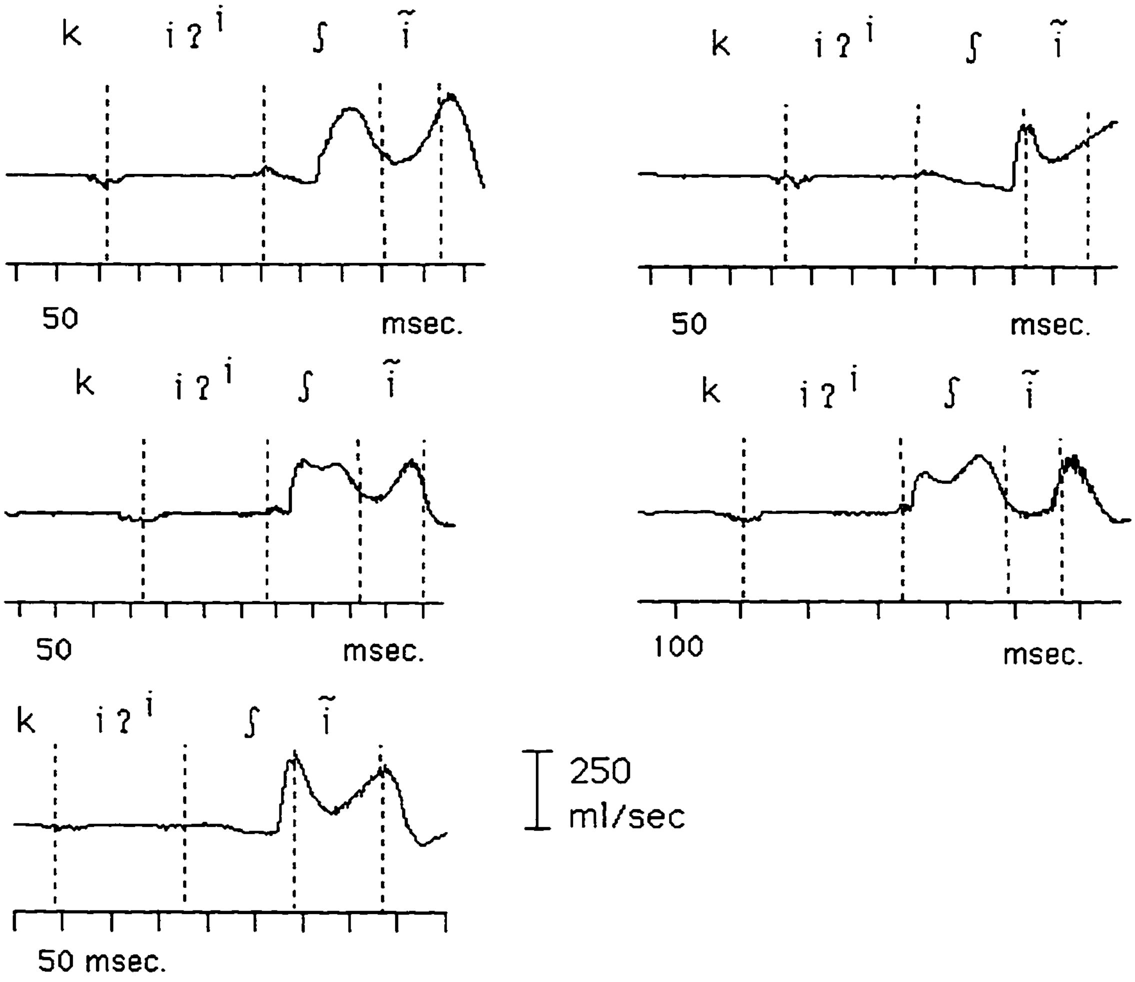
S2: [kuʔ^{u}t^{j}ũ] 'you (fam) will plow'



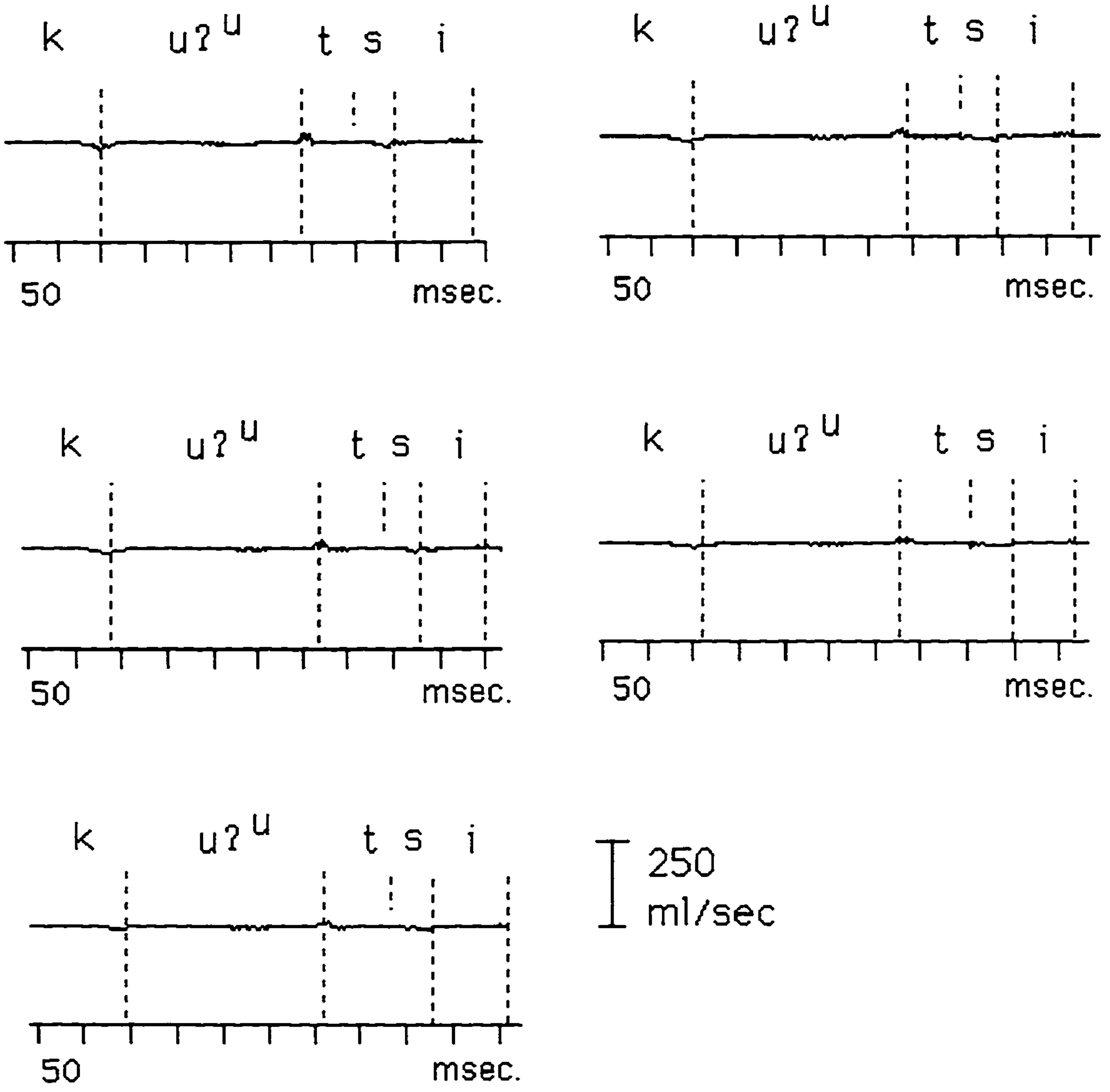
S2: [kiʔ^{i}ʃi] 'to come'



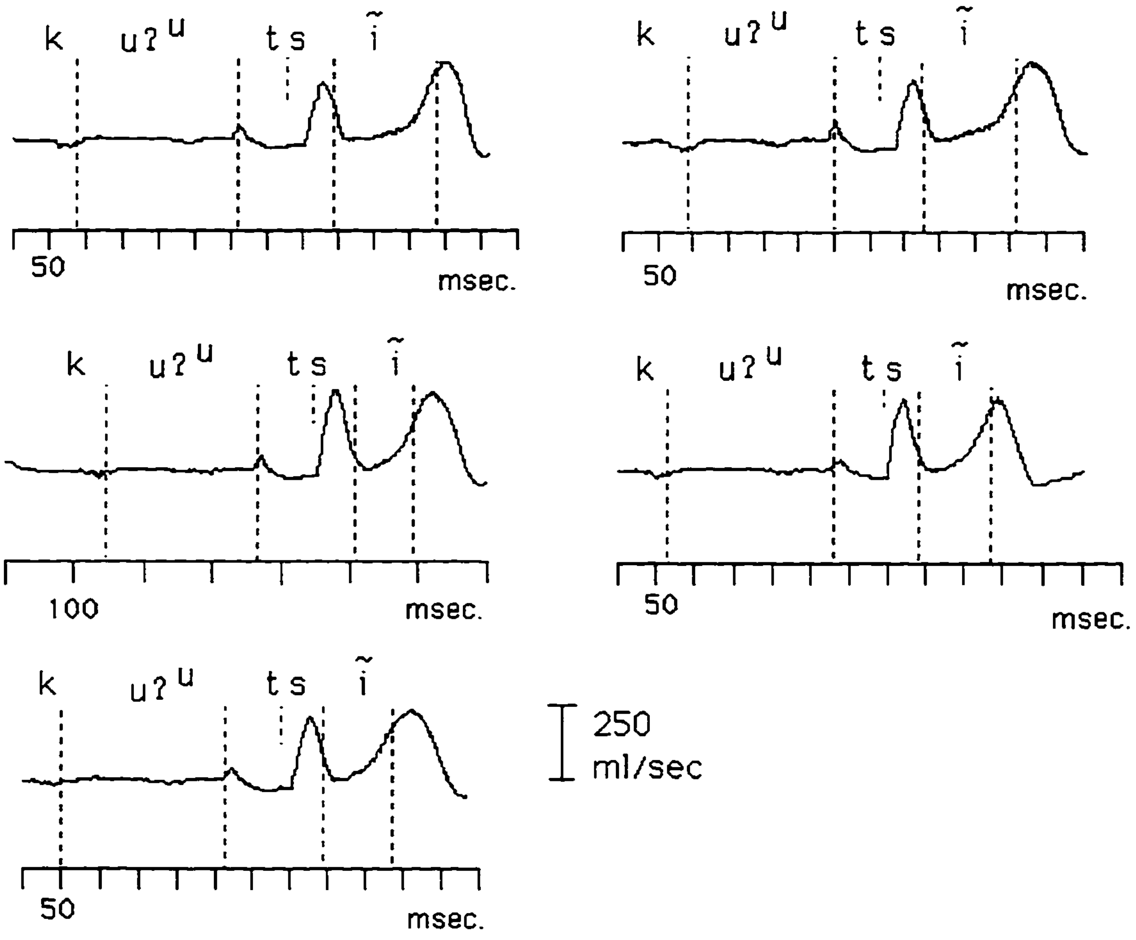
S2: [kiʔⁱʃĩ] 'you (fam) will come'



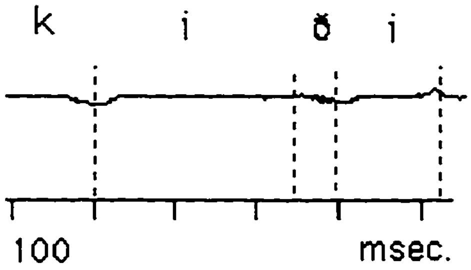
S2: [kuʔ^{u}tsi] 'to bathe'

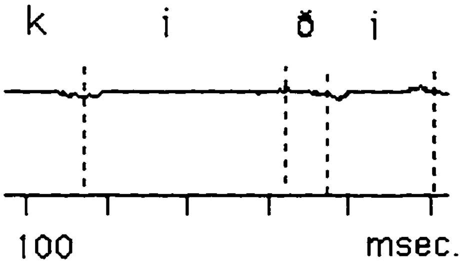


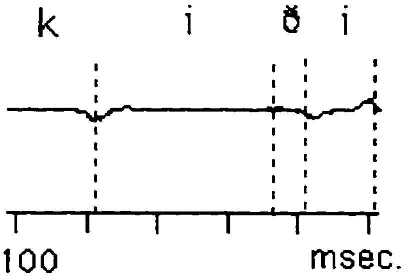
S2: [kuʔ^{u}tsĩ] 'you (fam) will bathe'

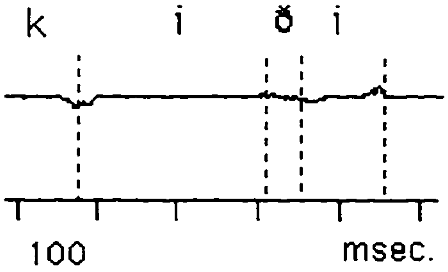


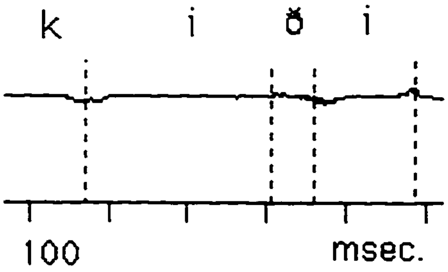
S2: [kiði] 'to sleep'



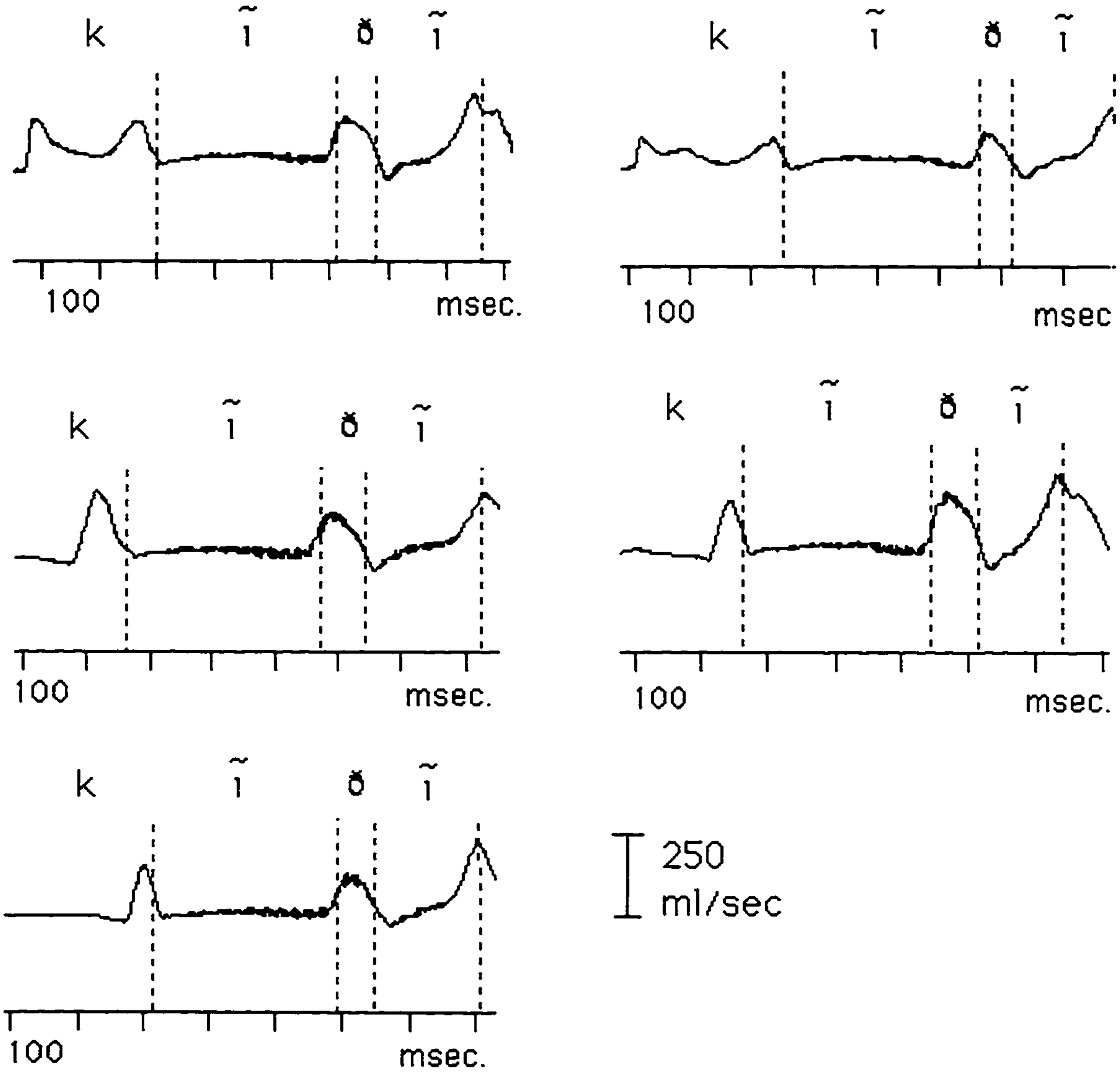




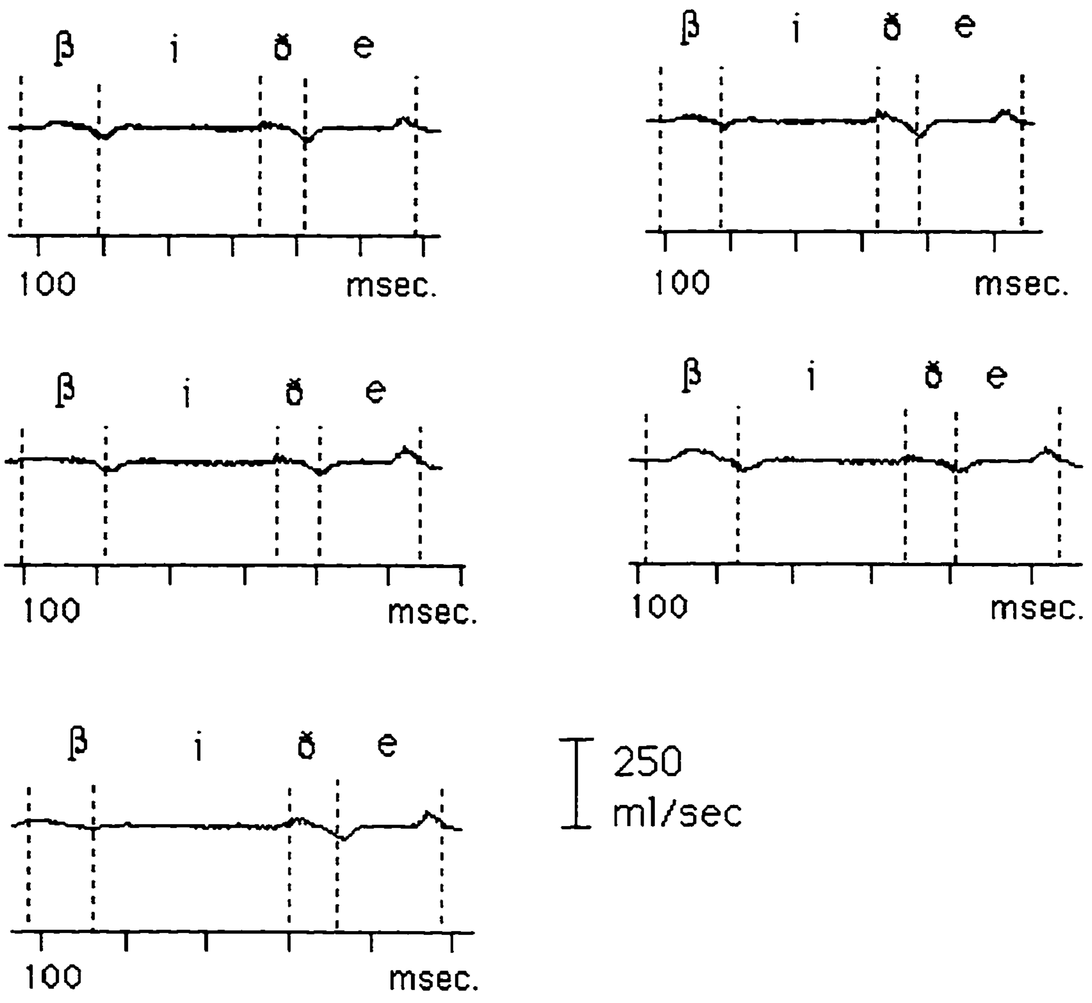




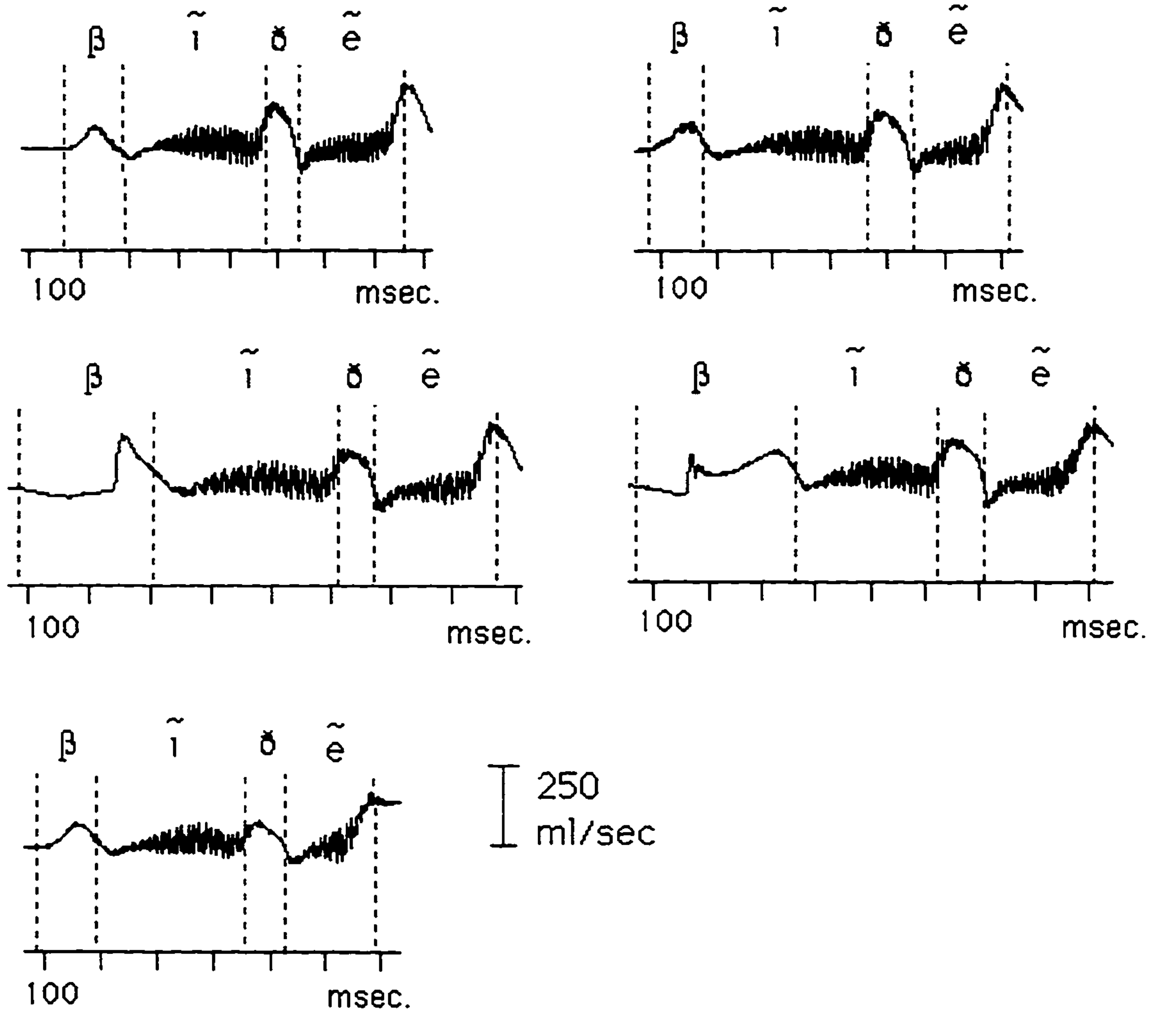
S2: [kĩðĩ] 'you (fam) will sleep'



