The Phonetics and Phonology of San Martín Itunyoso Trique

by

Christian Thomas DiCanio

B.A. (SUNY Buffalo) 2002
M.A. (University of California, Berkeley) 2004

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Linguistics

in the

GRADUATE DIVISION
of the
UNIVERSITY OF CALIFORNIA, BERKELEY

Committee in charge:
Dr. Keith Johnson, Chair
Dr. Ian Maddieson
Dr. Larry Hyman
Dr. Johanna Nichols

Fall 2008

The Phonetics and Phonology of San Martín Itunyoso Trique

Abstract

The Phonetics and Phonology of San Martín Itunyoso Trique

by

Christian Thomas DiCanio
Doctor of Philosophy in Linguistics

University of California, Berkeley

Dr. Keith Johnson, Chair

This dissertation investigates the phonology and phonetics of San Martín Itunyoso Trique, an Otomanguean language spoken in Mexico. Along with describing the language's phonological system, I examine two distinct aspects of the language's phonetics: the fortis-lenis consonant contrast and the interaction of laryngeals with tone. The investigation of the phonological system focuses on the structure of the morphological word, which is characterized by final syllable prominence. I show that prominence is instantiated by increased duration, the final syllable's ability to license all phonological contrasts, and its ability to license certain contrasts on preceding syllables.

I analyze the fortis-lenis contrast in Trique, observing its primary correlates to be durational with an additional glottal spreading gesture in fortis obstruents. Articulatory strength has been both encoded in phonological theory as a distinctive feature, e.g. [TENSE] (Jansen, 2004), and as a constraint determining target attainment in consonant gestures, e.g. LAZY (Kirchner, 2000). Contra Jansen (2004), I argue that the contrast in Trique does not involve differences in effort. Contra Kirchner (2000), I argue that the observed patterns of lenition are best explained by the contrast's phonetic correlates, not by abstract constraints on target attainment.

With respect to tone and laryngeals, I observe that post-vocalic /h/ is often realized as a large magnitude increase in vocalic breathiness that is gradually phased across the rime duration. Breathy phonation does not perturb pitch on lower tones, but it does on higher tones. Laryngeal consonants and non–modal phonation are known to induce vocalic pitch perturbations. This may both cause tonogenesis in a language's diachronic phonology and condition certain distributional patterns of tones and laryngeals in a synchronic phonology. Since pitch perturbations cause listeners to misperceive tone on vowels, it has been hypothesized that speakers abruptly phase laryngeals and tones to avoid listener misperception (Silverman, 1997b). My findings argue against this abrupt phasing view of intergestural prosodic timing but are predicted in a body-cover model of F_0 control (Titze, 1994).

Dr. Keith Johnson
Dissertation Committee Chair

To Paul,

whose love and support

energizes my every step.

Contents

List of Figures

List of Tables

Acknowledgments

This dissertation would not have been possible if it was not for the generous help and guidance of many people. I have had two advisors at Berkeley, both who had positive influences on this work and on my skills as a linguist. When I came to Berkeley, I was fortunate to be guided by Ian Maddieson. I have benefitted from his meticulous attention to detail, his knowledge of phonetic fieldwork, and his interest in phonetic patterns, both big and small. In 2005, Berkeley profited from the addition of Keith Johnson to the faculty. Keith has been a great advisor and teacher. I am especially grateful for hIs enthusiasm in phonetics, which has helped me persevere through graduate school. I have profoundly benefitted from his knowledge in experimental methods and analysis, his breadth of knowledge in phonetic theory, his direct style in advising, and his immense support for his students. Ian and Keith instilled confidence in me that one could write an important dissertation on an individual language that addresses larger theoretical issues with broader relevance. Larry Hyman has been a positive force both in my education at Berkeley and in this dissertation. His extremely thorough approach to doing phonology made me to look for patterns in the language that I would have otherwise missed. The result of this is a stronger phonological description of the language, which has made an impact on the entire dissertation. Larry has an unparallelled zest for phonology and linguistics. Johanna Nichols has also been a helpful source of advice throughout this dissertation. I thank her for her commentary and for carefully examining this thesis for any potential misunderstandings.

I have received excellent instruction and guidance in the linguistics program at Berkeley from professors in the department and from my fellow graduate students. This made my time at Berkeley enjoyable and rewarding. Outside of my committee, I thank professors Andrew Garrett and Jim Matisoff, both of whom were sources of personal inspiration in my graduate education. My cohort members Gabriela Caballero, Marc Ettlinger, Nick Fleisher, Anne Pycha, and Karen Sullivan are a unique and talented group of people who were both good friends and good colleagues throughout my time at Berkeley. I thank Karen Sullivan for many typographical comments on portions of the dissertation and Nick Fleisher for help with LaTeX, the format used to write this dissertation. Many other graduate students at Berkeley enhanced the intellectual dialogue within the department and were good friends, such as Reiko Kataoka, Grant McGuire, David Mortensen, Sam Tilsen, Molly Babel, Charles Chang, and Yuni Kim.

This dissertation would not have been possible without the work done by the creators of the software I used. Using LaTeXand BiBTeX made the dissertation easier to format and made it look professional. All the statistical analyses and plots of acoustic data were done using *R–Statistical Programming* (R Development Core Team, 2007), a free software package with an immense set of available statistical analyses and data visualization tools. The analysis of the acoustic data was done using *Praat: doing phonetics by computer* (Boersma and Weenink, 2008), which made the recording, labelling, and analysis of the acoustic data possible. I thank all the developers of these software packages for their contributions to the scholarly community and for distributing their work free of charge. I thank Ronald Sprouse of the Phonology Laboratory at Berkeley for writing a pitch–extraction script that I used. I thank Bert Remijsen for portions of a script analyzing spectral tilt which were used in a script that I wrote.

My education at Berkeley was funded by a fellowship from the Department of Linguistics, a fellowship from the U.S. Department of Education's Foreign Language and Area Studies Program, the Dean's Normative Time Fellowship at UC Berkeley, and numerous teaching appointments from the Department of Linguistics. I thank all these funding sources. My fieldwork research was funded by the Graduate Division at UC Berkeley, the survey of Californian and Other Indian languages at UC Berkeley, the Department of Linguistics, and a Tinker travel grant through the Center for Latin American Studies. I thank each of these sources for making my work possible.

Finally, I thank my family and friends for supporting me through my years of graduate school and I thank Paul for making my life wonderful.

Chapter 1

The Thesis and the Language

1.1 Introduction

This dissertation consists of both a description and an analysis of certain phonological and phonetic patterns found in San Martín Itunyoso Trique, an Otomanguean language spoken Oaxaca, Mexico. I describe the segmental and tonal phonology and I analyze the phonetics of a segmental contrast (the fortis-lenis contrast) and the phonetics of a pattern in tonal distribution (tone-laryngeal co-occurrence). These phonetic investigations are pertinent to two discussions in the phonetics/phonology literature. First, is strength or effort encoded in phonological representations? Second, are laryngeal consonants and nonmodal phonation types incompatible with certain pitch targets? The first discussion relates to the synchronic topic of phonological representations and distinctive features. The second discussion relates to both the synchronic topic of how laryngeal consonants affect the realization of tonal targets and the diachronic topic of how such consonants may cause tonal mutation or tonogenesis.

This chapter is organized as follows: In §1.2, I summarize the central arguments in the dissertation. In §1.3, I provide a background on the San Martín Itunyoso Trique language. In §1.4, I describe the methods used to analyze the language's phonology and phonetics. In §1.5, I summarize the contents of the dissertation chapters.

1.2 The Thesis

1.2.1 Theoretical Orientation

Phonologists and phoneticians generally agree that the set of distinctive features which represent a particular contrast ought to reflect aspects of its articulation or acoustic properties (Ohala, 1981, 1983, 2005; Keating, 1985; Stevens and Blumstein, 1981; Stevens and Keyser, 1989; Stevens, 2002; Kingston, 1985, 2007; Kingston and Diehl, 1994; Kingston et al., 2008; Hall, 2001). This *grounding* approach differs from a modular perspective of phonology. The modular approach argues that the representation of sound contrasts in the mind of a speaker may be wholly different from the articulatory commands or acoustic cues needed to produce and perceive the contrasts (Hale and Reiss, 2000). This is, in essence, a phonology free of any phonetic motivation or content; a modular phonology. The difference between these perspectives is illustrated with an example in Table 1.1.

Table 1.1: Stop Contrasts in Hindi and English

Hindi		English	
[bʰal]	*forehead*		
[bal]	*hair*		
[pal]	*to take care of*	[pɑɫ]	*ball*
[pʰal]	*knife blade*	[pʰɑɫ]	*Paul*

Both Hindi and English are considered to have a contrast in stop voicing. In Hindi, the stop types contrast both in terms of voicing, [b] vs. [p], and aspiration, [pʰ] vs. [p]. In English, word-initial voiced stops /b, d, g/ are realized as voiceless unaspirated. Voiceless stops /p, t, k/ are realized with aspiration after release (sensitive to a set of prosodic conditions). From the traditional modular perspective, stop types in English contrast in terms of voicing. The presence of aspiration is a language-specific characteristic in how the [voice] feature is implemented.

Phonologists and phoneticians have long known that voiced stops cause pitch-lowering on the following vowel while voiceless stops cause pitch-raising (Haudricourt, 1954; Matisoff, 1973; Hombert, 1979; Kingston and Diehl, 1994; Holt et al., 2001; Kingston et al., 2008). In the English data above, we expect both [p] and [pʰ] to cause pitch-raising. This is, in fact, not what we observe. Pitch is lowered after [p] but raised after [pʰ] in English.

In Hindi, pitch is raised after both [p] and [$\mathrm{p^h}$]. Kingston and Diehl (1994) argue that pitch perturbation effects like these are best predicted by the phonological feature [voice]. Even though they are often phonetically voiceless, word-initial stops in English are featurally [+voice].[1] In Hindi, both [p] and [$\mathrm{p^h}$] are phonologically [−voice].

Pitch perturbations are traditionally considered a low–level phonetic process, not something that interacts directly with phonological features. However, the compelling findings from Kingston and Diehl's work show that low level processes like these are not incidental effects of speech gestures, but rather, they derive from the set of distinctive features which encode contrasts in the phonology. If we assume a modular view of phonology, the set of phonetic observations from a language may reflect something specific to the production of the contrasts in that language. These observations may be part of universal tendencies of speech production or perception, but they would not be a part of the phonological representation itself. If we assume an integrated view of phonetics and phonology, then phonological features like [voice] are free to influence all aspects of surface phonetic implementation.

This latter, integrated approach better accounts for the pattern in Table 1.1. The modular approach would not predict any such interaction between distinctive features and low-level phonetic processes such as pitch perturbation. In failing to do so, a cross-linguistic generalization is missed. It is not the central goal in this dissertation to argue the relative merits of modularity in phonology. However, the work in this dissertation is characterized by an integrated approach where low–level phonetic characteristics in a language exist in phonological representations.

One consequence of the integrated view of phonetics and phonology is that any aspect of surface phonetic implementation may be encoded in a phonological representation. Another consequence is that distinctive features should be grounded in surface representations. This gives the linguist the ability to investigate surface representations both in terms of production and perception in order to characterize the featural identity of a contrast. The more robust articulatory differences and acoustic cues which distinguish two sounds should be reflected in the set of distinctive features. If the presence of phonetic voicing during consonant closure is a robust and consistent cue to stop contrasts, this reflects a [voice] feature. If phonetic voicing is entirely predictable on consonant duration, the contrast is one of duration (gemination) where voicing is a secondary cue for the contrast. The primary

---

[1] See Jansen (2004) for an alternative analysis

correlates of contrasts reflect their featural representation while the subordinate ones do not.

1.2.2 Strength in Phonology

Phonological research from a variety of language stocks (Indo-European, Austronesian, Niger-Congo, Afro-Asiatic, Otomanguean, Mixe-Zoque, Athabaskan, Pama-Nyungan, North Caucasian) describe consonants with a *fortis-lenis* contrast. In some cases, the labels “fortis” and “lenis” are cover terms for a phonological length contrast or a voicing contrast (in the case of obstruents). This is especially true for some older uses of the terms within the historical phonology of Indo-European (see Lehmann (1967)). In some cases, however, these terms are specifically used to capture a contrast in articulatory strength, where articulations are produced with greater muscular or pulmonic force.

As a natural consequence of our ability to produce speech, certain articulations may be more effortful than others. This is clear in the production of stress in many languages where increased intensity may be a cue to a syllable’s prominence. In this case, articulatory effort or strength is used in a language’s prosodic system, which is generally considered to have a distinct representation from the segments over which it is specified, e.g. Goldsmith (1976, 1990). However, does strength distinguish a contrast in the *segmental* phonology of a language?

There are three logical possibilities. The first possibility is that differences in articulatory strength are the most robust correlates of a phonological contrast. Following the set of assumptions in §1.2.1 above, this would necessitate the presence of a phonological feature [fortis] or [tense] in the distinctive feature system. I will call this view the *primary correlate possibility.*The second possibility is that strength differences are not robust and are subordinate to other cues/correlates. In this case, articulatory effort is used in tandem with other phonetic correlates to indicate a contrast. However, one may not need to posit strength as a distinctive feature. If the most robust correlates of a contrast are duration and glottal timing, for instance, differences in strength may be incidental.[2] Articulatory strength would be strictly phonetic. I will call this view the *subordinate correlate possibility.* The third possibility is that strength plays no role in distinguishing consonant types. I will

---

[2] This same logic applies, for instance, to a number of cues to obstruent contrasts. One would not argue that there is a universal distinctive feature [high amplitude burst] simply because voiceless stops have higher amplitude bursts than voiced ones (Stevens, 2000). Indeed, the burst amplitude is entirely predictable based on voicing.

call this view the *strengthless possibility.*

The relevant question among these possibilities is how *intentional* are strength differences in phonological contrasts? At one level there is only a physical difference in effort between two consonant types. At another level, strength is an intended target in the production of a speech sound which produces particular surface manifestations. The primary correlate possibility assumes that speakers intend to produce certain consonant types *stronger* than others. The subordinate correlate possibility assumes that speakers may produce differences in articulatory strength intentionally but this is not the primary way in which a contrast is encoded. The strengthless possibility assumes that strength is never intentional but *always* an unintentional byproduct of other articulations in the speech signal.

The primary correlate possibility is reflected in the early work of Jakobson et al. (1976) and later work by Kohler (1979, 1981, 1984). These approaches argue that the distinctive feature [fortis] reflects increased articulatory energy and is the primary correlate distinguishing obstruent types in many Germanic languages. The subordinate correlate possibility is reflected in more recent work by (Jessen, 1998; Jansen, 2004). In this research, the authors argue that the distinctive feature [tense] represents a set of divergent phonetic behaviors that typify obstruent contrasts in Germanic languages like German and English. The [tense] feature may include increased articulatory strength as one of its correlates, but it is mainly used as a cover term for obstruent contrasts involving passive voicing and active devoicing. The strengthless possibility is reflected in work by Iverson and Salmons (1995, 2003); Jessen and Ringen (2002). These authors propose that, aside from length, laryngeal features are the main features which define phonological obstruent contrasts. The laryngeal feature proposal argues that there is no need for [tense] in the set of distinctive features and processes of voicing in Germanic are better handled with the feature [spread glottis].

Assuming that the primary intentional correlates of a contrast are present in phonological representations as distinctive features, it is possible to examine the robustness of the correlates of a contrast in order to determine its distinctive feature representation. This particular approach is taken in examining the fortis-lenis contrast in Itunyoso Trique in this dissertation. Descriptions of related languages describe the obstruent contrasts in the language as a fortis vs. lenis distinction. Such a contrast is found in Copala Trique, for instance Hollenbach (1984b), shown in Table 1.2.

Hollenbach (1984b) represents the fortis or tense obstruents with a voiceless symbol,

Table 1.2: Copala Trique obstruents contrasts (Hollenbach, 1984b)

Contrast	Word	Gloss	Contrast	Word	Gloss
/p/	pih^{5}	*kind of frog*	/s/	sĩʔ^{3}	*is torn*
/b/	bah^{5}	*compadre of*	/z/	zih^{5}	*reaches*
/t/	to^{32}	*milk*	/š/	ših^{1}	*big*
/d/	do^{4}	*palm basket of*	/ž/	žih^{5}	*is tucked in*
/k/	ku^{5}	*bone*	/ṣ̌/	ṣ̌iʔ^{3}	*intestines of*
/g/	goh^{3}	*last year*	/r/	riʔ^{3}	*obtains*

e.g. /p, t, k, s, š, ṣ̌/ and lenis or lax ones with a voiced symbol, e.g. /b, d, g, z, ž, r/. The symbol /r/ represents a flap, but patterns as an obstruent. Hollenbach observes that fortis stops are voiceless, slightly lengthened, and unaspirated. Lenis stops are voiced fricatives between vowels but vary from voiced to voiceless in word-initial position or in onset clusters. She uses the features [VOICE] and [TENSE] to distinguish lenis obstruents from fortis ones. Lenis obstruents are [+voice] but [−tense] while fortis ones are [−voice] and [+tense].

Longacre (1952) observed that a fortis-lenis contrast also exists within Chicahuaxtla Trique. Unlike Copala Trique, the contrast occurs in obstruents *and* in sonorants. He states that fortis consonants are distinguished from lenis consonants by “a perceptible lengthening of the fortis phonemes, greater articulatory force and consistent voicelessness of the fortis stops and fortis sibilants, and consistent stop quality of p, t, and k as opposed to b, d, and g which have fricative/stop allophonic variation.” (Longacre, 1952:63). The description of the fortis-lenis consonant contrast in Trique mirrors the descriptions given in other Otomanguean languages, such as Zapotec (Nellis and Hollenbach, 1980). However, phonetic investigations into the Zapotec contrast by Jaeger (1983) and Avelino (2001) found it to be mainly a contrast in length with an additional glottal manner feature, not a contrast in articulatory strength. Within this dissertation I examine if the same is true for Itunyoso Trique.

This investigation is not only relevant for the description and comparative phonology of Otomanguean languages, but also for our general understanding of strength in phonological systems. First, investigating the phonetic implementation of this contrast can reveal the degree to which strength is contrastive. If robust correlates reflect distinctive feature specification, then the presence of robust physical correlates of strength would argue in favor of the distinctive feature [tense] distinguishing the contrast in the language. If, however, the contrast never involves strength and instead involves some other correlate (like duration or glottal timing differences), [tense] would not distinguish the contrast.

Second, the manner in which the contrast is implemented may also explain the patterns of lenition or variability in voicing among lenis consonants. Approaches to lenition in phonological theory argue that increased articulatory effort is exerted in the production of certain sound types to specifically prevent lenition from targeting them (i.e. inalterability). For instance, geminates are argued to be produced with increased biomechanical effort in order to avoid a violation of a [LAZY] constraint (Kirchner, 2000) which dominates faithfulness constraints within an optimality-theoretic perspective (Prince and Smolensky, 1993; Kager, 1999). Flemming (2001) motivates patterns of lenition with a similar type of constraint [Minimize-Effort]. However, it is possible that the durational differences or glottal timing differences alone can explain patterns of lenition among fortis and lenis consonants in Trique. If this is the case, there is no need to posit abstract phonological constraints on effort in the language.

1.2.3 Laryngeals and Tone

Laryngeals[3] have been shown to interact with prosodic contrasts like tone and stress in many of the world's languages, (e.g. Otomanguean, Tibeto-Burman, Austroasiatic, Athabaskan, Niger-Congo, Austronesian, Indo-European, etc.). Two of the major ways in which laryngeal contrasts affect phonological systems are by triggering processes of tonogenesis and by restricting the set of adjacent prosodic contrasts. The first type of interaction is diachronic while the second is synchronic. Yet, both share a common explanation in the phonetics of how laryngealization influences pitch. I provide two illustrative examples of how laryngealization influences pitch here.

Table 1.3 shows the differences between three dialects of Kammu (Austroasiatic, Mon-Khmer) (Svantesson and House, 2006). The eastern dialect maintains a contrast between voiced and voiceless sonorants and among voiced, voiceless unaspirated, and voiceless aspirated stops. The Northern and Western dialects are tonal but no longer have a contrast between voiced and voiceless sonorants and have simplified the stop contrasts to voiceless

---

[3] Here, and throughout this dissertation, the term "laryngeal" refers to both laryngeal consonants like /ʔ/ and /h/ and contrastive phonation types like breathiness or creak.

Table 1.3: Kammu Tonogenesis (data from Svantesson and House, 2006:310)

Eastern	Northern	Western	Gloss
taaŋ	táaŋ	táaŋ	*pack*
daaŋ	tàaŋ	t^hàaŋ	*lizard*
t^haaŋ	t^háaŋ	t^háaŋ	*to clear*
r̥aaŋ	ráaŋ	ráaŋ	*tooth*
raaŋ	ràaŋ	ràaŋ	*flower*

unaspirated and voiceless aspirated.

Svantesson and House (2006) argue that tone arose in the Northern and Western dialects because voiced stops introduced breathiness on the following vowel, which caused pitch lowering. Following this, voiced stops became voiceless. In the Western dialect, voice quality differences (breathy vs. clear) were maintained as aspiration. In the Northern dialect, voice quality differences were lost. As a result, one observes aspirated stops with low tone in the Western dialect as the reflex of the historically voiced stops but voiceless *unaspirated* stops with low tone as the reflex in the Northern dialect.

There is a clear relationship here between the presence of breathiness and low tone. Diachronically, breathy phonation conditioned pitch lowering. However, other laryngeals influence pitch as well. Haudricourt (1954) and Matisoff (1973) shows that coda */ʔ/ conditioned high tones on the preceding vowel in Vietnamese and other Southeast Asian languages. Krauss (2005) and Kingston (2005) show that coda */ʔ/ conditioned high tone in certain Athabasakn languages and low tone in others. A similar claim is made for Proto-Mixtecan */ʔ/ (Longacre, 1957; Dürr, 1987). At first glance, these findings seem to suggest that laryngeals' effect on pitch can not be predicted. However, I argue that one can predict laryngeally-induced pitch perturbation effects by examining the phonetic details of how laryngeals are articulated. In particular, the body-cover model of F_0 control (Titze, 1994; Story and Titze, 2002) (see Chapter 6) and the control of the cricothyroid muscles during different types glottal constriction (Kingston, 2005) predict the interaction of both breathiness and creakiness on pitch.

The second way that laryngeals may interact with the prosodic system of a language is by restricting the set of prosodic contrasts. Tables 1.4 and 1.5 show the set of tonal contrasts that may be realized on Itunyoso Trique monosyllables, organized by possible coda type.

Table 1.4: Monosyllabic Words in Itunyoso Trique

Tone	CV	Gloss	CVʔ	Gloss	CVh	Gloss
/4/	ββe^{4}	*hair*	tʃiʔ^{4}	*elderly man*	βeh^{4}	*beat.3sg (intr.)*
/3/	nne^{3}	*plow*	nneʔ^{3}	*mecate*	nneh^{3}	*dream*
/2/	nne^{2}	*to lie (tr.)*	nniʔ^{2}	*smelly*	ββeh^{2}	*cave*
/1/	nne^{1}	*naked*	ʔniʔ^{1}	*be.salty*	cnãh^{1}	*brother (voc.)*
/35/	*	*	*	*	ββeh^{35}	*petate*
/13/	*	*	*	*	keh^{13}	*barely*
/43/	li^{43}	*small*	*	*	*	*
/32/	nne^{32}	*water*	*	*	kkweh^{32}	*quelite*
/31/	nne^{31}	*meat*	*	*	*	*

Table 1.5: Summary of Tone-Laryngeal Co-occurrence Restrictions in Monosyllables

Tone	CV	CVʔ	CVh
/4/	✓	✓	✓
/3/	✓	✓	✓
/2/	✓	✓	✓
/1/	✓	✓	✓
/35/	*	*	✓
/13/	*	*	✓
/43/	✓	*	*
/32/	✓	*	✓
/31/	✓	*	*

There are only two possible codas on Trique syllables: /ʔ/ and /h/. In Table 1.4, we notice that the level tones may surface on open syllables or with any coda. All the falling tones surface on open syllables but only tone /32/ surfaces with coda /h/. Rising tones only surface on syllables with coda /h/. Contour tones (rising or falling) never surface on words with a coda /ʔ/. The laryngeal codas in the language restrict the set of tones which may surface on the preceding vowel.

Modern phonological theory is concerned with how to account for distributional restrictions within phonological systems such as these, and to discover whether such restrictions are motivated by phonetic patterns. There have been two major phonological approaches to explaining the distribution of laryngeals with respect to tone. The laryngeal feature approaches argue that certain pitch levels or registers may be associated with laryngeal features like [stiff vocal folds], [slack vocal folds], [constricted glottis], and [spread glottis] (Halle and Stevens, 1971; Yip, 1980, 1993, 2002; Duanmu, 1990, 2000). These approaches attempt to capture the range of possible tone + laryngeal combinations by restricting the set of combinable distinctive features in a phonological representation. The phasing approach (Silverman, 1997b,a) argues that speakers abruptly time the articulation of laryngealization so that laryngeal pitch-perturbation effects will not influence tone on a syllable. For instance, one would predict a coda /h/ to begin abruptly after vowels on Trique syllables so as to not influence the pitch on the preceding vowel. The other logical possibility is that speakers produce gradually increasing breathiness across a vowel prior to a coda /h/.

The phasing approach is qualitatively different from the featural perspective insofar as it aims to explain the surface manifestation of laryngeals with respect to tone and does not claim that certain tone-laryngeal combinations are impossible. However, it makes an interesting prediction that pertains to tone-laryngeal distribution: if certain laryngeals do not significantly perturb pitch, there is no necessity for a phasing relationship to hold. As a consequence, more tonal contrasts may be licensed in laryngeal contexts where little perturbation occurs. This particular prediction is tested for Itunyoso Trique. I argue that breathiness only causes pitch perturbation for higher tones and only when it crosses a threshold in magnitude. This finding accords with the body-cover model of pitch control (Titze, 1994) and provides empirical support for the prediction from the phasing approach.

1.3 Language Background

1.3.1 Genetic Background

There has been some disagreement on the genetic affiliation of Trique in past comparative work, but the general consensus now is that it belongs to the Mixtecan branch of Eastern Otomanguean (Rensch, 1976). The earliest grouping of Trique with Mixtecan languages is found in León (1902). Subsequent genetic grouping removed Trique from the Mixtecan family, until the work of Longacre (1957) which analyzed the structure of Proto-Mixtecan. Both Rensch (1976) and Beam de Azcona (2004) (citing Kaufman's (2004) work) place Trique in the Mixtecan family with Mixtec and Cuicatec.

1.3.2 Geographic Background

Itunyoso Trique is spoken in the western part of the state of Oaxaca, Mexico, in a region called “La Mixteca.” It is one of three established Trique languages. All work on Trique has focused on the language varieties spoken in the three towns of San Juan Copala Trique, San Andrés Chicahuaxtla, and, in this dissertation, San Martín Itunyoso. Itunyoso Trique speakers explain the three varieties of their language most often with a story of three brothers who settled in three separate areas. The colloquial concept of different language varieties may reflect the three most divergent varieties of Trique, but there may also be some diversity between the varieties spoken in other Trique towns. Variants of Trique are also spoken in the towns of La Concepción Itunyoso, La Laguna Guadalupe, San Miguel Progreso, San Isidro Morelos/Chicahuaxtla, Yosoyuxi Copala, Tilapa Copala, Ladera Copala, Sabana Copala, and Tierra Blanca Copala. Each of the towns with the word “Copala” apparently speak a variant of Trique close to the San Juan Copala variant. The towns San Isidro Chicahuaxtla, San Miguel Progreso, and La Laguna Guadalupe speak a variant of Trique similar to that of San Andrés Chicahuaxtla. The town of La Concepción Itunyoso speaks a variant of Trique apparently similar to that of San Martín Itunyoso. These judgments are based on Itunyoso Trique speakers’ opinions, however, and should be considered only possible hypotheses of language similarity. Work on these unstudied Trique variants will probably shed light on the set of sound changes that make the three established languages unique.

The map in Figure 1.1 shows the Trique region and identifies 5 different Trique towns. San Juan Copala is located in the lower left corner. Slightly north of it is Sabana Copala. San Andrés Chicahuaxtla is located at the bottom middle area. San Martín Itunyoso is in the middle to the left. La Laguna Guadalupe is between San Andrés Chicahuaxtla and San Martín Itunyoso. All of the towns surrounding the Trique region are Mixtec speaking. San Martín Itunyoso is the northern boundary between the Trique region and the region of Tepostlatongo Mixtec. Figure 1.2 shows the location of San Martín Itunyoso within the larger perspective of Southern Mexico.

Figure 1.1: Topographic map of the Trique Region in La Mixteca. courtesy of Google Maps 2008.

Figure 1.2: Location of San Martín Itunyoso, courtesy of Google Maps 2008.

1.3.3 Previous Work

The earliest work on Trique is found in Belmar (1897), who investigated Chicahuaxtla Trique. Subsequent work on this language was completed by Robert Longacre (1952; 1959), Barbara (Elena) Hollenbach (1977), Claude Good (1979), and more recently Jerold Edmondson (2007). The earliest work on Copala Trique is found in Hollenbach (1973b) and Hollenbach (1973a). Subsequently, Hollenbach published an immense number of publications on the language, the more comprehensive publications being Hollenbach (1984b, 1992, 2004b), and (2004a). Copala Trique syntax has been investigated more recently in Broadwell (2004). The work of this author (DiCanio, 2005, 2006, 2007a) and the work in this dissertation is the only research yet completed on the Itunyoso Trique language.

1.4 Methods

1.4.1 Fieldwork & Database

I began fieldwork on Itunyoso Trique in San Martín Itunyoso, Oaxaca, Mexico in summer 2004. I conducted fieldwork in Oaxaca in summer 2005, summer 2006, and summer 2008. I conducted additional fieldwork in Livingston, California between Fall 2006 and Fall 2008. All fieldwork was conducted with bilingual native speakers of Itunyoso Trique and Mexican Spanish.

As part of my fieldwork and a community project to develop a dictionary on the language, I created a lexical database of Itunyoso Trique. The lexical database contains 1,444 items, 990 of which are non-compounds and 454 of which are compounds. Compound words are common in Itunyoso Trique, both within the verbal and nominal morphology. Token counts of the number of words which have a particular phonological structure are taken from the set of non-compound words in the database. While this method of counting excludes certain compounds which may have bound morphemes not found elsewhere, it ensures that many morphemes are counted only once when investigating the frequency of a pattern. For instance, the word /kkweh^{32}/ '*vegetable green*' contains a fortis labialized velar stop /kkw/. There are only two words in the database with this onset type, but this particular word is common, as it is used as a classifier for any type of specific vegetable green, e.g. /kkweh^{32} si^{2}koh^{2}/ '*chervil*', /kkweh^{32} ʃi^{1}ri^{1}tũ^{1}/ '*purslane*'.

1.4.2 Stimuli

Two separate experiments were conducted in this dissertation. The first experiment, described in chapter 4, investigated the fortis-lenis consonant contrast. The second experiment, described in chapter 7, investigated the realization of tones both within the context of coda laryngeals and in open syllables. The stimuli for both experiments were collected in tandem. A list of 91 Trique words in natural carrier sentences were collected, which contained all of the examined contrasts. These stimuli appear in the appendix. The methods used for each experiment are described in chapters 4 and 7, but a general note on the stimuli is given here.

Given the nature of the fieldwork, it was preferable to provide natural contexts for each of the words rather than unnatural contexts like “Say ___ again.” Therefore, some of the carrier sentences differed. Most of the stimuli were nouns, which appeared in the carrier sentence /ni^{4} ʔya^{43} ___ nã^{3}/, ‘*see.1sg* ___ here, *I see* ___ *here.*’ The contexts used for adjectives or verbs varied, but the phonological context surrounding the target word did not. The word preceding the an adjective or verb target had the vowel /i/ realized with tone /43/. The word following the target word began with the nasal /n/ and had tone level /3/. With the exception of the change of vowel in these contexts, the phonological environment surrounding all tokens was kept consistent. Each carrier sentence was repeated 6 times for a total of 720 repetitions per subject. Sentences produced with disfluencies were discarded and not analyzed. This was uncommon (roughly 2-5% of all tokens).

1.4.3 Subjects and Data Collection

Four female and four male speakers were recruited for the investigation. Six speakers were between the ages of 18 - 26. One male speaker, (C), was 35 years old at the time of recording. Another female speaker, (G), was 56 years old. All participants were native, fluent speakers of Itunyoso Trique who were raised in San Martín Itunyoso. No participant reported having a history of speech or hearing disorders.

For seven of the speakers, recording took place in a quiet room in a house located in San Martín Itunyoso in Oaxaca, Mexico. The remaining speaker was recorded in his home in the central valley of California, USA. Upon reading a consent form in Spanish, speakers supplied their verbal consent to participate in the acoustic investigation. Speakers who did not understand aspects of the investigation discussed their concerns with the author’s primary consultant who acted as an interpreter. The stimuli were read aloud in Trique by either the author or his consultant, who helped create the stimuli, as a prompt for the participant.

Participants spoke into a uni-directional dynamic hand-held microphone that was maintained at a comfortable distance by the author. Recordings were made directly onto the author's Apple iBook G4 computer using an M-Audio MobilePre®USB preamplifier as an audio interface. Praat version 4.6 (Boersma and Weenink, 2008) was used to record all data. All data were sampled at 44.1 kHz.

1.5 Chapter Summary

The following is a summary of the contents of the chapters of this dissertation. Chapters 2-4 relate to the segmental phonology while chapters 5-7 relate to the tonal phonology and its interaction with laryngeals.

In chapter 2, I describe the segmental phonology of Itunyoso Trique. The language is characterized with word-final stress, which is implemented by obligatory bimoraic syllable structure in final syllables, and a larger set of licensed contrasts. I provide the segmental inventory and the distribution of sounds within the language. I argue that the asymmetrical distribution of phonological contrasts is easily captured with the notion of *licensing inheritance* (Harris, 1997). The maximal number of contrasts are licensed in final syllables, which may license phonological contrasts on preceding syllables, if such contrasts surface on the final syllable.

In chapter 3, I examine the phonological and phonetic literature on articulatory strength. This includes the set of phonological and phonetic motivations for the features [fortis] and [tense], the notion of strength as the ability to attain an articulatory target, and a precise phonetic definition of what is expected within a language with a true contrast in articulatory strength. This literature is contrasted with approaches defining obstruent and singleton-geminate contrasts solely in terms of duration and glottal width adjustments. This chapter lays the groundwork for the acoustic and articulatory investigation of the fortis-lenis contrast.

In chapter 4, I report on an experiment investigating the fortis-lenis contrast using both acoustic methods and electroglottography. I find that the fortis-lenis contrast is mainly a durational contrast for both obstruents and sonorants. However, fortis obstruents occur with glottal spreading, realized by abrupt devoicing which may coincide with or precede oral closure (causing preaspiration). In the lenis obstruents, there is partial passive voicing. I argue that the durational differences and the glottal manner differences between lenis and fortis obstruents define the fortis-lenis contrast and explain patterns of lenition observed in the lenis obstruents. These findings challenge the views of Kirchner (2000) and Flemming (2001), and suggest that there is no need to posit abstract constraints ensuring target attainment in the production of fortis or geminate consonants. Durational differences and processes of passive voicing alone explain patterns of lenition.

In chapter 5, I describe the tonal phonology and how it relates to the distribution of laryngeals. In a similar manner to the segmental patterns observed in chapter 2, most of the tonal contrasts are restricted to the final syllable of the morphological word. I describe three tone rules/generalizations which apply to all words: leftward tone association, leftward tone spreading, and [+High] markedness. The first applies to a large set of words where only a final syllable has an underlying tone. Tone is assigned on the rightmost syllable and spreads leftward across the morphological word. The second rule applies to those words which have a low /1/ tone on the right edge of the word. Low tone spreading spreads leftward iteratively across the morphological word. This pattern predicts the odd alignment and distribution of contour tone /31/ in relation to the other contour tones, and ties this pattern together with a rule in the enclitic morphology. The third pattern states that only one tone that is specified as [+High] may occur in a morphological word, in accordance with the features used in the tonal register system. This pattern properly predicts the distribution of tone in non-final syllables and is similar in scope to the labial markedness rule observed in Chapter 2 (stating that only one [labial] consonant may occur in a phonological word).

In chapter 6, I examine the phonological and phonetic literature on the interaction between tone and laryngeals. I examine certain processes of tonogenesis from the perspective of laryngeal features, (cf. Halle and Stevens (1971)), from the perspective of tone-laryngeal phasing (Silverman, 1997b), and from the phonetics literature concerning the manner in which pitch and laryngeals are produced. This chapter lays the groundwork for the acoustic investigation of tone and laryngeals in the following chapter.

In chapter 7, I discuss an experiment exploring how the different tones are realized both on open syllables and in the context of coda laryngeals. I find that tones in the context of a coda /ʔ/ are realized with very short duration with pitch lowering across the preceding vowel's duration. The coda glottal stop in Itunyoso Trique is realized with complete glottal closure. By contrast, a coda /h/ is realized with gradually increasing vocalic breathiness across the duration of a vowel. Even though breathiness has significant magnitude, it does not influence pitch on lower tones and only influences pitch on higher tones once it surpasses a threshold. This observation accords with predictions of the body-cover model of vocal fold vibration (Titze, 1994). In this model, thyroarytenoid contraction (produced with [+slack vocal folds]) does not cause pitch-lowering in the context of less cricothyroid contraction (low F_0) but *does* cause pitch perturbations in the context of greater cricothyroid contraction (high F_0). The findings here also support the idea that more tonal contrasts may be licensed in the context of phonetic breathiness as it does not perturb pitch as much as creak does.

Chapter 2

Segmental Phonology

2.1 Introduction

A number of generalizations can be made concerning San Martín Itunyoso Trique segmental phonology if we base our observations on the structure of morphological words in the language. We define a *morphological word* here as a lexical root with whatever bound affixes are obligatory for it to occur as a free stem in a sentence. Bare verb roots are always bound morphemes in Trique. Aspectual prefixes are obligatory.[1] Bare alienable nouns may occur as free morphemes but inalienable nouns are always bound with an enclitic. The structure of morphological words in Itunyoso Trique is given in (1) and (2) where VC = *valence changing*. Examples of these patterns are given in (3) - (6).

(1) Verbal Morphology: [VC/ASP+VERB]$_{MW}$+enclitic

(2) Nominal Morphology: Gen+[NOUN]$_{MW}$+enclitic

(3) na^{2}-tʃi$^{3\mathrm{h}}$ka^{2}-sih^{3} ni$^{2\mathrm{h}}$kãʔ^{3}
CAUS-gotten.up-3sg.MASC early
He gets up early.

(4) ja$^{3\mathrm{h}}$kweh^{3} k-a^{3}ʔŋga^{3}-sih^{3}
Oaxaca PERF-be.born-3sg.MASC
He was born in Oaxaca.

---

[1] This is true even for "infinitival" clauses where both the matrix verb and the embedded verb are marked for aspect.

(5) si^{3}-tʃi^{1}ʔi^{1}-sih^{3}
GEN-illness-3sg.MASC
his illness

(6) nni^{3}-sih^{3}
mother-3sg.MASC
his mother

On verbs, aspectual prefixes are obligatory and are marked in two ways: with a prefix /k(V)/- or with a tone change on the first syllable of the verb root. When verbs appear with an (unproductive) valence changing prefix, aspectual differences are often only indicated by tonal differences. Alienable nouns may be bare stems in Trique. Inalienably-possessed nouns take an obligatory pronominal enclitic but never require a genitive prefix. The set of generalizations on the segmental phonology will be restricted to morphological words. The phonology of enclitics is separate from this discussion.

Morphological words are governed by a principle of *licensing by prominence* which is sensitive to a prosodic hierarchy within the word. All contrastive consonants, vowels, and tones in the language occur within the final syllable of the morphological word. Other syllables within the word contain only a subset of each of these categories. Moreover, word-final syllables are bimoraic while penultimate or antepenultimate syllables are monomoraic, implying that final syllables are accentually prominent. This dialect of Trique is not unique in this aspect, as both Chicahuaxtla Trique (Longacre, 1952; Hollenbach, 1977; Good, 1979) and Copala Trique (Hollenbach, 1977, 1984b, 2004a) have final syllable prominence as well.

The organization of this chapter is as follows: In §2.2, I describe the syllable structure and stress, as these two phenomena license the distribution of both segments and tone. In §2.3, I describe the consonantal phonemes in the language and their distribution. In §2.4, I describe the vowel phonemes in the language and their distribution. I will preface both §2.3 and §2.4 with the more general phonological rules affecting consonants and vowels. In §2.5, I summarize the findings presented in this chapter.

2.2 The Phonological Structure of Morphological Words

Itunyoso Trique is prosodically complex, having both final stress and a rich tone inventory (9 tones).[2] There are strong motivations for positing stress in the language apart from tone. The main evidence is the many asymmetries in the distribution of tone, consonants, and vowels. Further evidence comes from the asymmetry in syllable types by their position within the morphological word. While word-final syllables license all segmental and autosegmental contrasts in the language, penultimate and antepenultimate syllables permit far fewer contrasts.

2.2.1 Minimal and Maximal Words

Morphological words in Trique may be one to three syllables. Final syllables are obligatorily bimoraic. This is distinct from the more prevalent pattern in Mixtecan languages where the minimal word size is the disyllabic couplet (Josserand, 1983; Macaulay and Salmons, 1995; Macaulay, 1996; Macken and Salmons, 1997; Gerfen, 1999; Daly and Hyman, 2007). Even though monosyllabic words occur, they are not nearly as frequent as disyllabic words in Trique. From a set of 988 monomorphemic words, most are disyllabic, with fewer monosyllabic words and even fewer trisyllabic ones. This data is shown in Table 2.1. Examples of words of different size are given in Table 2.2.

Table 2.1: Frequency of Morphological Word Size

Word Size	Frequency	Proportion
Monosyllabic	222	22.5%
Disyllabic	648	65.6%
Trisyllabic	118	11.9%
TOTAL	988	

The prevalence of disyllables in Itunyoso Trique resembles the wider Mixtecan pattern. Assuming that disyllabic couplets reflect an earlier Proto-Mixtecan structure (see Josserand (1983)), it is a mystery how Trique came to have monosyllabic words. One hypothesis is that many historical disyllables lost their pre-final syllable nuclei which resulted in either onset clusters or geminates. The loss of pre-tonic vowels is an especially robust

---

[2] Tone and laryngeals will be described in Chapter 5.

Table 2.2: Morphological Words of Various Sizes

Monosyllabic		Disyllabic		Trisyllabic	
nã^{4}	*sunbeam*	ni^{3}nã^{3}	*spittle*	tʃi^{3}ri^{3}$^{\mathrm{h}}$kih^{4}	*grasshopper*
ʔjã^{31}	*scar*	ra^{3}ʔjãʔ^{3}	*mute*	ra^{4}ru^{4}βa^{43}	*breakfast*
tʃo^{32}	*comal*	ka^{1}$^{\mathrm{h}}$tĩ^{1}	*thin*	ru^{3}ni^{3}ʔja^{2}	*tejocote fruit*

pattern throughout historical Otomanguean phonology and is responsible for complex clusters in many Zapotecan languages (Jaeger and Van Valin, 1982). Both Trique and Zapotec possess word-final stress, the accentual pattern reconstructed for Proto-Otomanguean as well (Rensch, 1976).

Another hypothesis is that the bisyllabic CVV and VV couplets in Mixtec were reanalyzed as bimoraic but monosyllabic roots in Trique. If this were the case, one would expect a similar distribution of tones on disyllables and monosyllables in Trique, which is not the case. However, there is some synchronic phonetic evidence for this hypothesis, as the final vowel in disyllabic roots of the shape (C)V.CV is often shorter in duration than the final vowel of (C)V words in Itunyoso Trique.[3] Future work on the prosodic structure in Proto-Trique and Proto-Mixtecan will be revealing in this regard.

2.2.2 Syllable Structure

All syllables are open and may contain a small set of onset clusters. Final syllables may contain one of two final laryngeal elements (/ʔ/, /h/). When the final laryngeal is absent, the vowel in this syllable is long. The mutual exclusivity of vowel length and final laryngeals suggests an analysis where word-final syllables are bimoraic. Accordingly, final laryngeal elements consist of a single mora. However, these laryngeals are not considered codas. Arguments for this perspective are given in section 2.2.3. Representations of this analysis are shown in Figure 2.1 where L = *laryngeal.* Monosyllabic and disyllabic examples of the representations are given in Table (2.3).

Given this representations for final syllables in Itunyoso Trique, we may conclude that all final syllables in the language are heavy, while non-final syllables are light. Many languages demonstrate this strong connection between syllable weight and stress, known

---

[3] Though, again, it is uncertain if this reflects a cross-linguistic tendency for shorter words to have longer syllables (Lehiste, 1970).

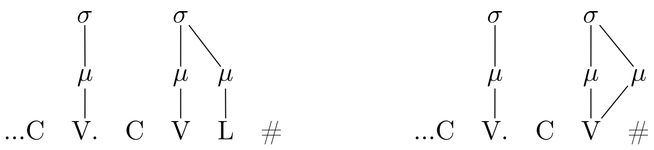


Figure 2.1

as the *weight to stress* principle (Hayes, 1981). The representations in (2.1) reflect such a connection. However, evidence from the asymmetries in the distribution of consonant and vowel types bolsters this argument. Many of the consonant and vowel types are licensed only within word-final syllables. The details of these phenomena will be further discussed in Sections 2.3 and 2.4.

Table 2.3: Examples of Syllable Structure

Monosyllabic	Example	Gloss	Disyllabic	Example	Gloss
V	ũ^{2}	*nine*	CV.V	tʃa^{3}ĩ^{3}	*mosquito*
Vʔ	oʔ^{3}	*question particle*	CV.Vʔ	ja^{1}iʔ^{1}	*bitter*
			CV.Vh	ri^{4}uh^{4}	*to whistle*
CV	βĩ^{3}	*to be (copular)*	CV.CV	tʃu$^{3\mathrm{h}}$ku^{3}	*animal*
CVʔ	βeʔ^{3}	*house*	CV.CVʔ	ru^{3}miʔ^{3}	*eclipse*
CVh	ruh^{3}	*fried pork rinds*	CV.CVh	si$^{4\mathrm{h}}$tuh^{3}	*bellybutton*
			V.CV	u$^{3\mathrm{h}}$tu^{2}	*to scratch (tr.)*
			V.CVʔ	a$^{3\mathrm{h}}$kwãʔ^{3}	*today*
			V.CVh	a^{4}sih^{3}	*clothing*

Onsets are not obligatory in Itunyoso Trique syllables. In a post-pausal position, a glottal stop is inserted before a vowel-initial word. This is deleted when the word appears embedded in a larger context (phrasal, sentential, utterance). When a final syllable in a polysyllabic word does not contain an onset, the preceding vowel does not form part of a diphthong with it. A clear length difference between these vowels is observed in accordance with final syllable vowel lengthening. For instance, the word /ja^{3}i^{3}/ '*serious*' is phonetically realized as [ja^{3}iː^{3}], not as *[jaɪ^{3}].

2.2.3 The Phonological Status of Laryngeals

A statement on the syllable structure of Trique would be trivial if it were not for the difficult issue of final laryngeals in the language. In descriptions of Mixtecan languages laryngeals are treated not as segments, but as prosodic features (Hollenbach, 1984b; Hinton, 1991; Macaulay and Salmons, 1995). Almost all Mixtecan languages, including the Trique languages, lack codas with an oral place of articulation. The only syllable-final phonetic material that seems to be allowed is a laryngeal (/ʔ/ or /h/). The reduced inventory of permissable codas and the tendency for laryngeal segments to be both contrastive and demarcative (Hyman, 1988) has led researchers to analyze laryngeal codas distinctly from the rest of the phonological inventory. There are essentially five analyses of laryngeals in phonological theory:

1. Laryngeals are segments, e.g. English, Tagalog, Trique (intervocalic), etc.
2. Laryngeals are a feature of vowels, e.g. Zapotec (Suárez, 1973; Beam de Azcona, 2004).
3. Laryngeals are a feature of tones, e.g. Chinese dialects (Zhang, 2001; Yip, 2002), Lahu (Matisoff, 1999), Trique (final) (Hollenbach, 1984b).
4. Laryngeals are features of a morpheme, e.g. Mixtec (Macaulay and Salmons, 1995).
5. Laryngeals are features of a prosodic unit (syllable, foot), e.g. Mixtec (Macken and Salmons, 1997).

Hollenbach (1984b) argues in favor of treating *final* laryngeals as autosegments belonging on the tonal tier in Copala Trique. An intervocalic glottal stop, however, is considered to be segmental and phonologically distinct from the final laryngeals. Her evidence for this analysis comes from both the distribution of laryngeals with tone and morphophonological alternations which delete/add a final laryngeal while altering tone. Since certain final laryngeals only occur with certain tones and alternate with tone in the morphology, tone and final laryngeals are considered partners on the same suprasegmental tier.[4] These distributional cooccurrence restrictions and morphophonological alternations do not affect other

---

[4] We will discuss more of the details regarding these interactions in Chapter 5. For instance, no contour tones may occur before a coda /ʔ/ and contour tones do not surface on the vowel before a coda /h/ in disyllabic words.

consonants, including the intervocalic glottal stop. There are both segmental and suprasegmental glottal stops in Copala Trique.

Macaulay and Salmons (1995) argue that laryngeal consonants are features of the root or couplet in Mixtec. Their evidence is mainly distributional: at most one glottal stop may appear in a root and none may occur in the affixal system. Laryngeals are morphemic features here. Previous authors had considered laryngeals to be segments or a prosodic feature on vowels in Mixtec. The segmental perspective would have to permit a syllable structure CV(C) where the only possible coda was a glottal stop in an otherwise coda-less group of languages. The vocalic perspective is unappealing because each /V+ʔ/ sequence would be considered an undecomposable syllable nucleus, resulting in a larger vowel inventory. There are 5-6 vowels in many Mixtec languages. Vowels may be oral or nasal, resulting in 10-12 vowels. Including laryngeals on vowels would double this inventory size (20-24). The root-based analysis avoids these problems while simultaneously according with the pattern whereby only one laryngeal may occur in a root and none in the affixal system.

2.2.3.1 Laryngeals in Itunyoso Trique

Like Copala Trique, Itunyoso Trique restricts all laryngeals and laryngealized consonants to the final syllable in the phonological word. Glottalized sonorants occur only as syllable onsets of final syllables while /h/ occurs only in final syllable coda position. A glottal stop may occur both as a syllable onset and in word-final position. Any combination of different laryngeal onsets and word-final laryngeals may occur in the final syllable of the language, shown in Table 2.4. Within this syllable, the presence of a final laryngeal prevents the lengthening of the preceding vowel. When there is no coda laryngeal in the final syllable, the vowel is long.[5] Neither coda laryngeals nor vowel lengthening occur in non-final syllables, which may only contain a short vowel.

When a glottal stop occurs intervocalically, it represents a true consonant; not part of a *rearticulated vowel* nucleus. Two pieces of evidence support this perspective. First, final syllable vowel lengthening occurs in sequences of the shape /VʔV/, where the second vowel is usually about twice or three times as long as the first[6]. Vowel lengthening is only

---

[5] This is true both in citation forms and in sentential contexts. There are no suffixes in the language. When personal enclitics attach, they do not prevent final vowel lengthening on the preceding root vowel.

[6] Since all laryngeal consonants are restricted to final syllables, such sequences are always restricted to the rightmost syllable.

Table 2.4: Possible Combinations of Laryngeals in Final Syllables

Combination	Word	Gloss	Word	Gloss
C+V	nne^{3}	*plough*	tʃa$^{3\,\mathrm{h}}$ta^{32}	*eagle*
C+Vʔ	nneʔ^{3}	*mecate*	tʃa$^{2\,\mathrm{h}}$taʔ^{2}	*sky*
C+Vh	nneh^{3}	*dream (N.)*	tʃa$^{3\,\mathrm{h}}$tah^{2}	*bird*
ʔC+V	ʔjo^{2}	*humid*	sti^{3}ʔni^{1}	*dinner*
ʔC+Vʔ	ʔniʔ^{1}	*be.salty*	si^{2}ʔniʔ^{2}	*dawn*
ʔC+Vh	ʔnih^{35}	*corn*	ni^{3}ʔnih^{3}	*open*
ʔ+V	ja^{3}ʔa^{3}	*brush*	ko^{3}no^{4}ʔo^{4}	*medicine*
ʔ+Vʔ	to^{3}ʔoʔ^{3}	*our chile (du.)*	ro^{3}ʔoʔ^{3}	*our hand (du.)*
ʔ+Vh	ja^{3}ʔah^{3}	*chile*	jo^{3}ʔoh^{5}	*land, earth*

conditioned in word-final syllables, suggesting that the second vowel in these sequences constitutes a distinct syllable nuclei, e.g. '*hand*' /ra^{3}ʔa^{3}/ –> [ra^{3}ʔaː^{3}]. Second, there is an absence of roots of the shape /CVCVCVʔV/ in Trique. When trisyllabic roots do occur do occur with a laryngeal, they either have the shape /CVCVCVL/ or /CVCVʔVL/. If /VʔV/ sequences comprised single syllabic nuclei, we would expect trisyllabic roots of the shape /CVCVCVʔV/ to occur. Their absence suggests that /VʔV/ sequences are parsed into distinct syllables.

In Itunyoso Trique, we observe the same pattern found in Copala Trique where there are segmental and suprasegmental glottal stops. Unlike Mixtec, it is not possible to say that laryngeals are a property of roots here because more than one may occur in a root and they also occur in the set of enclitics. Laryngeals, however, only surface in the *final* syllables of enclitics. Despite the differences between how laryngeals pattern in Mixtec and Trique, the argument that Macaulay and Salmons make against regarding final laryngeals as codas is useful in Trique. Given that no other coda may occur in a Trique syllable, it is compelling to regard final laryngeals as a "glottalic feature" as they do.

Since the root-based analysis can not apply to Itunyoso Trique, there are logically two alternatives: final laryngeals are either vocalic or autosegmental. Both Hollenbach (1984) and Macaulay and Salmons (1995) reject the vocalic perspective for the languages they examine, even though final glottalization is considered to be a vocalic property in Zapotecan languages (Pickett, 1959; Bartholomew, 1983; Munro and Lopez, 1999; Beam de Azcona, 2004) and in Chínantecan languages as well (Anderson et al., 1990; Rensch, 1990).[7]

---

[7] A survey of many languages with laryngealization associated to the syllable nucleus is found in Kehrein

The vocalic analysis of final laryngeals in Zapotec and Chínantec does result in larger vowel inventories. However, researchers on these languages do not consider larger vowel inventories to be a weakness in their analysis. Similarly, we can not out-right reject such an analysis for Itunyoso Trique on the basis of vowel inventory size. Rather, one must consider how laryngeals pattern with respect to the different vowels.

Table 2.5: Distribution of Vowels with Final Laryngeals

Final Laryngeal Vowel	none	/ʔ/	/h/
/i/	ri^{32} *harvest*	tsiʔ^{3} *pulque*	ttʃih^{2} *seven*
/e/	nne^{3} *plough*	βeʔ^{3} *house*	kkweh^{32} *quelite*
/a/	nna^{3} *bed*	kkaʔ^{3} *candle*	ttah^{3} *blue*
/o/	jo^{32} *sugarcane*	jjoʔ^{3} *year*	ttʃoh^{3} *zoyate*
/u/	ttu^{32} *thief*	a^{3}ruʔ^{3} *bowl*	ruh^{3} *pork rind*
/ĩ/	tsĩ^{3} *droplet*	ʈʈʂĩʔ^{3} *grass*	kĩh^{3} *nixtamal*
/ã/	jã^{32} *salt*	jãʔ^{3} *tooth*	jãh^{3} *paper*
/ũ/	sũ^{32} *work (N.)*	ku^{3}jũʔ^{2} *Friday*	ttũh^{2} *eight*

Table 2.22 shows the distribution of vowels in Itunyoso Trique with respect to final laryngeals. All vowels freely occur with a final laryngeal without exception. While this is not strong evidence *against* the vocalic perspective of laryngeals, it does not favor such an analysis.

Another approach is to consider final laryngeals to be autosegmental like tone. This is what Hollenbach argues in her dissertation (1984). Unlike the very free distribution with vowels, final laryngeals have a more restricted distribution with respect to tone. For instance, tones /35/ and /13/ only surface before a final /h/ while no contour tones are permitted before a final /ʔ/. The presence of cooccurrence restrictions like these suggest that laryngeals have the affect of restricting or licensing certain tonal patterns. Moreover,

---

(2002)

there are many morphophonological processes that target both tone and the occurrence of a final laryngeal at the same time. From these observations, there is more evidence in favor of the autosegmental view of final laryngeals in Itunyoso Trique than the vocalic view. While more details will be given in chapter 5, I argue that the autosegmental perspective of final laryngeals is correct for Itunyoso Trique. Final laryngeals are laryngeal features occupying a mora. Certain tones may or may not occur on the laryngeal mora. For practical purposes, I will continue to write them as segments.

2.2.4 Consonant Clusters

There is a very limited set of onset consonant clusters in Itunyoso Trique. Most of them occur in word-*initial* position. This probably reflects a process where vowels in penultimate syllables were reduced before final stressed syllables. A set of different words persist in Itunyoso Trique with two possible pronunciations: one with a deleted penultimate vowel and another without it. For instance, the word '*oil*' may be variably pronounced as either [ka^{3}sti^{43}] or [ka^{3}si^{4}ti^{43}]. The word '*mud*' is variably produced as either [si^{3}keʔ^{3}] or [skeʔ^{3}].

Related to this process of syncope is the fact that the morph /si$^{3}-$/ can apply to most nouns. This represents a productive prefix on possessed alienable nouns (non-animates) as a genitive marker. However, the morph also occurs word-initial in many non-possessed contexts, such as with all unpossessed color terms, e.g. /si^{3}ma^{2}re^{32}/ '*green*', or within a varied set of inalienable and alienable nouns, e.g. /si^{3}kiʔ^{4}/ '*chewing gum*', /si^{4}sno^{43}/ '*man*'. This morph only appears on noun roots. As a result, we might expect only nouns to have onset consonant clusters. This is exactly what we find: 40/42 tokens with onset clusters of the shape /s+C/ are nouns. The two exceptions are an adjective, /sko^{3}ʔloʔ^{3}/ '*skinny*', and a preposition, /ska^{4}nih^{3}/ '*between*'. Examples of the attested consonant clusters are given in Table (2.6).

With the exception of /gj/, a characteristic of the consonant clusters shown in Table (2.6) is their violation of the *sonority sequencing principle (SSP)* (Kenstowicz 1994). If fricatives and trills are more *sonorous* than stops, then we expect them to be sequenced after stops in onset consonant clusters. However, we mostly find clusters that disobey the SSP in Itunyoso Trique. In fact, Spanish loanwords with onset /kr/ clusters are borrowed as /rk/ or /kur/ in Itunyoso Trique. For example, the word /krus/ '*cross*' in Spanish is borrowed

Table 2.6: Itunyoso Trique Consonant Clusters

Consonant Cluster	Word	Gloss
/st/	sta^{3}ʔnah^{3} ta^{3}stu^{3}nde^{3}	*ghost* *Zaragoza (place name)*
/sk/	ske^{3}ʔeh^{3} skã^{31}	*mountain lion* *Santa María Tepostlatongo* (place name)
/sn/	snã^{4}ʔãh^{4} si^{4}sno^{43}	*language* *man*
/sw/	swa$^{3\,\text{h}}$te^{4}ʔe^{3} swe$^{4\,\text{h}}$koh^{4}	*mouse* *glasses*
/ʃkw/	si^{3} ʃkwih^{35}	*name*
/ʃk	na^{3}ʃkĩ^{32}	*reflect.3sg*
/rt/	kkweh^{32} rta^{3}ʔjã^{1} ma^{2}rtũ^{32}	*hierbamora* (herb classifier + name) *mayordomo*
/rk/	rka^{4}le^{43} si^{3} rku^{3}tʃih^{3}	*mayor* *purple*
/rkw/	rkwe^{3}tʃaʔ^{1}	*tejamanil*
/rm/	jah^{32} rma$^{3\,\text{h}}$tʃih^{3}	*sweet potato flower* (flower + species)
/gj/	ti^{3}gjãh^{4} ri^{3}gjaʔ^{3}	*Tlaxiaco (place name)* *chair (block))*

as *rku*^{4} *si*^{43} in Itunyoso Trique while the word /ɡɾiŋɡo/ '*gringo*' is borrowed as *ku*^{3} *ɾi*^{4} *ŋgu*^{43}. While the data set with clusters of this type is small, it shows that the language disfavors consonant clusters unless they conform to the set of possible ones permitted in the language.

The cluster /gj/ in Itunyoso Trique surfaces as a sequence /kij/ in the speech of some speakers, where the initial velar stop is lenis (see Section 2.3.2). However, this sequence occurs in a non-final syllable, which is shorter than a final syllable. The palatal glide and the front close vowel [i] coalesce here to create a single glide. In sentential contexts, this cluster often surfaces as [ɣj] where the stop is spirantized, similar to the lenis velar stop as described in §2.3.2.

Certain consonant clusters arise only in Spanish loanwords in Itunyoso Trique. For instance, most of the words for months of the year are borrowed from Spanish, where different consonant clusters occur. Examples of these clusters are given in Table 2.7.

Table 2.7: Consonant Clusters in Loanwords

Consonant Cluster	Word	Gloss	Spanish Origin
/fɾ/	fɾe^{4} ɾu^{43}	*February*	[feˈβɾeɾo]
/ɾs/	maɾ^{4} su^{43}	*March*	[ˈmaɾso]
/βɾ/	a^{2} βɾi^{3}	*April*	[aˈβɾil]
/lj/	hu^{4} lju^{43}	*July*	[ˈhulio]
/stj, mbɾ/	stje^{4} mbɾe^{43}	*September*	[septiˈemβɾe]
/skw/	skwe^{4} la^{43}	*school*	[esˈkwela]
/sr/	sɾa^{4} nu^{43}	*secretary (of government)*	[sekɾeˈtaɾio]

Loanwords are a part of the lexicon of any speaker of Itunyoso Trique, so they must not be separated from descriptions of the language's grammar or phonology. However, the set of loanwords are exceptional from a phonological standpoint, containing consonant clusters that do not occur elsewhere and segments which do not surface in the same position as in the rest of the language, such as /h/ in [hu^{4} lju^{43}] above. Loanwords agree with native tonology, where penultimate stress is on a disyllabic word is almost always borrowed as tone sequence /4+43/ (/3+4+43/ on trisyllabic words with penultimate stress). The phonological differences between native Trique vocabulary and loanwords suggest that speakers treat loanwords separately from the broader phonological generalizations found in the language. It is with this perspective that they are separated from the other consonant clusters in this chapter.

2.2.5 Discussion

The pattern of stress-driven phonological licensing found in Itunyoso Trique is similarly described in related Trique languages (Hollenbach, 1977, 1984a,b). In Copala Trique, Hollenbach observes that tone, the fortis-lenis consonant contrast, laryngeals, and vowel nasalization are maximally contrastive in word-final syllables. Copala Trique also has word-final vowel lengthening. In Chicahuaxtla Trique, Longacre (1952) discusses a general tendency of vowel lengthening in final syllables. The similar patterns among the three dialects suggest that final stress is a shared feature in the Trique languages.

In some Mixtec languages, the phonological unit of the *bisyllabic couplet* determines the distribution of both segments and tone (Macaulay and Salmons, 1995; Macaulay, 1996; Gerfen, 1999). In Chalcatongo Mixtec (Macaulay, 1996), glottalization is restricted to couplet-initial syllables. In Coatzospan Mixtec (Gerfen, 1999), glottalization is specifically licensed under stress. Stress alternations in lexical compounds condition an identical alternation in which syllables may allow glottalization to surface. However, the location of the stressed syllable in words is always the initial syllable and always the initial syllable of the head in compounds (the first word). While the distribution of glottalization in Coatzospan Mixtec is more complex than in Chalcatongo Mixtec, in both languages only the initial syllable of the couplet may license glottalization and other phonological contrasts. Initial syllables may be considered stressed in each of these languages. If this is true, then *licensing by prominence* is a characteristic of not only Trique languages, but perhaps the entire Mixtecan family.

2.3 Consonant Inventory

There are many distributional asymmetries among the consonants in Itunyoso Trique. While all 39 consonant phonemes occur in word-final (stressed) syllables, only 15 occur in non-final syllables. The set of consonants restricted to word-final syllables includes the fortis consonants, the laryngeals, the pre-nasalized stops, and the pre-glottalized sonorants. Only a subset of the consonant inventory may occur in both ultimas and non-ultimas, including lenis consonants and the pre-stopped nasal. The skewed distribution of consonants is one of the characteristics of *stress* described in Section 2.2.

The fortis-lenis distinction in Itunyoso Trique primarily involves a phonetic contrast in length, represented here with consonant doubling *C* vs. *CC*. The contrast is essentially one between geminates and singletons. I provide evidence for this perspective in Chapter 4 and in §2.3.2. For the time being, we will call the contrast "fortis-lenis." Many of the consonants have fortis and lenis counterparts, including stops, affricates, nasals, and approximants. The consonants that do not participate in this phonological contrast are the fricatives, preglottalized consonants, prenasalized stops, laryngeal consonants (/ʔ/, /h/), /p/, and /r/.

This section includes first a general statement on the consonantal phonology, followed by sections on obstruents, nasals, approximants, the pre-stopped nasal, and preglottalized sonorants. The plain consonant inventory is given in Table (2.8) and the glottalized consonants in Table (2.9).

2.3.1 General Phonological Patterns

Aside from the stress-conditioned distributional asymmetries noted above, there is one general phonological principle that extends across different consonants: Labial Culminativity. Consonants that are specified as [labial] do not occur in the same syllable as vowels that are [labial]. The entire set of labial consonants in Itunyoso Trique is affected (/p, kw, kkw, β, ββ, m, mm, ʔβ, ʔm/) such that none may occur as the onset of a syllable where the nucleus is /o, u, or ũ/. Sequences of /u, o/+ labial consonant are possible, but only occur across a syllable boundary. For instance, the word for '*dog*' is [tʃu^{3}βe^{3}] and the word for '*eclipse*' is [ru^{3}miʔ^{3}]. Thus, labial culminativity holds only within syllables. Since it applies to stops, fricatives, sonorants, and preglottalized consonants, it deserves mention prior to a more specific description of the phonological distribution of individual consonant types.

The pattern of labial culminativity is found within Chicahuaxtla Trique, as noted by Longacre (1957) and Silverman (2002). Silverman's paper explains the phonetic underpinnings of the development of labialized velar stops (/kw/, /gw/) in Trique. He argues that labialization spread rightward from labial vowels preceding a velar stop, e.g. /C**uk**V/, onto the stop itself. From an examination of Longacre's Trique wordlist, he notes that labialized segments are quite limited in their distribution. However, an examination of the data from Chicahuaxtla Trique and my database of Itunyoso Trique show another pattern

Table 2.8: Itunyoso Trique Plain Consonant Inventory

	Bilabial	Dental	Alveolar	Alveopalatal	Palatal	Retroflex	Velar	Labiovelar	Glottal
Stops	p	t, tt					k, kk	kw, kkw	ʔ
Pre-Nasalized	(mb)		nd				ŋg	ŋgw	
Affricates				tʃ, ttʃ		ʈʂ, ʈʈʂ			
Fricatives		s		ʃ					h
Nasals	m, mm		n, nn						
Pre-Stopped					cn				
Approximants	β, ββ		l, (ll)		j, jj				
Trills			r						

Table 2.9: Itunyoso Trique Glottalized Consonant Inventory

	Bilabial	Alveolar	Palatal	Velar
Pre-Nasalized Stops		ʔnd		ʔŋg
Nasals	ʔm	ʔn		
Approximants	ʔβ	ʔl	ʔj	
Trills		ʔr		

to be present. In both languages, only one labialized consonant may occur per word. While labialized vowels may be present heterosyllabically in a word with a labial consonant, only one labial *consonant* may occur. There are no apparent exceptions to this pattern, which we may call Labial Minimality.

The presence of both Labial Culminativity and Labial Minimality in Itunyoso Trique demonstrate that unique distributional patterns occur in the phonology of syllables and the phonology of roots. Labial consonants are distinct from other consonants in Trique in this regard. There are very few restrictions in the distribution of coronal and dorsal consonants. Most labial consonants are not reconstructable for Proto-Otomanguean (Longacre 1957, Rensch 1976) and are rare when they do occur. Their marked phonology in Trique may reflect both a broader historical pattern where labials were marked in Otomanguean. Such a hypothesis is best tested by examining labials in other Otomanguean languages and is outside the scope of this thesis.

2.3.2 Obstruents

Examples of words with obstruents are given in Table 2.10. The words in the left column show the stops surfacing word-initially in monosyllabic words. The words in the right column show the obstruents surfacing intervocalically in the final syllable of a disyllabic word.

Itunyoso Trique contrasts four oral places of articulation for stops, three for affricates, and three for fricatives. There are two types of obstruent contrasts in final syllables, shown above. There is no obstruent contrast in non-final syllables, where only voiceless unaspirated stops of short duration occur. The first final syllable contrast is in the onset of monosyllabic words and involves a difference in the phonetic duration of the obstruents, i.e. singleton-geminate. This contrast is depicted on the left side of Table 2.10. With the excep-

Table 2.10: Fortis-Lenis Obstruents in Final Syllables

Contrast	Word	Gloss	Contrast	Word	Gloss
/t/	toh^{13}	*a little bit*	/ð/	ɾu^{3}ðaʔ^{3}	*metate leg*
/tt/	tto^{32}	*metate*	/ʰt/	ka^{3}ʰto^{4}	*shirt*
/ts/	tsi^{32}	*ear of corn*	—	—	
/k/	kih^{1}	*ugly*	/ɣ/	ka^{3}ɣaʔ^{3}	*bottle, classifier for metal objects*
/kk/	kkih^{3}	*mountainside*	/ʰk/	a^{3}ʰka^{1}	*drip.3sg*
/kw/	kweh^{2}	*POT.jump.3sg*	/ɣw/	a^{2}ɣwah^{3}	*yell.3sg*
/kkw/	kkweh^{32}	*quelite*	/ʰkw/	tʃu^{3}ʰkwah^{3}	*ant*
/tʃ/	tʃuh^{3}	*pot*	/ʃ/	ka^{2}ʃih^{2}	*grow.3sg (person)*
/ttʃ/	ttʃuh^{3}	*egg*	/ʰtʃ/	tʃa^{3}ʰtʃih^{2}	*ram*
/ʈʂ/	ʈʂu^{3}	*tree*	—	—	—
/ʈʈʂ/	ʈʈʂĩʔ^{3}	*grass*	/ʰʈʂ/	tʃa^{1}ʰʈʂih^{1}	*wide*

tion of the bilabial stop /p/, all obstruents have singleton and geminate counterparts which are each voiceless, even in sentences where a voiced segment precedes them. In the stop category, singletons have a much shorter closure duration than geminates. For alveopalatal and retroflex affricates, there is a contrast in the duration of both the closure and the frication noise. I examine the phonetics of this particular contrast thoroughly in Chapter 4.

The second contrast is between voiceless preaspirated stops and [±voice] fricatives in the final syllable of polysyllabic words. This is depicted on the right side of Table 2.10. The fricatives [ð, ɣ, ʃ, ɣw] surface and contrast with the preaspirated stops in this position, but are quite rare. Leaving aside Spanish loanwords where the Spanish /ð/ is borrowed as /ð/ in Trique, there is only one native word (shown above) with an intervocalic [ð] in my database of Trique words. There are only two words with an intervocalic [ɣ], /ka^{3}ɣaʔ^{3}/ '*bottle*' and /ti^{3}ɣi^{3}jaʔ^{3}/ '*brush.oneself.3sg*', and only one native word with an intervocalic [ɣw] (above). There are 11 out of 988 morphemes in the database with the fricative /ʃ/. As a comparison, 125/988 morphemes in the database contain the fricative /s/. In spite of the contrast that is indicated above, certain voiceless intervocalic stops/affricates variably surface as voiced fricatives in frequent words, e.g. '*be.standing.3sg*' [ni^{3}kĩʔ^{3}]~[ni^{3}ɣĩʔ^{3}], '*POT.sleep.1sg*' [ka^{2}kwah^{2}]~[ka^{2}ɣwah^{2}]. Interestingly, this is most often observed with velar stops between identical vowels. The rarity of intervocalic fricatives and the variability in the production of intervocalic stops demonstrate that the intervocalic contrast between obstruents is functionally marginal.

Descriptions of other Trique languages treat the obstruent contrast in the onset position of monosyllables the same as the contrast in the final syllable of polysyllabic words. It is called a fortis-lenis contrast in both contexts (Longacre, 1952; Hollenbach, 1977, 1984b). In Copala Trique, Hollenbach (1984b) states that lax stops are weakened to fricatives between vowels, implying that they are realized as stops in word-initial position or in clusters. The same sort of pattern appears to exist in Chicahuaxtla Trique (Good, 1979) judging by the large number of words with intervocalic fricatives in the language. It is easy to consider an analysis for Copala or Chicahuaxtla Trique where the obstruent contrasts in different positions are underlyingly the same. One might surmise, as Hollenbach does, that the four fricatives [ð, ɣ, ʃ, ɣw] in Itunyoso Trique are underlyingly "lenis" while the preaspirated voiceless stops [^{h}t, ^{h}k, ^{h}tʃ, ^{h}kw] are underlyingly "fortis." In such an analysis, geminate obstruents in the onset position of monosyllabic words would be considered "fortis" while singletons would be considered "lenis." The following chapters investigate the issues with this analysis. For the purposes of this chapter, I will refer to both types of obstruent contrasts as "fortis-lenis" but transcribe them differently (as above).

2.3.2.1 Stops

While the major phonological patterns among the obstruents are described above, a few phoneme-specific points are worthy of mention here, such as those concerning /p/ and /ts/. In Itunyoso Trique, /p/ is quite rare.[8] It occurs in only 12/988 words in my Itunyoso Trique database. Seven of these cases are loanwords from Spanish. In native vocabulary, it surfaces only at the onset position in disyllabic words; i.e. /pa^{1}la^{3}/ '*lizard*' and /pa^{3}sĩh^{2}/ '*small kindling sticks*'. In loanwords like /la^{4}pi^{43}/ *pen* it may occur intervocalically. There is no fortis-lenis contrast for this phoneme.

The /ts/ phoneme has a rather restricted distribution in Itunyoso Trique, surfacing only before a high front [±nasal] vowel and only on monosyllables. The high vowel restriction follows directly from Rensch's (1976) reconstruction, where Proto-Mixtec */θ/ surfaces as [ts] before high vowels in Trique, as [t] before */a/ and */u/, and as [d] in final syllables of polysyllabic words. While /tt/ surfaces before vowels /a, o, u, and ũ/ in Itunyoso Trique monosyllables, it is does not surface before /i/ or /e/. The gap in the environments in which

---

[8] Surez (1973) does not reconstruct */p/ for Proto-Otomanguean and Rensch (1976) does not reconstruct it for Proto-Mixtec.

/tt/ surfaces as [tt] suggest that surface [ts] is underlyingly /tt/. Rensch's reconstruction utilizes data from Chicahuaxtla Trique, the only dialect that had been described at the time, but it fits the data in Itunyoso Trique as well. The historical evidence can therefore offer us an insight into the odd distribution of this particular sound.

2.3.2.2 Fricatives

Itunyoso Trique has 4 fricatives. Unlike the stops and affricates, they do not participate in the fortis-lenis contrast. The alveopalatal fricative /ʃ/ only surfaces before high vowels. The alveopalatal affricate /tʃ/ is often realized as [ʃ] intervocalically. The spirantization of the affricate appears to have spread across all instances of it in the related Trique dialects. Many cognates of Itunyoso words with /tʃ/ are transcribed as /ʃ/ "x" in both Copala and Chicahuaxtla Trique (Good, 1979; Hollenbach, 1984b, 2004b). For instance, the word for '*Yucunicoco*', a nearby town, is /tʃa$^{\mathit{3}\mathrm{h}}$ka$^{\mathit{3}}$/ in Itunyoso Trique, but xka$^{\mathit{3}}$ /ʃka$^{\mathit{3}}$/ in Copala Trique, and xa$^{\mathit{3}}$ka$^{\mathit{3}}$ /ʃa$^{\mathit{3}}$ka$^{\mathit{3}}$/ in Chicahuaxtla Trique. In both cases, the affricate cognate in Itunyoso Trique is realized as a fricative.

The glottal fricative /h/ only occurs in word-final syllables.[9] It is an exception among all consonants in Trique because it may only occur in word-final position, never word-internally.

2.3.3 Nasals and Pre-Nasalized Stops

Itunyoso Trique has a complex nasal inventory, having singleton and geminate nasals, pre-nasalized stops, a pre-stopped nasal, and nasalized vowels. While the geminate nasals and pre-nasalized stops have a restricted distribution, occurring only in word-final syllables, the other consonants do not. The bilabial nasals also conform to the labial culminativity rule in §2.3.1. Table 2.11 provides examples of the nasal consonant contrasts. The first column shows the nasal consonants in the final syllable position, the second in the nonfinal syllable position.

The restriction of both geminate nasals and pre-nasalized stops to word-final syllables is not accidental, as the cognates for the two geminate nasals in Trique are related to Proto-Mixtecan pre-nasalized stops */nd/ > /nn/, */mb/ > /mm/ (Rensch 1976). While

---

[9] The phonology of /h/ will be considered more extensively in Chapter 4 when I discuss laryngeals and tone.

Table 2.11: Nasal Consonant Data

Consonant	Word	Gloss	Word	Gloss
/m/	mã^{3}	*that (distal DEM.)*	ma^{3}kah^{5}	*Mexico City*
	ru^{2}mih^{3}	*bored*	me^{3}te^{3}	*skinny*
/mm/	mmãh^{2}	*fat, thick*		
/mb/	kã^{3}mbaʔ^{3}	*pumpkin*		
/n/	nã^{3}	*this (proximal DEM.)*	na^{3}mi^{32}	*lard*
	tʃi^{1}ni^{1}	*drunk*	nu^{3}kwãʔ^{3}	*word*
/nn/	nnãh^{3}	*bag*		
/nd/	nduh^{3}	*pimple*		
	su^{1}ndu^{3}	*doll*		
/ŋg/	ŋgah^{3}	Putla (place name)		
/ŋgw/	ŋgwi^{31}	person		

/mb/ and /nd/ still exist in Itunyoso Trique, they are very rare. Both /nn/ and /mm/ are more common. For instance, in a database of 988 morphemes, there is only one attestation of /mb/ (above) and 9 of /nd/. /mm/ surfaces 10 times and /nn/ 85 times. The restriction on where pre-nasalized stops can surface in Trique words was passed on through the process of sound change where they became geminate nasals. The pre-nasalized stop /ŋg/ still exists in Itunyoso Trique and is not uncommon (44 attestations). Unlike the other pre-nasalized stops, there is no singleton /ŋ/ or geminate /ŋŋ/ counterpart. The pre-nasalized labiovelar stop /ŋgw/ is very rare, surfacing in only 3 words in the lexicon. Nasal vowels never surface after pre-nasalized stops, similar to Copala Trique hollenbachɨəɵɥ. This restriction does not hold for geminate nasals, however, which may occur with a following oral or nasal vowel.

2.3.4 Pre-stopped Nasal /cn/

The pre-stopped nasal in Trique is an oddity in the phonological inventory. It appears to have derived from a historical process where the nominal prefix /ti/ became fused to roots beginning with an alveolar nasal. The pre-stopped nasal only surfaces word-initially, but occurs in both disyllabic and monosyllabic roots, which supports its origin as a fused prefix. The sequence [tin] underwent palatalization and vowel deletion, resulting in [cn]. The stop preceding the nasal here is palatal while the nasal itself is alveolar. Since this phoneme/sequence is rare, there is no particularly robust evidence for its origin, but the words that exist are suggestive. In Chicahuaxtla Trique, the word for '*brother (1.dual* *form)*' is [di^{4}nïʔ^{4}], while the word in Itunyoso Trique is [cnã^{32}].[10] Additionally, the word '*nopal cactus*' in Itunyoso Trique, [ti^{3}ni^{32}], has a variant [cni^{32}] produced by some speakers. While no sound of this sort exists in Copala Trique (Hollenbach 1984, p.c.), Itunyoso Trique has a pre-stopped nasal that appears in words which are cognate with the words written with "jn" in Chicahuaxtla Trique (Good, 1979).

Other Otomanguean languages may have pre-stopped nasals, but they have not been described in detail. For instance, in certain highland Mixtec languages there is a sound written as "tn" (Hollenbach, p.c.) while in others like Yosondúa Mixtec (Beatty de Farris et al., 2004), Atatlahuca Mixtec (Alexander, 1980), and Chicahuaxtla Trique (Good, 1979) there is a sound written as "jn". While "tn" straightforwardly represents a pre-stopped nasal, the "jn" sequence may either represent a voiceless nasal, or a nasally-released plosive. Examples of it in the Itunyoso Trique data are given in Table 2.12.

Table 2.12: Pre-stopped Nasal Data

Word	Gloss
cnã^{32}	*my.brother (of a male)*
cnah^{3}	*Yosoyuxi Copala (place name)*
cni^{4}ʔjãh^{4}	*comida (the event)*
cna^{4}kĩh^{3}	*opossum*
cne^{3}kwã^{32}	*guayava fruit*

2.3.5 Approximants

Itunyoso Trique contrasts two places of articulation in glide approximants: bilabial and palatal. There are two non-glide approximants: /r/ and /l/. There is a singleton and geminate counterpart for each approximant with the exception of /r/. Table 2.13 shows examples of each consonant. The column on the left gives all the approximants in word-final syllables. The column on the right shows the consonants that occur in nonfinal syllables.

While all lenis consonants have an unrestricted distribution, glides do not surface word-initially in trisyllabic words. There is not a large set of trisyllabic roots in Trique, but all the non-glide lenis consonants are attested in word-initial position. The lack of glide consonants in this position is also found in Chicahuaxtla (Good, 1979) and Copala Trique

---

[10] The vowel written ï in Chicahuaxtla Trique represents a high central unrounded vowel, phonetically [ɨ].

Table 2.13: Approximant Data

Consonant	Word	Gloss	Word	Gloss
/β/	βeʔ^{3}	*house*	βa$^{1\,\mathrm{h}}$tãh^{3}	*six*
	tʃa^{3}βi^{1}	*butterfly*	βa^{3}ne^{32}	*comadre*
/ββ/	ββe^{4}	*hair*		
	ββi^{13}	*two*		
/j/	joh^{35}	*forehead*	ja$^{4\,\mathrm{h}}$ku^{43}	*garlic*
	u^{3}jãh^{2}	*boil.3sg*	ju^{3}ʔβe^{32}	*tianguis*
/jj/	jjoʔ^{3}	*year*		
	jjeh^{3}	*stone*		
/l/	li^{43}	*small, little*	la^{3}kah^{3}	*skinny*
	tʃi^{3}luh^{5}	*worm*	la^{3}ʔβi^{3}	*poor person, orphan*
/ll/	llih^{3}	*little child*		
	lluh^{35} tʃi^{3}riʔ^{3}	*earthworm*		
/r/	ri^{32}	*harvest*	ra$^{3\,\mathrm{h}}$kah^{3}	*iguana*
	ku^{2}rih^{2}	*cricket*	re$^{3\,\mathrm{h}}$to^{32}	*blanket*

(Hollenbach, 2004b).

2.3.5.1 Bilabial Glides

The bilabial approximants surface with frication, while the palatal approximants do not. At first glance, this might suggest that the bilabial approximants are fricatives, but three pieces of phonological evidence indicate that they are underlyingly approximants. First, there is variation in how these consonants are produced. Most speakers pronounce /ββ/ as [ββ] and /β/ as [β]. For some speakers, either consonant can be realized with some complete closure, [b] or [bb], while for other speakers, the geminate consonant can be realized with less constriction as [ww]. The cases where there is complete closure seem to be exceptional variants in the speech of some speakers rather than their regular pronunciation. The labialized velar glide realizations, however, are consistent for those speakers who produce them. This pronunciation is perhaps more common among older speakers, as it was observed for two speakers (male, 35; female, 60), but not with the others I worked with (all under age 26). When the production of these consonants consistently varies, they are produced with less constriction, as glides. Second, Itunyoso Trique has a class of glottalized consonants, shown in Table (2.9) and described in Section 2.3.6. The consonants in this category are all phonetically sonorants (lacking turbulence), but a phonetically preglottalized bilabial fricative [ʔβ] also surfaces. If the bilabial fricatives were to be analyzed as underlying glides, then a stronger generalization could be made that the set of glottalized consonants consists of only sonorants. Finally, all cases of /β/ and /ββ/ are cognate with Chicahuaxtla Trique /w/ and /ww/ (Longacre, 1952; Hollenbach, 1977; Good, 1979). The bilabial fricatives that surface in Itunyoso Trique are underlyingly glides.

The bilabial glides obey the pattern observed in §2.3.1 as well, never surfacing before a rounded vowel (/o/, /u/, /ũ/). Following the stress-related phonological distribution shown in §2.2, fortis approximants do not surface in non-ultimate root syllables. The lenis ones do surface in this position though.

2.3.5.2 Palatal Glides

The lenis and fortis palatal glides contrast mainly in duration, with the latter having a longer duration of constriction than the former. The fortis /jj/ may only surface in monosyllables. The lenis glide approximant occurs in polysyllabic words, but is subject to a phonological restriction with other consonants. It may surface as the onset in the penultimate or antepenultimate syllables of a word, but when they do, no other palatal or retroflex consonant may occur within that word. It is only when a palatal glide is in this position that no other palatal or retroflex consonant may follow it. The class of consonants prohibited from occurring with /j/ is the alveopalatal fricative and affricates /tʃ, ttʃ/, the retroflex affricates /ʈʂ, ʈʈʂ/, and the palatal glides /j, jj/. Palatal glides may occur freely with other consonants in the word. For example, a word like /ja$^{3\mathrm{h}}$koʔ^{3}/ '*forest*' or /ja$^{4\mathrm{h}}$tu^{43}/ '*jícara*' is possible in Itunyoso Trique, but there are no words of the shape /jVtʃV/ or /jVjV/ in the language.

2.3.5.3 Liquids

The lenis non-glide approximants, /l, r/, have a very free distribution, surfacing in all positions in words. The fortis lateral approximant, /ll/, is marginal, being found only in a few words, e.g. /llih^{3}/ '*little child*', /lluh^{35} tʃi^{3}riʔ^{3}/ '*earthworm*'. The latter example here is a reduction of the root for '*worm*' /tʃi^{3}luh^{5}/. The fortis /ll/ may also surface when the root for '*cat*' is reduced /llu^{3}/ (from /tʃi^{3}lu^{3}/).[11] There is some variability in how the

---

[11] Such processes, while idiosyncratic, support the hypothesis that the singleton-geminate contrast arose from the loss of pre-tonic vowels.

/r/ is produced in Itunyoso Trique. In word-initial position it is either produced as a voiced alveolar tap, [ɾ], or as a voiceless alveolar trill [r̥]. Pre-glottalized trills, [ʔr̥] are produced with voicelessness as well. The presence of devoicing in the trill is very salient, as it often occurs with high amplitude post-alveolar frication.

2.3.6 Glottalized Consonants

The glottalized consonants in Table 2.9 are all restricted to word-final syllables following the general pattern of stress-conditioning given in §2.2. This class of consonants almost entirely consists of sonorants, with one exception: pre-nasalized stops may be glottalized. There is phonological rationale for expecting these consonants to pattern with sonorants though as they are partially specified as [+nasal].

Phonetically, all glottalized consonants are realized with pre-glottalization in Itunyoso Trique, even at word-initial position. All glottalized consonants occur intervocalically, but only a subset of them occur in word-initial contexts. Examples showing the distribution of the different glottalized consonants are found in Table 2.14. The column on the left shows all glottalized consonants intervocalically while the one on the right shows the ones which surface word-initially.

Table 2.14: Glottalized Consonant Data

Consonant	Word	Gloss	Word	Gloss
ʔβ	ru^{3}ʔβiʔ^{3}	*carbon*	ʔβi^{1}	*raw*
	tu^{3}ʔβa^{3}	*lid (of container)*		
ʔj	sni^{3}ʔjo^{4}	*jaguar*	ʔjã^{31}	*scar*
	ta^{3}ʔjũh^{3}	*Huajuapan (place name)*	ʔjo^{2}	*humid*
ʔn	tʃu^{3}ʔnu^{2}	*huipil*	ʔnih^{5}	*corn*
	tu^{3}ʔna^{32}	*rash*	ʔnaʔ^{3}	*come.3sg*
ʔm	tʃu^{3}ʔmã^{3}	*skunk*		
	a^{3}ʔmih^{3}	*speak.3sg*		
ʔl	to^{3}ʔloh^{3}	*rooster*		
	tʃu^{3}kwah^{5} ku^{2}ʔluh^{2}	*rainbow (compound)*		
ʔr	ni^{3}ʔru^{3}a^{32}	*much, a lot*		
ʔŋg	kwe^{3}ʔŋgo^{32}	*Monday*		
	a^{3}ʔŋgah^{3}	*hurt.3sg (intr.)*		
ʔnd	ku^{3}ʔndiʔ^{3}	*cactus fruit*		
	nne^{31} se^{3}ʔndeh^{3}	*calf (of a leg)*		

Hollenbach (1984b) analyzes glottalized consonants in Copala Trique as sequences of two phonemes, /ʔ/+ Consonant. There are reasons to reject this hypothesis for all Trique languages though. First, the two phoneme analysis expands the inventory of complex onsets that may be allowed in the language. In Copala Trique, where there is already a series of complex onsets, this analysis seems unproblematic. However, Itunyoso Trique contains few complex onsets, as was shown in Table 2.6. The lack of consonant clusters does not restrict the set of glottalized consonants though; they are found in all Trique languages regardless of the consonant cluster types found within the languages. If we consider them to be a sequence of phonemes, we would have to stipulate why they do not follow the patterns found among other consonant clusters in the languages. Second, a two phoneme analysis does not offer a principled explanation for why obstruents or fortis consonants are not permitted in /ʔ/ + C clusters. We would have to stipulate that only lenis sonorants occur with glottal stops in a cluster, rather than stating that these consonants are a separate phonemic category in the Trique languages. Finally, most consonant clusters occur word-*initially* in Trique. Glottalized consonants are restricted to final syllables. If we considered glottalized consonants to be sequences, then we would have to stipulate why they are restricted to final syllables and do not uniformly occur in word-initial position. All arguments suggest that glottalized sonorants are a distinct phonemic type in Itunyoso Trique and the other Trique languages as well.

2.3.7 Summary

While many consonant types occur in word-final syllables in Itunyoso Trique, a limited set occur in nonfinal syllables. Somewhat orthogonal to this distribution are the more specific restrictions on consonants that may surface in monosyllables or word-initial. The distribution of consonants in polysyllabic words in Itunyoso Trique is summarized in Table 2.16. Table 2.15 provides the contrasts appearing in monosyllabic words and Table 2.17 provides the contrasts occurring in syllables further from the rightmost, tonic syllable.

In Table 2.16 we observe that the position of maximal phonological contrast is the final syllable, where there are 29 contrastive consonants. Non-final syllables contrast 15 different consonants. Antepenultimate syllables may only contain 10 contrastive consonants. The leftmost syllable in the word has the minimal licensing capability while the rightmost syllable has maximal licensing capability. This pattern reflects a right-edge bias in a prosodic

Table 2.15: Contrasts in Monosyllables

Singleton Obstruents	/t/, /k/, /kw/, /tʃ/, /ʈʂ/, /s/, /ʃ/
Geminate Obstruents	/tt/, /kk/, /kkw/, /ttʃ/, /ʈʈʂ/
Singleton Sonorants	/m/, /n/, /β/, /j/, /l/, /r/
Geminate Sonorants	/mm/, /nn/, /ββ/, /jj/, /ll/
Glottalized Sonorants	/ʔn/, /ʔj/, /ʔβ/
Pre-nasalized Stops	/nd/, /ng/, /ngw/

Table 2.16: Contrasts in Initial-σ and Final-σ Onset Position in a Polysyllable

Contrast	Word-Initial	Intervocalic (Final σ)
Stops	/p/, /t/, /k/, /kw/	/^{h}t/, /^{h}k/, /^{h}kw/
Pre-nasalized Stops		/nd/, /ŋg/, /ŋgw/
Affricates	/tʃ/, /ʈʂ/	/^{h}tʃ/, /^{h}ʈʂ/
Fricatives	/s/, /ʃ/	(/ð/), /s/, /ʃ/, (/ɣ/), (/ɣw/)
Nasals	/m/, /n/	/m/, /n/
Approximants	/β/, /j/, /l/, /r/	/β/, /j/, /l/, /r/
Pre-Stopped Nasals	/cn/	
Glottalized Sonorants		/ʔm/, /ʔn/, /ʔj/, /ʔβ/, /ʔl/ /ʔnd/, /ʔŋg/, /ʔr/

Table 2.17: Contrasts by Syllable Position in a Polysyllable

Contrast	Antepenultimate-σ	Penultimate-σ	Ultimate-σ
Stops	/t/, /k/, /kw/	/p/, /t/, /k/, /kw/	/^{h}t/, /^{h}k/, /^{h}kw/
Pre-nasalized Stops			/nd/, /ŋg/, /ŋgw/
Affricates	/tʃ/	/tʃ/, /ʈʂ/	/^{h}tʃ/, /^{h}ʈʂ/
Fricatives	/s/, /ʃ/	/s/, /ʃ/	(/ð/), /s/, /ʃ/, (/ɣ/), (/ɣw/)
Nasals	/m/, /n/	/m/, /n/	/m/, /n/
Approximants	/l/, /r/	/β/, /j/, /l/, /r/	/β/, /j/, /l/, /r/
Pre-Stopped Nasals		/cn/	
Glottalized Sonorants			/ʔm/, /ʔn/, /ʔj/, /ʔβ/, /ʔl/, /ʔr/ /ʔnd/, /ʔŋg/

hierarchy where each consecutive syllable to the left of this position licenses fewer contrasts. We will return to this generalization in §2.5.

2.4 Vowel Inventory

The phonology of Itunyoso Trique vowels also manifests the pattern of licensing by prominence. While there is no phonological restriction on the most peripheral vowels (/i/, /a/, /u/), there are two distinct patterns affecting the distribution of nasal vowels and mid-vowels. These patterns are described in §2.4.2, 2.4.3, and 2.4.4. Similar to the consonant inventory, vowels are very restricted in nonfinal syllables. The complete vowel inventory is given in Table 2.18 along with examples in Table (2.19). The column on the left in Table 2.19 shows all vowels that occur underlyingly in final syllables while the column on the right shows all vowels that occur underlyingly in nonfinal syllables.

Table 2.18: Itunyoso Trique Vowel Inventory

	Front	Central	Back
Close	i, ĩ		u, ũ
Close-Mid	e		o
Open		a, ã	

The vowels /i/, /e/, /a/, /o/, and /u/ are realized [i], [e], [a], [o], and [u] in all positions, respectively. Occasionally one observes a lower variant of [ɛ] for /e/ in nonfinal syllables. A lower variant is not observed for /o/, which is restricted in nonfinal syllables (see §2.4.4).

2.4.1 Vowel Sequences

Where a syllable lacks an onset, sequences of two vowels are permitted. Vowel sequences are not diphthongs in Itunyoso Trique however. One of the main correlates of final stress is vowel lengthening. Vowels in word-final syllables have longer duration than vowels in non-final syllables. Upon analyzing 5 repetitions of 26 disyllabic words from 6 speakers in sentential contexts[12], I found that the mean duration of penultimate syllable

---

[12] This is the same data used to analyze the effect of tone on duration in disyllabic and monosyllabic words in Chapter 7.

Table 2.19: Vowel Data

Vowel	*Final Syllables*	*Gloss*	*Non-Final Syllables*	*Gloss*
/i/	tsi^{32} tu^{3}ri^{3}	*ear of corn* *blind*	tʃi$^{3\mathrm{h}}$koh^{5}	*wing*
/e/	tʃe^{32} ru^{3}ne^{32}	*my.father* *bean*	re$^{3\mathrm{h}}$to^{32}	*blanket*
/a/	ʈʂa^{3} tʃa$^{3\mathrm{h}}$ta^{32}	*tortilla* *eagle*	tʃa$^{3\mathrm{h}}$to^{32}	*rabbit*
/o/	tʃo^{32} na$^{2\mathrm{h}}$ko^{2}	*comal* *dry*	to^{3}ʔloh^{3}	*rooster*
/u/	ttu^{32} tʃi^{3}lu^{3}	*thief* *cat*	tʃu$^{3\mathrm{h}}$tʃe^{32}	*chicken*
/ĩ/	tsĩ^{3} ka$^{1\mathrm{h}}$tĩ^{1}	*droplet* *thin, narrow*		
/ã/	ʈʂã^{32} tʃa$^{3\mathrm{h}}$tã^{3}	*floor, cement* *pineapple*		
/ũ/	ttũ^{3} tʃa$^{2\mathrm{h}}$tũ^{2}	*blood* *youngest sibling*		

rimes is 80.8 ms. (24.9 ms. sdev) while the mean duration of final syllable rimes is 125.9 ms. (27.0 ms. sdev). This data is shown in Figure 2.2. A one-factor repeated measures ANOVA with Speaker as an error term found word position (penultimate vs. ultimate) to have a significant effect on vowel duration ($F[1, 5] = 310.0$, $p < 0.001$ ***).

In two vowel sequences that occur at the right edge of the root[13], the second vowel is longer than the first vowel. The process of vowel lengthening here targets the final, stressed syllable, the same as above. This would imply that two vowel sequences are in separate syllables. If the sequence were a true diphthong, one might expect an equal timing relationship where both vocalic targets of the diphthong are lengthened in a final syllable. Vowel sequences consist of independent vowels.

In V+V sequences, the first vowel must be one of the three most peripheral vowels /i, a, u/ and the second must be another one of the peripheral oral or nasal vowels, /i, a, u, ĩ, ã, ũ/. Sequences of the same vowel quality are not permitted, which leaves 12 possible V+V sequences in the language. Of these, 9 are attested. Examples of these are given in Table 2.20.

---

[13] The majority of VV sequences occur at the right edge.

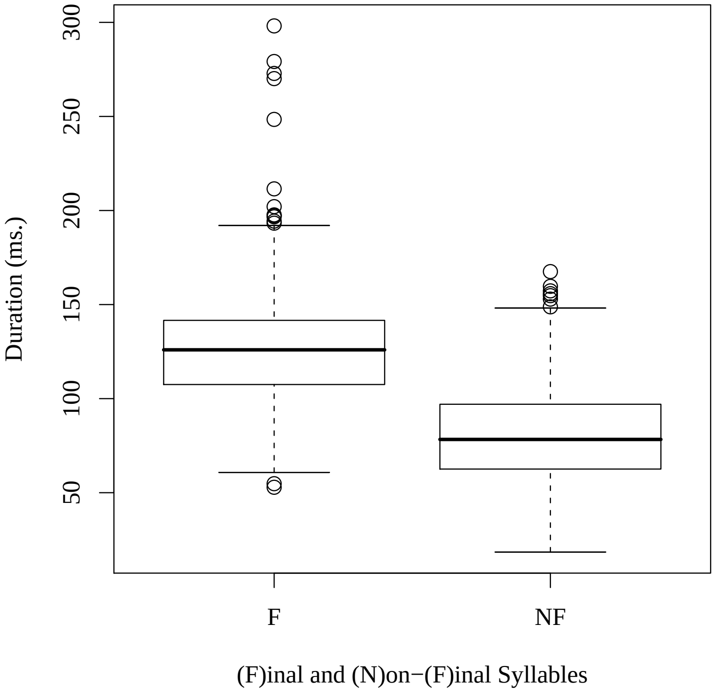


Figure 2.2: Vowel Duration Measurements

Table 2.20: Vowel-Vowel Sequences

VV Sequence	Word	Gloss
/i/+/u/	ri^{4}u^{4}	*hummingbird*
/i/+/a/	ni^{3}a^{1}	*sweat*
/i/+/ũ/	na^{3}ri^{3}ũ^{3}	*compare/measure.3sg*
/i/+/ã/	ri^{3}ã^{32}	*face (N)*
/u/+/i/	si^{3}ru^{1}ih^{1}	*knee*
/u/+/a/	ni^{2}ʔru^{3}a^{32}	*very*
/a/+/i/	ja^{1}iʔ^{1}	*bitter*
/a/+/u/	ru^{4}ma^{4}u^{4}	*pink*
/a/+/ĩ/	tʃa^{3}ĩ^{3}	*mosquito*

2.4.2 Nasal Vowels

We observe in Table 2.19 that all nasal vowels are restricted to word-final syllables. Nasalization does not occur underlyingly in non-final syllables. There is little variation in the realization of nasal vowels. The vowels /ĩ/ and /ũ/ are realized [ĩ] and [ũ], respectively. The phonologically nasal /ã/ is phonetically realized as a mid-central unrounded vowel [ə̃]. For example, the word *eleven* /tʃã^{1}/ is realized as [tʃə̃^{1}].

Vowels occurring after a nasal consonant are always phonetically nasalized in Itunyoso Trique. Contrastive vowel nasalization is neutralized in this position for the high vowels but not for the low vowels /ã/ and /a/. This contrast is probably maintained because of the differences in phonetic vowel quality between the oral vowel [a] and its nasal counterpart [ə̃]. For example, the word /na^{4}/ ([nã^{4}]) *old* contrasts with the word /nã^{3}/ ([nə̃^{3}]) *there (distal)*. The former example does not have an underlying nasal vowel while the latter one does. The phonetic process of coarticulatory nasalization does not condition vowel raising and is not limited to final syllables as phonologically nasal vowels are. There may be differences between these two types of nasalization in relative degree and timing, but this is an issue that will not be addressed here.

2.4.3 Nasal Spreading

Underlying nasalized vowels are restricted to word-final syllables. However, there is a phonological process of nasal spreading that nasalizes the vowel on the preceding syllable. This process applies across syllables where there is no intervening consonant, as well as when the intervening consonant is a glottal stop, a glide, or a glottalized glide. Nasalization does not spread across other consonants with greater oral constriction. Interestingly, nasalization does not spread through a nasal consonant. I provide examples of nasal spreading in Table 2.21.

A secondary effect of this nasal spreading is the nasalization of the syllable's onset. This occurs in syllables beginning with a phonological lenis glide /j, β/, where each consonant may be optionally produced as either [j̃, β̃] or [ɲ, m]. While nasalization continues to spread across the syllable boundary for the palatal glide, it does not spread further than the onset consonant for the bilabial glide. There are relatively few examples of nasal vowels following the bilabial glide in Itunyoso Trique. It may be the case that nasal spreading applied to historical */β + Ṽ/ contexts and produced /m+Ṽ/ sequences. Some words with a medial

Table 2.21: Nasalization Spreading

Context	Underlying Form	Surface Form	Gloss
No onset	/ri^{3}ã^{32}/	[rĩ^{3}ə̃^{32}]	*face*
	/tʃi^{3}ũ^{2}/	[tʃĩ^{3}ũ^{2}]	*bat (animal)*
	/tʃa^{3}ĩ^{3}/	[tʃã^{3}ĩ^{3}]	*mosquito*
/ʔ/	/na^{3}ʔã^{3}/	[nə̃^{3}ʔə̃^{3}]	*burn.3sg*
	/ni^{3}ʔĩ^{3}/	[nĩ^{3}ʔĩ^{3}]	*know.3sg*
	/ju^{3}ʔũh^{3}/	[jũ^{3}ʔũh^{3}]	*woman*
/j/	/u^{3}jãh^{2}/	[ũ^{3}j̃ə̃h^{2}]	*boil.3sg*
	/a^{3}jãh^{3} ttũ^{3}/	[ã^{3}j̃ə̃h^{3} ttũ^{3}]	*bleed.3sg*
	/jũ^{4}/	[j̃ũ ∼ ɲũ^{4}]	*earthquake*
	/jã^{32}/	[j̃ə̃∼ ɲə̃^{32}]	*salt*
/ʔj/	/ki^{3}ʔjãh^{3}/	[kĩ^{3}ʔj̃ə̃h^{3}]	*party*
	/tʃi^{3}ʔjãh^{3}/	[tʃĩ^{3}ʔj̃ə̃h^{3}]	*breast (of meat)*
/β/	/βĩ^{3}/	[β̃ĩ∼mĩ^{3}]	*to be (copular)*
	/βãh^{4}/	[β̃ə̃h^{4}]	*dig.3sg*

/m/ are suggestive of this. For instance, the verb '*sink.3sg*' is /na^{3}ʔmã^{4}/. The word appears to be the combination of the causative /na^{3}/ prefix and the word for '*dig.3sg*' above, both in segmental content and tone. There is a close semantic relationship between a verbal meaning of '*CAUS+dig*' and '*sink*'. While there are not many such examples, they support an analysis where nasalization spreading conditioned a historical change of */β/ > /m/ before nasal vowels.

2.4.4 Mid-Vowel Licensing

Mid vowels in Itunyoso Trique have a restricted distribution. The vowels /e/ and /o/ differ in the way they are restricted though. The vowel /o/ may only occur in non-final syllables when all the following vowels are also [o]. Another way of stating this is that the vowel on the stressed syllable must be /o/ in order to license /o/ on non-final syllables. The vowel /e/ freely occurs on both ultimate and penultimate syllables but surfaces in antepenultimate syllables only when it also surfaces on the penult. Essentially, the further away a vowel is from the stressed final syllable in a word, the greater the set of phonological restrictions. A Table showing the vowel distribution in disyllabic and trisyllabic words is given in Tables 2.22, 2.23, and 2.24. While final syllables license all vowel contrasts, penultimate syllables license more vowel contrasts than antepenultimate syllables.

Table 2.22: Distribution of Vowels in Disyllabic Words

σ_2 σ_1	/i/	/e/	/a/	/o/	/u/	/ĩ/	/ã/	/ũ/
/i/	ri^{3h}ki^{3} stomach	tʃi^{3h}tʃe^{3} devil	ni^{4h}ka^{43} to carry	ki^{3}ʔjo^{1} zacate	tʃi^{3}lu^{3} cat	tʃi^{3h}kĩ^{32} scorpion	mi^{2}rã^{32} to write	ni^{1h}tʃũʔ^{1} near, close
/e/	ne^{3}nih^{1} ground bean	me^{3h}te^{3} skinny	ne^{3h}ka^{3} scissors	re^{3h}to^{32} blanket	le^{4}ru^{43} ram	kwe^{4h}kĩ^{43} onion	ne^{3h}tã^{3} ejote	X
/a/	tʃa^{3}βi^{1} butterfly	sta^{3}re^{4} spider	tʃa^{3h}ka^{3} Yucunicoco (place name)	ka^{3h}to^{4} shirt	ja^{4h}ku^{43} garlic	na^{3}sĩ^{3} tomato	la^{3h}kwã^{3} cripple	ka^{3h}tʃũʔ^{1} shade
/o/	X	X	X	ko^{3}lo^{3} turkey	X	X	X	X
/u/	nu^{3}βi^{32} church	tʃu^{3h}tʃe^{32} hen	tʃu^{3}βa^{4} armadillo	X	tʃu^{3h}ku^{3} animal	ku^{3}sĩ^{32} beard	tʃu^{3h}tã^{3} bee	ku^{2}ʃũ^{2} to scoff
/ĩ/	X	X	X	X	X	X	X	X
/ã/	X	X	X	X	X	X	X	X
/ũ/	X	X	X	X	X	X	X	X

Table 2.23: Distribution of Initial Vowels in Trisyllabic Words

σ_2 σ_1	/i/	/e/	/a/	/o/	/u/
/i/	ri^{2}ki^{2}βeh^{2} San Pedro Yoyoscua (place name)	X	tʃi^{3}ka^{3}βiʔ^{3} sister, female cousin	tʃi^{2}ko^{3}ʔo^{32} sibling of opposite sex	ʃi^{2}ru^{3}ʔβe^{32} rich, wealthy
/e/	X	ke^{3}re^{3}ŋgaʔ^{4} early morning greeting	X	X	X
/a/	ka^{2}ni^{2}ʔja^{1} Puebla (place name)	sma^{3}te^{3}ʔe^{3} rat	ka^{2}ra^{3}ʔah^{3} to whisper	na^{1}no^{1}ʔo^{1} to pray	ta^{3}stu^{3}nde^{3} Zaragoza (place name)
/o/	X	X	X	ko^{3}no^{4}ʔo^{4} medicine	X
/u/	tʃu^{2}kwi^{3}ʔi^{32} sister (of female)	X	tʃu^{3}a$^{4\mathrm{h}}$tu^{43} billygoat	X	tʃu^{3}ku$^{4\mathrm{h}}$ti^{43} large basket without cover

Table 2.24: Distribution of Final Vowels in Trisyllabic Words

σ_3 σ_2	/i/	/e/	/a/	/o/	/u/	/ĩ/	/ã/	/ũ/
/i/	ti^{3}ri^{3}ʔi^{3} nervous	ri^{2}ki^{2}βeh^{2} San Pedro Yoyoscua (place name)	ka^{2}ni^{2}ʔja^{1} Puebla (place name)	X	ki^{3}ri^{3}ʔjuh^{3} rotten	ki^{3}ʃi$^{3\text{h}}$kĩ^{32} early morning greeting	ru^{2}tʃi^{3}jã^{32} pomegranate	na^{3}ri^{3}ũ^{3} to measure
/e/	X	sma^{3}te^{3}ʔe^{3} rat	X	X	X	X	X	X
/a/	tʃi^{3}ka^{3}βiʔ^{3} sister of a male (voc.)	ra^{4}tʃa^{3}ne^{3} San Isidro del Estado (place name)	ka^{2}ra^{3}ʔa^{3} to whisper	X	tʃu^{3}a$^{4\text{h}}$tu^{43} billygoat	tʃi^{2}ra$^{3\text{h}}$kĩ^{3} cockroach	ʃi^{2}ka^{2}mã^{2} jícama	a^{4}ra^{4}sũ^{43} to use
/o/	so^{1}ʔo^{3}ntʃeʔ^{3} compadre (vocative)	X	X	ka^{1}no^{1}ʔo^{1} to wait	X	X	X	X
/u/	ku^{3}ru^{3}βiʔ^{3} monkey	ta^{3}stu^{3}nde^{3} Zaragoza (place name)	ra^{4}ru^{4}βa^{43} breakfast	X	ku^{2}tu^{3}ŋgu^{32} Sunday	X	ra^{3}tʃu^{3}mãh^{3} Cuquila (place name)	X

The restricted distribution of /o/ is not entirely surprising in Itunyoso Trique. Rensch (1976) does not reconstruct */o/ in Proto-Otomanguean, but instead reconstructs only one back rounded vowel, */u/. As a result, there is a tendency in some Otomanguean languages to restrict the distribution of either /o/ or /u/. This is true of the other Trique dialects Hollenbach (1977, 1984b, 2004b); Good (1979), Chalcatongo Mixtec (Macaulay, 1996:30), and Yatzachi el Bajo Zapotec (Butler, 2000).

2.4.5 Summary

Vowels in Itunyoso Trique are subject to a set of phonological restrictions which are primarily explained through the principle of licensing by prominence. Essentially all vowel contrasts are licensed in the final, stressed syllable of the word. A subset of these contrasts are licensed in nonfinal syllables under the condition that the same contrast appears in the final syllable of the word. Both the distribution of nasalization and /o/ fall under this condition. A nasal vowel in a nonfinal syllable only appears when its nasal vowel trigger occurs in the final syllable and when the intervening consonant is a glide or glottal stop. The vowel /o/ only appears in a nonfinal syllable when it also appears in the final syllable.

The distribution of the mid vowel /e/ is distinct from /o/, as it freely occurs in penultimate syllables without it appearing in a final syllable. There may be a similar type of contingency in its distribution: its occurrence in an *antepenultimate* syllable necessitates its concurrent appearance in the penultimate. However, /e/ was only found in the first syllable of one trisyllabic word, /ke^{3}re^{3}ŋgaʔ^{4}/ '*early morning greeting*'. The relative paucity of trisyllabic roots prevents a strong distributional claim for /e/.

Shown in Table (2.25), the patterns in the vowel distribution demonstrate a tendency towards the licensing of maximal phonological contrast in word-final position and minimal phonological contrast in positions further leftward in the phonological word. The asterisk in the table indicates that the vowel contrast may only appear in such a position when followed by the same vowel contrast.

In final syllables in Itunyoso Trique, there are 5 contrastive vowel qualities and contrastive vowel nasalization. In penultimate syllables, only 4 vowels are licensed while both /o/ and vowel nasalization are restricted. In antepenultimate syllables, only three vowels are licensed with /e/ possibly having restrictions on its distribution. The general pattern here is one of increasing phonological contrast toward right edge of the morphological word.

Table 2.25: Vowel Phonology Summary

Antepenultimate-σ	Penultimate-σ	Ultimate-σ
/i/, /a/, /u/	/i/, /a/, /u/	/i/, /a/, /u/
/e/*	/e/	/e/
/o/*	/o/*	/o/
	[+nasal]*	[+nasal]

The vowel pattern resembles the pattern shown in §2.3.7 for the consonant inventory.

2.5 Discussion

2.5.1 Prosodic Licensing in Itunyoso Trique

The distribution of segments in Itunyoso Trique is heavily asymmetrical. Stress licenses many of the phonological contrasts in the language. The fortis-lenis contrast, glottalized sonorants, pre-nasalized stops, final laryngeals, and vowel nasalization are each only licensed in stressed syllables. In unstressed syllables, syllable structure is simpler with fewer contrasts.

The summaries given in §2.4.5 and §2.3.7 demonstrate the phonological asymmetries in the distribution of both vowels and consonants. These data fit neatly within the principle of *Licensing Inheritance* described in Harris (1997) where *the ability of a syllabic position to license melodic material directly reflects its status within the prosodic hierarchy* (p. 317). In his theory, Harris combines patterns of consonantal neutralization and vowel neutralization under a single set of principles. One principle is *Licensing Inheritance* and the other is a *Licensing Principle* where each prosodic or melodic unit in a representation must be bound in some way to some other unit in order to receive phonetic interpretation.

Harris distinguishes between prosodic and autosegmental licensing. While the former refers to the legitimization of a whole segment by the syllabic position to which it is attached (McCarthy, 1979; Itô, 1986), the latter refers to the legitimisation of particular feature specifications by syllabic constituent nodes (Goldsmith, 1990; Itô and Mester, 1993). Harris states that there is some dependency between both types of licensing, where the ability of a position to support autosegmental contrasts crucially depends upon its place within the prosodic hierarchy. All positions have a-licensing (autosegmental licensing) potential, which is their ability to either directly a-license a melodic unit or to confer a-licensing potential on another position. A position obtains its ability to license autosegmental contrasts from its prosodic licensor.

In Itunyoso Trique, the prosodic hierarchy ranks the rightmost syllable the highest, as the most accentually prominent. This is followed in decreasing order by penultimate and antepenultimate syllables. Final syllables license laryngeals, glottalized sonorants, final laryngeals, fortis consonants, prenasalized stops, and contrastive vowel nasalization; all the most restricted segment types in the language. Non-final syllables do not license these contrasts. While penultimate syllables permit /p/, /cn/, and glides, none of these are licensed in antepenultimate syllables. These licensing asymmetries follow the prosodic hierarchy ranking as an example of prosodic licensing.

Another type of licensing occurs in Itunyoso Trique, based on dependency between adjacent positions within the prosodic hierarchy. A final syllable may license either vowel nasalization or /o/ on a penultimate syllable. A penultimate syllable may license /e/ on the antepenult, but the antepenult does not hold any privelaged status over the other syllables. The ability of a position to license phonological units in other syllables is distinct from the intra-syllabic licensing referred to above. However, Harris' theory permits the two types of licensing to be combined under *Licensing Inheritance*. The more prominent position within the phonological word not only licenses the contrasts within its own position but also confers such an ability on adjacent positions it governs.

2.5.2 Final Comments

The description of the segmental phonology given here differs in many ways from the descriptions provided for related Trique languages (Hollenbach, 1977, 1984b). First, while Hollenbach considers glottalized sonorants to be sequences, I analyze them as single units in Itunyoso Trique. Second, for Copala Trique, Hollenbach does not observe any difference between sonorants in terms of a fortis-lenis contrast. They do appear in the descriptions of Chicahuaxtla Trique in Longacre (1952) and Good (1979). Third, there is no pre-stopped nasal in Copala Trique, but there may be one present in Chicahuaxtla Trique (Good, 1979). While Copala Trique is stated as having 22 consonant phonemes, Itunyoso Trique has 40. The difference in the segmental inventories arises out of both differences between the languages and from the arguments that I provide in favor of treating certain sequences as single units.

While a statement of the segmental phonology is a necessary prerequisite to an analysis of the language's phonetics, one aspect of the segmental phonology is particularly relevant here: the fortis-lenis contrast. Descriptions of what is called a "fortis-lenis" contrast often do not include any mention of its phonetics. So researchers are left to assume that the contrast involves any one of the following phonetic parameters: consonantal duration, voicing, aspiration, or articulatory strength. We know that languages are diverse in how stops may contrast with each other(Ladefoged and Maddieson, 1996). So one ought to be specific about how contrasts are produced in a language that has not yet been described, at least qualitatively or impressionistically. In Chapter 4 I examine the phonetics of this contrast in Itunyoso Trique. This work is prefaced with an investigation of the literature on articulatory strength and consonant types in Chapter 3.

Chapter 3

The Phonetics and Phonology of Strength

3.1 Introduction

In this chapter I examine the literature on consonantal strength. While substantial research argues that articulatory strength is merely a secondary correlate to a primary length or laryngeal feature contrast, other research argues that strength can be a *primary* correlate of a phonemic contrast. The former view argues against the inclusion of strength features in the set of distinctive features while the latter argues that strength can be directly encoded as a feature.

Jaeger (1983) mentions that the terms *fortis* and *lenis* may be considered phonological categories which are associated with a set of phonetic cues. One can also consider these terms from a purely phonetic perspective, where a *fortis* articulation involves more effort than a *lenis* one. These two perspectives are at the heart of a debate on articulatory strength: is it phonological or phonetic?

The phonological approach to distinctive features has been historically grounded in a set of alternations that reflect a particular natural class. For instance, the English plural suffix alternates as /ɨz/, /z/, or /s/ depending on the voicing and stridency features on the noun stem. A noun stem with a final [+voice], [−strident] segment conditions /z/, e.g. /lɛgz/ '*legs*', a noun stem with a final [−voice], [−strident] segment conditions /s/, e.g. /laks/ '*locks*', and a noun stem with a final [+strident] consonant conditions /ɨz/, e.g. /fɪʃɨz/

'*fishes*'. The alternations between plural allomorphs are predictable based on the distinctive feature specification on the final segment in the stem. There is evidence for natural classes of voiceless, voiced, and strident segments due to the fact that sounds belonging to each group behave in a predictable way. Regardless of whether the phonological [+voice] class here contains *phonetic* voicing, elements belonging to this class behave differently from the phonological [−voice] class. Features both define a contrast and condition specific phonological alternations. Here, the featural "label" may simply be a cover term expressing a phonologized difference between sounds.

However, distinctive features are more than just cover terms. Certain featural combinations are constrained by their phonetic nature. For instance, the feature [+nasal] rarely co-occurs with the features [+continuant] and [strident], i.e. voiced nasalized fricatives [z̃, ɣ̃]. There are convincing aerodynamic (phonetic) explanations for the paucity of nasalized fricatives in languages of the world (Ohala and Ohala, 1993). The combination of distinctive features is constrained by the phonetics. Furthermore, from a phonetic perspective one may ask which acoustic and articulatory correlates typify a particular contrast and which are most important perceptually. Insofar as phonological theory seeks to ground distinctive features in speech production and perception, the primary phonetic correlates of phonological contrasts may define their featural representation.

In investigating the phonetics of particular contrasts I adopt strong notions of contextual stability and phonetic invariance (Jessen, 1998; Stevens, 2002). In a phonological [VOICE] contrast, one predicts that the presence of low frequency spectral energy is the primary acoustic correlate and all other correlates are subordinate. Similarly, one predicts that for a phonological length contrast, duration is the most robust acoustic correlate. If *fortis* is a phonological category, one predicts articulatory strength and its acoustic correlates to be similarly robust. These primary acoustic and articulatory properties of segments are favored by speakers and hearers in producing and perceiving sound contrasts.

This line of reasoning allows us to formulate a strong hypothesis. If it is found that articulatory strength differences are either not present or subordinate to other phonetic correlates, then there is no need to posit strength features. If it is found that articulatory strength differences are primary, then such differences ought to be encoded in a set of distinctive features.

In this chapter I examine the phonetics and phonology of articulatory strength. I will discuss two theoretical perspectives on strength: the [TENSE] theory of Jansen (2004) and the [LAZY] theory of Kirchner (1998) and Flemming (2001). The [TENSE] and [LAZY] theories argue that articulatory strength is encoded in the phonological system and that it accounts for patterns of voicing and lenition in obstruents. I conclude that such patterns are better explained by the set of glottal width features discussed in Iverson and Salmons (1995, 2003) and Jessen and Ringen (2002). This particular view agrees with the phonetic correlates of articulatory strength examined in §3.3. There is no need to encode strength in the phonology to account for these patterns. I extend this glottal feature analysis to Otomanguean languages in §4.6 which motivates the type of phonetic analysis in Chapter 4.

This chapter is organized as follows. In §3.2, I review the research on consonant strength in phonological theory. In §3.3, I examine the acoustic and articulatory correlates of strength. I examine which phonetic correlates/cues would typify a true [tense] contrast as one involving articulatory strength and which correlates/cues tend to pattern with other distinctive feature contrasts. In §3.4, I examine the phonetics and phonology of the fortis-lenis contrast in Otomanguean languages. In §4.6, I discuss the points examined in this chapter with reference to the phonetic study in the following chapter. I will pay particular attention to distinguishing between the terms *fortis* and *lenis* as phonological labels and as phonetic descriptors of articulatory differences.

3.2 Theories of Strength

The notion of strength in phonetics and phonology has various interpretations. *Strength* may be encoded within the set of distinctive phonological features, within a set of phonetic correlates/cues, or within both the phonetics and the phonology. For instance, the *phonological* strength feature [tense] does not necessarily include increased articulatory strength as one of its correlates, but instead represents a set of divergent phonetic behaviors that typify a linguistic contrast and explain a set of phonological alternations (Jessen, 1998; Jansen, 2004). On the other hand, *phonetic* strength refers to articulatory and acoustic correlates which reflect greater muscular tension and biomechanical energy, as discussed in Section 3.3. Approaches that assume a phonogical feature [fortis] which is manifested with increased articulatory energy are reflected in Jakobson et al. (1976) and in Kohler (1979, 1981, 1984). The analysis of obstruents in terms of the features [fortis] and [tense] is distinct from the proposal that laryngeal features like [voice], [spread glottis], and [constricted glottis] define the phonological contrast. The laryngeal feature proposal argues that there is no need for [tense] in the set of distinctive features and processes of voicing in Germanic are better handled with the feature [spread glottis] (Iverson and Salmons, 1995, 2003; Jessen and Ringen, 2002).

Articulations which succeed in reaching a particular articulatory or acoustic target have also been described as stronger or involving more effort (Kirchner, 1998; Flemming, 2001). Most theories of strength in phonology discuss consonants because their articulatory targets are more easily measured.[1] Certain consonant types (like obstruents) have historically been described in terms of articulatory tension (Jakobson et al., 1976; Chomsky and Halle, 1968). I review these various featural proposals here.

3.2.1 The Feature [tense]

The distinctive feature [tense] can refer to three distinct notions within the consonant type literature. First, it may reflect a difference in articulatory strength. In this perspective, it is grounded in the details of the phonetic manifestation of the contrast. Second, it may be a phonological cover term representing a set of disparate phonetic correlates/cues which may or may not include articulatory strength. Third, it may represent a stable or invariant articulatory/acoustic target in speech production. In this perspective, articulations which are maintained in a variety of conditions or contexts are stronger than ones which undergo processes of lenition. This is a slightly different idea of strength than the previous notions because it is more general and reflects the ability of a set of articulators to reach an intended target, whether it be consonantal or vocalic. It is not a cover term for a set of phonetic characteristics representing obstruent contrasts.

While the presence of vocal fold vibration is considered to be the primary correlate of a phonological [VOICE] contrast, the presence of other phonetic correlates which co-occur with voicing has led many researchers to question the status of [VOICE] as a distinctive feature for certain contrasts. Implicit in many phonological theories of strength is the idea that consonants with invariant articulatory targets are stronger than ones which are subject to more contextual modification. The phonological feature [tense] has been used to represent this notion of strength (Jakobson et al., 1976; Chomsky and Halle, 1968; Jessen,

---

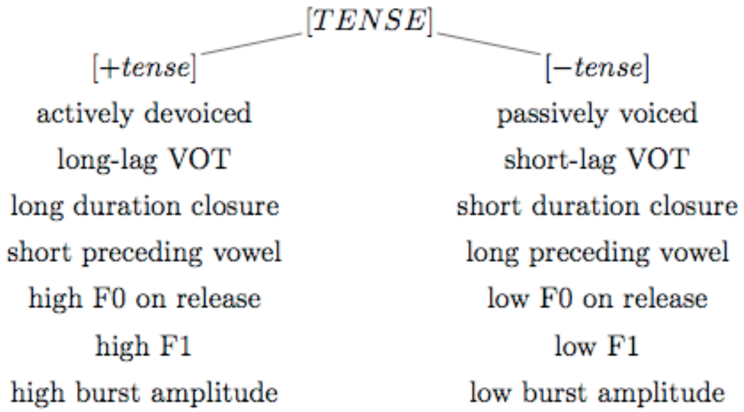
[1] For instance, one can not measure how a speaker reaches a vocalic target with articulatory measures like electropalatography (EPG).

1998; Jansen, 2004). From this perspective, one predicts [+tense] or *fortis* consonants to be less vulnerable to phonological processes of weakening than [−tense] or *lenis* consonants. I define *weakening* here as the set of processes which result in an increase in the contextual sensitivity of a segment. Any assimilatory process is therefore a type of weakening, as the place, manner, or laryngeal feature specifications of the target consonant are contextually-determined. Resistance to weakening would therefore be a characteristic of phonologically strong consonants.

Within phonological theory one seeks to both describe the weakening processes affecting particular segment types and to capture them with a set of distinctive features. When certain features naturally account for why such processes apply, one posits them as part of the consonants underlying representation. When the set of existing features does *not* capture such processes, other more abstract features may be necessary. Investigating data from English, Dutch, and German, Jansen (2004) and Jessen (1998) argue for the feature [tense] in Germanic obstruents precisely because the range of phonological processes affecting them is not easily accounted for using only the laryngeal features [voice] or [spread glottis]. There are three arguments for their analysis. First, they observe that phonetic voicing is not present in all positions where a phonologically "voiced" stop occurs. In both English and German, there may be no phonetic voicing during a stop closure when it occurs utterance-initially but voicing when intervocalic. For instance, the English words [kʰɒɫ] *call* and [kɒɫ] *gall* do not contrast in voicing, but in short-lag vs. long-lag VOT (Lisker and Abramson, 1964; Keating, 1984).

Second, there is a lack of phonetic correspondence between stops which have been described as both voiceless ([−voice]) and unaspirated ([−spread glottis]). In a language like English where aspiration may be phonologically contrastive, [+voice] stops are voiceless unaspirated word-initially but voiced intervocalically. In a language like Polish where a series of [+voice] consonants always occur with pre-voicing, the voiceless unaspirated series never occurs with voicing intervocalically (Keating, 1984; Jansen, 2004). Both languages have what would be transcribed as voiceless unaspirated stops word-initially, i.e. Polish [tak] *yes* vs. English [tak] *dock*, but labelling each stop as [−voice], [−spread glottis] does not capture the differences between them. Polish voiceless unaspirated stops never undergo passive voicing while English voiceless unaspirated stops do. Jansen (2004) argues that the feature [tense] better distinguishes between the English and Dutch "voiced" and "voiceless" obstruents than the feature [voice]. Jessen (1998) argues the same for German. Unlike

Figure 3.1: Jansen (2004) - Correlates of [TENSE]



Polish, voicing arises only passively in English, Dutch, and German voiced stops. The third argument is that obstruent contrasts in most Germanic languages are realized mainly via vowel duration word-finally, where vowels are systematically shortened before a voiceless obstruent (House and Fairbanks, 1953; Lehiste, 1970; Kluender et al., 1988; Jessen, 1998; Jansen, 2004). There is nothing inherent in the phonological feature [voice] that would capture this phenomenon.

Jansen and Jessen argue that both [voice] and [tense] are necessary in the distinctive feature specification of Germanic obstruent types. Similar to the analysis of voicing given in Kingston and Diehl (1994), Jessen states that [tense] and [voice] share a set of phonetic cues/correlates and will overlap to a certain degree. I provide a schematic of Jansen's proposal in Figure 3.1 and Jessen's proposal in Figure 3.2. Each proposal associates a set of phonetic correlates with the feature [tense].

Jansen (2004) and Jessen (1998) account for the disconnect between the phonological feature [voice] and true phonetic voicing in terms of a [tense] feature in the phonological representation. In their approach, there is a direct mapping between the phonological feature and the set of phonetic correlates with which it is realized. However, Keating (1984) proposes that the disconnect is resolved if an intermediate level of phonetic implementation features are specified. In her model, languages differ in terms of both a phonological [voice] feature and a continuum of phonetic implementations: voiced, voiceless unaspirated, and voiceless aspirated. This directly incorporates the VOT continuum discussed in Lisker and Abramson (1964): prevoiced, short-lag VOT, and long-lag VOT. Depending on the

Figure 3.2: Jessen (1998) - Correlates of [TENSE]

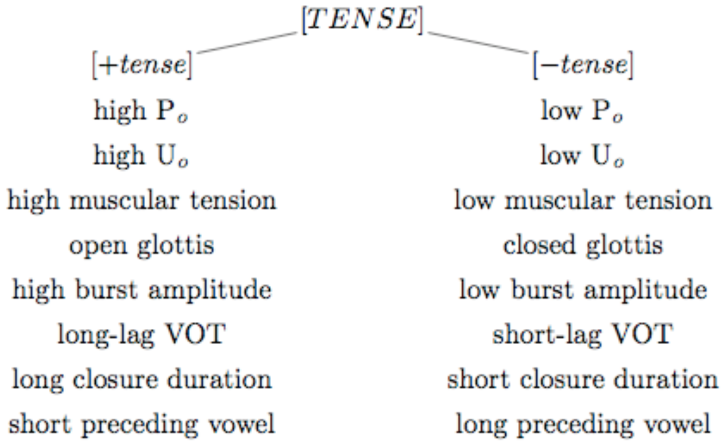
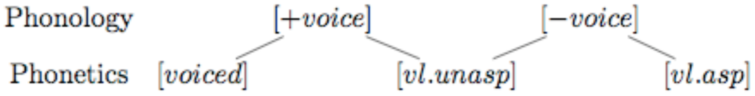


Figure 3.3: Keating (1984) - Model of [VOICE]

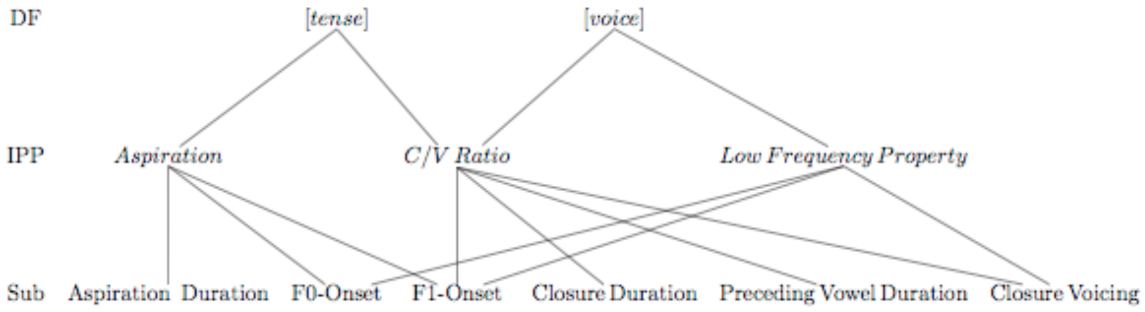


context, a language may realize phonologically [+voice] obstruents as either voiced or voiceless unaspirated just as it may realize phonologically [-voice] obstruents as either voiceless unaspirated or voiceless aspirated. A schematic of Keating's proposal is shown in Figure 3.3.

This model permits voicing to be phonetically underspecified in certain languages, where the contrastive phonological features may be [+voice] and [0 voice], or even [0 voice] and [−voice]. Yet, Jansen states that the crucial *phonological* feature here is not [voice], but [tense]. When [tense] is underspecified for an obstruent, voicing is entirely dependent on passive processes of voicing and devoicing.

While Jansen argues in favor of [tense] as a phonological feature in English and Dutch instead of [voice], Jessen argues that both [tense] and [voice] may occur as phonological features within the same language but may share phonetic correlates. Borrowing from the three-level model in Kingston and Diehl (1994), he states that there is a set of immediate perceptual properties (IPP) as well as a set of subproperties (Sub) which define a contrast. His model is shown in Figure (3.4). Unlike Keating's model, the nodes at the IPP are not complementary, but the set of different cues that may realize the distinctive feature.

Figure 3.4: Jessen (1998) - Model of [VOICE] and [TENSE]



Jessen's model allows the C/V Ratio to be a shared, but substitute correlate of either a [voice] contrast or a [tense] contrast. Aspiration is the main cue for a [tense] contrast and the Low Frequency Property (Stevens and Blumstein, 1981; Kingston and Diehl, 1994) the main cue of a [voice] contrast. Each of these immediate cues has a number of possible subproperties that may be shared.

Apart from voicing, the ratio between the duration of a consonant and the preceding vowel is often considered a correlate of a singleton-geminate contrast (Ham, 2001). Shorter preceding vowels occur with longer following consonants while longer preceding vowels occur with shorter following consonants. This is generally considered to be a property of the prosodic structure of geminate and singleton consonants where the former occupies an additional timing slot (a mora) in the preceding syllable. The presence of this additional timing slot results in closed-syllable vowel shortening (Maddieson, 1985). This property of geminate consonants, while not universal, is not a property of a distinctive feature.

Upon considering these points, Jessen argues that consonantal length contrasts are featurally-triggered: the presence of a [+tense] feature in a consonant results in a two-to-one mapping at the autosegmental level. Jessen's critique of the autosegmental representation of geminates is that it predicts length and aspiration to be independently contrastive cross-linguistically, but the presence of both of them is in fact rare cross-linguistically. His analysis diverges from Jansen (2004), who predicts that singleton-geminate contrasts are distinct from the feature [tense], even though both utilize the V/C ratio as a cue.

3.2.1.1 Voicing Control

Phoneticians distinguish articulations which involve active adjustments from those that involve passive adjustments. Passive processes are essentially byproducts from other articulations. For instance, the production of the [k] between [ŋ] and [θ] in the English word [stɹɛŋkθ] *strength* arises because the preceding sound has velic closure while the following fricative does not. Devoicing and velic raising precedes the interdental fricative which creates an emergent stop (Ohala, 2005). This is a passive process insofar as the stop is an unintentional consequence of the gestural timing of consonants in American English. Laryngeal voicing and devoicing gestures may also be active or passive processes in the same way.

A crucial component to Jansen and Jessen's analysis of [tense] is the idea of voicing control. One of the difficulties in labelling obstruents phonologically [+voice] or [-voice] (or [0 voice] assuming privativity (Cho, 1990)) is that neither label accounts for how voicing or devoicing may come about. Jansen (2004) argues that the conditions on *phonetic* voicing depend on the [tense] specification of consonant. A [+tense] obstruent in a voicing language will be actively devoiced while the [−tense] obstruent is actively voiced. A [+tense] obstruent in an aspirating language will be actively devoiced while the [−tense] obstruent is passively voiced.[2]

Passive devoicing will occur if aerodynamic conditions for voicing are not met. There are a number of contexts which will impede voicing, each of which has been used to explain historical and typological patterns of devoicing in obstruents. Greater subglottal pressure is required for the initiation of voicing than for its continuation (Ohala, 1983; Löfqvist and McGowan, 1992; Stevens, 2000). For this reason, utterance-initial [+voice] obstruents often lack voicing during their closure duration. Subglottal pressure does not build up fast enough for prevoicing to occur. Second, obstruents with longer closure duration may undergo passive devoicing. Longer duration will result in a greater buildup in intraoral air pressure and a decrease in subglottal pressure, two conditions which will inhibit voicing (Ohala, 1983). As a consequence, it is common cross-linguistically for voiced geminates to devoice. Third, obstruents with a more posterior constriction will be devoiced more quickly. The volume of the back cavity is smaller in such cases which causes intraoral air pressure

---

[2] The distinction that Jansen draws here is similar to the phonological and phonetic voicing features proposed by Lisker and Abramson (1964) and Keating (1984) discussed in §3.2.1.

to rise more quickly. As a result, it is common to find a voiced bilabial stop in the sound inventories of different languages but a voiced velar stop is less common. If a language contains voiced velar stops, it will always have a voiced stop at a more anterior place of articulation (Maddieson, 1984). Understanding the conditions on passive devoicing, Jansen argues, can explain the positional effects of obstruent voicing as well as patterns of voicing assimilation in English and Dutch.

Active voicing occurs where specific articulatory adjustments are made to sustain voicing in a context where it may be inhibited, such as those described above. There are many articulatory maneuvers that may permit sustained voicing, such as laryngeal lowering (Kingston, 1985), slacking the vocal folds, and venting intraoral air pressure via the nasal cavity (Ohala, 1983; Iverson and Salmons, 1996). There are particular acoustic consequences associated with these adjustments, which I discuss in §3.3.1.2.

Voicing may also occur passively in particular speech contexts. A voiceless obstruent which follows a voiced segment will have 20-60 ms. of *passive voicing* unless specific laryngeal adjustments are made to prevent it (Westbury, 1983; Westbury and Keating, 1986; Stevens, 2000; Jansen, 2004). These active adjustments include laryngeal raising, glottal spreading, and glottal constriction. *Active devoicing* occurs when one of these adjustments is made. For instance, the English *voiceless* stop may occur with aspiration in stressed or word-initial syllables not following /s/ or it may occur with glottal constriction, [t͡ʔ] when word-final or before a syllabic nasal. In both cases, an active laryngeal adjustment is made to prevent passive voicing from spreading into the closure duration, either glottal spreading or glottal constriction.

3.2.2 The Feature [fortis]

Kohler (1984) posits that there is a phonological feature [fortis] that reflects articulatory power. Here, *power* is realized with differences in articulatory timing or phonatory power/tension, i.e. Lindblom (1983). Like the [tense] proposals in §3.2.1, Kohler argues that a general contrast like fortis-lenis better fits most languages, as it may subsume categories like voicing and aspiration. Two phonetic parameters are universal characteristics of this featural contrast: the VC transition, burst amplitude, and F0 differences following stop closure release. Kohler conceives of each of these as products of articulatory speed. For instance, the goal of producing a faster VC transition will cause vowel shortening before a

[+fortis] obstruent (Kohler, 1979). A faster release will result in greater burst amplitude (see §3.3.2.1). Higher F0 upon release with a rapid decay will reflect the speed at which laryngeal adjustments are made.

The manifestation of consonant voicing, aspiration, and glottalization are language specific parameters which implement [fortis]. While Jansen (2004) and Jessen (1998) consider aspiration to be a primary correlate of the feature [tense], it is considered subordinate to phonetic differences in articulatory timing by Kohler. All approaches, however, assert that the feature [voice] is inadequate at capturing the range of phonetic manifestations of obstruent contrasts in languages of the world.

3.2.3 Strength as Target Attainment

Separate from the featural approaches of articulatory strength mentioned above is the notion that speech gestures which reach an invariant articulatory target involve a stronger articulation (Kirchner, 1998; Flemming, 2001; Dogil, 2007). Kirchner states:

> Precise gestures require the recruitment of more muscle groups, antagonistically counteracting one another to some extent, in order to control the approach to the target, temporally and spatially. (p. 52)

Kirchner defines gestures as more effortful based on the degree of biomechanical effort expended. A product of a more effortful production is resistance to coarticulatory effects. This is the motivation behind Kirchner's phonological constraint [LAZY] that he uses to account for various patterns of lenition.