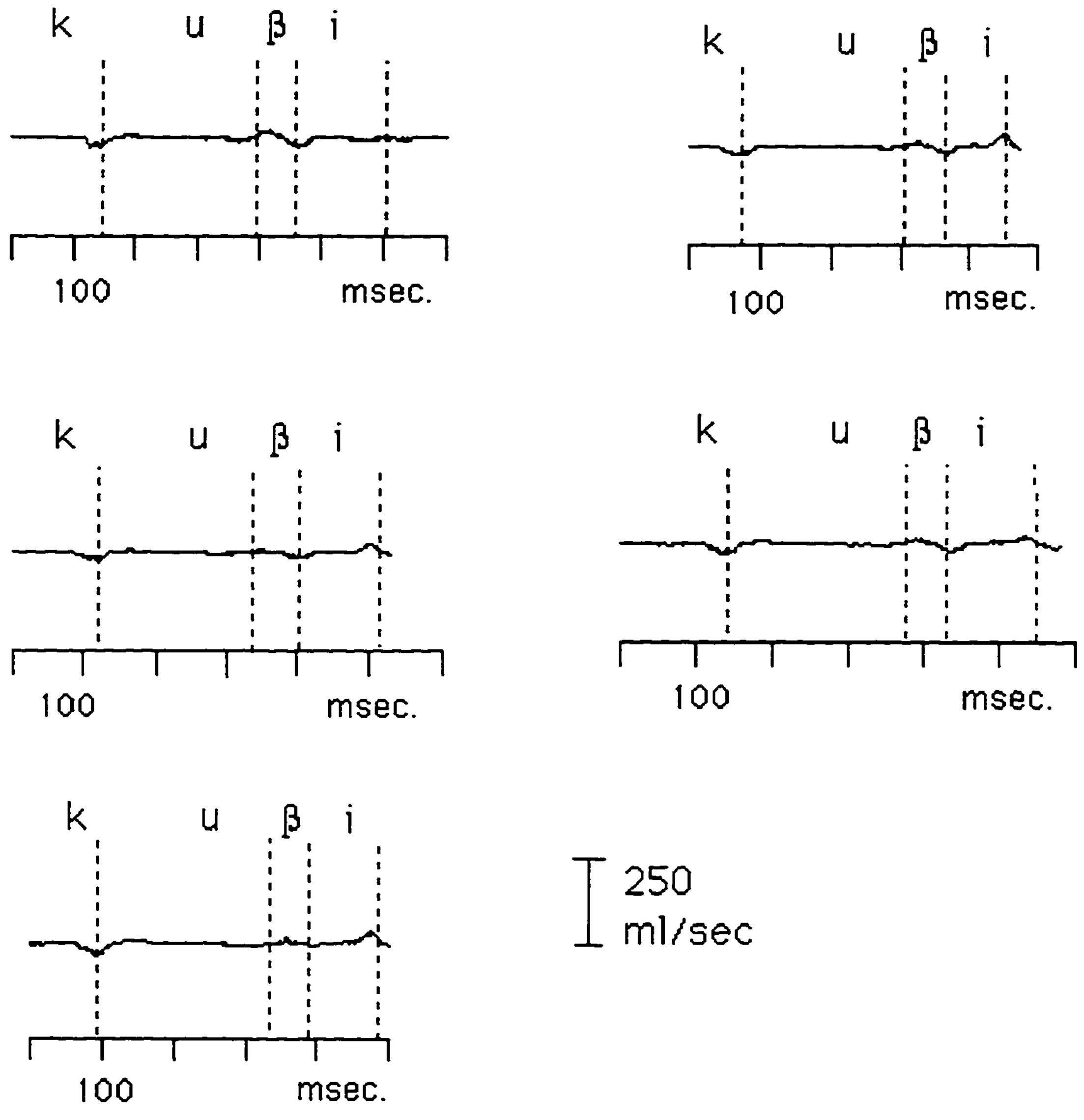
S2: [βiðe] 'wet'



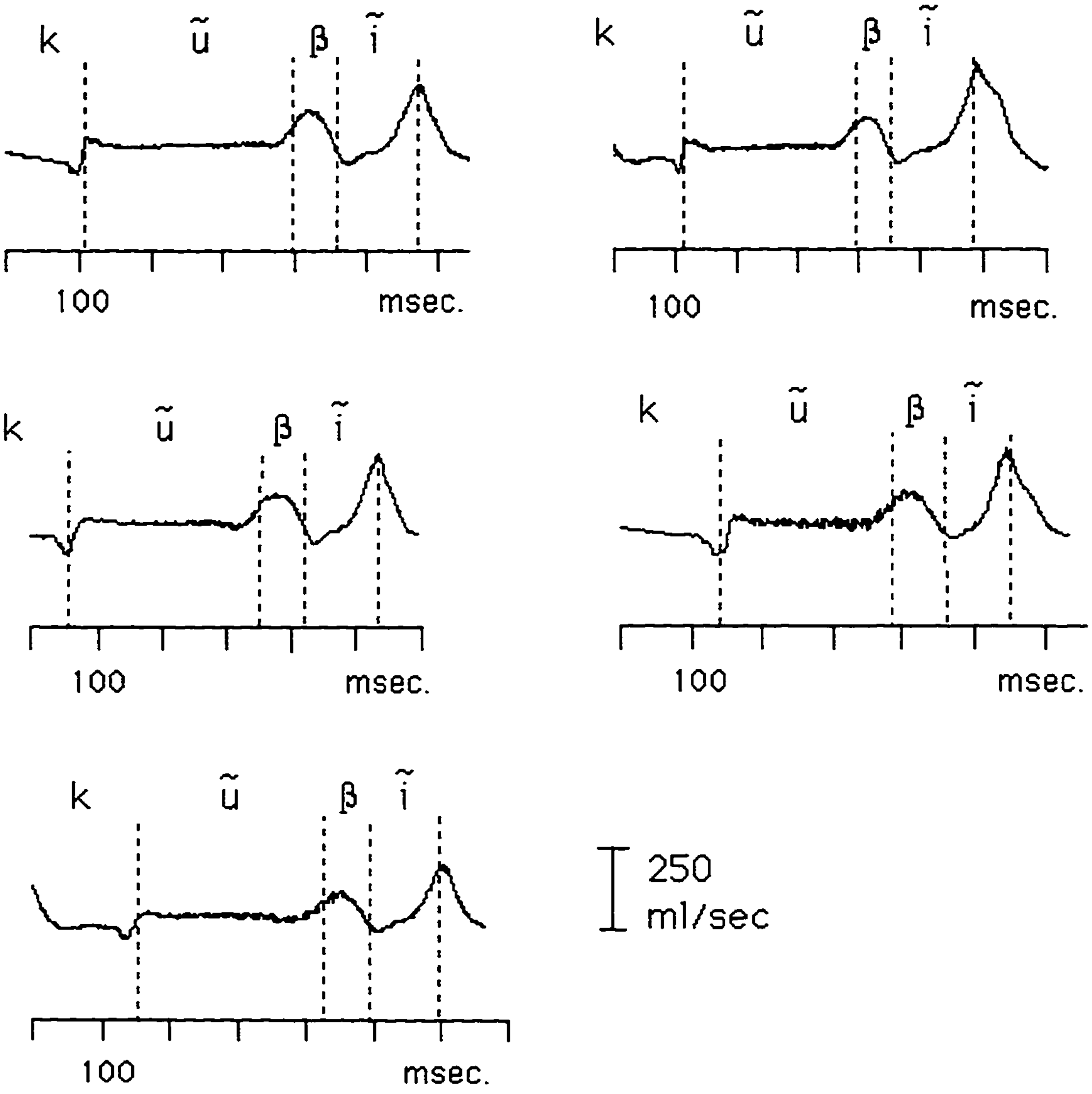
S2: [βĩðẽ] 'you (fam) are wet'



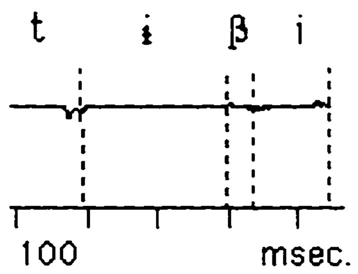
S2: [kuβi] 'to die'

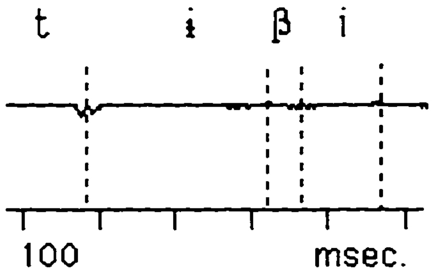


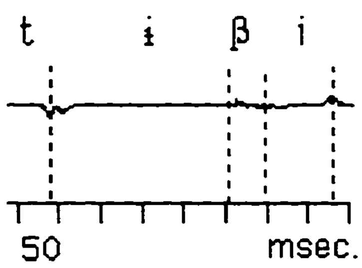
S2: [kũβĩ] 'you (fam) died'

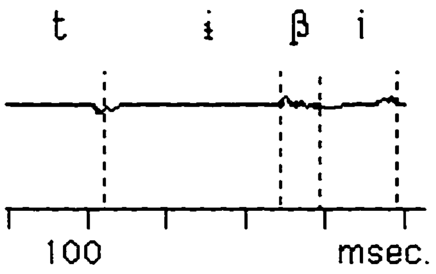


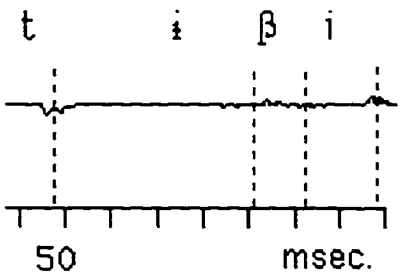
S2: [tɨβi] 'to blow'

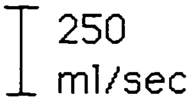




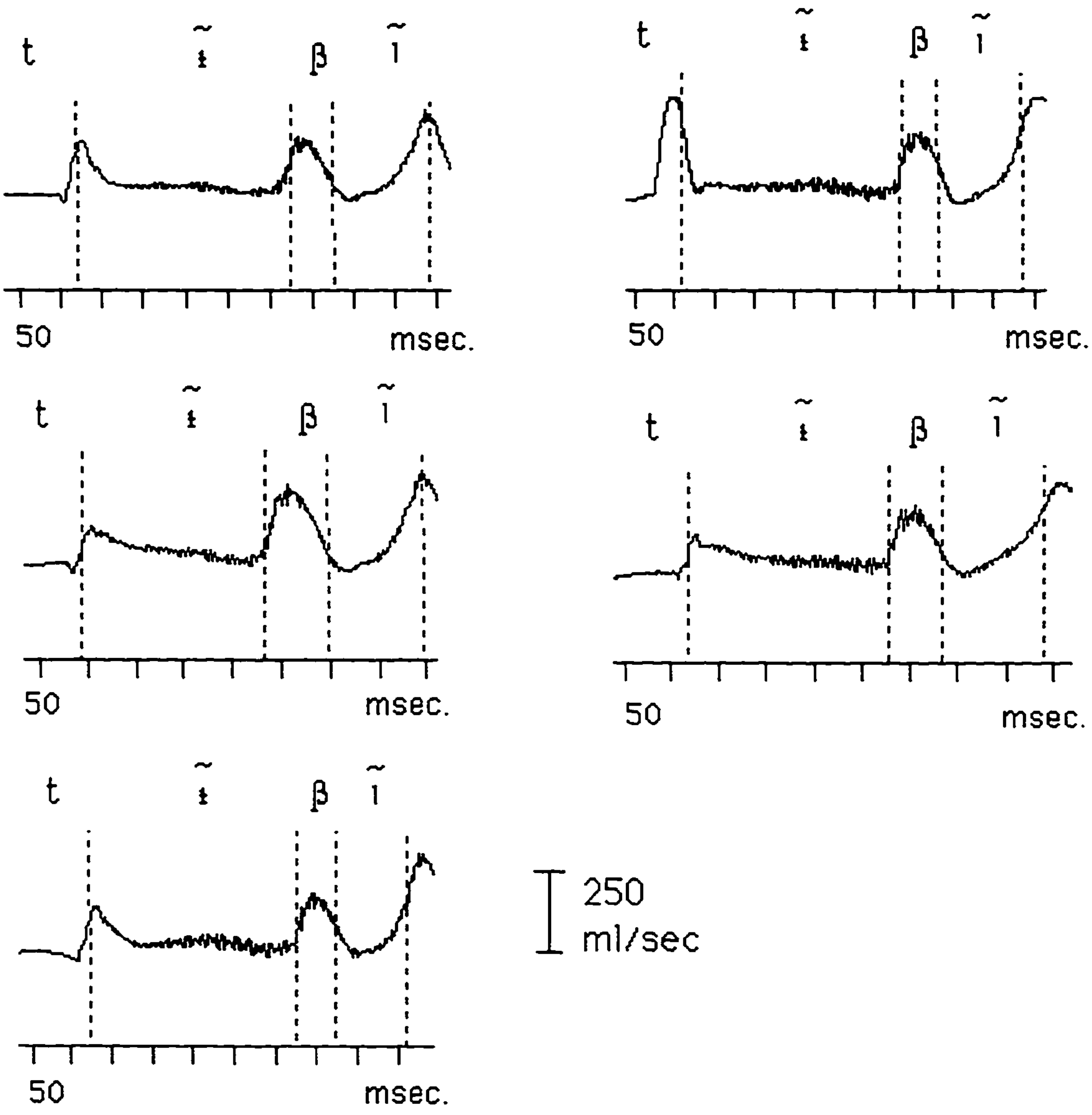




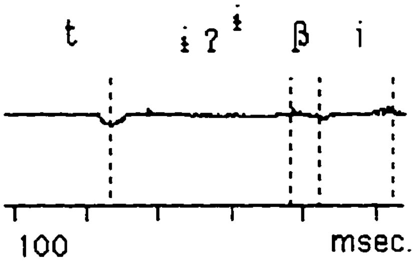


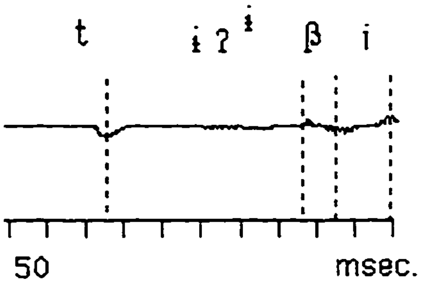


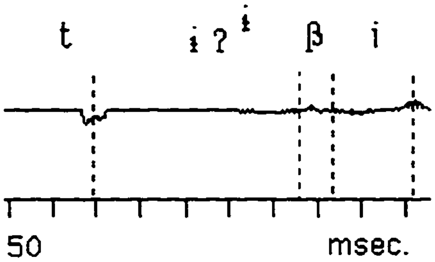
S2: [tĩβĩ] 'you (fam) will blow'

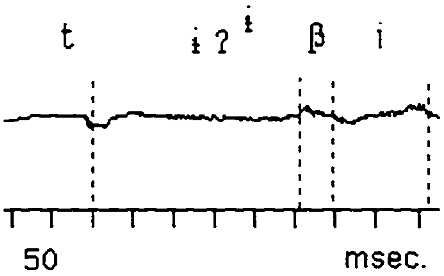


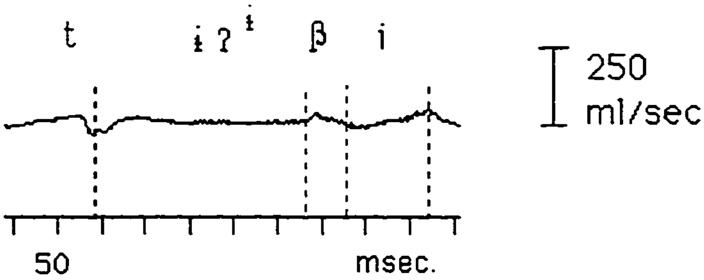
S2: [tɨʔ^{ɨ}βi] 'to push'



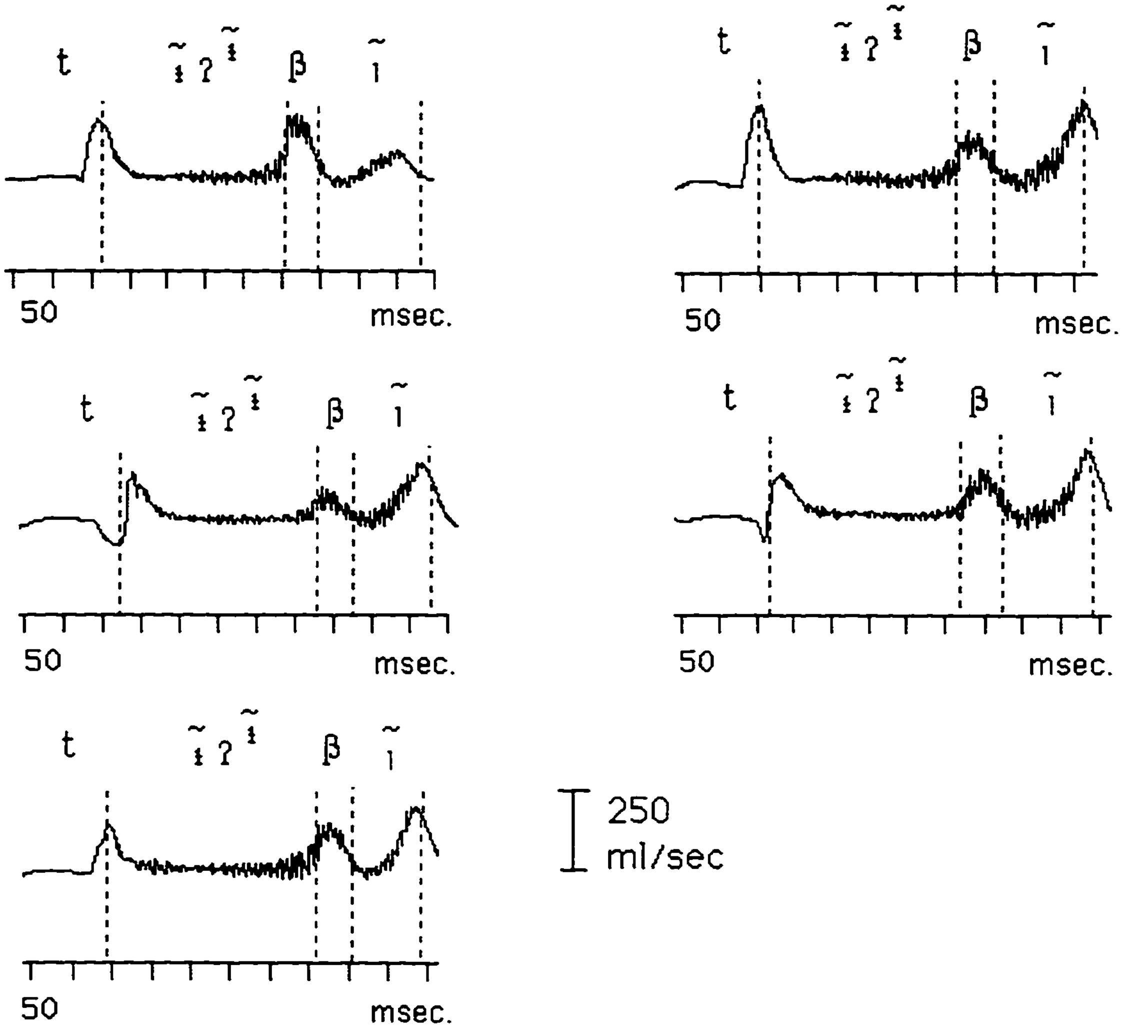




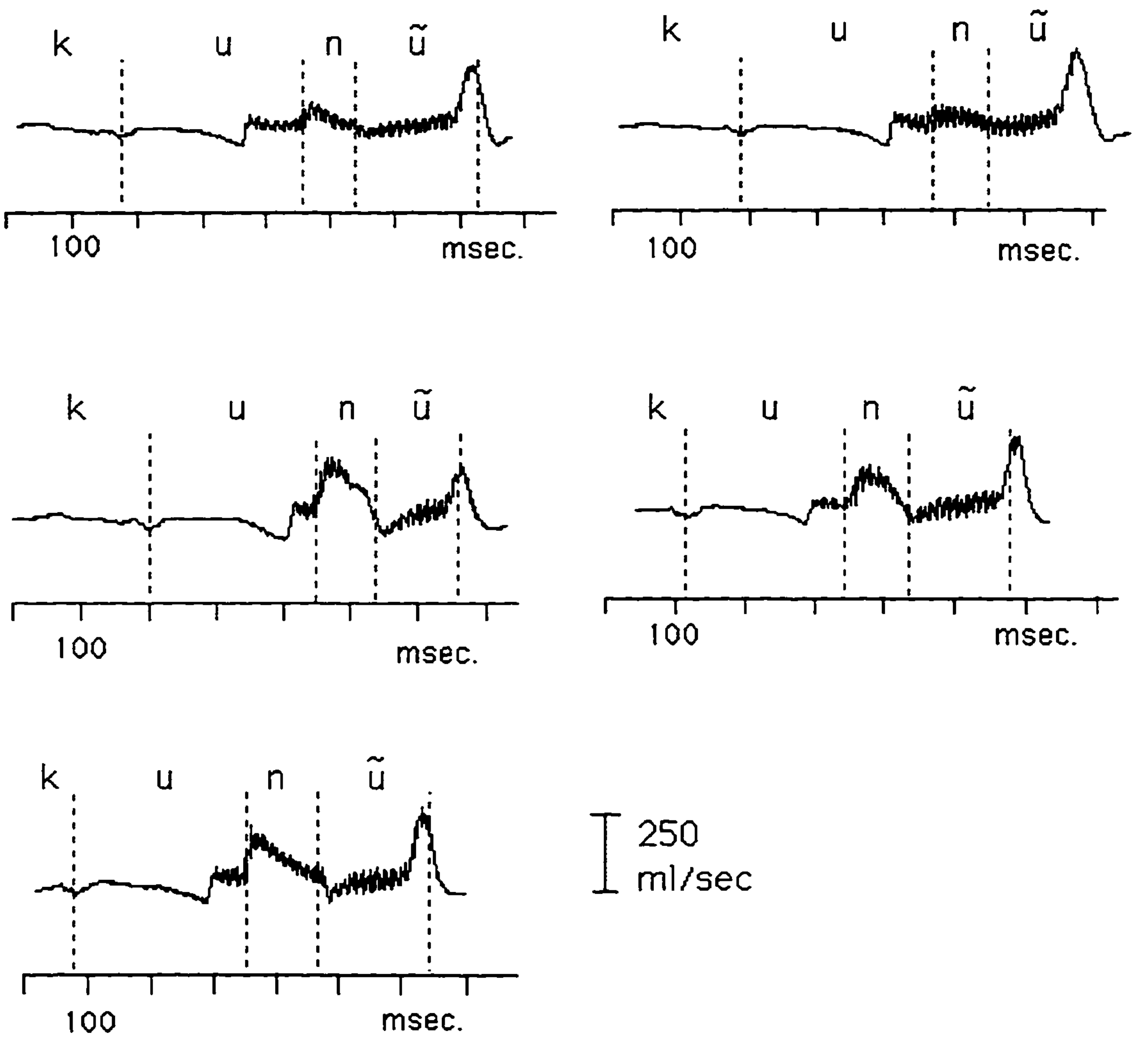




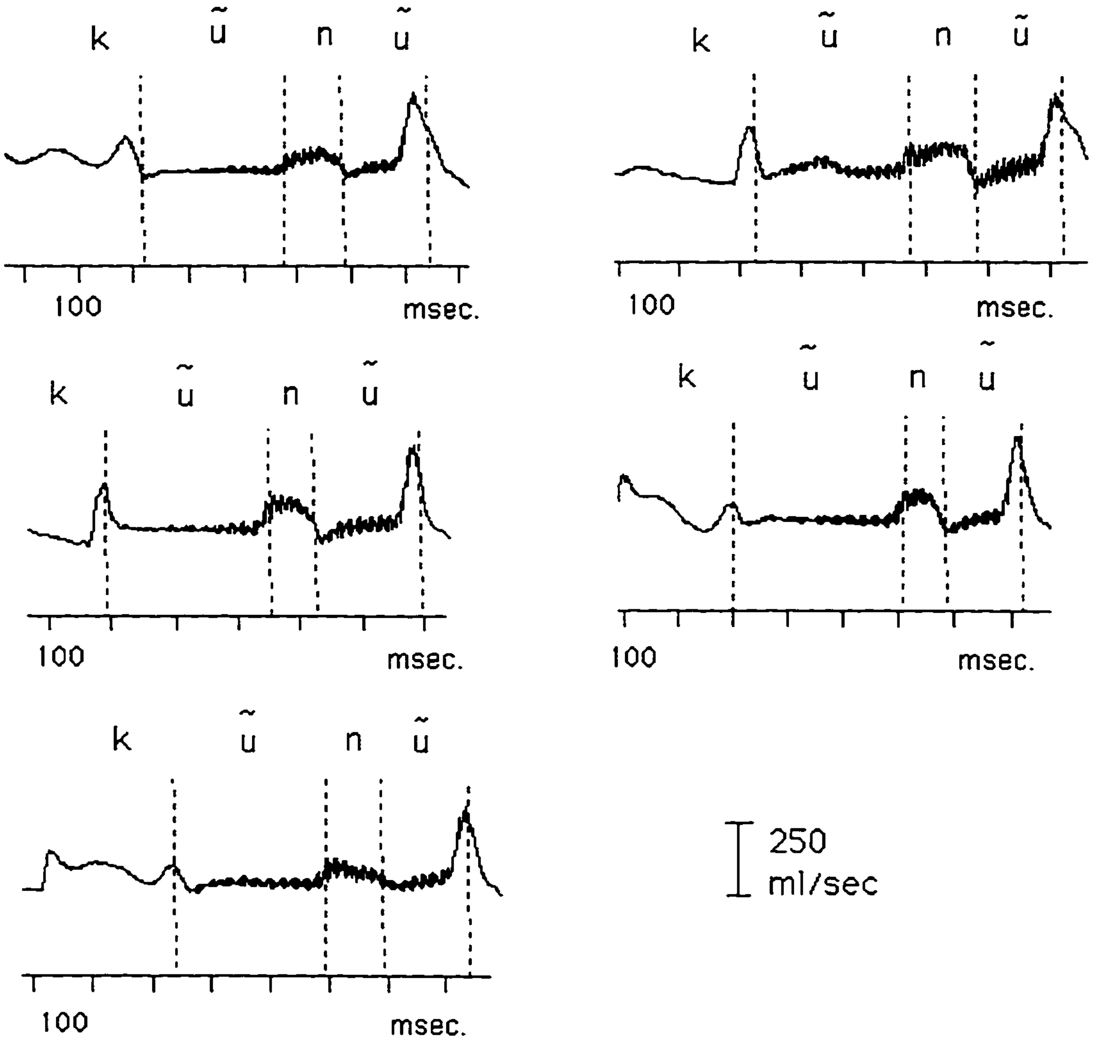
S2: [tĩʔ$^{\tilde{\imath}}$βĩ] 'you (fam) will push'