Under Kirchner's proposal, articulatory effort is not tied to a particular consonant type, but to a phonetic context. For instance, voicing in obstruents is less effortful in word-medial, intervocalic position because passive conditions on voicing permit its continuation without active laryngeal adjustments (see Section 3.2.1.1). Intervocalic *devoicing* is more effortful here. Temporally-controlled articulations which involve some steady-state constriction (but not closure) require a "negative force impulse" which prevents the active force impulse from achieving a full closure. Of course, if such articulations occur in contexts where less active force impulse is required, they require less effort. The constraint [LAZY] is realized by a number of possible repair strategies, some of which may involve featural modifications and others which are strictly phonetic. Kirchner's approach to optimality theory permits the existence of scalar and categorical constraints, drawing from proposals found in Flemming (1995) (and later Flemming (2001)).

The Converter-Distributor model of prosodic control in Fujimura (2000) ties articulatory effort to the magnitude of a syllable pulse. His model is a generative description of how articulatory gestures are organized during speech production. A base function is first generated which defines the prosodic organization of an utterance where vowel units are fixed. Prominence is based on the metrical structure of the utterance, independently defined by the phonological system, i.e. Hayes (1981). The prominence of individual syllables is conferred to the consonantal gestures at the syllable boundaries via a set of impulse response functions (IRFs). For example, in the phonetic sequence [kʰə.ɹɛkt] '*correct*' there is less prominence in the first syllable than in the second. The strength of the IRFs generally correspond to the syllable's prominence. In this way, a strong syllable will produce more strongly articulated segments. Adjustments in the articulatory strength of a segment are achieved via changes in the strength of the IRF. In this model, articulatory strength is always relative to the syllabic strength.

Citing work in Lindblom (1983), Flemming (2001) argues that coarticulatory effects of undershoot result from a phonological preference to minimize the difference between two articulations. The constraint [Minimize-Effort] and a class of Identity constraints determine the possible output candidates. In his model, Flemming states that surface phonetic realizations with the lowest constraint weighting are chosen from the set of candidates. Instead of being ranked, scalar constraints are weighted. In the context of V-C coarticulation, it may cost more to diverge more strongly from the vowel's acoustic target than it does to diverge to the same degree from the consonant's. [Minimize-effort] constrains that no actual movement take place between two articulations. Certain movements are more costly than others.

Under a unified model of phonology and phonetics, each of these approaches resemble Kohler's analysis using the scalar power feature (IRF strength in Fujimura's work). While Fujimura does not specifically address consonant strength, Kirchner and Flemming assert that articulatory speed is a direct measure of degree of articulatory strength. Their work provides a testable prediction: consonant types which involve greater articulatory strength ought to be realized with greater speed and faster transitions.

Figure 3.5: Iverson and Salmons (1995) - Representation of [spread glottis] in English

3.2.4 Glottal Width as Primary

Iverson and Salmons (1995, 2003), and Jessen and Ringen (2002) propose an alternative analysis of obstruent contrasts in Germanic languages to the [tense] and [fortis] proposals reviewed in §3.2.1 and 3.2.2. They argue that the glottal width feature [spread glottis] is not a secondary feature assigned to phonologically voiceless consonants, but is actually the primary feature that will determine voicing characteristics. In their view, the English obstruents /p, t, tʃ, k, f, θ, s, ʃ, h/ are each specified with the privative feature [spread glottis] while the obstruents /b, d, dʒ, g, v, ð, z, ʒ/ are laryngeally unmarked. Obstruents in most Germanic languages (with the exception of Dutch) do not have a phonological [voice] feature. Voicing occurs in obstruents only passively, as discussed above.

This particular approach to obstruent contrasts in Germanic languages elegantly ties together certain phonological alternations like initial [voice] obstruent devoicing, non-aspiration in /sT/ sequences, and sonorant devoicing. For instance, Iverson and Salmons (1995) assert that the feature [spread glottis] is doubly-linked in /s/ + voiceless stop clusters, where the duration of the glottal abduction gesture is equivalent to voiceless aspirated stops. They motivate their analysis with the observation that the peak glottal opening occurs early in the production of /s/ in isolation but between /s/ and a voiceless stop when they occur together in a cluster (Kim, 1970; Kingston, 1990). Isolated voiceless stops have peak glottal opening upon release. This peak in glottal opening would therefore reflect the midpoint in a shared representation, as shown in Figure 3.5.

Aspiration does not occur in the cluster in Figure 3.5 because glottal adduction has resumed by the time the stop is released. This representation of laryngeal features not only fits with the phonetic data, but also avoids a potential OCP violation if each segment were to be associated to a separate laryngeal feature (McCarthy, 1986).

Another consequence of the double-linking of [spread glottis] is that it accounts for the patterns of sonorant devoicing after voiceless stops in English. Devoicing may occur in contexts where aspiration is present (subject to prosodic conditions (Nespor and Vogel, 1986)). However, it does not occur after an /s/ + stop cluster. Forms like *please* [pl̥iz] and *treat* [tɹ̥it] have devoicing while forms like *spleen* [splin] and *street* [stɹit] do not. The lack of sonorant devoicing in these contexts is captured if laryngeal features are only binary branching.[3]

The authors argue that the [spread glottis] view of Germanic obstruents also better explains the pattern whereby *voiced* obstruents are voiceless unaspirated when word-initial or word-medial. While the pattern of word-initial devoicing is well-attested in many Germanic languages (for an overview, see Jansen (2004)), Jessen and Ringen (2002) also observe that such obstruents in German may be partially devoiced between sonorants as a function of the obstruents' place of articulation or closure duration. Obstruents with longer closure and with more retracted constriction will passively devoice (see above), suggesting that it is not an active process of voicing, the phonological [voice], that defines these obstruents, but rather their absence of an active devoicing gesture, [spread glottis].

On the surface the laryngeal feature perspective seems identical in all characteristics but name to the argument for [tense] in Section 3.2.1. After all, all authors agree that passive processes of voicing and devoicing better explain obstruent voicing characteristics than the feature [voice]. However, the feature [spread glottis] is more grounded in name to the phonetic gesture that causes active devoicing. Furthermore, the presence of a [spread glottis] feature need not include any phonetic correlates of articulatory strength, like increased amplitude, constriction degree, or articulator stiffness. Insofar as our approach is to ground features in phonetic reality, the absence of these correlates of articulatory strength in obstruent contrasts would argue against [tense] and [fortis] as features. I turn to the phonetic evidence for this perspective in the following section.

3.2.5 Summary: Theories of Strength

The motivations for the feature [tense] put forward by Jansen (2004), Jessen (1998), and Kohler (1984) are both phonological and phonetic in nature. Certain acoustic and articulatory properties in obstruents are better explained by the presence of [tense] than by the feature [voice]. Kirchner (1998) and Flemming (2001) contend that articulatory effort should be grounded within particular phonetic contexts. Unlike the approaches to strength

---

[3] The implicit assumption in this view is that aspiration constitutes a timing unit in the underlying representation, the details of which have not been fully addressed by the authors.

argued for by Jansen, Jessen, and Kohler, effort-minimization does not replace a set of features with one which is more invariant. As an alternative, (Iverson and Salmons, 1995, 2003; Jessen and Ringen, 2002) argue that glottal width features are primary in obstruent contrasts to the exclusion of constraints or features targeting strength.

While it is not the goal of this dissertation to settle the argument over voicing features in Germanic languages, these various approaches to strength in phonology make certain testable predictions. Jessen and Jansen's [tense] feature predicts that laryngeal manner features alone can not account for the patterning of obstruent contrasts. It also predicts that obstruent systems will be distinguished by the set of correlates shown in Figures (3.1) and (3.2). Kohler's [fortis] feature and Kirchner and Flemming's effort constraints predict that consonant types requiring more articulatory effort will have faster formant transitions. On the other hand, the laryngeal feature proposal of (Iverson and Salmons, 1995, 2003; Jessen and Ringen, 2002) would predict that strength plays no primary role in obstruent contrasts. Obstruents may only be distinguished phonologically by laryngeal features or consonant length.

3.3 Phonetic Correlates of Articulatory Strength

A variety of articulatory and acoustic characteristics may indicate a difference in articulatory strength. The amount of muscular energy exerted during an articulation is the most direct measure. This can be determined through electromyography (EMG) where the electrical potential in the muscle fibers indicates their energy. While EMG captures muscular tension differences in speech production (Fromkin and Ladefoged, 1966), it is a difficult method in practice.[4] Thus, phoneticians have often relied on less direct articulatory measures and indirect acoustic measures of strength. I will discuss these measures in Sections 3.3.1 and 3.3.2. On the articulation side, differences in the amount of intraoral air pressure, laryngeal settings (via EMG), and degree of constriction are examined. On the acoustic side, amplitude, pitch, and formant trajectory differences are examined. The focus of this investigation is both to determine which articulatory and acoustic correlates reflect articulatory strength and which ones are independent targets in speech production. The

---

[4] If the method involves needle insertion, it is difficult to find subject participants. If the method involves surface electrodes, there is a loss in the ability of EMG to localize the precise muscle producing changes in electrical potential.

perceptual relevance to these correlates will be considered separately from this discussion.

3.3.1 Articulatory/Aerodynamic Measures

Increases in articulatory force may arise from adjustments in the pulmonic, laryngeal, or supralaryngeal settings. I explore each of these measures below.

3.3.1.1 Pulmonic Force

Both the elastic recoil of the lungs and active contraction of the internal intercostal muscles contribute to exhalation (Stevens, 2000), creating egressive pulmonic airflow. Additional contraction of the intercostals during the period of an oral constriction would cause an increase in the air pressure behind the oral constriction, P_o. This relationship between pulmonic force and P_o holds only when a set of conditions are met. Consistent impedance to oral airflow, consistent glottal abduction, consistent larynx height, and consistent cavity wall tension must be maintained with a raised velum position during an increase in air pressure (Kingston, 1985). Given these conditions, it is possible to measure intra-oral pressure as a way to examine the pulmonic force in the production of a particular consonant.

It is perhaps because an intra-oral airflow measure is so sensitive to laryngeal and supralaryngeal articulatory configurations that it is not utilized as the sole predictor of articulatory contrast. Malécot (1970) investigated consonant strength by measuring intra-oral air pressure differences in a variety of speech rate conditions. He examined articulatory and acoustic differences between the English consonants /p/, /s/, labelled *fortis*, and the homorganic *lenis* ones, /b/, /z/. Measuring duration, peak amplitude, and P_o, he found substantial differences between these two consonant types. Yet, he did not consider differences in voicing to contribute to the observed lower P_o and amplitude values for /b/ and /z/. Voicing, in his opinion, was frequently missing or difficult to hear in conversational speech. It was therefore disregarded. He concluded his study stating that "Force of articulation thus appears to be a linguistic reality but is primarily a synesthetic response to intra-buccal air pressure impulse, with closure duration perhaps playing a secondary role."

This finding is questionable, however, precisely because the investigated consonants had different glottal configurations. Aerodynamic conditions on voicing militate against increases in intraoral air pressure (Ohala, 1983). One might expect lower peak pressure and amplitude to occur in voiced consonants and higher values in voiceless consonants. Speakers may also control laryngeal height to maintain conditions necessary for sustained voicing or to achieve a specific acoustic goal that will cue voicing (Kingston, 1985; Kingston and Diehl, 1994). It is not possible to consider Malécot's findings as indicative of a consonantal strength difference because measuring P_o is confounded by the presence of voicing. Indeed, voicing is often considered the primary contributor to observed differences in intraoral pressure (Fischer-Jørgensen, 1963, 1968; Dixit and Brown, 1978; Löfqvist and McGowan, 1992).

Butcher (2004) investigates both the durational properties and the peak P_o in bilabial stop contrasts in 7 languages. Three of these languages, English, French, and Italian, unequivocally lack what has been described as a fortis-lenis contrast. French has a clear voicing contrast while Italian has both a voicing and singleton-geminate contrast. English, while subject to some debate (see Kohler (1984); Jansen (2004)), contains a laryngeal feature contrast which involves passive voicing (Keating, 1984; Iverson and Salmons, 1995). The other four languages are Burarra, Murrinh-Patha, LuGanda, and Javanese. All of these have been described as having a fortis-lenis contrast, although various researchers disagree on the use of this term to describe these obstruent contrasts.

The goal of Butcher's study is to compare these languages with the question of how peak intra-oral pressure and duration values differ according to the contrast type. He finds substantial differences in P_o as a function of voicing in French, Italian and LuGanda, as a function of consonant length in Italian, and as a function of the dimension *fortis-lenis* in Burarra, Murrinh-Patha, and LuGanda. He observes that in both Burarra and LuGanda, the product of P_o over time (the pressure impulse) is explained by differences between the consonant types in peak pressure and stricture duration. Such an effect is explained by only adjustments in peak P_o in the case of Murrinh-Patha, where substantial durational differences between the consonant types were not observed. Butcher concludes that there is no single, independent correlate of the fortis/lenis distinction in any of the languages. Closure duration and intra-oral pressure (via glottal aperture adjustments) are manipulated by speakers to realize these consonantal contrasts. There are no cases where speakers independently control intra-oral air pressure (or pulmonic force) to convey a linguistic contrast. Butcher's study demonstrates that observed changes in P_o are usually wholly dependent on phonetic factors independent of increased pulmonic force, a claim supported in subsequent work on Australian languages by Stoakes et al. (2007).

Dart (1987) and Cho et al. (2002) investigate the aerodynamics of obstruents in Korean, which contrasts lenis, fortis, and aspirated stops, e.g. [t, t*, t^h]. Only two types of fricatives are contrastive, lenis and fortis, [s, s*]. Word-initially, all these obstruents are voiceless, although lenis ones undergo voicing word-medially between vowels (Kim and Duanmu, 2004).[5] Cho et al. (2002) find that fortis and aspirated stops have greater P_o than lenis stops, but fortis stops have lower intraoral airflow (U_o) than either lenis or aspirated stops. Phonation-type differences (derived via spectral tilt measures) on the vowel following the word-initial stop were significant as well. The authors argue that greater subglottal pressure, vocal tract wall stiffness, and vocal fold tension contribute to both the observed patterns of greater intraoral air pressure and lower glottal airflow. The Korean obstruents are robustly distinguished by voice quality which results in different aerodynamic effects. Aerodynamic differences between consonants vary as a function of voicing, duration, or phonation type. In each of the studies reviewed here, P_o is ultimately subordinate to another articulatory goal.

3.3.1.2 Laryngeal Height

A variety of phonetic contrasts involve changes in laryngeal configuration. While aerodynamic conditions influence the vocal folds, the extrinsic and intrinsic laryngeal muscles control voicing, pitch, and voice quality. The goals of these adjustments may be to achieve a voicing target, a pitch target, or a glottal aperture target. However, a targeted increase in articulatory strength is another possible goal of such adjustments. For instance, Kohler (1984) and Jansen (2004) assert that devoicing or active laryngeal adjustments may be articulatory reflexes of either [+FORTIS] or [+TENSE] phonological features.

It is useful to distinguish between muscular adjustments which modify the relative position of the larynx as a whole and those adjustments which modify vocal fold tension and abduction. Extrinsic muscles control the position of the larynx and have some effect on voicing and pitch. The larynx may be lowered incidentally by the effects of gravity or intentionally lowered using the thyrohyoid, sternohyoid, and omohyoid muscles (Laver, 1980). Intentional laryngeal lowering occurs most robustly during the production of voiced obstruents and implosives (Ewan and Krones, 1974; Hombert et al., 1979; Kingston, 1985).[6]

---

[5] Lenis stop voicing is dependent on the position of the stop in the accentual phrase and its duration (Jun, 1995). Many researchers regard Korean lenis stops as underlyingly voiceless where voicing is allophonic (Halle and Stevens, 1971; Silva, 1992; Jun, 1993, 1995; Iverson and Salmons, 1995) while others assert that voicing is underlying (Kingston and Diehl, 1994; Kim and Duanmu, 2004). I will not address this particular question here, but will focus more on the word-initial obstruents which are always phonetically voiceless.

[6] While it may also occur during pitch lowering, it is doubtful that it actually contributes to the process

Laryngeal lowering during these consonant types has the articulatory goal of maintaining aerodynamic conditions for voicing (Ohala, 1983; Stevens, 2000). A decrease in subglottal cavity volume will increase subglottal pressure, P_g, and result in a positive transglottal airflow.

Phonologically [tense] or [−voice] obstruents occur with abrupt, active devoicing and increased pitch (Hombert et al., 1979; Löfqvist et al., 1989; Kingston and Diehl, 1994; Jessen, 1998; Jansen, 2004). The articulatory basis for increased pitch in the production of these obstruents is both laryngeal raising (Hombert et al., 1979) and constriction of the cricothyroid, the intrinsic laryngeal muscle most resposible for controlling pitch.

Raising the larynx would have two articulatory consequences: lowering subglottal pressure and increasing vocal fold tension (Stevens, 2000). It indirectly results in increased F0. The principal elevators of the larynx will raise the hyoid bone, which in turn elevates the thyroid cartilage via the thyrohyoid and cricoarytenoid muscles (Bateman and Mason, 1984; Stevens, 2000). While laryngeal lowering may increase subglottal pressure in order to sustain voicing, a decrease in subglottal pressure as a product of laryngeal raising will impede voicing. Hirose et al. (1978); Löfqvist et al. (1989) and Stevens (2000) assert that increased activity of the cricothyroid during the production of voiceless obstruents has the goal of increasing vocal fold stiffness. The coordination of active laryngeal raising and cricothyroid activity would create aerodynamic and articulatory conditions to inhibit voicing. The goal of laryngeal raising is most often to devoice a segment, not to increase articulatory strength.

3.3.1.3 Laryngeal Tension and Voicing

Apart from laryngeal height, certain intrinsic laryngeal muscle adjustments are considered correlates of consonantal strength contrasts. Two types of laryngeal articulations occur with voiceless or [tense] obstruents: cricothyroid contraction and active vocal fold spreading. Using EMG data, Kagaya and Hirose (1975); Hirose et al. (1978); Löfqvist et al. (1989) and Hoole et al. (2004) demonstrate increased activity of the cricothyroid and posterior cricothyroid muscles during the production of voiceless consonants in a variety of languages. Hirose et al. (1978); Löfqvist et al. (1989) and Stevens (2000) assert that the goal of these articulatory maneuvers is to achieve a period of devoicing by increasing the tension

---

(Kingston, 1985).

of the vocal folds, thereby increasing their impedance to vibration.[7] While some languages have clear voicing contrasts, the status of [VOICE] as the feature distinguishing obstruents in Germanic languages is debated (Kohler, 1984; Jessen, 1998; Jessen and Ringen, 2002; Iverson and Salmons, 1995). In particular, it is argued that the presence of vocal fold vibration in *voiced* obstruents can arise incidentally from aerodynamic and articulatory constraints, such as laryngeal lowering and shorter overall duration (Keating, 1984; Jessen, 1998; Jansen, 2004).[8].

Löfqvist et al. (1989) find increased activity of the cricothyroid (CT) accompanying voiceless stop production in English and Dutch. They maintain that this muscular activity is related to the need to ensure voicelessness during stop closure. They also observe a correlation between CT activity and the presence of increased F0 after obstruent release. The authors assert the F0 differences are the result of a devoicing target in speech production, contra Kingston (1986) who asserts it is related to the phonological category [voice]. It is difficult for Löfqvist et al. (1989) to make a strong claim regarding F0, however, as their recordings were designed to elicit stops in a context where voicing may be used to distinguish them. Speakers produced words within the carrier phrase “The *man* went to market.” where the italicized word was replaced with a word beginning in a consonant from a set of voiceless and voiced obstruents. One might expect voicing to occur passively throughout the obstruent’s duration in this context, as the word is preceded by a vowel. Hoole et al. (2004) find similar results in their analysis of CT activity in intervocalic /p/ and /b/ in German. In their recordings as well, the contrast always includes voicing.

Kagaya and Hirose (1975); Hirose et al. (1978) examine EMG data from 7 languages: Hindi, American English, Japanese, French, Danish, Korean, and Swedish. They find that there is reciprocal activity between the abductor and adductor muscles of the larynx during consonant production. The posterior cricothyroid (PCA) is most active during speech sounds with an open glottis while the interarytenoids (INT) are most active during modal voicing and inhibited during devoicing. They find a strong correlation between glottal width, as measured by fibroscopy, and activity in the PCA. While they do not examine word-initial stop contrasts in English or Swedish, they examine them in Danish. Like English, word-initial stops in Danish are voiceless; it contrasts a word-initial voiceless unaspirated [p]

---

[7] A consequence of this maneuver is increased F0 after the obstruent release, which I will discuss in Section 3.3.3.3.

[8] This is discussed in section 3.3.1.3

with a word-initial aspirated [p^h]. Despite the lack of phonetic voicing during the production of these stops, there is increased activity of the PCA during the production of the aspirated stop with less activity in the unaspirated stop. From the majority of their data, the authors conclude that the activity of the PCA during obstruent production most likely is a devoicing maneuver. Increased PCA activity will increase the longitudinal tension on the vocal folds which impedes vibration and increases F0.

Contraction of the cricoarytenoid and posterior cricoarytenoid muscles can be viewed as laryngeal adjustments which have multiple acoustic consequences. On the one hand, increased activity is associated with processes of obstruent devoicing. On the other hand, it may be associated with a process of glottal spreading which causes aspiration. A normal consequence of this spreading process is devoicing, except in those cases where voicing and aspiration are phonologically distinct (as in Hindi or Thai). In fact, Kagaya and Hirose (1975) find increased PCA activity in both Hindi voiceless unaspirated and voiced aspirated stops. This activity may result in either breathy phonation or a short devoicing gesture (compared to the longer one found in the voiceless aspirated series). Increased activity of the INT during voiced Hindi stops would contribute to the presence or absence of voicing. It is insufficient to talk about PCA activity as contributing to either a laryngeal tension gesture or a devoicing gesture. It may contribute to one or the other depending on the complementary activity of other laryngeal muscles.

Increased PCA and CT activity are muscular adjustments that result in both devoicing and increased F0 after obstruent release. INT activity and laryngeal lowering occur during the production of voiced stops. We may conclude that laryngeal adjustments during obstruent production are implemented in order to produce one of many targets: a voicing target, a devoicing target, an aspiration target, or an F0 target. Each of these phonetic goals involve some degree of muscular activation. Thinking of laryngeal modifications in terms of articulatory strength, we might consider the energy expenditure of each of these targets.

For instance, one might consider how much muscular energy expenditure occurs during the production of a voiceless or aspirated consonant compared to a voiced or unaspirated one. To do this, it would be necessary to measure the combined energy of all muscles used in the process of devoicing and the process of voicing and then to compare them. Most studies involving strength have either focused on articulatory constriction differences in the supraglottal cavity or have inferred articulatory parameters from the acoustic signal.

3.3.1.4 Constriction Degree

Most articulatory investigations of strength have examined constriction degree differences via palatography, electropalatography (EPG), or, more recently, electro-magnetic midsagittal articulometry (EMMA). The approach using these methods is to determine if certain articulations involve greater linguapalatal contact than others. Increased contact between the tongue and a passive articulator reflects greater articulatory strength (Fougeron and Keating, 1997; Keating et al., 2000; Lavoie, 2001). Most of the work on this topic investigates how *prosodic* distinctions may be encoded with both increased constriction degree and increased duration. While some of this work is relevant here, I will focus mostly on those articulatory studies investigating phonemic contrasts.

It is tempting to examine stops and fricatives in terms of articulatory strength. Most of the languages of the world (93.1 %) have phonemic contrasts in obstruent manner, containing at least one fricative in their sound inventories (UPSID-451). Among other adjustments, contrasts between stops and fricatives are instantiated by differences in the degree of articulatory stricture. Yet, changes in the degree of occlusion which produce such contrasts does not always reflect strength differences. For instance, it is argued that the production of geminate fricatives involves more articulatory effort than corresponding geminate stops (Kirchner, 2000). One may distinguish between fricatives that arise synchronically from spirantization and phonologically underlying fricatives (arguably the contrast Kirchner (2000) is evaluating). For our purposes, I will exclude phonemic stop-fricative contrasts.[9]

There are languages which have phonemic contrasts in constriction degree. Maddieson (1999) examines coronal fricatives in three Dagestanian languages which were previously argued to have contrasts in articulatory strength. Each of these languages has a singleton-geminate contrast word-medially, but a different contrast among word-initial fricatives. Maddieson investigated the word-initial fricative contrast using acoustic measures and palatography. In one of these languages, Bagwala, the *weak* fricatives, [s, ʃ], are audibly aspirated while the *strong* ones, [s̄, ʃ̄], are not. Maddieson does not find differences in the contact area between the fricatives nor does he find any durational correlates of the contrast. He does find the weak fricatives to have a substantial aspiration duration though. He concludes that aspiration, a laryngeal parameter, is the main correlate of the fricative contrast in this language.

---

[9] Processes of lenition or fortition that are allophonic will be addressed however.

However, Maddieson does observe constriction degree differences in the fricative contrasts in two other languages, Dargi and Archi. In Dargi, the weak alveopalatal fricative has a wider escape and less lateral contact than the strong one. Unlike Bagwala, there is no noticeable aspiration in the weak fricatives and a small durational difference (161 vs. 200 ms.). In Archi, there is a marked difference between the alveolar fricatives, where the strong /s̄/ occurs with a narrower escape channel than the weak /s/. Like Dargi, there is a small but significant durational difference (186 vs. 229 ms.). Maddieson concludes that articulatory strength may be subordinate to laryngeal settings in Bagwala, but the primary correlate of the fricative contrast in Dargi and Archi. Maddieson (1999) is the only articulatory study to date concluding that strength may be a primary correlate of a phonemic contrast. In most of the languages where constriction degree distinguishes consonants, it is found to be subordinate to laryngeal settings or durational differences (Ladefoged and Maddieson, 1996). There may be a functional explanation for the presence of this contrast in Archi, as the language has 91 contrastive phonemes (Kodzasov, 1977; Maddieson, 1999), which is a very large sound inventory. The sheer number of contrasts to encode may have permitted certain uncommon features to be used.

In their analysis of Korean, Cho and Keating (2001) used EPG in analyzing the effect of additive prosodic positions (utterance-initial, intonational-phrase-initial, etc.) on word-initial stops. They observe that both the fortis /t*/ and aspirated /t^h/ have greater peak linguapalatal contact than lenis /t/. This increased constriction is strongly correlated with observed differences in seal duration ($R^2 = 0.60$ to 0.74). They conclude that there is a strong relationship between constriction degree and duration of closure. In addition to the voice quality differences between obstruents noted above, both aspirated and fortis stops in Korean have longer duration than lenis stops.

Payne (2006) uses EPG to analyze consonant closure in her analysis of lexical and postlexical geminates and non-geminates in Italian (Roman dialect). She observes that complete occlusion is uncommon for singleton consonants, but common for geminates. There is greater linguapalatal contact and more palatalized constriction with geminate stops than for singletons (although this pattern only holds for lexical geminates). The tongue is in a higher and flatter position for geminates than it is for singletons. For fricatives, there is a narrower escape channel in the production of /ss/ than in /s/ (both voiceless here). Unlike Cho & Keating's results for Korean above, Payne finds that increased constriction degree and palatalization does not correlate with duration. Palatalization is restricted to

/lː/.[10]. If increased contact were always the result of increased duration, Payne argues, then one would expect palatalization on all geminate coronals. She concludes by stating that gemination is a process of fortition. Geminate consonants are not only durationally distinct from singletons, but spatially distinct in having a different gestural target.

Maddieson's reasearch suggests that increased constriction degree may be the primary correlate of certain phonemic contrasts in some languages. Yet, in the findings in Cho and Keating (2001) and Payne (2006) it always occurs with increased duration or an added laryngeal feature. In Cho & Keating's perspective, increased constriction degree co-occurs with increased duration. While the authors mention that fortis and aspirated stops could be understood as geminates (Jun, 1994), they conclude that real durational differences between them and the lenis stops were only about 20%. Constriction degree and duration are best understood as a single effect of strengthening in Korean. In Payne's perspective, geminates have a special type of strengthening which results in more palatalized constriction. Out of the articulatory parameters used to distinguish consonant types, constriction degree is arguably the one correlate that can be considered independent of voicing and laryngeal feature contrasts.

3.3.2 Acoustic Measures

Two acoustic measures undisputedly derive from changes in articulatory tension: amplitude and formant trajectory. While many other acoustic measures are considered in phonetic analyses of articulatory strength, they are arguably related to other types of phonological contrasts not involving strength. They will be considered in section 3.3.3.

3.3.2.1 Amplitude

Consonant amplitude may vary as a function of intraoral pressure adjustments, laryngeal tension, oral constriction area, and tension within the articulators. Amplitude is often examined in the release portion of a stop consonant as an indirect measure of P_o and its relative strength.[11] Generally speaking, greater air pressure behind an oral constriction will produce greater amplitude upon release. Burst amplitude increases as a function of

---

[10] Phonologically distinct from /ʎː/

[11] The amplitude of steady-state frication in fricatives is also measured for similar purposes (Jaeger, 1983; Holton, 2001).

both the volume velocity and the cross-sectional area at the constriction (Stevens, 2000). This depends on laryngeal tension parameters to a certain degree, as a more open vocal fold configuration will permit a faster and greater buildup in P_o than a more closed configuration (see Section 3.3.1.1). Voicing will result in lower P_o than devoicing due to glottal spreading.

Apart from the size of the constriction, the speed of the articulators contributes to the burst intensity. Faster stop release results in greater airflow at the constriction which will in turn produce greater amplitude (Stevens, 2000:115). The rate of the opening transition is determined by both the inherent speed of the articulators and their degree of tension. Smaller articulators, like the lips and the tongue apex have a faster release than larger articulators like the tongue dorsum (partially explaining inherent VOT differences among languages). Articulators with more muscular tension will also close and release more quickly. In precisely this way, the speed of constriction formation and the relative amplitude of the release burst reflect the degree of articulatory strength (Debrock, 1977; Kohler, 1984).

Burst amplitude is a correlate of stop contrasts in some languages, but does not distinguish stops in others. In a language where amplitude is a correlate of a phonological contrast, it may be subordinate to other articulatory/acoustic parameters. Since amplitude is a significant correlate in languages with contrastive voicing, contrastive laryngealization, and contrastive length, it is possible for amplitude differences to stem from articulatory adjustments not involving strength. While amplitude may be a perceptual cue to stop contrasts, it may not be an independent target in speech production. I will consider its relevance to languages with fortis-lenis, voicing, laryngeal feature, and length contrasts.

In Korean, aspirated stops have greater burst amplitude than the fortis and lenis stops (Cho and Keating, 2001). There is no apparent difference in amplitude between the fortis and lenis stops. These findings are best explained by the increased P_o present in aspirated stops which causes greater amplitude upon release. It is also consistent with findings that the fortis stops have increased vocal fold tension (Cho et al., 2002). A tense vocal-fold configuration would result in greater impedance to glottal airflow, thereby *reducing* amplitude upon release. Even if fortis stops in Korean had greater constriction degree than aspirated stops (see Section 3.3.1.4), increased amplitude due to lingual tension would be attenuated for aerodynamic reasons. While Korean stops are described in terms of strength, increased acoustic amplitude does not distinguish fortis stops from other stops.

Many Germanic languages are classified as having either phonological voicing, [spread glottis], or [tense] contrasts (Jessen and Ringen, 2002; Iverson and Salmons, 1995;

Jansen, 2004). Burst amplitude is a secondary correlate in stop contrasts in these languages. Jessen (1998) describes it as a concomitant correlate of [tense] and [-voice] phonological features in German. While VOT is the main acoustic correlate of the stop contrast in English, burst amplitude may cue it given sufficient VOT differences(Repp, 1979). Both Slis and Cohen (1969) and van Alphen and Smits (2004) find significant differences in burst amplitude between phonologically voiced and voiceless stops in Dutch. However, van Alphen and Smits find that burst amplitude neither sufficiently distinguishes the stop types in a classification and regression tree (CART) analysis nor is it perceptually relevant. Rather, the percentage of prevoicing in the stop, the f0 upon release, and the spectral composition of the burst are the robust correlates and cues to the contrast. While increased burst amplitude may enhance obstruent contrasts, it is not a *primary* acoustic correlate in any of these languages.

Burst amplitude may distinguish singleton and geminate stops in some languages but it is not a robust correlate across all languages. While geminate stops may have greater release amplitude in Berber (Ridouane, 2007) and Pattani Malay (Abramson, 1991, 2003), there is no significant amplitude difference between geminates and singletons in Italian (Esposito and Di Benedetto, 1999) or Cypriotic Greek (Arvaniti and Tserdanelis, 2000). This might suggest that burst amplitude is not a reliable correlate of stop length contrasts cross-linguistically. However, it is notable that in both Berber and Pattani Malay, geminate consonants are permitted word-initially while they only may occur word-medially in Italian and Greek.[12] Utterance-initial geminate voiceless stops lack acoustic cues to indicate the onset of stop closure. While duration is the primary correlate distinguishing singleton and geminate contrasts cross-linguistically, it may not be a strong cue in such positions. It is therefore plausible that existing phonetic tendencies, such as greater burst amplitude due to a greater buildup in P_o during geminate stop closure, would be useful for the perception of a contrast. Yet, even within these two languages, the authors find that burst amplitude is subordinate in its perceptual relevance to other acoustic parameters, like f0 upon release.

In languages with a fortis-lenis stop contrast, a voicing contrast, an aspiration contrast, or a length contrast, burst amplitude is not a robust phonetic correlate. While many of the languages investigated here have been described as having a phonological strength contrast (for a discussion, see Jessen 1998; Arvaniti and Tserdanelis 2000; Ridouane 2007), they lack phonetic evidence for such a classification.

---

[12] Italian does have derived geminates that occur word-initially via radoppiamento sintattico. Esposito and Di Benedetto (1999) did not consider their amplitude characteristics.

3.3.2.2 Speed & Formant Trajectory

One may increase the tension in one agonistic and antagonistic muscle while preventing movement or moving slowly. Speed correlates with increased articulatory tension only when the set of agonist muscles has greater tension than the antagonist muscles. The result of this is a spring-like movement of an articulator from one position to another. In this context, faster articulations correspond with greater articulatory tension. This is most transparent within speech production models which view articulatory movements in terms of a critically-damped spring-mass system (Saltzman and Munhall, 1989). In such a model, greater input tension results in faster movement to an articulatory target. As mentioned in the previous section, the speed of a stop release will also result in greater burst amplitude. Kohler (1984) asserts that the speed of articulatory stricture formation and release is a universal characteristic of increased power in supralaryngeal movements (see §3.2.2. Other acoustic correlates like voicing, aspiration, and glottalization are language-specific instantiations of the phonological feature [fortis] (Kohler, 1984:168). Increased stiffness among articulators will result in more abrupt formant transitions into and out of a consonant. It will also result in faster falling and rising intensity contours (Debrock, 1977). Yet, to what degree are these patterns phonetic correlates of phonological contrasts?

It has been observed that low monophthongs preceding phonologically [−voice] consonants are realized with a higher F1 than vowels preceding [+voice] consonants. Offgliding diphthongs, however, are realized with a lower F1 before [−voice] consonants (for an overview of both phenomena, see Moreton 2004). For instance, the vowel /a/ will be realized as a slightly raised allophone before voiceless consonants, e.g. [a̝], but as a slightly lowered allophone before voiced consonants, e.g. [a̞]. While these patterns before voiceless consonants seem unconnected, they are related insofar as the context conditions a more peripheral formant value of the vowels. Moreton (2004) argues that both effects stem from a process of hyperarticulation before a [-voice] consonant. He argues that the feature [-voice] is enhanced postvocalically because the cues to postvocalic (here word-final) voicing are perceptually-weak. Citing work by Hirose and Gay (1972); Fujimura and Miller (1979); Kohler (1984), and others, he argues that the closing gesture for voiceless obstruents is faster and more forceful than for voiced obstruents. The articulatory reflexes of this acoustic effect are wider and faster jaw movements before [-voice] consonants (Fujimura and Miller, 1979; Kohler, 1981; Summers, 1987). Vowel hyperarticulation would, he argues, increase in proximity to this stop gesture.

This is in stark contrast to the perspective that low frequency spectral energy is the strongest cue to stop voicing in obstruents (Kingston, 1986; Kingston and Diehl, 1994; Kingston, 2007; Kingston et al., 2008; Holt et al., 2001). Moreton (2004) observes that F1 lowering may trigger the perception of *voicelessness* in stops if such lowering produces a more hyperarticulated vowel target. It is possible that both analyses have some validity. Moreton considers VC formant transitions while the low frequency property discussed by Kingston and others is generally considered a characteristic of the CV transition. The production and perception of voicing targets may vary as a function of the consonant's position within the word.

Investigating VCV contexts, Löfqvist and Gracco (1997) find no difference in the degree of jaw and lip opening as a function of bilabial consonant voicing. Löfqvist and Gracco (1994) find the opposite result of Moreton (2004) when investigating movements of the tongue body in the production of velar stops. In this study, the [+voice] velar stops condition faster and greater amplitude movements than [-voice] stops. While the former study was articulatory and the latter acoustic, the findings suggest that the effect of voicing on formant trajectory is dependent on the consonant's position in the word. If the speed of stricture formation is a universal characteristic of fortis stops (including the [-voice] English stops examined here) (Kohler, 1984), then faster formant transitions with greater amplitude should be expected across different contexts. The results here suggest that [-voice] consonant targets may have increased articulatory strength only in *prosodically* weak environments. Insofar as articulatory speed correlates with strength, it may only be a characteristic of certain positions in the prosodic word and not a characteristic of particular consonant phonemes.

While the main correlate/cue of consonantal length contrasts is duration, geminates may be produced with greater articulatory strength. Like consonantal voicing contrasts, formant trajectory may cue consonant length contrasts. A general phonological property of geminates is their resistance to undergo phonological rules that affect singleton consonants (Guerssel, 1977; Schein and Steriade, 1986; Hayes, 1986). Kirchner (2000) asserts that this property, called *inalterability* (Hayes, 1986), arises out of increased biomechanical effort exerted in the production of geminate consonants. The biomechanical energy of a gesture is specifically defined as the sum of all force exerted during a gesture from its initial position to its final position (Kirchner, 1998). Force is defined as the product of mass and the change in velocity over time, $F(t) = m \times \frac{dv}{dt}$. Thus, an increase in the velocity of a gesture where duration is constant will result in an increase in articulatory force.

Kirchner (2000) uses this approach to motivate a phonological constraint, LAZY, which dominates faithfulness constraints within an optimality-theoretic perspective (Prince and Smolensky, 1993; Kager, 1999). Inalterability in geminates occurs because reduction of a geminate would result in too many violations of this constraint. Yet, as this approach is grounded in the physical aspects of speech articulation, it makes a prediction that geminates will always involve greater articulatory effort than singletons. To what extent is this prediction borne out?

Using X-ray microbeam data, Smith (1995) tests two models of coarticulation: vowel-to-vowel timing (Öhman, 1967) and combined vowel and consonant timing (Fowler, 1980). She compared the lip movement gestures during the production of Japanese and Italian geminate and singleton consonants. For both Japanese and Italian speakers, the lips moved significantly more slowly during the production of geminate /pp/ than in the production of singleton /p/. Smith argues that a longer period of activation and a decreased stiffness have the effect of increasing the duration of the gesture for a geminate (p. 217). On the surface, this suggests that geminates may have less articulatory force than singletons. Yet the gesture here is be slower and it occurs over a longer period of time. The gesture might contain an amount of articulatory force equal to that of singletons. In a later study by Löfqvist (2007) on kinematics in Japanese singleton and geminate consonants, the calculated speed of articulatory movement takes the duration into account. Löfqvist observes slower articulatory movements in the production of geminates than in singletons, effectively reproducing Smith's findings. These findings suggest that geminates do not necessarily involve any greater articulatory force than singletons do. If increased force does not exist for geminates, the notion of inalterability need not be tied to notions like effort.

Increased articulatory tension will result in faster formant trajectories into and out of a consonant constriction. This is a correlate of articulatory strength. If articulatory strength is phonologically contrastive, then one expects it to occur in a variety of contexts and languages. Consonant voicing contrasts sometimes include articulatory strength as a secondary correlate, but this may be restricted to particular prosodic positions. Geminate consonants may be produced with more articulatory strength than singletons in terms of burst amplitude or constriction degree, but not in terms of transition speed.[13] The speed of

---

[13] There are however relatively few studies which have investigated formant transitions and articulatory

formant transitions is an informative measure of articulatory kinematics which may inform theories of speech production and gestural overlap. However, it is not a universal correlate of either a obstruent voicing or length contrast.

3.3.2.3 Summary

I have examined the set of articulatory and acoustic correlates of articulatory strength in the literature with the following question in mind: *To what extent does the measure of articulatory strength correlate with other phonological contrasts?*. Table (3.1) summarizes these findings.

Articulatory/Acoustic Measure	Phonological Relevance
High P_o	Correlate of [-voice] Correlate of [spread glottis]
Laryngeal Raising	Correlate of [-voice] Concomitant with increased F0
Contraction of CT, PCA	Correlate of [-voice] Correlate of [spread glottis] Concomitant with increased F0
Increased constriction degree	Correlate of [tense] Correlate of consonant length
Greater burst amplitude	Correlate of [spread glottis] Correlate of [-voice]
Speed of stricture formation	Correlate of [-voice]

Table 3.1: Correlates of Articulatory Strength

Researchers have posited the existence of phonological features like [tense] or constraints like LAZY as a way of explaining a set of phonetically distinct patterns in consonant contrasts. Each of the measures in Table (3.1) reflect increased articulatory strength. For the most part, the measures are secondary correlates/cues to other more primary ones, such as voicing, duration, and laryngealization. Only constriction degree is a primary correlate of a phonological contrast where other correlates do not play a substantial role. Languages like Dargi and Archi may suggest the need for a separate strength feature in phonological theory. Yet, if articulatory strength is mainly subordinate to other phonetic correlates in indicating a phonological contrast, there is no place for [tense] in the set of distinctive features for most languages.

---

kinematics in languages with contrastive consonant length.

3.3.3 Putative cues to articulatory strength

The phonetic measures in sections 3.3.1 and 3.3.2 are clearly related to articulatory adjustments involving greater articulatory strength. However, the literature on phonological strength contrasts includes other more indirect measures as correlates for strength. These include absolute consonant duration, complementary duration, and pitch. These are considered in a separate section not because they are considered unimportant, but because they are not unequivocably related to increases in biomechanical effort.

3.3.3.1 Duration

Two types of durational measures are discussed in relation to phonological strength contrasts: absolute consonant duration and relational durational cues (Port and Dalby, 1982). Absolute consonant duration is a correlate/cue of consonantal voicing contrasts, laryngeal feature contrasts, and length contrasts. Relational (or compensatory) changes involve a shortening or lengthening of a vowel as a cue to a voicing or length contrast as well. The literature on duration in consonant voicing and length contrasts is quite large. I will restrict my review of this literature to those studies which have some focus on articulatory strength.

The attainment of an articulatory target with greater constriction may require longer duration than an articulation with less constriction (see Section 3.2.3). Furthermore, obstruent targets with phonetic voicing may be shortened so that passive devoicing processes do not prevent glottal vibration near consonant release, the perceptually relevant position for laryngeal feature contrast in obstruents (Kingston, 1985, 1990; Silverman, 1997b).[14]

In some cases durational differences are merely a byproduct of reaching a target position or avoiding devoicing. They may also be exaggerated by processes of perceptual enhancement (Diehl and Kluender, 1989; Stevens and Keyser, 1989; Silverman, 1997b; Stevens, 2002). When duration is the primary correlate of a contrast and does not vary with other acoustic correlates, this is evidence for a consonantal length contrast. If duration is dependent on other strength-based correlates, it may act as a cue for these stronger articulations.

In languages where voicing and duration are not the *primary* correlates of a consonant contrast, duration may still be a secondary correlate. In Korean, lenis stops are consistently shorter in closure duration than either fortis or aspirated stops (Cho and Keating,

---

[14] Contrastive [voice] however, need not involve greater articulatory strength; see Section 3.3.1.3.

2001). This durational difference is highly correlated with the greater degree of linguapalatal contact. The authors observe R^2 values from 0.77 - 0.91. While the obstruent contrast in Korean primarily involves adjustments of glottal tension and constriction degree, duration is a strong secondary correlate. In Section 3.3.1.4, we observed slight durational differences between the strong and weak fricatives in Dargi and Archi. Articulatory differences in constriction degree would be acoustically cued by spectral differences between the fricatives. While the difference in their duration is not quite substantial enough to resemble a true singleton-geminate contrast, it is nonetheless a significant correlate of the contrast and may be a secondary cue.

There is a also marked tendency for voiced consonants to be shorter in duration than voiceless ones (Lehiste, 1970; Catford, 1977; Ohala, 1983; Jessen, 1998; Lavoie, 2001). The explanation of the shorter duration is that in order to maintain positive transglottal airflow throughout closure, the overall duration is shortened. Passive expansion of the oral cavity and laryngeal lowering may permit some sustained voicing, but shortening the duration of the closure will prevent excessive buildup of intraoral air pressure. A consequence of this aerodynamic effect on closure duration is that speakers utilize duration as a cue for obstruent voicing. Shorter duration closure may cue the presence of a phonologically voiceless obstruent independent of the actual amount of voicing present (Denes, 1955; Lisker, 1957; Port, 1979; Port and Dalby, 1982).

While this particular pattern is robust for many languages, it may be dependent on position. For instance, Jessen (1998) observes a durational difference between tense and lax German stops, but only reliably in word-medial, intervocalic contexts. Luce and Charles-Luce (1985) do not observe reliable differences in closure duration among voiced and voiceless English stops, but they examined this contrast in coda position in carrier sentences (before a vowel). It is possible that intervocalic position better lends itself to the use of durational cues. For instance, it is cross-linguistically more common to observe consonantal length contrasts restricted to intervocalic position than permitted word-initially and word-finally (Ladefoged and Maddieson, 1996). It is probable that this typological tendency reflects a pattern whereby contrasts are historically maintained in contexts where they are better-perceived (Blevins, 2004). Blevins also notes that processes of degemination are more common word-initially and finally than intervocalically.

Duration is most robust as a correlate and cue in languages with consonantal length contrasts. In many cases, languages previously described as having a fortis-lenis consonant contrast have been reanalyzed as having a geminate-singleton contrast. For instance, both Ham (2001) and Kraehenmann (2001) observe significant differences in the closure duration of stops in different Swiss German dialects. These durational differences fall within the range of singleton-geminate duration ratios observed in Ham's cross-linguistic study. Obstruents in Swiss German had previously been analyzed in terms of consonantal strength (fortis-lenis) (Marti, 1985; Goblirsch, 1994). Ham and Kraehenmann convincingly show this to be false not only with phonetic evidence but also with distributional data. Swiss German has a three-way obstruent contrast with voiced singletons, voiceless singletons, and voiceless geminates. Previous approaches had collapsed the voiceless categories into one *fortis* group. Such proposals did not account for the pattern whereby long vowels may only surface before singletons but short vowels before geminates. Similar reanalyses of strength contrasts have been made for Greek (Arvaniti, 1999; Arvaniti and Tserdanelis, 2000), Turkish (Lahiri and Hankamer, 1988), and Italian (Cerrato and Falcone, 1998; Esposito and Di Benedetto, 1999; Stevens and Hajek, 2004; Payne, 2006).

In Greek, Arvaniti (1999) investigates how changes in speech rate affect singleton and geminate duration. Contrary to approaches that have assumed geminates to be more durationally stable (or incompressible), Arvaniti observes that both consonant types undergo some shortening when rate is increased. While raw duration is not stable when speed is increased, the contrast is also not neutralized because the durational ratio remains stable. This particular finding would argue against the view that geminates do not undergo lenition because they are subject to a constraint on effort (Kirchner, 2000) (see Section 3.3.2.2). Singletons and geminates in Greek undergo the same type of reduction. Duration may cue consonantal strength, but only when it can be shown to be independent of voicing, laryngeal features, or an underlying length contrast.

3.3.3.2 C/V Ratio

The ratio of the preceding vowel duration and following consonant duration is considered a correlate of the obstruent features [tense] or [fortis] (Chen, 1970; Kohler, 1979, 1981, 1984; Jessen, 1998; Jansen, 2004). Obstruents which are [+tense] are realized with a shorter preceding vowel and a long closure duration while [−tense] obstruents are realized with a long preceding vowel and a short closure duration (see §3.2.1). These authors argue that a consequence of increased articulatory stiffness is a faster transition into the obstruent closure. A consequence of a faster transition is that the vowel is shortened. Thus, the target articulation which triggers a change in preceding vowel duration is the [tense] obstruent.

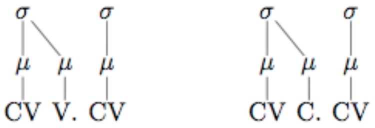
However, there are other approaches to the vowel-length effect that have nothing to do with an increased stiffness target in articulation. A number of researchers argue that it is directly related to voicing, not strength (House and Fairbanks, 1953; Fischer-Jørgensen, 1968; Javkin, 1976; Port and Dalby, 1982; Kluender et al., 1988). When a vowel is lengthened before an obstruent, it may cue the percept of voicing (Denes, 1955; Raphael, 1972; Port and Dalby, 1982; Luce and Charles-Luce, 1985). Kluender et al. (1988) and Javkin (1976) argue in particular that this effect has an auditory explanation, not one having to do with articulatory speed or strength. The voicing on the preceding vowel is perceptually integrated with the following voiced stop which results in continuous voicing. This is perceived as a vowel + voiced stop. Exaggerated vowel-length differences arise out of a tendency for speakers to enhance the closure-duration cue of the stop voicing contrast.

A potential problem with this auditory enhancement hypothesis is that vowel lengthening is also found before sonorants (Harris, 1994; Jansen, 2004). If lengthening occurs to enhance a voicing contrast, then one might expect it to be restricted to voiced obstruents. It is, however, conceivable that all voicing targets undergo enhancement.

The literature on the vowel-length effect in voicing also has a different orientation from the strength-based arguments. Durational differences arise from a process of vowel-lengthening before voiced obstruents, not from a process of vowel-shortening before voiceless ones. One might argue that there are two separate processes: lengthening before voiced stops in voicing languages and shortening before aspirated stops in aspirating languages. Kohler (1979, 1984) uses vowel-shortening to support his feature [fortis] with data from German intervocalic stops. We noted before that German does not have voicing in lenis intervocalic obstruents (Jessen and Ringen, 2002). Denes (1955); Port and Dalby (1982); Luce and Charles-Luce (1985) and Kluender et al. (1988) all investigated English intervocalic obstruents which always have voicing during closure. Observed differences in vowel-lengthening patterns among languages may stem from featural differences of the type discussed in Section 3.2.4 where [spread glottis] may trigger vowel shortening while [voice] triggers lengthening.

Relational durational cues also serve as percepts for consonant length. In many languages, short vowels are restricted to occur before geminates while long vowels occur before singletons (Keyser and Kiparsky, 1984; Maddieson, 1985; Ogden, 1995; Ham, 2001).

Figure 3.6: Prosodic Representation of Complementary Lengthening in Geminates



The representation of this phenomenon here is generally considered prosodic, not featural (but see Jessen (1998) for a featural analysis). Geminates and long vowels each constitute an additional mora within the syllable, as shown in Figure (3.6) (Hayes, 1986).

The two intervocalic consonants in the representation on the right illustrate a geminate while the representation on the left illustrates an intervocalic singleton. Ham (2001) hypothesizes that the type of compensation observed here is restricted to languages with syllable-based timing as opposed to mora-based timing. He finds that this hypothesis is borne out in languages like Madurese and Bernese (Swiss) German, both of which have syllable-based timing strategies and a singleton-geminate contrast. Levantine Arabic and Hungarian do not show vowel compensation effects with geminates because the languages are mora-timed. We expect larger differences between the duration of singletons and geminates in mora-timed languages because the consonant carries more of the burden of indicating the contrast. Ham's findings make interesting predictions for geminate-timing cross-linguistically. In support of Ham, Cohn et al. (1999) observe closed-syllable shortening before geminates in three Indonesian languages: Buginese, Madurese, and Toba Batak, each of which has syllable-based timing.

Durational complementarity in geminates is distinct from the type of compensation we observe with consonant voicing. In fact, Ham observes that both occur in Levantine Arabic which contrasts voiced and voiceless geminates and singletons (but only at an alveolar place of articulation). Singletons are substantially shorter than geminates in the language, with a duration ratio of 1:2.29 (Ham, 2001:130). Yet, voiced singletons are shorter than voiceless ones (by 10-20 ms.) and voiced geminates are slightly shorter than voiceless ones (by 10-15 ms.). Long vowels are longer before voiced singleton consonants and shorter before voiceless singleton consonants. Short vowels are longer before voiced geminates and shorter before voiceless geminates. Yet, the effect of voicing on the duration of preceding short vowels was only marginally significant compared to the effect on long vowels. Voicing also seems marginal in its effect on preceding vowel duration when compared to consonant length. While the length contrast involves a robust duration difference, the voicing contrast conditions marginal duration differences.

Such findings are problematic for strength-based views of the vowel-length effect as one might expect similar compression effects before all voiceless consonants (if they are underlyingly [tense]). Similarly, they are problematic for prosodic views of durational changes associated with strength or voicing (insofar as such views are cross-linguistic). Syllable-cut prosody, for instance, asserts that durational changes associated with strength/voicing in Germanic obstruents arise out of prosodic differences expressed on the autosegmental tier (Harris, 1994; Murray, 2000). Prosody can not explain the presence of both voicing-conditioned and length-conditioned durational changes in the same language. In the case of Levantine Arabic, it would seem that only the latter is prosodic.

Mora-timed languages may still use relational durational correlates to indicate a length contrast but such correlates may not be as robust perceptually as they are predicted to be in syllable-timed languages (Idemaru and Holt, 2007). Yet, this particular type of compensation in geminates most often occurs word-internally, not across word-boundaries. Among languages with word-initial geminates, relational timing may not be robust. Word-initial geminates in Pattani Malay are distinguished from singletons by closure duration, F0, and burst amplitude (Abramson, 1986, 1991, 2003). While initial geminate continuants and voiced stops can be reliably perceived using closure duration, Abramson notes that durational cues are not robust (at least utterance-initially) for voiceless (unaspirated) stops. As a result, voiceless stops are realized with greater burst amplitude and a higher F0 upon release. This characteristic of voiceless initial geminates, he argues, is extending to other words in the language with initial voiced geminates as a type of accentual prominence. Such a maneuver may reflect a process of perceptual enhancement by active glottal spreading which would result in both greater burst amplitude and raised F0 upon release.

Relational duration differences may reflect increased articulatory stiffness and faster movement. They may also be directly attributable to voicing contrasts or consonantal length contrasts. While it has been argued that devoicing targets or geminates are realized with greater articulatory strength, substantial evidence asserts that strength need not play any role in achieving such targets (see Sections 3.3.1: Laryngeal Tension & Voicing and 3.3.2: Speed and Formant Trajectory). Relational durational cues do not a priori indicate differences in strength but if other phonetic correlates like closure duration or voicing are absent, they do.

3.3.3.3 Pitch

It has long been observed that voicing or other laryngeal adjustments in obstruents cause local pitch perturbations on a following vowel (House and Fairbanks, 1953; Haggard et al., 1969; Halle and Stevens, 1971; Hombert, 1979; Hombert et al., 1979). In their early and seminal work, Halle and Stevens (1971) argue that vocal fold stiffness is the primary determinant of F0 perturbation in obstruents. Increased vocal fold stiffness usually refers to increased *longitudinal* tension, a state caused by the contraction of the cricothyroid. Lengthening the vocal folds increases their impedance to vibration. Less vocal fold stiffness occurs with less cricothyroid contraction, which is both conducive to voicing and lowers pitch. Halle and Stevens capture vocal fold stiffness adjustments with the distinctive features [stiff] and [slack]. Consonants specified as [+slack] will be realized with lower pitch and those specified as [+stiff] will be realized with higher pitch. These features are distinct from those which specify glottal width, [spread glottis] and [constricted glottis].

The phenomenon of pitch perturbation in obstruents is still a matter of debate though. One dispute concerns the intentionality of the effect. Another dispute concerns its robustness and yet another concerns its cuase. Löfqvist et al. (1989) describe F0 increase as a passive and automatic consequence of increased cricothyroid activity that occurs with devoicing. A prerequisite for F0 adjustment here is the presence or absence of phonetic voicing. Investigating pitch perturbation effects in word-initial German obstruents, Jessen (1998) finds a small difference in F0 as a function of stop type (fortis/lenis) but a more robust difference among fricatives. In the particular cases where an effect was observed, actual vocal fold vibration was present in the lenis obstruents. Indeed more of the fricatives than stops were voiced word-initially.[15] While it would seem to the present author that this effect is purely phonetic, Jessen contests that this effect is phonological, being a characteristic of the feature [-tense].

F0 lowering accompanying obstruents may be part of a controlled acoustic target (Kingston, 1986; Jansen, 2004; Kingston, 2007; Kingston and Diehl, 1994). Borrowing on the work of Stevens and Blumstein (1981), Kingston and Diehl (1994) assert that a cluster of cues called the *low frequency property* are independently controlled by speakers in order to cue the phonological feature [+voice]. This cue cluster includes voicing during closure, low

---

[15] This also would explain the findings in Kohler (1982) where he observed an F0 effect in VCV sequences. Indeed, actual voicing is almost always present in such a position.

F1 after consonant release, and low F0 after consonant release. While Löfqvist et al. would claim that actual voicing is required to create the conditions for an F0 effect, these authors argue that the effect is purely phonological. In languages where short-lag VOT obstruents are phonologically [+voice] (as in English), F0 lowering occurs. In languages where the same obstruents are phonologically [-voice] (as in French), F0 raising occurs.

In some languages it may simply be a unintentional phonetic effect while in others it has been phonologized. For instance, Francis et al. (2006) argue that higher pitch occurs after voiceless aspirated stops than voiceless unaspirated stops in Cantonese, but only within the first 10 ms. Citing data from other tone languages, they argue that F0 is not recruited as a cue in languages which use F0 as a cue for lexical tone contrasts. In a perceptual study, they find that Cantonese speakers are able to use pitch to distinguish stop types, but only when the magnitude and duration of F0 perturbations are increased to the same degree as found in nontonal languages like English.

In these studies cricothyroid activity is a requirement for the presence of increased pitch. If it is the case that F0 differences following the release of obstruents are part of an independent and controlled process, speakers may be able to adjust cricothyroid activity to cue to presence of certain phonological features. Increased pitch on obstruent release is considered a cue to phonological strength contrasts (Kohler, 1984; Jessen, 1998; Jansen, 2004).[16] If it can be shown that laryngeal raising occurs in contexts where there is no explicit voicing contrast, one might argue that it has a separate goal of cueing a phonological feature [tense].

In addition to voicing or laryngeal feature contrasts, pitch may sometimes cue consonantal length contrasts. In Pattani Malay, F0 is used as a cue for word-initial voiceless geminates (Abramson, 1986, 1991, 2003). Geminates have higher pitch than singletons. Muller (2001) observes the same pattern in Chuukese. In Berber, F0 only seems to be a correlate of gemination when it results in devoicing (Ridouane, 2007). It is intriguing that pitch may act as a correlate to consonant length only in voiceless contexts and in languages which have word-initial geminates. Laryngeal adjustments to vocal fold tension may be used to enhance consonantal length contrasts where closure duration is not an audible cue (utterance-initially).

Like durational correlates to stop contrasts, pitch is used secondarily as an enhance-

---

[16] Although Jessen (1998) considers it to be dependent on duration.

ment to the feature [tense]. However, pitch perturbations in obstruents may alternatively indicate that a different phonological feature is contrastive. Pitch is used as a correlate of both phonological voicing and length contrasts. When pitch is contrastive independent of these features, it may arguably be enhancing phonological strength.

3.3.4 Summary: Correlates of Strength

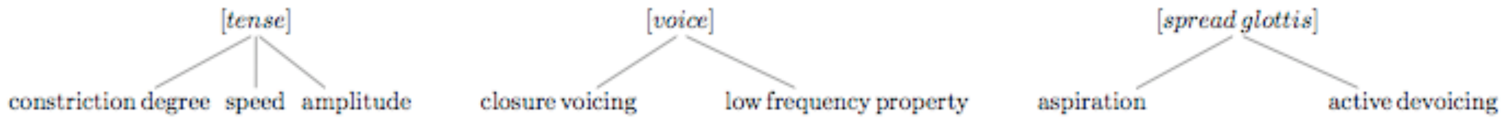
Since the work of Jakobson and Halle (1956), Chomsky and Halle (1968), and Jakobson et al. (1976) phonologists have assumed that each segment is composed of a set of distinctive features defined in terms of some phonetic property. The two perspectives differ on whether features should be defined acoustically or articulatorily. However, both argue for grounding phonological features in phonetic reality. Distinctive features allow linguists to capture the notion of natural classes and contrasts in natural language (Hall, 2001). They also allow linguists to capture processes of assimilation as autosegmental spreading.

If [tense] or [fortis] are features encoding articulatory strength as a phonetic property, assuming featural groundedness one may expect their primary correlates to reflect this phonetic property. Secondary correlates or cues may serve to enhance this contrast and may not be directly related to strength. This perspective, along with the review of the correlates of strength in the preceding sections, suggests a model of featural representation where the primary correlates/cues correspond most closely to the type of distinctive feature and secondary correlates/cues may diverge or be dependent on the primary ones. This model, which compares three privative laryngeal features: [tense], [voice], and [spread glottis], is shown in Figure (3.7).

The purpose of this model is to both ground distinctive features in their phonetic exponents and to allow us to make phonological feature predictions from the phonetic characteristics of a language. Additional correlates like duration and pitch are not included in this model. If these were the primary correlates of a phonological contrast one might argue that the contrast was either one of length or tone. A number of possible secondary correlates also are used to cue the presence of any one of these features, but which secondary cues are utilized in marking a contrast is language-specific.

An implicit assumption in much of the literature on the phonetics-phonology interface is the notion of invariance. One seeks to describe which features represent a particular sound across all phonological contexts. This approach is similar to a phonemic representa-

Figure 3.7: Obstruent features and their primary correlates



tion of sound structure. Both seek an invariant descriptor that unites a set of sounds realized distinctly in different environments. However, invariance may not always exist. The same underlying segment may have quite distinct allophones which have no featural content in common. In such cases one would argue that the set of distinctive features would be wholly dependent on the context in which they appear. The model provided in Figure (3.7) assumes this particular perspective where invariance applies only within a certain phonotactic context.

This model predicts that consonants with a [tense] feature will contain the phonetic properties of increased constriction degree, faster formant trajectory (speed), and greater amplitude. The absence of these properties and the presence of others suggests that a particular contrast does not involve strength but will be encoded with a different distinctive feature altogether. The phonetic study of Trique obstruents in the following chapter tests the predictions of this model. If there is truly a fortis-lenis contrast, realized with the feature [tense], one expects the particular phonetic properties that are associated with it.

3.4 Fortis-Lenis in Otomanguean

A consonantal fortis-lenis contrast has been described for numerous Otomanguean languages. It is found in Zapotec (Zapotecan) (Nellis and Hollenbach, 1980; Jaeger, 1983; Butler, 2000; Long and Cruz, 2000; Avelino, 2001; Kaufman, 2003; Beam de Azcona, 2004), Otomi (Otopame) (Gibson, 1956; Bartholomew, 1960; Blight and Pike, 1976), Amuzgo (Amuzgan) (Bauernschmidt, 1965), and within Trique (Mixtecan) (Longacre, 1952; Hollenbach, 1977, 1984b, 2004a). In all these languages, the fortis-lenis contrast spans the consonantal inventory; it is not restricted to the obstruent series. For some researchers, the labels *fortis* and *lenis* are used as cover terms for underlying consonant length or obstruent voicing contrasts. For others, they are used to describe what is at least impressionistically an underlying contrast in articulatory strength (Bauernschmidt, 1965; Nellis and Hollenbach, 1980). In this section I review both the range of phonological phenomena which researchers have used to posit the existence of a fortis-lenis contrast and the phonetic studies which have examined it as well.

3.4.1 The Phonology of Fortis-Lenis Contrasts in Otomanguean

Phonological descriptions of several Otomanguean languages mention a fortis-lenis contrast, but the most extensive arguments in favor of the contrast come from work on Zapotec (Nellis and Hollenbach, 1980; Jones and Knudson, 1977). In this work, four types of phenomena are presented which argue in favor of a strength-based contrast: spirantization, variable devoicing, assimilation, and compensatory vowel lengthening. Other researchers have not provided phonological arguments for their classification, but have simply stated that the consonantal contrast involved strength (Butler, 2000; Long and Cruz, 2000).[17]

In their analysis of Cajonos Zapotec (a northern variety), Nellis and Hollenbach (1980) in favor of the strength-based contrast. They find that lenis obstruents undergo processes of spirantization and may be variably voiced. Fortis obstruents are never spirantized and always surface as voiceless. For instance, the lenis stops /b/ and /g/ surface as fricatives except when following a consonant, as shown in Table 3.2. The fortis bilabial and velar stops are transcribed as [p] and [k] here, while the lenis stops are transcribed as [b] and [g], respectively. Fortis sonorants are indicated with a half-length diacritic (nˑ). Unlike the bilabial or velar stops, Nellis and Hollenbach (1980) mention that the alveolar lenis stop /d/ always surfaces as a weak stop (p.95), not as a fricative.

Table 3.2: Cajonos Zapotec Lenis Stop Spirantization
(data from Nellis and Hollenbach (1980))

βát	*when?*	βkòɣ	*aisle*
βèɣ	*nuisance*	βɣôɣ	*inca dove*
dòβée	*feather*	ɣòpée	*fog*
lˑbérɣ	*pea*	ɣrîngw	*gringo*

While the authors transcribe the lenis stop allophones as voiced ([b], [d], and [g]), they mention that each of the lenis stops may undergo devoicing in certain contexts.[18] All lenis consonants other than /n/ or /w/ devoice word-initially when preceding any consonant. For instance, the words [b̥jínˑé] *bird* and [l̥nì] *fiesta* both occur with devoiced lenis consonants.

---

[17] In these particular cases, the terms *fuerte* "strong" and *débil* "weak" are used, instead of *sordo* "voiceless" and *sonoro* "voiced."

[18] This process of devoicing is independent from a process word-final devoicing which affects all consonants in Zapotec (Nellis and Hollenbach, 1980; Avelino, 2001).

While only one example is given, the authors mention that when the lenis alveolar nasal precedes a stop, it undergoes place assimilation. This process does not occur for the fortis variant. The conclusion that the authors reach based upon these observations is that voicing does not sufficiently capture the differences between the consonants. It can not explain the patterns of devoicing, spirantization, or the loss of place information.

Nellis & Hollenbach mention that a process of vowel lengthening occurs before lenis consonants. Examples of this are shown in Table 3.3.

Table 3.3: Cajonos Zapotec Vowel Lengthening
(data from Nellis and Hollenbach (1980))

jáp	*will care for*	jáːβ	*will weave*
jàʔ	*the squash*	jîːdàʔ	*the leather*
nís	*water*	nèːz	*road*
bèn	*give!*	dʒèːn	*blood*

The vowel lengthening observed in Table 3.3 is restricted to simple (short) vowels, as Zapotec has a phonemic vowel length contrast. A similar process occurs in Guelavia Zapotec where oral vowels are long when preceding a lenis consonant or pause (Jones and Knudson, 1977). Vowel lengthening before voiced consonants is a common process cross-linguistically, as is the process of vowel lengthening before singleton consonants (see Section 3.3.3.2 for a review of both processes). Thus, it is compelling to consider the vowel lengthening pattern cited by Nellis and Hollenbach (1980) as evidence in favor of a length or voicing contrast, not one which requires a difference in phonological strength.

However, Nellis & Hollenbach reject the length-based analysis outright. They note that accepting such an analysis would predict long onset consonant clusters to become longer still. So, a possible onset cluster in the word [ʂt+lʁʂiʐ] *even San Francisco Cajonos* would be [ʂʂtt+lʁʂʂiʐ] if all fortis consonants were to be considered geminate. Since 8 consonant onset clusters are rare, this analysis is disfavored. Second, the authors mention that native speakers never choose to write the contrast with two consonants in an orthography.

Both these arguments have weaknesses. First, the fact that the length analysis would produce a rare type of heteromorphemic consonant cluster does not argue, a priori, against the validity of such an analysis. Second, there is also no evidence that native speakers tend to represent a phonemic distinction in their orthography in a way that mirrors their cognitive representation of the contrast. The widespread knowledge of Spanish for Zapotec speakers might also bias them towards using a more familiar Spanish orthography which does not contain doubled consonants. Accordingly, it is possible to consider the fortis-lenis contrast in Zapotec as one based on length. However, a length-based analysis must also explain the patterns where one consonant type is more vulnerable to weakening processes than the other.

Even if such a length-based analysis were valid, Kirchner's view of geminate inalterability does not offer an account for why lenis consonants in Zapotec undergo processes of assimilation and pre-consonantal devoicing. In his view, such consonants assimilate because there is a greater energy cost to maintain distinct place of articulation. While there is some phonetic basis for obstruent devoicing in a variety of contexts, there is no phonetic basis for sonorant devoicing before sonorants.

Instead, it can more convincingly be argued that lenis consonants in Zapotec are unmarked for laryngeal features and only undergo passive processes of voicing (see Section 3.2.1.1). Following the model proposed in Figure (3.7), passive voicing is arguably most common in languages which do not contrast [voice], but instead use glottal width features like [spread glottis] or [constricted glottis]. In such languages the laryngeally-unmarked segment will undergo passive voicing in contexts where voicing can spread from a preceding segment (see Section 3.2.4). If fortis consonants are longer than lenis ones, then the effect of passive voicing and devoicing processes would be more robust on lenis consonants. I test this laryngeal feature analysis on another language with a fortis-lenis contrast, Trique, in the next chapter.

3.4.2 The Phonetics of Fortis-Lenis Contrasts in Otomanguean

There have been few studies of the phonetics of Otomanguean languages to date. However, two of them, Jaeger (1983) and Avelino (2001), specifically focus on the fortis-lenis contrast in two related Northern (Villa Alta) Zapotec languages. Both studies conclude that duration and completeness of closure are robust correlates of the contrast, but differ in whether glottal width also plays a role.