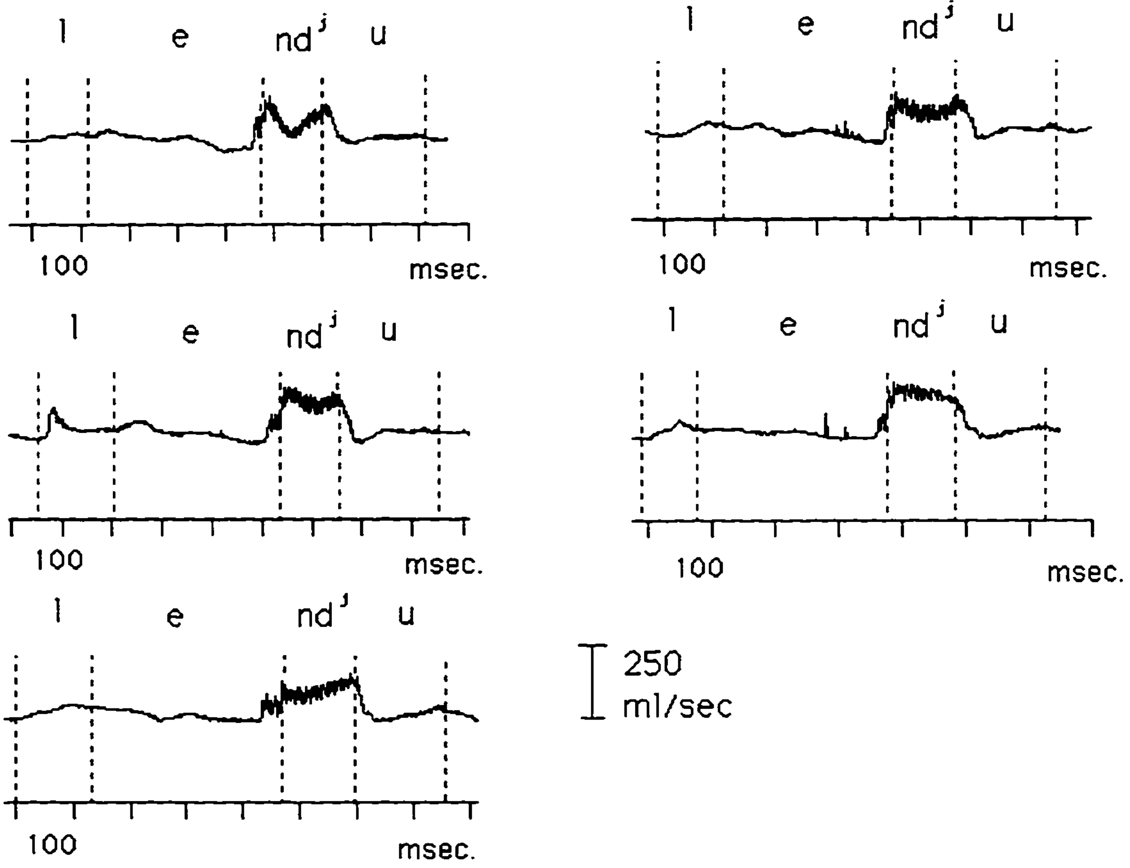
S2: [kunũ] 'to run'



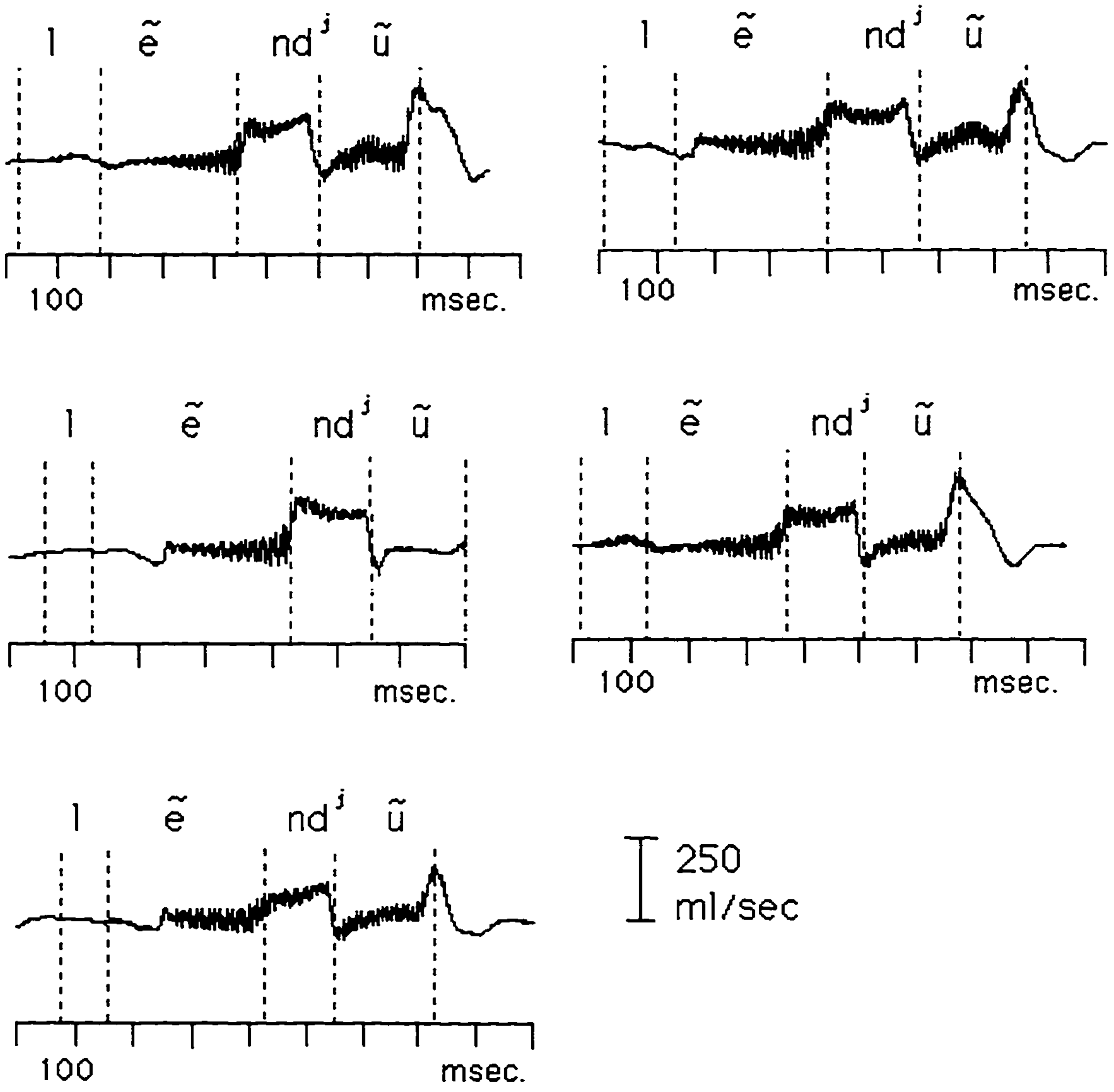
S2: [kũnũ] 'you (fam) will run'



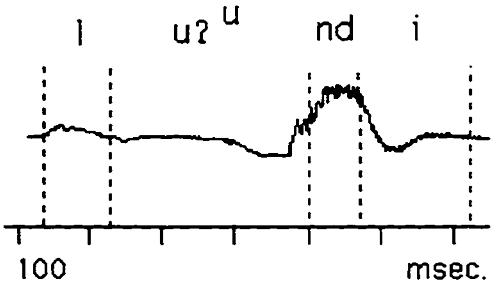
S2: [lendʲu] 'dirty'

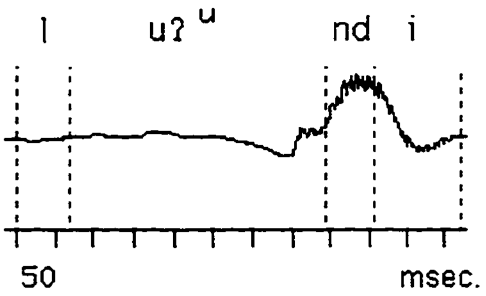


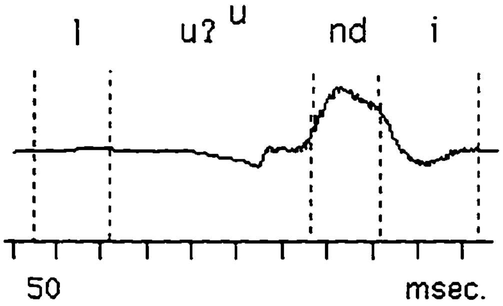
S2: [lẽndʲũ] 'you (fam) are dirty'

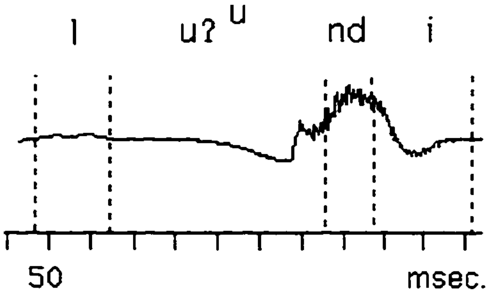


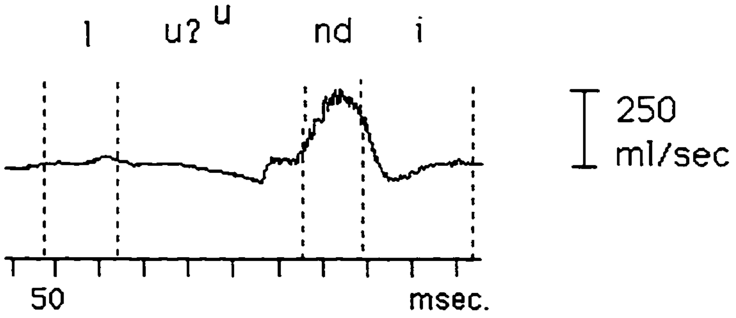
S2: [luʔᵘndi] 'small'



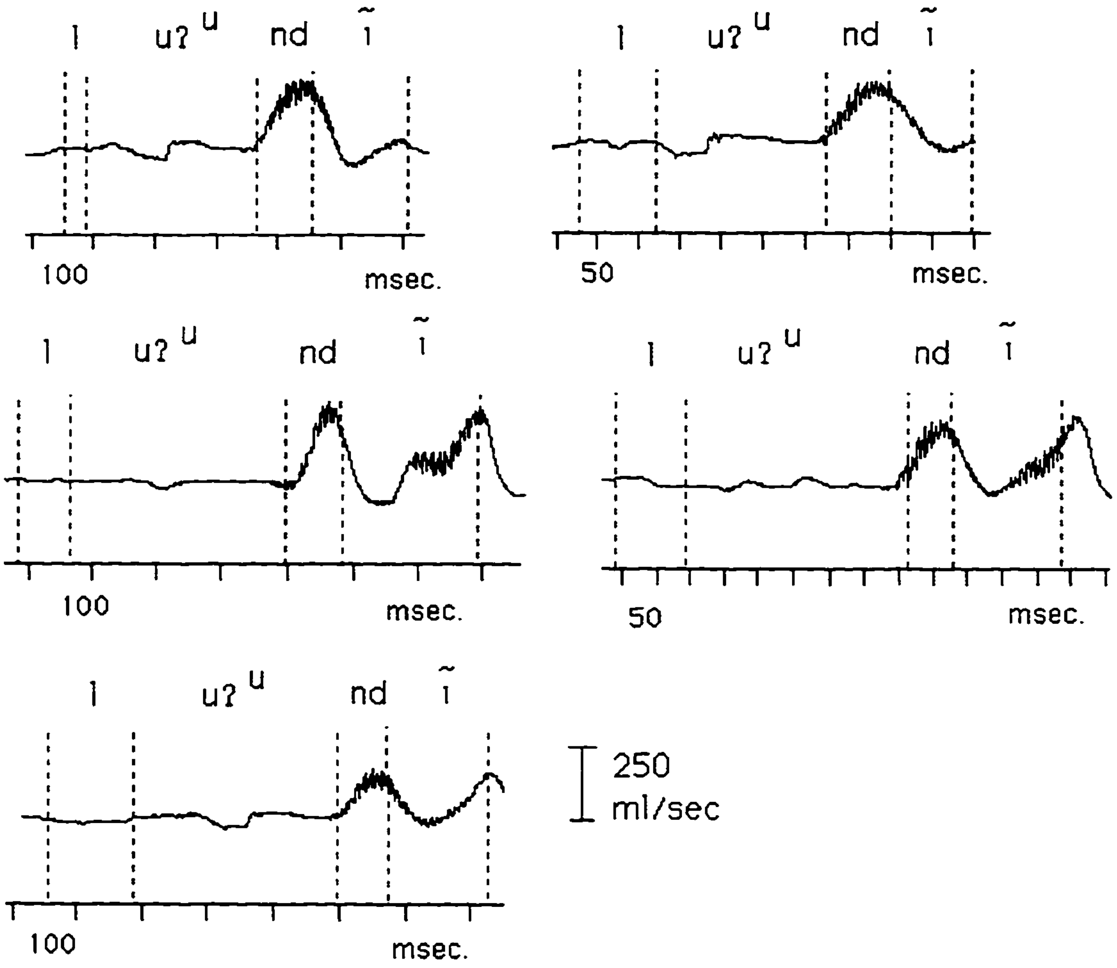




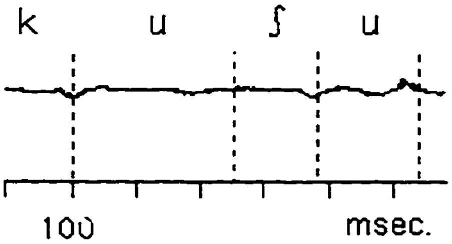


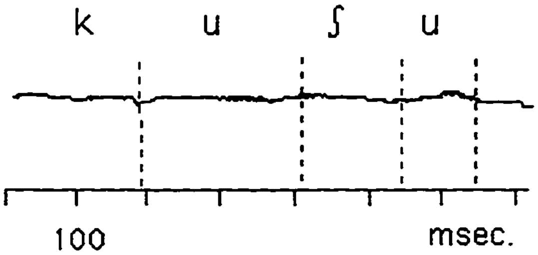


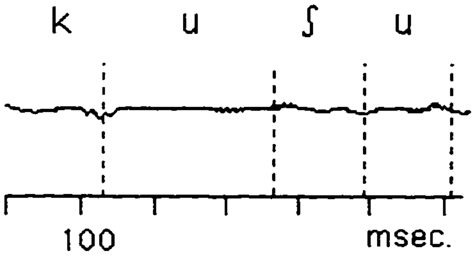
S2: [luʔ^{u}ndĩ] 'you (fam) are small'

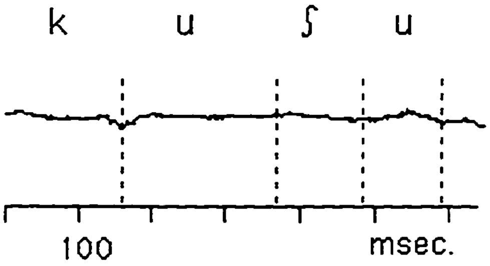


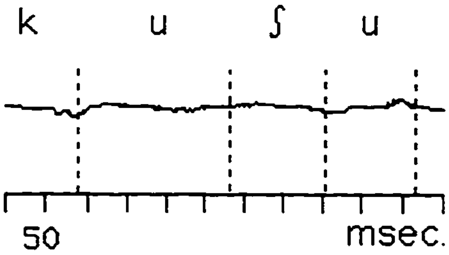
S2: [kuʃu] 'diligent'

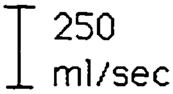




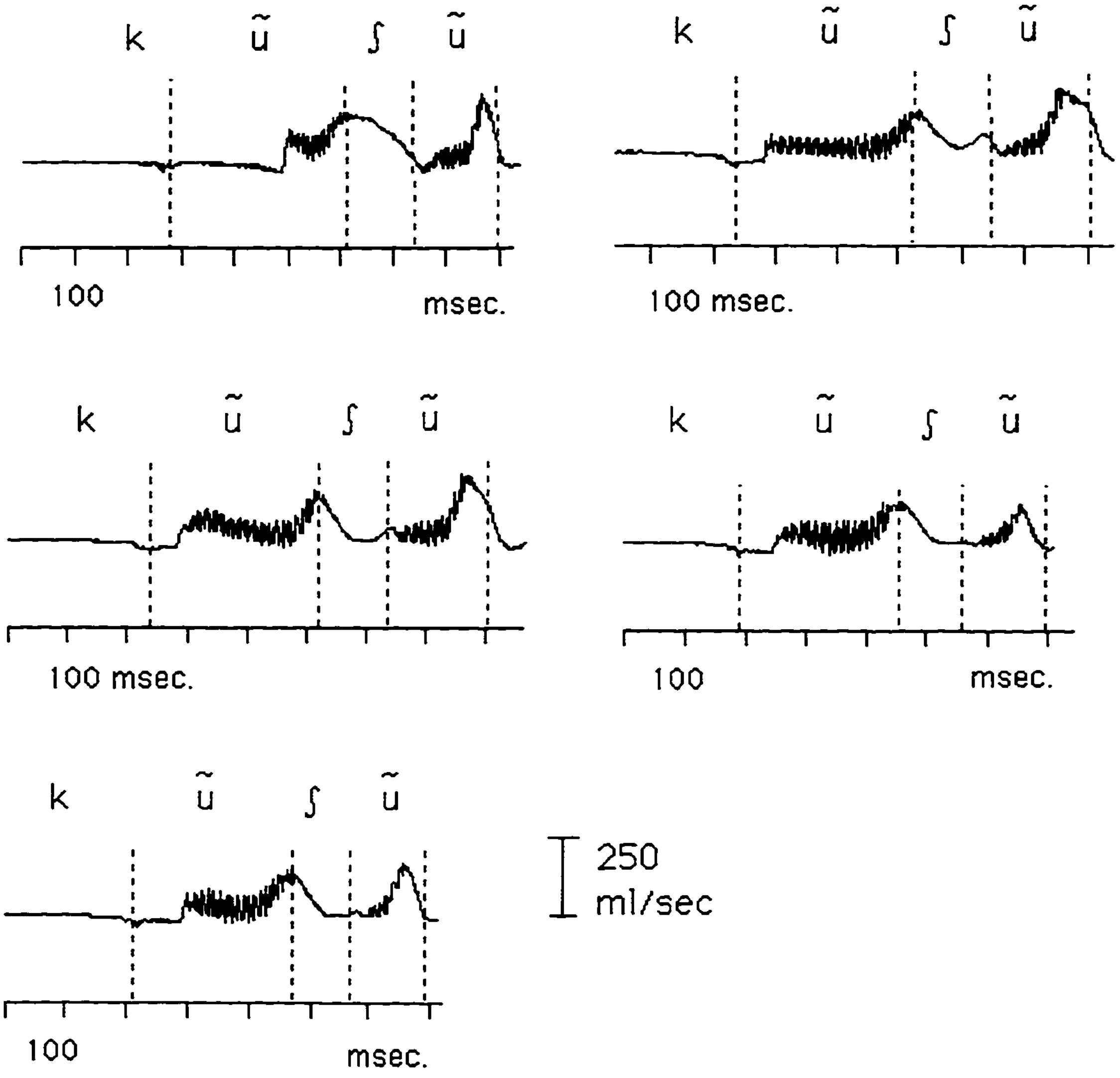




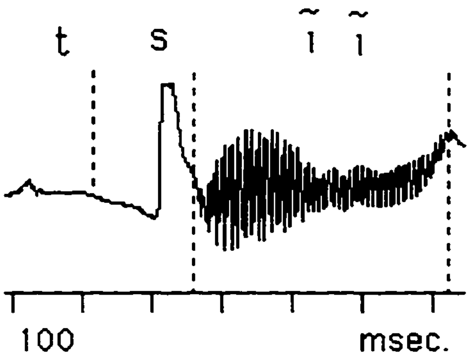


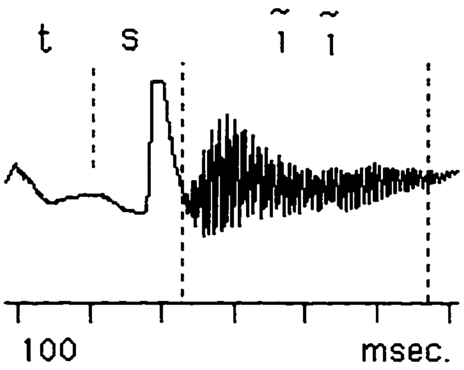


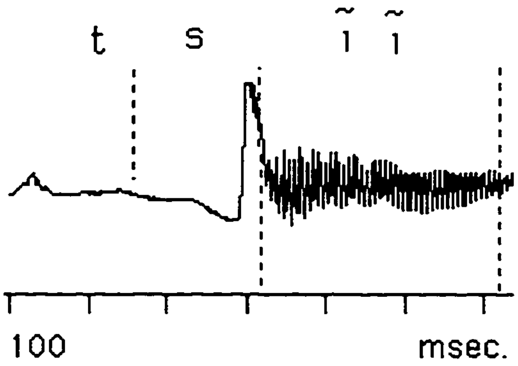
S2: [kũʃũ] 'you (fam) are diligent'