Jaeger (1983) analyzes obstruent data from Yatée Zapotec and Djauan, an Australian (Gunwingguan) language. She observes that fortis obstruents in Zapotec are always voiceless and unaspirated while lenis ones are partly or fully voiced. Voicing is more common word-medially than initially or finally, but occurs in all contexts where lenis consonants occur. VOT does not distinguish the obstruents even though both may be voiceless and unaspirated. Furthermore, there is some variation in the completeness of closure for lenis stops and affricates. Jaeger observed that full closure occurred in only 43% of her data. When closure is not reached, the lenis stop/affricate is realized as a fricative. Complete closure is more common in word-initial position than medial or final. Regarding consonant duration, there were substantial differences between the lenis and fortis obstruents. Lenis obstruents had approximately 50% the duration of fortis obstruents.[19] Fortis stops were also realized with stronger release bursts than lenis stops.

From these observations, Jaeger concludes that duration, glottal width, and the completeness of closure are the main correlates of the fortis-lenis distinction in Yatée Zapotec, not articulatory strength. Voicing differences between the obstruents result from different glottal width parameters. Fortis obstruents are realized with fully abducted vocal folds. The optionality of voicing in Jaeger's lenis obstruent data suggests that voicing is passive in the lenis obstruents while glottal spreading is an active process in the production of fortis obstruents. This explanation jibes well with Jaeger's description and also would explain the lack of lenis obstruent voicing in word-initial and final contexts. It is precisely in these prosodic boundary positions that consonant lengthening would occur (Keating et al., 2000; Cho and Keating, 2001) and cause passive devoicing (see Section 3.2.1.1).

Contra Jaeger, Avelino (2001) argues that glottal manner features do not characterize the fortis-lenis contrast in Yalálag Zapotec, but VOT and duration do. Combining data from stops in a variety of contexts (initially, medially, and finally), he observes that lenis stops are consistently produced with negative VOT, with values between -63 ms (for velars) and -115 ms. (for alveolars). Fortis stops are produced with positive, short-lag VOT, with values between 14 - 49 ms. However, Avelino qualifies his findings stating that all word-final obstruents undergo devoicing. In this context, lenis obstruents are produced with voicing during 27% of their closure. With respect to duration, Avelino observes that fortis segments are longer than lenis ones (157 ms. vs. 92 ms.). The duration of the preceding vowel is also affected by the consonant type. Vowels are shorter before fortis consonants and longer before lenis ones. Avelino argues that vowel lengthening is related to phonological voicing in lenis obstruents for Yalálag Zapotec. Avelino observes a pattern of vowel lengthening before lenis

---

[19] Jaeger measures the entire consonant duration here, not simply closure.

obstruents which occurs regardless of the syllable affiliation of the lenis consonant, i.e. in both $C_1V.C_LV$ and $C_1VC_L.CV$ contexts. Lengthening does not occur before lenis sonorants in the language. No process of vowel shortening occurs before fortis obstruents. From these findings, he concludes that vowel lengthening is triggered solely by the presence of a feature in the lenis obstruents, namely [VOICE]. As sonorants are underspecified for [VOICE], they do not trigger vowel lengthening. Unlike Jaeger, Avelino does not find amplitude to be a reliable correlate of the fortis-lenis contrast.

Avelino considers the fortis-lenis contrast in Zapotec to be both a singleton-geminate and voicing contrast. He rejects the notion that glottal width parameters are adjusted independent from voicing. He argues that fricative realizations of lenis stops are implemented as a strategy "for the goal of keeping voicing in the entire segment" (Avelino, 2001:47). However, the fricative realization of stops could just as easily be explained as a process of target undershoot (Lindblom, 1983; Flemming, 2001) where complete closure is not reached during the shorter durational window of a singleton consonant. Avelino also does not specifically address the variable devoicing patterns observed by Nellis and Hollenbach (1980) or Jaeger (1983). More investigation of this Zapotec language may be needed to address these concerns. It may also be the case that Yalálag Zapotec is substantially different from Yatée and that glottal width features vary cross-linguistically, even within linguistic subfamilies in geographic proximity.

Both Jaeger (1983) and Avelino (2001) argue against the view that articulatory strength characterizes the fortis-lenis consonant opposition in Zapotec. Using phonetic evidence, they argue that consonant duration is the major correlate typifying the contrast. In these particular cases, durational characteristics and laryngeal feature specification account for observed phonetic tendencies in the consonant contrast. These findings are in agreement with historical reconstructions of Proto-Zapotec and Proto-Otomanguean where a length contrast spanned the entire consonant inventory (Suárez, 1973; Rensch, 1976; Kaufman, 2003).

3.4.3 Fortis-Lenis in Trique

While phonological descriptions of both Chicahuaxtla and Copala Trique exist, there has been little phonetic study of either language (but see recent work by Edmondson (2007)). Longacre (1952) and Hollenbach (1977) mention that there is a fortis-lenis contrast in both the obstruent and sonorant inventory in Chicahuaxtla Trique. The fortis-lenis contrast is restricted to final syllables. Fortis sonorants are longer than lenis ones, which Longacre indicates with a length diacritic. Fortis obstruents are mentioned to be "voiceless and slightly lengthened" (Hollenbach, 1977). Like the descriptions of Zapotec, Hollenbach states that lenis obstruents vary from voiced to voiceless.

The fortis-lenis contrast in Copala Trique is less robust. Hollenbach states that it is limited to the obstruent series (Hollenbach, 1977, 1984b). She observes that fortis stops are voiceless, slightly lengthened, and unaspirated. Lenis stops are voiced fricatives between vowels but vary from voiced to voiceless in word-initial position or in onset clusters. Hollenbach uses the features [VOICE] and [TENSE] to distinguish lenis obstruents from fortis ones. Lenis obstruents are [+voice] but [-tense] while fortis ones are [-voice] and [+tense].[20] Apart from this author's work, no previous investigation of Itunyoso Trique exists.

The observations on Copala and Chicahuaxtla Trique by previous authors is similar to the observations for Zapotec. However, there is currently no phonetic research investigating the acoustic correlates of the fortis-lenis contrast. If lenis obstruents are phonologically voiced in Trique, then one might expect voicing to occur in a variety of contexts, not only those where a consonant tends to have the shortest duration (intervocalic position). The restriction of voicing to short duration contexts suggests that voicing is passive in these environments (see Section 3.2.1.1). If fortis obstruents are produced with greater articulatory force, then one might expect them to be realized with a greater constriction degree, increased amplitude, and faster formant transitions. I examine both the articulatory dynamics of voicing and the acoustics of the contrast for Itunyoso Trique in the following chapter.

3.5 Discussion

Descriptions of voicing in lenis obstruents in Otomanguean languages resemble the descriptions of voicing in lenis (or voiced) obstruents in Germanic languages. In both

---

[20] While the fortis-lenis contrast in Copala Trique does not include sonorants, Hollenbach (1984b) mentions that sonorants (but not obstruents) are lengthened when they occur before short vowels. The interaction between vowel length and consonant lengthening has led some researchers to argue in favor of moraic onsets in Copala Trique, i.e. Muller (2001).

cases, voicing may vary by position within the word. In both cases, such consonants can undergo spirantization. In both cases, fortis/tense consonants are never voiced. This has led researchers to utilize the terms *fortis* and *lenis* or features like [tense] to describe the contrast. In certain cases these labels are mere misnomers for some other type of phonological contrast (i.e. Dutch). In other cases, such labels are used to argue in favor of a consonantal strength contrast (i.e. German). If consonantal strength is encoded directly via a feature like [tense] or [fortis], one expects the presence of acoustic, aerodynamic, or articulatory phonetic correlates which correspond to increased articulatory effort.

In this chapter I have examined two theories of strength at the phonology-phonetics interface. The [TENSE] hypothesis of obstruent contrasts espoused by Jessen (1998), and Jansen (2004) argues that obstruents are distinguished with the abstract feature [tense] which has various phonetic correlates, one of which is an active devoicing gesture present in phonologically voiceless consonants. This view predicts that [tense] consonants are realized with correlates of articulatory strength, such as increased constriction degree, greater amplitude, and increased articulator stiffness (resulting in faster formant transitions).

The [LAZY] hypothesis examined in Kirchner (1998) and Flemming (2001) states that articulations with greater biomechanical effort will be realized with greater articulator stiffness and faster formant trajectories. Since increased effort is needed with greater articulatory displacement from adjacent positions, one expects greater stiffness during their production. Voicing does not occur in utterance-initial phonologically voiced stops in English because it requires more effort than voicing in a medial context. Kirchner (2000) argues that patterns of lenition in languages with consonantal length are explained via a crucial ranking of the constraint [LAZY]. Under his hypothesis, geminates are always realized with greater articulatory strength. Ergo, one expects them to be realized with greater articulator stiffness.

Both the [TENSE] and [LAZY] theory argue that articulatory strength accounts for patterns of voicing and lenition in obstruents. Iverson and Salmons (1995, 2003) and Jessen and Ringen (2002) propose an alternative hypothesis where glottal width features like [spread glottis] account for such patterns. Glottal spreading accounts for a set of additional phonological patterns of voicing and aspiration (described in Section 3.2.4). It also does not predict any correlates of articulatory strength to occur with [+spread glottis] consonants. Rather, it predicts that glottal width is the active parameter distinguishing phonetically voiced and voiceless consonants in Germanic languages. Under such a view, voicing may only occur passively, in those contexts where shorter duration results in its perseveration. Unlike the hypotheses mentioned above, the glottal width approach is more directly grounded in the details of articulation.

I test these particular hypotheses in the following chapter where I analyze data from the fortis-lenis contrast in Itunyoso Trique. I include both phonetic correlates purportedly related to strength, such as duration and voicing, and those directly related to it, such as amplitude and formant trajectory. This investigation has ramifications for phonological theories of articulatory strength, models of the phonetics-phonology interface, and comparative Otomanguean phonology.

Chapter 4

Acoustic and Articulatory Investigations of the Fortis-Lenis Contrast

4.1 Introduction

In this chapter I investigate the phonetic characteristics of the fortis-lenis contrast in Itunyoso Trique. I examine two hypotheses. First, the contrast involves differences in articulatory strength and these particular correlates are primary in indicating the contrast. Second, duration and articulatory strength are closely related. Kirchner (2000) argues that geminates resist processes of lenition because they require greater biomechanical effort than singletons. I test these hypotheses with both an acoustic investigation of the correlates of the contrast and an electroglottographic experiment investigating glottal timing relative to obstruent gestures. I conclude that the fortis-lenis contrast in Itunyoso Trique is one of length (singleton-geminate), with an additional secondary [SPREAD GLOTTIS] feature specified for the fortis obstruent series. These phonological differences between fortis and lenis consonants not only define the contrast, but also explain the variable patterns of consonant lenition. The Trique data suggests that there is no need for the constraint [LAZY] in explaining patterns of geminate inalterability.

This chapter is organized as follows. In Sections 4.2 and 4.3 I outline the methods used in conducting the acoustic investigation and the results, respecively. In Sections 4.4

and 4.5 I outline the methods used in conducting the laryngographic investigation and the results. In Section 4.6 I discuss the findings from each experiment in light of the hypotheses examined in the previous chapter.

4.2 Acoustic Experiment Methodology

4.2.1 Stimuli

The stimuli for this experiment consisted of 40 monosyllabic words contrasting obstruents and sonorants.[1] The obstruents investigated were: /t/, /T/, /tʃ/, /Tʃ/, /ʈʂ/, /Tʂ/, /k/, /K/, /kw/, and /Kw/.[2] The sibilant /s/ was excluded from this investigation as its fortis variant is realized as an affricate in word-initial position (/ts/). Two sonorant contrasts were investigated: /n/, /N/, /w/, /W/. The bilabial nasal /m/ and the lateral approximant /l/ were excluded because they are relatively rare phonemes and there are few words which demonstrate the fortis-lenis contrast with them.

Each word appeared in a natural carrier sentence. Given the nature of the fieldwork, it was preferable to provide natural contexts for each of the words rather than unnatural contexts like "Say ___ again." Therefore, some of the carrier sentences differed. Most of the stimuli were nouns, which appeared in the carrier sentence /ni^{4}ʔya^{43} ___ nã^{3}/, see.1sg ___ here, *I see ___ here*. The contexts used for adjectives or verbs varied, but the phonological context surrounding the target word did not. The word preceding the an adjective or verb target had the vowel /i/ realized with tone /43/. The word following the target word began with the nasal /n/ and had tone level /3/. With the exception of the change of vowel in these contexts, the phonological environment surrounding all tokens was kept consistent. Each carrier sentence was repeated 6 times for a total of 240 repetitions per subject. Sentences produced with disfluencies were discarded and not analyzed. This was uncommon though (roughly 2-5% of all tokens).

---

[1] Most words which contain this contrast are monosyllabic in Itunyoso Trique. The fortis-lenis contrast among sonorants is fact restricted to monosyllables, as it is in Chicahuaxtla Trique (Hollenbach, 1977).

[2] The fortis variant indicated with a capital letter.

4.2.2 Subjects and Data Collection

Eight speakers were recruited for the investigation, 4 female, 4 male. Six speakers were between the ages of 18 - 26. One male speaker, (C), was 35 years old at the time of recording. Another female speaker, (G), was 56 years old. All participants were native, fluent speakers of Itunyoso Trique who were raised in San Martín Itunyoso. No participant reported having a history of speech or hearing disorders.

For seven of the speakers, recording took place in a quiet room in a house located in San Martín Itunyoso in Oaxaca, Mexico. The remaining speaker was recorded in his home in the central valley of California, USA. Upon reading a consent form in Spanish, speakers supplied their verbal consent to participate in the acoustic investigation. Speakers who did not understand aspects of the investigation discussed their concerns with the author's primary consultant who acted as an interpreter. The stimuli were read aloud in Trique by either the author or his consultant as a prompt for the participant.

Participants spoke into a uni-directional dynamic hand-held microphone that was maintained at a comfortable distance by the author. Recordings were made directly onto the author's Apple iBook G4 computer using an M-Audio MobilePre®USB preamplifier as an audio interface. Praat version 4.6 (Boersma and Weenink, 2008) was used to record all data. All data were sampled at 44.1 kHz.

4.2.3 Procedure: Acoustic Study

Five acoustic measures were examined in this investigation, all with the use of a script. Acoustic boundaries were hand-labelled. For stops and affricates, the closure boundary was defined as the position where spectral energy above 200-300 Hz. ceased. The preaspiration boundary was defined as the moment where spectral energy below 200-300 Hz. ceased while higher frequency spectral energy continued. While this method may have underestimated the degree of preaspiration realized as breathiness during voicing, this conservative measure avoided an accidental attribution of any vocalic breathiness to the following consonant. For the bilabial glide, the acoustic boundaries were determined by taking the midpoint between maximal F1 values in the VC or CV transition.

Some participants' acoustic data contained a low frequency harmonic at 61 Hz.[3] This was particularly noticeable in low signal amplitude recordings where participants did

---

[3] Most likely due to the recording table's proximity to an AC wall socket.

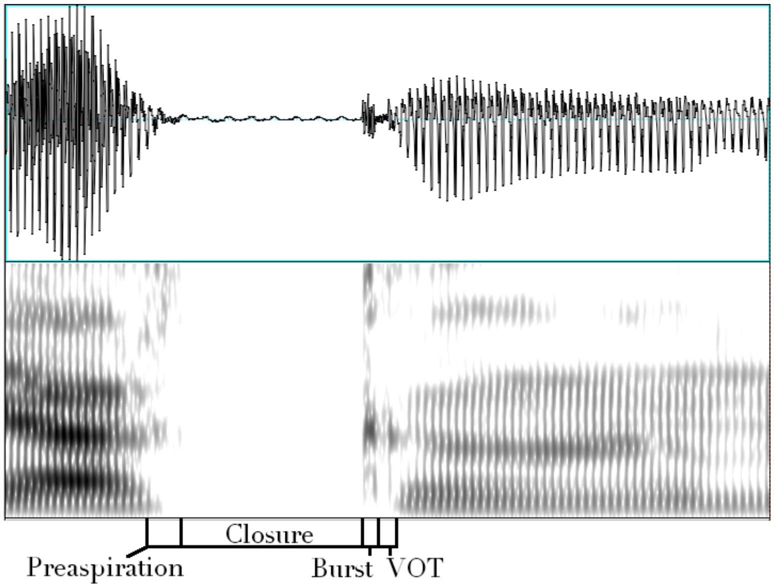


Figure 4.1: Obstruent Duration Measurements

not speak loudly. These data were high-pass filtered with a lower cut-off frequency of 65 Hz. prior to segmentation. The duration and amplitude extraction scripts used the unfiltered recording.

For stops, durational measures were made for preaspiration, closure, burst, and VOT. The frication duration of affricates was labelled as VOT in this study to allow for a simple comparison of total consonant duration among obstruents. Non-durational measures consisted of relative burst amplitude and formant trajectory. Relative burst amplitude was defined as the difference between the maximum amplitude on the following vowel and the maximum amplitude during the burst duration, $A_R = A_{burst} - A_{vowel}$. The vowels differed in this context. As visible bursts were obscured or missing in many affricate tokens, this measure was not made for them. A waveform with a corresponding spectrogram for the word /kkã^3/ *squash* is shown in Figure 4.1, illustrating the durational measures.

Formant trajectory was measured on the vowel which preceded the target consonant. As vowel devoicing damps formant amplitude, only those tokens without preaspiration were examined. Where the elimination of too many fortis tokens would have biased the comparison between fortis and lenis obstruents, the speaker's data was not used. Since a majority of the fortis affricates, fortis velars, and fortis labiovelars had preaspiration, I was only able to examine formant trajectory differences for alveolar stops. Only those speakers who produced a majority of fortis obstruents without preaspiration (four of the eight speakers) were included in this part of the study.

The acoustic data was resampled at 16 kHz prior to formant estimation. The script divided the vowel's duration into 10 chunks of equal duration and extracted mean F1, F2, and F3 frequencies across the duration of each chunk. Formant values were determined using the Burg algorithm for LPC. Formant tracking utilized a set of reference values that differed by the participant's gender. For male speakers, the reference values were F1 = 500 Hz., F2 = 1485 Hz., F3 = 2475 Hz. For female speakers, the reference values were F1 = 550 Hz., F2 = 1650 Hz., F3 = 2750 Hz. These reference values reflect the resonance frequencies found in a close-ended tube with a length of 17.5-17.7 cm. for males and 15.9 cm. for females. The method followed here permitted simple comparison of formant trajectories because duration was normalized. In all cases the vowel /a/ context was used. For those obstruent contrasts where the preceding vowels differed (see Section 4.2.1), formant trajectory differences were not measured. Results for the four speakers at the alveolar place of articulation were examined.

4.2.4 Procedure: Lenition Study

In order to investigate the susceptibility of consonant types to patterns of obstruent lenition, all data was coded as to whether there was complete closure or spirantization. The presence of broadband spectral energy instead of closure was used as a criteria for whether or not a stop/affricate was spirantized. Since there was noise present in the data, all judgments of spirantization were done by hand. I examined the tendency for lenition to occur as a function of the fortis-lenis contrast and place of articulation. In addition, I examined lenition relative to the rate of speech with the use of a script. All syllable boundaries were hand-labelled in the recordings. The number of syllables within a particular recording were then divided by their sum duration. Speech rate was calculated as the number of syllables per second. As each recording consisted of the set of repetitions of one target word, this measure does not reflect the rate of speech for each individual trial. Rather, it reflects the average speech rate used by a participant when repeating the carrier sentence associated with one target word.

4.3 Acoustic Experiment Results

4.3.1 Obstruent Data

4.3.1.1 Duration Measures

For all obstruents, lenis variants had substantially shorter closure duration from fortis variants. However, the differences in closure duration varied substantially with respect to the manner of articulation. Fortis affricates had quite short closure duration when compared to fortis stops. I present the results for each place of articulation in the stacked bar graph shown in Figure 4.2 where /ch/ = /tʃ/ and /chr/ = /ʈʂ/. Lenis obstruents are in lowercase while the fortis ones are in uppercase.

Each of the duration measures was statistically analyzed using a repeated measures analysis of variance (ANOVA) with two within-subjects factors, Type (fortis vs. lenis) and Onset (/t/, /ch/, /chr/, /k/, /kw/). For closure duration, the main effect of Type was significant (F[1,7] = 25.13, $p < 0.01$). The average closure duration for fortis was 113.4 ms, while lenis closures averaged 73.7 ms, however these values include the affricate data. The Onset main effect was also significant (F[4,27] = 8.12 , $p < 0.001$). As seen in Figure 4.2, closure duration varied substantially depending on the consonant's place of articulation. The Onset by Type interaction was marginally significant (F[4,26] = 3.5, $p < 0.05$). The robustness of closure duration differences among stops and the more marginal differences between the affricate types is reflected in such an interaction. Tukey's post-hoc pairwise comparisons of fortis and lenis stops/affricates showed that closure duration as a function of type was significant for /t/, /chr/, /k/, /kw/ ($p < 0.001$) but not for the alveopalatal affricate, /ch/. The difference in closure duration between this lenis and fortis affricate was only 11.1 ms. The difference in closure duration between the retroflex lenis and fortis affricate was small (only 24.3 ms.) but significant. For each of the other stops, the difference in closure duration was more robust, between 45 - 74 ms.

For burst duration, the main effect of Type was not significant (F[1, 7] = 3.49, $p = 0.10$) but the main effect of Onset was marginally significant (F[4, 25] = 3.21, $p < 0.05$). Tukey's post-hoc pairwise comparisons of Type X Onset interaction showed that burst duration as a function of place of articulation was significant for all comparisons ($p < 0.001$) except /k/ vs. /kw/. The onset effects reflect the tendency for more posterior articulations to be realized with longer burst durations than more anterior ones. Yet, as

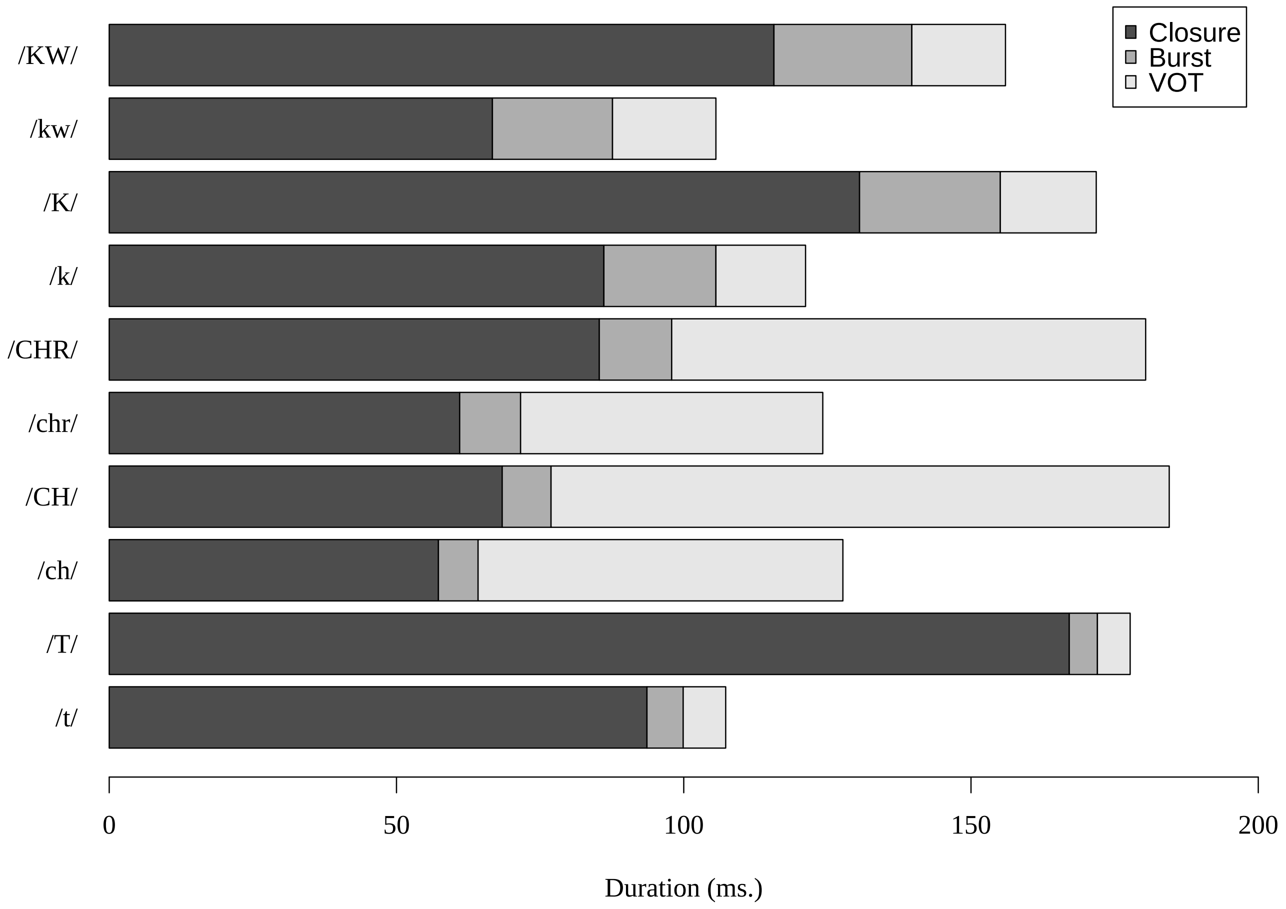


Figure 4.2: Fortis-Lenis Obstruent Duration

velar and labiovelar stops have closure at the same place of articulation, it is unsurprising that there is no significant difference in burst duration between them.

The frication duration of affricates was categorized as VOT in this investigation. For VOT, the main effect of Type was marginally significant ($F[1, 7] = 8.56$, $p < 0.05$) while the main effect of Onset was more strongly significant ($F[4, 28] = 10.77$, $p < 0.001$). Tukey's post-hoc pairwise comparisons showed that VOT as a function of place of articulation was significant for all comparisons ($p < 0.01$) except /k/ vs. /kw/. There was a strong interaction between Type and Onset ($F[4, 28] = 12.34$, $p < 0.001$). A post-hoc Tukey test showed that VOT as a function of Type was only significant for the affricate contrasts /ch/-/CH/ and /chr/-/CHR/. The average VOT values for the alveolar stops were 6-7 ms. while velar and labiovelar stops had average values between 16-18 ms. The average VOT difference between the lenis and fortis alveopalatal affricate was 44 ms. (64 vs. 108 ms.) while the difference in the retroflex series was 30 ms. (53 vs. 83 ms.). There is some complementarity between the degree in which closure duration and frication duration distinguish the fortis and lenis affricates. The retroflex series is distinguished by both closure duration and frication duration (almost equally) while the alveopalatal series is distinguished mostly by frication duration.

4.3.1.2 Preaspiration

Aspiration noise was observed preceding stops and affricates in much of the data. This preaspiration often resulted in minor breathiness on the vowel preceding the fortis or lenis obstruent. Two separate analyses were made to evaluate the possible relevance of preaspiration. In the first investigation, I considered Type, Onset, and Speaker as factors under logistic regression. A step-wise procedure using Akaike An Information Criterion (AIC) was used to evaluate which ordering of factors was most stable. A χ^2 test of significance was then used to evalute this model. The data were dummy-coded for the presence vs. absence of preaspiration. This method evaluates whether the probability of preaspiration (rather than its duration) varies significantly as a function of Type and Onset. In the second investigation, a repeated measures ANOVA was used with Type and Onset as factors. This evaluates whether the average *duration* of preaspiration varied significantly.

The probability data are shown in Figure 4.3. Preaspiration was much more frequent on fortis tokens (68%) than on lenis tokens (13%). This main effect of Type was

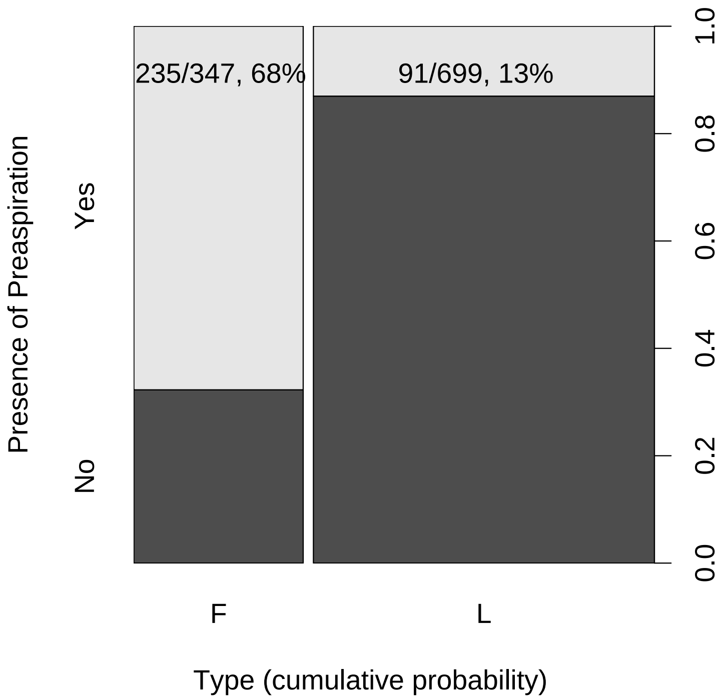


Figure 4.3: Probability of Preaspiration on Obstruents as a function of Type: **F**ortis vs. **L**enis

significant ($G^2[1] = 320.8$, $p < 0.001$). The main effect of Speaker was very significant ($G^2[7] = 178.9$, $p < 0.001$). There was an interaction between Type X Speaker ($G^2[7] = 54.8$, $p < 0.001$). This arose mainly out of the differences between two speakers. While most of the speakers produced preaspiration with similar likelihood in the fortis obstruents, speaker C produced fewer fortis tokens with preaspiration ($16/41 = 39\%$) while speaker G produced all fortis tokens with preaspiration ($38/38 = 100\%$).

The main effect of Onset was significant ($G^2[4] = 177.0$, $p < 0.001$). This arose out of a tendency for obstruents realized at a more retracted place of articulation (retroflex and velar) to be more likely to have preaspiration than more advanced places of articulation (alveolar and alveopalatal). Figure 4.4 illustrates these differences. However, these results are presented with some caution. There were largely unequal sample sizes between the different places of articulation as a function of Type. A larger sample of lenis tokens at one place of articulation would bias this place of articulation towards having fewer tokens realized with preaspiration. There was also a substantial interaction between Onset X Speaker ($G^2[28] = 110.9$, $p < 0.001$).

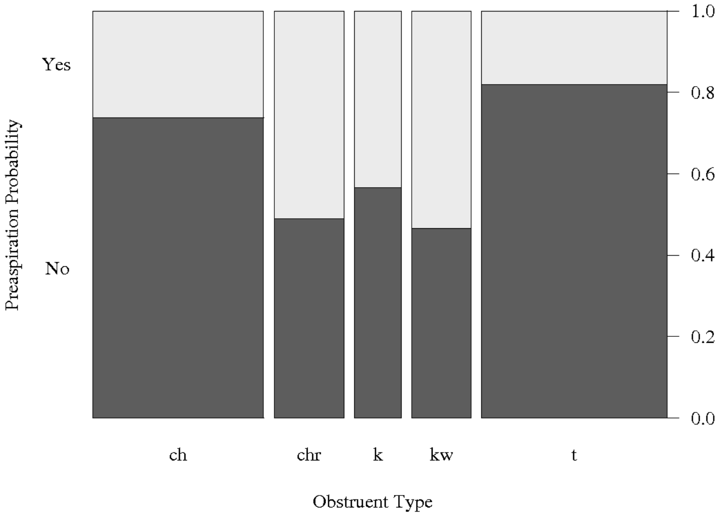


Figure 4.4: Probability of Preaspiration by Place of Articulation

Preaspiration *duration* differed as a function of Type, with fortis obstruents having a mean preaspiration duration of 37.2 ms. (sd = 17.2 ms.) and lenis obstruents having a mean preaspiration duration of 21.0 ms. (sd = 9.4 ms.). These differences were not significant though. A repeated measures ANOVA with Type and Onset as factors found that neither the main effect of Type ($F[1, 7] = 2.29$, $p = 0.17$) nor Onset ($F[4, 28] = 1.65$, $p = 0.19$) were significant. The relevance of preaspiration for fortis obstruents will be further examined in §4.5 where the more fine-grained details of glottal timing are evaluated using electroglottography.

4.3.1.3 Amplitude Measures

For relative burst amplitude (A_R), neither the main effect of Type ($F[1, 7] = 0.78$, $p = 0.41$) nor the main effect of Onset ($F[4, 25] = 1.08$, $p = 0.39$) were significant. Individual comparisons between fortis and lenis obstruents revealed that the lenis series had greater amplitude bursts than the fortis series for the /t/-/T/, /chr/-/CHR/, and /kw/-/KW/ contrasts, but the fortis series had greater amplitude bursts than the lenis for the /ch/-/CH/ and /k/-/K/ contrasts. There are some complications in these findings. Amplitude varied substantially by speaker and the recording conditions were sub-optimal for intensity measurements (i.e. lack of head-mounted microphone, background noise in fieldwork site). It is also possible that the following vowel context does not provide a stable environment for the burst amplitude to be compared against. However, the presence of greater amplitude in the *lenis* series for 3/5 of the obstruents suggests that amplitude is not used as a consistent correlate in distinguishing the fortis-lenis contrast in Itunyoso Trique.

4.3.1.4 Formant Trajectory Measures

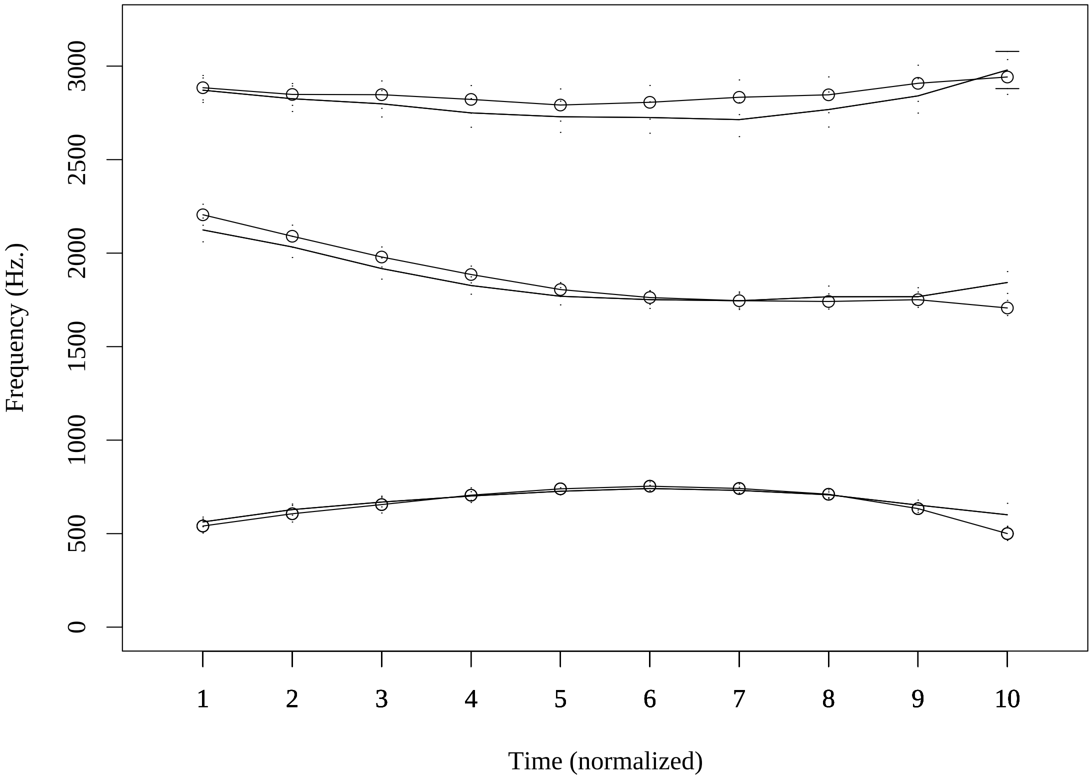
Both absolute formant values and changes in formant values were examined. F1, F2, and F3 values are plotted in Figure 4.5. Time is normalized here because there were no significant differences in the duration of vowels preceding fortis and lenis /t/. The vowel duration preceding a fortis /t/ was 149.0 ms. while it was 156.7 ms. before a lenis /t/. A one-factor repeated measures ANOVA with Type as the factor and Speaker as the error term found no effect of Type on preceding vowel duration for the data shown here (F[1, 3] = 0.57, p = 0.28). In the figure, lines with circles are average values for those vowels which preceded the lenis alveolar stop. Solid lines are average values for those vowels which preceded the fortis one.

The higher F2 and lower F1 values at the beginning of the vowel reflect a transition from a preceding palatal glide /j/. Confidence intervals at $p < 0.01$ are plotted along with the formant values. Where these intervals were quite small and would therefore overlap with the plotted formant trajectory, they are not shown. Qualitatively, the formant values for /a/ preceding the lenis stop are quite similar to those preceding the fortis. A repeated-measures analysis of variance was used for each formant at each point in the normalized duration (30 tests) with Type (fortis vs. lenis) as a factor. The main effect was not significant at any point along in the vowel's duration for any of the formant values.

There is some difference in the F1 and F2 values as a function of Type at the last time index (10). The mean F1 value preceding a fortis /T/ was 600.8 Hz. while the value preceding a lenis /t/ was 500.2 Hz. The mean F2 value was 1842.3 Hz. preceding the fortis but 1706.7 Hz. preceding the lenis. However, the F1 differences were not significant here (F[1, 3] = 2.15, p = 0.24) and the F2 differences only approached significance (F[1, 3] = 5.94, p = 0.09).

Two measures of formant trajectory were examined using a repeated measures

Figure 4.5: Formant Values on vowel preceding /t/ and /T/



ANOVA: Fn_{t6} - Fn_{t10} and Fn_{t8} - Fn_{t10}, where n = the formant evaluated and t = time index. The first measure determines if the change in formant values in the latter half of the vowel varied as a function of Type. The second measure determines if the change in formant values in the final 30% of the vowel's duration varied as a function of Type. Both measures were used to test if the vowel's formant trajectory was faster preceding the fortis stop. For the measure Fn_{t6} - Fn_{t10}, the main effect was not significant for any of the formants (F1: F[1, 3] = 4.65, p = 0.12; F2: F[1, 3] = 2.88, p = 0.19; F3: F[1, 3] = 2.34, p = 0.22). For the measure Fn_{t8} - Fn_{t10}, the main effect was also not significant for any of the formants (F1: F[1, 3] = 1.60, p = 0.30; F2: F[1, 3] = 3.45, p = 0.16; F3: F[1, 3] = 2.54, p = 0.21).

The results here demonstrate that for alveolar stops, formant trajectory is not a reliable and consistent correlate of the fortis-lenis contrast. Differences in F2 values in the last 10% of the vowel suggest that the fortis stop is realized with a slightly more retracted place of articulation, yet such differences only approach significance. Faster formant trajectory is a reflection of articulatory strength. Its absence here in the fortis context suggests that fortis stops are not realized with increased effort.

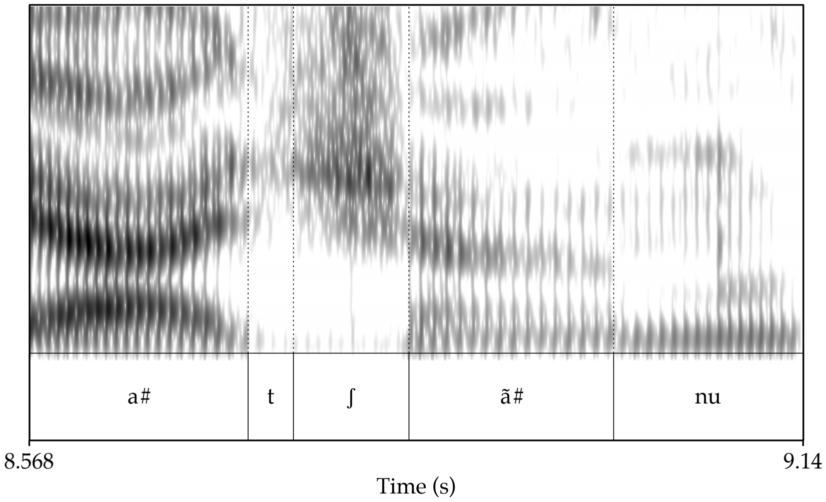
4.3.1.5 Lenition Data

With respect to obstruent lenition, two separate analyses were made. In the first, I investigated the factors involved in whether an obstruent was realized with incomplete oral closure. In this investigation, I considered Type, Onset, and Speaker as factors under logistic regression. A step-wise procedure using Akaike An Information Criterion (AIC) was used to evaluate which ordering of factors was most stable. A χ^2 test of significance was then used to evalute this model. In the second investigation, I evaluated how speech rate affected the closure duration of lenis and fortis consonants. The prediction from the literature (see chapter 3) is that fortis consonants are more resistant to processes of compression due to speech rate (Kirchner, 2000). A repeated measures ANOVA was used to investigate the effect of rate on closure duration as a function of Type. The null hypothesis is that there is no difference in the adjusted R^2 values between the models.

More lenis tokens than fortis tokens were realized with incomplete closure, but incomplete closure was not very frequent even in lenis cases. Of the lenis tokens, 83/699 (11.9%) were realized with incomplete closure while 5/347 (1.4%) of the fortis tokens were realized with incomplete closure. The main effect of Speaker was significant ($G^2[7] = 157.9$, $p < 0.001$) as well as the main effect of Onset ($G^2[4] = 196.2$, $p < 0.001$). There were substantial differences in which obstruents were realized with incomplete closure. Of the lenis tokens, 57/292 alveopalatal affricates (19.5%) and 25/96 (26.0%) of the retroflex affricates were realized with incomplete closure. By contrast, only 1/226 alveolar stops was realized with incomplete closure and none of the velar or labialized velar stops were realized with incomplete closure. An example of lenition of the lenis alveopalatal affricate /tʃ/ in the word /tʃã^1/ '*eleven*' is given in Figure 4.6. Stop closure is incomplete but still acoustically distinct from the following period of frication.

There was a strong interaction between Speaker x Onset ($G^2[28] = 61.8$, $p < 0.001$). This reflected the tendency for some speakers to realize more obstruents with incomplete closure than other speakers did. The main effect of Type was also significant, but not as

Figure 4.6: Lenition of affricate closure



strongly as the Onset effect ($G^2[1] = 22.9$, $p < 0.001$). There was no significant Speaker X Type effect, indicating that the fortis-lenis contrast was realized similarly for all speakers.

For the analysis of rate effects, data from all speakers was pooled together. The effect of speech rate on closure duration was then compared for each Type (fortis and lenis). Figure 4.7 shows plots of rate by closure duration. Regression lines are plotted on each graph along with the Adjusted R^2 values.

The main effect of Rate on closure duration was marginally significant ($F[1, 7] = 10.43$, $p < 0.05$). The interaction between Rate and Type was not significant ($F[1, 7] = 0.39$, $p = 0.55$) within Speakers but significant across them ($F[1, 7] = 22.25$, $p < 0.001$). The closure duration of fortis obstruents was more sensitive to changes in speech rate than the closure duration of lenis obstruents. This is reflected in the differences in adjusted R^2 values shown in Figure 4.7.

There was substantial variability in the speech rate among speakers. This led to an investigation of the effect of two between subjects factors, Speaker and Gender, on speech rate. A two-factor ANOVA revealed a strong main effect of gender ($F[1, 1038] = 174.1$, $p < 0.001$) and a weaker main effect of Speaker ($F[6, 1038] = 5.7$, $p < 0.001$). The mean speech rate for female speakers was 4.34 syllables/second while it was 4.89 syllables/second for male speakers. A post-hoc Tukey test revealed the only significant Speaker differences to be between Speakers B & C, B & G, B & W, C & R, and R & W.

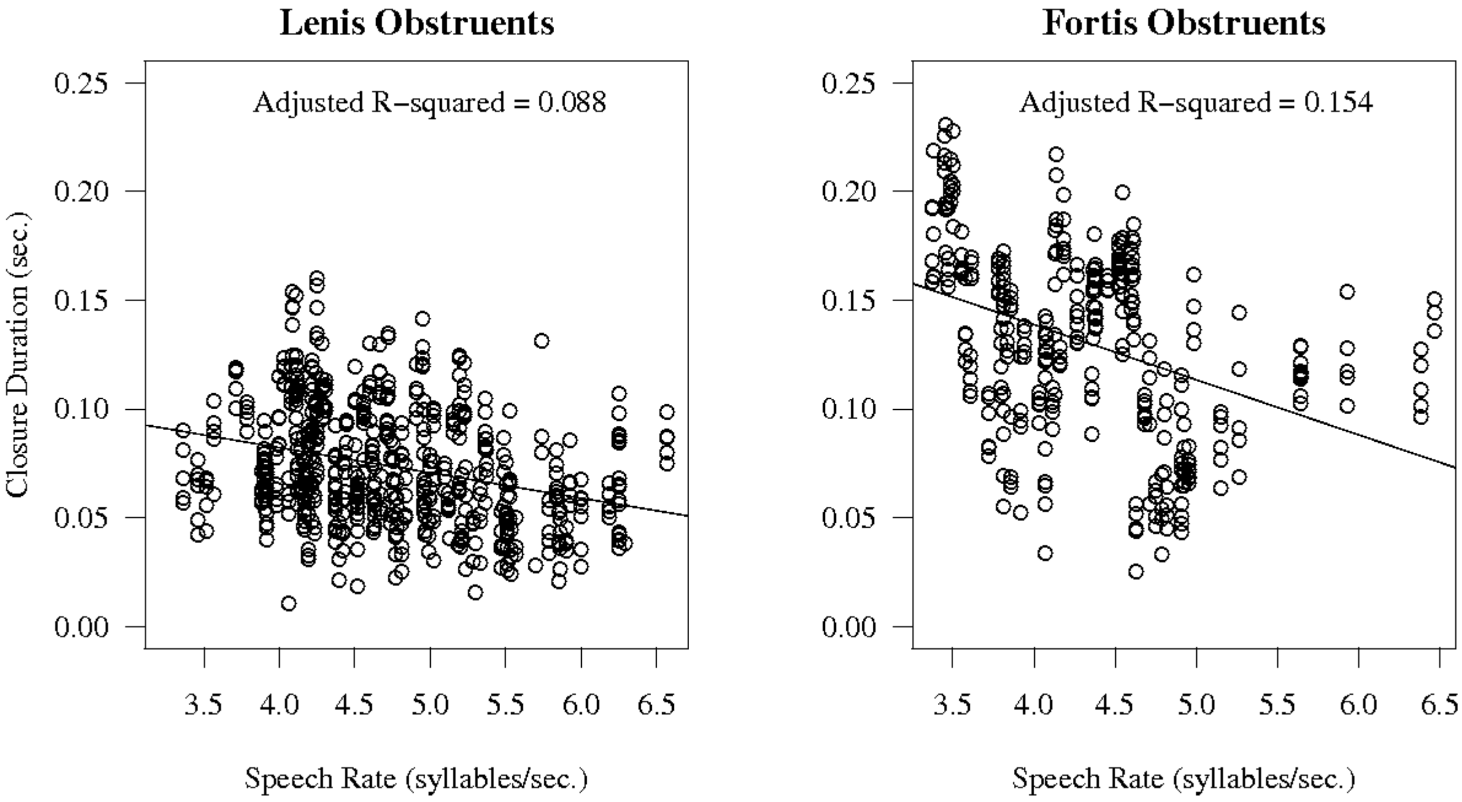


Figure 4.7: Effect of Rate on Closure Duration

4.3.2 Sonorant Data

4.3.2.1 Duration Measures

For both sonorants that were examined, lenis variants had substantially shorter closure duration from fortis variants. The average duration of lenis /n/ was 101.7 ms. while fortis /N/ was 184.8 ms. The average duration of lenis /b/ was 90.0 ms. while fortis /B/ was 152.7 ms. A barplot of the differences is shown in Figure 4.8.

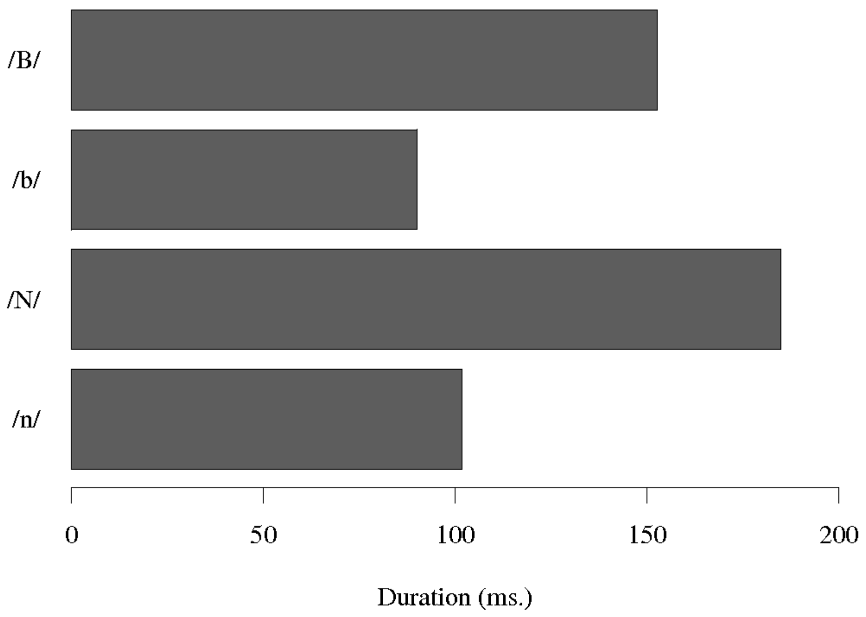


Figure 4.8: Fortis-Lenis Sonorant Duration

The duration measure was statistically analyzed using a repeated measures analysis of variance (ANOVA) with two within-subjects factors, Type (fortis vs. lenis) and Onset (/n/, /b/). The main effect of Type was significant ($F[1,7] = 55.9$, $p< 0.001$). The Onset main effect only approached significance ($F[1, 7] = 5.0$, $p = 0.06$). There was no significant interaction between Type and Onset. Tukey's post-hoc pairwise comparisons showed that duration as a function of type was significant for both alveolar nasals and bilabial glides ($p < 0.001$).

4.3.3 Discussion of Acoustic Results

Among the acoustic correlates of the fortis-lenis contrast investigated for the obstruent data, closure duration and the presence of preaspiration were significant. Differences in the duration of fortis and lenis sonorants closely matched durational differences between the obstruents. The acoustic measures of articulatory strength, such as adjusted burst amplitude and differences in the formant trajectory of the preceding vowel do not distinguish between fortis and lenis obstruents. Moreover, the patterns of lenition observed in Section 4.3.1.5 indicate that only the affricates were realized with incomplete closure. As observed in Section 4.3.1.1, these affricates had the shortest closure duration of all obstruents.

If one accepts the hypothesis that there is a phonological constraint targeting biomechanical energy expenditure that explains patterns of lenition, then one would infer that all consonants labelled as phonologically *weak* or *lenis* undergo lenition to the same extent. Under such a perspective, all *lenis* consonants would be subject to a higher ranked leniting constraint, i.e. LAZY. This particular hypothesis does not explain why reduction in the Trique data is restricted to only those obstruents with the shortest closure duration. An alternative, and simpler hypothesis is that lenition does not discriminate between phonological categories, but is more likely to occur when closure duration is short. A natural consequence of this hypothesis is that those obstruents typically realized with the shorter closure duration will more likely surface with incomplete closure when they undergo lenition. This hypothesis better fits the data observed here.

These findings support the perspective that the fortis-lenis contrast in Itunyoso Trique involves both duration and glottal timing differences. There is no evidence to consider the consonant contrast to involve articulatory strength. The contrast is better characterized as one involving consonant length, where lenis consonants are singletons and fortis consonants are geminates. However, differences in voice offset time are not inherent in the production of consonantal length contrasts (but see Pycha (2008)). Significant differences in preaspiration among the lenis and fortis obstruents led me to consider a closer analysis of vocal fold vibration using electroglottography. Fine details of glottal timing are often not easily discernible from the acoustic signal alone. Given the additional noise in the field recordings, electroglottography is well-suited to determine if there are differences in the articulatory timing between the oral and glottal gestures.

4.4 Laryngographic Experiment Methodology

4.4.1 Stimuli

The stimuli for this experiment consisted of the same stimuli that were used for the acoustic experiment except the sonorant stimuli.

4.4.2 Subjects and Data Collection

Four subjects, 3 male (Speakers B, C, J) and 1 female (Speaker M) participated in the electroglottographic study. Electroglottographic (EGG) data was acquired using a Laryngograph model portable electroglottograph recorded directly onto the author's Apple iBook G4 computer concurrently with the acoustic recordings using an M-Audio MobilePre®USB preamplifier as an audio interface. Praat version 4.6 (Boersma and Weenink, 2008) was used to record all data. All data was sampled at 44.1 kHz.

4.4.3 Procedure

Electroglottography (EGG) involves the use of electrical current to determine the contact area of the vocal folds. EGG maxima correspond to the moment of maximum contact between the vocal folds while minima correspond to the moment of minimum contact between the vocal folds (Childers and Krishnamurthy, 1985; Childers and Lee, 1991; Heinrich et al., 2004). The presence of EGG maxima and minima indicates that there is glottal vibration.

Using the acoustic boundaries defined in Section 4.2.3 for the acoustic experiment, an additional boundary was added representing the moment when the EGG signal indicated that voicing had ceased. There are three logical possibilities in the timing of devoicing relative to closure: devoicing may occur prior to closure, coinciding with closure, or during closure. When voicing ceased prior to oral closure, the duration between the point of voicing cessation and the onset of consonant closure was labelled as VST (Voice OffSet Time). When oral closure was timed exactly to coincide with devoicing, no additional labels were added. When voicing ceased after oral closure was achieved, this was labelled as VTT (Voice Termination Time). This effectively measured the duration of the oral closure that was voiced. These three possibilities are represented in Figures 4.9, 4.10, and 4.11. These methods followed a similar procedure used in Jansen (2004).

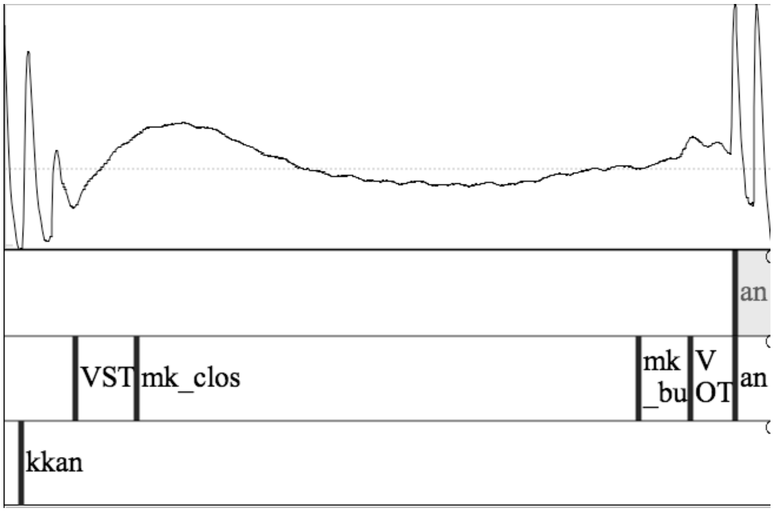


Figure 4.9: Voice Offset Time (VST)

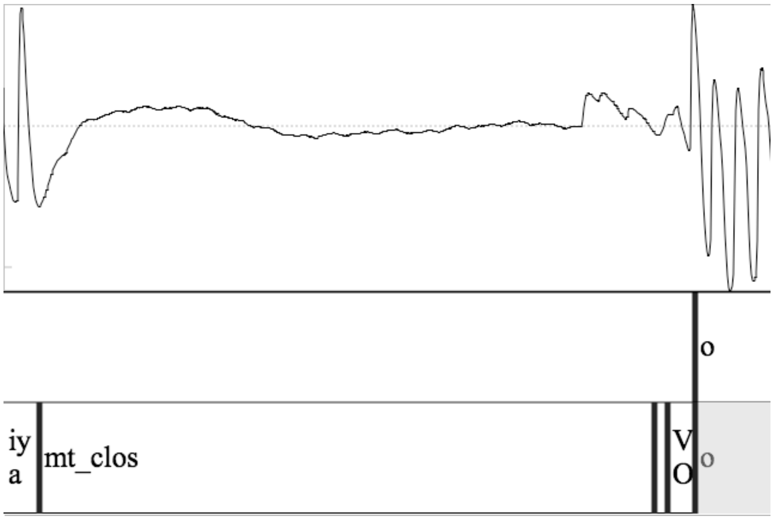


Figure 4.10: Devoicing coincidental with oral closure

In Figure 4.9, oral closure occurs at the boundary labelled "mk-clos." Note, however, that there is no voicing in the laryngographic signal immediately preceding the closure. In Figure 4.10, voicing ceases approximately simultaneously with the moment of consonant closure, shown at the boundary labelled "mt-clos." If closure occurred within 5 ms. or less of the cessation of voicing, the token was considered to have simultaneous closure and devoicing. In Figure 4.11, closure occurs at the left boundary of the label "VTT" but voicing continues well into the oral closure, ceasing at the boundary labelled "mt-clos." Similar

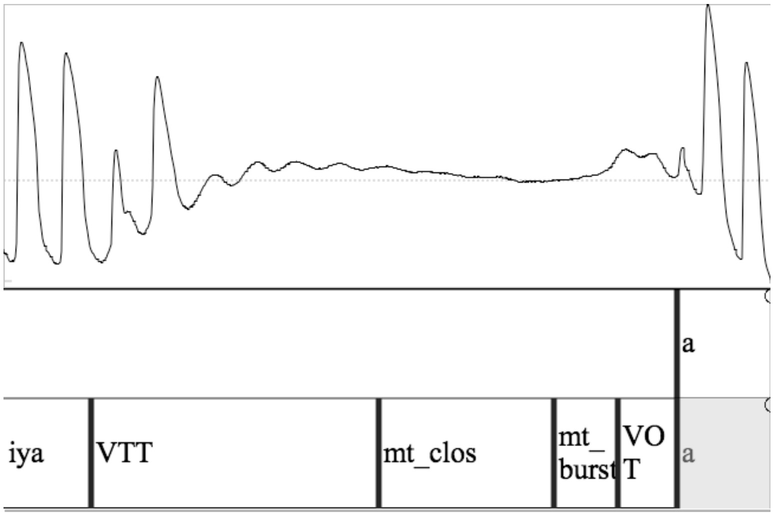


Figure 4.11: Voice Termination Time (VTT)

to the procedure in the preaspiration data in Section 4.3.1.2, both the relative frequency of these glottal timing patterns and the duration between closure and devoicing were evaluated. Data were dummy-coded for the glottal timing strategy employed: VTT (P), Simultaneous (S), and VST (V).

4.5 Laryngographic Experiment Results

4.5.1 Glottal Timing Strategy

Type, Onset, and Speaker were tested as factors under logistic regression. A stepwise procedure using Akaike An Information Criterion (AIC) was used to evaluate which ordering of factors was most stable. A χ^2 test of significance was then used to evalute this model. This method evaluates whether the probability of the glottal timing strategy varies significantly as a function of Type and Onset. The model with the best ordering of factors under AIC was one with Type (Fortis vs. Lenis), Onset, and Speaker, respectively ordered. A barplot of the probability data is provided in Figure 4.12.

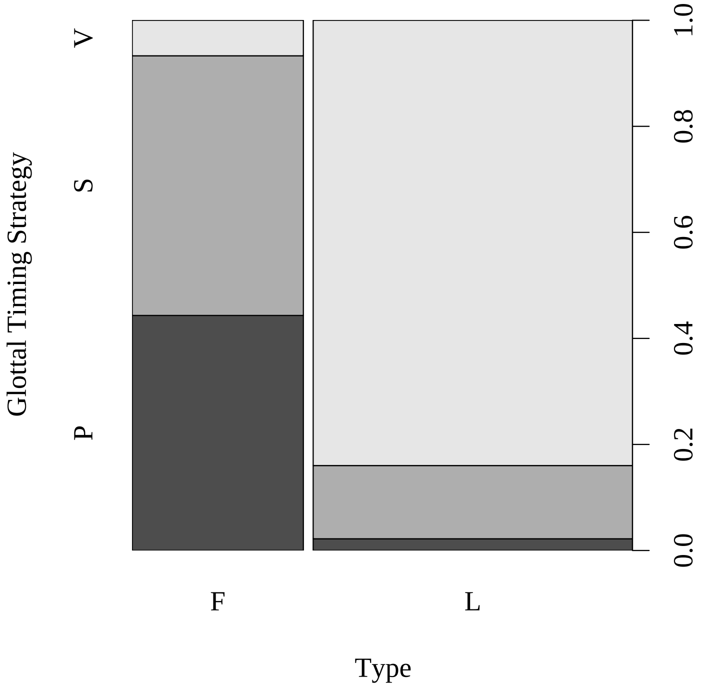
The main effect of Type was significant ($G^2[1] = 162.0$, $p < 0.001$). Most of the lenis tokens were realized with devoicing following consonant closure (304/362 = 84%). This manner of glottal timing was rare for the fortis tokens (13/194 = 6.7%). While simultaneous closure and devoicing was common among the fortis obstruents (96/194 = 49.4%), it was

Figure 4.12: Glottal Timing Strategy by Consonant Type:

P = Devoicing Precedes Closure

S = Devoicing Simultaneous with Closure

V = Devoicing Follows Closure

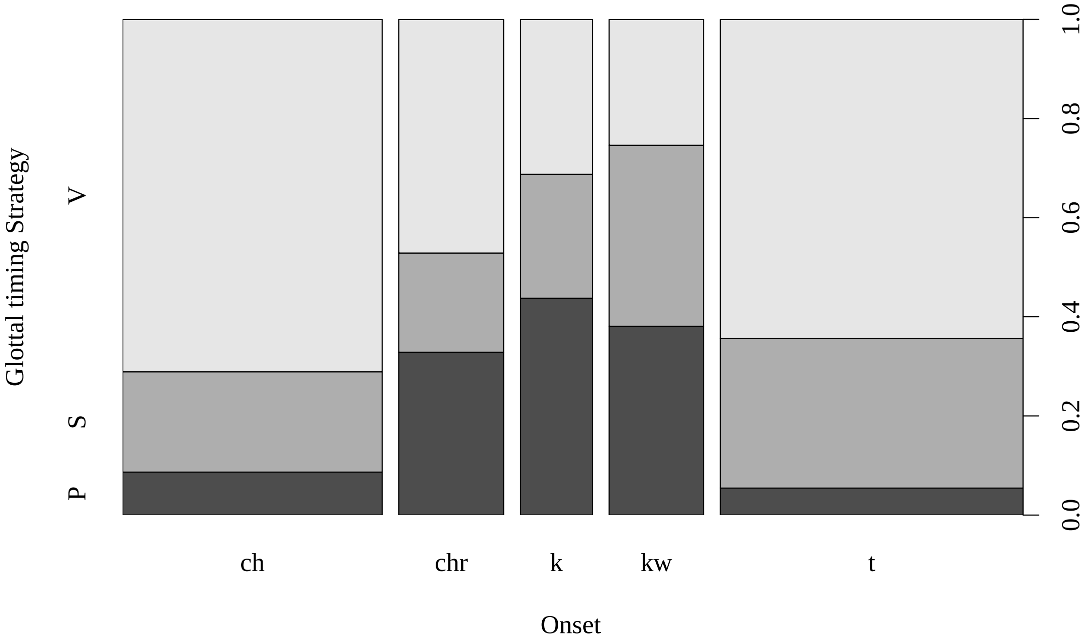


uncommon among the lenis obstruents (51/362 = 14.1%). Devoicing prior to closure was also common among the fortis obstruents (85/194 = 43.8%) but rare among the lenis obstruents (7/362 = 1.9%).

The main effect of Onset was also significant ($G^2[4] = 79.0$, $p < 0.001$). There was a marked tendency for posterior places of articulation to be more often realized with devoicing prior to closure than more anterior places. The converse was also true: anterior places of articulation were more often realized with voicing during closure than more posterior places. These differences may reflect a trading relation between the duration of voicelessness and the closure duration. Posterior places of articulation have shorter closure duration but more preaspiration. These tendencies are shown in Figure 4.13.

The main effect of speaker was also significant ($G^2[3] = 39.8$, $p < 0.001$). This

Figure 4.13: Glottal Timing Strategy by Obstruent Place of Articulation



reflected the tendency for speakers B and C to realize more tokens with voicing during closure than speakers J and M. There was a significant interaction between Onset and Speaker ($G^2[12] = 62.7$, $p < 0.001$) but no interaction between Type and Speaker. The Onset X Speaker interaction is reflected mainly in the behavior of Speaker J, who produced more fortis alveolar tokens with VST than the other speakers, and in the behavior of Speaker C, who produced more lenis labiovelar stops with voicing during closure than the other speakers.

The data here demonstrate that the fortis-lenis contrast among obstruents is realized with differences in glottal timing. Fortis obstruents are more often realized with devoicing prior to closure or simultaneous with closure. On the other hand, voicing is maintained into the closure of lenis obstruents. These probability data do not capture the magnitude of the phase differences however. The durational differences in the oral-glottal phasing are the topic of the following investigation.

4.5.2 Oral-Glottal Phasing

The investigation in 4.5.1 utilized three categories of glottal timing because it was useful to qualitatively determine how often different obstruent types and places of articulation were phased in a particular fashion. However, the timing of vocal fold adjustments relative to oral articulations is not inherently categorical. The two gestures may be distant from each other, may be adjacent, or may overlap. What makes more sense in an investigation of the magnitude of these phase differences is the relative timing of the gestures. For this investigation, all tokens were coded for their duration relative to oral closure. The measure "relative glottal timing" or RGT was used, which reflected the time at which voicelessness began relative to closure. Tokens with devoicing simultaneous with oral closure were assigned a value of zero. Tokens with with devoicing prior to closure were assigned a negative value. Tokens with devoicing following closure were assigned a positive value.

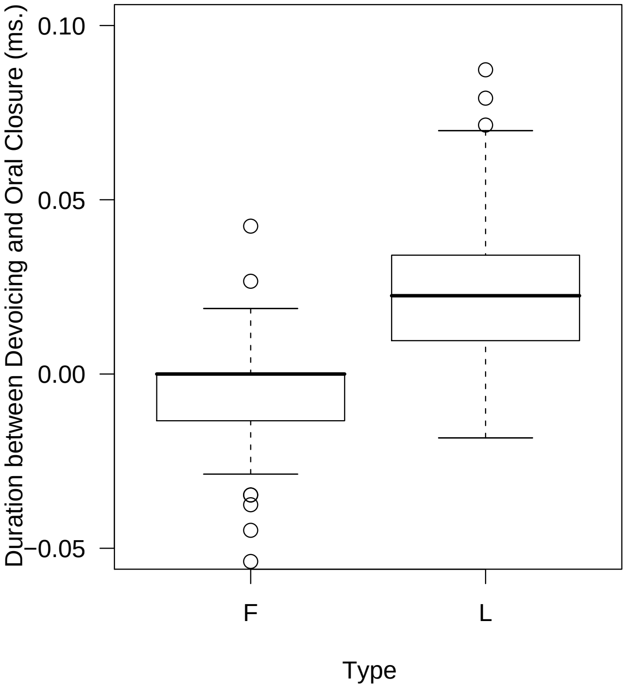
RGT was statistically analyzed using a repeated measures ANOVA with two within-subjects factors, Type (fortis vs. lenis) and Onset (/t/, /ch/, /chr/, /k/, /kw/). The main effect of Type was significant ($F[1,3] = 60.5$, $p < 0.01$). The main effect of Onset was not significant ($F[4, 3] = 3.8$, $p = 0.15$). For fortis obstruents, the mean glottal timing relative to consonant closure was -6.2 ms. (sd = 11.5 ms.). For lenis obstruents, the mean glottal timing relative to consonant closure was 23.0 ms. (sd = 17.2 ms.). Thus, devoicing occurred on average 29.2 ms. later for lenis obstruents than it did for fortis obstruents. This data is shown in Figures 4.14 and 4.15.

In Figure 4.15, VTT reflects the duration of voicing during closure. It overlaps the consonant closure (the lightest bar). VST reflects the duration of voicelessness before closure and does not overlap with the consonant closure. I observed that fortis obstruents at varying places of articulation had either devoicing prior to or at the moment of consonant closure. Lenis obstruents all had late devoicing, where voicing has spread into the consonant closure. Slightly longer VTT values were observed for more anterior places of articulation.

4.5.3 Discussion of Laryngographic Results

The laryngographic data on Trique obstruents illuminates differences in glottal timing strategy indiscernible from the acoustic signal alone. Lenis obstruents are more often realized with voicing during closure and fortis obstruents are more often realized with devoicing either simultaneous with closure or timed before closure (resulting in preaspiration).

Figure 4.14: Glottal Timing by Type

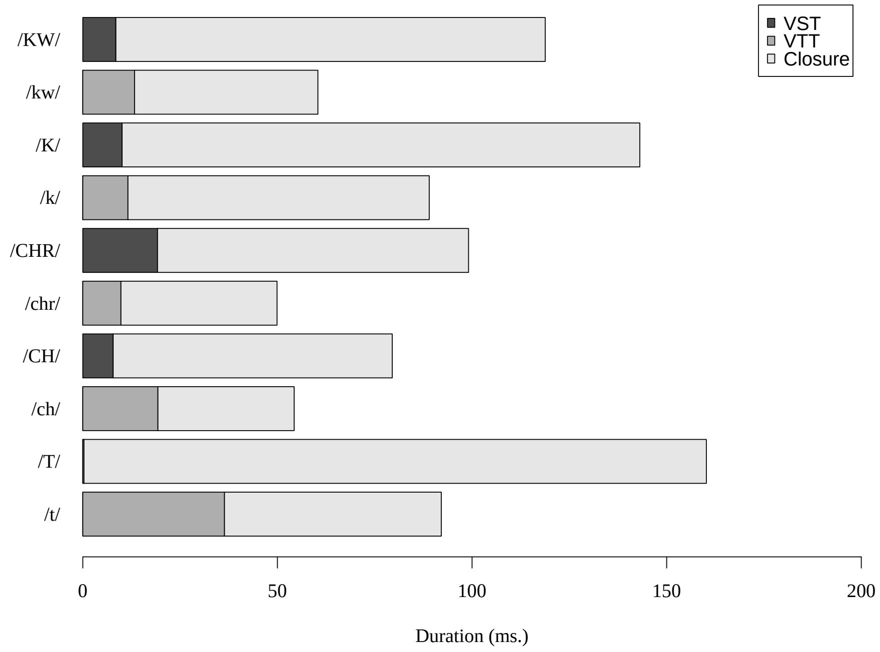


The phasing of devoicing relative to consonant closure varies significantly as a function of consonant type (fortis vs. lenis).