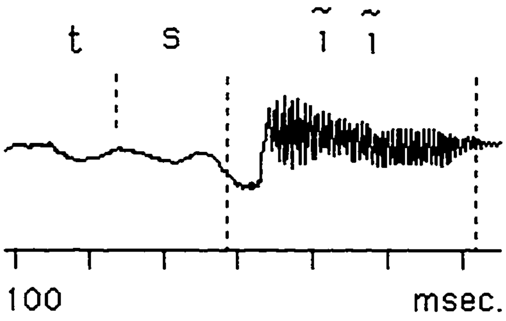


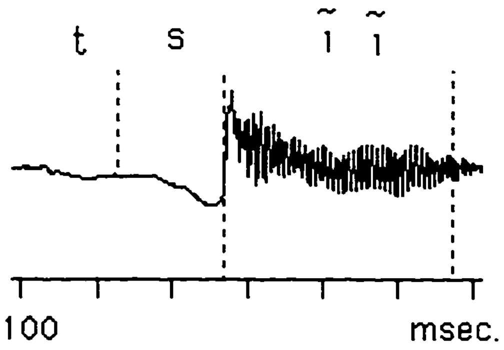
S3: [tsĩĩ] 'nail (fingernail)'

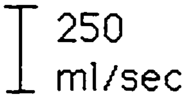




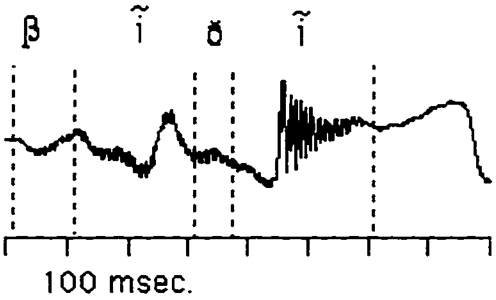


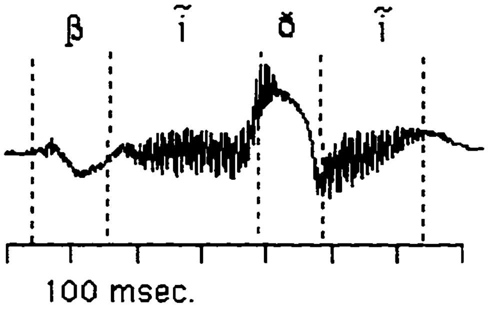


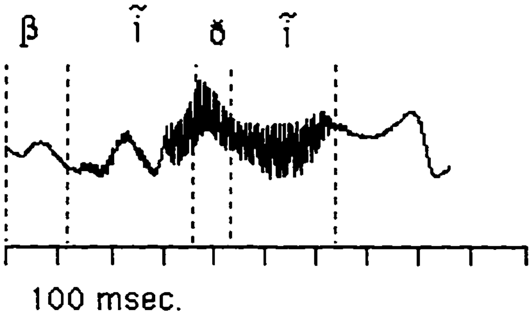


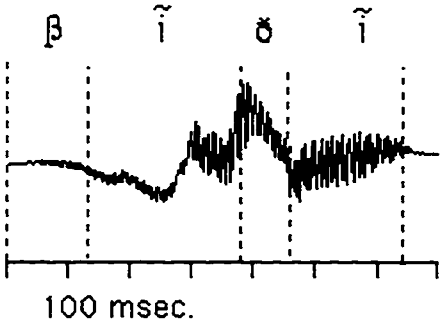


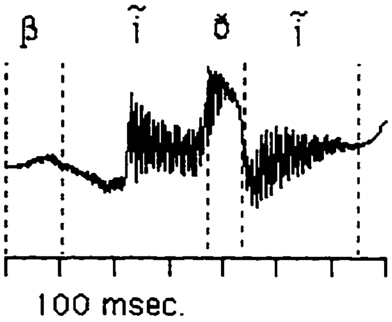
S3: [βĩðĩ] 'sweet'

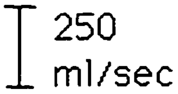




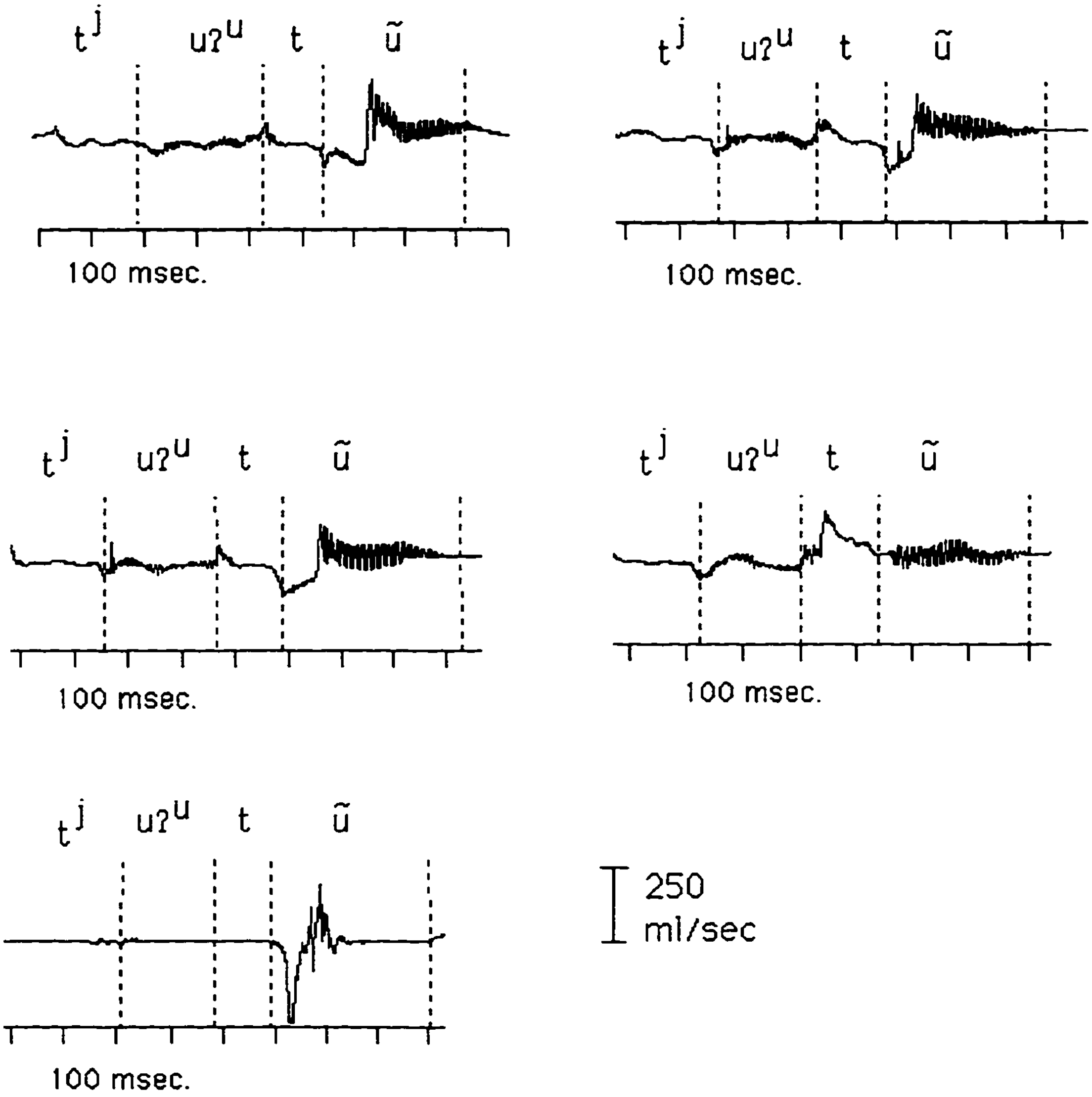




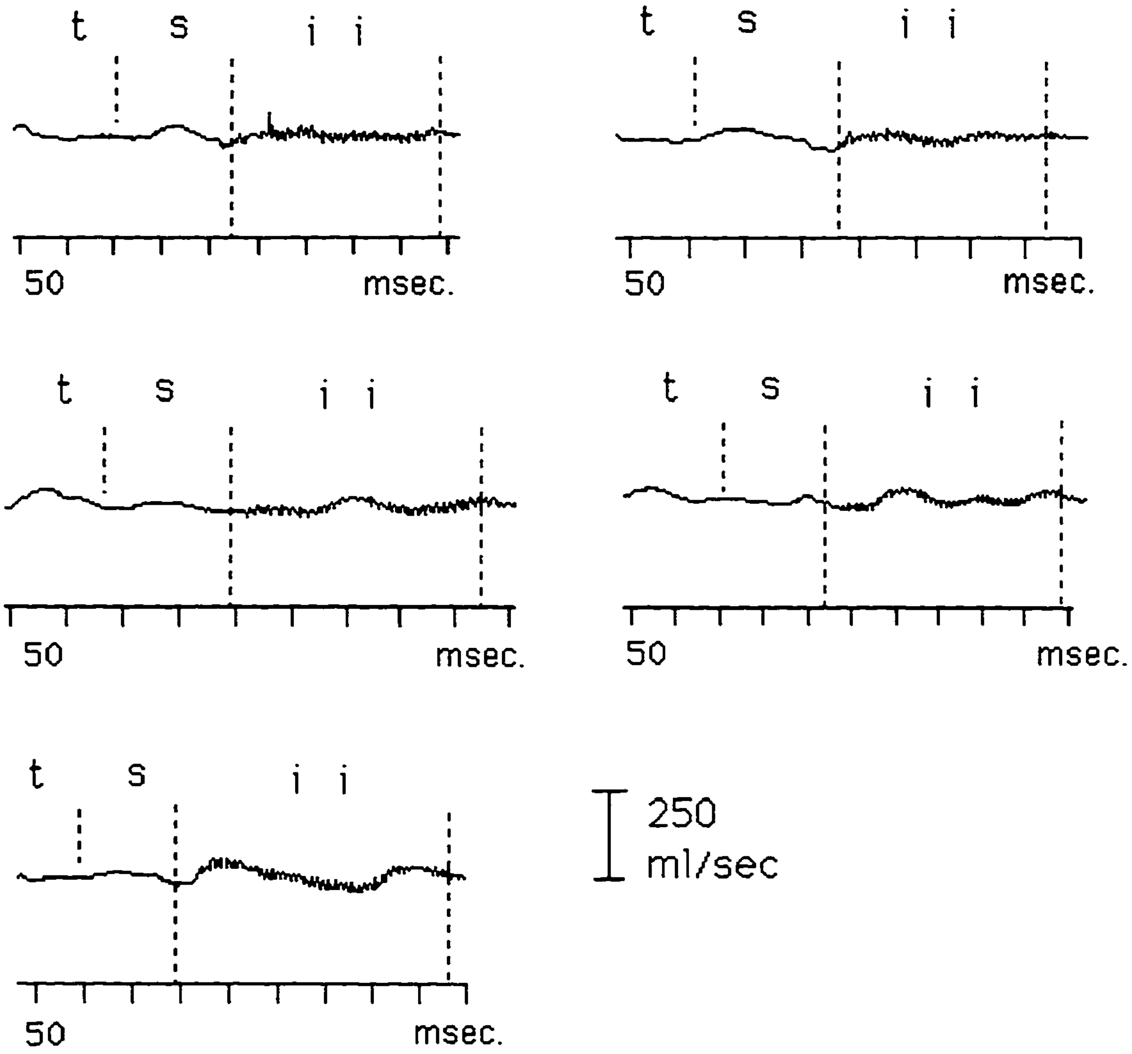




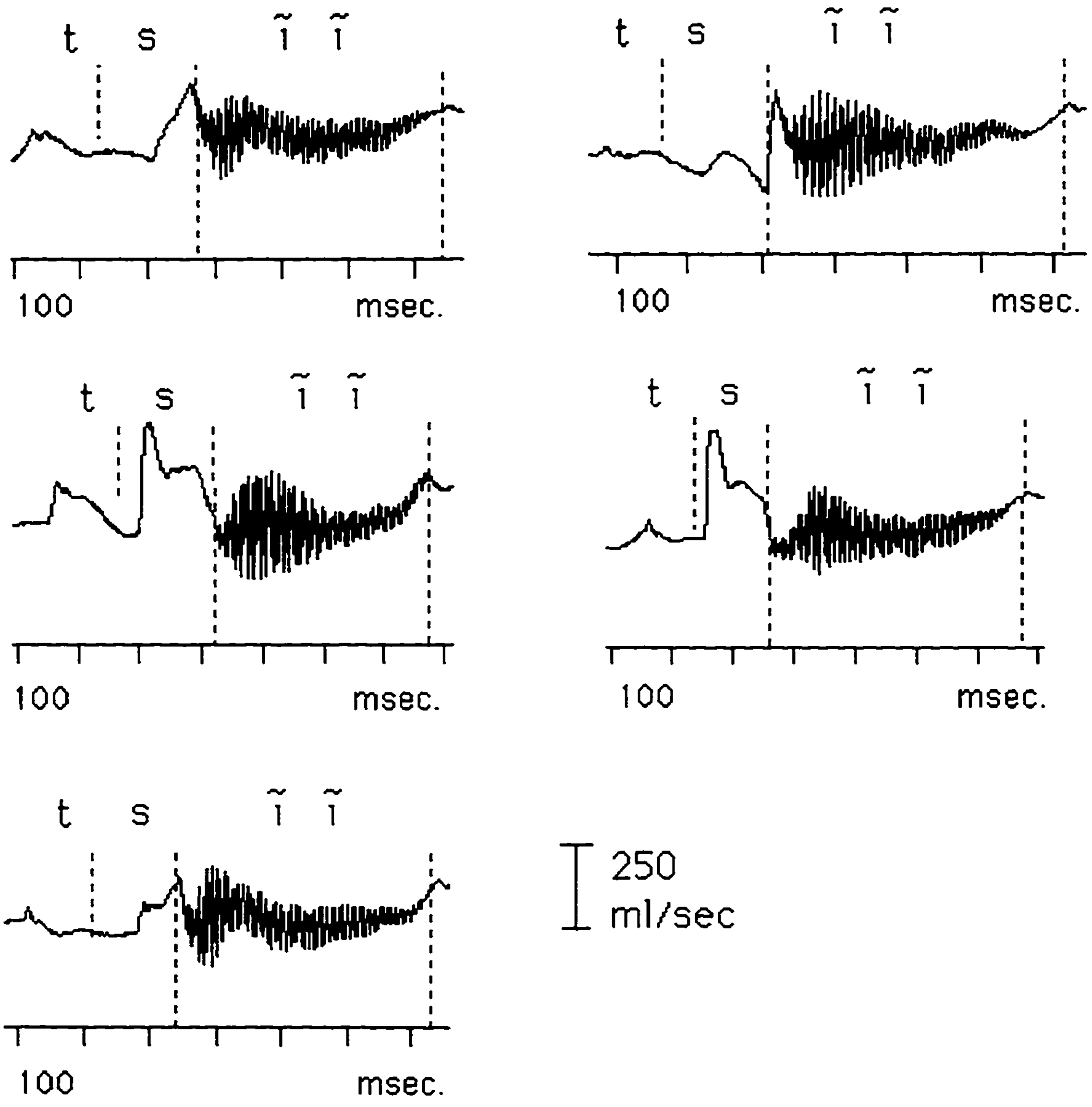
S3: [tʲuʔᵘtũ] 'firewood'



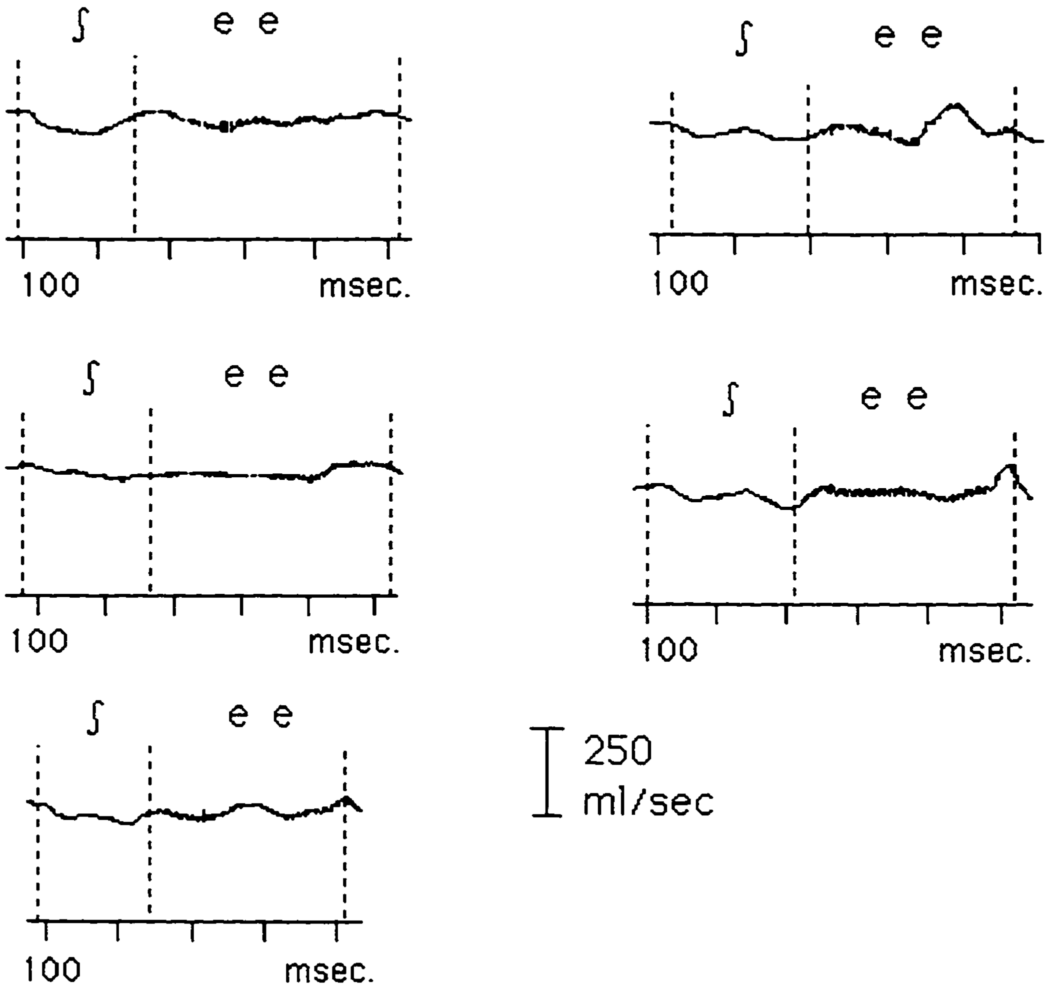
S3: [tsii] 'to get wet'



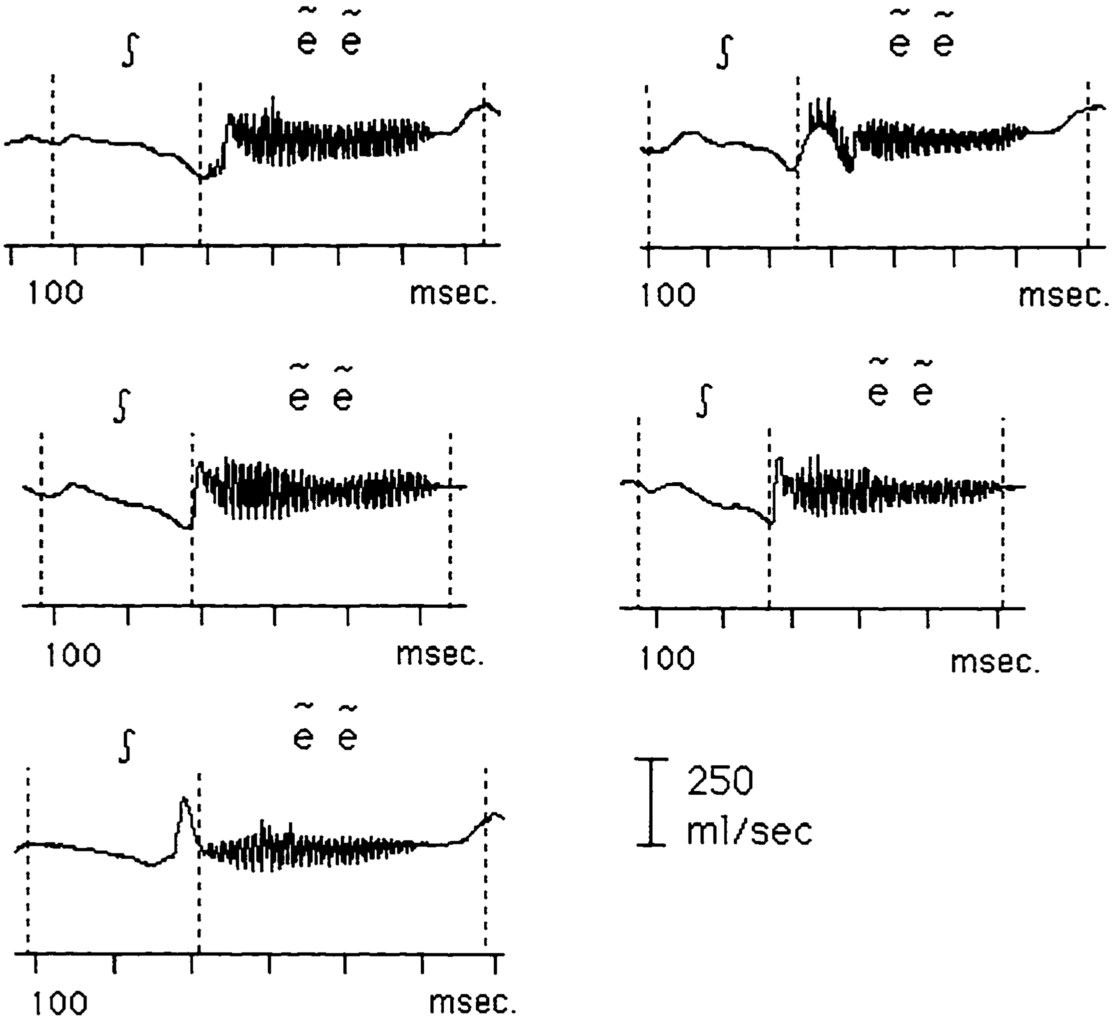
S3: [tsĩĩ] 'you (fam) get yourself wet'