There is no inherent reason for longer consonants (fortis) to utilize a different glottal timing strategy. If voicing were to passively cease, one expects the same decay in glottal vibration to occur in the context of long and short consonants realized at the same place of articulation. Such passive devoicing occurs primarily due to aerodynamic conditions on voicing (see Chapter 3). However, this pattern characterizes only the lenis obstruents in the Trique data. The fortis obstruents are realized with a more restricted glottal timing strategy. This suggests that there is an active devoicing mechanism at work in the implementation of fortis obstruents: glottal spreading.

This additional phonetic characteristic of fortis obstruents is phonologically captured with the feature [spread glottis]. The implementation of this obstruent feature involves both aspiration and active devoicing, both of which are observed in the Trique data. The presence of this specific glottal timing strategy agrees with the observation that consonant

Figure 4.15: Glottal Timing by Obstruent Place of Articulation



strength oppositions often are only consonantal length contrasts with additionally specified glottal manner features.

4.6 Discussion

This study found that in Itunyoso Trique, the fortis-lenis contrast among sonorants and obstruents is primarily characterized by differences in duration. Fortis obstruents are additionally realized with active glottal spreading. Acoustic correlates relating to strength of articulation, such as amplitude and formant trajectory, do not distinguish the consonant types. The absence of these acoustic correlates and the significant differences in duration suggest that the fortis-lenis contrast is not characterized by differences in strength, but length.

The patterns of lenition in the Trique data support this hypothesis. The only obstruents realized with incomplete closure were the lenis affricates, which had the shortest closure duration among all obstruents. The hypothesis that the fortis-lenis contrast is phonologically one of length is a better explanation of this than the hypothesis that the contrast is distinguished by the phonological feature [tense].

Durational compression due to changes in speech rate affected all obstruents equally. While speech rate was not specifically controlled in the data, the findings suggests that there is no need to posit a set of scalar lenition constraints that affect geminates differently than singletons. Rather, patterns of geminate inalterability which arise in leniting conditions (fast speech, phonotactic context) are best explained by differences in the phonetic duration between singletons and geminates.

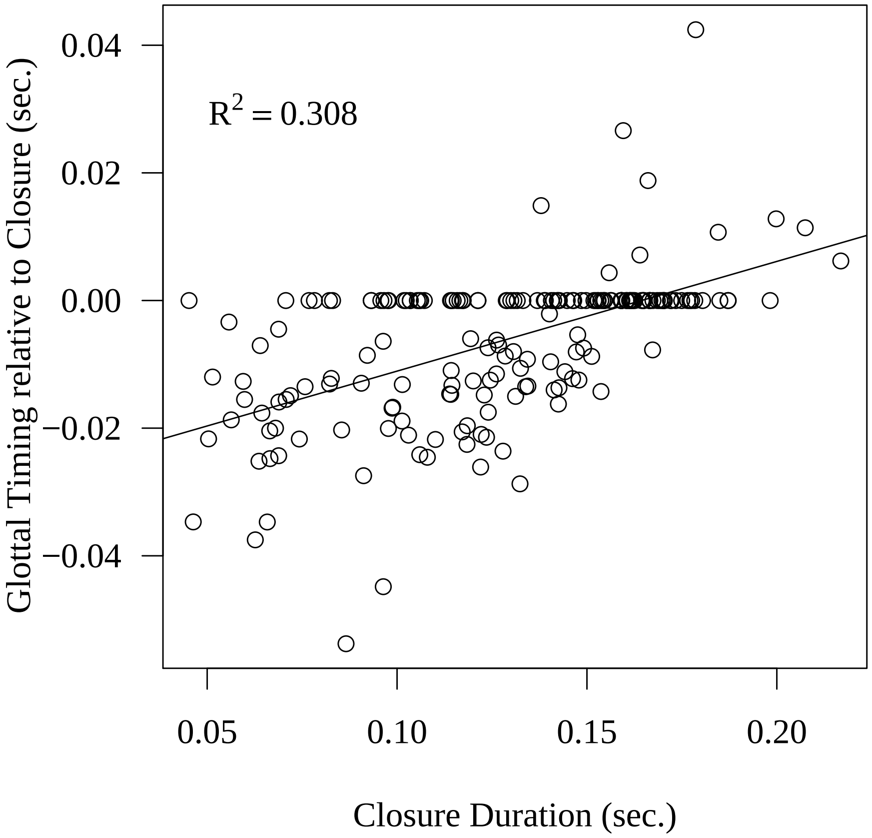
The presence of passive voicing in the lenis obstruents and active devoicing among fortis obstruents indicates that the obstruents are realized with different glottal gestures. Why should this be the case? There are two possible explanations. The first hypothesis is that specific glottal adjustments are made with the goal of maintaining the phonological distinction. Such adjustments are independent of the normal set of phonetic correlates (durational) associated with a phonological length contrast. This view, called *enhancement*, is represented in the work of Stevens and Keyser (1989) and Flemming (1995, 2001).

The second hypothesis is that a primary correlate or cue for the presence of obstruent gemination is the duration of voicelessness, not the duration of closure. If the duration of voicelessness is the primary phonetic target for consonant length, then preaspiration or abrupt devoicing via glottal spreading would increase the fortis-lenis contrast. I will call this hypothesis the *[−voice]-duration cue for geminates* hypothesis, VDCG. The VDCG hypothesis is represented in the work of Stevens and Hajek (2004). The authors observe the presence of preaspiration in Sienese Italian. They argue that the devoicing mechanism for voiceless geminates remains constant in a variety of speech rate conditions while the closure duration may vary.

Each hypothesis here makes unique predictions. The VDCG hypothesis predicts that glottal spreading will take place earlier relative to the closing gesture for fortis obstruents which have a shorter closure duration. If the duration of voicelessness is the more consistent correlate of the fortis-lenis obstruent contrast, fortis stops with shorter oral closure will have greater preaspiration. The enhancement hypothesis predicts that glottal spreading will take place earlier *only* in those places of articulation where the differences in closure duration between singletons and geminates are not robust. The idea here is that preaspiration will enhance the contrast between singletons and geminates where it is weak, not simply where oral closure is shorter. Enhancement will *not* take place at those places of articulation where differences in closure duration remain robust.

To test each hypothesis, I investigated the influence of closure duration and onset type on the RGT of fortis obstruents, using the same data described in Section 4.4. The interaction between closure duration and RGT is shown in Figure 4.16.

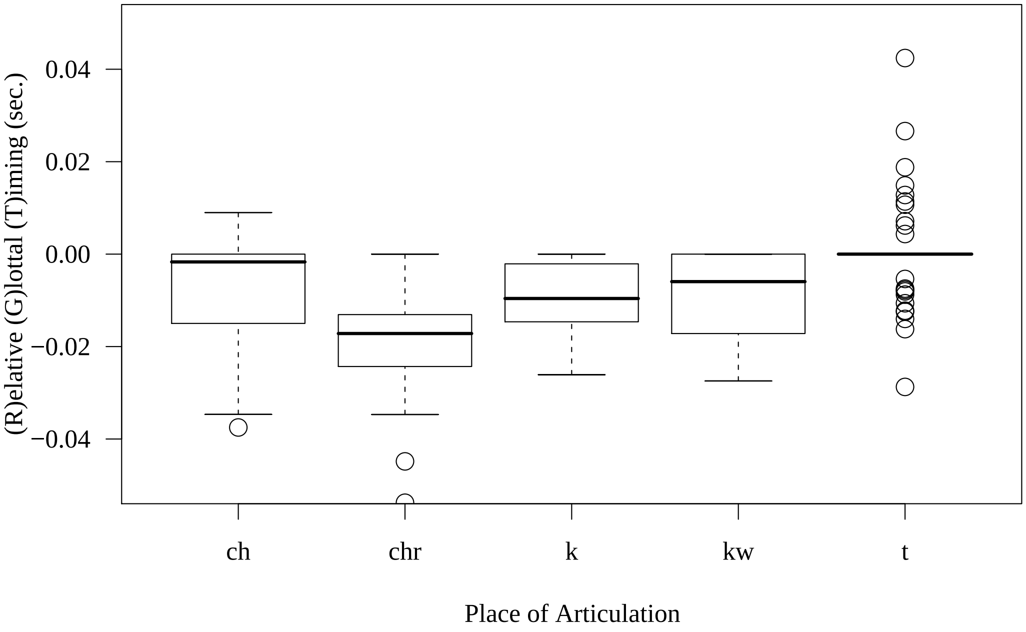
Figure 4.16: Glottal Timing by Closure Duration (fortis obstruents)



There was a significant tendency for fortis obstruents with shorter closure durations to be realized with earlier glottal spreading relative to closure, and vice-versa. This is evidenced by the adjusted R^2 value of 0.31. A repeated measures two-factor ANOVA was performed with closure duration and onset as factors. The main effect of closure duration was marginally significant ($F[1, 3] = 13.6$, $p < 0.05$) while the main effect of onset type was not ($F[4, 11] = 0.86$, $p = 0.98$). There were no significant interactions.

The differences in the closure duration between fortis and lenis obstruents are shown in Figure 4.2 in Section 4.3.1.1. The ratio between the duration of lenis and fortis obstruents in decreasing order is /chr/ 1:1.70, /t/ 1:1.66, /ch/ 1:1.53, /kw/ 1:1.52, and /k/ 1:1.42. From these ratios, one would expect glottal spreading to be timed earlier where the durational ratio is not as robust. One predicts fortis retroflex affricates to have the later glottal spreading and fortis velar stops to have the earliest glottal spreading. The effect of onset type on GLT is shown in Figure 4.17.

Figure 4.17: Glottal Timing by Onset Place (fortis obstruents)



The data in Figure 4.17 illustrate that glottal spreading occurs earliest with fortis retroflex affricates, not latest. This contradicts the enhancement hypothesis of glottal timing. While glottal spreading is timed to occur along with closure for both the alveopalatal affricate and the alveolar stop, it occurs earlier for the velar and labiovelar stops.

These data and statistics support the VDCG hypothesis of glottal timing. The relevant predictor of whether or not preaspiration will occur in fortis obstruents is the closure duration of the obstruent. Where closure duration is short, glottal spreading occurs earlier. Given that closure duration is reduced in both lenis and fortis obstruents under faster speech rate conditions, the overall duration of voicelessness is a more consistent correlate of the presence of the fortis obstruent than the closure. For Trique speakers, various factors may influence the duration of oral closure for fortis consonants but the oral closure gesture is always bound to a consistent duration of voicelessness. This is consistent with findings in (Stevens and Hajek, 2004).

Both the durational data and the laryngographic data support an analysis where the fortis-lenis contrast in Itunyoso Trique is one of length with an added glottal width feature. For obstruents, the duration of voicelessness is a consistent correlate of the contrast, rather than simply the closure duration. There is no evidence supporting an analysis of the contrast in terms of consonant strength or articulatory effort, e.g. Kohler (1979, 1984); Jansen (2004); Kirchner (2000); Flemming (2001).

Chapter 5

The Phonology of Tone and Laryngeals

5.1 Introduction

Otomanguean languages are known for having complex tone systems and laryngeal contrasts. Apart from tone, these languages may have phonologically contrastive phonation type, phonation types that cross-classify with tonal contrasts, or a complex phasing of glottal segments with tone (Silverman, 1997b,a). The presence of contrastive stress in many of the languages adds further complexity to the phonological distribution of tone and its realization in prosodically strong or weak contexts.

There is a diversity in the size of tone inventories within the Otomanguean stock. Oto-Pamean languages like Pame have 2 tones (Berthiaume, 2004) while certain Zapotecan languages like Chatino (Cruz and Woodbury, 2005) have 11 tones.[1] While tone is not a recent development within Otomanguean, its diversification due to sound change is. Rensch (1976), for instance, reconstructs 3 register tones in Proto-Otomanguean (and 4 in Proto-Mixtecan), but subsequent sound changes created additional contours and registers throughout the different language families.

The Trique languages each have large tone inventories. Copala Trique has 8 lexical tones (Hollenbach, 1984b), while Itunyoso Trique has 9 and Chicahuaxtla Trique has at

---

[1] We are conflating certain surface tone contrasts with underlying contrasts here, but the diversity in system size is evident.

least 10 (Good, 1979) but may have as many as 19 (Longacre, 1952; Hollenbach, 1977).[2] Similar to the segmental phonology (see Chapter 2), tones in all Trique languages have an asymmetrical distribution, with more contrasts occurring on the final syllable of the root. Fewer contrasts occur in affixes and on non-final root syllables. Table 5.1 shows the set of surface tonal contrasts in the different Trique languages, following Hollenbach (1977, 1984b, 2004b), Longacre (1952), and Good (1979).[3]

Table 5.1: Surface Tonal Contrasts in Trique

	Chicahuaxtla Trique		Copala Trique		Itunyoso Trique	
Tone	Word	Gloss	Word	Gloss	Word	Gloss
/(3)5/	–	–	ku^{5}	*bones*	kuh^{35}	*bones*
/4/	jo^{4}	*palm-basket*	jo^{4}	*palm-basket*	jo^{4}	*palm-basket*
/3/	kã^{3}	*squash*	kã^{3}	*squash*	kkã^{3}	*squash*
/2/	ʌ̃^{2}	*nine*	ũ^{2}	*nine*	ũ^{2}	*nine*
/1/	ʒã^{1}	*eleven*	ʃã^{1}	*eleven*	tʃã^{1}	*eleven*
/13/	doh^{13}	*a little bit*	doh^{13}	*a little bit*	toh^{13}	*a little bit*
/43/	dũ^{43}	*mayordomo*	–	–	li^{43}	*small*
/32/	nne^{32}	*water*	na^{32}	*water*	nne^{32}	*water*
/31/	nne^{31}	*meat*	ne^{31}	*meat*	nne^{31}	*meat*
/45/	dɨ^{45}	*calm*	–	–	–	–
/34/	ma^{3}ka^{34}	*Mexico City*	–	–	–	–
/23/	na^{3}to^{23}	*banana*	–	–	–	–
/15/	ga^{3}wĩ^{3} jo^{15}	*I was quick*	–	–	–	–
/14/	ga^{3}wĩ^{3} jo^{14}-reʔ^{1}	*you were quick*	–	–	–	–
/12/	za^{32} na^{4}ko^{12}	*dried stuff*	–	–	–	–
/54/	ku^{54}	*bones*	–	–	–	–
/53/	ã^{53}	*yes*	–	–	–	–
/21/	a^{3}ʔi^{21} nĩh^{3}	*they're heavy*	–	–	–	–
/323/	tsi^{323}	*elote*	–	–	–	–
/312/	to^{312}	*milk*	–	–	–	–

In this chapter I examine the distribution of tone and laryngeal consonants in Itunyoso Trique words. Apart from providing a description of the phonology of a complex tone

---

[2] Hollenbach (1977) qualifies this stating that four of these tones were observed in one lexical item only. It is possible that allotonic differences in specific words may have caused expansion of a smaller tonal inventory in Longacre's original analysis.

[3] The tonal analysis of Chicahuaxtla Trique here reflects Hollenbach's (1977) work. The other sources were used for examples.

system, this chapter serves as background to investigating the phonetics of tone-laryngeal timing in the following chapter. The organization of this chapter is in many ways a reflection of the organization of the tonal phonology. Determining the size of the tone inventory of Itunyoso Trique depends crucially on the analysis of the laryngeal consonants. Laryngeal consonants are restricted to final syllables but certain tones always co-occur with certain a final laryngeal. Therefore, if we separate a discussion of tone from the laryngeal consonants, we would be leaving out certain tonal contrasts, and vice-versa. As such, I will discuss the distribution of tone along with the distribution of laryngeal consonants.

The organization of this chapter is as follows: In §5.2, I describe the distribution of tone and laryngeals in monosyllables. In §5.3.1, I describe the distribution of tone and laryngeals in disyllables. In §5.3.2, I describe their distribution in trisyllabic words, the maximal word size in Trique. I will then provide a comparison of the Itunyoso variant of Trique to the other variants. I conclude the chapter with a discussion of theoretical issues in tone-laryngeal distribution patterns.

5.2 Tone and Laryngeals in Monosyllables

As a monosyllabic word is a word-final syllable, every tone and laryngeal combination may occur on them. Apart from this, monosyllables also license all the vowel qualities and vowel nasalization (see Chapter 2). Monosyllables may be either open with a long vowel or closed with a laryngeal consonant (/h/, /ʔ/). The vowel produced in a closed syllable is shorter than the vowel occurring in an open syllable.

5.2.1 Open Syllables

Open syllables permit seven contrastive tones, shown in Table 5.2. Throughout this dissertation, 1 is equivalent to the lowest tone level and 5 to the highest.

In the data above, we notice that there are four register tones and three falling contours which may occur on open syllables. The level tones and the higher falling tones (/43/, /32/) are produced without any appreciable different in voice quality. Tone /31/ is occasionally realized with creak in the final half of the vowel's duration. This creak is characteristically different from laryngealization that occurs with a coda glottal stop. It is infrequent, shorter, does not cause any shortening of the vowel, and never involves complete

Table 5.2: Monosyllabic Open Syllable Words

Tone	Tokens	Word	Gloss	Word	Gloss
/4/	N=12	ββe^{4}	*hair*	jũ^{4}	*earthquake*
/3/	N=30	nne^{3}	*plough*	jũ^{3}	*palm (of tree)*
/2/	N=9	nne^{2}	*to lie (tr.)*	ũ^{2}	*nine*
/1/	N=12	nne^{1}	*naked*	jju^{1}	*sour*
/43/	N=6	li^{43}	*small*	ʃũ^{43}	*to take out from an enclosure*
/32/	N=18	nne^{32}	*water*	sũ^{32}	*work (N.)*
/31/	N=12	nne^{31}	*meat*	ʈʂo^{31}	*soot, carbonization found on pots*

glottal closure. A spectrogram of the word [nne^{31}] *meat* produced by a male speaker is given in Figure 5.1.

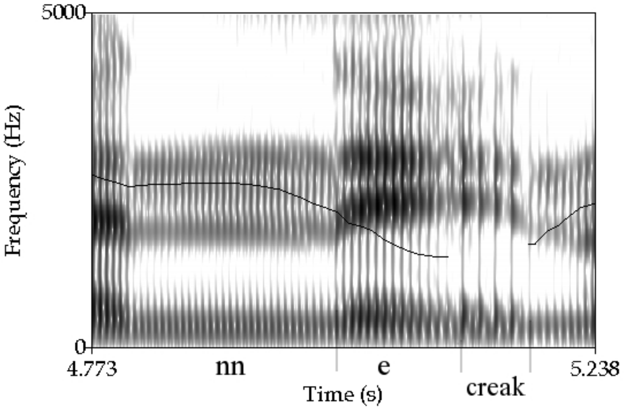


Figure 5.1: Realization of Tone /31/ with creak

In Figure 5.1, we notice increased amplitude of alternating glottal pulses (shimmer) occurring in the latter half of the vowel corresponding to the fall in pitch (indicated as a dark line through the spectrogram). This particular realization of the falling /31/ tone is variable. Within the same set of repetitions, the same speaker produced realizations of this word without any noticeable creak, shown in Figure 5.2.

The optional change in voice quality in the presence of tone lowering is similar to the pattern found in Mandarin Chinese 3rd (/214/) and 4th (/51/) tones (Davidson, 1991;

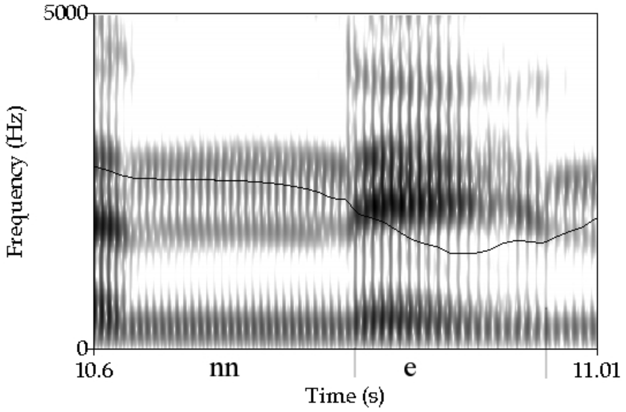


Figure 5.2: Realization of Tone /31/ without creak

Silverman, 1997b). In both cases, pitch lowering results in creak. Keating and Esposito (2006) hypothesize that the presence of additive glottalization in Chinese may provide listeners with context-free cues to the identity of the tone and the pitch range of the speaker. In this particular context in Trique, creak may allow listeners to distinguish tone /31/ from tones /32/ and /1/. Neither of these latter tones are ever realized with creak. Additionally, in a language like Trique with many tone levels, slight creak would indeed assist listeners in determining a speaker's pitch target.

5.2.2 Closed Syllables

The codas /h/ and /ʔ/ behave differently in Itunyoso Trique with respect to the number of tones which may occur on vowels preceding them. Unlike the open syllable contexts discussed in §5.2.1, tones are more restricted before a coda glottal stop in Trique. Four level tones contrast before a coda glottal stop in monosyllables, shown in Table 5.3. There are no contours possible on the vowels preceding a glottal stop.

In Table 5.3, we observe that the set of tones which precede a glottal stop is a subset of the tones occurring on open syllables. However, the distribution of tones before a coda /h/ is more complex. Tones /13/ and /35/ are always realized with a coda /h/ but do not occur in open syllables. Additionally, tone /32/ may occur with a coda /h/ but the other falling tones may not. Observe the data in Table 5.4.

Both Longacre (1952) and Hollenbach (1984b) argue that there are 5 level tones

Table 5.3: Monosyllabic Words with Coda /ʔ/

Tone	Tokens	Word	Gloss	Word	Gloss
/4/	N=4	tʃiʔ^{4}	*elderly man*	sĩʔ^{4}	*boy, lad*
/3/	N=19	tsiʔ^{3}	*maguey liquor*	nneʔ^{3}	*mecate*
/2/	N=7	ttʃiʔ^{2}	*ten*	nniʔ^{2}	*disgusting, smelly*
/1/	N=7	tsiʔ^{1}	*sweet*	tʃãʔ^{1}	*delicious*

Table 5.4: Monosyllabic Words with Coda /h/

Tone	Tokens	Word	Gloss	Word	Gloss
/4/	N=10	yãh^{4}	*wax, muck*	βeh^{4}	*to beat (intr.)*
/3/	N=34	nnãh^{3}	*paper*	ββeh^{3}	*to jump*
/2/	N=8	mmãh^{2}	*fat*	ttũh^{2}	*eight*
/1/	N=4	kãh^{1}	*naked*	tah^{1}	*how*
/35/	N=14	nãh^{35}	*to wash (fabric)*	ββeh^{35}	*straw mat*
/13/	N=10	yah^{13}	*dust*	toh^{13}	*little*
/32/	N=5	nnãh^{32}	*cigarette*	kkweh^{32}	*vegetable greens*

Table 5.5: Summary of Tone-Laryngeal Co-occurrence Restrictions in Monosyllables

Tone	CV	CVʔ	CVh
/4/	✓	✓	✓
/3/	✓	✓	✓
/2/	✓	✓	✓
/1/	✓	✓	✓
/35/	*	*	✓
/13/	*	*	✓
/43/	✓	*	*
/32/	✓	*	✓
/31/	✓	*	*

in the Chicahuaxtla and Copala variants, respectively. The fifth level tone /5/, is cognate with the tone I have labelled /35/ in Itunyoso Trique. In all Trique languages this particular tone is realized with a pitch level higher than that found for tone level /4/. These authors take this as evidence in favor of a 5-level tone analysis. Citing an observation of Maddieson

(1978), Hollenbach further argues that there is a tendency for high tones in many languages to be phonetically realized as rising tones. While these arguments could favor a 5-level tone analysis in Itunyoso Trique as well, the phonological evidence is in disagreement.

5.2.3 Tone /35/ and Tonal Register

Evidence for the rising tone analysis is found in the structural symmetry in the prosodic system. First, if a high rising tone were underlying, the distribution of tones in coda /h/ contexts could be symmetrically represented as distinct tonal registers following Yip (1993, 2002). Each register would have two level tones and a rising tone: tones /4/, /3/, and /35/ in the upper register and tones /2/, /1/, and /13/ in the lower register. The register split is given in Table 5.6 using the tonal feature system from Yip (2002).

Table 5.6: Tonal Register in Itunyoso Trique

Tone Feature		Level Tone	Falling Tone	Rising Tone
+Upper	+High	/4/	/43/	/35/
	−High	/3/		
−Upper	+High	/2/	/32/	/13/
	−High	/1/		

There is ample morphological evidence in favor of such a register split. Aspect in Trique is marked on verbs with either a prefix /kV/- or with a tone change on the verb root. If this prefix carries a tone /2/ or if the root tone changes to /2/, it indicates potential aspect. If the prefix carries a tone /3/ or if the root tone changes to /3/, it indicates completive aspect. Potential aspect would be featurally represented as [−Upper][+High] while completive aspect would be represented as [+Upper][−High]. Moreover, 1.sg enclitic marking involves a toggling alternation between tones /4/ and /43/ just as tones /2/ and /32/ alternate with one another. While Copala Trique has a fifth level tone, Hollenbach (1984b) argues for an identical register split between tones /2/ and /3/ on similar grounds.

The second piece of evidence in favor of a rising tone analysis is found in the tone-laryngeal distribution. If a high rising tone were underlying, then the same number of levels would be found to occur in open syllables, in coda /ʔ/ contexts, and in coda /h/ contexts. Such an analysis would also avoid positing a greater number of tone levels in closed syllables than in open syllables, which tend to license more tonal contrasts cross-linguistically (Zhang, 2001).

The third piece of evidence for the rising tone analysis is found in the realization of rising tones in polysyllabic words. While both tones /35/ and /13/ are realized as rising tones on monosyllables, they surface as sequences of tones on polysyllabic words, e.g. /3.5/ and /1.3/. If /35/ were considered an underlying rising tone, a strong generalization could be made that rising tones are dispreferred on final syllables. Rising tones will spread leftward to avoid surfacing on final syllables but are unable to spread in monosyllabic words.[4] Tones /43/ and /32/ do not work this way, as the disyllabic patterns /4.3/, /4.43/, /3.2/, /3.32/ are possible. The association of the leftmost tone level to the preceding syllable in these falling contours does not prevent a contour on the final syllable.

Evidence from structural symmetry in the phonological system, the distribution of laryngeals relative to tone, and the similarity in the patterning of tones /13/ and /35/ favor a rising tone analysis of tone /35/ in Itunyoso Trique. Even though this tone may surface with higher pitch and one expects high tones to surface as rises, it fits neatly into the set of phonological generalizations in the language. The alternative treatment of this tone as level provides no explanation why it would not surface as a rise in the final syllable of polysyllabic words nor why it would surface with final aspiration.

One issue with the tonal register system here is that it leaves out tone /31/. However, as we shall see in §5.4.2.2, this tone behaves unlike any of the other tones in the language in both its distribution and alignment. These observations favor an alternative analysis of this tone not as a contour tone, but as a tonal cluster.

5.3 Tone in Polysyllabic Words

5.3.1 Tone and Laryngeals in Disyllables

While 4 possible contour tones and 5 level tones are possible on final syllables in Itunyoso Trique, fewer are licensed in non-final syllables. No contour tones are possible in any non-final syllable. As all non-final syllables are pre-tonic and shorter than final syllables, this restriction jibes well with a general cross-linguistic tendency for contour tones to be restricted to longer vowels (Zhang, 2001, 2004).

---

[4] In Optimality Theoretic terms (Prince and Smolensky, 1993; Kager, 1999; Yip, 2002), this is conceivably due to high-ranked *FLOAT and MAX(T) constraints barring tonal stranding.

5.3.1.1 Open Syllables

With five possible level tones on non-final syllables and 7 tones possible in final open syllables, the possible number of tone combinations in a disyllable is 35. However, only 13 combinations are attested in the language, shown in Table 5.7.

Table 5.7: Disyllabic Open Syllable Words

σ_2	/4/	/3/	/2/	/1/	/43/	/32/	/31/
σ_1 /4/	ku^{4}tu^{4} *owl* N=8	ta^{4}ko^{3} *to dry (tr.)* N=3	X	X	sna^{4}ŋga^{43} *day of the dead* N=96	X	X
/3/	ka^{3}to^{4} *shirt* N=14	ta^{3}kã^{3} *hill* N=76	tʃi^{3}nũ^{2} *bat* N=16	ku^{3}ʈʂ̩u^{1} *rotten* N=34	ka^{3}sti^{43} *oil* N=10	ti^{3}ni^{32} *nopal cactus* N=50	X
/2/	X	ya^{2}ko^{3} *poor* N=14	ru^{2}ku^{2} *behind* N=9	X	X	ka^{2}mi^{32} *car* N=5	X
/1/	X	ta^{1}mã^{3} *bug* N=5	X	ku^{1}nu^{1} *deep* N=10	X	X	X

The tones surfacing on penultimate syllables have a restricted distribution relative to the tone on final syllables. Tone /5/ never surfaces on penultimas before open ultimas. This is unsurprising given the restriction of this tone to coda /h/ contexts, shown in §5.2.2. Tone /1/ may only surface in penultimas when the tone on the final syllable is /1/ or /3/. Tone /3/ has a free distribution in penultimas, surfacing before any final syllable tone. Tone /2/ may only surface before tones /2/, /3/ or /32/. Tone /4/ may only surface before tones /3/, /4/, and /43/. Despite the fact that 4 different tone levels surface on penultimas, only two tone levels are contrastive before a final open syllable.

5.3.1.2 Closed Syllables

As shown in §5.2.2, four tone levels contrast before a coda /ʔ/ while 5 levels and two contours contrast before a coda /h/. With five possible level tones on non-final syllables, there are 20 possible patterns on disyllables with a final syllable /ʔ/ coda and 35 patterns with a final syllable /h/ coda. Table 5.8 shows the attested tonal patterns with a coda /ʔ/.

Table 5.8: Disyllabic words with a final syllable coda /ʔ/

σ_2	/4/	/3/	/2/	/1/
σ_1 /4/	tʃa^{4}βiʔ^4 *armadillo* N=4	a^{4}kĩʔ^3 *to break (tr.)* N=3	X	X
/3/	si^{3}kiʔ^4 *chewing gum* N=4	ka^{3}kĩʔ^3 *sin* N=60	ni^{3}koʔ^2 *to follow (moving)* N=2	X
/2/	X	ni^{2}kãʔ^3 *early (adv.)* N=4	ru^{2}miʔ^2 *dark* N=6	X
/1/	X	X	X	ni^{1}kaʔ^1 *short* N=10

Similar to the patterns described in §5.3.1.1, tone /4/ only contrasts before tone /4/ and /3/ while tone /2/ only contrasts before /3/ and /2/. Tones /4/, /3/, and /2/ contrast before tone /3/ but there are no contrastive tones before tone /1/ in the final syllable. As above, tone /5/ does not occur on a penultimate syllable.

The set of attested patterns on disyllabic words with a final syllable coda /h/ are shown in Table 5.9. Out of 35 possible patterns, only 12 are attested. Tones /4/ and /2/ have the same distribution in penultimas before an ultima with a coda /h/ as they do before a coda /ʔ/. Tone /3/ surfaces before all level tones. Tone /1/ may surface before either tone /1/ or tone /3/.

5.3.2 Tone and Laryngeals in Trisyllables

The distribution of tone in trisyllabic roots in Trique resembles tone distribution in disyllabic roots. Four level tones (/1/, /2/, /3/, /4/) may surface on antepenultimate syllables. Combining these tones with the set of 5 levels surfacing on penultimate syllables and 9 possible tonal sequences on final syllables, there are 180 different tonal combinations. Rather than permute a table of 180 possibilities in this section, I divide the trisyllabic word into the set of tones surfacing on the first two syllables and the set of tones surfacing on the

Table 5.9: Disyllabic words with a final syllable coda /h/

σ_2	/4/	/3/	/2/	/1/	/32/	/13/	/35/
σ_1 /4/	a^{4}tah^{4} *day after tomorrow* N=26	a^{4}tah^{3} *to say* N=19	X	X	X	X	X
/3/	a^{3}rah^{4} *to sing* N=9	la^{3}kah^{3} *skinny* N=56	tʃa^{3}tah^{2} *bird* N=15	ne^{3}nih^{1} *ground bean* N=5	X	X	a^{3}tah^{5} *to load* N=29
/2/	X	na^{2}rãh^{3} *to close* N=8	tʃa^{2}kah^{2} *to grab, marry* N=12	X	X	X	X
/1/	X	βa^{1}tãh^{3} *six (pron.)* N=5	X	ta^{1}tãh^{1} *wrinkled* N=10	X	X	X

last two syllables.

In Table 5.10, I provide a matrix of the distribution of tone in the first two syllables of trisyllabic words. The distribution of tone in these syllables was identical regardless of the coda laryngeal on the final syllable so I have not divided the distributional patterns here based on the final syllable coda.

The data in Table 5.11 shows the distribution of those tones surfacing in penultimate syllables with those surfacing in final open and closed syllables. Except for tones /5/ and /13/, which always surface with a coda /h/, the patterns on penultimate syllables before open ultimas are identical to the patterns found before closed ultimas.

In the first two syllables of trisyllabic words, shown in Table 5.10, we notice that tone /4/ may only surface before tone /4/ and tone /1/ may only surface before tone /1/. Tone /3/ surfaces before any of four different level tones, /4/, /3/, /2/, /1/. Tone /2/ surfaces before tone /3/ or /2/. There is a gap in the distribution relative to what is noted for disyllabic words: there is no tone pattern 1.3 attested.

In the latter two syllables of trisyllabic words, shown in Table 5.11, we notice that tone /4/ may surface only before tone /4/ or tone /43/.[5] Tone /3/ may surface before any

---

[5] Tone /4/ may surface before tone /3/ when a coda /h/ is present, as in the word /tu^{3}kwa^{4}tʃih^{3}/ *my niece* but this is the only attestation, which reflects an underlying tone /43/, not a sequence. It is also a

Table 5.10: Tone in σ-1 and σ-2 in Trisyllabic words

σ_2	/4/	/3/	/2/	/1/
σ_1 /4/	ra^{4}ru^{4}βa^{43} *breakfast* N=9	X	X	X
/3/	tʃu^{3}ku^{4}ti^{43} *basket* N=18	ru^{3}ni^{3}ʔja^{2} *tejocote fruit* N=30	ku^{3}nu^{2}βa^{3} *needle* N=7	a^{3}tʃ^{1}ʔi^{1} *to start* N=7
/2/	X	tʃu^{2}tʃu^{3}βa^{32} *peanut* N=29	tu^{2}kwa^{2}na^{3} *swallow (bird)* N=10	X
/1/	X	X	X	a^{1}skwa^{1}ʔa^{3} *a short while* N=5

of the level tones except tone /1/ (so /4/, /3/, and /2/). It may also surface before final contour tones /43/, and /32/. Tone /2/ may surface before level tones /3/, /2/, and /1/. Tone /1/ may surface before ultima tones /3/ and /1/.

5.4 Generalizations on Tonal Patterns

We can account for the many different surface tone patterns in Itunyoso Trique with a few generalizations on how tone is assigned underlyingly, how tone is associated over the phonological word, and how tone may be aligned in the phonological word. The principles and representations in autosegmental phonology (Goldsmith, 1976; Leben, 1973) are useful tools for characterizing the tonal generalizations in Trique and will be utilized here.[6]

5.4.1 The Mora as the TBU

Chapter 2 describes some of the motivations for the existence of the mora as a prosodic unit in Itunyoso Trique. The distribution of tone is the strongest evidence in favor

---

morphologically complex form which we are excluding from the present study. Underlying tones will be described in the following section.

[6] See Hollenbach (1984b) for a similar description of the Copala Trique dialect.

Table 5.11: Tone in σ-2 and σ-3 in Trisyllabic words

σ_3	/4/	/3/	/2/	/1/	/43/	/32/	/31/	/13/	/35/
σ_2 /4/	ru^{4}ma^{4}u^4 *pink* N=5	X	X	X	a^{4}ra^{4}sũ^{43} *to use* N=22	X	X	X	X
/3/	na^{3}nu^{3}βa^4 *to sew* N=4	ta^{3}stu^{3}nde^3 *Zaragoza* *(toponym)* N=31	ru^{3}ni^{3}ʔja^2 *tejocote fruit* N=4	X	ka^{3}ra^{3}jũ^{43} *stallion* N=4	tʃi^{2}ru^{3}ʔβe^{32} *rich* N=21	X	X	si^{3}a^{3}rah^5 *recording* *device* N=1
/2/	X	ku^{3}nu^{2}βa^3 *needle* N=5	na^{2}ni^{2}ki^2 *to pay* N=10	X	X	X	X	X	X
/1/	X	a^{1}skwa^{1}ʔa^3 *a short while* N=2	X	tu^{1}kuʔ^{1}nah^1 *correct* N=10	X	X	X	X	X

of such an analysis. Moras are tone-bearing units (TBUs) in Itunyoso Trique. Contour tones may only surface in final syllables, an observation which suggests that contours are only licensed when the syllable is heavy or bimoraic. Level tones may surface on any syllable in the phonological word. The moraic analysis is reflected in the representation of tone in Figure 5.3 for the word /na^{2}nu^{32}/, '*to get dressed*' and in Figure 5.4) for the word /tʃa^{4}kwi^{43}/, '*to help*'.

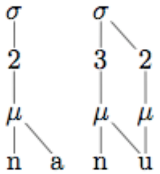


Figure 5.3

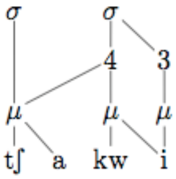


Figure 5.4

In this analysis, contour tones are decomposed into sequences of level tones, each associated with a mora (Hyman, 1985). Positing the mora as the TBU has both consequences for the representation of tones which co-occur with laryngeal segments and consequences for processes in the morphology where laryngeals enclitics apply to the root.

Phonological words surfacing with a final syllable coda /h/ permit certain contour tones (/35/, /13/, /32/) while those surfacing with a coda /ʔ/ do not permit any contours. Coda /h/ is most often realized as vocalic breathiness or voiced glottal frication on the latter half of the rime duration, [aa̤]~[aɦ], while a coda /ʔ/ is most often realized with complete glottal closure. In the former case, the duration of voicing is longer than in the latter case, where it is cut short by closure. In only the former case may a tonal contour be overlaid on both moras of the V+h sequence. That is, one of the level tones from the contour is associated with the laryngeal mora /h/. A representation of this tone assignment is given in Figure 5.5 for /kkweh^{32}/, '*vegetable green*' and in Figure 5.6 for /ʈʂũh/, '*box.*'

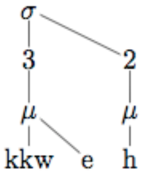


Figure 5.5

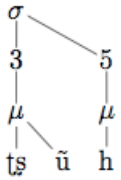


Figure 5.6

Final laryngeal moras may only be associated with a tone in monosyllabic words. On the surface, this appears to be an odd restriction on contour tones. After all, final syllables in monosyllabic words are often slightly longer in duration than they are in disyllabic words. However, the reasons underlying this restriction become clear when we consider a general picture of how tone is assigned to moras in polysyllabic words. We address this in the next section.

5.4.2 Tonal Constraints on Final Syllables

Like the segmental contrasts, all tonal contrasts are licensed in final syllables. In the data in §5.3, we observed that the set of tones surfacing in non-final syllables is more restricted than the set surfacing in final syllables. For instance, only final syllables may carry a contour tone. Furthermore, the tones which surface on non-final syllables are often predictable from the tone in the final syllable. The leftmost tone level in the final syllable's tone may always surface on preceding syllables in the morphological word. Thus, patterns like /1.1/, /2.2/, /3.3/, /4.4/, /3.32/, /4.43/, etc. are possible on disyllables even though tones /1/ and /4/ have a very restricted distribution in non-final syllables. Table 5.12 shows the set of patterns surfacing on penultimate and ultimate syllables in polysyllabic words.

If the set of tonal patterns on polysyllabic words matched the patterns found on monosyllabic words (the nine contrasts shown in §5.2) then we would expect only nine

Table 5.12: Summary of Tone Patterns on Penultimate (P) and Ultimate (U) syllables in polysyllabic words

σ-P	/4/	/3/	/2/	/1/
σ-U				
/4/	✓	✓	*	*
/4h/	✓	✓	*	*
/4ʔ/	✓	✓	*	*
/3/	✓	✓	✓	✓
/3h/	✓	✓	✓	✓
/3ʔ/	✓	✓	✓	*
/2/	*	✓	✓	*
/2h/	*	✓	✓	*
/2ʔ/	*	✓	✓	*
/1/	*	✓	*	✓
/1h/	*	✓	*	✓
/1ʔ/	*	*	*	✓
/35h/	*	(✓)	*	*
/13h/	*	*	*	*
/43/	✓	✓	*	*
/32/	*	✓	✓	*
/32h/	*	*	*	*
/31/	*	*	*	*

possible tonal patterns on disyllabic words or trisyllabic words. However, this is not the case. Certain tonal combinations may surface on polysyllabic words that never surface on monosyllabic words. For instance, the tonal patterns /2+3/ and /3+4/ surface in disyllables but there are no /23/ or /34/ rises in monosyllables. Despite this, the most common tonal patterns are those where the non-final tone matches the final tone, i.e. /4+43/, /3+32/, /3+3/, /1+1/, etc. Note, for instance, that tone /1/ most often surfaces on a non-final syllable if the final syllable is /1/.

From an autosegmental perspective, there are two ways to analyze these more frequent tonal patterns. Non-final syllables may be tonally-unmarked where the tone from the final syllable spreads leftward onto the preceding syllable. Alternately, non-final syllables may be tonally-marked but with a restricted set of licensed tones. However, assuming that these non-final tones are underlying causes the loss of important generalizations on *which* tones may occur on non-final syllables. Specifically, all tones on final syllables may occur with an identical preceding tone level or with a default tone /3/. The restrictions on the set of tones permitted in non-final syllables are thoroughly examined in §5.4.3. As a result of this analysis, there are two types of tones in non-final syllables: surface tones that result from leftward tone association and underlying tones. A similar analysis is argued for Copala Trique in Hollenbach (1984b).

Both the larger inventory of tones on the final syllable and the restricted distribution of tones on non-final syllables suggest a representation where tone is obligatorily associated with the final syllable and spreads leftward across the word if no other tones block such spreading. A representation of this process on the disyllabic word /ru^{4}ne^{43}/ ‘*avocado*’ is given in Figure 5.7. A representation of the process on the trisyllabic word /ku^{3}ru^{3}βiʔ^{3}/ *monkey* is given in Figure 5.8.

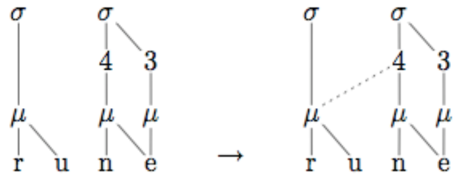


Figure 5.7

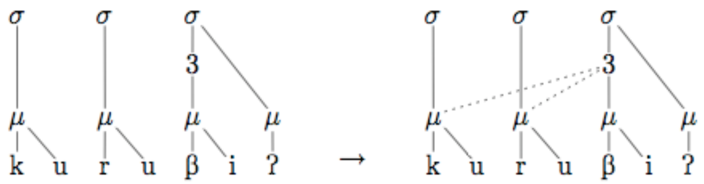


Figure 5.8

The pattern shown in Figures 5.7 and 5.8 we will call *leftward tone association.* Tones are associated leftward up to the edge of the morphological word but may be blocked if a non-final syllable has an underlying or default tone, as will be shown in §5.4.3. This principle represents the majority of tone patterns found on polysyllabic words and provides a basis for most of the tones surfacing in non-final position: they are non-underlying and the result of spreading.

5.4.2.1 Contour Tones

As it stands, *leftward tone association* does not adequately explain the distribution of contour tones /31/, /35/, and /13/. These tones may not surface as contours on the final syllable of a polysyllabic word. Thus, patterns of the shape /3.1/, /3.5h/, and /1.3h/ are possible (as are /3.1.1/, /3.3.5h/, and /1.1.3h/) but */3.31/, */3.35h/ and */1.13h/ are never possible. Leaving tone /31/ aside for the moment, we note that /13/ and /35/ are rising tones which always surface with a coda /h/.

Falling tones are not sensitive to any constraints on distribution in final *open* syllables. Thus, the language permits disyllabic sequences /3.32/ and /4.43/ as well as trisyllabic sequences /3.3.32/ and /4.4.43/. However, neither falling tones /32/ nor /43/ surface on the final syllable in a polysyllabic word when there is a coda /h/. Tone /43/ never surfaces on a syllable with a laryngeal coda in any context and tone /32/ only does so in monosyllabic words. Instead, in polysyllabic words, we observe tone patterns /3.2h/ and /4.3h/ in disyllables and /3.3.2h/ and /4.4.3h/ in trisyllables. On purely phonetic grounds, this is unexpected: final syllables have the longest duration in most word types. Since the final syllable is longer than the non-final syllable in Itunyoso Trique (as shown in Chapter 2) and contours generally take longer than level tones to produce (Sundberg, 1979; Zhang, 2001, 2004), the final syllable is the precise context where we expect contours to surface. However, separate durational differences are part of the motivation for the restrictions on contour tones in final syllables. Contour tones are prohibited on shorter syllables with a coda laryngeal /h/.

Tonal contrasts are realized over the rime in Itunyoso Trique. There are three possible rimes types: /VV/, /Vh/, and /Vʔ/. Each of these rimes has similar duration, but vowels are shorter before a coda /ʔ/ than on the other two rime types. Coda glottal stops are realized with abrupt glottal closure (see Chapter 7). By contrast, a coda /h/ is always realized as vocalic breathiness or voiced glottal frication ([ɦ]). The presence of voicing permits pitch to be conveyed in the acoustic signal. As a result, the voicing duration where pitch may be conveyed is longer in /VV/ or /Vh/ rimes. In Chapter 7, I observe that the final rimes in disyllabic words are shorter than final rimes in monosyllabic words. The former have an average duration of 125.9 ms. while the latter have an average duration of 167.8 ms. The duration difference between rimes as a function of word size is similar across rime types. There is a strong cross-linguistic preference for contour tones to be realized on longer rimes

(Gordon, 2001; Zhang, 2004). The shortness of the final /Vh/ rime on disyllables prohibits contours on this syllable. However, this is only part of the explanation.

Tones in Itunyoso Trique may also not be deleted. The consequence of this is that contour tones which surface on monosyllables must be tolerated, whether they occur with a coda /h/ or not. Thus, processes of leftward tone association and low tone spreading, discussed in §5.4.2.2, never eliminate the leftmost tone on the word. Tone may only reassociate. Contour tones on final syllables with a coda /h/ on polysyllabic words can reassociate to non-final syllables. However, the same is not true for monosyllabic words. Since tone can not reassociate, contours are permitted in final syllables.

In §5.4.1, we observed that the mora is the TBU in Itunyoso Trique. Contour tones which surface on a /Vh/ rime (/13/, /35/, /32/) have a tone level associated with the laryngeal mora. This representation of contour tone in monosyllables is shown in Figures 5.5 and 5.6. However, coda laryngeals perturb tone (Silverman, 1997b,a), especially in the context of a shorter rime. The degree of pitch perturbation induced by laryngeals is the topic of a deeper investigation in chapter 7. Yet, the avoidance of contour tones in final /Vh/ rimes in disyllabic words reflects a tendency to avoid tonal contrasts on syllables with nonmodal phonation. The distribution of contour tones in disyllables is explained by durational factors, an avoidance of tone patterning on syllables with laryngeally-induced pitch-perturbation, and a general constraint against tonal deletion. The explanations I propose for the distribution of contour tones on final syllables are summarized below.

1. No tone may delete on morphological words in Itunyoso Trique.
2. Contour tones surface on rimes of long duration. This predicts that contours will most freely surface on monosyllables and final syllables. This prediction is corroborated.
3. Contour tones are prohibited on syllables with a coda laryngeal /ʔ/ and avoided on syllables with a coda /h/.

While I do not pursue a thorough Optimality-Theoretic analysis (Prince and Smolensky, 1993; Yip, 2002) in this chapter, the tonal patterns would predict that a MAX(T) (or *FLOAT) constraint be higher ranked than a *CONTOUR constraint. This constraint ranking would predict contour tones to produce violations of *CONTOUR in monosyllabic words but no violations when they surfaced on polysyllables. In the latter case, tonal reassociation is possible. A constraint *TBU/[spread glottis] would have to be lower-ranked than a

*CONTOUR constraint as tones are associated with laryngeals in monosyllables but may not be in disyllabic ultimas.

5.4.2.2 Low Tone Spreading and Tone /31/

While the constraint ranking above is applicable to contour tones /32/, /43/, /35/, and /13/, it does not predict the odd patterning of tone /31/ in polysyllabic words. First, the other contours and tone /31/ differ in alignment. This is only visible on trisyllabic words though. For tone /31/, tone level /3/ obligatorily surfaces on the leftmost syllable in the word where every syllable to the right surfaces as tone level /1/. For tone /13/, tone level /3/ surfaces on the rightmost syllable where every syllable to the left surfaces with tone level /1/. For tone /35/, tone level /5/ surfaces on the rightmost syllable where every syllable on the left surfaces with tone level /3/. These apparent differences in alignment are shown in Figure 5.9 for the word /a^{1}skwa^{1}ʔa^{3}/ '*a short while*', in Figure 5.10 for the word /si^{3}a^{3}rah^{5}/ '*recording device*', and in Figure 5.11 for the word /si^{3}ru^{1}ih^{1}/ '*knee.*'

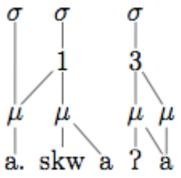


Figure 5.9

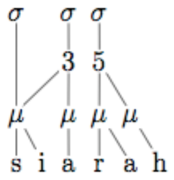


Figure 5.10

In Figure 5.11, tone /3/ is only associated with the first syllable and tone /1/ with the remaining syllables. There are no tonal patterns of the shape */3.31/, */3.3.1/, or */T.31/, where T = any tone. The absence of the tone pattern /3.3.1/ is unexpected given the patterns shown in Figures 5.9 and 5.10.

The alignment of the rising tones resembles the more common pattern of leftward

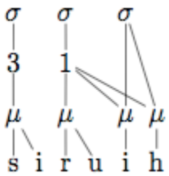


Figure 5.11

tone association with initial alignment of the contour to the right edge of the phonological word (subject to the constraints proposed in §5.4.2.1). Tone /31/ is exceptional in lacking this alignment pattern, but such exceptionality is due to an effect of the final /1/ tone which spreads leftward across the word. This pattern is unique to the Itunyoso variant of Trique. Tone /31/ does not have the same type of distribution in the Copala variant of Trique (Hollenbach, 1984b) and is free to surface as a contour on the final syllable of monosyllabic and polysyllabic words.

Evidence for a general low-tone spreading rule is found in the morphophonology of pronominal enclitics. Certain enclitics will affect the tone on the final syllable of the morphological word. While the complete set of morphophonological changes is quite complex, one productive pattern for the 2.sg.fam enclitic /reʔ^{1}/ is for it to induce low-tone spreading one syllable leftward if the final syllable contains tone /43/, /3/, /32/, or /2/. The 2.sg.fam enclitic is the only enclitic with tone /1/ and the only one to induce low-tone spreading. This process is shown in the data in Table 5.13 where the enclitic is the subject on verbs. The same process applies to nouns when this enclitic is affixed in nominal possession.

Table 5.13: Low Tone Spreading - 2.sg.fam enclitic

Word	Gloss	Word + enclitic	Gloss
a^{4}rũ^{43}	*to write*	a^{4}rũ^{1}-reʔ^{1}	*you are writing*
ni^{3}ʔjah^{3}	*to see*	ni^{3}ʔjah^{1}-reʔ^{1}	*you see*
ko^{3}ʔo^{32}	*to drink*	ko^{3}ʔo^{1}-reʔ^{1}	*you are drinking*
a^{3}ja^{2}	*to read*	a^{3}ja^{1}-reʔ^{1}	*you are reading*

The effect of this morphological process is to delink the tone assigned on final syllables but never to delink the leftmost tone in the phonological word. Most verbs in Trique are disyllabic. All verbs are marked for aspect with either a segmental prefix /k(V)/

which carries tone or an alternation of tone on the first syllable of the word. There is a functional motivation for restricting the low-tone spreading only one syllable to the left: further application of this rule would result in the elimination of aspectual information or lexical contrast. While low tone spreading occurs in polysyllabic words, its absence in monosyllabic verb stems supports this functional motivation.

The distribution of tone /31/ in phonological words resembles the expected surface patterns from a process of low-tone spreading similar to what we observed above. In both cases, tone associates leftward and delinks the preceding tone. In both cases, the leftmost tone may not be delinked. However, the application of low tone spreading (LTS) appears to occur iteratively on the morphological word. This process is shown in Figures 5.12 and 5.13 for the word /a^{3}tʃi^{1}ʔi^{1}/, '*begin.3sg.*'

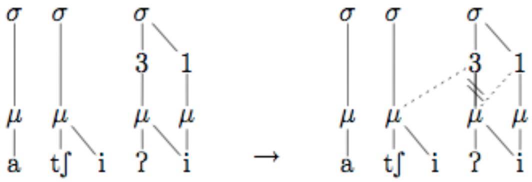


Figure 5.12

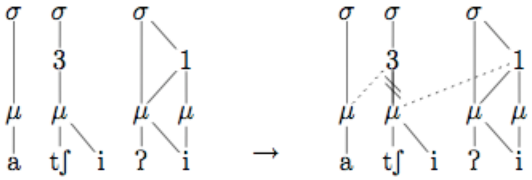


Figure 5.13

In figure (5.12) we observe low tone spreading one syllable to the left, which causes the preceding tone to delink and reassociate with the preceding mora. In figure (5.13) we observe a revised input where tone level /3/ is associated with the penultimate syllable. However, low tone spreading applies again, resulting in the attested surface pattern with an apparent left-edge tone alignment. The result of this process is to make the distribution of the contour tone /31/ appear odd in comparison with the other contour tones in the language. It is the only contour which does not remain aligned at the right edge of the phonological word. However, the generality of this spreading process in the language provides an explanation for the odd distribution.

5.4.3 Tonal Constraints on Non-final Syllables

Fewer tones contrast in non-final syllables than in final syllables in morphological words. I have already established a general rule of *leftward tone association* which predicts that the tone on the first mora of the final syllable may spread leftward. This spreading process only occurs if there are no associated tones on non-final syllables to block it. For this analysis, I assume that tone levels on non-final syllables that are identical to the tone on the leftmost mora of the final syllable share a single representation at the autosegmental level. Thus, a surface tone pattern [4.4.43] on a trisyllabic word is underlyingly /T.T.43/, where T = no underlying tone. It is assumed that these non-final tones are the result of the leftward tone spreading rule. This assumption both avoids a violation of the obligatory contour principle (OCP) (Leben, 1973; Kenstowicz, 1994) and captures a broader generalization on the nature of tones in non-final syllables.

As we observed in Table 5.7, tone /3/ has a free distribution before final syllable tones. Many tones may only be preceded by a specified tone /3/. Table 5.14 summarizes the possible tonal patterns found in §5.3. The rising tones and tone /31/ are excluded here because they never surface on a single syllable in polysyllabic words. Tone patterns /3.1/ and /1.3/ are excluded since it is presumed they are the surface manifestation of underlying contour tones associated on the final syllable of the word.

Table 5.14: Tonal Patterns on Polysyllabic Words

Disyllables

Final Tone	4	3	2	1	43	32
Penultimate Tone	4, 3	4, 3, 2	3, 2	1	4, 3	3, 2

Trisyllables

Penultimate Tone	4	3	2	1
Antepenultimate Tone	4, 3	4, 3, 2	3, 2	1

We read Table 5.14 as the set of surface tones on penults which may precede ultimas (above) and the set of surface tones on antepenults which may precede penults (below). If a final syllable tone is /4/, then it may be preceded by either tones /3/ or /4/ in penultimate syllables. Similarly, if the penultimate syllable tone is /4/ it may be preceded by tones /3/

or /4/ in the antepenult. One observes that tone /4/ or /43/ may only be preceded by tone /3/ or /4/, tone /3/ may be preceded by tones /2/, /3/, or /4/, tone /2/ or /32/ may only be preceded by tones /3/ and /2/, and tone /1/ may only be preceded by tone /1/. Barring contour tones, these patterns are identical for penults and antepenults.

If one eliminates the set of tones which are copies of the following syllable's tone in Table 5.14, a distinct pattern emerges. The result is shown in Table 5.15.

Table 5.15: Tonal Patterns on Polysyllabic Words - Revised

Disyllables

Final Tone	4	3	2	43	32
Penultimate Tone	3	4, 2	3	3	2

Trisyllables

Penultimate Tone	4	3	2
Antepenultimate Tone	3	4, 2	3

Here, tones /4/, /43/, and /2/ may only be preceded by tone /3/. Tone /32/ may only be preceded by tone /2/ and tone /3/ may be preceded by either tone /4/ or /2/. These patterns may appear disordered, but are in fact easily explained with reference to the tonal register system in the language. Either a nonfinal tone is specified as /3/ or it must agree in terms of tonal features with the tone on the final syllable. Tones /2/ and /32/ are specified as [−Upper] and may be preceded by tone /3/ or the [−Upper][+High] tone /2/. Tones /4/ and /43/ are specified as [+Upper] and may be preceded by tone /3/ or the [+Upper][+High] tone /4/. Tone /3/ may license either of the [+High] tones /2/ or /4/ on the preceding syllable.

The absence of tonal patterns /4.2/ and /2.4/ (and /1.4/ and /4.1/) in disyllabic phonological words results from a prohibition of more than one underlying [+High] tone in the same morphological word.[7] Tone patterns resulting from leftward tone association do permit sequences of tone /4/ or tone /2/. However, in these cases, there is only one *underlying* [+High] marked tone.

This principle not only accounts for the disyllabic avoidance of tones /4/ and /2/ within the same word, but also for their avoidance in trisyllabic words. Furthermore, it

---

[7] Tone /2/ may precede tone /4/, /43/, or /35/ in morphological words when it indicates potential aspect on verb roots with these tones, e.g. /ki^{3}-ʔja^{43}/, COMP-do.1sg *I did* vs. /ki^{2}-ʔja^{43}/, POT-do.1sg '*I will do*'.

accounts for why tone /3/ may occur with either tone /4/ or /2/: it is [−High].[8] The three constraints on non-final syllables (non-heads) are summarized below.

1. Non-head syllables may be specified with an underlying tone /3/.
2. A Non-head syllable must agree in register with the head syllable tone.
3. Only one underlying [+High] tone may be specified per phonological word.

The results of these conditions are that three types of surface tones are predicted on non-final syllables: tones resulting from leftward-spreading, tone /3/, and [+High] tones which agree in register with the final tone. This is exactly what we find in Itunyoso Trique.

Similar to the segmental phonology (in Chapter 2), it is possible to view the set of non-final tones in terms of prosodic licensing. While all tones are permitted in final syllables, only tone /3/ or those which agree in register with final syllables may be licensed on non-final syllables. Tone /3/ acts as a default tone which is always licensed on non-final syllables and may also license either of the registers on non-final tones. When tone /3/ surfaces on final syllables, tones /2/, /3/, or /4/ are possible on the preceding syllable. Tones /2/, /32/, /4/, and /43/ may only license [+High] tones on non-final syllables and may only license tones of the same register. The process of *licensing inheritance* permits final syllables the ability to determine the set of tonal contrasts permitted on non-final syllables.

5.5 Summary & Discussion

The set of prosodic contrasts and their distribution in Itunyoso Trique resemble the patterns shown for the segmental phonology observed in Chapter 2. Final syllables license a larger set of tonal contrasts than non-final syllables, just as they license a larger set of segmental contrasts. For instance, since final syllables are minimally bimoraic, only they may license contour tones. Only a smaller set of level tones is permitted in non-final syllables.

There are three tone rules/generalizations which apply to all words: leftward tone association, low tone spreading, and [+High] markedness. The first applies to a large set

---

[8] An alternative analysis would be that no two underlying [+Upper] tones may occur on the same phonological word. This hypothesis would fail to explain why tone /3/ may freely co-occur with both [+Upper] and [−Upper] tones.

of words where only a final syllable has an underlying tone. The second applies to those words which have a low /1/ tone on the right edge of the word. This pattern predicts the odd alignment and distribution of contour tone /31/ in relation to the other contour tones. The third pattern states that only one tone that is specified as [+High] may occur in a phonological word. This pattern properly predicts the distribution of tone in non-final syllables and is similar in scope to the labial markedness rule observed in Chapter 2 (stating that only one [labial] consonant may occur in a morphological word).

For final syllables, there are a number of interactions predicting the surface distribution of tone. In §5.4.2, we observe an interaction between a prohibition on contour tones and a prohibition on deleting tones. Monosyllabic words permit more prosodic contrasts than final syllables in polysyllabic words because only the latter allows tonal reassociation. Contour tones will not surface on final rimes in disyllabic words with a coda /h/.

A non-final tone may consist of either the tone which is spread via leftward tone association or an underlying tone /3/. If an underlying /3/ is not associated on a non-final syllable, the non-final syllable tone must agree in register with the head syllable's tone. Thus, a final syllable /32/ may be preceded by either /3/, which is either a default or specified tone, or by /2/, since this tone agrees in register ([−Upper]) with the final tone.

While the primary goal of this chapter is to describe and account for the full set of distributional patterns of tone in Itunyoso Trique, certain patterns remain unexplained. We accounted for the patterning of contour tones in final syllables by stating that contours are only permitted on longer syllables and preferably on those which lack a laryngeal coda. The shortness of final syllables in disyllabic words and the presence of a coda laryngeal causes them to reassociate leftward.

A greater number of tonal contrasts are permitted on final syllables with a coda /h/ than with a coda /ʔ/. Moreover, certain contour tones (/13/, /32/, and /35/) may surface with a coda /h/ in monosyllabic words but do not do so in polysyllabic words. Yet, in *no* context does a coda /ʔ/ permit a contour tone. So far, the reasons for the distributional differences of tone before different laryngeal codas is unexplained.[9] The motivation

---

[9] In an OT account, it would be possible to account for the patterning of tone relative to different laryngeal moras by splitting our coda constraint into a set of two constraints: *TBU/[spread glottis] and *TBU/[constricted glottis]. The latter would be ranked higher than the former in a constraint hierarchy, thereby permitting more contrasts on vowels with a coda /h/. While this would work to *represent* the patterns in a synchronic phonology, it is not independently motivated.

for phonological patterns within a language is the set of articulatory, acoustic, and cognitive tendencies which guide how speakers produce speech and how listeners hear it. When such patterns become a part of a grammatical system, they may acquire a life of their own which may be divorced from the factors which motivated them. This pattern, called phonologization (Hyman, 1977; Ohala, 1981; Blevins, 2004), is explanatory in phonology because it provides an independent basis for observed patterns. As phonology is a scientifically rigorous field, it seeks answers in the general characteristics of human behavior.

We do not have such an independent motivation for why different laryngeal consonants have specific effects on the distribution of tone. Why should we expect more tonal contrasts in the context of a coda /h/ than in the context of a coda /ʔ/? The answer to this question lies in understanding its phonetic basis. A phonetic exploration of tone in the context of these different laryngeal consonants will reveal the motivation for this observed asymmetry. It also permits us to determine how specific articulatory modifications in the larynx will affect pitch. This not only has relevance to our understanding of the phonological patterns in Trique, but to our understanding of the factors that give rise to tone and tone changes diachronically. We turn to such an investigation in the following chapter.

Chapter 6

Phonological and Phonetic Explanations for the Patterning of Tone and Laryngeals

6.1 Introduction

6.2 Introduction

Two primary concerns in modern phonological theory are how to account for distributional restrictions within phonological systems and how such restrictions are motivated by phonetic patterns. The relationship between laryngeals[1] and tone is specifically relevant for phonological theory because in many languages there are distributional restrictions on which tones and laryngeals may co-occur. Pitch perturbations caused by laryngeals may motivate such restrictions. Perturbations may either create new tones within a language or mutate existing tones within a language.

In the previous chapter, we observed a set of restrictions on which tones can occur with final laryngeal consonants /ʔ/ and /h/ in Itunyoso Trique. We observed that a larger

---

[1] I refer to the term *laryngeal* in a broad sense here to include laryngealized consonants, e.g. [ʔn, p'], laryngeal consonants, e.g. [ʔ, h], and constrastive phonation types, e.g. [a̤, a̰].

set of tones may occur with a final syllable coda /h/ than with a /ʔ/. One way to account for this set of restrictions in phonological theory is with a set of crucially-ranked laryngeal markedness constraints barring contour tones from co-occurring with a [+constricted glottis] or a [+spread glottis] feature. While this type of approach may correctly represent the observed patterns, it does not provide an explanation for *why* such features may only occur with certain tones. To answer this question, we must investigate the phonetic motivations for these patterns and test them using phonetic data from Itunyoso Trique.

This chapter is organized as follows: In §6.3, I describe some cases where laryngeal consonants and phonation type gave rise to tonogenesis. I will exclude a discussion of voicing and its relation to tonogenesis as it is outside the scope of this dissertation and has been heavily discussed in recent work (Bradshaw, 1999; Tang, 2008). In §6.4 I describe some of the distributional restrictions on laryngeal consonants and phonation type and summarize the phonological explanations that have been offered to account for them. In §6.5 I describe the phonetic motivations for tone-laryngeal distributional restrictions by examining the articulatory phonetics of both pitch and laryngealization. In §6.6, I discuss these various approaches as a motivation for the phonetic study in the following chapter.

6.3 Tonogenesis

Laryngeal consonants have been shown to give rise to tone in the evolution of phonological systems. This process, later called tonogenesis (Matisoff, 1973), is described in the classic article on Vietnamese tonogenesis by Haudricourt (1954). In Vietnamese, word-final /h/ caused pitch-lowering to occur while word-final /ʔ/ caused pitch-raising. The voicing difference on the onset consonant also conditioned differences in pitch level on the following rime. Table 6.1 shows the stages of tonogenesis in Vietnamese (reprinted in Matisoff (1999)) where S = a fricative and T = a voiceless stop.

At stage 1, the language is toneless and maintains a voicing distinction in onset position and a manner distinction in coda position. At stage 2, final obstruents become final laryngeals. At stage 3, these final laryngeals condition a change in pitch contour. Between stages 3 and 4, the voicing distinction in onset position conditions differences in pitch level. The result is modern Vietnamese with 6 tones which are divided into higher and lower registers (Matisoff, 1999; Brunelle, 1999).

Voicing-triggered pitch perturbations in onsets are a much more widely-attested

Table 6.1: Vietnamese Tonogenesis (Haudricourt, 1954)

	Stage 1:	pa	paS	paT
		ba	baS	baT
	Stage 2:	pa	pah	paʔ
		ba	bah	baʔ
	Stage 3:	pa	pâ	pǎ
		ba	bâ	bǎ
Modern:	Higher	pa (ngang)	pâ (hoˀi)	pǎ (sắc)
	Lower	pa (huyền)	pâ (ngã)	pǎ (nạng)

pathway through which languages may develop tone, as shown in the final stage of Vietnamese tonogenesis above. Both Bradshaw (1999) and Tang (2008) provide surveys of languages where there is an affinity between high tone and voiceless onsets and between low tone and voiced onsets. In some of these languages, historical voicing contrasts gave rise to the development of tone. In many others, such processes persist within synchronic phonologies as *depressor consonants* (e.g. Bantu). In these languages, the distribution of tone and consonant voicing interact in processes of tone spreading. Voiced obstruents block the spreading of a H tone (Hyman and Schuh, 1974; Bradshaw, 1999; Pearce, 2007).

The phonetic explanation for the relationship between onset voicing and pitch perturbation is clear. It is well-known that voicing induces pitch-lowering in a variety of languages synchronically (Haggard et al., 1969; Halle and Stevens, 1971; Hirose and Gay, 1972; Wolf, 1978; Hombert, 1979; Hombert et al., 1979; Kingston, 1986; Löfqvist et al., 1989; Kingston and Diehl, 1994; Holt et al., 2001; Hoole et al., 2004; Pearce, 2007). It is not entirely clear whether the active process in these cases is one of pitch-lowering after a voiced obstruent or pitch-raising after a voiceless one. However, evidence from a variety of languages suggests that pitch-lowering after voiced consonants is the more robust cue, called the *Low Frequency Property* (see Chapter 3). Processes of pitch-raising *following* a voiceless consonant are considered to be cues for a phonological contrast where there is an active processes of glottal spreading (see Chapter 3). Pitch perturbation occurs on the following vowel in these cases because the peak in glottal spreading is aligned with the consonant's release (Hombert et al., 1979; Kingston, 1985, 1990; Munhall and Löfqvist, 1992). The increased glottal tension associated with active devoicing will decay on the following vowel but persists for a perceivable part of its duration. This increased tension most likely causes pitch-raising due to the increased crico-thyroid tension (Hombert et al., 1979; Löfqvist et al., 1989). However, the basis for the relationship between final laryngeals and pitch perturbation is less clear. We explore some cases studies of this phenomenon in the following section.

The pattern of tonogenesis and tonomutation from coda laryngeals is not unique to Vietnamese, but found in many languages. Haudricourt (1954) describes a pattern in Middle Chinese where a postvocalic /h/ caused a lowering effect on the preceding tone. Gathercole (1983) observes pitch-lowering both before all final fricatives, /h/, and before preaspirated stops in Kickapoo, an Algonquian language. Kingston (2005) describes a pattern where postvocalic /ʔ/ induces either pitch-raising or lowering in the origin of tone in certain Athabaskan languages, all of which have developed tone. We begin with the most relevant example: tonal mutation following the loss of coda */ʔ/ in Mixtecan.

6.3.1 Proto-Mixtecan /ʔ/ Tonal Mutation

Both Longacre (1957) and Dürr (1987) describe a pattern whereby the Proto-Mixtecan */ʔ/ is realized synchronically as either a floating H or floating L tone (via a [modify] feature in Longacre's terms). We observe the following synchronic tonal patterns in couplets in modern Mixtec languages as reflexes of Proto-Mixtec:

Table 6.2: Mixtec Tonogenesis (Dürr, 1987)

Proto-Mixtec:	*H–H	*H–Hʔ	*L–L	*L–Lʔ
Molinos Mixtec:	M–M	M–M+(M)	L–L	L–L+(M)
San Miguel el Grande Mixtec:	M–M	M–M+(M)	M–L	M–L+(M)
Silacayoapan Mixtec:	M–M	H–L	L–L	L–L
Alacatlazala Mixtec:	M–M	M–L	L–L	L–L
Mixtepec Mixtec:	M–M	M–H / ML–LH	L–L	L–H / L–LH

There are three patterns shown in Table 6.2. In both Molinos and San Miguel El Grande Mixtec, certain words with a M–M or L–L tone cause a M tone to surface on the following word. This floating M tone here is cognate with the historical final */ʔ/. In Silacayoapan and Alacatlazala Mixtec, */ʔ/ conditioned pitch-lowering on the preceding syllable of the couplet. This process is invisible for the low tones but apparent when a high or mid-tone preceded the final /ʔ/. In Mixtepec Mixtec, there are no floating tones, but in this case the */ʔ/ has caused pitch-raising on the preceding syllable in the couplet. The pattern on the left within these columns is the tone pattern on disyllabic couplets of the shape /CVʔV/ while the pattern on the right is found in couplets of the shape /CVCV/. In both contexts, the historical coda /ʔ/ conditioned a higher preceding tone.

We may leave aside the issue of whether the loss of final laryngeal is more likely to induce processes of tone sandhi or induce changes in the preceding vowel. From the data here and in the rest of Dürr (1987), it is clear that the synchronic reflex of the historical Mixtec *H tone is M. Where the final laryngeal conditioned pitch raising, it raised the tone to M.[2] Where it conditioned tone lowering, it lowers to L. A /ʔ/ patterns with both high and low tones.

Daly and Hyman (2007) find that the historical */ʔ/ conditioned a L tone in Peñoles Mixtec. They contrast this finding with data from Chalcatongo Mixtec (Hinton, 1991) where the glottal stop is cognate with a synchronic high tone. They speculate that low tone may have arisen in dialects of Mixtec where /ʔ/ was realized as creak ([a̰]) while high tone may have arisen in dialects where /ʔ/ was realized with complete glottal closure ([ʔ]). While compelling, this explanation is founded on the idea that complete glottal closure always produces pitch-raising. This is not the case, as I describe in the next chapter, for Itunyoso Trique. As opposed to tense phonation, creaky phonation usually patterns with pitch lowering. Whether complete glottal closure produces pitch lowering or raising, however, depends on the way in which it is produced. As I discuss in §6.5.4.2, both may occur but each has a separate explanation.

6.3.2 Athabaskan Tonogenesis

This pattern where a historical coda */ʔ/ has modern H and L reflexes occurs in Athabaskan (Krauss, 2005; Leer, 1999; Kingston, 2005). The languages which have a H tone reflex include Chipewyan, Beaver, Slave, Kaska, Northern Tutchone, Hare-Bearlake-Mountain, Tanacross, and Chilcotin while the L reflex languages include Navajo, Southern Tutchone, Upper Tanama, Dogrib, Sarcee, Sekani, and Tahltan (Krauss, 2005:69-70). The H tone reflex languages are mostly continuous geographically, a fact that is relevant to the discussion of laryngeals in Southeast Asian languages in §6.3.3. Table 6.3 shows some

---

[2] This suggests an order in historical tone change where a final */ʔ/ conditioned pitch raising to H which was subsequently lowered to M.

modern reflexes of Proto-Athabaskan /ʔ/.

Table 6.3: Athabaskan Tonogenesis (data from Krauss, 2005)

Proto-Athabaskan	*taʔ *father*	*qeʔ *foot*	*č^{w}'aːnʔ *excrement*	*yaʔ *louse*
Sarcee	tàʔ	kɑ̀ʔ	cà	yàʔ
Navajo	tàːʔ	kèːʔ	čą̀ːʔ	yàːʔ
Kaska	táʔ	cíʔ	cǫ́ʔ	yáʔ
Tanacross	táʔ	kéʔ	cą́ːʔ	šyáʔ

For both Sarcee and Navajo, a final */ʔ/ conditioned pitch lowering. For both Kaska and Tanacross, it conditioned pitch raising. In each of these languages the glottal stop is maintained. In others it has been subsequently lost, e.g. in Dogrib (a */ʔ/ > L language) and in Chipewyan (a */ʔ/ > H language) (Krauss, 2005). While Athabaskan languages have notably fewer tones than Mixtecan languages[3], the final glottal stop has conditioned two tone variants on the preceding vowel. There are also Athabaskan languages which have not developed tone. In many of these languages, the historical */ʔ/ is intact. Languages without tone or a final /ʔ/ include Tanaina (Krauss, 2005:118-119), the Western Alaskan languages Deg Hit'an and Holikachuk (Kingston, 2005), and certain dialects of Koyukon and Babine (ibid).

Kingston (2005) offers a few explanations for why different pitch patterns are observed preceding glottal stops in Athabaskan languages. In the first explanation, differences in how speakers produced glottal stops led to differences in pitch perturbation patterns. In the second explanation, the late realization of tone in short syllables led speakers to make a mistake perceiving the tone's identity. The first explanation states that speakers produced final /ʔ/ with concomitant glottal constriction in the form of creak on the preceding vowel. The incidental pattern of F0 lowering accompanying creak was interpreted by speakers as an intended speech production target and gradually replaced the glottal constriction. Kingston observes that glottalization often precedes final glottal stops or glottalized stops in a variety of Athabaskan languages. He also argues that glottalization is more likely to shift to the preceding vowel before stops both historically and synchronically because it can not be

---

[3] This is conceivably due to differences in the time depth of tonogenesis in the language families. Proto-Athabaskan was non-tonal (Krauss, 2005) while Proto-Otomanguean is reconstructed with at least 3 tones (Rensch, 1976).

produced at the same time as stop closure. Glottalization can overlap the sonorant speech gestures and will be timed later in /V+Nʔ/ sequences than in /V+Tʔ/ sequences. The details of these phonetic explanations for tonogenesis are given in §6.5.4.2.

DeJong and McDonough (1993) argue against the traditional model of consonant-induced tonogenesis in Navajo. Using phonetic data from the language, they observe no synchronic effect of a following glottal stop or glottalized sonorant on the preceding vowel's pitch. They do, however, observe a pitch-lowering effect of the preceding glottalized consonants on the following vowel's tone. If the coda laryngeal account of tonogenesis is rejected, however, it is unclear what other factors would have motivated tonogenesis in Athabaskan languages. The authors' observations do argue that there may be no pitch effect in the production of final laryngeals. The evidence of two types of laryngeally-induced pitch patterns is robust in the rest of the Athabaskan language family.

6.3.3 Mon-Khmer Tonogenesis

Distinct from consonant-motivated tonogenesis are patterns where contrastive phonation type on *vowels* conditions tonogenesis. Languages with contrastive phonation type are called *register languages.* The original use of this term includes a bundle of features like phonation type, pitch, duration, and vowel quality (Henderson, 1952). Thus, researchers of these languages are careful to note that pitch is an acoustic cue in register contrasts, but perhaps secondary to phonation type (which is clearly the case in Wa (Watkins, 2002), for instance). Pitch differences associated with different registers are common in many Mon-Khmer languages. They have been observed in Chong (Thongkum, 1988, 1991; DiCanio, 2007b), in Wa (Watkins, 2002), in So (Premsrirat, 1996), and in Chanthaburi Khmer (Wayland and Jongman, 2003). Matisoff (1973) echoes this point in his description of the two "laryngeal attitudes" found in Southeast Asian languages: the tense-larynx syndrome (with higher pitch and tense voice) and the lax-larynx syndrome (with lower pitch and breathy voice).

The Mon-Khmer language family consists mainly of register languages (Henderson, 1952; Huffman, 1976; Ferlus, 1979), but in certain cases, register systems have become tone systems which may maintain some phonation differences between tones.[4] This is most

---

[4] Exactly how this change from register to tone occurs in the minds of speakers is unresolved, but it probably involves some shift in the relative weight of pitch as a cue for the prosodic contrast.

notable in the Vietic languages like Vietnamese (Thurgood, 2002) but is also observed in Kammu (Khmuic) (Svantesson and House, 2006).

The same process that accounts for registrogenesis in Mon-Khmer is used to explain the origin of tone in Kammu (Svantesson and House, 2006). There are three major dialects of the language: North, Western, and Eastern. Svantesson and House observe that the Northern and Western dialects use F0 to distinguish words while the Eastern dialect does not. The Northern and Western dialects have lost some of the onset VOT contrasts while the Eastern dialect has maintained a 3-way VOT contrast with a voicing contrast in sonorants as well. Data showing the dialectal differences is given in Table 6.4.

Table 6.4: Kammu Tonogenesis (data from Svantesson and House, 2006:310)

Eastern	Northern	Western	Gloss
taaŋ	táaŋ	táaŋ	*pack*
daaŋ	tàaŋ	tʰàaŋ	*lizard*
tʰaaŋ	tʰáaŋ	tʰáaŋ	*to clear*
r̥aaŋ	ráaŋ	ráaŋ	*tooth*
raaŋ	ràaŋ	ràaŋ	*flower*

Voiced stops became voiceless unaspirated stops with low tone in the Northern dialect while they became voiceless aspirated stops with low tone in the Western dialect. These dialects also lost voiceless sonorants which became voiced with high tone. All vowels which followed voiceless unaspirated or aspirated stops in Proto-Kammu have high tone in the Northern and Western dialects. Investigating the phonetics of the contrast, Svantesson and House (2006) found that even though the Eastern dialect is not tonal, voiceless onset consonants induced pitch-raising on the following vowel while voiced onsets did not.

On the surface, the patterns in Table 6.4 and the authors' phonetic data suggest a common course whereby tone develops from voicing differences in onset consonants. Yet, the presence of the two synchronic reflexes (/t/, /tʰ/) of the voiced stops is more amenable with an account where tone arose out of phonation type differences on the syllable rime in Kammu. The authors argue that tonogenesis in Kammu crucially passed through this step of having a phonation type contrast. The four stages of tonogenesis are as follows:

1. Voiced stops induce breathiness on the following vowel which causes pitch to lower.
2. Voiced stops become voiceless.

3. In some dialects (Western), voice quality is maintained as consonantal aspiration.
4. In some dialects (Northern), voice quality differences are lost.

The principle responsible for the appearance of contrastive phonation type after voiced stops is the aerodynamic voicing constraint (Ohala, 1983). Voicing is difficult to maintain during stop closure because oral air pressure quickly becomes equivalent to subglottal air pressure. Voicing may persist however if speakers actively decrease vocal fold tension which lowers the impedance to transglottal airflow (Stevens, 2000). A product of this decreased tension is breathiness in the acoustic signal. As voicing is best perceived in consonant release (Kingston, 1985, 1990; Silverman, 1997b), one expects slacker vocal folds to immediately precede release. The vowel will be more breathy just after the consonant than later in the vowel.

This particular account of tonogenesis via phonation differences is the central claim in Thurgood (2002). He observes that Haudricourt's analysis of Vietnamese only works if differences in voice quality are taken into account. Following Gage (1985) and Diffloth (1989), he states that a number of the words with the *sắc* and *nạng* tones synchronically appear to derive from words which did *not* end in a stop, but in a sonorant (i.e. cognate forms in Chong). Along Haudricourt's analysis, we expect these words to have either the *ngang* tone or the *huyền* tone. In the data in Table 6.1 both tones derive from open syllables or those with a final sonorant. Diffloth (1989) revises Haudricourt's analysis of Vietnamese tonogenesis, shown in Table 6.5.

Table 6.5: Vietnamese Tonogenesis (taken from Thurgood, 2002)

		Proto-Modal	Proto-Creaky	Fricative-Final	Stop-Final
	Stage 1:	pa	pa̰	paS	paT
		ba	ba̰	baS	baT
	Stage 2:	pa	pa̰	pah	paʔ
		ba	ba̰	bah	baʔ
	Stage 3:	pa	pă	pâ	pă
		ba	bă	bâ	bă
Modern:	Higher	pa (ngang)	pă (sắc)	pâ (hoˀi)	pă (sắc)
	Lower	pa (huyền)	pă (nạng)	pâ (ngã)	pă (nạng)

Diffloth (1989) argues that many apparent irregularities in the historical reconstruction of Austroasiatic languages can be accounted for by positing a Proto-Austroasiatic creaky voice which influenced pitch the same way that final voiceless stops did.[5] Thurgood (2002) takes this analysis a step further arguing that any pitch perturbations which are tonogenetic are mediated by a voice quality distinction in the language. Thus, voiced onsets first condition vocalic breathiness (see above) which then influences pitch.

Thurgood (2002:339) motivates his approach by arguing that the magnitude or the timing of laryngeal height adjustments does not correlate well with consonantal effects on vowel pitch (Gandour and Maddieson, 1976; Riordan, 1980). He argues that there are strong correlations between phonation type and pitch. His analysis and the one offered for Athabaskan by Kingston (2005) suggest that phonation type is most often responsible for pitch changes in processes of tonogenesis. The interaction of these two laryngeal configurations is our focus in §6.5.

6.4 Distribution and Phonological Explanation

Laryngeals are exceptional in their behavior in many phonological systems. They interact in unique ways with syllable structure, tone, and suprasegmental processes of feature spreading. In Chong, the tense phonation types are restricted to closed syllables (DiCanio, 2007b). As we observed in Chapter 5, fewer tones are permitted in the context of laryngeals than in open syllables. As we observed in Chapter 2, an intervocalic /ʔ/ is one of the few consonants in Itunyoso Trique which permits leftward nasalization spreading. In this section I examine two phonological patterns relevant to our discussion of tone-laryngeal patterning: tone-laryngeal phasing and the representation of laryngeal pitch effects. I begin with an illustrative example from the other Trique languages.

6.4.1 Tone and Laryngeals in Trique languages

The other two described Trique languages: San Juan Copala and San Andrés Chicahuaxtla Trique are similar in how tone is distributed relative to the laryngeal codas: /h/ and /ʔ/. These languages similarly do not have syllable codas apart from these laryngeal consonants. Like Itunyoso Trique, laryngeal consonants are restricted to the final syllable

---

[5] Most final voiceless stops are realized with final glottal constriction in Mon-Khmer languages Henderson (1952); Thurgood (2002).

of the word. Therefore, any interaction between tone and laryngeal consonants takes place on this syllable.

The tone systems of each of these languages differ slightly from the tone system in Itunyoso Trique. Copala Trique has 8 underlying tones /1, 2, 3, 4, 5, 13, 32, 31/ which surface in final syllables (Hollenbach, 1977, 1984b). These tones are mostly cognate with these same tones in Itunyoso Trique.[6] Certain tones have distinct surface representations in Copala Trique as a result of an abstract ballistic laryngeal /!/ which conditions both vowel shortening and onset lengthening (Hollenbach, 1984b).

Chicahuaxtla Trique (Longacre, 1952, 1957, 1959; Hollenbach, 1977) has the largest tonal inventory. Longacre provides evidence for a five level tone system and a huge set of contour tones. The 5 level tones /1, 2, 3, 4, (4)5/ surface in final syllables and are mostly cognate with the Itunyoso Trique tones /1, 2, 3, 4, 35/, respectively. There are 6 rising tones /34, 23, 15, 14, 13, 12/, 6 falling tones /54, 53, 43, 32, 31, 21/, and two convex tones /323, 312/ as well (ibid). However, the number of contour tones given by Longacre is a bit misleading. He mentions that tones /14/ and /15/ are restricted to one particular lexical item each (Longacre, 1952:76). Hollenbach (1977) finds the same to be true for Longacre's tones /53/ and /34/. She goes further, stating that the large inventory of tones in Chicahuaxtla Trique originates from an unstressed particle of the form *V^{3}, meaning "end of noun phrase" fused to the end of many words. Tone sequences of the form /54, 23, 13, 12, 323, 312/ all have this source. Once we eliminate the morpheme-specific and phrase-final tones, we have a tone inventory /1, 2, 3, 4, (4)5, 43, 32, 31, 21/ which resembles the tone systems of Copala and Itunyoso Trique much more closely.

In Copala Trique, all 5 level tones and the /13/ rising tone may surface with a coda /ʔ/ and every tone except for /4/ surfaces with a coda /h/. In Chicahuaxtla Trique, level tones /1, 2, 3, 4/ and contour tones /32/, /31/, /21/ surface with a coda /ʔ/. Level tones /1, 2, 3, 4/ and contours /32, 31, 21, 43, 23/ surface with a coda /h/. Examples from Hollenbach (1984b) for Copala Trique shown in Table 6.6 and examples from Hollenbach (1977) for Chicahuaxtla Trique are shown in Table 6.7.

In Copala Trique, almost all tones surface with a coda /h/ but falling tones do not surface with a coda /ʔ/. The phonological rising tone /13/ and the phonetic rising tone /5/,

---

[6] The one exception being tone /35/ in Itunyoso Trique, which is cognate with /5/ in the other languages. As I do in this study, Hollenbach (1984b) uses /5/ as high and /1/ as low. I have adapted all other work on Otomanguean languages to accord with this.

Table 6.6: Copala Trique Tone-Laryngeal Distribution

	Coda /ʔ/		Coda /h/	
Tone	Word	Gloss	Word	Gloss
/1/	ki^{1}riʔ^{1}	*will obtain*	ki^{1}nãh^{1}	*will wash*
/2/	i^{2}tʃiʔ^{2}	*ten*	ku^{2}nãh^{2}	*will run*
/3/	ka^{3}no^{3}koʔ^{3}	*followed*	na^{3}wih^{3}	*ended*
/4/	niʔ^{4}	*we (incl.)*	X	
/5/	rũʔ^{5}	*only*	ku^{5}nãh^{5}	*ran*
/13/	ka^{1}no^{1}koʔ^{13}	*will follow*	na^{1}wih^{13}	*will end*
/31/	X		ma^{3}jah^{31}	*yellow*
/32/	X		ku^{3}ʈʂuh^{32}	*laid down*

Table 6.7: Chicahuaxtla Trique Tone-Laryngeal Distribution

	Coda /ʔ/		Coda /h/	
Tone	Word	Gloss	Word	Gloss
/1/	zi^{3}-ga^{1}kɨʔ^{1}	*our nails*	ʒu^{1}wih^{1}	*twelve*
/2/	tʃiʔ^{2}	*ten*	tʃih^{2}	*seven*
/3/	gɨ̃ʔ^{3}-zi^{3}	*stinks-3sg.*	ruh^{3}	*clay pot*
/4/	di^{3}ʔnɨ̃ʔ^{4}	*our corn*	zi^{3}-neh^{4}	*my meat*
/5/	X		X	
/43/	X		tah^{43}	*Dad!*
/32/	da^{3}rãʔ^{32} nĩh^{3}	*all of them*	ʒu^{3}gweh^{32}-zi^{3}	*his sister*
/31/	u^{3}taʔ^{31}-zi^{3}	*fight-3sg.*	X	
/21/	zdu^{3}kũʔ^{21}	*nephew*	ru^{3}gu^{3}tsɨh^{21}	*armpit*
/23/	X		ni^{3}kah^{23}	*her husband*
/13/	X		zi^{3}-neh^{13}	*her meat*

realized as [35] (Hollenbach, 1984b), both surface with a coda /ʔ/. Tone /4/ never surfaces with a coda /h/ here. Longacre (1957) suggests the absence of tone /5/ in this context has to do with the origin of this fifth tone. He argues that the Proto-Mixtecan tone */4/ was realized with higher pitch before a coda /h/. This coda was subsequently lost leaving a gap in the distribution. This historical analysis is problematic however as tone /4/ surfaces with a coda /h/ in both Chicahuaxtla and Itunyoso Trique. In Chicahuaxtla Trique, tone /5/ never surfaces with a coda laryngeal. Rising tones and tone /43/ do not surface with a coda /ʔ/ but the other level and falling tones do. Like Copala Trique, most tones are able to surface with a coda /h/.

The patterning of tone with respect to /h/ is relatively free in the Trique languages but it is more restricted before a coda /ʔ/. The patterns observed in these languages are distinct. In Copala Trique, the final glottal stop prevents falling tones from surfacing while in Chicahuaxtla Trique, the final glottal stop prevents rising tones from surfacing. In Itunyoso Trique no contours of any type are permitted before a glottal stop. Within the Trique family of languages, the behavior of tone in the context of a coda /ʔ/ varies. This is unexpected if one predicts /ʔ/ to be pitch-raising in its tonogenetic or tonomutational properties. However, the variability in patterning is explainable if we consider that speakers of different dialects produce glottal stops with different accompanying phonation types.

6.4.2 Tone-Laryngeal Phasing

In his dissertation, Silverman (1997b) states that laryngeals are timed on segments so that they may be perceptually recovered by the listener. In languages with contrastive use of phonation type and tone, the two are timed so that listeners can perceptually recover the tone and laryngeal as distinct. Since phonation type or laryngeal consonants will effect pitch, their sequencing preserves optimal tone contrasts in the language. Tone is optimally perceived on modal vowels. The implication of this perspective is that non-modal phonation will not overlap with a modal portion of a vowel and obscure the perception of pitch. Silverman (1997a:256) explains this view stating:

> Prevocalic nonmodal phonation followed by modal phonation is the optimal timing pattern to cue vocalism, voicelessness, glottal closure, or tone: all these contrastive values are optimally recoverable from the speech signal if timed in this fashion.

Kingston (1985, 1990) argues that the peak in glottal opening is aligned with prevocalic stop release as this best cues the noise associated with glottal spreading. Silverman (1997b) makes a similar claim using data from a variety of languages. He argues that laryngeal features on vowels are phased so that tone may be recovered in contexts where the phonation would alter F0. There is substantial evidence for Silverman's perspective from the distribution of laryngeals in phonological systems. For instance, /h/, aspiration, and breathiness commonly pattern in syllable onsets across many languages. Glottalization is usually restricted to the initial portion of the syllable as well. Many languages have distributional restrictions where laryngeals may only appear in onset position. These synchronic patterns between tone and laryngeals are widespread in languages of the world.

Itunyoso Trique seems to be a difficult case from this perspective. For instance, /h/ only surfaces in word-final position while /ʔ/ surfaces intervocalically and word-finally. Given that Silverman states that laryngeals pattern with syllable onsets in tone languages, the distribution of these laryngeals seems problematic, c.f. Chamicuro Parker (2001). In these cases, Silverman argues that the perceptual recovery of tone and laryngeals is achieved through a non-overlap of the gestures used to signal these two things (borrowing from Browman and Goldstein (1986, 1990)). In Jalapa Mazatec for instance (Kirk et al., 1993), nonmodal phonation is associated with the release of the syllable onset and tone is associated with the rest of the vowel where the nonmodal phonation is weakened (Silverman, 1997b:154). In this case, nonmodal phonation and tone are timed so as to not overlap.

An alternative perspective on the issue of timing is found in Howe and Pulleyblank (2001). The authors state that it is the syllable-structure constraints in particular languages that control the timing of laryngeals. Rather than encoding patterns of articulatory timing into the phonology, as Silverman does, they argue that constraints on the location of glottal constriction in Yowlumne, Kashaya, and Nuu-chah-nulth are dependent on the language-specific phonology. For instance, Silverman (1997b) predicts that laryngeals are timed with the release of a syllable onset. Howe and Pulleyblank show that in both Nuu-chah-nulth and Yowlumne pre-glottalized consonants occur in onset position, where the timing of the laryngeal is before the onset release. In Kashaya and Yowlumne, post-glottalized consonants occur in coda position. This is the opposite of Silverman's predictions, but follows directly from the syllable structure constraints of these languages. In particular, glottalization is moraic in these languages, which predicts that glottalized sonorants or ejectives pattern in coda position.

Regarding the Trique data in §6.4.1, these approaches are inapplicable. There is no explicit account given of *which* tones will co-occur with which phonation types. It is correctly assumed that nonmodal phonation will affect pitch on words, as we have seen in the cases of tonogenesis and tonomutation, but no explanation is provided as to how much phasing may occur with breathiness as opposed to creaky or tense phonation. Some of the claims related to tone-laryngeal phasing are explicitly addressed in Chapter 7 along with an investigation of exactly which tones are more affected by changes in phonation type.

6.4.3 The Representation of Consonant-Tone Interaction

There are three approaches in modern phonological theory for representing consonantal pitch perturbation effects: the laryngeal featural account (Halle and Stevens, 1971), the tonal register account (Yip, 1980, 1993, 2002; Bao, 1999; Duanmu, 1990, 2000), and the tonal domain account (Pearce, 2007; Tang, 2008). These approaches are not mutually exclusive. All utilize the same laryngeal features originally proposed in Halle and Stevens (1971).

6.4.3.1 Halle and Stevens (1971)

Halle and Stevens (1971) argue that speakers may independently control two laryngeal parameters: glottal width by movement of the arytenoid cartilages and vocal fold tension by controlling the cricothyroid and thyroarytenoid muscles. One may adjust glottal width to produce either a spread state, where the vocal folds are actively abducted from a resting position, or a constricted state, where the vocal folds are adducted with greater medial compression along the vocalis muscle. One may adjust vocal fold tension to produce either a stiff state, where contraction of the cricothyroid (and optionally the thyroarytenoid (Titze, 1994; Kingston, 2005)) increase the tension per unit area of the vocal folds, or a slack state, where contraction of the thyroarytenoid or vocalis muscle and laryngeal lowering causes decreased longitudinal tension.

The authors describe the activity of these four adjustments using a set of four distinctive features: [spread glottis], [constricted glottis], [stiff vocal folds], and [slack vocal folds]. Their approach is a departure from the original glottal source features proposed in Chomsky and Halle (1968): [voiced] and [heightened subglottal pressure]. This earlier account was unable to represent the differences among vowel and consonant types that

Halle and Stevens were concerned with. Their proposed features are used to represent such contrasts. The mapping between these features and some laryngeal consonant articulations is given in Table 6.8. Following Ladefoged and Maddieson (1996), an asterisk * is used to represent tense phonation.

Table 6.8: Laryngeal Feature Mapping (from Halle and Stevens, 1971:203)

Consonant:	/b/	/b/	/p/	/p/	/bʰ/	/pʰ/	/ɓ/	/ʔb/	/p’/
Vowel:	/a/	/à/	/á/	/ḁ/	/a̤/			/a̰/	/*a/
[spread gl.]	−	−	−	+	+	+	−	−	−
[constr. gl.]	−	−	−	−	−	−	+	+	+
[stiff v.f.]	−	−	+	−	−	+	−	−	+
[slack v.f.]	−	+	−	−	+	−	−	+	−

The conditions on voicing during the production of a consonant or vowel crucially depend on the interaction of these laryngeal features. If vocal fold stiffness is large and the glottis spread, voicing will be actively inhibited (for further discussion, see Chapter 3). The vocal folds may continue to vibrate with a wider glottal opening but only if they are slack. Increased vocal fold tension causes impedance to transglottal flow. There are more restrictions on voicing with a [+stiff v.f.] feature specification than without one.

Halle and Stevens (1971) argue that the cricothyroid is the principal articulator responsible for controlling vocal fold stiffness, but this is also the primary articulator responsible for the control of F_0 (Munhall and Löfqvist, 1992; Titze, 1994). As a result, high tones are specified as [+stiff v.f.] while low tones are specified as [+slack v.f.]. Creaky voice and breathy voice have opposite glottal width specifications here, but crucially have the same glottal tension specification: [+slack v.f.]. Pitch is lowered in both these phonation types because the cricothyroid (CT) is not contracted. The opposite is true for tense phonation, where increased glottal constriction and vocal fold stiffness result in higher pitch due to CT contraction. The prediction from Halle and Stevens' model is clear: any articulation produced with [slack] vocal folds will have lower pitch while any produced with [stiff] vocal folds will have higher pitch. A consequence of this is that consonants that are produced with these features will inadvertently affect pitch on the neighboring vowel. This process of spreading, however, is not formally addressed in Halle and Steven's work.

6.4.3.2 Tone and Laryngeal Register

Yip (2002) summarizes the various approaches of how laryngeal features interact with tone. Her first criticism of the laryngeal feature approach in Halle and Stevens (1971) is its use of such features to define both tone and phonation type. This system is ill-equipped to describe languages where both occur, like Mpi, Mazatec, Zapotec, or others (Kirk et al., 1993; Silverman et al., 1994; Silverman, 1997b; Gordon and Ladefoged, 2001; Blankenship, 2002). The laryngeal features are useful in representing non-modal phonation type however. The second criticism is that Halle & Stevens' approach only permits three contrastive tone levels. Four-level tone systems are somewhat rare, but are found in many language families, as are five-level systems (in Copala and Chicahuaxtla Trique). Any set of tonal and laryngeal features must account for such systems.

Following Yip (1980), Duanmu (1990) proposes a set of three registers which differ in laryngeal feature specification. The highest register is [+stiff], [−slack], the middle [−stiff], [−slack], and the lowest [−stiff], [+slack]. Each register may be specified with two additional pitch features [above] and [below]. There are three possible tones in any register, featurally-specified with combinations of these binary pitch features (excluding [+above] [+below]). This featural model is an improvement over the approach of Halle & Stevens because it is able to separate tonal features from phonation-type features. However, it both overgenerates and undergenerates the set of possible tones found in human languages. It predicts that there will be languages with as many as 9 level tones. The maximum number of level tones in any language is apparently 5 (Yip, 2002). It also predicts that no language will contrast more than 3 levels without a phonation-type contrast. As we observed in the Trique data above, as many as 5 level tones can occur in open syllables and syllables with a final laryngeal.

Duanmu (2000) revises this analysis by stating that the principal articulator responsible for the [stiff] and [slack] features is the vocalis muscle, not the cricothyroid. Since the vocalis muscles controls isometric vocal fold tension, it is argued, it is responsible for differences in register. Pitch is specified with the vocal fold features [thin] and [thick]. As in his previous proposal, the feature [slack] reflects breathy phonation but [stiff] here does not represent tense phonation, but modal phonation. This approach still combines phonation type with tone insofar as tones of a lower register are obligatorily [+slack]. This is problematic for the representation of any language where breathiness is contrastive among lower tones. However, it permits more tone levels and for higher tones to have phonation-type contrasts.

6.4.3.3 Pearce (2007) & Tang (2008)

Recent work in consonant-tone interaction has both focused on which phonetic characteristics tend to be associated with pitch perturbation effects and how to represent the domain over which such perturbations are implemented (Bradshaw, 1999; Pearce, 2007; Tang, 2008). One of the primary motivations in Bradshaw's and Pearce's work is to account for phonological patterns with depressor consonants in Bantu and Chadic languages (respectively). Bradshaw (1999) primarily focuses on voicing and its interaction with tone, but Pearce (2007) utilizes Halle & Stevens' laryngeal features to account for the tonal patterning and consonant pitch perturbation effects.

Pearce (2007) provides a comprehensive description of Kera, a Chadic language. Her dissertation examines the segmental phonology of the language, its prosodic structure (feet, tone), and processes related to these (harmony, voice spreading). She argues that the distribution of tone on feet and the interaction of tone and consonant voicing in Kera are best explained if one posits the foot as the feature-bearing unit (FBU). The laryngeal features [stiff] and [slack] are associated with consonants or vowels which spread across the foot domain in accordance with laryngeal feature alignment constraints. This analysis elegantly predicts the distribution of tone with respect to depressor consonants in Proto-Chadic. Pitch perturbation effects are handled by associating laryngeal features across a larger prosodic domain.[7]

Tang (2008) argues against the feature-sharing approach of the sort argued by Pearce (2007). Borrowing heavily from the grounded phonology approach of tone-voicing interactions in Peng (1992), Tang argues that there is a large range of laryngeal features interacting with tone and pitch. For instance, she states that [spread glottis] and [constricted glottis] each result in pitch raising and lowering. Some of the tone-laryngeal interactions are also microprosodic while others have larger domains. Approaches which assume feature sharing predict that only certain laryngeal features will have an effect on pitch. This approach, Tang argues, is too narrow to account for the observed phenomena cross–linguistically. An

---

[7] While not precisely used to predict tonal patterns, glottalization is considered a characteristic of the couplet or foot in Mixtecan languages (Macaulay and Salmons, 1995; Gerfen, 1999).

analysis where F-elements (features) are restricted by a set of grounding conditions on tone-laryngeal feature co-occurrence is better able to account for any interaction.

The domain of tone-laryngeal interaction in Tang (2008) is defined as a *tone-span*. These are defined on a language-specific basis according to what is the TBU. A span of a tone consists of all segments in its temporal domain and must contain at least one TBU. Such spans may not overlap. Tone-laryngeal co-occurrence restrictions are handled by stating that certain laryngeal features may not occur within such spans. Tang provides an example from Bade, where tone spans may not contain a [-voice] feature. For instance, in the word /gàtàvén/ '*senna*', only two underlying tones occur, L and H. However, there are three tone spans: g[à]t[à]v[én]. The effect of separating laryngeal feature co-occurrence constraints from an autosegmental representation is that differences in lexically-permitted sequences and blocked spreading sequences will result from a difference in structure.

6.4.4 Interim Summary & Discussion

The discussion in §6.3 and §6.4 demonstrate a diachronic and synchronic connection between pitch and laryngeals. Various approaches from phonological theory attempt to account for this relationship. The phasing approach (Silverman, 1997a,b) states that speakers will sequence modal vowels and laryngeal features to avoid potential overlap. This perspective is both synchronic and listener-oriented, where speakers actively seek to enhance contrasts for the sake of the listener (Stevens and Keyser, 1989; Flemming, 1995, 2001). The laryngeal feature approaches represent these interactions within the synchronic phonology of a speaker. They do this either by permanently associating certain tones/registers with laryngeal features or by permitting features to spread across prosodic domains.

Whether pitch perturbation effects are best represented by associating laryngeal features to tonal registers (Yip, 1980, 1993, 2002; Bao, 1999; Duanmu, 1990, 2000), via laryngeal feature spreading (Pearce, 2007), or using a tone-span approach with grounding conditions (Tang, 2008), each perspective must account for which interactions are phonetically-grounded. In any approach, it is not sufficient to assume that what is transcribed as aspiration will always reflect a [+spread glottis] feature representation. Neither is it sufficient to assume that voicing always reflects an underlying [+voice] feature specification (see Chapter 3). Insofar as phonological theory seeks to ground articulatory features in phonetic reality, the timing of individual speech gestures and their concomitant effects on the acoustic signal are keys to accurately determining underlying distinctive feature specification. While theories of how to represent laryngeals depend crucially upon phonetic detail, so do theories of tone-laryngeal phasing. Such details are described in the following section.

6.5 Phonetic Explanations

The glottis is a complex articulator whose control and function depend upon a set of extrinsic laryngeal muscles, intrinsic laryngeal muscles, and the aerodynamic state of the subglottal and oral cavities. There are a range of states that the human vocal folds are capable of producing. The primary articulation the vocal folds are responsible for is voicing. This may be accomplished both with varying states of adductive, longitudinal, and isometric tension. It may also be accomplished with varying degrees of laryngeal height (lowered or raised). The adjustment of laryngeal tension and glottal width have consequences for both how pitch may be controlled and the permitted variability in F_0 that may occur. These details are relevant to work on tonogenesis and the patterning of tone with laryngeals because there are clear consequences on pitch for different laryngeal states.

This section is organized as follows: In §6.3, I describe the anatomy of the larynx. In §6.5.2, I describe the articulatory phonetics of F_0 control, borrowing heavily from the work of Laver (1991, 1980); Bateman and Mason (1984); Titze (1994). In §6.5.3, I describe the articulatory parameters in the production of phonation type. I follow this with a discussion of how laryngeals may affect pitch and its consequence for laryngeal features in §6.5.4.

6.5.1 The Larynx

6.5.1.1 Extrinsic Muscles

The larynx can be divided into two sets of muscles: extrinsic muscles used for the movement of the entire laryngeal structure and intrinsic muscles which control glottal width, glottal tension, and resultingly, F_0. The larynx is composed of six major cartilages: the hyoid, thyroid, cricoid, arytenoid, epiglottic, and corniculate cartilages. The vocal folds are located between the thyroid and cricoid cartilages, with muscular attachments on both (hidden from view). An exterior view of the larynx with some of the described muscles is shown in Figure 6.1.

Most of the extrinsic muscles of the larynx attach to the hyoid bone. They consist of

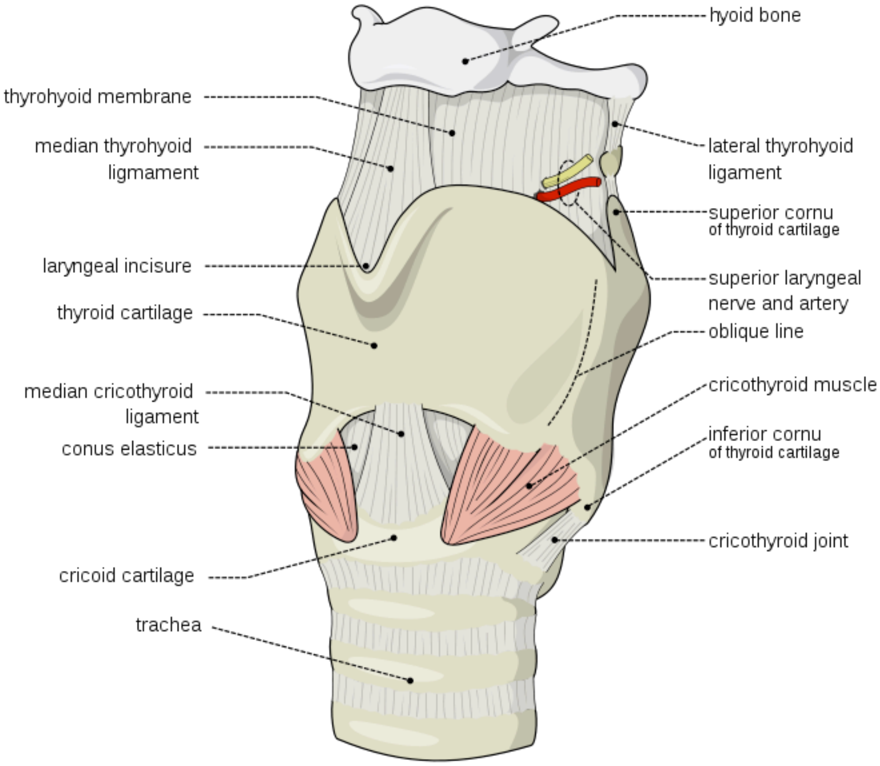


Figure 6.1: Exterior view of larynx, courtesy of Remesz

both elevators and depressors (Bateman and Mason, 1984). The elevating muscles include the digastricus, mylohyoid, geniohyoid, and stylohyoid muscles. The digastricus elevates the hyoid bone (indirectly raising the larynx) when the chin is held closed. The mylohyoid depresses the hyoid bone. The geniohyoid draws the hyoid bone upward and forward, toward the chin, while the stylohyoid draws the hyoid backwards and upwards, due to its attachment at the styloid processes.

Because the hyoid bone is connected to the thyroid via the thyrohyoid, any action that raises the hyoid bone will raise the larynx. The extrinsic muscles that depress the hyoid consist of three muscles: the sternothyroid, the sternohyoid, and the omohyoid. Generally speaking, any articulatory activity that can be done “for free” by nature is exploited. Thus, there are fewer extrinsic depressor muscles of the larynx than elevator muscles because gravity will naturally lower a structure when it is not elevated, passively depressing the larynx. The three muscles mentioned here are used when laryngeal activity necessitates an active lowering of the larynx. The sternothyroid and sternohyoid connect the sternum to the thyroid and hyoid cartilages, respectively. The sternothyroid acts antagonistically to the cricothyroid, used in pitch control. The omohyoid draws the hyoid bone downward and rearward, because it attaches to the hyoid from the scapula. How these muscles work together is best understood as a set of *slings* (Laver, 1980). Elevation and retraction of the larynx utilizes one ‘sling’, which consists of the combination of the stylopharyngeal, stylohyoid, middle pharyngeal constrictor, and posterior belly of the digastric muscle.

Laryngeal raising and lowering are the most relevant articulations for understanding phonation and pitch production. The larynx often raises during the production of a higher pitch (Hirose, 1997). The external elevator muscles are active in such a process. Active laryngeal lowering tends to co-occur with lower pitch. The extrinsic depressors muscles are involved in this process. Lowering the larynx has the additional effect of increasing the length of the laryngopharynx, the result of which is to lower resonant frequences (mostly for F1 and F2) (Laver, 1980). Considering that certain phonation types are described as having a lowered or raised pitch, it may be the case that they involve active laryngeal raising or lowering that induces a pitch effect indirectly.

6.5.1.2 Intrinsic Muscles

There are three sets of intrinsic laryngeal muscles: tensor muscles, adductor muscles, and abductor muscles (Bateman and Mason, 1984). The tensor muscles regulate the stricture of the vocal folds while the the other muscle types control the aperture between them. The four most relevant tensor muscles in the production of pitch and phonation are the cricothyroid, the thyroarytenoid, the ventricularis and the vocalis muscles. These intrinsic muscles are represented in Figure 6.2.

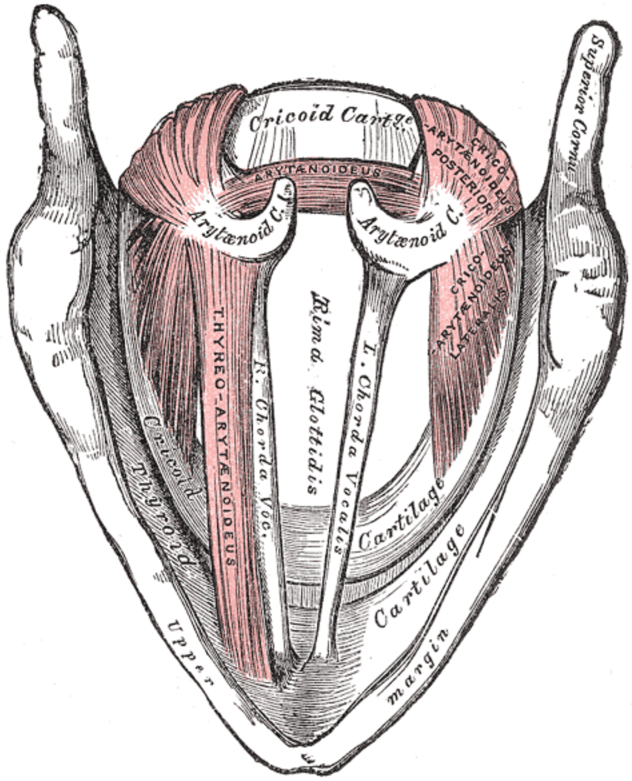


Figure 6.2: Interior view of larynx (Gray and Standring, 1995)

The cricothyroid muscle has an anterior insertion at the cricoid cartilage and a posterior insertion along the base of the thyroid cartilage (better shown in Figure 6.1. It is the is the main muscle that regulates pitch. The thyroarytenoid muscle makes up the essential mass of the vocal folds and inserts into the lateral base of the arytenoid cartilages. Its contraction draws the arytenoids forward, which relaxes the cover of the vocal folds. During tense phonation, it may act together with the vocalis muscle to increase the medial compression along the vocal folds (Laver, 1991). The ventricularis muscle, often called the "false vocal folds", may be used during the production of certain phonation types involving glottal constriction. However, it is not utilized during modal vocal fold vibration. The last tensor muscle is the vocalis muscle, which makes up the medial portion of the thyroarytenoid. Its contraction thickens the vocal folds, which may lower pitch (Hirose, 1997).

The adductor muscles each involve some attachment to the arytenoid cartilages. They include the lateral cricoarytenoid, the transverse arytenoid, and the oblique arytenoid muscles. The contraction of the lateral cricoarytenoid rotates the arytenoid cartilages, bringing the vocal folds together along the medial dimension. The contraction of the transverse arytenoids (interarytenoids) also pulls the vocal folds together medially, (although more directly, via a direct muscular attachment between the arytenoid cartilages, rather than an indirect movement of the arytenoids). The oblique arytenoid muscles attach in an X-shaped manner from the base of one arytenoid to the apex of the other, the contraction of which adducts the vocal folds. There is only one abductor muscle: the posterior cricoarytenoid. This muscle counters the thyroarytenoid muscle by rotating the arytenoids so as to abduct the vocal folds.

There are two types of stricture that are possible with the vocal folds (Laver, 1991). First, adductive tension involves the action of the interarytenoids and lateral cricoarytenoids, which bring the arytenoid cartilages together. This involves a closure of the aperture between the vocal folds, which have an attachment at the arytenoid cartilages. Second, medial compression refers to the adductive pressure on the arytenoid cartilages. It is achieved by an increase in the tension of the lateral cricoarytenoid muscles and is aided by the contraction of the lateral parts of the thyroarytenoid muscles. This compression involves both an adductor muscle and a tensor muscle. Since the thyroarytenoid contracts along the longitudinal axis of the vocal folds, it relaxes the cover.

During voicing, the glottis is nearly closed. Abduction and adduction of the vocal folds involves a "reciprocal activation of the abductor and adductor muscle groups" (Hirose, 1997:128). For modal voicing, there is moderate adductive tension and moderate medial compression of the vocal folds (Laver, 1991). The compression of the vocal folds creates an impedance to pulmonic airflow that is overcome eventually by a buildup in subglottal pressure behind the impedance. Once the folds separate, air passes through them with high flow velocity. The increase in velocity causes a decrease in pressure at the folds via the Bernoulli effect. Once pressure has decreased substantially, the folds are again brought together. The combination of subglottal pressure, vocal fold elasticity, and the Bernoulli effect create regular oscillation (Catford, 1977; Hirose, 1997) in the myoelastic theory of phonation.

The description of the the laryngeal anatomy gives insight into the muscles responsible for the production of different laryngeal gestures. The activity of the abductor and adductor muscles illustrate how voicing is produced. However, the control of pitch is a more detailed process which requires an additional model. I describe this in the following section.

6.5.2 The Production of Pitch

A useful diagram of the mechanical effect of muscles in the larynx is given in Figure 6.3. Control of F_0 in voice production is primarily determined by contraction of the cricothyroid (CT) and thyroarytenoid (TA) muscles. The cricothyroid elongates the vocal fold tissue because its contraction will pull the cricoid and thyroid cartilages together while the vocal folds are held in place at the posterior end of the cricoid cartilage. In the lower portion of Figure 6.3, the bar transversing the larynx is the slip-joint connecting the cricoid and thyroid cartilages. Contraction of the CT pulls the thyroid forward and downward along this axis.

The activity of the CT is counteracted by TA contraction, which will decrease the length of the vocal folds and therefore decrease the tension in the vocal fold cover. It is important to note that the vocal folds consist of three layers: the epithelial mucosa, the ligament, and the muscle itself (both the vocalis and the TA). The mucosa is the cover while the muscle is the body of the vocal folds (with ligamental tissue connecting them). Contracting the TA results in greater tension within the body of the vocal folds but actually reduces the tension in the vocal fold cover. This is akin to tying a string to two ends of a spring and then compressing the spring. The compression will result in greater tension along the spring's length but will make the string more slack. As the cover of the vocal folds has greater proximity to the glottis, it is the cover tension that usually determines F_0. The vocal fold mass contributes to F_0 mainly within a lower F_0 range.

The activity of the CT and TA interact within a body-cover model of the vocal folds. They each contribute differently to F_0 control within the F_0 range. CT contraction most clearly correlates with F_0 within a medium to high F_0 range. Here, both the cover and the body have greater longitudinal tension when the CT contracts. When CT contraction

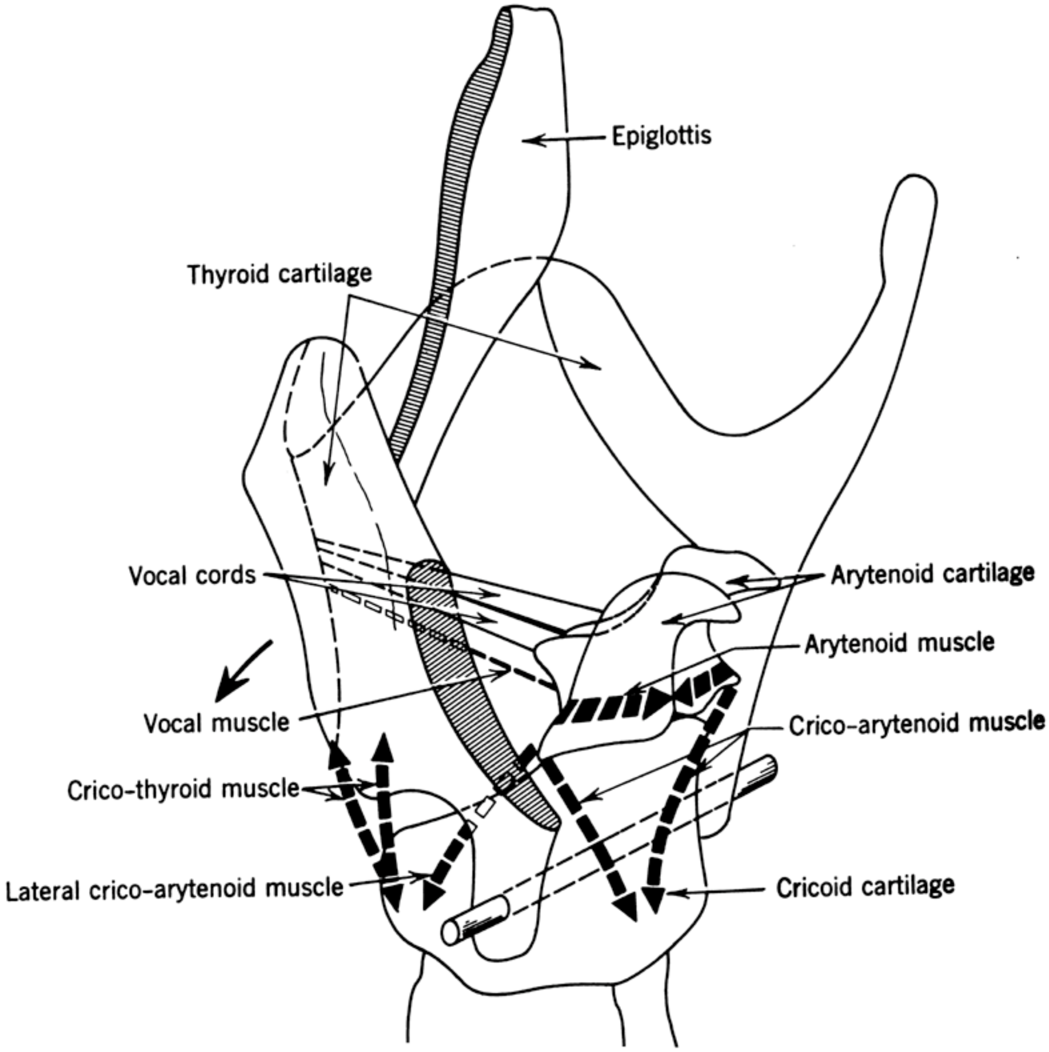


Figure 6.3: Intrinsic Muscle Mechanics, courtesy of Mark Liberman

is not near its maximum, TA contraction also raises F_0. Within a low to intermediate F_0 range, the vocal fold body is set in motion. The cover of the vocal folds does not determine F_0 to the same degree here, the body of the vocal folds does. TA contraction has a greater effect on F_0 within this range than when there is substantial CT contraction. When there is low CT contraction, additional contraction of the TA has little effect on F_0. This arises mainly when speakers produce very low pitch. Pitch control here may be determined by the activity of other intrinsic muscles like the vocalis muscle (Hirose, 1997). The vocalis muscle is the interior portion of the TA, but may be contracted independently from the TA body.

The phonetics of pitch production have an important consequence for the associated laryngeal features. Pitch-raising will increase longitudinal tension in the vocal folds, reflected in the [+stiff] laryngeal feature. However, not all increases in tension result in higher F_0. TA contraction increases stiffness but may lower F_0. Thus, it is useful to distinguish which component of the vocal folds has greater tension when one argues that laryngeal features like [stiff] reflect higher F_0. Table 6.9 shows the consequences of muscular constriction on pitch.

Table 6.9: Articulatory parameters controlling pitch

Vocal-Fold Component	Setting	Muscle	Effect
Body	Greater Longitudinal Tension	CT	high F_0
Body	Greater Medial Tension	TA	low F_0 if cover slack
Cover	Stiff	CT	high F_0
Cover	Slack	TA	low F_0

While the description here of pitch control interfaces with voice quality, most models of pitch control assume modal voicing. Pitch perturbation effects may be related to aerodynamic changes resulting from adjustments in glottal width or vocal fold mass changes induced by laryngeal height movement (or ventricular incursion). As the model we have described here does not assume variability in glottal width or in a number of other possible laryngeal parameters, we must describe voice quality separately.

6.5.3 The Phonetics of Voice Quality

Edmondson and Esling (2006) divide the articulators involved in the production of voice quality into a set of six valves: glottal vocal-fold adduction, ventricular incursion, upward and forward sphincteric compression of the arytenoids via the thyroarytenoid muscles, epiglotto-pharyngeal constriction, the valve created via upward motion of the larynx, and pharyngeal narrowing. The set of articulators used to produce a distinct voice quality varies according to both the language and the speaker. The authors state that characteristic "tense" or "pressed" phonation is produced by bracing the vocal folds against the ventricular folds (ventricular incursion) with a sphincteric compression of the arytenoids. In languages like Dinka Bor, speakers also use pharyngeal narrowing during their production of this voice quality. However, this articulation is not found in all languages described as having tense phonation.

In this way, distinct phonation types are similar to other phonological contrasts which differ in articulatory detail. The target low F2 in the vowel /u/ may require a large degree of lingual retraction and less lip-rounding in one language and more lip-rounding with less lingual retraction in another. Yet, both articulations produce a similar acoustic consequence.

This particular perspective on phonation type differs in many ways from models which assume that phonation type falls along a continuum defined solely by the aperture between the arytenoid cartilages, i.e. Gordon and Ladefoged (2001). Such models do not adequately capture the activity of the other valves utilized in the production of particular phonation types. The necessity to revise them has been prompted mainly through advances in technology that have permitted detailed laryngoscopic investigations of the human larynx in various languages (Esling et al., 1998; Esling, 1999; Edmondson et al., 2001, 2004; Carlson and Esling, 2004; Esling, 2005; Edmondson and Esling, 2006). Such studies have demonstrated the importance of both the supraglottal cavity and larynx in the production of phonation type.

While there are a number of possible laryngeal configurations, linguistically constrastive phonation types fall within fewer categories : modal voice, creaky voice, tense (harsh) voice, breathy voice, lax voice, epiglottalized voice, and faucal voice. I will define the relevant phonation types investigated in this study in terms of their articulatory configuration.

Modal phonation is characterized by neither broadband spectral energy in the upper harmonics nor irregular vocal fold vibration where the arytenoid cartilages are neither pulled apart nor pushed together (Ní Chasaide and Gobl, 1997; Ladefoged and Maddieson, 1996). During the production of modal phonation, there is moderate adductive tension and medial compression of the vocal folds (Laver, 1991). There is adequate subglottal pressure present to overcome vocal fold impedance. As a result, sustained voicing with regular periodicity characterizes this phonation type.

Both lax and breathy phonation involve an increase in the aperture between the vocal folds, such that the posterior portion to the midline of one vocal fold never comes in contact with the other fold (Laver, 1991; Pennington, 2005). The vocal folds have minimal adductive tension, weak medial compression, and little longitudinal tension (ibid). In both Bor Dinka (Nilo-Saharan) and Bai (Sino-Tibetan), breathy phonation occurs with laryngeal lowering (Edmondson and Esling, 2006). In Bai, this lowering is accompanied by tongue advancement. What distinguishes lax from breathy phonation though is the *degree* of vocal fold tension and the amount of aperiodic noise that dominates the upper spectrum. Breathy phonation contains substantial broadband spectral energy that arises due to greater vocal fold aperture. Lax phonation does not contain substantial high amplitude noise components (Pennington, 2005).

A consequence of the laryngeal lowering found in breathy phonation is pitch lowering. This is accomplished via the sternothyroid muscle which acts antagonistically to the CT. Cross-linguistically, breathy phonation patterns with lower pitch and has resulted in the genesis of low tones in many languages. This is the described pattern of tonogenesis in Vietnamese, for instance.

Creaky and tense phonation are similar in that both involve decreased aperture between the vocal folds. The vocal folds are mostly closed for this phonation type, vibrating mainly at the ligamental portion between the arytenoids. Both phonation types are characterized with increased adductive tension and medial compression (Ní Chasaide and Gobl, 1997). While tense phonation is characterized with mostly periodic vocal fold vibration, creaky phonation contains substantial frequency modulation (jitter) and amplitude modulation (shimmer) (Childers and Lee, 1991; Blomgren et al., 1998; Pennington, 2005).

A key articulatory difference between these two phonation types is larynx height and ventricular incursion. In many cases, tense voice is produced with a raised larynx position while creaky voice is produced with the larynx in a lower position. In Bai, Bor

Dinka, Chong, and Somali, for instance, the tense vocal register is produced with laryngeal raising (Edmondson et al., 2001; Tumtavitikul, 2004; Esling, 2005; Edmondson and Esling, 2006). Tense voice is also produced with a lowering of the ventricular vocal folds. Ventricular incursion produces contact between their inferior surfaces and the superior surfaces of the true vocal folds. Normally, such an articulation would result in a compressed and thick structure that would inhibit voicing (Laver, 1991). However, the increased stiffness of the vocal folds during tense voice allows voicing to be maintained.[8]

6.5.4 Laryngeals and Pitch

Just as the CT and TA muscles interact to produce changes in F_0 during vocal fold vibration, changes in vocal fold tension and glottal width interact in their effect on pitch. Phonation types have distinct pitch effects depending on the set of laryngeal gestures which produce them. The same is true of /h/ and /ʔ/, the two relevant articulations for our investigation of Itunyoso Trique. I include a discussion of phonation type here as it is relevant to the coarticulatory effects observed in the production of /h/ and /ʔ/.

6.5.4.1 Breathiness and /h/

As a starting point, we must distinguish between two articulations of /h/: as a voiceless glottal fricative [h] and as a voiced glottal fricative [ɦ]. The [h] variant may be produced with varying degrees of glottal spreading and glottal tension. During the production of aspirated consonants in some languages, the glottis is actively spread with the purpose of maintaining devoicing. Glottal spreading is accompanied by active tensing of the vocal folds via the CT. This gesture ensures that the vocal folds do not vibrate as there is greater impedance to flow. The added CT tension during spreading results in higher F_0 values after release (Stevens, 2000).

The [ɦ] variant is produced with glottal spreading but must be produced with slack vocal fold cover tension. Some of the transglottal airflow is lost by an opening at the posterior end of the glottis. As a result, less pressure is available to cause vibration at the anterior end (Hombert, 1979). Vibration can only be produced here with a slack

---

[8] This is apparently true regardless of the fundamental frequency of the vocal folds, as tense voice is produced with low pitch and ventricular incursion in Bor Dinka (Edmondson and Esling, 2006) and with medium or high pitch and ventricular incursion in Bai (Edmondson et al., 2001; Edmondson and Esling, 2006), Somali (Edmondson and Esling, 2006), and Chong (Tumtavitikul, 2004).

cover, which has low impedance. The result of cover slackness in the production of [ɦ] is F_0 lowering, as discussed above. If speakers normally produce voiceless variants of /h/, it will result in pitch raising. However, speakers in many languages fail to completely devoice for at least part of the pronunciation of /h/ (Ladefoged et al., 1988; Pierrehumbert and Talkin, 1992; Kirk et al., 1993; Silverman, 1997b). The result in these cases is pitch-lowering.

This phonetic description allows us to explain the multiple pitch personalities of /h/ cross-linguistically. In many cases presence of breathiness or a postvocalic /h/ causes pitch-lowering. This is synchronically true for Arabic (Hombert et al., 1979), Chong (Thongkum, 1991; DiCanio, 2007b), and a number of other languages surveyed in Esposito (2006). It is diachronically true for Vietnamese (Haudricourt, 1954; Diffloth, 1989; Thurgood, 2002), Kickapoo (Gathercole, 1983), U (Svantesson, 1989), and more recently, Kammu (Svantesson and House, 2006). Absent are cases where *breathiness* causes pitch-raising to occur. However, there are cases where the presence of a postvocalic /h/ or *aspiration* triggers pitch-raising. For instance, Longacre (1957) argues that the presence of a postvocalic /h/ conditioned a higher variant of tone /4/ in Chicahuaxtla Trique which became tone /5/. There is higher pitch after aspirated stops in Korean (Hardcastle, 1973; Dart, 1987; Jun, 1993, 1995; Cho et al., 2002) and after aspirated stops in English (Hombert, 1975), but lower pitch after aspirated stops in Mandarin (Xu and Xu, 2003). Differences in the timing of glottal spreading in these particular languages for the production of aspiration or /h/ may account for differences in pitch perturbation. This claim must be tested in a number of languages to be proven valid however.

The production of breathy phonation is similar to the [ɦ]. Edmondson and Esling (2006) remark that there is a stretching of the aryepiglottal folds during breathy phonation (in Dinka). This stretching may result from active laryngeal lowering. Tumtavitikul (2004) found that the larynx was lowered during breathy phonation for Chong speakers. In addition to this, she noted that the ventricular folds were fully sphinctered "with a slight opening at the posterior end." While the vocal fold covers are slack during the production of breathy voice, there may also be some supralaryngeal constriction involved. Lowering the larynx results in pitch-lowering. Apart from F_0 lowering induced from cover slackness, laryngeal lowering may contribute to the pitch-lowering effects observed in the production of [ɦ].

6.5.4.2 Creaky Voice, Tense Voice, and /ʔ/

The production of a glottal stop involves a marked increase in the activity of the lateral cricoarytenoid muscle in synergy with the interarytenoids (Hirose and Gay, 1972; Pennington, 2005). These two muscles produce a strong adductive tension on the vocal folds and are also active during the production of both creaky and tense phonation (though not to the same degree). However, we observe different pitch effects in the context of each of these phonation types and in the production of /ʔ/ cross-linguistically.

Kingston (2005) provides a compelling explanation. In his paper, he argues that different patterns of tonogenesis in Athabaskan languages are explainable if we consider that the /ʔ/ is produced differently. As discussed in §6.3.2, certain Athabaskan languages developed a low tone from a post-vocalic glottal stop while others developed a high tone. His argument assumes that final glottal stops produce coarticulatory glottalization on the preceding vowel, a common cross-linguistic pattern. Marked tone developed in these languages in contexts not preceding a final ejective, as glottalization is bound to the stop's release and would not have spread leftward onto the preceding vowel, following Kingston (1985, 1990). The discussion of phonation type is therefore pertinent to how tone develops.

During the production of creaky voice, only the anterior portion of the vocal fold cover vibrates due to greater adductive tension ([constricted glottis]). There is little CT activity during the production of creak. This phonation type differs from tense or pressed voice where both the CT and TA are contracted. If the vocal fold covers are slack during the production of [ʔ], the voice quality will be creaky. If they are stiff, it will be tense. As summarized in Table 6.9, we expect pitch lowering in the former case but pitch raising in the latter.[9]

There are, however, other routes by which tone may develop in the context of creaky phonation that Kingston (2005) mentions. The asynchronization of vocal fold vibration during constriction may cause two different acoustic consequences. On the one hand, if one vocal fold vibrates with substantially greater amplitude than the other, speakers will judge pitch based on the duration between these high amplitude periods. This effectively cuts the F_0 in half and would lower the perception of pitch. On the other hand, if both vocal

---

[9] These details in the production of /ʔ/ may reflect areal tendencies. Leer (1999) finds that the creaky coarticulation of a glottal stop is more common among Athabaskan languages than the tense coarticulation variant. This is distinct from the pattern in Southeast Asia where a /ʔ/ almost always is realized with tense phonation and pitch-raising (Matisoff, 1973).

folds vibrate out-of-phase with high amplitude, then speakers will hear doubled or tripled F_0, inducing the perception of pitch-raising. This particular explanation of tonogenesis is problematic however. In many languages speakers are quite systematic in whether they produce a /ʔ/ with pitch lowering or raising. Speakers do not have muscular or neural control over individual vocal folds during vibration (as it is aerodynamically controlled). It is more likely that the control of the CT during glottal stop production was a controlled process that led to tonogenesis than the perspective where speakers more often perceived pitch-doubling or halving leading to tonogenesis.

A glottal stop may also be produced in a condition where there is low subglottal pressure but moderate adductive tension and TA contraction. Such environments of low subglottal pressure are usually associated with a marked lowering in pitch (Hombert, 1979). While it is useful to consider the articulation involved in the production of these laryngeals, their association with pitch may also be based on the aerodynamic context.

6.6 Discussion

There is a substantial effect of laryngeals on pitch and tone in the world's languages. Diachronic patterns of tonogenesis and tonomutation arise from laryngeals. Synchronic patterns where certain tone and laryngeals are restricted from co-occurring, as we have observed in Trique, may have laryngeally-induced pitch perturbation effects as their cause.

The phonological approaches discussed in §6.4 make specific predictions as to how tone and laryngeal features are represented in Itunyoso Trique. As we determined in Chapter 5, Itunyoso Trique has tonal registers. Approaches associating tonal register to laryngeal features predict that lower tones will cross-linguistically be produced with a more lax or breathy phonation type. As Trique has a large tone inventory, the timing of laryngeal consonants is also predicted to be sequenced so as to avoid potential listener misperception (Silverman, 1997a,b). Both the tonal register prediction and the tone-laryngeal phasing prediction are explicitly tested in the following chapter where I analyze the timing of laryngeal consonants and their pitch effects on Trique words.

Apart from addressing these theoretical topics, the phonetic investigation describes the nature of coarticulatory pitch effects in a complex tone language. While much is known cross-linguistically of how laryngeals affect pitch, the previous work is limited to languages without any tonal contrasts or with very few.[10] This study serves the secondary purpose of examining whether the degree of coarticulatory pitch effects is constrained in a language with a large tone inventory.

---

[10] One recent exception is Francis et al. (2006).

Chapter 7

The Phonetics of Tone-Laryngeal Patterning

7.1 Introduction

In this chapter I examine the phonetic aspects of tones and laryngeals in Itunyoso Trique. There are three major goals to this work. First, I will examine how voice quality differences are implemented within the tonal register system. This investigation will focus on differences between the different tones when produced on open syllables. Second, I will examine how laryngeally-induced pitch perturbations are implemented, both in terms of magnitude and duration. These pitch perturbations are compared to data showing changes in spectral tilt as vowels become more breathy or more glottalized. This latter study is relevant to the discussion of tone-laryngeal phasing described in the previous chapter. It also is relevant to our general phonetic understanding of how changes in spectral tilt correlate with pitch when they vary as a function of tone and phonation type.

Investigating voice quality differences in the register system, I observe tone /2/ to be implemented with greater glottal tension (lower H1-H2, H1-A3 values) than higher register tones and tone /1/. This finding is at odds with predictions from work on tonal register (Duanmu, 2000) which predicts that lower register tones are obligatorily [+slack]. Investigating changes in spectral tilt and laryngeally-induced pitch perturbations, I observe that coda /ʔ/ is regularly implemented with abrupt glottal closure which causes preceding vowel shortening and pitch-lowering. Coda /h/ is regularly implemented as increasing breathiness across the vowel duration. Despite the large degree of breathiness on these vowels, the pitch on lower tones is unaffected while the pitch on higher tones is perturbed, although only once breathiness has increased substantially. A large degree of variability in breathiness is permissible without substantial pitch effects. These findings argue against proposals that gradual phasing of nonmodal phonation causes pitch perturbation (Silverman, 1997b,a). However, the findings accord well with the body-cover model of F_0 control (Titze, 1994). The asymmetries in pitch perturbation effect arise due to the asymmetrical nature of how TA contraction affects F_0 within a speaker's pitch range.

This chapter is organized as follows: In §7.2, I describe the measures used in the analysis of phonation type. In §7.3, I describe the methods used in this chapter for the investigation of pitch and phonation type. In §7.4, I briefly describe the durational differences among the different tones in open syllables and between open syllables and closed syllables. In §7.5, I examine pitch differences between tones in different laryngeal contexts and among tones within each laryngeal context. In §7.6, I examine spectral tilt differences between tones in different laryngeal contexts and among tones within each laryngeal context. I summarize these results in §7.6.4 and discuss them in §7.7.

7.2 Measures

7.2.1 Acoustic Measures

Apart from examining the glottal source directly, a number of acoustic measures are correlates of phonation type (Ladefoged et al., 1988; Ní Chasaide and Gobl, 1997; Pennington, 2005; Kreiman et al., 2007). An examination of power spectra often reveals differences between phonation types. The theory behind this method is that the increased closing velocity of the vocal folds that occurs with greater adductive tension (as found in tense or creaky phonation) causes an excitation of higher harmonics. Slower vocal fold closure which occurs with less adductive vocal fold tension (as found in breathy phonation) does not excite the upper harmonics and causes a lowering of the harmonics' amplitude (Ladefoged et al., 1988; Ní Chasaide and Gobl, 1997; Pennington, 2005). Thus, one measures the amplitude of higher harmonics to see, albeit indirectly, how stiff the vocal folds are during their vibration.

Spectral tilt measures can be divided into those which compare low-range, mid-range, and high-range regions of the spectrum. Low range measures like H1-H2 have a close correlation to OQ values and are therefore good measures of the degree of glottal tension present in different phonation types (Stevens and Hanson, 1995; Holmberg et al., 1995; Sundberg et al., 1999). H1-H2 successfully distinguishes modal from breathy (and creaky) phonation in a variety of languages, e.g. !Xóõ (Traill and Jackson, 1987), Gujarati (Fischer-Jørgensen, 1967; Pennington, 2005), Tsonga (Ladefoged and Antoñanzas Barroso, 1985), Wa (Watkins, 2002), Jalapa Mazatec (Blankenship, 2002; Pennington, 2005), Chanthaburi Khmer (Wayland and Jongman, 2003), and Fuzhou, Green Hmong, White Hmong, Santa Ana del Valle Zapotec, San Lucas Quiaviní Zapotec, and Tlacolula Zapotec (Esposito, 2006). Ladefoged and Maddieson (1985) mention that H1-H2 values were greater for lax syllables[1] than for tense syllables in Jingpho, Hani, Yi, and Wa.