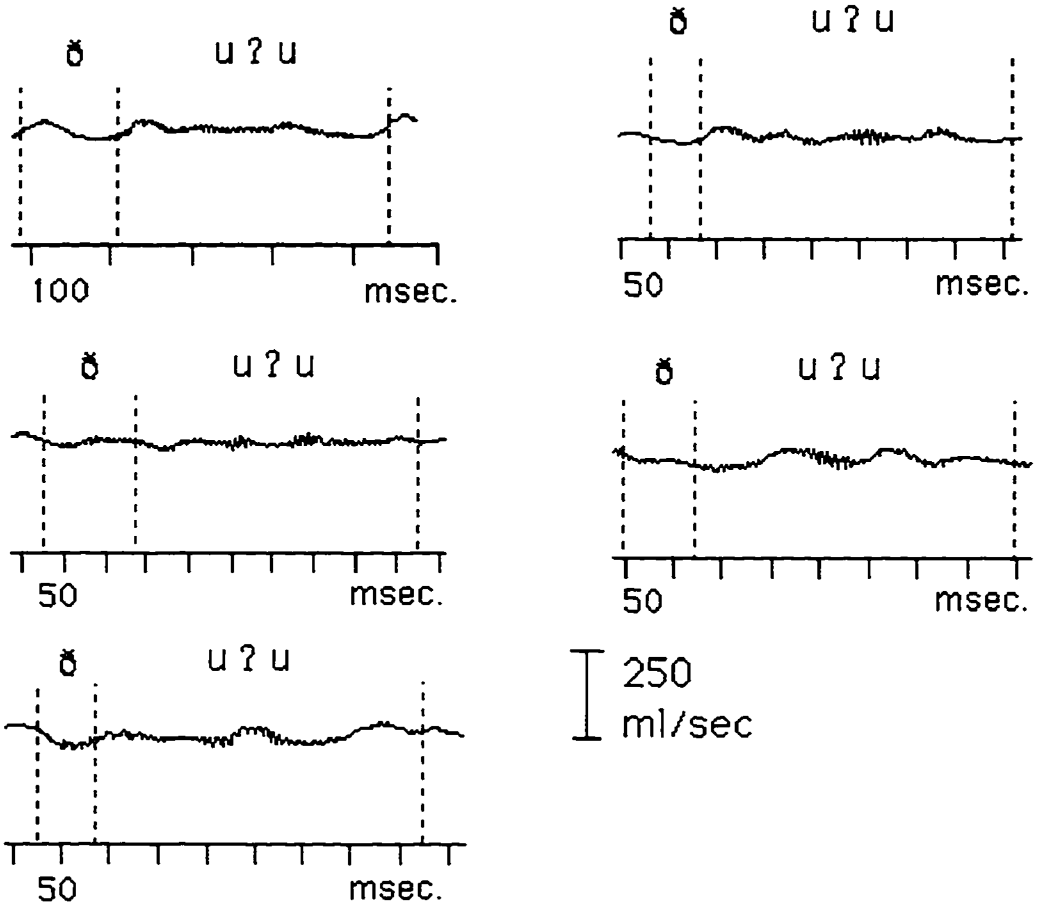
S3: [ʃee] 'to arrive'



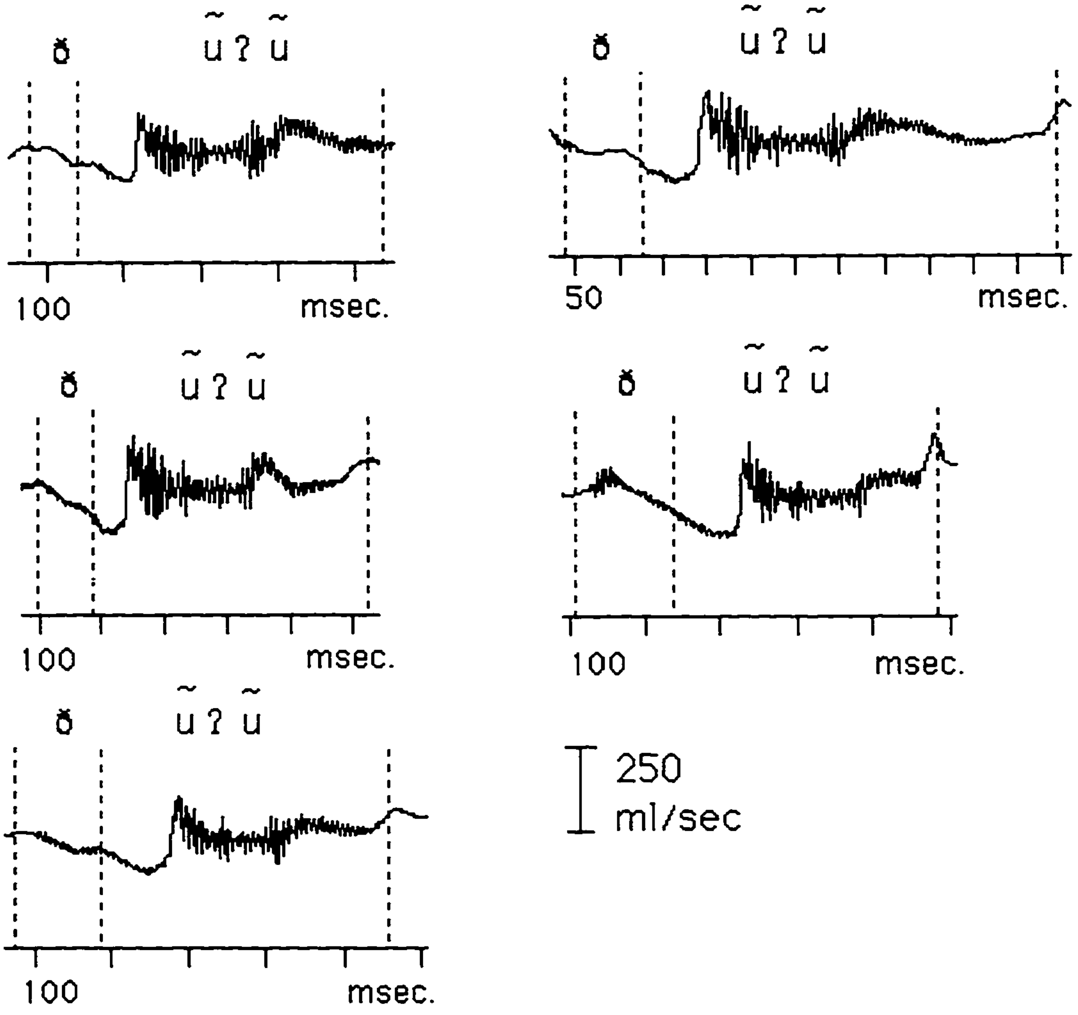
S3: [ʃẽẽ] 'you (fam) arrived'



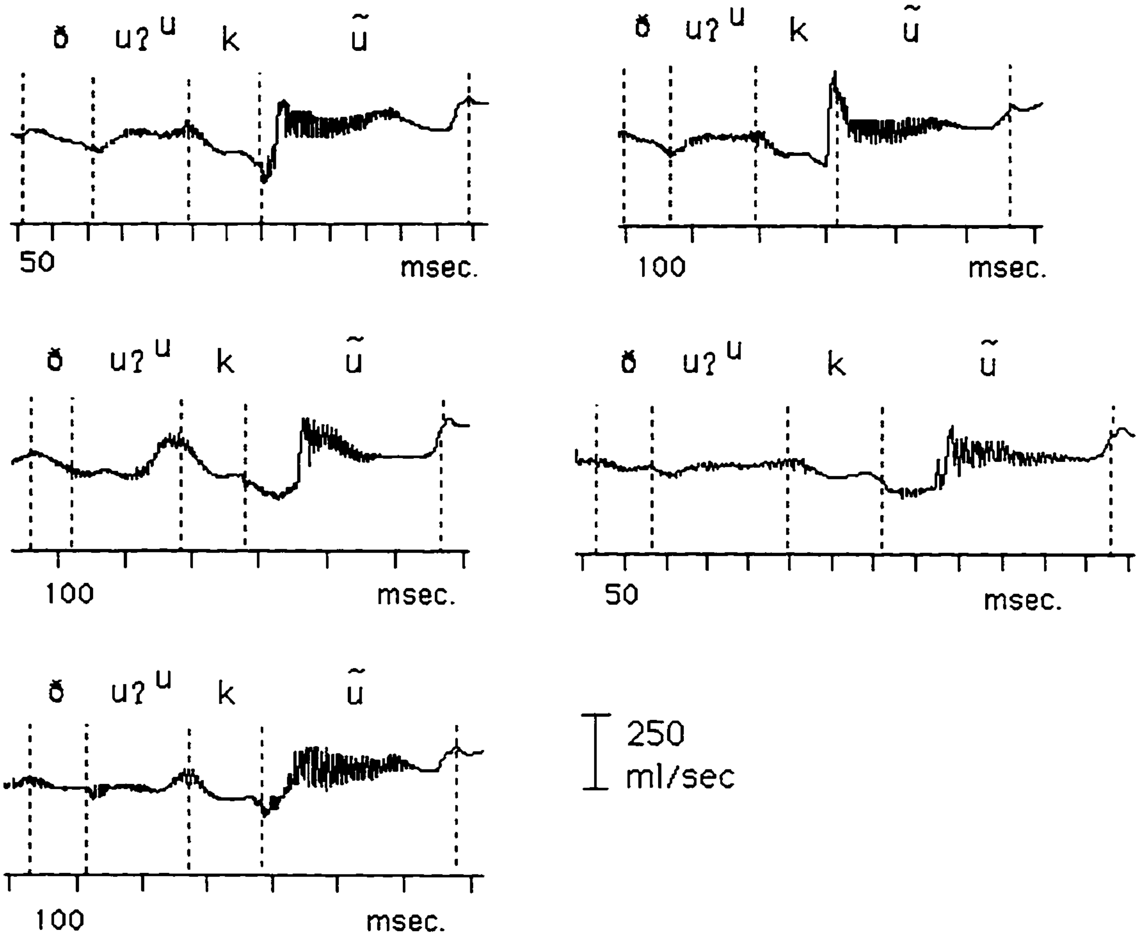
S3: [ðuʔu] 'to rob, steal'



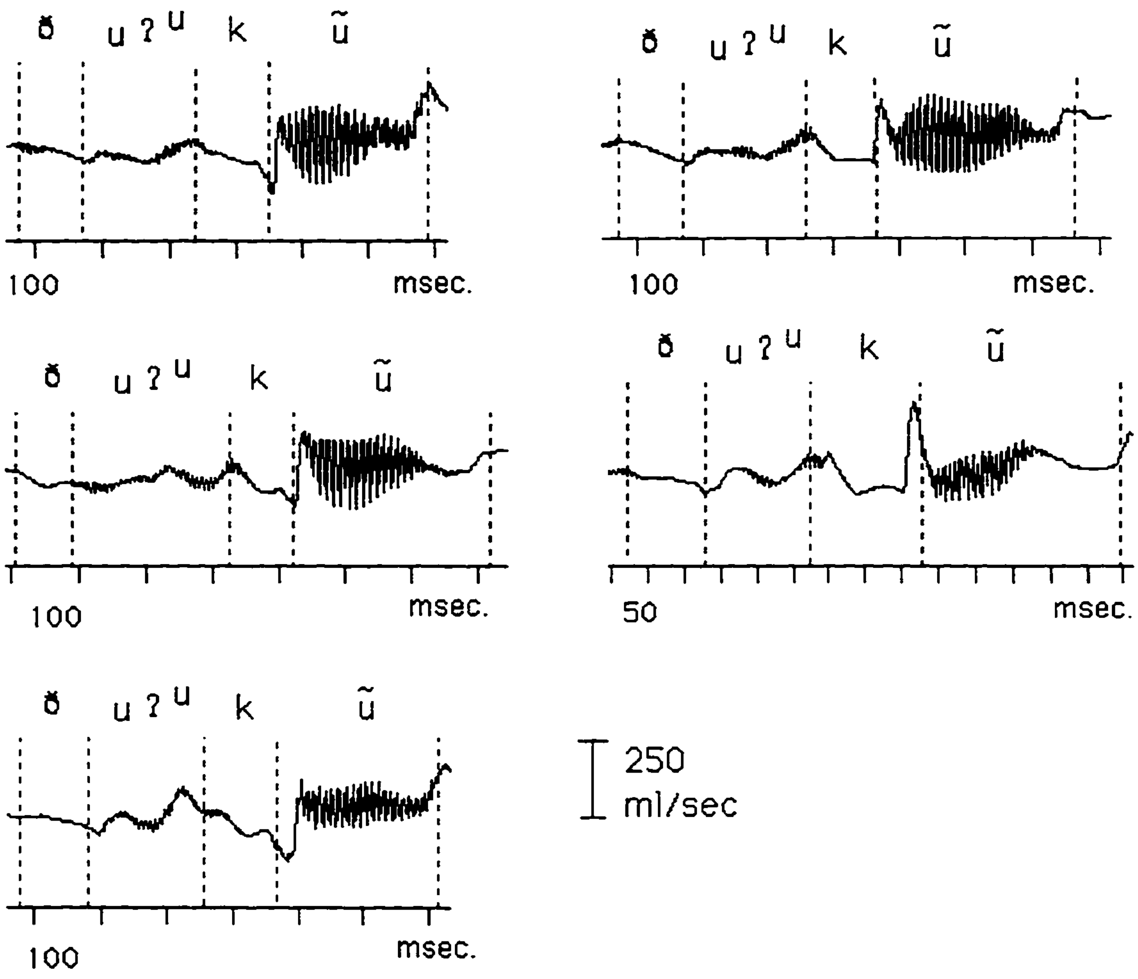
S3: [ðũʔũ] 'you (fam) will rob'



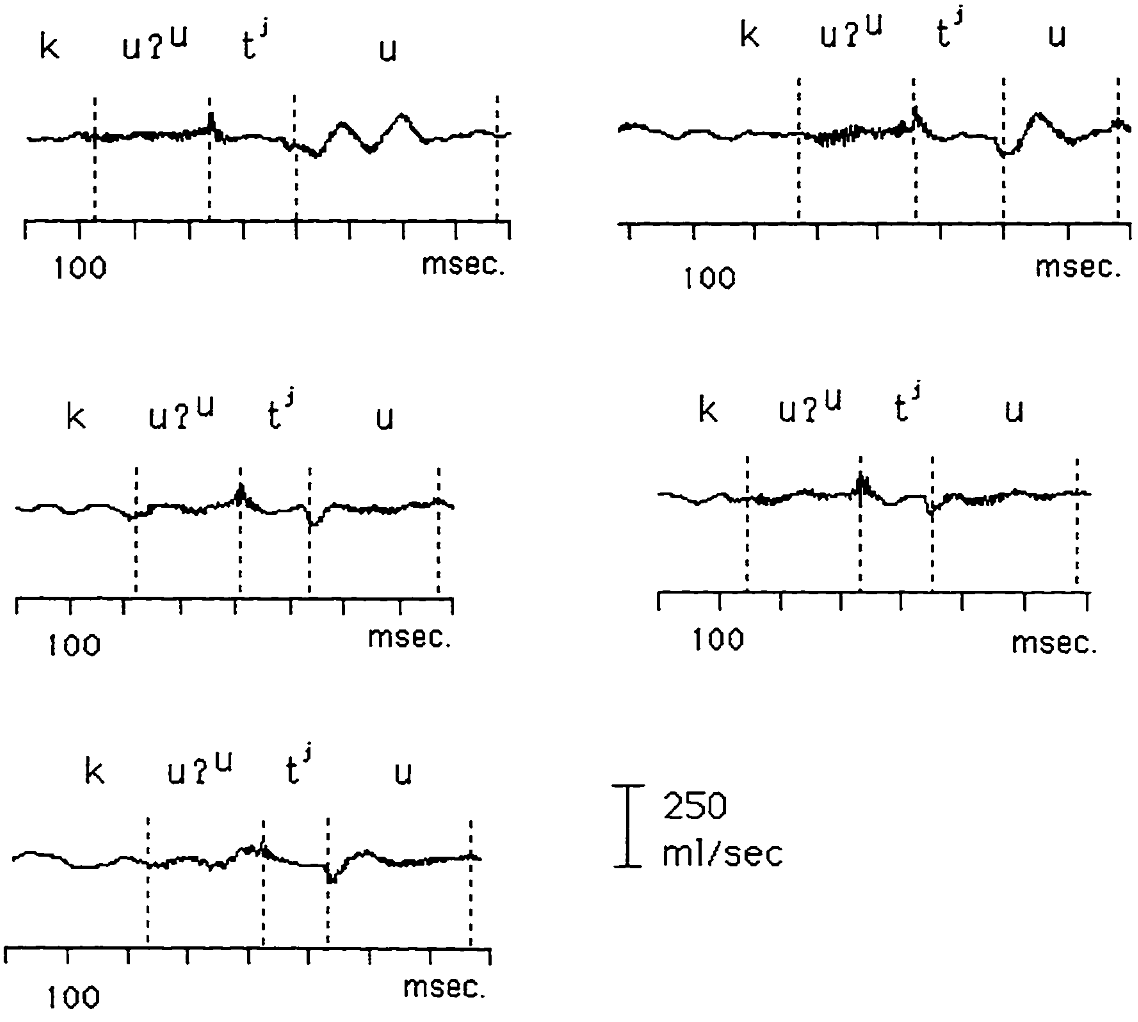
S3: [ðuʔ^{u}kũ] 'tall'



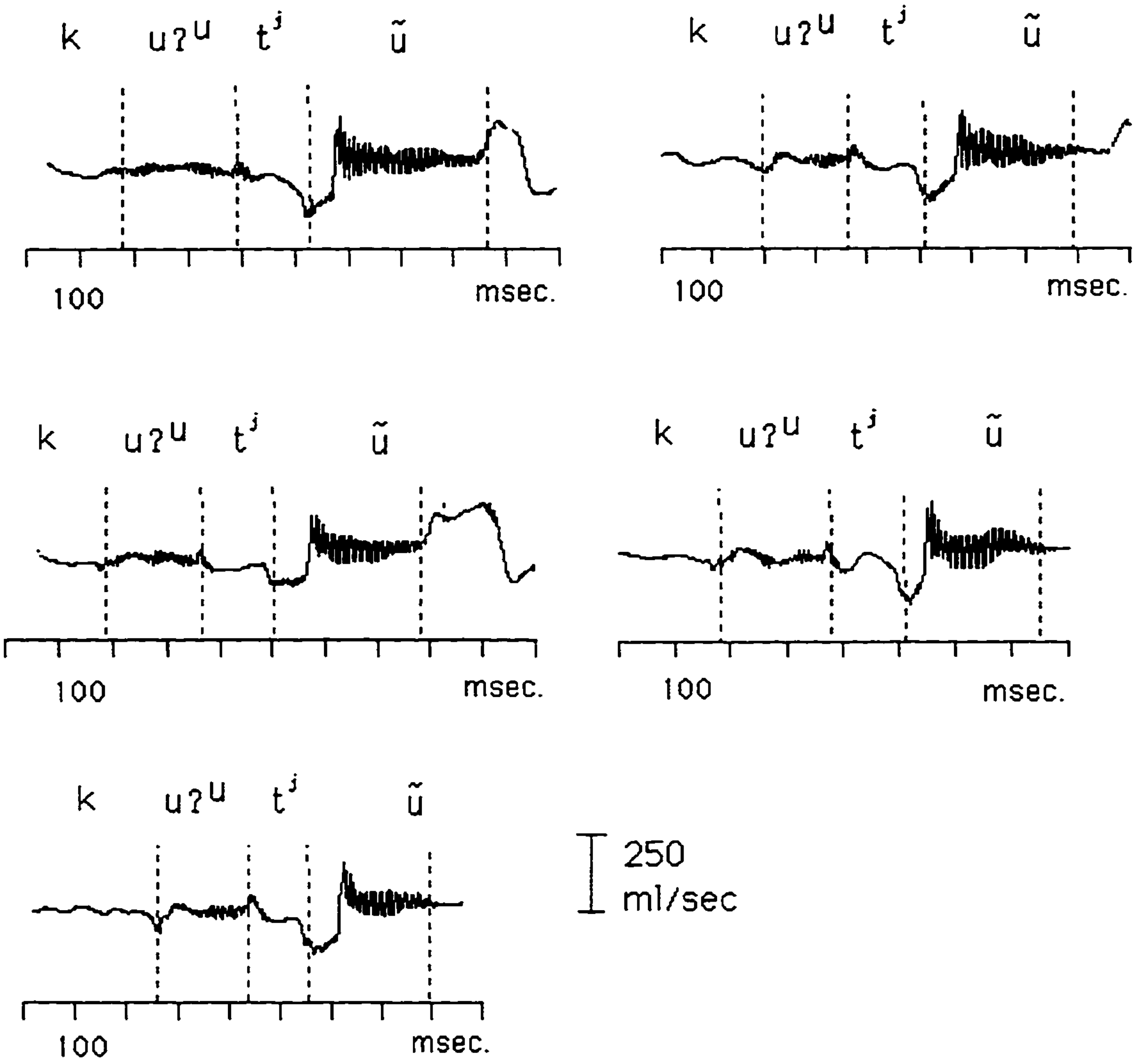
S3: [ðuʔ^{u}kũ] 'you (fam) are tall'



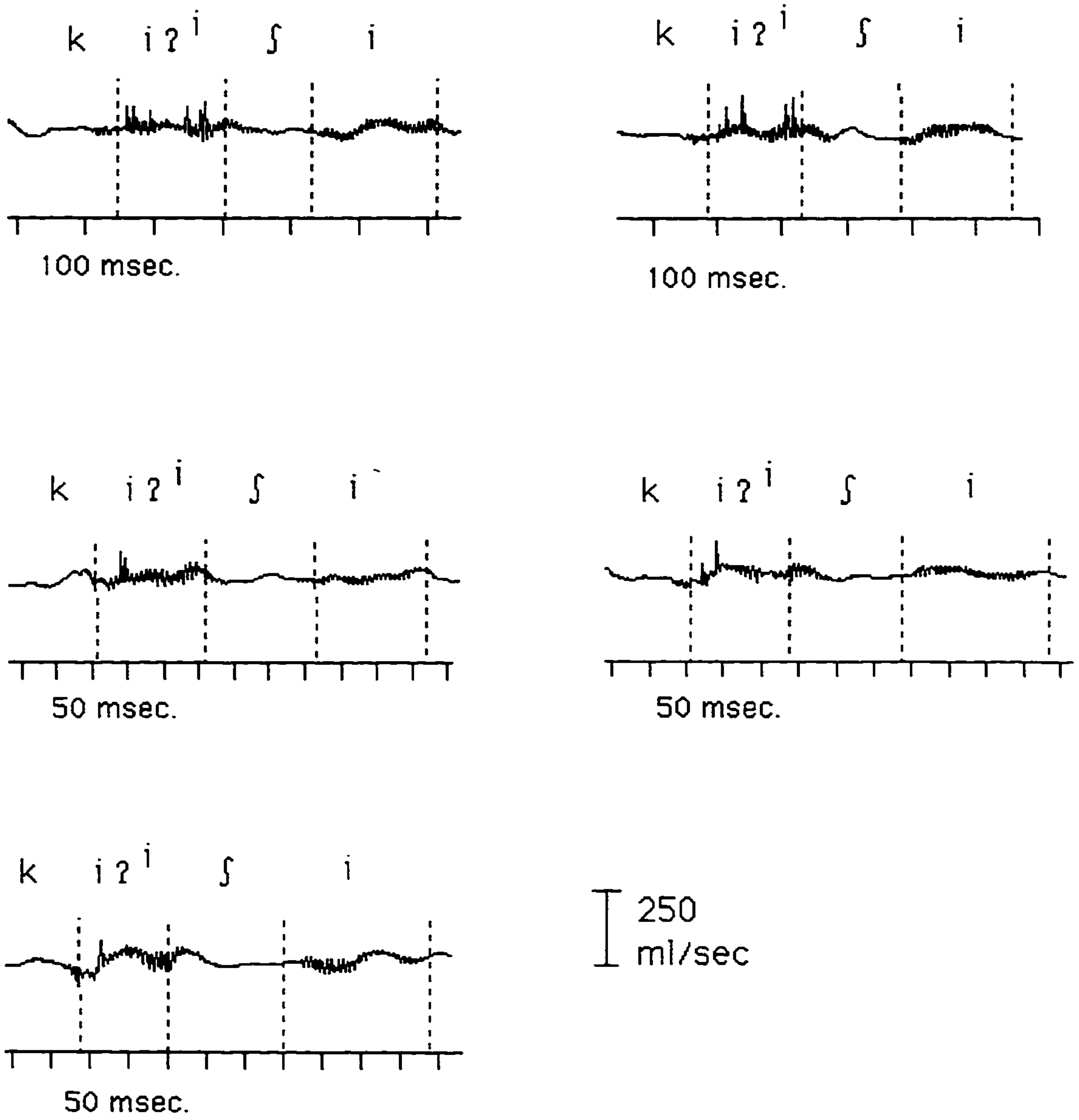
S3: [kuʔ^{u}t^{j}u] 'to plow, hoe'



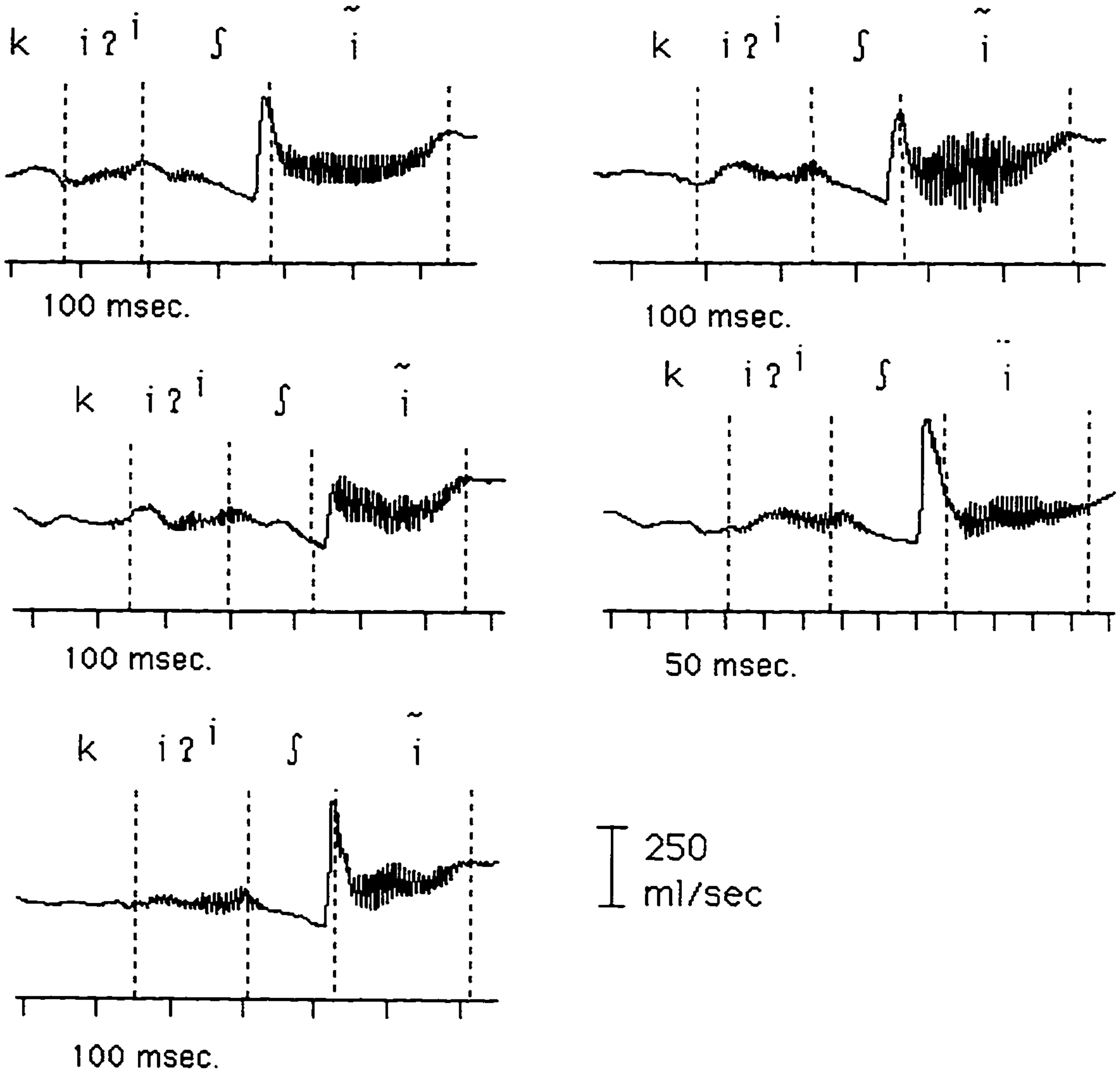
S3: [kuʔᵘtʲũ] 'you (fam) will plow'



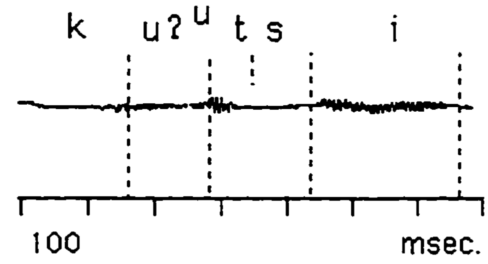
S3: [kiʔ^{i}ʃi] 'to come'

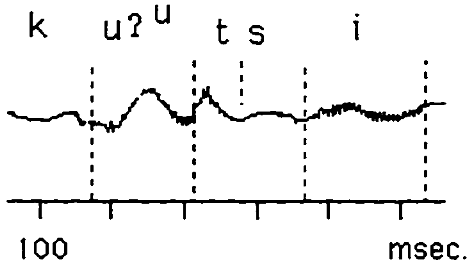


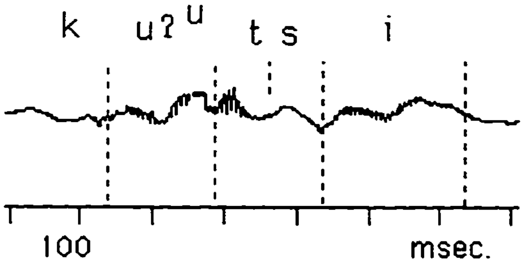
S3: [kiʔ^{i}ʃĩ] 'you (fam) will come'

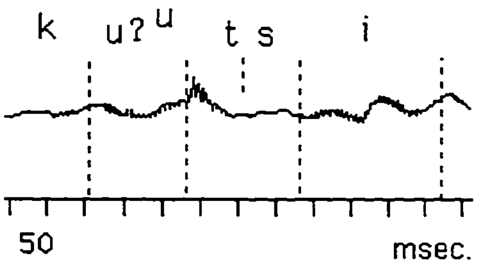


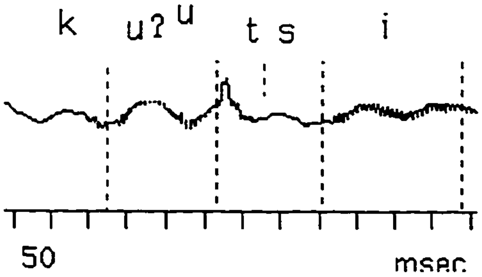
S3: [kuʔ^{u}tsi] 'to bathe'

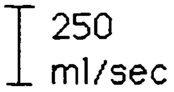




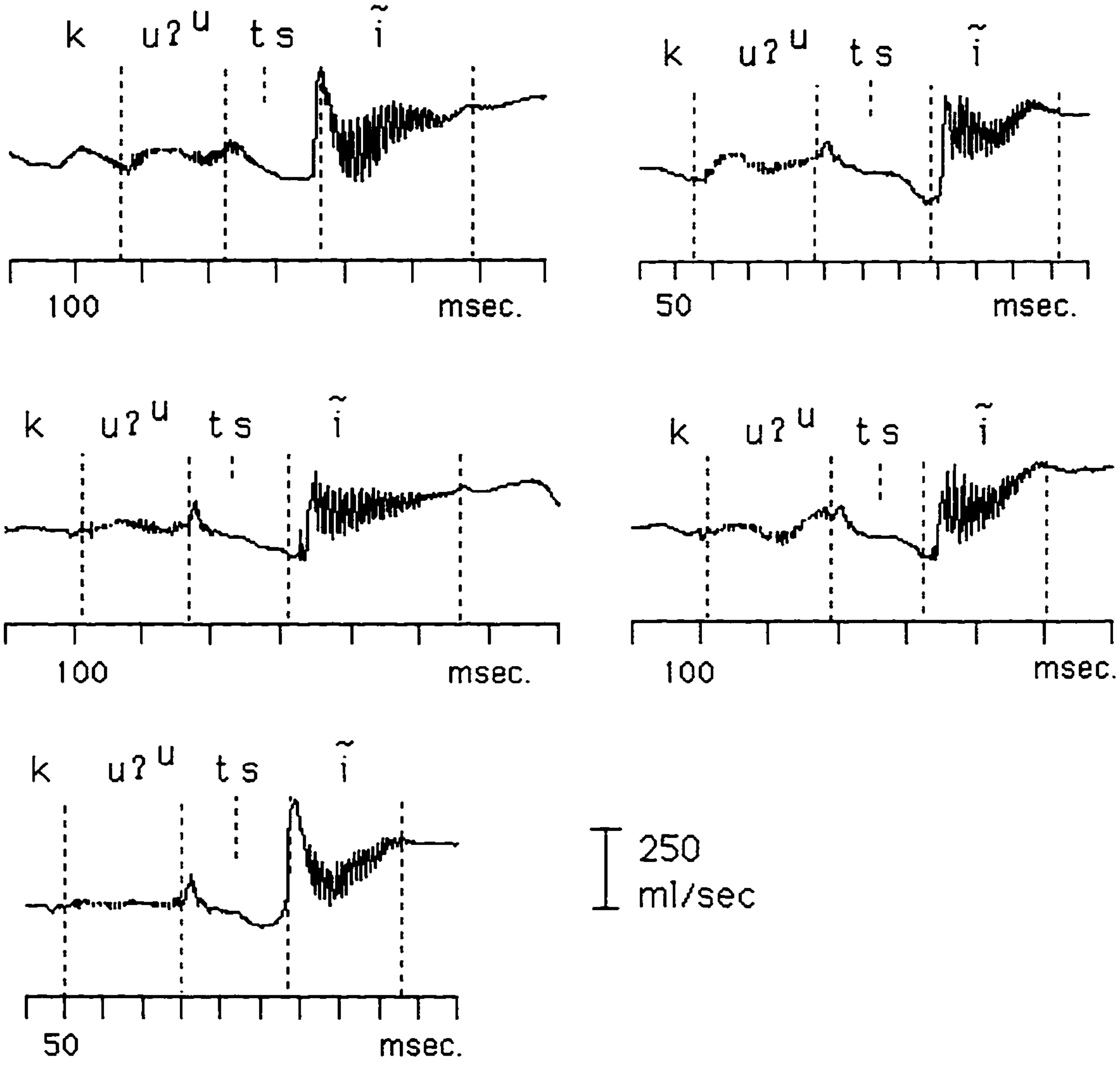




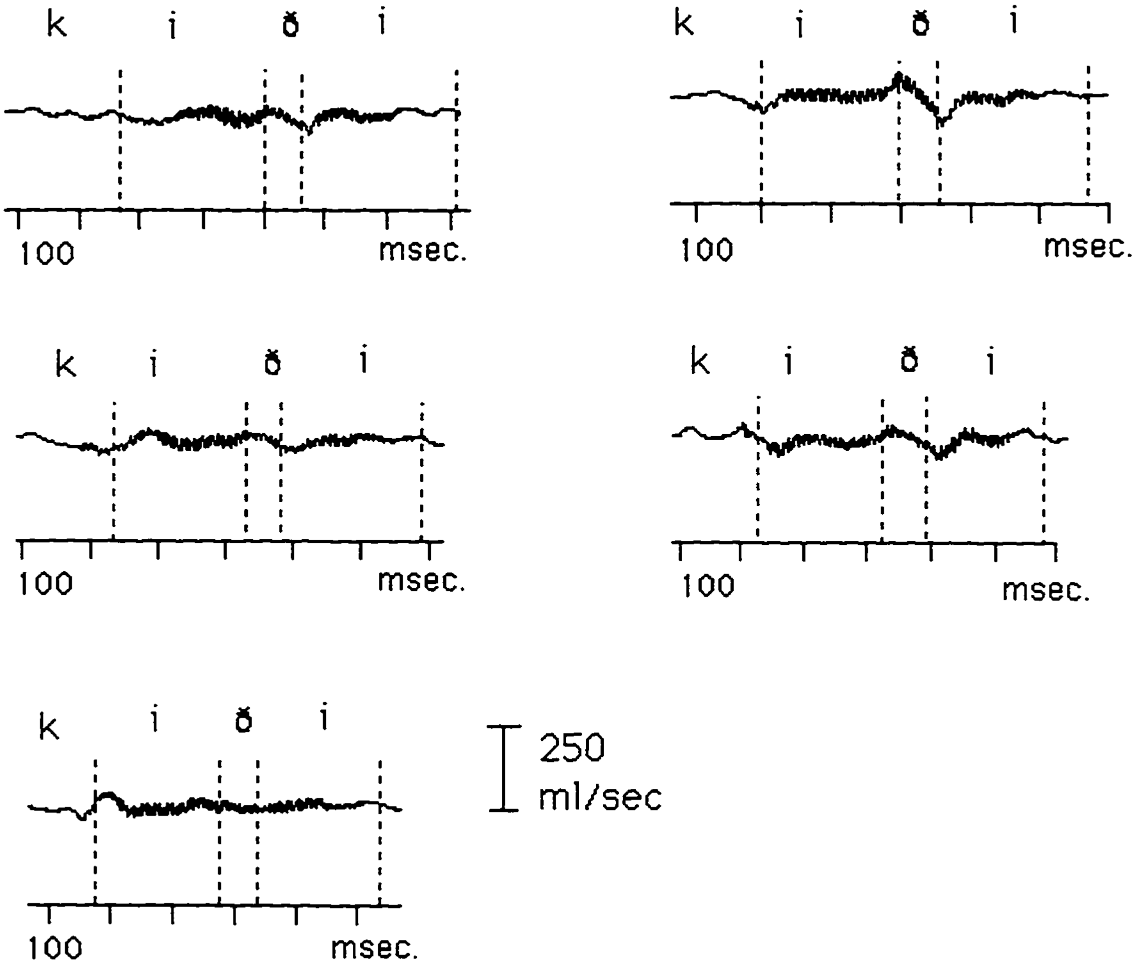




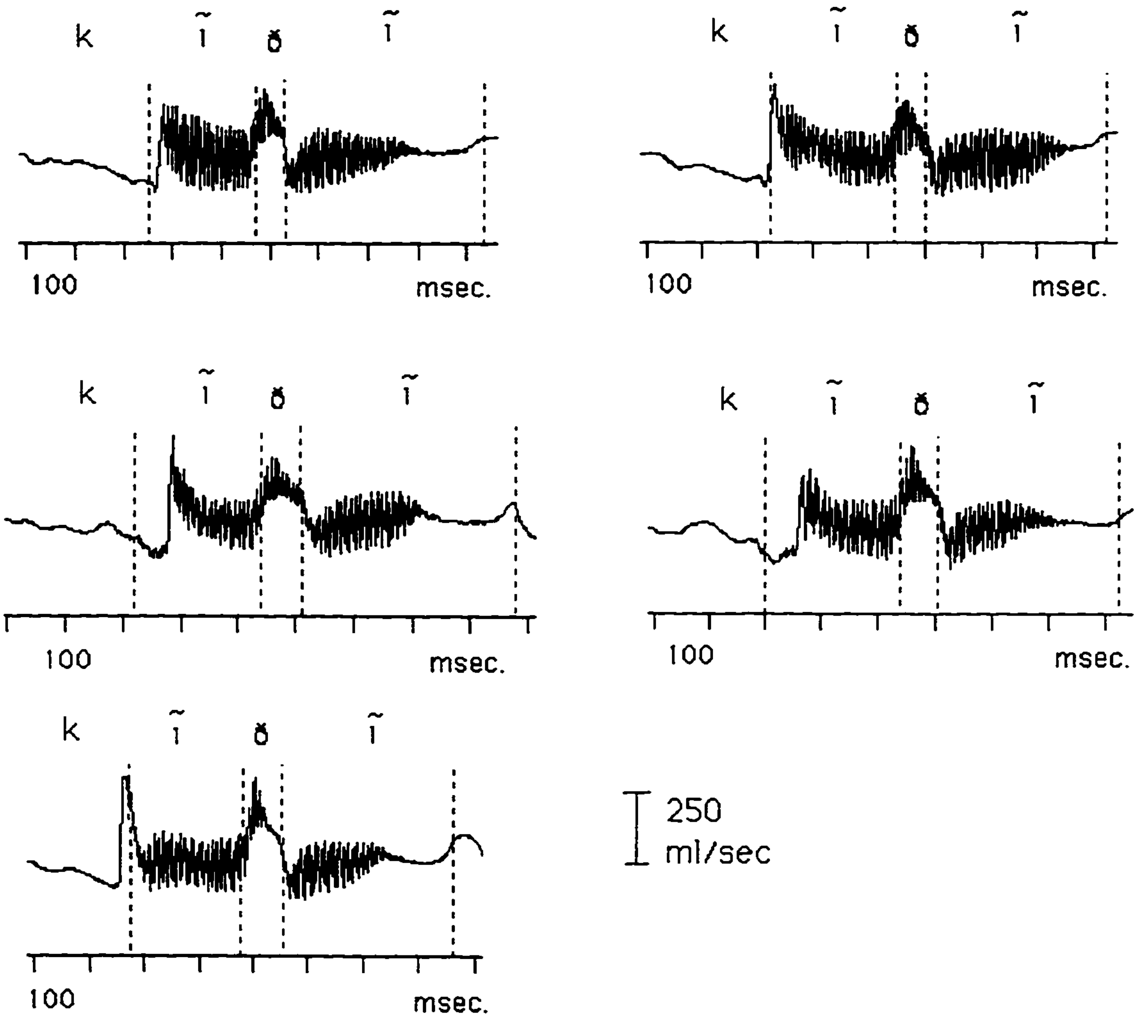
S3: [kuʔ^{u}tsĩ] 'you (fam) will bathe'



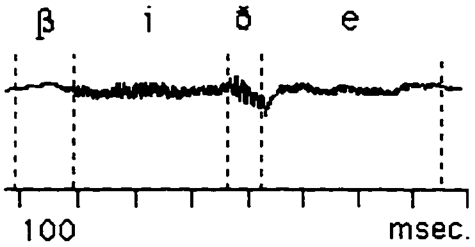
S3: [kiði] 'to sleep'



S3: [kĩðĩ] 'you (fam) will sleep'



S3: [βiðe] 'wet'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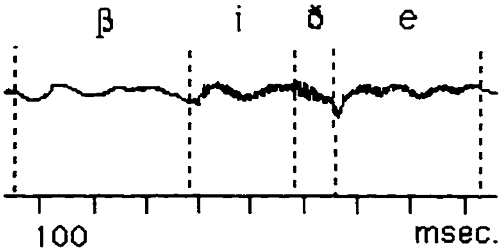
β
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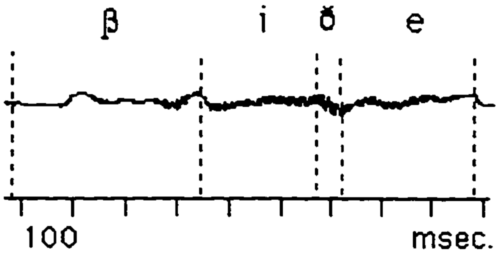
msec.


β
i
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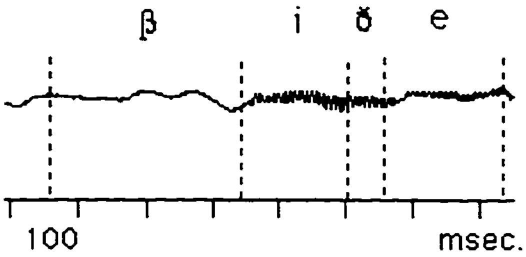
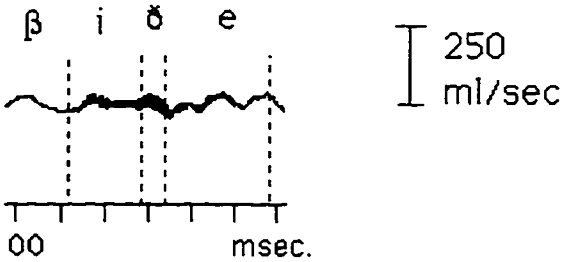
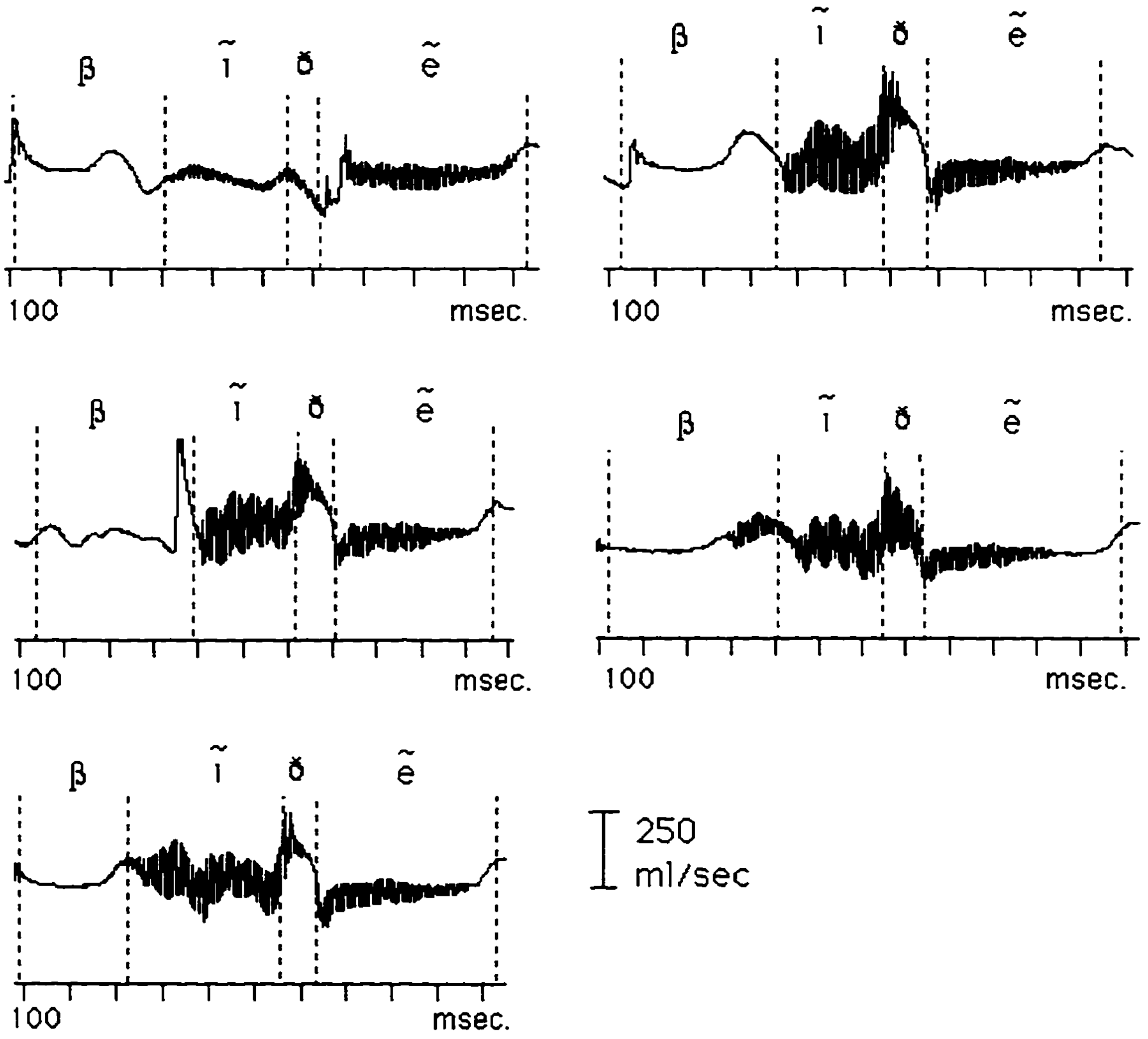
msec.