Kreiman et al. (2007) examined 78 different spectral measures of voice quality within a principal components analysis where the first factor accounting for the most variance between different glottal wave shapes corresponded to H1-H2. While substantial evidence supports the use of this measure in distinguishing certain phonation types, both Blankenship (2002) and (Esposito, 2006) report that it does not distinguish the breathy from modal register in Chong, Mon, and Tamang. Mid range spectal tilt measures do however.

Mid range measures of spectral tilt include H1-A1, H1-A2, H1-A3, and A1-A3. Each of these measures involve a calculation of the amplitude of the different formants, i.e. A1 = amplitude of F1, A2 = amplitude of F2, etc. Accordingly, changes in vowel quality will alter formant frequency and thus indirectly, formant amplitude. Since radiation impedance is approximately proportional to frequency, the wide-band spectral slope is approximately -6 dB/octave for modal phonation (Klatt, 1980; Pennington, 2005). Shifts in the center formant frequency due to vowel quality changes will affect these measures. So, given a vowel [i] with a high F2 frequency value and a vowel [u] with a low F2 frequency value, the H1-A2 calculation for these vowels will be substantially different even if phonation type parameters remain constant. This has caused some researchers to question the validity of using mid range measures of spectral tilt. However, such measures have been used to reliably distinguish phonation type in a variety of languages. (Esposito, 2006) shows that H1-A1, H1-A2, and H1-A3 distinguish breathy from modal phonation in a variety of languages, concluding that the most successful measure of spectral tilt is H1-A3. Blankenship (2002) found that H1-A2 and H1-A3 distinguished creaky and modal phonation type in Jalapa

---

[1] The authors are specifically referring to a lax *laryngeal* setting here.

Mazatec but these same measures did poorly distinguishing breathy from modal voice. Yet, Traill and Jackson (1987) found that H1-A2 is a strong correlate that distinguishes the same phonation types in Tsonga. The acoustic importance of mid range spectral tilt measures seems to be dependent on both particular languages and particular phonation types.

Among the other relevant measures of phonation type are jitter (frequency modulation), shimmer (amplitude modulation), and HNR (harmonics to noise ratio). These particular measures were not used in this study due to the nature of the recording context which contained some background noise. For an comprehensive overview of the various acoustic measures used in the analysis of voice quality, see Pennington (2005).

7.3 Method

7.3.1 Stimuli

The stimuli for this experiment consisted of 82 monosyllabic and disyllabic words contrasting for both tone and final laryngeal. Between 3-5 words were examined per tone-laryngeal context, e.g. 3-5 words with tone /3/ and a coda /h/. There were 38 words with final open syllables, 9 with a final syllable coda /ʔ/, and 35 with a final syllable coda /h/. The differences in the number of stimuli for each context partly reflect the way stimuli were collected during fieldwork, but are also a consequence of each context having fewer contrastive tones. Only 4 tones are contrastive before a coda /ʔ/ while 7 are contrastive in open syllables or before a coda /h/.

Certain stimuli had to be discarded from the coda /ʔ/ context as not all speakers were familiar with the elicited word. Furthermore, upon further investigation, the elicited tokens in the tone /4/ + coda /ʔ/ context were mislabelled examples of tone /3/ + coda /ʔ/. Thus, no examples from the former context were examined.[2] There are also fewer stimuli overall that have a coda /ʔ/ than have a coda /h/ or final open syllable.

Final syllable rimes from words in natural carrier sentences were examined. Given the nature of the fieldwork context, it was preferable to provide natural contexts for each of the words rather than unnatural contexts like "Say ___ again." Therefore, some of the carrier sentences differed. Most of the stimuli were nouns, which appeared in the carrier

---

[2] Tone /4/ is contrastive in this context. One of the pitfalls of collecting a variety of contexts where many tones contrast is mistakes like this.

sentence /ni^{4} ʔya^{43} ___ nã^{3}/, see.1sg ___ here, *I see* ___ *here.* The contexts used for adjectives or verbs varied, but the phonological context surrounding the target word did not. The word preceding the adjective or verb target had the vowel /i/ realized with tone /43/. The word following the target word began with the nasal /n/ and had tone level /3/. The adjacent tones were kept consistent to control for any possible coarticulatory pitch effects. With the exception of the change of vowel in these contexts, the phonological environment surrounding all tokens was kept consistent. Each carrier sentence was repeated 6 times for a total of 492 word repetitions per subject. Sentences produced with disfluencies were discarded and not analyzed.

7.3.2 Speakers & Data Collection

Eight speakers were recruited for the investigations, 4 female, 4 male. Six speakers were between the ages of 18 - 26. One male speaker, (C), was 35 years old at the time of recording. Another female speaker, (G), was 56 years old. All participants were native, fluent speakers of Itunyoso Trique who were raised in San Martín Itunyoso. No participant reported having a history of speech or hearing disorders. Upon examining the data, two speakers' recordings were eliminated (G and R). The recordings of these speakers had exceptionally low amplitude and contained substantial background noise (rain on a corrugated roof). Only 6 of the original 8 speakers' data was used.

For 7 of the speakers, recording took place in a quiet room in a house located in San Martín Itunyoso in Oaxaca, Mexico. The remaining speaker was recorded in his home in the central valley of California, USA. Upon reading a consent form in Spanish, speakers supplied their verbal consent to participate in the acoustic investigation. Speakers who did not understand aspects of the investigation discussed their concerns with the author's primary consultant who acted as an interpreter. The stimuli were read aloud in Trique by either the author or his consultant as a prompt for the participant.

Four subjects, 3 male (Speakers B, C, J) and 1 female (Speaker M) participated in the electroglottographic study. This study had a separate consent form that required written consent of the speaker. The data was collected at the same time as the acoustic data. In all statistical tests, a repeated measures design was used with Speaker as a factor. This method ensured that the observed data reflected effects common to all or most speakers who were recorded (Johnson, 2008).

Participants spoke into a uni-directional dynamic hand-held microphone that was maintained at a comfortable distance by the author. Recordings were made directly onto the author's Apple iBook G4 computer using an M-Audio MobilePre®USB preamplifier as an audio interface. Electroglottographic (EGG) data was acquired using a Laryngograph model portable electroglottograph concurrently with the acoustic recordings. Praat version 4.6 (Boersma and Weenink, 2008) was used to record all data. All data was sampled at 44.1 kHz.

7.3.3 Measures

7.3.3.1 Acoustic Analysis

Three separate Praat scripts were written to extract duration, pitch, and spectral tilt measures in word-final syllables. Individual sound files were hand-labelled in associated textgrid files. The pitch script extracted pitch contours from labelled durations where 10 pitch values were taken at equal intervals across the rime duration. The pitch range was set to 75-300 Hz. for male speakers but 75-400 Hz. for female speakers. The extracted data was analyzed using R (2007).

The spectral tilt script downsampled sound files to 16 kHz before analysis. It extracted F0, H1-H2, and H1-A3 measures at 10 even time indices along the duration of each vowel along with its total duration. Spectral tilt was acquired by first calculating the position of F2 and F3 with an LPC analysis. Maximum amplitude peaks were then extracted from ranges in a power spectrum within 10% of the frequency of a particular formant, i.e. if F3 = 2500 Hz., peak maxima were extracted from the 2250-2750 Hz. range. The amplitude value of the highest amplitude harmonic within these ranges corresponds to A3. Two sets of formant reference values were used depending on the speaker's gender. For males, these reference values were F1 500 Hz., F2 1485 Hz., and F3 2475 Hz. For females the values were F1 550 Hz., F2 1650 Hz., and F3 2750 Hz. H1 and H2 were determined by taking the highest amplitude peak to within 10% of the fundamental and twice the fundamental, respectively. Data from all subjects were grouped together and statistically analyzed using R (2007).

Onset consonants varied among the different tone-laryngeal contexts. To control for any onset-related effects on spectral tilt or F_0, pitch, H1-H2, and H1-A3 values within the first 10% of the vowel duration were excluded from analysis. This was similarly done for the final 10% of the rime duration where devoicing in coda /Vh/ contexts prohibited these measures. Spectral tilt and pitch were only measured for the first 40% of the /Vʔ/ rime duration as substantial creak and jitter characterized the latter half of this rime. Two mechanisms adjusted for accuracy in pitch-estimation in these cases. First, the voicing threshold was set to 0.55, which prevented pitch values from being calculated during substantial jitter. Second, the pitch data was visually inspected. Pitch-doubled or pitch-halved outliers were removed.

7.4 Duration

A number of factors may influence duration in a tone language. Cross-linguistically, contour tones are longer than level tones (Zhang, 2001; Gordon, 2001; Zhang, 2004). Vowel duration is also longer in monosyllabic words than in disyllabic ones (Lehiste, 1970). I examined the duration of the rimes on the different tones in Itunyoso Trique. The rimes with laryngeal codas were realized with gradually increasing glottalization or breathiness in the language. As a result, no boundary was placed between the more modal portion of the vowel and the more breathy or creaky portion. The rime duration here includes both the vowel and the laryngeal in these cases.

Since the contrastive tones differ under each laryngeal context, the factor "Laryngeal" must be separated in a model comparing the effect of tone on duration. Four separate repeated measure analyses of variance were performed. In the first model, Laryngeal and Word Size (monosyllable vs. disyllable) were considered as factors without the effect of tone. Since no attempt was made to control for word size in the different tone-laryngeal contexts, tone was used as the sole factor in a one-factor ANOVA for each laryngeal context (/VV/, /Vʔ/, /Vh/). For each of these contexts, duration on only monosyllabic words was considered as this context included more tones.

In the first model, the main factors were each significant. There was a significant effect of laryngeal context on duration ($F[2, 8] = 6.8$, $p < 0.05$ *) and of word size on duration ($F[1, 8] = 231.9$, $p < 0.05$ *). The interaction of these factors was not significant. The top values in Table 7.1 shows the durational differences as a function of word size and coda laryngeal consonant. The bottom values in Table 7.1 show the differences in rime duration as a function of rime type.

The difference between the duration of final rimes in disyllabic words and monosyllabic words is substantial: 125.9 ms. to 167.8 ms., respectively. This is a ratio difference

Table 7.1: Rime duration as a function of Word Size (top) and Rime Type (bottom)

Context	*Mean Duration (ms.)*	*St. Dev. (ms.)*
Monosyllable Rime	167.8	42.1
Final Disyllable Rime	125.9	27.0
/VV/ Rime	147.1	40.2
/Vh/ Rime	165.8	43.4
/Vʔ/ Rime	135.8	36.7

of 1:1.33. In many Mixtecan languages where the minimal word size is the bisyllabic couplet (Macaulay, 1996; Macaulay and Salmons, 1995; Macken and Salmons, 1997), words may be composed of either an onset consonant and a long (bimoraic) vowel or two monomoraic syllables where the vowels are shorter. This is not the case in Itunyoso Trique as the final syllable is always longer than non-final ones.

In these figures we observe that the context with a coda /ʔ/ had the shortest duration and the context with a coda /h/ had the longest duration. The differences between final rime duration may be specifically due to the fact that no contour tones occur in the /Vʔ/ context and the rising tones occur in the coda /h/ context. Contour have longer duration than level tones and rising tones have longer duration than falling tones.

In the /Vʔ/ context, a one factor RM-ANOVA with tone as a factor showed a significant effect of tone on duration (F[2, 10] = 9.3, $p < 0.01$**). As shown in Figure 7.1, rimes with tones /1/ and /3/ were longer than those with tone /2/. In the /VV/ context, the analysis also found tone to be strongly significant (F[6, 30] = 15.0, $p < 0.001$ ***). As shown in Figure 7.1, tones /3/, /32/, and /31/ are longer than tones /1/, /2/, /4/, and /43/ in this context. In the /Vh/ context, the analysis found tone to be strongly significant as well (F[6, 30] = 14.6, $p < 0.001$ ***). Figure 7.1 shows tones /1/ and /35/ to be the shortest and tone /3/ to be the longest in this context.

There are a few patterns in the data in Figure 7.1. In each laryngeal context, tone /3/ is longer than tone /2/. In the /VV/ and /Vh/ contexts, there is a pattern where tone /1/ is shorter than tone /2/ as well. Tone /4/ is shorter than tone /3/ in these contexts as well. Some of the contour tones are longer than level tones, but there is no general pattern. The falling tones /32/ and /31/ are relatively long but falling tone /43/ is very short. Tone /43/ only occurred in one monosyllabic word in the data, /li^{43}/ *small*, so it is unclear if its

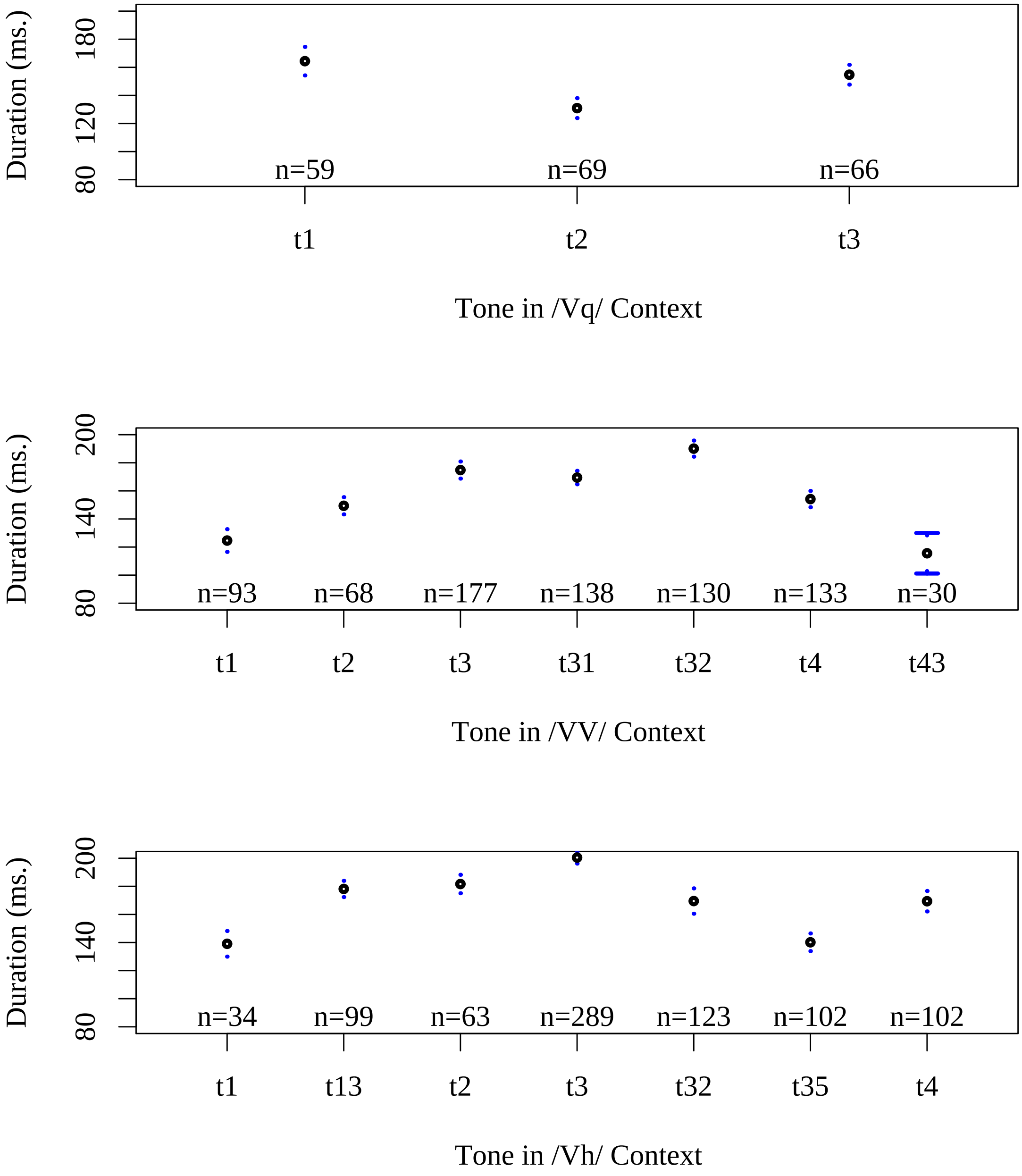


Figure 7.1: Rime duration as a function of Tone in Laryngeal Context

durational properties reflect something lexically-specific. High vowels also tend to be shorter than low vowels. Among the two rising tones, tone /13/ is relatively long while tone /35/ is short. This is unexpected given both a tendency for rising contours to be longer than falling contours. Table 7.2 shows the durational differences for all the data in Figure 7.1.

Table 7.2: Rime Duration in Monosyllables as a function of Tone

Tone	*Context*	*Mean Duration (ms.)*	*St. Dev. (ms.)*
/3/	Vʔ	154.7	28.6
/2/	Vʔ	131.0	29.5
/1/	Vʔ	164.4	39.0
/4/	VV	154.1	33.9
/3/	VV	174.8	41.0
/2/	VV	149.4	25.3
/1/	VV	124.6	39.2
/43/	VV	115.6	38.6
/32/	VV	190.0	33.0
/31/	VV	169.5	28.4
/4/	Vh	169.4	37.0
/3/	Vh	200.5	36.9
/2/	Vh	181.7	26.1
/1/	Vh	139.1	26.2
/32/	Vh	169.5	50.5
/35/	Vh	140.2	32.0
/13/	Vh	178.1	29.0

Using the data in the table above, we can rank tones in their order of decreasing duration by context. These rankings are given below:

1. **/Vʔ/ Context**: /1/ > /3/ > /2/
2. **/VV/ Context**: /32/ > /3/ > /31/ > /4/ > /2/ > /1/ > /43/
3. **/Vh/ Context**: /3/ > /2/ > /13/ > /32/, /4/ > /35/ > /1/

7.5 Pitch Analysis

7.5.1 Open Syllables

Seven tones are contrastive in open syllables: four level tones and three contour tones (/43/, /32/, /31/). Pitch contours for all of these tones are given in Figures 7.2 and 7.3. All contours are shown with confidence intervals ($p < 0.05$).

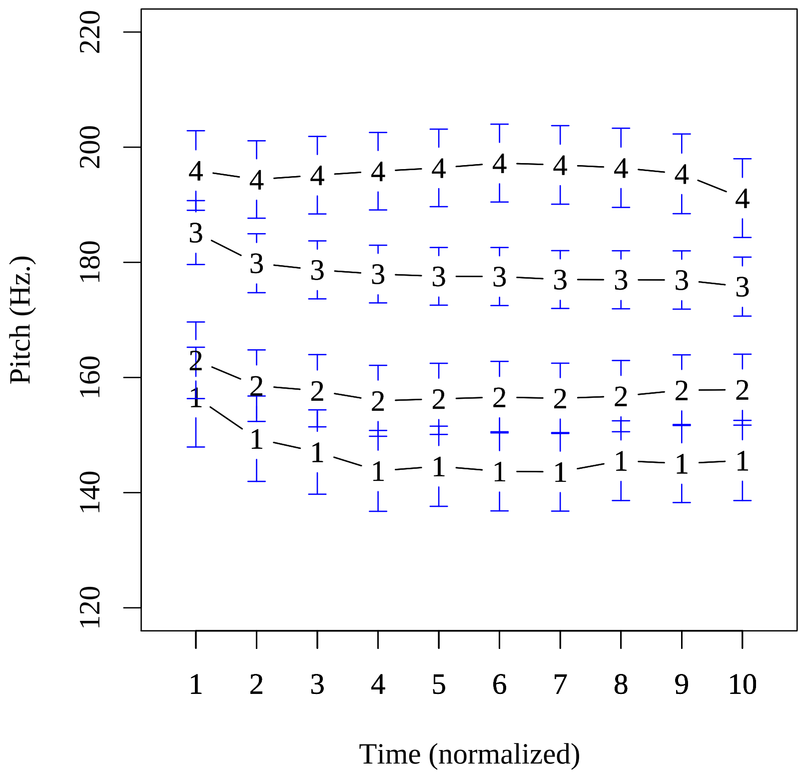


Figure 7.2: Pitch on Level Tones on Open Syllables

Phonological level tones in Itunyoso Trique are realized with no significant changes in pitch. The lowest tone, /1/, appears to fall slightly during the first 40% of the vowel duration. However, these pitch changes are not significant. Comparing the mean pitch found for this tone at time index 2 (149.4 Hz.) and time index 4 (143.8 Hz.), there are no significant differences ($t=1.08$, $p = 0.28$). The pitch differences between tones /1/ and /2/ are smaller than those between tones /2/ and /3/ or /3/ and /4/. At time index 5, tones /1/ and /2/ have only an 11.7 Hz. difference while tones /2/ and /3/ have an 21.3 Hz. difference and tones /3/ and /4/ have an 18.8 Hz. difference.

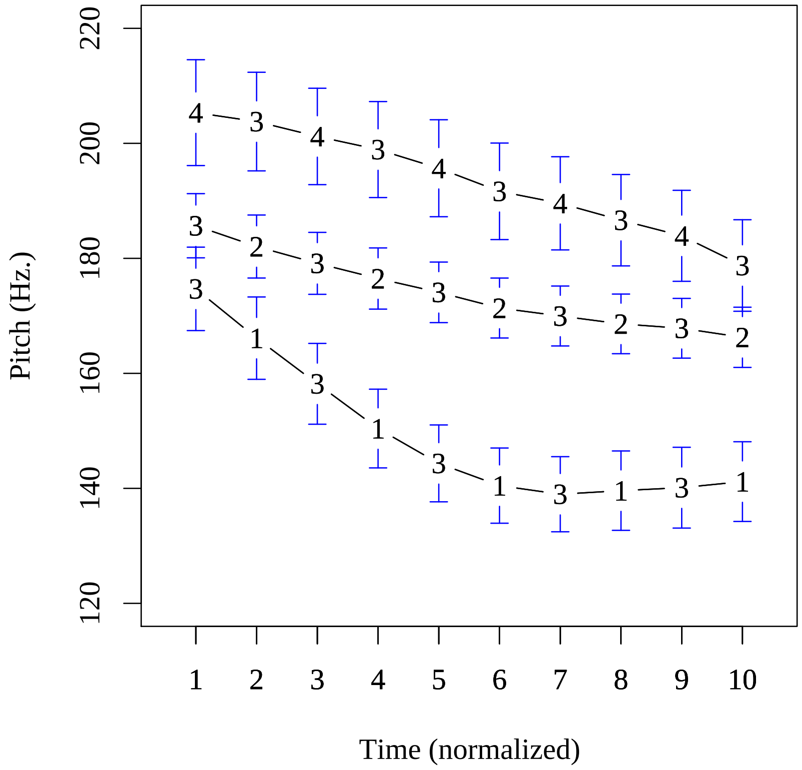


Figure 7.3: Pitch on Contour Tone on Open Syllables

The (falling) contour tones in open syllables differ in both pitch level and their degree of pitch fall. Tone /43/ begins at a higher pitch than tone /4/ does. At time index 2, the mean pitch of tone /4/ is 194.4 Hz. and the mean pitch of tone /43/ is 203.8 Hz, but this difference only approaches significance (t=-1.71, p = 0.09). Tone /32/ begins at approximately the same pitch level as tone /3/ (no significant difference). Tone /31/ begins at a pitch level between tone level /3/ and /2/. At time index 2, the mean pitch of tone /3/ is 179.8 Hz. while the mean pitch of tone /31/ is 166.1. This difference is significant (T = 3.1, $p < 0.01$ **).

Each of these falling tones differ in terms of slope. Tone /31/ has the greatest pitch change among all falling tones, followed by tones /43/ and/32/. Across the vowel duration (time index 2 to time index 9), pitch on tone /31/ falls 27.4 Hz., pitch on tone /43/ falls 21.0 Hz., and pitch on tone /32/ falls 14.3 Hz. A one-factor repeated measures ANOVA with tone as a factor found these differences to be significant ($F[2, 4] = 54.5$, $p < 0.005$ **). While pitch on tone /43/ falls to approximately the level of tone /3/, for tone /32/ it does not fall as low as the pitch on tone /2/. The average pitch at time index 9 for tone /32/ is 167.8 Hz. while it is 157.8 Hz. for tone /2/. This difference is significant ($t=-2.5$, $p < 0.05$*). For tone /31/, pitch falls lower than level tone /1/ (140.1 vs. 145.0 Hz.), but this difference is not significant.

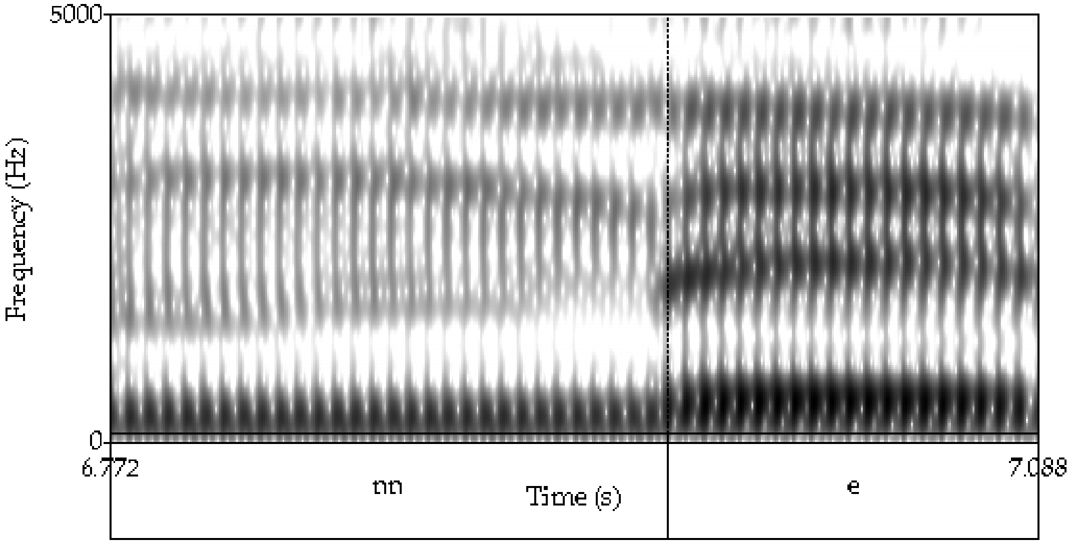
7.5.2 Coda /ʔ/ Context

Glottalization surfaces in four contexts in Trique. It occurs non-constrastively in some speakers' productions of tone /31/, which, as we just observed, surfaces with the lowest pitch of any of the tones in open syllables. Glottalization surfaces in glottalized sonorants which occur as onsets to final syllables. It also occurs intervocalically in disyllabic words like /ra^{3}ʔa^{3}/ '*hand*' or /jo^{3}ʔoh^{5}/ '*land, earth*'. In these contexts, glottalization is often realized with slight creak and a small pitch perturbations (DiCanio, 2006) and does not interact with the distribution of tone. The last context of glottalization is in word-final coda position. In these contexts, a full [ʔ] is often produced with accompanying creak on the preceding vowel. Approximately half of the /Vʔ/ duration is occupied by substantial aperiodicity and/or full glottal closure. Figure 7.4 shows the realization of a final /ʔ/ compared with an open syllable.

Since glottalization begins approximately halfway into the rime duration, pitch from only the first 40% of the rime was analyzed. Three tones which surface before a coda /ʔ/ were analyzed: /1/, /2/, and /3/. Figure 7.5 shows the pitch values for these three tones in this context. Here, A = tone /1/, B = tone /2/, and C = tone /3/. As a comparison, these tones are plotted along with the open syllable level tones described in §7.5.1.

In Figure 7.5 we observe that tones /2+ʔ/ and /1+ʔ/ are realized with lower pitch immediately after the onset consonant is released. Before the coda [ʔ], the pitch of tone level /2/ overlaps almost completely in pitch with tone level /1/ from the open syllable context. These tones are distinct in this context, but this particular case may be an example of a near merger. The pitch of tone /1/ before the [ʔ] is lower than the pitch of this tone in an open syllable. The pitch of tone /3/ is unaffected by the presence of a coda [ʔ] until time index 4, immediately prior to the coda.

A repeated measures ANOVA for pitch with tone and laryngeal context (/VV/ vs.



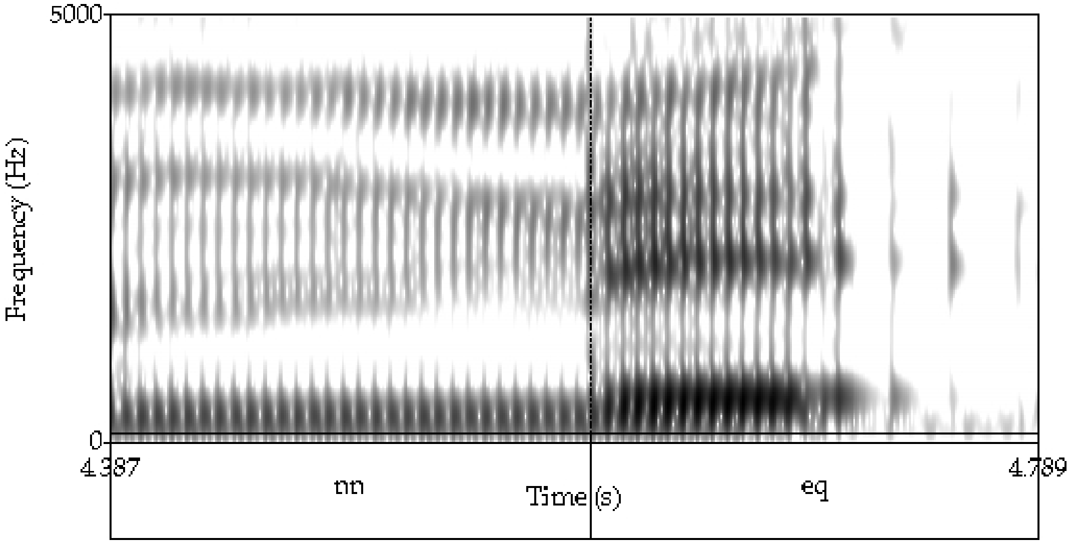


Figure 7.4: Realization of open syllable /nne^3/ *plow* (top) and /nneʔ^3/ *maguey rope* (bottom)

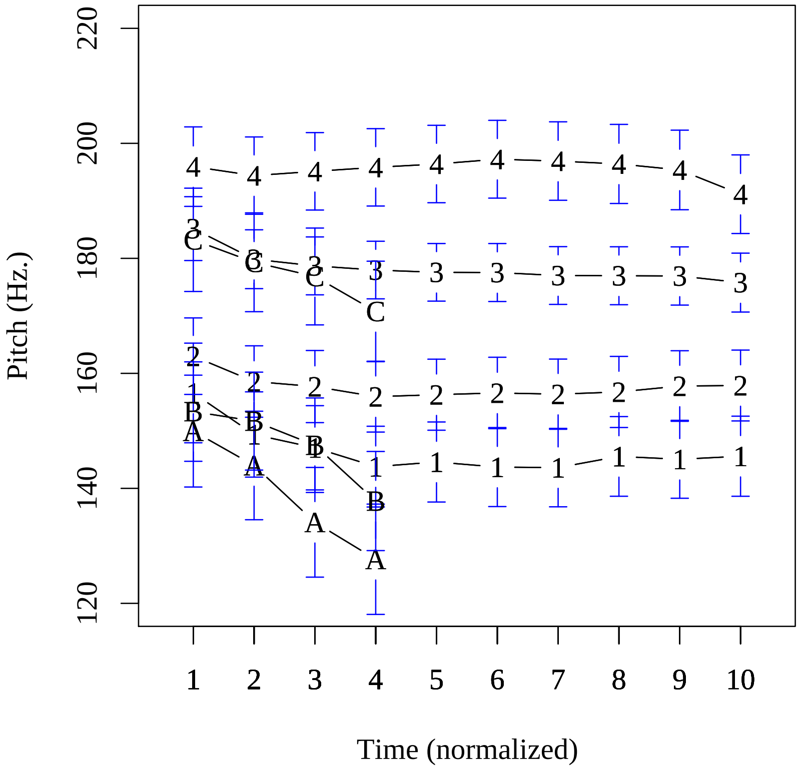


Figure 7.5: Pitch on Open Syllable Level Tones and on Syllables with a Coda /ʔ/

/Vʔ/) as factors was performed. As expected, there was a significant effect of tone on pitch for both laryngeal contexts. There was a near significant effect of laryngeal on pitch at time index 4 (F[1, 3] = 7.0, p = 0.08). At time index 3, this near effect was diminished (F[1, 3] = 3.6, p = 0.15).

The lack of significant results here may reflect a few different possibilities: greater variability in the realization of pitch prior to a coda /ʔ/, the larger data sample in the open syllable context, or the more abrupt timing (phasing) found with the coda. The first possibility is unlikely however as the standard deviation of pitch prior to the coda /ʔ/ was smaller (31-39 Hz.) than the standard deviation of pitch in open syllables (40-42 Hz.). The pitch differences between tone /1/ and /2/ in the open syllable context are comparable to those found within each of these tones for the coda /ʔ/ context. However, only the between tone differences are significant. Tone contexts /1/ and /2/ had larger sample sizes in the open syllable context (N=155, N=173, respectively) than in the coda /ʔ/ context (N=87, N=100).

A post-hoc Tukey HSD test revealed a significant effect of a coda /ʔ/ on pitch at time index 3 ($p < 0.05$ *) and time index 4 ($p < 0.001$ ***). However, within this analysis data from all subjects was pooled. Examining the pitch differences between the laryngeal contexts for tones /1/ and /2/, significant results were found at time index 3 for tone /1/ (T=-2.1, $p < 0.05$*) and for tone /2/ (T=-2.0, $p = 0.05$). Significant results were also found at time index 4 for tone /1/ (T=-2.7, $p < 0.01$ **) and for tone /2/ (T=-3.9, $p < 0.001$ ***). Even though the significance of these results is not reflected in a larger central tendency, it may be the case that coda glottalization affects the tones differently. For instance, the lower register tones are more strongly influenced than the higher register one (/3/).

7.5.3 Coda /h/ Context

Unlike the coda /ʔ/, coda /h/ is almost always produced with voicing throughout its duration. The coda is realized with devoicing only in isolated words and occassionally in the final 10% of the rime's duration in contexts. Its realization varies between substantial breathiness, e.g. [aɦ], and reduced breathiness gradually phased onto the latter half of the vowel, e.g. [aa̤]. Even though all the contexts that I tested had adjacent voiced segments, /h/ is voiced even when preceding a voiceless consonant. In a separate recording with a voiceless lenis stop /t/ following the word /tʃa^{1}kãh^{1}/ *tall.1sg*, the /Vh/ rime is almost completely voiced, as shown in Figure 7.6. The elicited sentence here was /kwãh^{3} tʃa^{1}kãh^{1} toh^{13} ri^{3}ã^{32}-sih^{3}/ (today tall.1sg little.bit face/toward-3sg.masc) *Today I am a little taller than him.*.

In the spectrogram in Figure 7.6, we observe vertical striations representing voicing extending to the boundary between the preceding word's rime and the following /t/. The signal itself contained some background noise due to the presence of a nearby wall socket. The result of this noise is a regularly repeating 60 Hz. signal throughout the data. This is visible in the spectrogram above, but the vertical striations representing voicing are clearly distinct from this noise.

The typical realization of coda /h/ is shown in Figure 7.7. In this particular example, the fortis onset consonant /ββ/ is realized with complete closure, [βb] throughout part of its duration in the word for *cave*. We observe here that voicing continues throughout

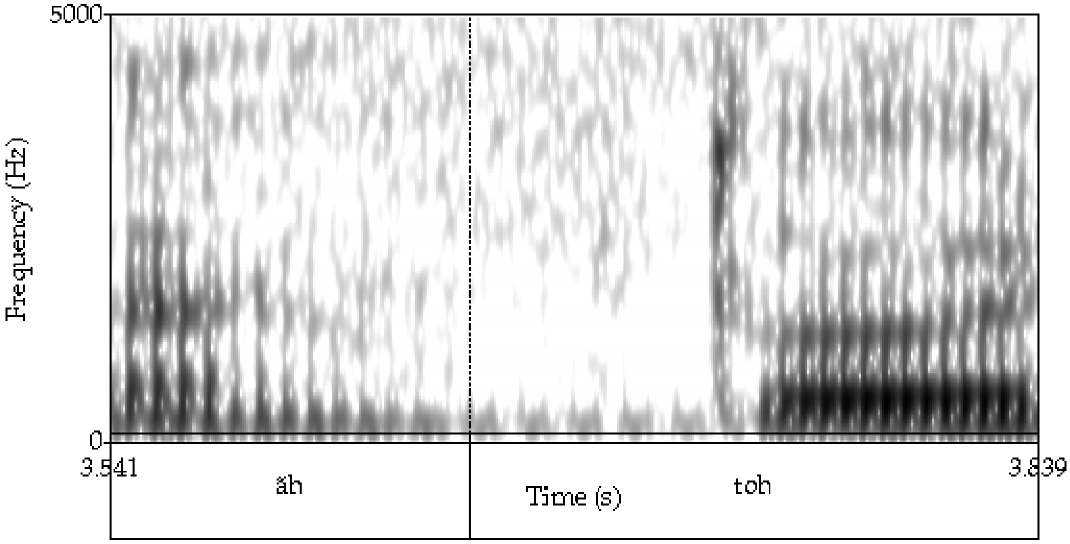


Figure 7.6: Realization of coda /h/ before voiceless stop /t/

the rime in both examples but it is attenuated in the latter 40% of the rime duration in the /ββeh^{3}/ *cave*. This is typical for the realization of coda /h/.

Figure 7.8 shows the pitch on level tones on rimes with a coda /h/ and, as a comparison, on open syllables. Here, A = tone /1/, B = tone /2/, C = tone /3/, and D = tone /4/. The presence of a coda /h/ on the rime affects pitch differently for each tone level. For tones /4/, /3/, and /2/, /h/ lowers pitch, although the time course is distinct. For tone /4/, pitch begins to fall after 40% into the rime duration. For tone /3/ and tone /2/, pitch begins to fall after 70% of the rime duration. The presence of a coda /h/ does not cause pitch lowering for tone /1/. Surprisingly, the presence of a coda /h/ causes pitch raising as well. For tones /4h/ and /2h/, pitch is higher after the release of the onset consonant than for tone /4/ or /2/ in open syllables.

Five tones occurred in the context of both open syllables and a coda /h/: /1/, /2/, /3/, /4/, /32/. A repeated measures ANOVA on pitch with tone and laryngeal as the main factors was performed. As we are interested in the effect of the coda /h/ on individual tones, the interaction between these two factors was considered. A near significant tone X laryngeal interaction was found at time index 2 ($F[4, 20] = 2.4$, $p = 0.09$) and at time index 7 ($F[4, 20] = 2.7$, $p = 0.06$. Significant interactions were found at time index 8 ($F[4, 20] = 5.4$, $p < 0.005$ **) and time index 9 ($F[4, 18] = 6.5$, $p < 0.005$ **). The lack of a significant result earlier in the rime here is a result of how early the coda /h/ affected pitch in the tonal contexts. For higher tones, the pitch lowering occurred earlier in the rime. For lower tones, it was later or nonexistent.

A post-hoc Tukey HSD test revealed no significant differences in pitch as a function of laryngeal consonant at time index 7 or time index 8. At time index 9, there was a significant difference in the pitch of tone /4/ vs. /4h/ and /32/ vs. /32h/. There is a general lowering pitch effect of the coda /h/ for all tones but fewer significant differences when comparing individual tones. Figure 7.9 shows the pitch differences between tone /32/ and /32h/. Similar to tones /3/ and /2/, the coda [h] induces pitch perturbations beginning at time index 7.

The two rising tones in Itunyoso Trique only surface in the context of a coda /h/ laryngeal. The pitch values for these tones are shown in Figure 7.10. Similar to the tones before coda /h/ shown in Figure 7.8, for tone /35h/ pitch begins to fall on the rising tone at after time index 7. This pitch declination is not observed for tone /13/. Tone /35/ begins at a pitch level near that found for tone level /4/ and rises throughout the rime. Tone /13h/

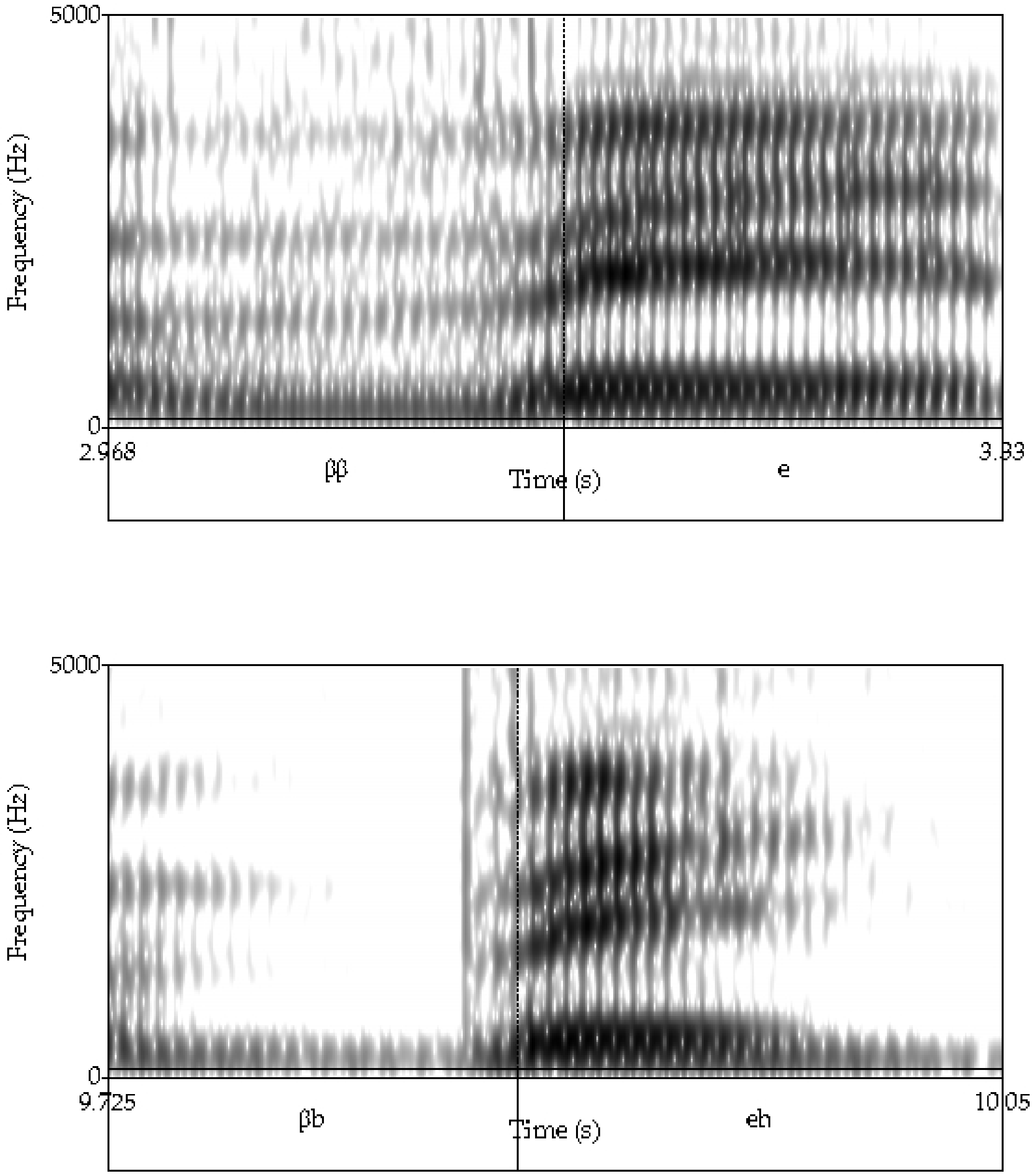


Figure 7.7: Realization of open syllable /ββe^{32}/ *maguey cactus* (top) and /ββeh^{3}/ *cave* (bottom)

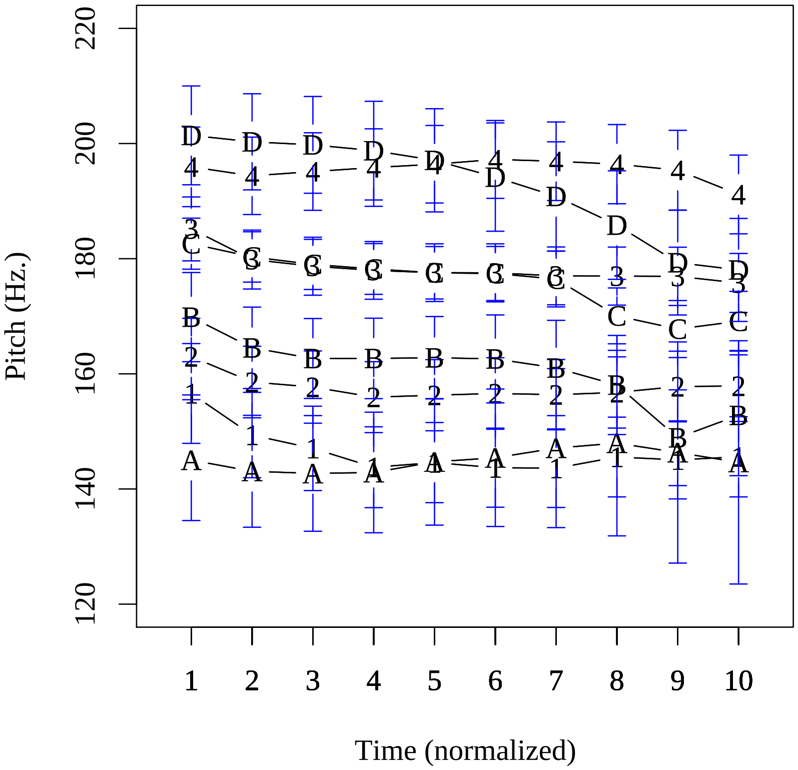


Figure 7.8: Pitch on Open Syllable Level Tones and on Syllables with a Coda /h/

begins at a pitch level slightly higher than tone /1/ and rises to approximately the level of tone /3/. Comparing the change in pitch between time indices 7 and 2 for each of the rising tones, tone /35h/ rises 23.7 Hz. and tone /13h/ rises 20.2 Hz. This difference is not significant though.

7.6 Spectral Tilt Analysis

I examined the timing of phonation type for all rime types using two measures of spectral tilt: H1-H2 and H1-A3. The first hypothesis I investigated was that tones with lower pitch are produced with steeper spectral tilt values corresponding to increased breathiness. The second hypothesis I investigated was that the timing of non-modal phonation corresponds to the pitch perturbations observed in §7.5. I examined three rime contexts: /VV/,

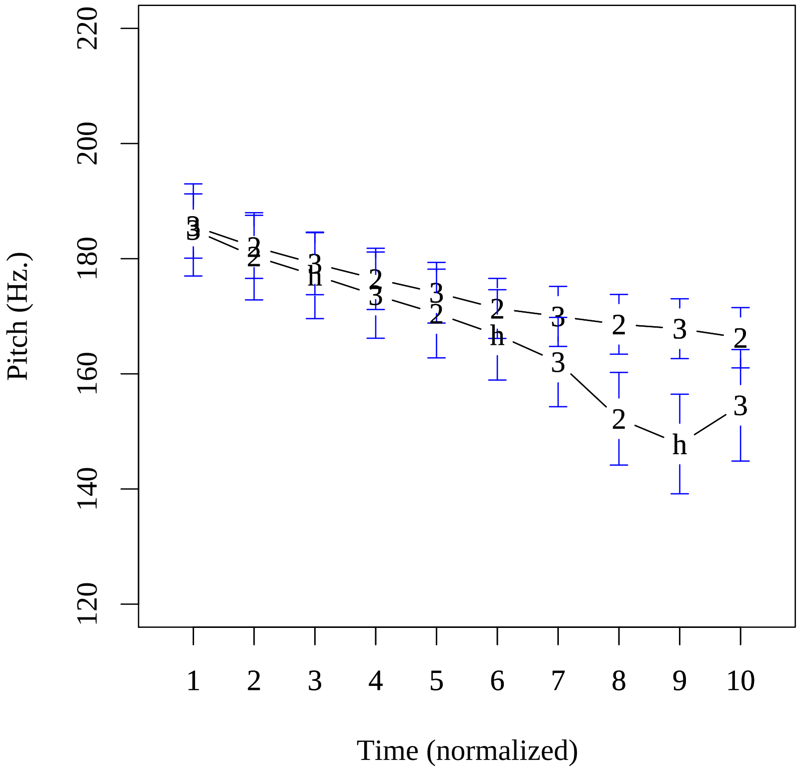


Figure 7.9: Pitch on Tone /32/ in open syllables and with a coda /h/

/Vʔ/, and /Vh/. I evaluated the first hypothesis by examining the *within* context differences among tones. I evaluated the second by examining the *between* context differences.

7.6.1 Open Syllables

H1-H2 values for tones in open syllables are shown in Figures 7.11 and 7.12. A repeated measures ANOVA on H1-H2 with Tone as a factor showed a significant effect for the first three time indices (t2-t4, F[6, 30] = 3.29, 4.25, 3.11, $p < 0.05$ *) and at the last time index (t9, F[6, 30] = 3.51, $p < 0.01$*). A post-hoc Tukey HSD test showed that the main differences were observed between tones /43/, /32/, and /2/ compared with all others (e.g. no significant differences between tones /1/ and /3/).

In Figures 7.11 and 7.12, a higher H1-H2 value indicates decreased vocal fold stiffness while a lower value indicates increased vocal fold stiffness. We observe substantial

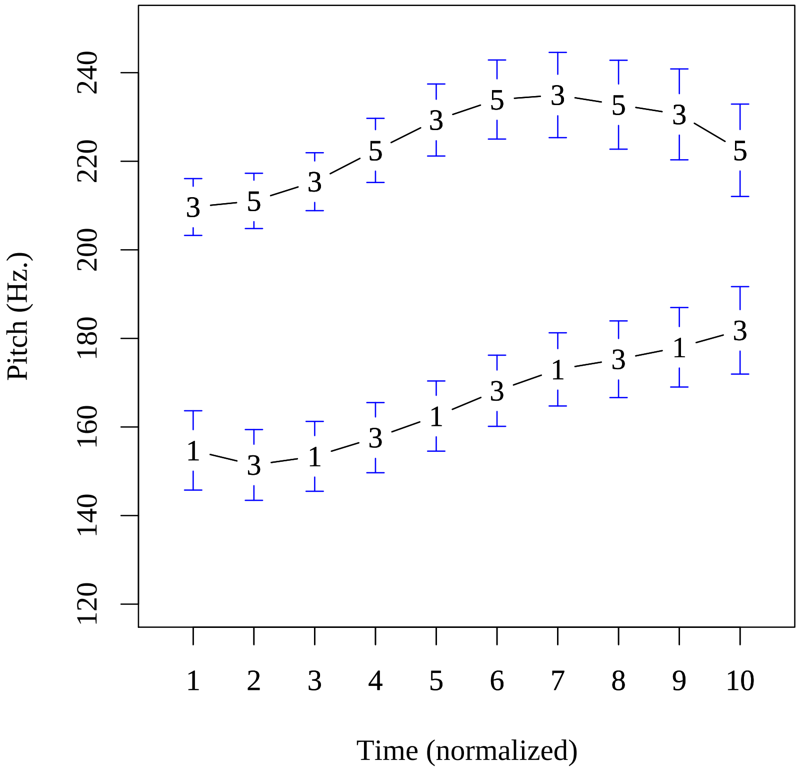


Figure 7.10: Pitch on Rising Tones

overlap in H1-H2 values for tones /1/, /3/, and /4/. For this measure, each of these tones was produced with little difference in spectral tilt. Tone /2/ was produced with a lower H1-H2 value than the other level tones as reflected in the post-hoc results. Tones /32/ and /4/ (and to a lesser degree /2/ and /31/) were produced with a lower H1-H2 value at the beginning of the vowel's duration which decreased throughout the vowel. The differences in H1-H2 spectral tilt among the tones in open syllables do not correspond to their pitch level. While tone /43/ does not show much change in H1-H2 throughout its duration, falling tones /32/ and /31/ have slightly raising H1-H2 values throughout their duration.

H1-A3 values for tones in open syllables are shown in Figures 7.13 and 7.14. A repeated measures ANOVA on H1-A3 with tone as a factor showed strongly significant results at every time index except t9 (t2: F[6, 30] = 7.2, $p < 0.001$***, t3: F[6, 30] = 8.2, $p < 0.001$ ***, t4: F[6, 30] = 9.1, $p < 0.001$ ***, t5: F[6, 30] = 4.6, $p < 0.005$ **, t6: F[6,

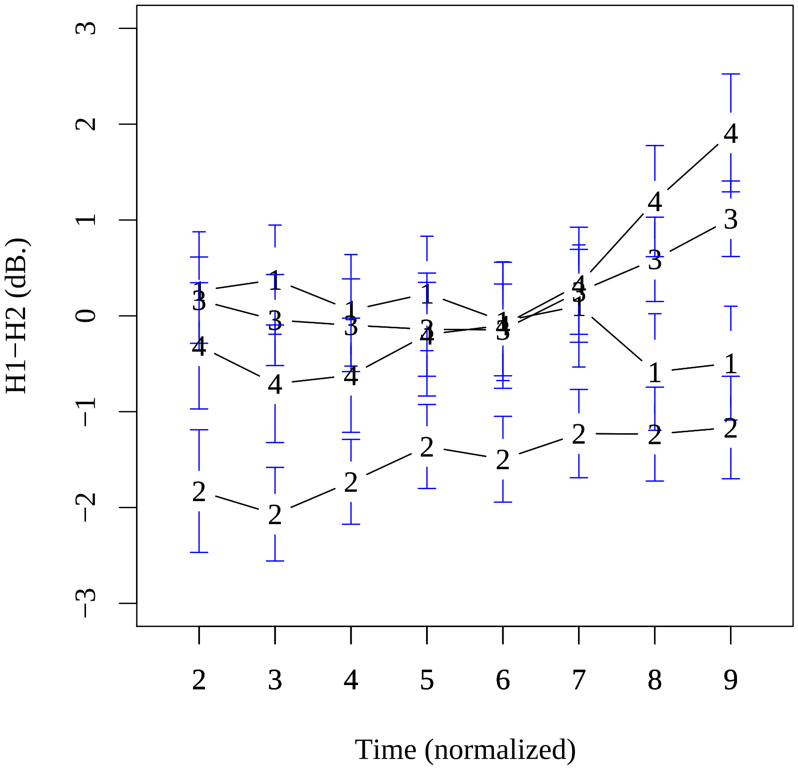


Figure 7.11: H1-H2 on Level Tones on Open Syllables

30] = 6.5, $p < 0.001$ ***, t7: F[6, 30] = 5.7, $p < 0.005$ **, t8: F[6, 30] = 4.8, $p < 0.005$ **). A post-hoc Tukey HSD test showed that, for every time index, the spectral tilt of tones /1/ and /43/ was different from all other tones.

The significant findings here are attributed to two patterns. First, tone /1/ is produced with a high H1-A3 value. Second, all falling tones are produced with H1-A3 values lower than found with the level tones. For tones /32/ and /31/, these values increase across the rime duration. This change is significant for tone /32/ (T=-4.9, $p < 0.001$ ***) and for tone /31/ (T=-2.4, $p < 0.05$ *) although the change in H1-A3 is only 2-3 dB between t2 and t9.

The *degree* of change in H1-A3 for contour tones was not significantly different than the change in H1-A3 for level tones. Indeed, H1-A3 values increased for tone /2/ with a similar magnitude as for the falling tones. A repeated measures ANOVA on Δ_{T2-T9}(H1-

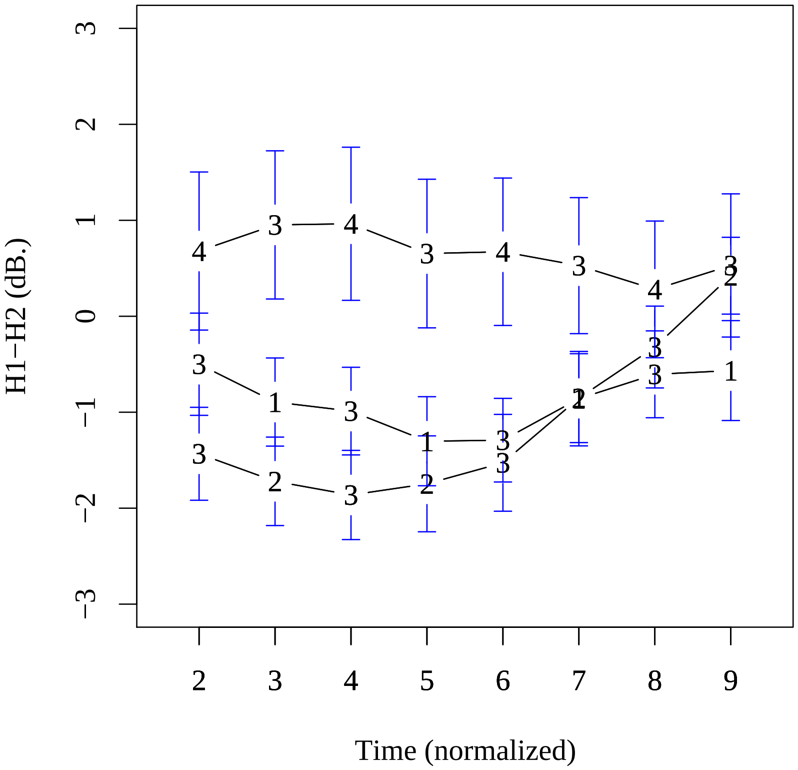


Figure 7.12: H1-H2 on Contour Tone on Open Syllables

A3) with tone and tone type (level vs. contour) as factors found no significant differences for tone type.

Certain observations of spectral tilt changes are consistent between the two measures. For both the H1-H2 and H1-A3 measure, the falling tones /32/ and /31/ are realized with greater vocal fold tension (lower values) early in the vowel duration with less tension toward the end of the vowel. While the H1-H2 measure does not distinguish tone /1/ from /3/ or /4/, the H1-A3 measure does. Conversely, the H1-H2 measure indicates increased vocal fold tension in tone /2/ but the H1-A3 measure does not distinguish it from tones /3/ or /4/. It is unclear why the H1-H2 measure singles out tone /2/ here while the other singles out tone /1/. However, if tone /2/ is produced with greater glottal tension and tone /1/ with less glottal tension and increased breathiness, the results closely match those observed for Chong (DiCanio, 2007b). In this language, the strongest correlate of breathiness

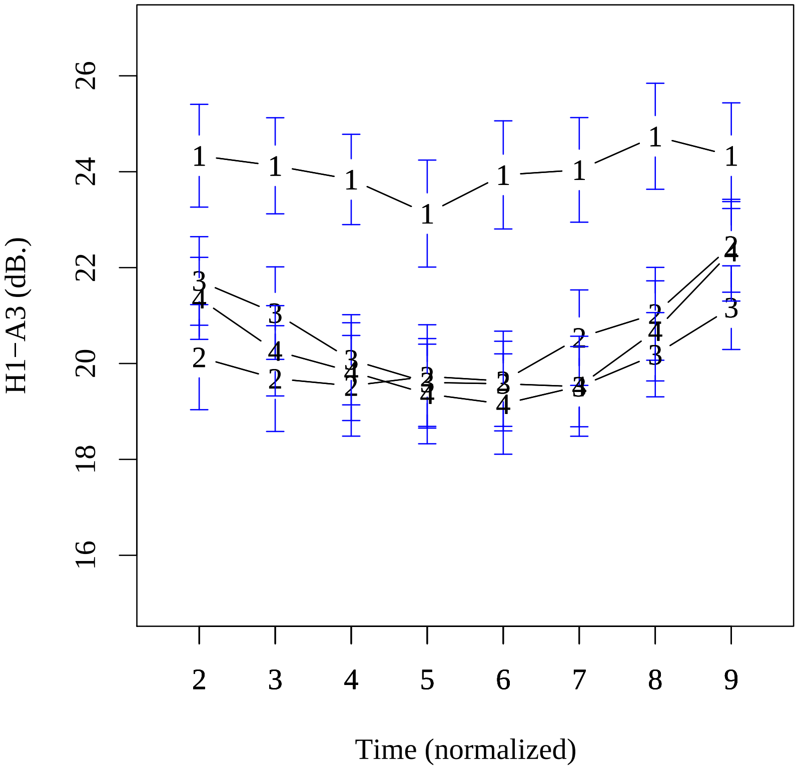


Figure 7.13: H1-A3 on Level Tones on Open Syllables

is H1-A3 while the strongest correlate of glottal tension is H1-H2. For speakers of Itunyoso Trique, the contrast between tones /2/ and /1/ may not only be defined by pitch differences but also by changes in the degree of glottal tension.

7.6.2 Coda /ʔ/ Context

H1-H2 values for /Vʔ/ rimes are shown in Figure 7.15. Here, A = tone /1/, B = tone /2/, and C = tone /3/. H1-H2 values for the compared laryngeal conditions did not differ here. A repeated measures ANOVA on H1-H2 with tone and laryngeal context as factors found no significant differences.

H1-A3 values are shown in Figure 7.16. Unlike the data showing H1-H2 values, differences in H1-A3 correlated with the laryngeal condition. Lower H1-A3 values are observed in the /Vʔ/ condition than in the /VV/ condition. We expect lower H1-A3 values before

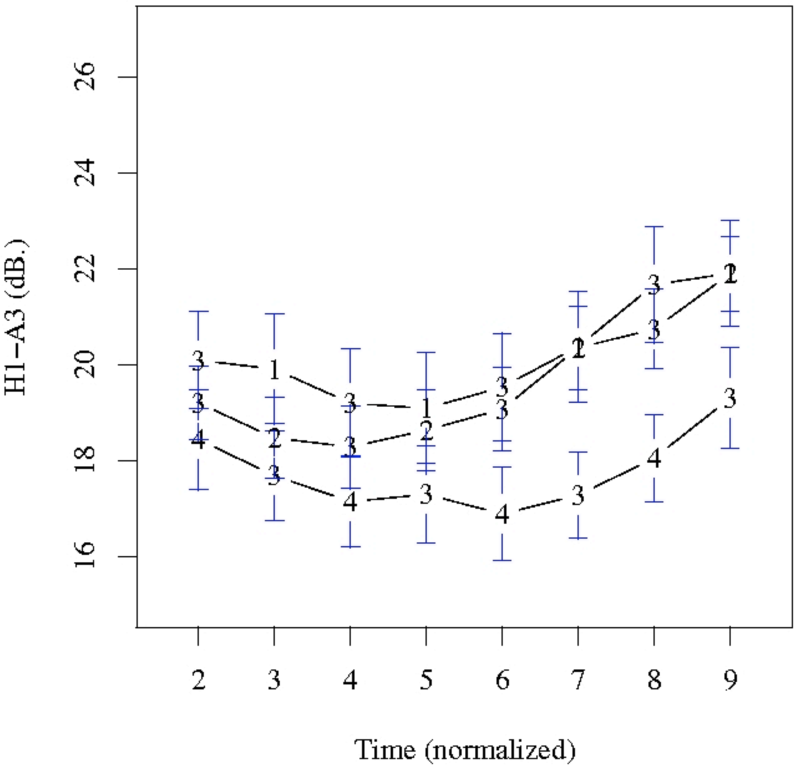


Figure 7.14: H1-A3 on Contour Tone on Open Syllables

glottalization as this reflects an increase in glottal constriction and tension between the vocal folds. The observed differences here were examined in a repeated measures ANOVA with tone and laryngeal condition as main factors. The main factor of laryngeal condition was significant at time index 2 (F[1, 3] = 39.4, $p < 0.01$ **) and at time index 3 (F[1, 3] = 15.6, $p < 0.05$ *) but only approached significance at time index 4 (F[1, 3] = 8.4, p = 0.06). The main factor of tone was only significant at time index 2 (F[2, 7] = 5.8, $p < 0.05$*). There was a significant interaction of tone X laryngeal condition at both t3 (F[2, 10] = 4.8, $p < 0.05$*) and t4 (F[2, 10] = 5.2, $p < 0.05$*).

Tukey's (HSD) pairwise comparisons revealed that H1-A3 differences always correlated with the laryngeal condition for tones /1/ and /3/ but only for tone /2/ at time index 3. The lack of significance for this tone can be attributed to the fact that it is realized with greater glottal tension in the open syllable context than the other tones are.

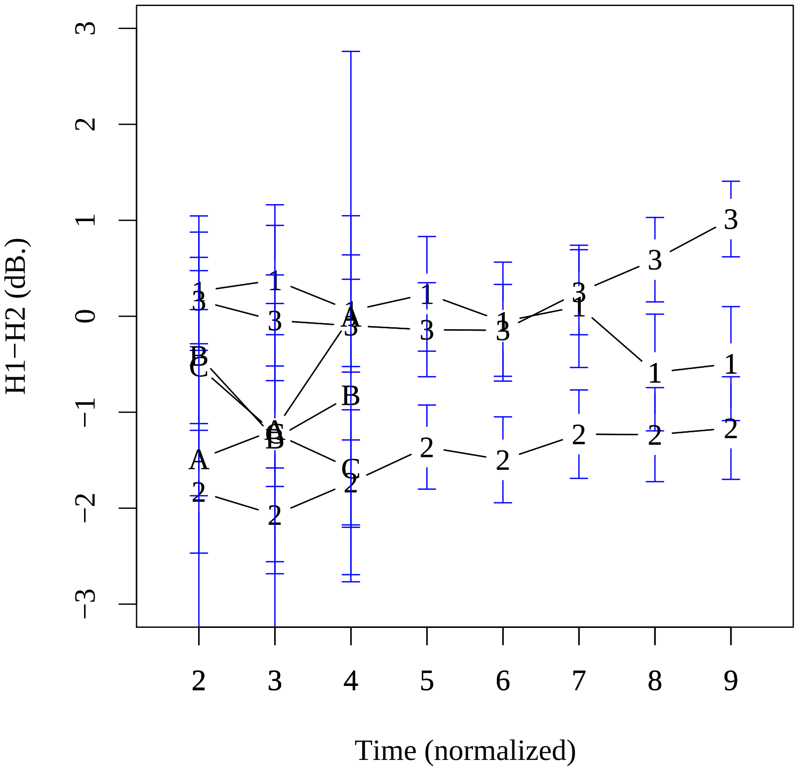


Figure 7.15: H1-H2 on Open Syllable Level Tones and on Syllables with a Coda /ʔ/

The spectral tilt differences between the two laryngeal conditions here are stronger than the pitch differences between them. We observed no significant effects on pitch for the /Vʔ/ context in §7.5.2. Even though abrupt glottalization characterizes this laryngeal condition, spectral tilt differences are observed early in the preceding vowel. The lack of a pitch effect in the presence of greater glottal tension is a notable finding if we hypothesize that laryngealization affects pitch.

7.6.3 Coda /h/ Context

H1-H2 values for the /Vh/ rime condition are given in Figure 7.17. We observe large differences in H1-H2 values by laryngeal condition here. All tones with a coda /h/ are realized with rising H1-H2 values. At time index 2, there is no difference in H1-H2 by laryngeal condition, but the tones in the /Vh/ context diverge from those in the /VV/

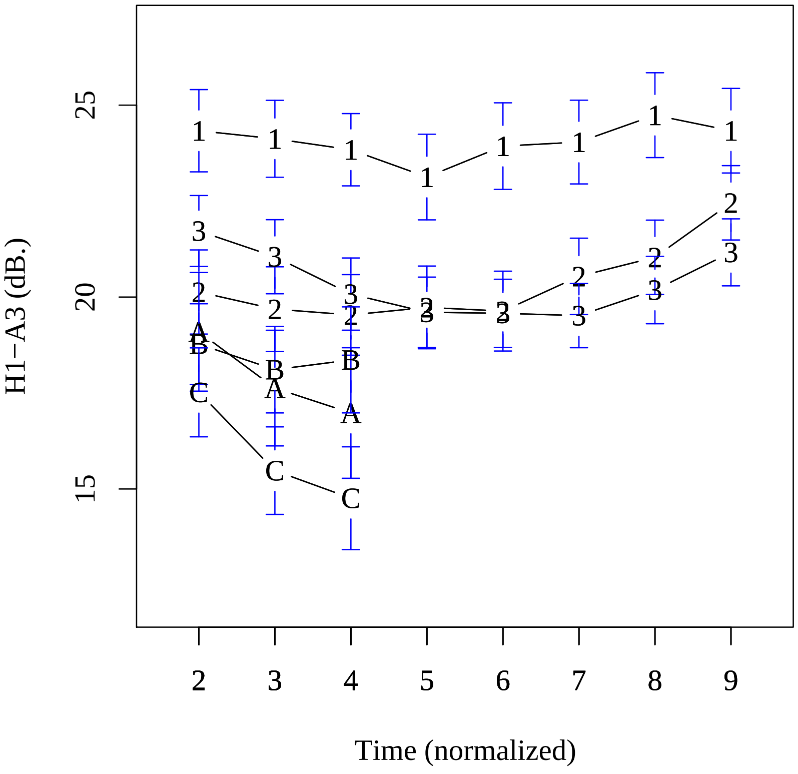


Figure 7.16: H1-A3 on Open Syllable Level Tones and on Syllables with a Coda /ʔ/

context at time index 3.

A repeated measures ANOVA with tone and laryngeal condition as factors revealed significant effects for laryngeal condition on H1-H2 from time index 3 - 9 (shown in Table 7.3. A significant effect of tone on H1-H2 was only observed at time index 9 (F[4, 20] = 3.9, $p < 0.05$*). There was a significant interaction of tone X laryngeal context throughout the first half of the vowel duration (t2-t6) (t2: F[4, 20] = 4.70, $p < 0.01$ **, t3: F[4, 20] = 6.75, $p < 0.005$ **, t4: F[4, 20] = 4.00, $p < 0.05$ *, t5: F[4, 20] = 3.41, $p < 0.05$ *, t6: F[4, 20] = 4.03, $p < 0.05$ *).