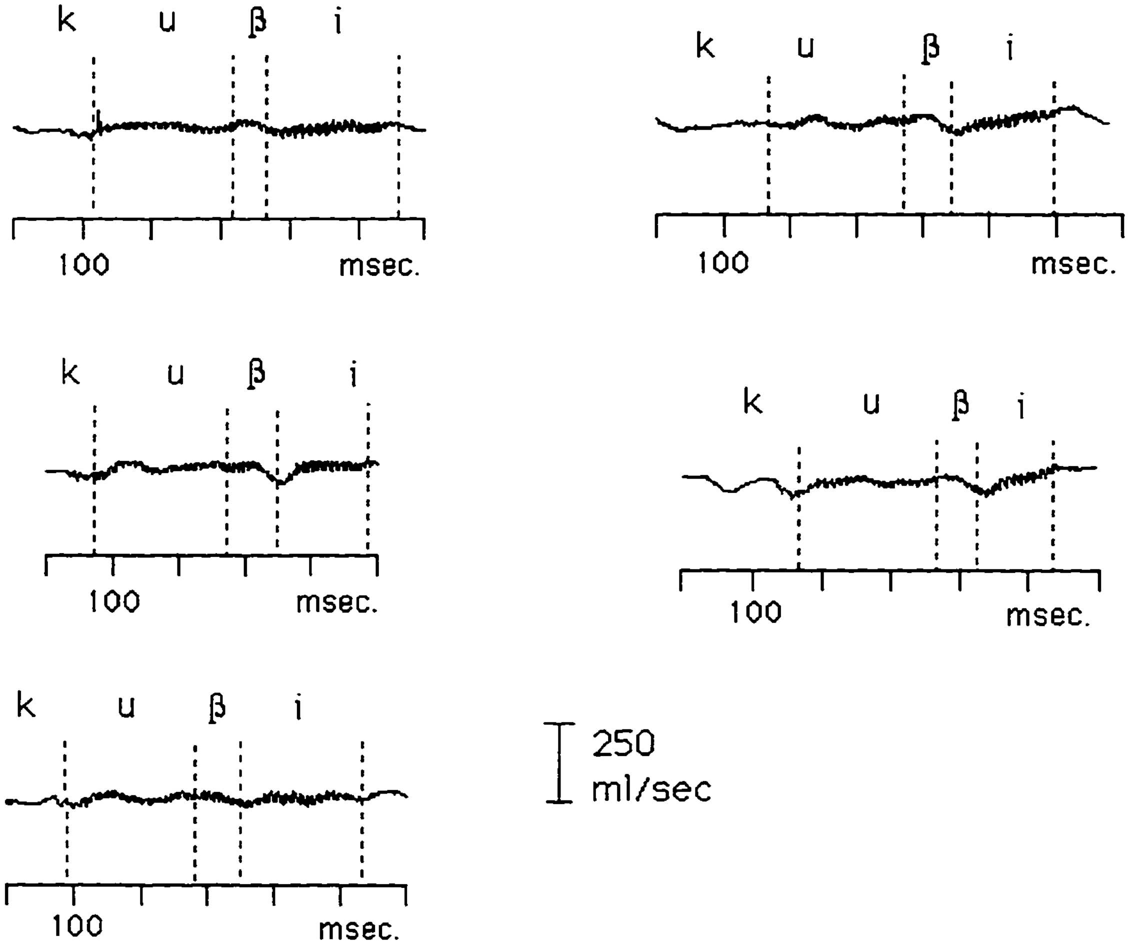

β
i
ð
e
100
msec.


β
i
ð
e
100
msec.
250
ml/sec

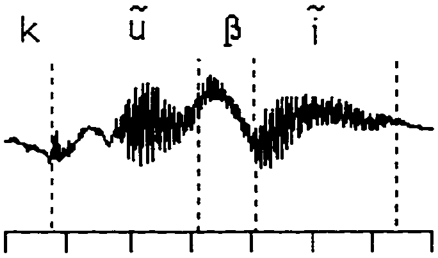
S3: [βĩðẽ] ' you (fam) are wet'

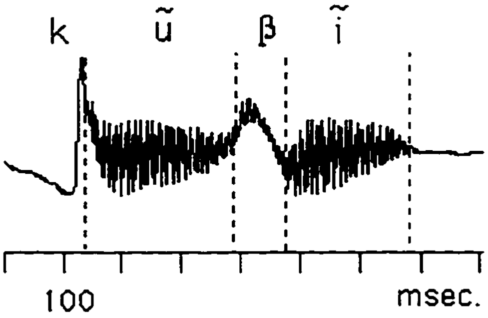


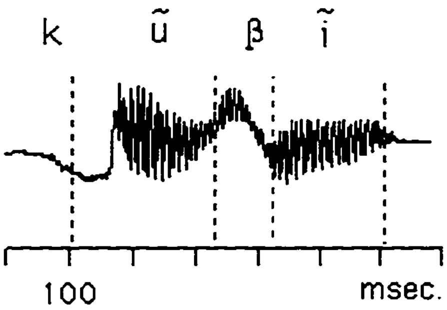
S3: [kuβi] 'to die'

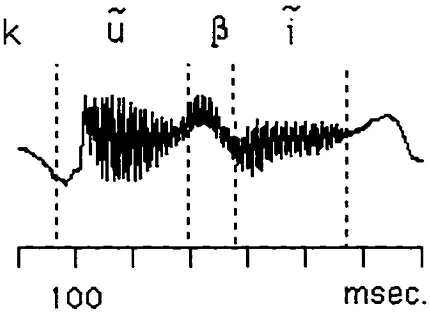


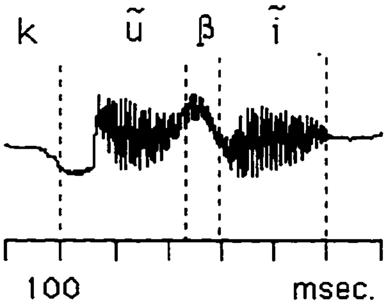
S3: [kũβĩ] 'you (fam) died'

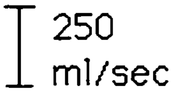




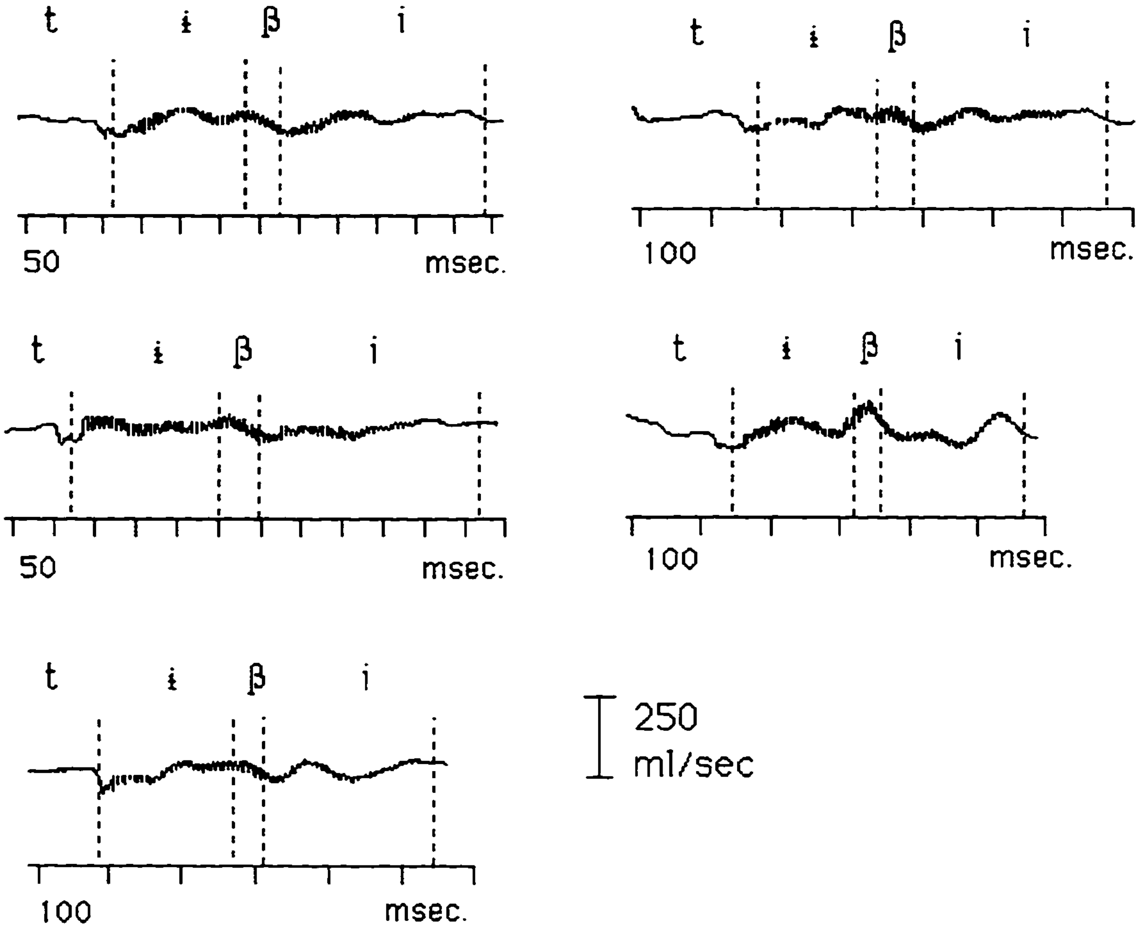




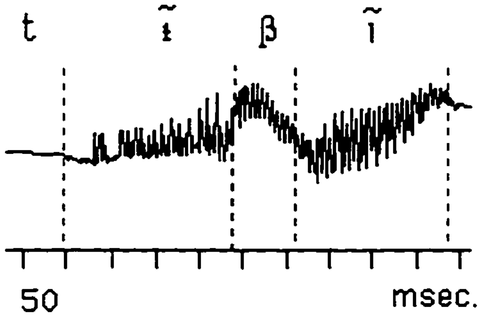


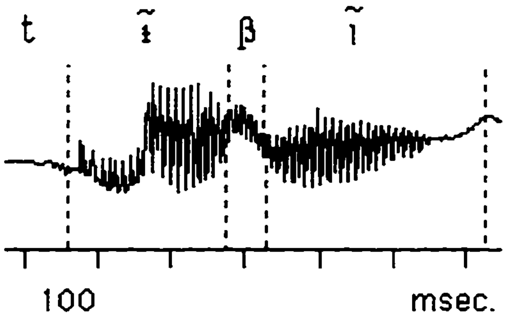


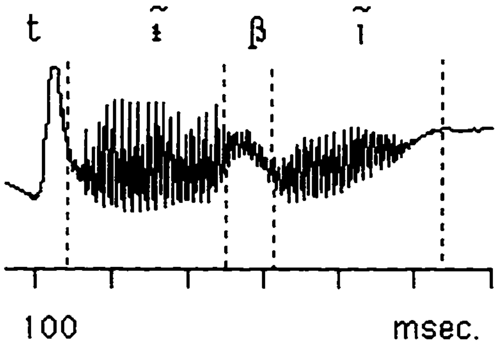
S3: [tɨβi] 'to blow'

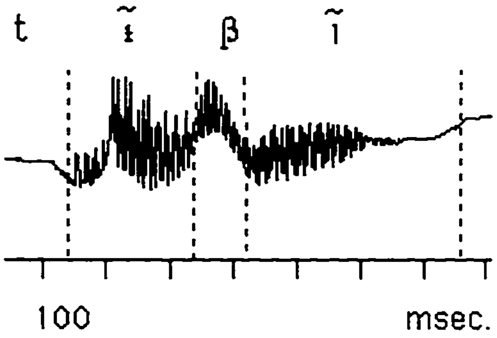


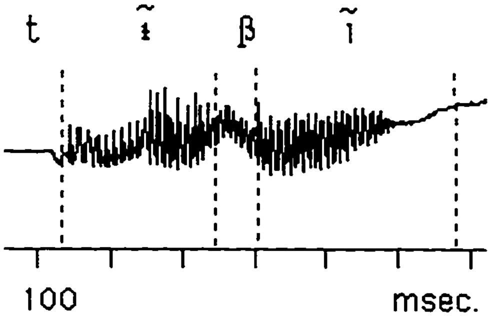
S3: [tɨ̃βĩ] 'you (fam) will blow'



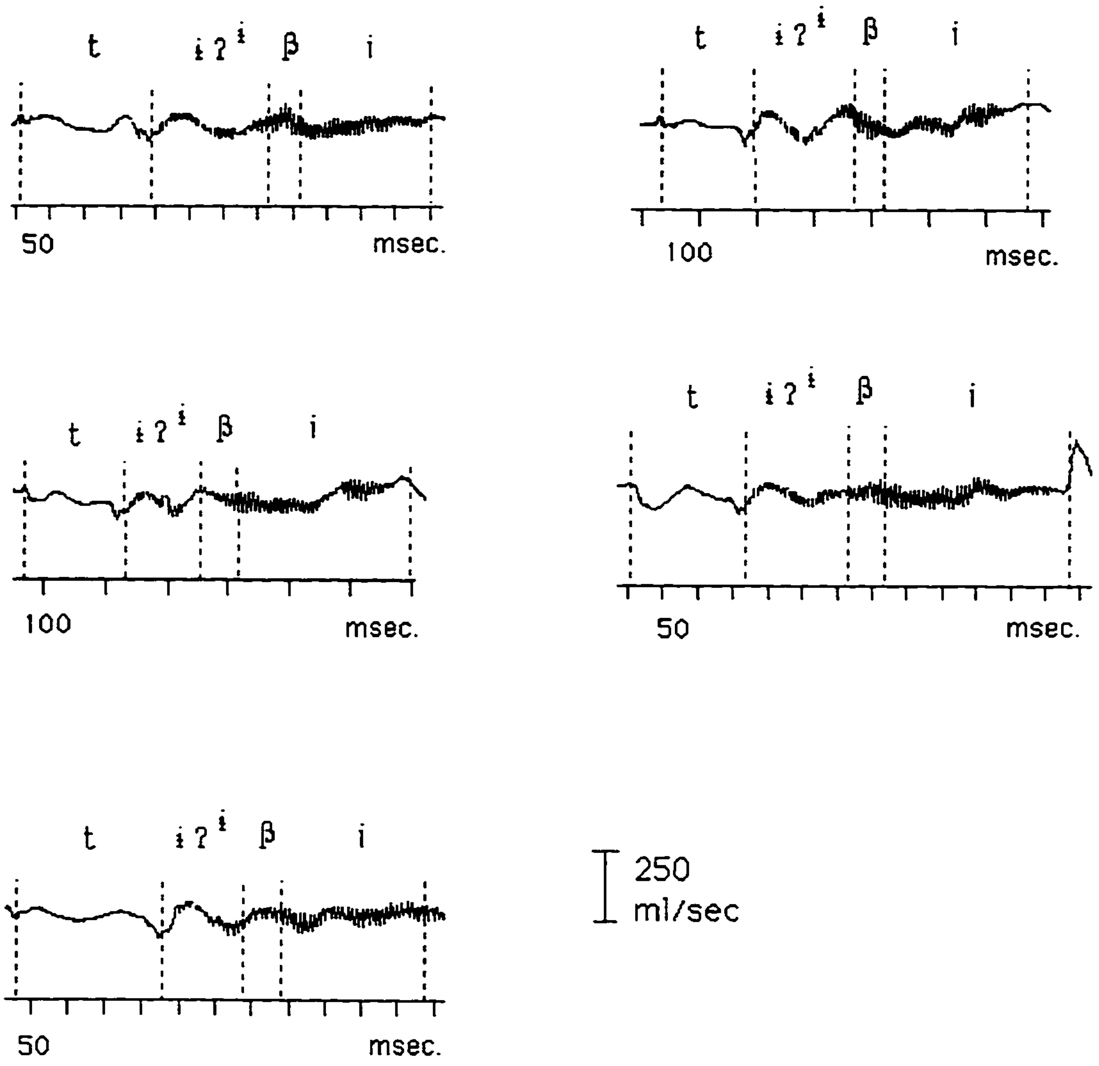




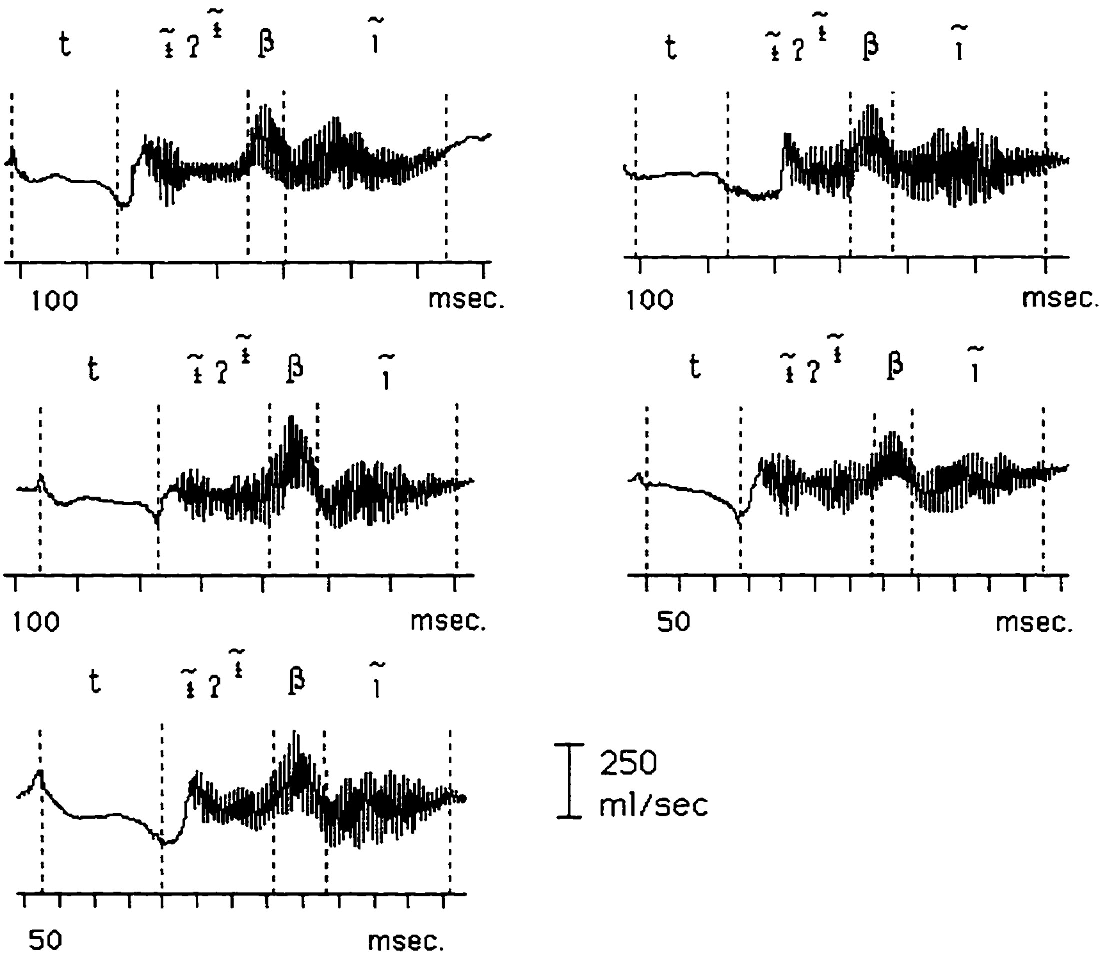




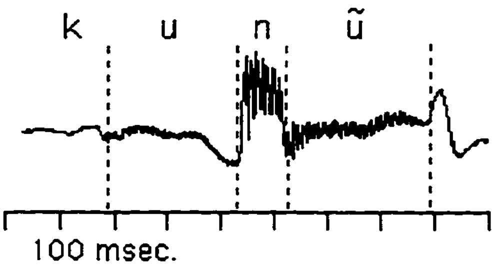
S3: [tɨʔᶤβi] 'to push'

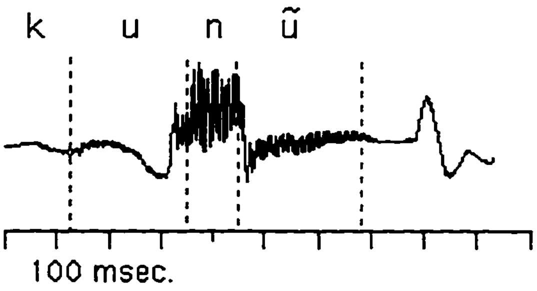


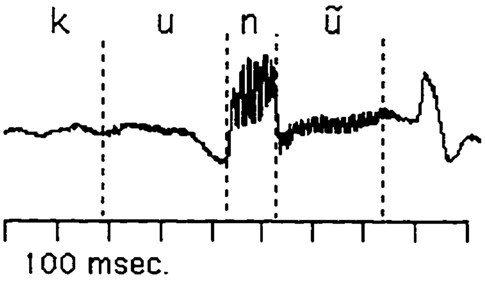
S3: [tɨ̃ʔ$^{ɨ̃}$βĩ] 'you (fam) will push'

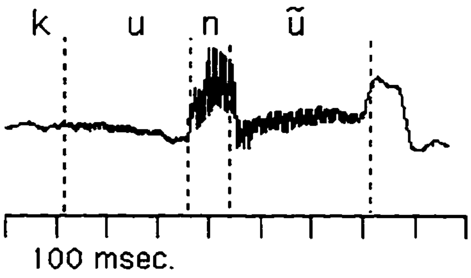


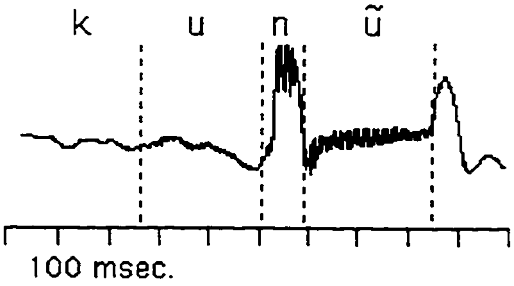
S3: [kunũ] 'to run'

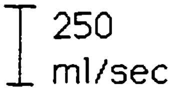




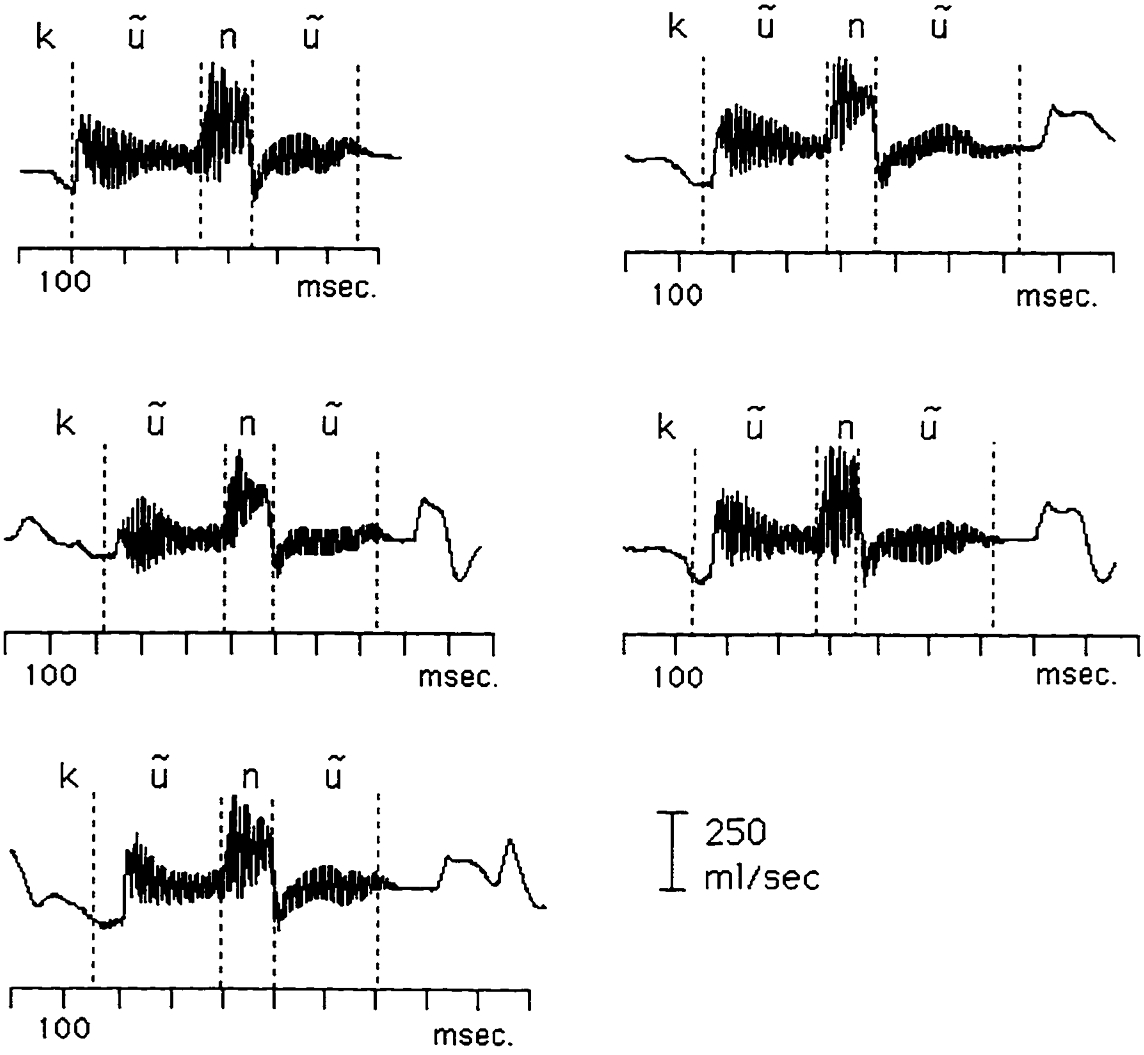




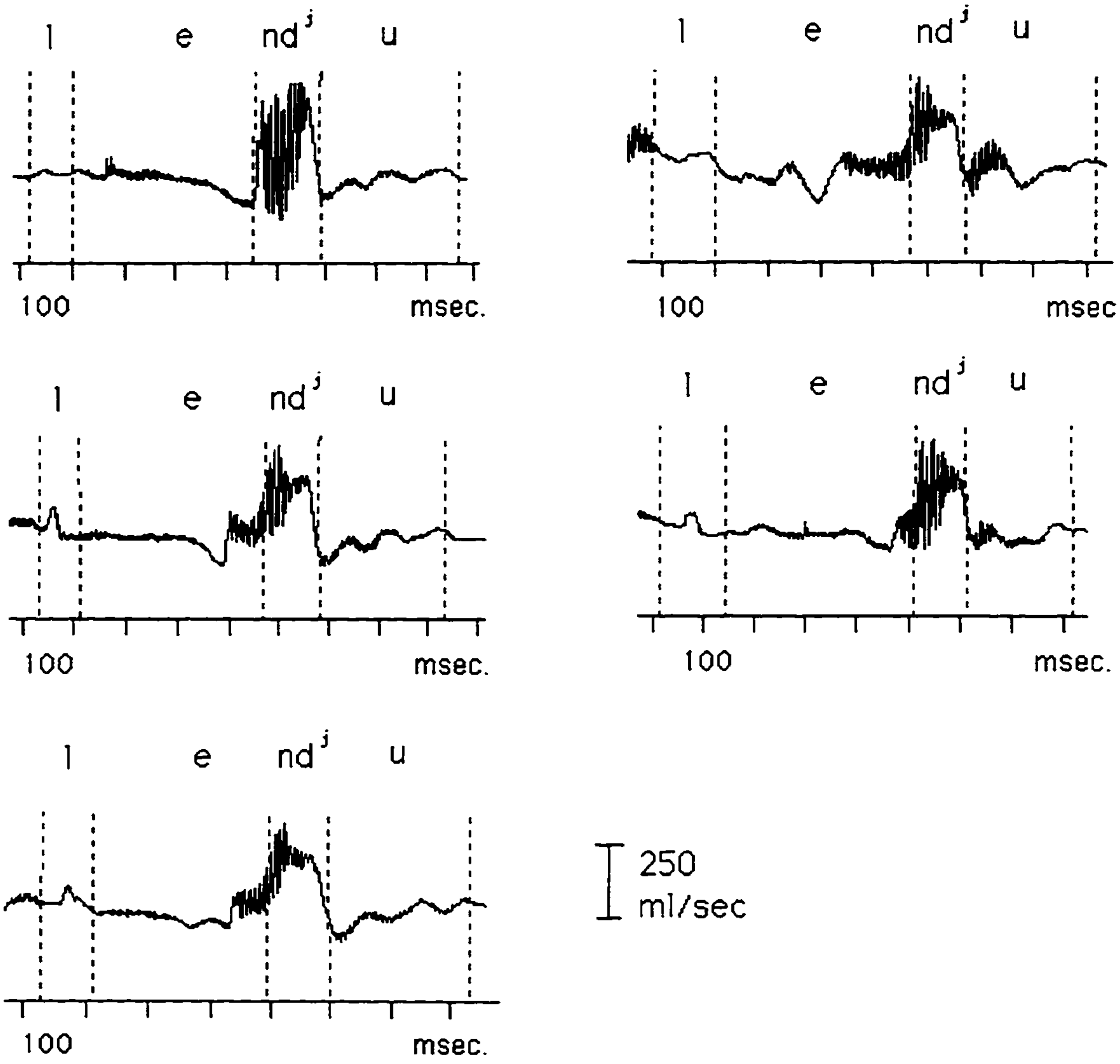




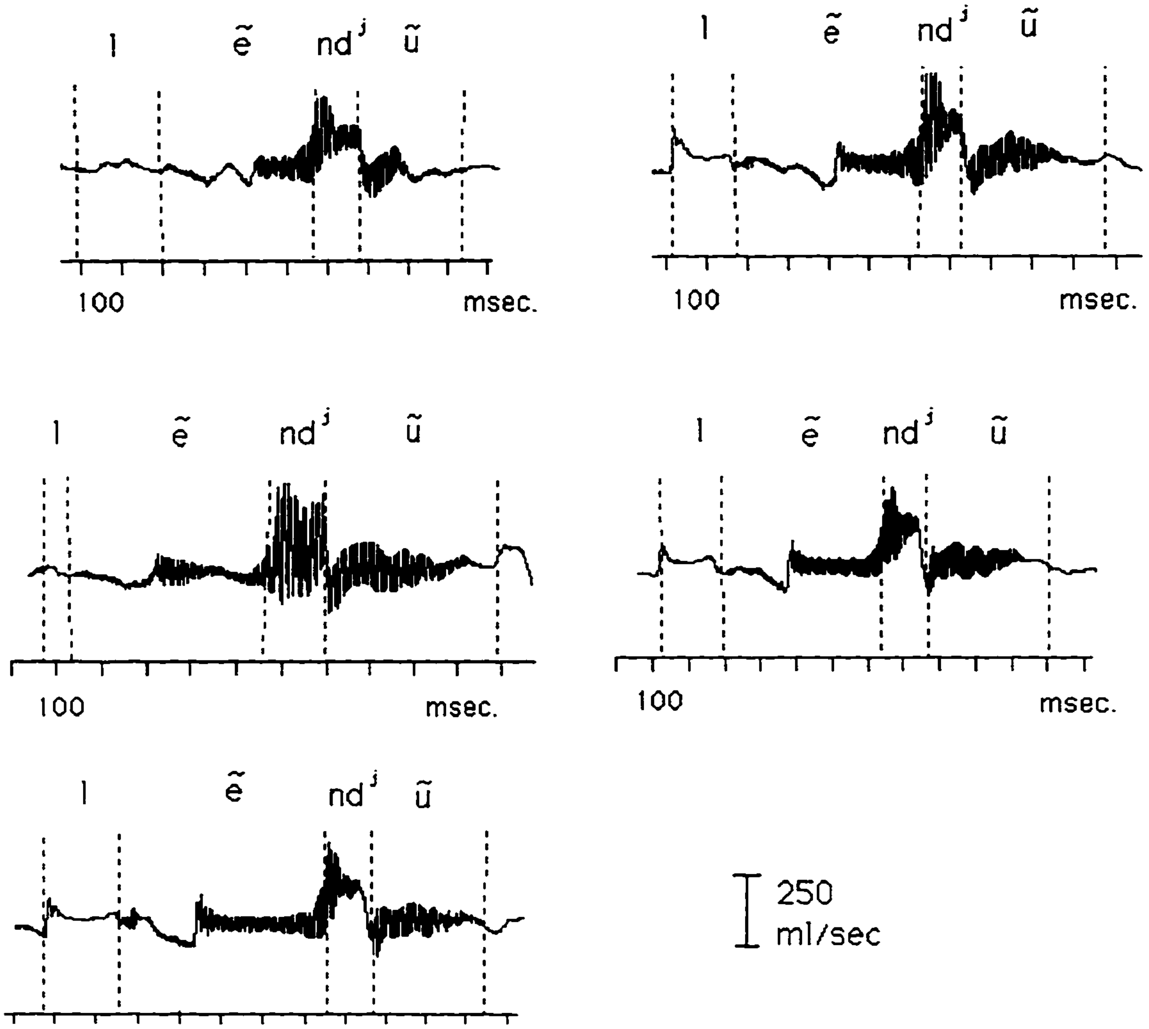
S3: [kũnũ] 'you (fam) will run'



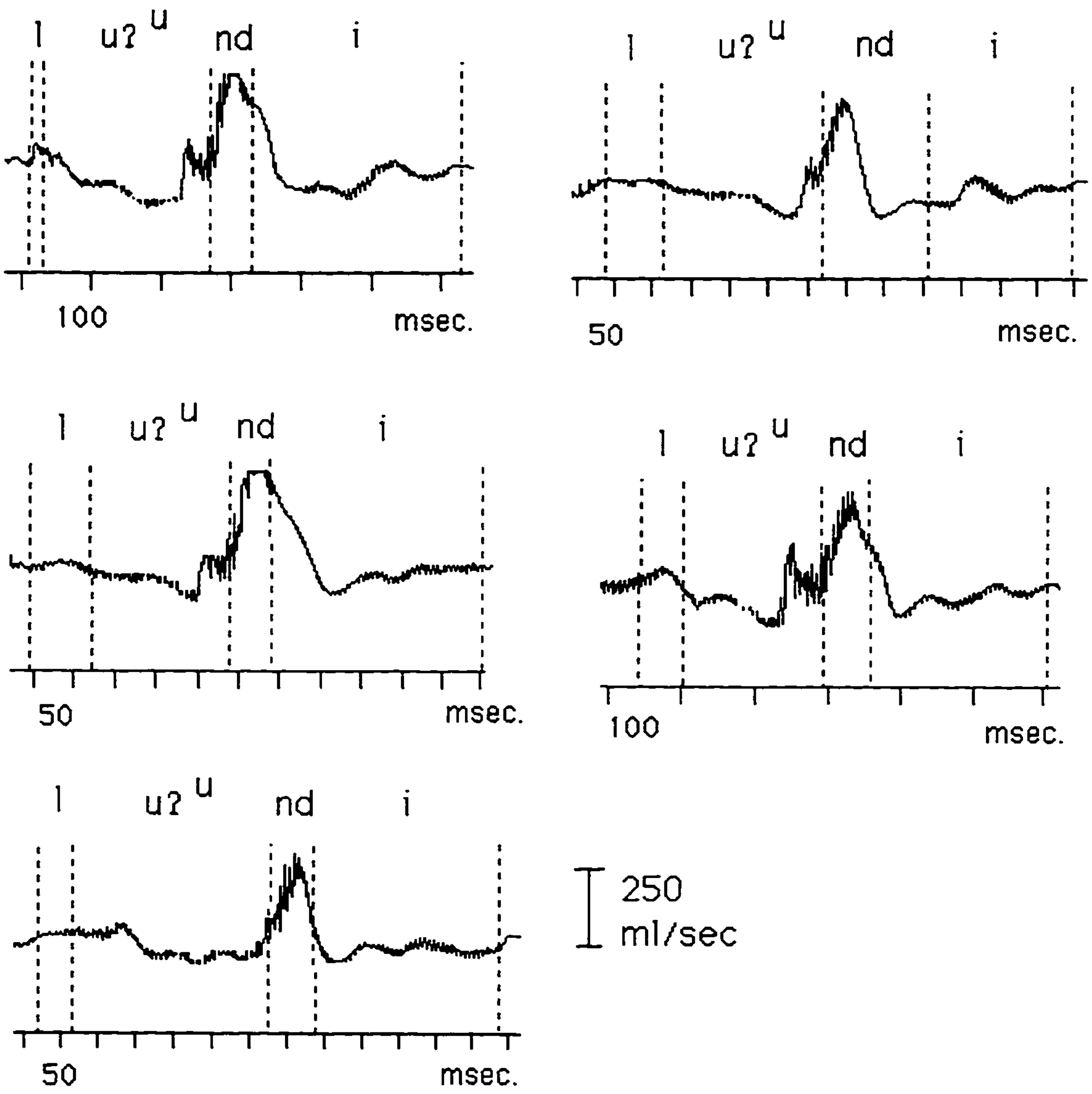
S3: [lend^{j}u] 'dirty'



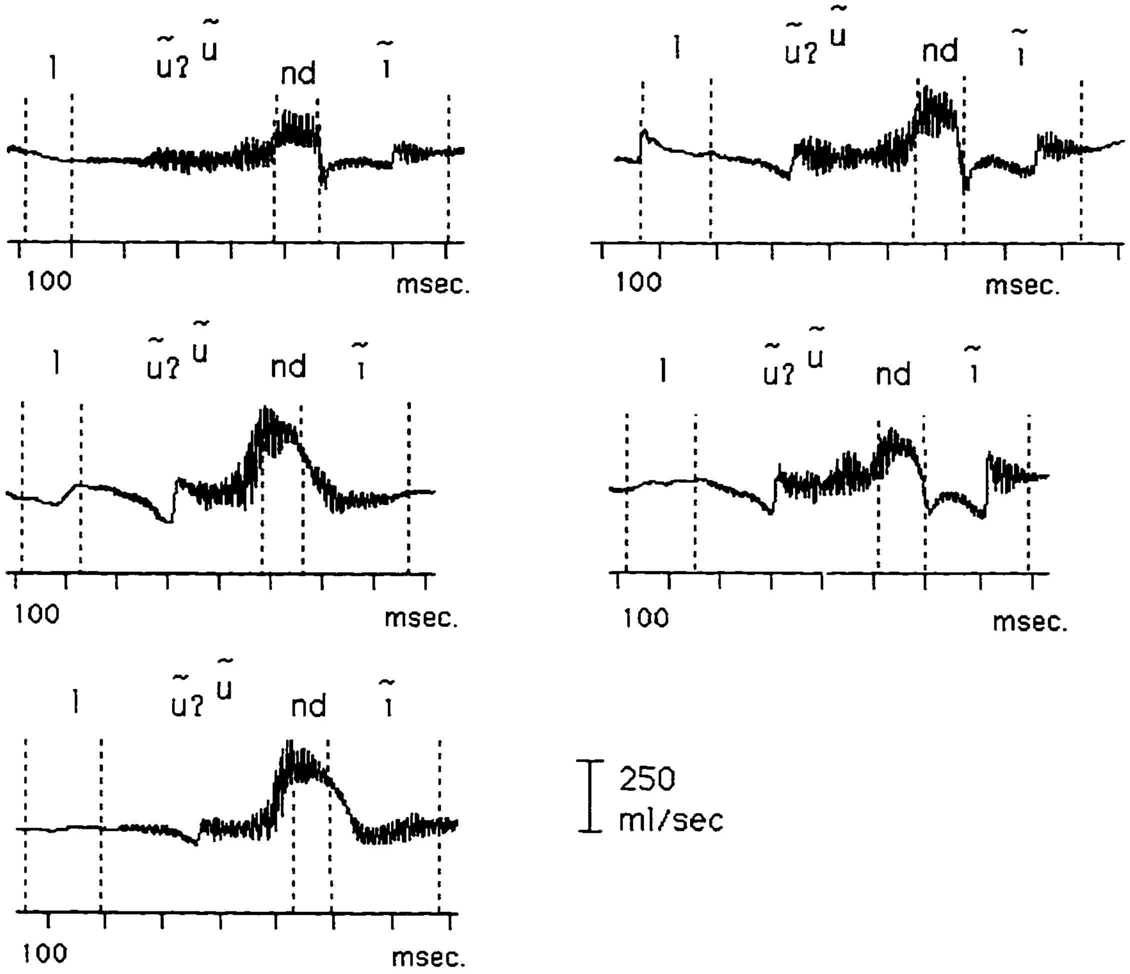
S3: [lend^{j}u] 'you (fam) are dirty'



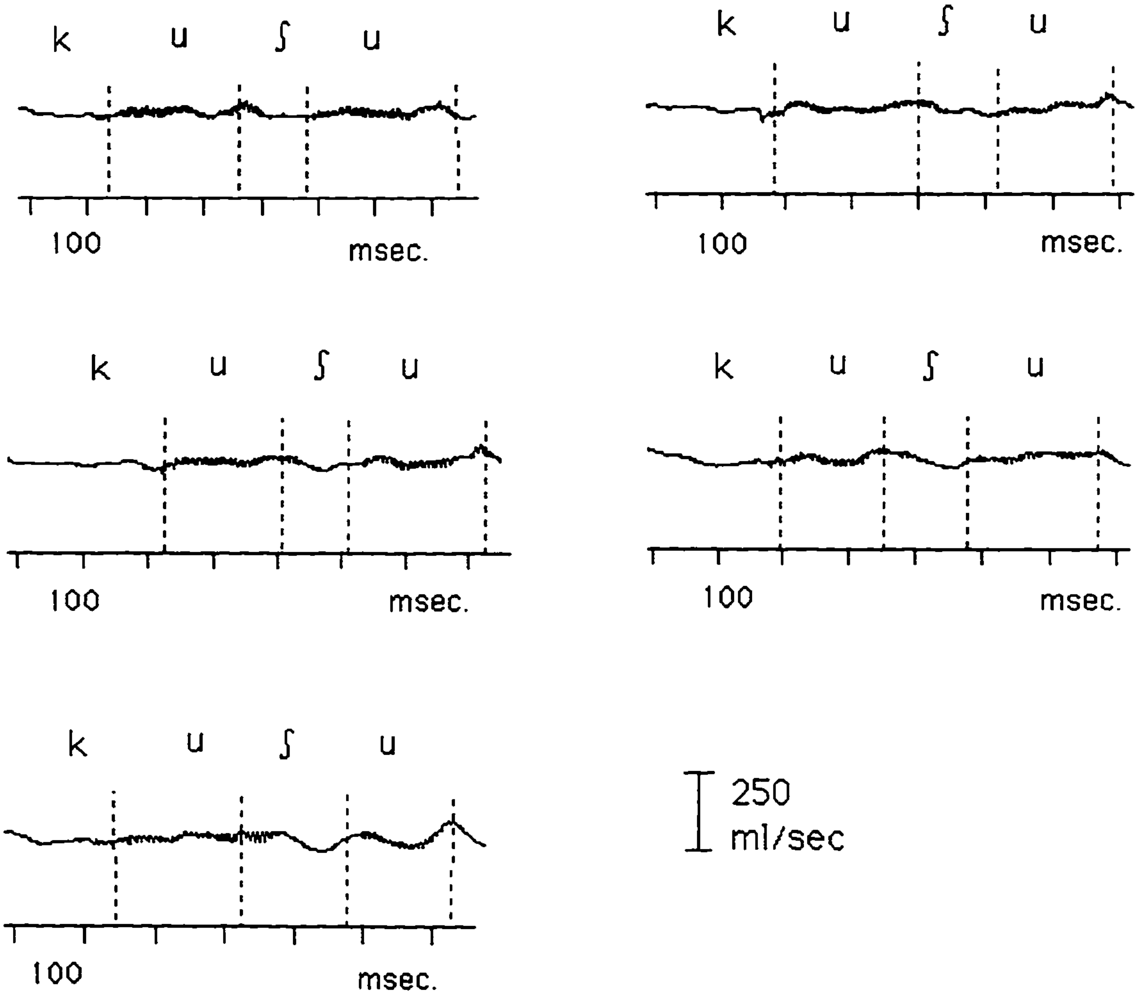
S3: [luʔ^{u}ndi] 'small'



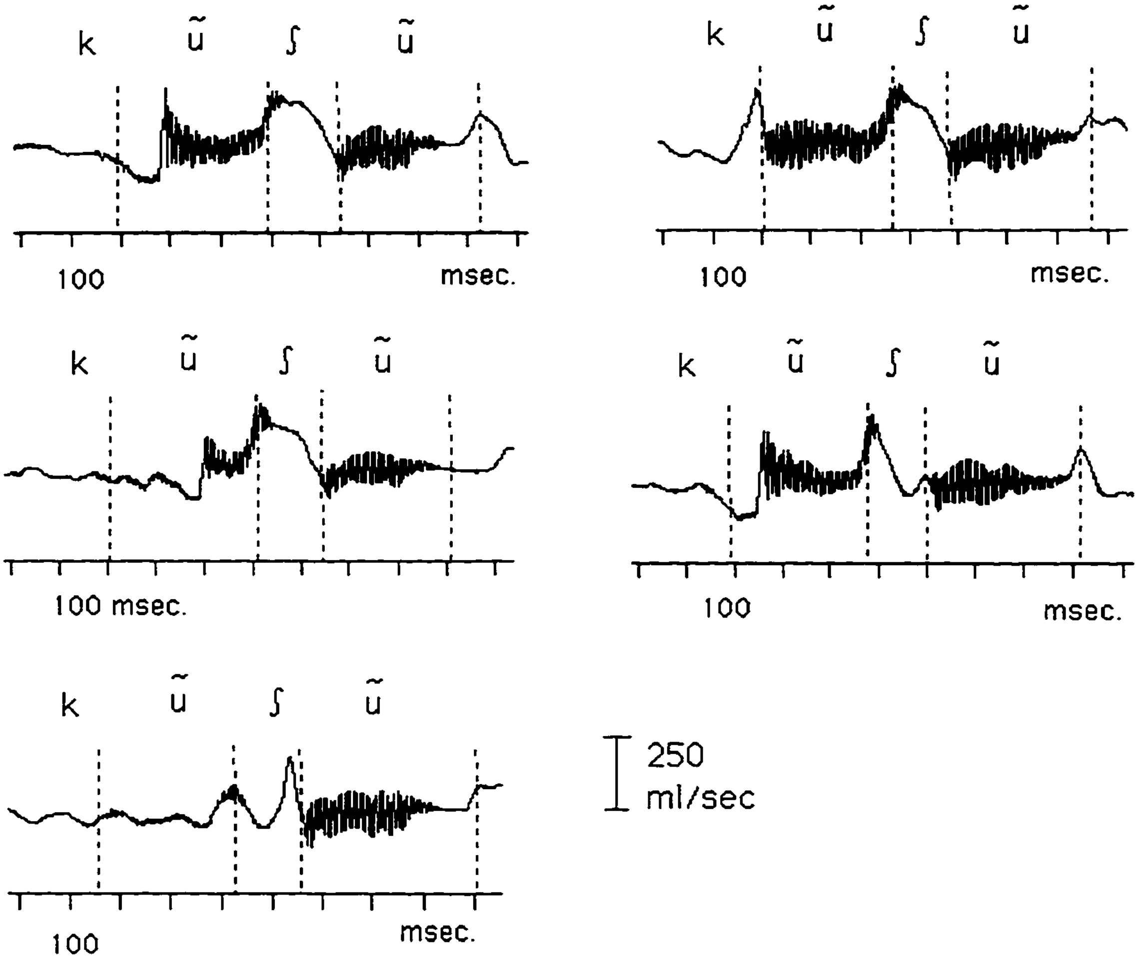
S3: [lũʔ$^{\tilde{u}}$ndĩ] 'you (fam) are small'



S3: [kuʃu] 'diligent'



S3: [kũʃũ] 'you (fam) are diligent'



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