H1-A3 values for the /Vh/ rime condition are given in Figure 7.18. Similar to the H1-H2 data, we observe large differences in H1-A3 values by laryngeal condition here, but between time indices t4-t9. All tones with a coda /h/ are realized with rising H1-A3 values. At time index 2 or 3, there is no difference in H1-A3 by laryngeal condition. Tone

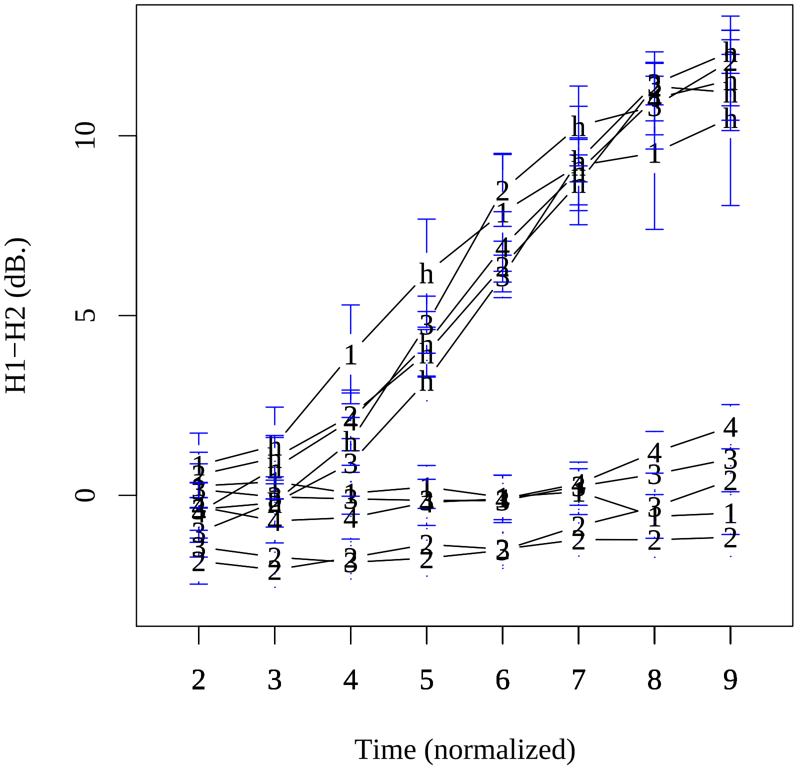


Figure 7.17: H1-H2 on Open Syllable Level Tones and on Syllables with a Coda /h/

/2/ is realized with less steep spectral tilt than the other tones in the /Vh/ context. This is similar to the spectral profile of tone /2/ in the open syllable context observed in §7.6.1. A repeated measures ANOVA with tone and laryngeal as factors found a significant effect of laryngeal condition on H1-A3, shown in Table 7.3. There was a significant interaction of Tone X Laryngeal condition at time index 2 and throughout the latter half of the vowel duration (t2: $F[4, 20] = 3.31$, $p < 0.05$ *, t5: $F[4, 20] = 4.77$, $p < 0.01$ **, t6: $F[4, 20] = 14.39$, $p < 0.001$ ***, t7: $F[4, 20] = 12.05$, $p < 0.001$ ***, t8: $F[4, 20] = 8.53$, $p < 0.001$ ***, t9: $F[4, 20] = 6.03$, $p < 0.005$ **).

There was a significant effect of tone on the H1-A3 spectral tilt measure, shown in Table 7.4, but little effect on the H1-H2 measure. There was more variability in the H1-A3 values within the laryngeal contexts. In the /Vh/ context, tones /2/ and /32/ were realized with slightly lower H1-A3 values than the other tones. In the /VV/ context, tone /1/ was

Table 7.3: Effect of Laryngeal Conditions /VV/ and /Vh/ on Spectral Tilt Measures

Time	*H1-H2*	*H1-A3*
t2	$F[1, 5] = 1.1$, $p = 0.34$, NS	$F[1, 5] = 0.12$, $p = 0.75$ NS,
t3	$F[1, 5] = 39.5$, $p < 0.005$**	$F[1, 5] = 0.25$, $p = 0.64$ NS
t4	$F[1, 5] = 126.0$, $p < 0.001$ ***	$F[1, 5] = 9.8$, $p < 0.05$ *
t5	$F[1, 5] = 109.6$, $p < 0.001$ ***	$F[1, 5] = 43.0$, $p < 0.005$ **
t6	$F[1, 5] = 108.4$, $p < 0.001$ ***	$F[1, 5] = 135.1$, $p < 0.001$ ***
t7	$F[1, 5] = 96.0$, $p < 0.001$ ***	$F[1, 5] = 116.2$, $p < 0.001$ ***
t8	$F[1, 5] = 94.9$, $p < 0.001$ ***	$F[1, 5] = 69.3$, $p < 0.001$ ***
t9	$F[1, 5] =99.5$, $p < 0.001$ ***	$F[1, 5] = 65.0$, $p < 0.001$ ***

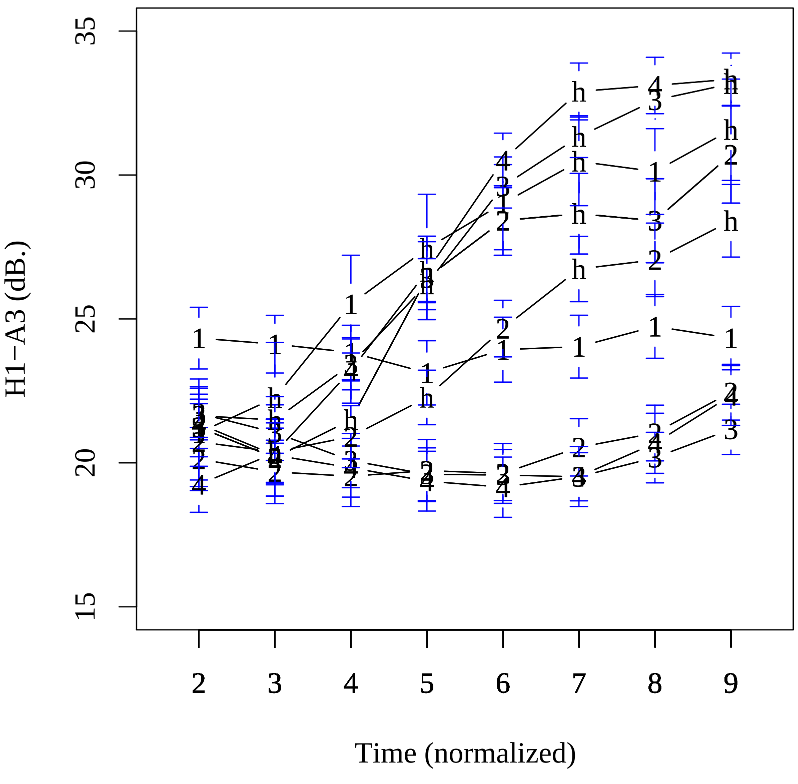


Figure 7.18: H1-A3 on Open Syllable Level Tones and on Syllables with a Coda /h/

realized with higher H1-A3 values than the other tones.

The patterns of increasing H1-H2 and H1-A3 values were also observed in the two

Table 7.4: Effect of Tone on Spectral Tilt Measures

Time	*H1-H2*	*H1-A3*
t2	$F[4, 20] = 1.6, p = 0.21$ NS	$F[4, 20] = 5.6, p < 0.005$ **
t3	$F[4, 20] = 1.8, p = 0.17$ NS	$F[4, 20] = 9.0, p < 0.001$ ***
t4	$F[4, 20] = 2.0, p = 0.14$ NS	$F[4, 20] = 11.4, p < 0.001$ ***
t5	$F[4, 20] = 1.6, p = 0.21$ NS	$F[4, 20] = 5.4, p < 0.005$ **
t6	$F[4, 20] = 1.1, p = 0.38$ NS	$F[4, 20] = 10.1, p < 0.001$ ***
t7	$F[4, 20] = 0.9, p = 0.50$ NS	$F[4, 20] = 5.1, p < 0.01$ **
t8	$F[4, 20] = 2.0, p = 0.13$ NS	$F[4, 20] = 8.4, p < 0.001$ ***
t9	$F[4, 20] = 3.9, p < 0.05$ *	$F[4, 20] = 2.5, p = 0.08$ NS

rising tones which were non-contrastive in the /Vh/ context: /13h/ and /35h/. This data is shown in Figures 7.19 and 7.20. Changes in spectral tilt here resemble the patterns described above for the level tones and tone /32/ in the /Vh/ context. H1-H2 values do not change as substantially over the duration of the rime for tone /13/ as it does for tone /35/ and the other tones in the /Vh/ context. H1-A3 values rise slightly later for tone /13/ than for tone /35/. This pattern resembles the later change in spectral tilt observed for tone /2/ in the /Vh/ context above.

With the exception of tones /2/ and /13/, changes in spectral tilt in /Vh/ contexts occur very early in vowel, approximately 30% into the rime duration. These changes in spectral tilt reflect breathiness which gradually increases throughout the rime duration. Despite these significant changes in phonation type, pitch perturbations in the /Vh/ context do not occur until later in the rime duration, after approximately 70% of the rime duration. The data here suggest a nonlinear relationship between breathy phonation and its effect on pitch. Only after 70% of the rime's duration, where spectral slope becomes steep (H1-H2 = 10 dB.), is pitch perturbed by phonation type. At this point, only pitch on the higher tones /32/, /3/, /4/ is affected. The pitch on lower tones /2/ and /1/ is not substantially affected by changes in phonation type. Greater H1-A3 differences were observed for higher tones in the /Vh/ context. This suggests that increased breathiness is at odds with the production of higher pitch and will have a more profound and earlier affect on F_0. The consequences of these findings for phonological theories of tone-laryngeal patterning are discussed in §7.7.

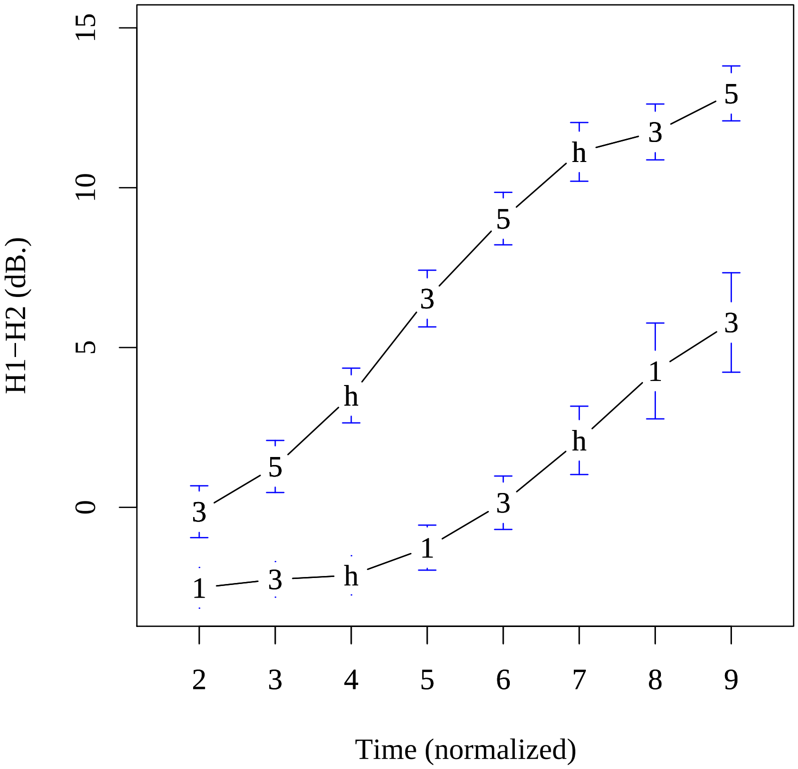


Figure 7.19: H1-H2 on Rising Tones

7.6.4 Summary: Pitch and Phonation Type

The presence of coda laryngeal consonants on final rimes in Itunyoso Trique has a significant effect on spectral tilt on the preceding vowel but a smaller effect on pitch. A coda /ʔ/ does not correspond to any general pitch lowering effects but pitch lowering is observed for tones /1/ and /2/ immediately preceding the glottal stop. A coda /h/ corresponded to significant pitch lowering perturbations late into the rime duration, after time index 7 (70-80%). These effects differed according to the tone on which they occurred. Tones /4/ and /2/ were realized with higher pitch after onset release in the coda /h/ context. The pitch of tone /1/ was unaffected by the presence of the coda /h/ while this effect was timed earlier with higher tone levels. Pitch perturbation occurred earliest for tone /4/, later for tone /3/, and later for tone /2/.

Measures of spectral tilt were robustly affected by the presence of a coda laryngeal.

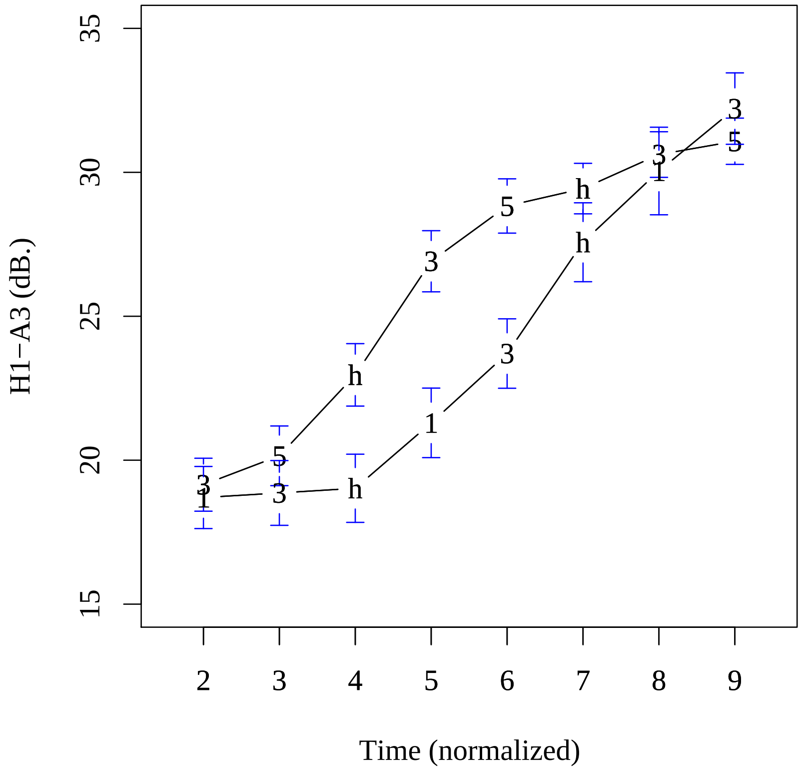


Figure 7.20: H1-A3 on Rising Tones

A coda /ʔ/ did not correspond to changes in H1-H2 value on the vowel of any preceding tone however it did correlate with a significant lowering in H1-A3 value for all preceding tones. While this effect was most robust immediately preceding the heavy glottalization, it occurred early in the vowel duration. A coda /h/ corresponded with significant rises in H1-H2 and H1-A3 early in the preceding vowel. This pattern was observed with all tones, however, the effect was diminished for tones /2/ or /13/, both of which were produced with less steep spectral slope. The findings here suggest that there is a nonlinear relationship between pitch and spectral tilt in Itunyoso Trique. The timing of spectral tilt changes does not correspond to the observed pitch perturbation effects. Pitch lowering effects were mostly small and local while changes in spectral tilt were large and earlier timed. In Itunyoso Trique, both final laryngeals cause a pitch-lowering effect.

7.7 Discussion

7.7.1 Explanations and Theory

The fact that certain tones are more substantially affected by changes in phonation type suggest the need for a detailed model of *how* nonmodal phonation may combine with pitch. Lower tones are affected differently by increases in breathiness than higher tones are. There is a threshold over which substantial changes in spectral tilt will cause pitch perturbation. However, a large degree of variability in phonation type is permissible without substantial effect on pitch. The timing differences between spectral tilt & pitch perturbation and tone-specific pitch perturbation effects argue against phonological approaches assuming that any nonmodal phonation type will affect pitch.

7.7.1.1 Phasing

The tone-laryngeal phasing approach (Silverman, 1997a,b) predicts that nonmodal phonation will be abruptly phased on the latter portion of the vowel so as to not obscure pitch immediately after onset consonant release. The data here show that nonmodal phonation is *gradually* phased in the context of a coda /h/ but abruptly phased in the context of a coda /ʔ/. In the /Vʔ/ context, pitch perturbation effects are small and local. In the /Vh/ context, there is some pitch raising after the onset consonant for tones /4/ and /2/. The data here support the hypothesis that maximum phonation differences occur later on vowels. However, there appears to be a threshold at which pitch will be perturbed if vocal fold tension changes substantially. If speakers produce differences in nonmodal phonation under this threshold, there will be little correlation between changes in pitch and phonation type. The data do not support the hypothesis that a gradual phasing of nonmodal phonation will produce substantial pitch perturbation. Indeed, changes in nonmodal phonation may still fall under this threshold.

The presence of non-local pitch-raising for tones /2/ and /4/ suggest that speakers may anticipate the potential pitch lowering effect of a coda /h/. Since both of these tones are specified as [+high] in different registers, it is unsurprising that pitch raises significantly at the beginning of the rime duration. If this is the position in the syllable where pitch is optimally perceived (Kingston, 1985; Silverman, 1997b), slight pitch raising here serves to maximize the distance between tones /2/ and /4/ and tones /1/ and /3/, respectively.

Speakers do not adjust the timing of breathiness to avoid pitch overlap but instead adjust the pitch target on tones so as to counteract the effect of breathiness.

In the /Vh/ condition, less overall breathiness was observed in the context of tone /2/, as shown by the attenuated change in H1-A3. The other tones in this context were produced with greater breathiness. However, differences in the magnitude of breathiness did not translate into pitch perturbation effects. The pitch in higher tones was more sensitive to increases in spectral tilt. Models of F_0 control and tone-laryngeal interaction must account for this asymmetry.

7.7.1.2 Body-Cover Model

Increased breathiness does not induce pitch-lowering perturbations for lower tones in Itunyoso Trique. This fits neatly into the body-cover model of F_0 control (Titze, 1994). As previously stated, the contraction of the cricothyroid results in increased longitudinal tension on the cover of the vocal folds which increases pitch. Contraction of the thyroarytenoids will raise pitch when the CT is not near its maximum degree of tension (maximum F_0) (Hirano et al., 1969; Shipp and McGlone, 1971; Gay et al., 1972; Atkinson, 1978; Kempster et al., 1988). However, once the CT is contracted toward the maximum region of the pitch range, TA contraction results in pitch lowering. TA contraction causes increased slackness in the vocal fold covers which reduces pitch when F_0 is high. Within a mid to high F_0 range, pitch is controlled primarily by cover tension via the CT. Within a lower F_0 range, pitch is controlled by body tension via the TA.

During the production of breathy phonation, the covers of the vocal folds become more slack due to TA contraction. From this, we predict that tones with the highest pitch would be asymmetrically affected by TA contraction. This is in fact what we observe in Itunyoso Trique. Tones /35/ and /4/ exhibit earlier pitch perturbation effects corresponding with the presence of increasing breathiness on the rime. Tones /1/ and /2/ are little affected by increased vocal fold slackness since contraction of the TA within this pitch region does not cause pitch lowering. The asymmetries in pitch perturbation effect arise due to the asymmetrical nature of how TA contraction affects F_0 within a speaker's pitch range.

The phonological prediction from this is that the laryngeal feature [+slack] will cause pitch-lowering effects, but only for high tones. If nonmodal phonation is timed to avoid pitch perturbation effects, we predict more abrupt phasing with breathy voice and high tones than for low tones.

7.7.1.3 Register Effects

The asymmetry in pitch perturbation effects in the /Vh/ condition does not fit exactly within the tonal register system of Itunyoso Trique. Lower register tones /1/ and /2/ are not as affected by the feature [+slack] as higher register tones are. Yet, pitch on tone /32/ is more substantially perturbed than on tone /2/. A better explanation for these differences is a gradient one where higher pitch values are more influenced by breathiness than lower ones, regardless of the tonal register.

Tones /2/, and /32/ are realized with slightly more tense vocal fold vibration both in the open syllable and /Vh/ context. This is observed with the lower H1-H2 values found for these tones in both contexts. This finding argues against the proposal in Duanmu (2000) stating that lower register tones are obligatorily [+slack]. In Itunyoso Trique there are a range of permissible differences in glottal tension which are not associated to a particular tonal register. In the case of tones /2/ and /32/, glottal tension differences may be used by speakers to distinguish them from tones /1/ and /43/, respectively. As we observed in Figure 7.2, the smallest difference in pitch existed between tone levels /1/ and /2/. Greater glottal tension for tone /2/ may enhance this contrast.

7.7.2 Itunyoso Trique Tone

Three of the findings in this chapter relate directly to the distribution of laryngeal codas and tone in Itunyoso Trique. First, the abruptness of glottal closure reduces the duration over which tones may be realized in the /Vʔ/ context. As we observed in Chapter 5, only level tones are realized in such contexts. Given that most contour tones in Itunyoso Trique are longer than level tones, shorter duration would restrict these contours from surfacing before a /ʔ/. Even though tones /35/ and /43/ are realized with relatively short duration, their duration is still 1.5–2 times as long as a vowel on a /Vʔ/ rime.

Second, the persistence of voicing over the /Vh/ rime permits pitch differences to be realized on this rime duration. As we observed in Chapter 5, a larger range of tonal contrasts surfaces before a coda /h/. The reassociation of contour tones on a disyllabic word also appears to be motivated by the phonetic data. We observed that final syllable rimes in disyllabic words were shorter in duration than those in monosyllabic words. If contour tones (specifically tone /32/ and /31/) are necessarily realized on a longer duration, we expect tonal reassociation or spreading of contour tones in the context of polysyllabic words.

Third, pitch perturbations in the /Vh/ rime context have low magnitude and are timed relatively late. The consequence of this is that more tonal contrasts can be realized on such rimes with minimal effect of increases in spectral tilt. Tone and breathiness can co-occur in Trique precisely because of this later timing. The durational and timing factors of tone and laryngeals in Itunyoso Trique explain the phonological restrictions of tone in the language.

Bibliography

Abramson, A. S. (1986). The perception of word-initial consonant length: Pattani Malay. *Journal of the International Phonetic Association*, 16:8–16.

Abramson, A. S. (1991). Amplitude as a cue to word-initial consonant length: Pattani Malay. In *Proceedings of the 12th International Congress of Phonetic Sciences*, volume 3, pages 98–101. Université de Provence, Aix-en-Provence.

Abramson, A. S. (2003). Acoustic cues to word-initial stop length in Pattani Malay. In *Proceedings of the 15^{th} International Congress of the Phonetic Sciences*, pages 387–390. Universidad autónoma de Barcelona.

Abramson, A. S., Nye, P. W., and Luangthongkum, T. (2007). Voice Register in Khmu': Experiments in Production and Perception. *Phonetica*, 64:80–104.

Alexander, R. M. (1980). *Gramática Mixeca: Mixteco de Atatlahuca.* Serie de Gramáticas de Lenguas Indígenas de México, 2. Instituto Lingüístico de Verano: Mexico, D.F.

Anderson, J. L., Martínez, I. H., and Pace, W. (1990). Comaltepec Chinantec Tone. In Merrifield, W. R. and Rensch, C. R., editors, *Syllables, Tone, and Verb Paradigms: Studies in Chinantec Languages*, volume 4. SIL Arlington.

Anttila, A. and Bodomo, A. B. (2000). Tonal Polarity in Dagaare. In Carstens, V. and Parkinsons, F., editors, *Trends in African Linguistics 4: Advances in African Linguistics*, pages 119–134. African World Press, Trenton, NJ.

Arvaniti, A. (1999). Effects of speaking rate on the timing of single and geminate sonorants. In Ohala, J. J., Hasegawa, Y., Ohala, M., Granville, D., and Bailey, A. C., editors, *Proceedings of the 14th International Congress of Phonetic Sciences*, volume 1, pages 599–602. University of California, Berkeley.

Arvaniti, A. and Tserdanelis, G. (2000). On the phonetics of geminates: evidence from Cypriot Greek. In *Proceedings of the 6th International Conference on Spoken Language Processing*, volume 2, pages 559–562, Beijing, China.

Atkinson, J. E. (1978). Correlation analysis of the physiological factors controlling fundamental voice frequency. *Journal of the Acoustical Society of America*, 63(1):211–222.

Avelino, H. (2001). Phonetic correlates of fortis-lenis in Yalálag Zapotec. Master's thesis, UCLA.

Avelino, H. (2003). Categorical Perception of Phonemic Tone in Yalálag Zapotec. In *Proceedings of the 15th International Congress of the Phonetic Sciences.*

Baayen, R. H. (2008). *Analyzing Linguistic Data: A Practical Introduction to Statistics Using R.* Cambridge University Press.

Bao, Z. (1999). *The Structure of Tone.* Oxford University Press.

Bartholomew, D. (1960). Some Revisions of Proto-Otomi Consonants. *International Journal of American Linguistics*, 26(4):317–329.

Bartholomew, D. (1983). *Gramática zapoteca.* Vocabularios y Diccionarios Indígenas "Mariano Silva y Aceves" 27. Mexico: Instituto Lingüístico de Verano.

Bateman, H. E. and Mason, R. M. (1984). *Applied Anatomy and Physiology of the Speech and Hearing Mechanism.* Charles C. Thomas.

Bauernschmidt, A. (1965). Amuzgo syllable dynamics. *Language*, 41(3):471–483.

Beam de Azcona, R. Proto-Zapotec Coronal Stops in Coatlán-Loxicha Zapotec and Other Southern Zapotec Languages.

Beam de Azcona, R. (2004). *A Coatlán-Loxicha Zapotec Grammar.* PhD thesis, University of California, Berkeley.

Beatty de Farris, K., García Sánchez, P., García Sánchez, R., Ojeda Sánchez, J., San Pablo García, A., and Santiago Jiménez, A. (2004). *Diccionario Básico del Mixteco de Yosondúa, Oaxaca.* Number 46 in Serie de Vocabularios y Diccionarios Indígenas "Mariano Silva y Aceves". Instituto Lingüístico de Verano: Mexico, D.F.

Belmar, F. (1897). *Lenguas del Estado de Oaxaca: Ensayo sobre lengua Trique*. Imprenta de Lorenzo San-Germán.

Berthiaume, S. (2004). *A Phonological Grammar of Northern Pame*. PhD thesis, University of Texas at Arlington.

Blankenship, B. (2002). The timing of nonmodal phonation in vowels. *Journal of Phonetics*, 30:163–191.

Blevins, J. (2004). *Evolutionary Phonology: The emergence of sound patterns*. Cambridge University Press.

Blight, R. C. and Pike, E. V. (1976). The phonology of Tenango Otomi. *International Journal of American Linguistics*, 42(1):51–57.

Blomgren, M., Chen, Y., Ng, M. L., and Gilbert, H. R. (1998). Acoustic, aerodynamic, physiologic, and perceptual properties of modal and vocal fry registers. *Journal of the Acoustical Society of America*, 103(5):2649–2658.

Boersma, P. and Weenink, D. (2008). Praat: doing phonetics by computer [computer program]. www.praat.org.

Borroff, M. L. (2007). *A Landmark Underspecification Account of the Patterning of Glottal Stop*. PhD thesis, Stony Brook University.

Bradshaw, M. (1999). *A Cross-Linguistic Study of Consonant-Tone Interaction*. PhD thesis, The Ohio State University.

Broadwell, G. A. (2004). Pied-piping with inversion in Copala Trique. Paper presented at the Society for the Study of the Indigenous Languages of the Americas.

Browman, C. and Goldstein, L. (1986). Towards an articulatory phonology. *Phonology Yearbook*, 3:219–252.

Browman, C. and Goldstein, L. (1990). Tiers in articulatory phonology, with some implications for casual speech. In Kingston, J. and Beckman, M. E., editors, *Papers in laboratory phonology 1: between the grammar and the physics of speech*, pages 341–376. Cambridge University Press.

Brunelle, M. (1999). Tonogénèse, registrogénèse, et traits laryngals binaires. *Cahiers de Linguistique - Asie Orientale*, 28(1):23–52.

Butcher, A. (2004). ‘fortis/lenis’ revisited one more time: the aerodynamics of some oral stop contrasts in three continents. *Clinical Linguistics & Phonetics*, 18(6-8):547–557.

Butler, I. M. (2000). *Diccionario Zapoteco de Yatzachi: Yatzachi el bajo, Yatzachi el alto, Oaxaca*, volume 37 of *Serie de Vocabularios y Diccionarios Indígenas.* Instituto lingüistico de verano, Tuscon, AZ.

Byrd, D. and Saltzman, E. (1998). Intergestural dynamics of multiple phrase boundaries. *Journal of Phonetics*, 26:173–199.

Byrd, D. and Tan, C. C. (1996). Saying consonant clusters quickly. *Journal of Phonetics*, 24:263–282.

Campbell, W. and Isard, S. (1991). Segment durations in a syllable frame. *Journal of Phonetics*, 19:37–47.

Carlson, B. F. and Esling, J. H. (2004). Phonetics and Physiology of the Historical Shift of uvulars to pharyngeals in Nuuchahnulth (Nootka). *Journal of the International Phonetic Association*, 33(2):183–193.

Catford, J. (1977). *Fundamental Problems in Phonetics.* Indiana University Press.

Cerrato, L. and Falcone, M. (1998). Acoustic and perceptual characteristics of Italian stop consonants. In *Proceedings of the 5th International Conference on Spoken Language Processing.* Sydney.

Chen, M. (1970). Vowel length variation as a function of the voicing of the consonant environment. *Phonetica*, 22:129–159.

Childers, D. G. and Krishnamurthy, A. K. (1985). A critical review of electroglottography. *CRC Critical Reviews in Biomedical Engineering*, 12(2):131–161.

Childers, D. G. and Lee, C. K. (1991). Vocal quality factors: Analysis, synthesis, and perception. *Journal of the Acoustical Society of America*, 90(5):2394–2410.

Cho, T., Jun, S.-A., and Ladefoged, P. (2002). Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of Phonetics*, 30:193–228.

Cho, T. and Keating, P. (2001). Articulatory and acoustic studies of domain-initial strengthening in Korean. *Journal of Phonetics*, 29(2):155–190.

Cho, T. and Ladefoged, P. (1999). Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics*, 27:207–229.

Cho, Y.-M. Y. (1990). *Parameters of Consonantal Assimilation.* PhD thesis, Stanford University, Stanford, CA.

Chomsky, N. and Halle, M. (1968). *The sound pattern of English.* MIT Press.

Choosri, I. (2002). Dialects of chong. *Mon-Khmer Studies*, 32:55–70.

Cohn, A. C., Ham, W. H., and Podesva, R. J. (1999). The phonetic realization of singleton-geminate contrasts in three languages of indonesia. In Ohala, J. J., Hasegawa, Y., Ohala, M., Granville, D., and Bailey, A. C., editors, *Proceedings of the 14th International Congress of Phonetic Sciences*, volume 1, pages 587–590. University of California, Berkeley.

Cruz, E. and Woodbury, A. (2005). El sandhi de los tonos en el Chatino de Quiahije. In *Memorias del Congreso de Idiomas Indígenas de Latinoamérica-II.* University of Texas, Austin.

Daly, J. P. and Hyman, L. M. (2007). On the representation of tone in Peñoles Mixtec. *International Journal of American Linguistics*, 73(2):165–207.

Dart, S. (1987). An aerodynamic study of Korean stop consonants: measurements and modeling. *Journal of the Acoustical Society of America*, 81(1):138–147.

Davidson, D. S. (1991). An acoustic study of so-called creaky voice in Tianjin Mandarin. *UCLA Working Papers in Phonetics*, 78:50–57.

de Lacy, P. (2002). The interaction of tone and stress in Optimality Theory. *Phonology*, 19:1–32.

Debrock, M. (1977). An acoustic correlate of the force of articulation. *Journal of Phonetics*, 5:61–80.

DeJong, K. and McDonough, J. (1993). Tone and tonogenesis in Navajo. *UCLA Working Papers in Phonetics*, 84: Fieldwork Studies of Targeted Languages:165–182.

Denes, P. (1955). Effect of duration on the perception of voicing. *Journal of the Acoustical Society of America*, 27(4):761–764.

DiCanio, C. (2005). On non-optimal laryngeal timing: the case of Trique. In *Proceedings of the 32*nd *Annual Meeting of the Berkeley Linguistics Society.*

DiCanio, C. (2006). Sensitivity of Glottalization to Prosodic Structure in Itunyoso Trique. Annual Meeting of the Society for the Study of the Indigenous Languages of the Americas.

DiCanio, C. (2007a). The phonetics of fortis-lenis: The case of Trique. Talk Presented at the Linguistic Society of America Annual Meeting.

DiCanio, C. (2007b). The Phonetics of Register in Takhian Thong Chong. *Annual Report of the UC Berkeley Phonology Laboratory*, 3:459–482.

Diehl, R. L. and Kluender, K. R. (1989). On the objects of speech perception. *Ecological Psychology*, 1(2):121–144.

Diffloth, G. (1989). Proto-Austroasiatic creaky voice. *Mon-Khmer Studies*, 15:139–154.

Dixit, R. P. and Brown, W. S. (1978). Peak magnitudes of supraglottal air pressure associated with affricated and nonaffricated stop consonant productions in Hindi. *Journal of Phonetics*, 6:353–365.

Dogil, G. (2007). Phonetic dimensions of segmental strength. In Trouvain, J. and Barry, W. J., editors, *Proceedings of the 16*th *International Congress of Phonetic Sciences*, pages 89–92, University of Saarbrücken.

Duanmu, S. (1990). *A formal study of syllable, tone, stress, and domain in Chinese Languages.* PhD thesis, MIT.

Duanmu, S. (2000). *The Phonology of Standard Chinese.* Oxford: Oxford University Press.

Dürr, M. (1987). A Preliminary Reconstruction of the Proto-Mixtec Tonal System. *Indiana: Contributions to the Ethnology and Archaeology, Linguistics, Social Anthropology, and History of Indigenous Latin America*, 11:19–60.

Edmondson, J. A. (1997). Voice qualities and inverse filtering in Chong. *Mon-Khmer Studies*, 26:107–116.

Edmondson, J. A. (2007). Fuerza articulatoria en la fonética del idioma Triqui de Chicahuaxtla. Paper presented at the Roundtable on Mixtecan Languages, Mexico City, Mexico.

Edmondson, J. A. and Esling, J. H. (2006). The valves of the throat and their functioning in tone, vocal register, and stress: laryngoscopic case studies. *Phonology*, 23(2):157–191.

Edmondson, J. A., Esling, J. H., Harris, J. G., and Wei, J. (2004). A phonetics study of Sui consonants and vowels. *Mon-Khmer Studies*, 34:47–66.

Edmondson, J. A., Ziwo, L., Esling, J. H., Harris, J. G., and Shaoni, L. (2001). The aryepiglottic folds and voice quality in the Yi and Bai languages: Laryngoscopic case studies. *Mon-Khmer Studies*, 31:83–100.

Esling, J. H. (1999). The IPA Categories "Pharyngeal" and "Epiglottal": Laryngoscopic Observations of Pharyngeal Articulations and Larynx Height. *Language and Speech*, 42(4):349–372.

Esling, J. H. (2005). There are No Back Vowels: The Laryngeal Articulator Model. *Canadian Journal of Linguistics*, 50:13–44.

Esling, J. H., Clayards, J., Edmondson, J. A., Fuyuan, Q., and Harris, J. G. (1998). Quantification of Pharyngeal Articulations using Measurements from Laryngoscopic Images. In *Proceedings of the 5th International Conference on Spoken Language Processing*, number 0618.

Esposito, A. and Di Benedetto, M. G. (1999). Acoustical and perceptual study of gemination in Italian stops. *Journal of the Acoustical Society of America*, 106(4):2051–2062.

Esposito, C. (2004). Santa Ana del Valle Zapotec Phonation. In *UCLA Working Papers in Phonetics*, volume 103, pages 71–105.

Esposito, C. (2006). *The Effects of Linguistic Experience on the Perception of Phonation.* PhD thesis, UCLA.

Ewan, W. G. and Krones, R. (1974). Measuring larynx movement using the thyroumbrometer. *Journal of Phonetics*, 2:327–335.

Farnetani, E. and Recasens, D. (1999). Coarticulation models in recent speech production theories. In Hardcastle, W. J. and Hewlett, N., editors, *Coarticulation: Theory, Data, and Techniques*, chapter 2, pages 31–65. Cambridge University Press.

Ferlus, M. (1979). Formation des Registres et Mutations Consonantiques dans les langues Mon-Khmer. *Mon-Khmer Studies*, 8:1–76.

Fischer-Jørgensen, E. (1963). Beobachtungen über den Zusammenhang swischen Stimmhaftigkeit und intraoralem Luftdruck. *Sprachwissenschaft und Kommunikationsforschung: Zeitschrift für Phonetik*, 16:19–36.

Fischer-Jørgensen, E. (1967). Phonetic analysis of breathy (murmured) vowels in Gujarati. *Indian Linguistics*, 28:71–139.

Fischer-Jørgensen, E. (1968). Voicing, tenseness, and aspiration in stop consonants, with special reference to French and Danish. *Annual Report of the Institute of Phonetics of the University of Copenhagen*, 3:63–114.

Flemming, E. (1995). *Auditory features in phonology.* PhD thesis, UCLA.

Flemming, E. (2001). Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology*, 18:7–44.

Fougeron, C. and Keating, P. A. (1997). Articulatory strengthening at edges of prosodic domains. *Journal of the Acoustical Society of America*, 101(6):3728–3740.

Fourcin, A. (2002). Precision stroboscopy, voice quality, and electrolaryngograpy. Technical report, Laryngograph Ltd.

Fowler, C. A. (1980). Coarticulation and theories of extrinsic timing. *Journal of Phonetics*, 8:113–133.

Francis, A. L., Ciocca, V., Ka Man Wong, V., and Ka Lam Chan, J. (2006). Is fundamental frequency a cue to aspiration in initial stops? *Journal of the Acoustical Society of America*, 120(5):2884–2895.

Fromkin, V. A. and Ladefoged, P. (1966). Electromyography in speech research. *Phonetica*, 15.

Fuchs, S. (2005). *Articulatory correlates of the voicing contrast in alveolar obstruent production in German*. PhD thesis, Centre for General Linguistics, Berlin.

Fuchs, S. and Perrier, P. (2003). An EMMA/EPG study of voicing contrast correlates in German. In *Proceedings of the 15th International Congress of the Phonetic Sciences*.

Fujimura, O. (2000). The C/D Model and Prosodic Control of Articulatory Behavior. *Phonetica*, 57:128–138.

Fujimura, O. and Miller, J. E. (1979). Mandible height and sylleble-final tenseness. *Phonetica*, 36:263–272.

Gage, W. (1985). Glottal stops and Vietnamese tonogenesis. In Acson, V. Z. and Leed, R. L., editors, *Oceanic Linguistics Special Publication: For Gordon H. Fairbanks*, volume 20, pages 21–36. Honolulu: University of Hawaii Press.

Gandour, J. and Maddieson, I. (1976). Measuring larynx height in Standard Thai using the cricothyrometer. *Phonetica*, 33:241–267.

Gathercole, G. (1983). Tonogenesis and the Kickapoo Tonal System. *International Journal of American Linguistics*, 49(1):72–76.

Gay, T. (1977). Articulatory movements in VCV sequences. *Journal of the Acoustical Society of America*, 62(1):183–193.

Gay, T., Strome, M., Hirose, H., and Sawashima, M. (1972). Electromyography of intrinsic laryngeal muscles during phonation. *Annals of Otology, Rhinology, and Laryngology*, 81:401–410.

Gerfen, C. (1999). *Phonology and phonetics in Coatzospan Mixtec*. Dordrecht & Boston : Kluwer.

Gibson, L. F. (1956). Pame (Otomí) Phonemics and Morphophonemics. *International Journal of American Linguistics*, 22(4):242–265.

Goblirsch, K. (1994). *Consonant Strength in Upper German Dialects*. Odense: Odense University Press.

Goldsmith, J. (1976). *Autosegmental Phonology*. PhD thesis, MIT.

Goldsmith, J. (1990). *Autosegmental and metrical phonology.* Oxford: Blackwell.

Golston, C. and Kehrein, W. (2004). A prosodic theory of laryngeal contrasts. *Phonology*, 21:1–33.

Good, C. (1979). *Diccionario Triqui*, volume 20 of *Serie de Vocabularios Indigenas.* Summer Institute of Linguistics, Mexico.

Google Inc. (2008). Google Maps: http://maps.google.com.

Gordon, M. (2001). A Typology of Contour Tone Restrictions. *Studies in Language*, 25(3):423–462.

Gordon, M. and Ladefoged, P. (2001). Phonation Types: A cross-linguistic overview. *Journal of Phonetics*, 29:383–406.

Gordon Jr., R. G., editor (2005). *Ethnologue: Languages of the World.* SIL International, Dallas, Texas, 15^{th} edition.

Gray, H. and Standring, S. (1995). *Gray's Anatomy of the Human Body.* Elsevier Churchill Livingston.

Guerssel, M. (1977). Constraints on phonological rules. *Linguistic Analysis*, 3:267–305.

Gussenhoven, C. (2004). *The Phonology of Tone and Intonation.* Research Surveys in Linguistics. Cambridge University Press.

Haggard, M., Ambler, S., and Callow, M. (1969). Pitch as a voicing cue. *Journal of the Acoustical Society of America*, 47(2):613–617.

Hale, M. and Reiss, C. (2000). Phonology as cognition. In Burton-Roberts, N., Carr, P., and Docherty, G. J., editors, *Phonological Knowledge: Conceptual and Empirical Issues.* Oxford University Press.

Hall, T. A. (2001). *Phonological representations and phonetic implementation of distinctive features*, chapter 1, pages 1–40. Mouton de Gruyter.

Halle, M. (1983). On distinctive features and their articulatory implementation. *Natural Language and Linguistic Theory*, 1:91–105.

Halle, M. and Stevens, K. N. (1971). A note on laryngeal features. Technical report, MIT Research Laboratory in Electronics.

Ham, W. H. (2001). *Phonetic and Phonological Aspects of Geminate Timing*. Outstanding Dissertations in Linguistics. Routledge.

Hardcastle, W. J. (1973). Some observations on the tense-lax distinction in initial stops in korean. *Journal of Phonetics*, 1:263–272.

Harris, J. (1994). *English Sound Structure*. London: Blackwell.

Harris, J. (1997). Licensing inheritance: an integrated theory of neutralisation. *Phonology*, 14:315–370.

Haudricourt, A. G. (1954). De l'origine de tons en Viênamien. *Journal Asiatique*, 242:69–82.

Hayes, B. (1981). *A metrical theory of stress rules*. PhD thesis, MIT.

Hayes, B. (1986). Inalterability in CV phonology. *Language*, 62:321–351.

Heinrich, N., D'Alessandro, C., Doval, B., and Castellengo, M. (2004). On the use of the derivative of electroglottographic signals for characterization of nonpathological phonation. *Journal of the Acoustical Society of America*, 115(3):1321–1332.

Henderson, E. J. A. (1952). The Main Features of Cambodian Pronunciation. *Bulletin of the School of Oriental and African Studies*, 14(1):149–174.

Henderson, E. J. A. (1985). Feature shuffling in southeast asian languages. In Ratanakul, S., Thomas, D., and Premsrirat, S., editors, *Southeast Asian Linguistic Studies presented to Andre-G. Haudricourt*, pages 1–22. Mahidol University.

Henton, C., Ladefoged, P., and Maddieson, I. (1992). Stops in the world's languages. *Phonetica*, 49:65–101.

Hinton, L. (1991). An Accentual Analysis of Tone in Chalcatongo Mixtec. In Redden, J. E., editor, *Papers from the American Indian Languages Conferences Held at the University of California, Santa Cruz*, Occasional Papers on Linguistics, No.16, pages 173–182. Carbondale: Southern Illinois University.

Hirano, M., Ohala, J. J., and Vennard, W. (1969). The function of the laryngeal muscles in regulating fundamental frequency and intensity of phonation. *Journal of Speech, Language, and Hearing Research*, 12:616–628.

Hirose, H. (1997). Investigating the physiology of laryngeal structures. In Hardcastle, W. J. and Laver, J., editors, *The handbook of phonetic sciences*, pages 116–136. Oxford: Basil Blackwell.

Hirose, H. and Gay, T. (1972). The activity of the intrinsic laryngeal muscles in voicing control: an electromyographic study. *Phonetica*, 25:140–164.

Hirose, H., Yoshioka, H., and Niimi, S. (1978). A cross language study of laryngeal adjustment in consonant production. *Annual Bulletin, Research Institute of Logopedics and Phoniatrics*, 12:61–71.

Hollenbach, B. E. (1973a). El parentesco entre los triques de Copala, Oaxaca. *América Indígena*, 33:167–186.

Hollenbach, B. E. (1973b). La aculturación lingüística entre los triques de Copala, Oaxaca. *América Indígena*, 33:65–95.

Hollenbach, B. E. (1977). Phonetic vs. phonemic correspondence in two Trique dialects. In Merrifield, W. R., editor, *Studies in Otomanguean Phonology*, number 54 in Publications in Linguistics, pages 35–67. Summer Institute of Linguistics, Dallas.

Hollenbach, B. E. (1984a). Copala Trique tone and universal features. *Coyote Papers*, 5:96–119.

Hollenbach, B. E. (1984b). *The Phonology and Morphology of Tone and Laryngeals in Copala Trique*. PhD thesis, University of Arizona.

Hollenbach, B. E. (1992). A syntactic sketch of Copala Trique. In Bradley, C. H. and Hollenbach, B. E., editors, *Studies in the syntax of Mixtecan Languages*, volume 4. Dallas: Summer Institute of Linguistics and University of Texas at Arlington.

Hollenbach, B. E. (2004a). *Gramática popular del triqui de Copala*. Summer Institute of Linguistics, Mexico.

Hollenbach, B. E. (2004b). *Vocabulario breve del triqui de San Juan Copala.* SIL International.

Holmberg, E., Hillman, R., Perkell, J., Guiod, P., and Goldman, S. (1995). Comparisons among aerodynamic, electroglottographic, and acoustic spectral measures of female voice. *Journal of Speech, Language, and Hearing Research*, 38:1212–1223.

Holt, L. L., Lotto, A. J., and Kluender, K. R. (2001). Influence of fundamental frequency on stop-consonant voicing perception: A case of learned covariation or auditory enhancement? *Journal of the Acoustical Society of America*, 109(2):764–774.

Holton, G. (2001). Fortis and lenis fricatives in Tanacross Athapaskan. *International Journal of American Linguistics*, 67(4):396–414.

Hombert, J. M. (1975). Perception of contour tones: an experimental investigation. *Proceedings of the 1st Annual Meeting of the Berkeley Linguistics Society*, 1:221–232.

Hombert, J. M. (1979). Consonant types, vowel height and tone. In Fromkin, V. A., editor, *Tone: A Linguistic Survey*, pages 77–111. Academic Press: New York.

Hombert, J. M., Ohala, J. J., and Ewan, W. (1979). Phonetic explanations for the development of tones. *Language*, 55(1):37–58.

Hoole, P., Gobl, C., and Ní-Chasaide, A. (1999). Laryngeal coarticulation. In Farnetani, E. and Recasens, D., editors, *Coarticulation: Theory, Data, and Techniques*, chapter 5, pages 105–143. Cambridge University Press.

Hoole, P., Honda, K., Murano, E., Fuch, S., and Pape, D. (2004). Cricothyroid activity in consonant voicing and vowel intrinsic pitch. In *Proceedings of the Conference on Voice Physiology and Biomechanics*, Marseille.

House, A. S. and Fairbanks, G. (1953). The influence of consonantal environment upon the secondary acoustical characteristics of vowels. *Journal of the Acoustical Society of America*, 25:105–113.

Howe, D. and Pulleyblank, D. (2001). Patterns and timing of glottalisation. *Phonology*, 18:45–80.

Hubbard, K. (1994). *Duration in Moraic theory.* PhD thesis, University of California, Berkeley.

Huffman, F. E. (1976). The register problem in fifteen Mon-Khmer languages. *Austroasiatic Studies*, Part 1:575–589.

Huffman, F. E. (1985). The phonology of chong, a mon-khmer language of thailand. In Ratanakul, S., Thomas, D., and Premsrirat, S., editors, *Southeast Asian Linguistic Studies presented to Andre-G. Haudricourt*, pages 355–388. Mahidol University.

Huffman, M. K. (2005). Segmental and prosodic effects on coda glottalization. *Journal of Phonetics*, 33:335–362.

Hyman, L. M. (1977). Phonologization. In Juilland, A., editor, *Linguistic Studies offered to Joseph Greenberg*, pages 407–418. Alma Libri, Saratoga, CA.

Hyman, L. M. (1985). *A Theory of Phonological Weight.* Foris Publications, Dordrecht.

Hyman, L. M. (1988). The phonology of final glottal stops. In *Proceedings of the Western Conference on Linguistics (WECOL)*, volume 1, pages 113–130.

Hyman, L. M. (2007). Universals of tone rules: 30 years later. In Riad, T. and Gussenhoven, C., editors, *Tones and Tunes*, volume 1: Typological Studies in Word and Sentence Prosody. Mouton de Gruyter.

Hyman, L. M. and Schuh, R. G. (1974). Universals of tone rules: Evidence from west africa. *Linguistic Inquiry*, 5:81–115.

Idemaru, K. (2005). *An acoustic and perceptual investigation of the geminate and singleton stop contrast in Japanese.* PhD thesis, University of Oregon.

Idemaru, K. and Holt, L. L. (2007). Relational timing or absolute duration? cue weighting in the perception of Japanese singleton-geminate stops. In *Proceedings of the 16th International Congress of Phonetic Sciences*, pages 753–756.

Itô, J. (1986). *Syllable theory in prosodic phonology.* PhD thesis, University of Massachusetts.

Itô, J. and Mester, R. A. (1993). Licensed segments and safe paths. *Revue Canadienne de Linguistique*, 38:197–213.

Iverson, G. K. and Salmons, J. C. (1995). Aspiration and laryngeal representation in Germanic. *Phonology*, 12:369–396.

Iverson, G. K. and Salmons, J. C. (1996). Mixtec Prenasalization as Hypervoicing. *International Journal of American Linguistics*, 62(2):165–175.

Iverson, G. K. and Salmons, J. C. (2003). Laryngeal enhancement in early Germanic. *Phonology*, 20:43–74.

Jacob, J. (1968). *Introduction to Cambodian.* Oxford University Press, London.

Jaeger, J. J. (1983). The fortis-lenis question: evidence from Zapotec and Jawoñ. *Journal of Phonetics*, 11:177–189.

Jaeger, J. J. and Van Valin, R. (1982). Initial Consonant Clusters in Yatée Zapotec. *International Journal of American Linguistics*, 48(2):125–138.

Jakobson, R., Fant, C. G. M., and Halle, M. (1976). *Preliminaries to Speech Analysis: The Distinctive Features and their Correlates.* MIT Press, 11^{th} edition.

Jakobson, R. and Halle, M. (1956). *Fundamentals of Language.* The Hague: Mouton.

Jansen, W. (2004). *Laryngeal Contrast and Phonetic Voicing: A Laboratory Phonology Approach to English, Hungarian, and Dutch.* PhD thesis, Groningen University.

Javkin, H. R. (1976). The perceptual basis of vowel duration differences associated with the voiced/voiceless distinction. In *Reports of the Phonology Laboratory*, volume 1, pages 78–92. University of California, Berkeley.

Jessen, M. (1998). *Phonetics and Phonology of Tense and Lax Obstruents in German*, volume 44 of *Studies in Functional and Structural Linguistics.* John Benjamins.

Jessen, M. and Ringen, C. (2002). Laryngeal features in German. *Phonology*, 19:189–218.

Johnson, K. (2008). *Quantitative Methods in Linguistics.* Blackwell Publishing.

Jones, T. and Knudson, L. (1977). Guelavía Zapotec phonemes. In Merrifield, W. R., editor, *Studies in Otomanguean Phonology*, pages 163–180. Summer Institute of Linguistics, Dallas.

Josserand, J. K. (1983). *Mixtec Dialect History.* PhD thesis, Tulane University.

Jun, S.-A. (1993). *The Phonetics and Phonology of Korean Prosody.* PhD thesis, The Ohio State University.

Jun, S.-A. (1994). Metrical weight consistency in Korean partial reduplication. *Phonology*, 11:69–88.

Jun, S.-A. (1995). Asymmetrical prosodic effects on the laryngeal gesture in Korean. In Connell, B. and Arvaniti, A., editors, *Phonology and Phonetic Evidence: Papers in laboratory phonology 4*, chapter 17, pages 235–253. Cambridge University Press.

Kagaya, R. and Hirose, H. (1975). Fiberoptic, electromyographic, and acoustic analysis of Hindi stop consonants. *Annual Bulletin, Research Institute of Logopedics and Phoniatrics*, 9:27–46.

Kager, R. (1999). *Optimality Theory.* Cambridge University Press.

Kaufman, T. (2003). Proto-Zapotec Reconstructions. ms.

Kavitskaya, D. (2002). *Compensatory Lengthening: Phonetics, Phonology, Diachrony.* Routledge: New York.

Keating, P. (1984). Phonetic and phonological representation of stop consonant voicing. *Language*, 60:286–319.

Keating, P., Cho, T., Fougeron, C., and Hsu, C.-S. (2000). Domain-initial articulatory strengthening in four languages. In Local, J., Ogden, R., and Temple, R., editors, *Papers in laboratory phonology 6*, chapter 10. Cambridge University Press.

Keating, P. A. (1985). Universal phonetics and the organization of grammars. In Fromkin, V. A., editor, *Phonetic linguistics: essays in honor of Peter Ladefoged.* Academic Press.

Keating, P. A. and Esposito, C. (2006). Linguistic voice quality. *UCLA Working Papers in Phonetics*, 105:85–91.

Kehrein, W. (2002). *Phonological representation and phonetic phasing: affricates and laryngeals.* Niemeyer, Tübingen.

Kempster, G. B., Larson, C. R., and Kistler, M. K. (1988). Effects of electrical stimulation of cricothyroid and thyroarytenoid muscles on voice fundamental frequency. *Journal of Voice*, 2(3):221–229.

Kenstowicz, M. (1994). *Phonology in Generative Grammar*. Blackwell Publishing.

Keyser, S. J. and Kiparsky, P. (1984). Syllable structure in Finnish phonology. In Aronoff, M. and Oehrle, R. T., editors, *Language Sound Structure*, pages 7–31. MIT Press, Cambridge, MA.

Khouw, E. and Ciocca, V. (2007). Perceptual correlates of cantonese tones. *Journal of Phonetics*, 35:104–117.

Kim, C. (1970). A theory of aspiration. *Phonetica*, 21:107–116.

Kim, M.-R. and Duanmu, S. (2004). "Tense" and "lax" stops in Korean. *Journal of East Asian Linguistics*, 13:59–104.

Kingston, J. (1985). *The Phonetics and Phonology of the Timing of Oral and Glottal Events.* PhD thesis, University of California, Berkeley.

Kingston, J. (1986). Are F0 differences after stops accidental or deliberate? *Journal of the Acoustical Society of America Supplemental*, 79(1):S27.

Kingston, J. (1990). Articulatory binding. In Kingston, J. and Beckman, M. E., editors, *Papers in laboratory phonology 1: between the grammar and the physics of speech*, pages 406–434. Cambridge University Press.

Kingston, J. (2005). The phonetics of Athabaskan tonogenesis. In Hargus, S. and Rice, K., editors, *Athabaskan Prosody.* Amsterdam: John Benjamins.

Kingston, J. (2007). The phonetics-phonology interface. In DeLacy, P., editor, *The Cambridge Handbook of Phonology*, chapter 17, pages 401–434. Cambridge University Press.

Kingston, J. and Diehl, R. L. (1994). Phonetic knowledge. *Language*, 70(3):419–454.

Kingston, J., Diehl, R. L., Kirk, C. J., and Castleman, W. A. (2008). On the internal perceptual structure of distinctive features: the [voice] contrast. *Journal of Phonetics*, 36:28–54.

Kirchner, R. (1998). *An effort-based approach to consonant lenition.* PhD thesis, UCLA.

Kirchner, R. (2000). Geminate inalterability and lenition. *Language*, 76(3):509–545.

Kirk, P. L., Ladefoged, J., and Ladefoged, P. (1993). Quantifying acoustic properties of modal, breathy, and creaky vowels in jalapa mazatec. In Mattina, A. and Montler, T., editors, *American Indian Linguistics and Ethnography in honor of Lawrence C. Thompson*, pages 435–450. University of Michigan, Ann Arbor.

Kirk, P. L., Ladefoged, P., and Ladefoged, J. (1984). Using a spectrograph for measures of phonation types in a natural language. *UCLA Working Papers in Phonetics*, 59:102–113.

Klatt, D. (1980). Software for a Cascad/Parallel Formant Synthesizer. *Journal of the Acoustical Society of America*, 67:971–995.

Kluender, K. R., Diehl, R. L., and Wright, B. A. (1988). Vowel-length differences before voiced and voiceless consonants: an auditory explanation. *Journal of Phonetics*, 16:153–169.

Kodzasov, S. V. (1977). Fonetika archinskogo jazyka. In Kibrik, A. E., Kodzasov, S. V., Olovjannikova, I. P., and Samedov, D. S., editors, *Opyt Strukturnogo Opisanija Archinskogo Jazyka*, Part 2. Izdatel'stvo Moskovskogo Universiteta, Moscow.

Kohler, K. J. (1979). Dimensions in the perception of fortis and lenis plosives. *Phonetica*, 36:332–343.

Kohler, K. J. (1981). Timing of articulatory control in the production of plosives. *Phonetica*, 38:116–125.

Kohler, K. J. (1982). F0 in the perception of lenis and fortis plosives. *Phonetica*, 39:199–218.

Kohler, K. J. (1984). Phonetic explanation in phonology: The feature fortis/lenis. *Phonetica*, 41:150–174.

Kraehenmann, A. (2001). Swiss German stops: geminates all over the word. *Phonology*, 18:109–145.

Krauss, M. (2005). Athabaskan Tone. In Hargus, S. and Rice, K., editors, *Athabaskan Prosody*. Amsterdam: John Benjamins.

Kreiman, J., Gerratt, B., and Antoñanzas Barroso, N. (2007). Measures of the glottal source spectrum. *Journal of Speech, Language, and Hearing Research*, 50:595–610.

Ladefoged, P. (1971). *Preliminaries to Linguistic Phonetics.* Chicago, University of Chicago.

Ladefoged, P. (2003). *Phonetic Data Analysis.* Blackwell.

Ladefoged, P. and Antoñanzas Barroso, N. (1985). Computer measures of breathy phonation. *UCLA Working Papers in Phonetics*, 61:79–86.

Ladefoged, P. and Maddieson, I. (1985). Tense and lax in four minority languages of china. *Journal of Phonetics*, 13:433–454.

Ladefoged, P. and Maddieson, I. (1996). *Sounds of the World's Languages.* Oxford: Blackwell.

Ladefoged, P., Maddieson, I., and Jackson, M. (1988). Investigating phonation types in different languages. In Fujimura, O., editor, *Vocal Physiology: voice production, mechanisms and functions*, pages 297–317. Raven Press, Ltd., New York.

Lahiri, A. and Hankamer, J. (1988). The timing of geminate consonants. *Journal of Phonetics*, 16:327–338.

Laver, J. (1980). *The Phonetic Description of Voice Quality.* Cambridge University Press.

Laver, J. (1991). The description of voice quality in general phonetic theory. In *The Gift of Speech: Papers in the Analysis of Speech and Voice.* Edinburgh University Press.

Lavoie, L. M. (2001). *Consonant Strength: Phonological Patterns and Phonetic Manifestations.* Outstanding Dissertations in Linguistics. Garland Publishing, Inc.

Leben, W. (1973). *Suprasegmental Phonology.* PhD thesis, MIT.

Leer, J. (1999). Tonogenesis in Athabaskan. In Kaji, S., editor, *Cross-linguistic Studies of Tonal Phenomena: Tonogenesis, Typology, and Related Topics*, pages 37–66. Institute for the Study of Languages and Cultures of Asia and Africa, Tokyo University of Foreign Studies.

Lehiste, I. (1970). *Suprasegmentals.* MIT Press, Cambridge, MA.

Lehmann, W. P. (1967). *A Reader in Nineteenth Century Historical Indo-European Linguistics*. Bloomington: Indiana University Press.

León, N. (1902). Familias Lingüísticas de México. *Anales del Museo Nacional de México*, Primera Época(Tomo VII):279–335.

Lindblom, B. (1983). The economy of speech gestures. In MacNeilage, P. F., editor, *The Production of Speech*, pages 217–243. Springer-Verlag.

Lisker, L. (1957). Closure duration and the intervocalic voiced-voiceless distinction in English. *Language*, 33:42–49.

Lisker, L. and Abramson, A. S. (1964). A cross-language study of voicing in initial stops: acoustical measurements. *Word*, 20:384–422.

Liu, S. and Samuel, A. (2004). Perception of mandarin lexical tones when f0 information is neutralized. *Language and Speech*, 47(2):109–138.

Löfqvist, A. (1980). Interarticulator programming in stop production. *Journal of Phonetics*, 8:475–490.

Löfqvist, A. (2007). Tongue movement kinematics in long and short Japanese consonants. *Journal of the Acoustical Society of America*, 122(1):512–518.

Löfqvist, A., Baer, T., McGarr, N. S., and Seider Story, R. (1989). The cricothyroid muscle in voicing control. *Journal of the Acoustical Society of America*, 85:1314–1321.

Löfqvist, A. and Gracco, V. L. (1994). Tongue body kinematics in velar stop production: influences of consonant voicing and vowel context. *Phonetica*, 51:52–67.

Löfqvist, A. and Gracco, V. L. (1997). Lip and jaw kinematics in bilabial stop consonant production. *Journal of Speech, Language, and Hearing Research*, 40:877–893.

Löfqvist, A. and McGowan, R. S. (1992). Influence of consonantal environment on voice source aerodynamics. *Journal of Phonetics*, 20:93–110.

Löfqvist, A. and Yoshioka, H. (1979). Laryngeal articulation in Swedish obstruent clusters. In Wolf, J. and Klatt, D., editors, *Speech Communication Papers Presented at the 97th Meeting of the Acoustical Society of America*, New York. Acoustical Society of America.

Long, R. C. and Cruz, S. M. (2000). *Diccionario Zapoteco de San Bartolomé Zoogocho, Oaxaca.* Number 38 in Serie de Vocabularios y Diccionarios Indígenas. Instituto Lingüistico de Verano, Mexico City, Mexico, segunda edición, (electronic) edition.

Longacre, R. E. (1952). Five phonemic pitch levels in Trique. *Acta Linguistica*, 7:62–81.

Longacre, R. E. (1957). Proto-Mixtecan. In *Indiana University Research Center in Anthropology, Folklore, and Linguistics*, volume 5. Indiana University Research Center in Anthropology, Folklore, and Linguistics, Bloomington.

Longacre, R. E. (1959). Trique Tone Morphemics. *Anthropological Linguistics*, 1(4):5–42.

Lubder, J., McAllister, R., and Lindblom, B. (1977). On the notion of interarticulator programming. *Journal of Phonetics*, 5:213–226.

Luce, P. A. and Charles-Luce, J. (1985). Contextual effects on vowel duration, closure duration, and the consonant/vowel ratio in speech production. *Journal of the Acoustical Society of America*, 78(6):1949–1957.

Lyman, L. and Lyman, R. (1977). Choapan Zapotec phonology. In Merrifield, W. R., editor, *Studies in Otomanguean Phonology*, pages 137–161. Summer Institute of Linguistics, University of Texas at Arlington.

Macaulay, M. (1996). *A Grammar of Chalcatongo Mixtec*, volume 127 of *University of California Publications in Linguistics.* University of California Press.

Macaulay, M. and Salmons, J. C. (1995). The Phonology of Glottalization in Mixtec. *International Journal of American Linguistics*, 61(1):38–61.

Macken, M. A. and Salmons, J. C. (1997). Prosodic templates in sound change. *Diachronica*, 14(1):31–66.

Maddieson, I. (1978). Universals of tone. In Greenberg, J. H., Ferguson, C. A., and Moravcsik, E. A., editors, *Universals of Human Language*, volume 2, Phonology. Stanford University Press.

Maddieson, I. (1984). *Patterns of Sounds.* Cambridge University Press.

Maddieson, I. (1985). Phonetic cues to syllabification. In Fromkin, V. A., editor, *Phonetic linguistics: essays in honor of Peter Ladefoged*, pages 203–221. Academic Press: New York.

Maddieson, I. (1999). Strength matters? In Ohala, J. J., Hasegawa, Y., Ohala, M., Granville, D., and Bailey, A. C., editors, *Proceedings of the 14th International Congress of Phonetic Sciences*, volume 3, pages 1965–1968. University of California, Berkeley.

Maddieson, I. (2001). Phonetic fieldwork. In Newman, P. and Ratliff, M., editors, *Linguistic Fieldwork*, pages 211–229. Cambridge University Press.

Malécot, A. (1966). Mechanical pressure as an index of 'force of articulation'. *Phonetica*, 14:169–180.

Malécot, A. (1970). The lenis-fortis opposition: its physiological parameters. *Journal of the Acoustical Society of America*, 47:1588–1592.

Marlett, S. A. and Pickett, V. B. (1987). The Syllable Structure and Aspect Morphology of Isthmus Zapotec. *International Journal of American Linguistics*, 53(4):398–422.

Marti, W. (1985). *Berndeutsch-Grammatik.* Bern: Francke.

Martínez Ríos, J. (1961). Los Estudios Lingüísticos en el Estado de Oaxaca, México. *Revista Mexicana de Sociología*, 23(3):933–971.

Matisoff, J. (1973). Tonogenesis in Southeast Asia. In Hyman, L., editor, *Consonant Types and Tone: Southern California Occasional Papers in Linguistics*, volume 1, pages 73–95. University of Southern California.

Matisoff, J. A. (1999). Tibeto-Burman Tonology in an Areal Context. In Kaji, S., editor, *Cross-linguistic Studies of Tonal Phenomena: Tonogenesis, Typology, and Related Topics*, pages 3–32. Institute for the Study of Languages and Cultures of Asia and Africa, Tokyo University of Foreign Studies.

McCarthy, J. (1979). *Formal problems in Semitic phonology and morphology.* PhD thesis, MIT.

McCarthy, J. (1986). Ocp effects: Gemination and antigemination. *Linguistic Inquiry*, 17:207–263.

Mechling, W. H. (1912). The Indian Linguistic Stocks of Oaxaca, Mexico. *American Anthropologist*, 14:643–682.

Michaud, A. (2004). Final consonants and glottalization: New perspectives from Hanoi Vietnamese. *Phonetica*, 61:119–146.

Moreton, E. (2004). Realization of the English postvocalic [voice] contrast in F$_1$ and F$_2$. *Journal of Phonetics*, 32:1–33.

Mugele, R. L. (1982). *Tone and Ballistic Syllable in Lalana Chinantec.* PhD thesis, University of Texas, Austin.

Muller, J. S. (2001). *The Phonology and Phonetics of Word-Initial Geminates.* PhD thesis, The Ohio State University.

Munhall, K. G., Kawato, M., and Vatikiotis-Bateson, E. (2000). Coarticulation and physical models of speech production. In Broe, M. and Pierrehumbert, J., editors, *Papers in laboratory phonology 5: acquisition and the lexicon*, pages 9–28. Cambridge University Press.

Munhall, K. G. and Löfqvist, A. (1992). Gestural aggregation in speech: laryngeal gestures. *Journal of Phonetics*, 20:93–110.

Munro, P. and Lopez, F. H. (1999). *Di'csyonnary x:tèe'n dìi'zh Sah Sann Lu'uc / San Lucas Quiaviní Zapotec Dictionary.* Los Angeles: Chicano Studies Research Center Publications.

Murray, R. W. (2000). Syllable cut prosody in Early Middle English. *Language*, 76(3):617–654.

Murry, T. and Brown, W. S. (1971). Subglottal air pressure during two types of vocal activity: Vocal fry and modal phonation. *Folia Phoniatria*, 23:440–449.

Nellis, D. G. and Hollenbach, B. E. (1980). Fortis versus Lenis in Cajonos Zapotec Phonology. *International Journal of American Linguistics*, 46(2):92–105.

Nespor, M. and Vogel, I. (1986). *Prosodic Phonology.* Dordrecht: Foris.

Ní Chasaide, A. and Gobl, C. (1997). Voice source variation. In Hardcastle, W. J. and Laver, J., editors, *The handbook of phonetic sciences.* Blackwell.

Ogden, R. (1995). “Where” is timing? Comments on Smith. In Connell, B. and Arvaniti, A., editors, *Phonology and Phonetic Evidence: Papers in laboratory phonology 4*, chapter 16, pages 223–234. Cambridge University Press.

Ohala, J. J. (1981). The listener as a source of sound change. In Masek, C. S., Hendrick, R. A., and Miller, M. F., editors, *Papers from the parasession on language and behavior*, pages 178–203. Chicago: Chicago Linguistics Society.

Ohala, J. J. (1983). The origin of sound patterns in vocal tract constraints. In MacNeilage, P. F., editor, *The Production of Speech*, pages 189–216. Springer-Verlag.

Ohala, J. J. (2005). Phonetic explanations for sound patterns: Implications for grammars of competence. In Laver, J., Hardcastle, W. J., and MacKenzie Beck, J., editors, *A Figure of Speech: A Festschrift for John Laver*, chapter 2. Routledge.

Ohala, J. J. and Ohala, M. (1993). The phonetics of nasal phonology: theorems and data. In Huffman, M. K. and Krakow, R. A., editors, *Nasals, Nasalization, and the Velum*. San Diego: Academic Press.

Öhman, S. E. G. (1967). Numerical model of coarticulation. *Journal of the Acoustical Society of America*, 41:310–320.

Parker, S. (2001). Non-optimal onsets in Chamicuro: an inventory maximised in coda position. *Phonology*, 18:361–386.

Paster, M. and Beam de Azcona, R. (2005). A phonological sketch of the Yucunany dialect of Mixtepec Mixtec. In *Proceedings of the Seventh Annual Workshop on American Indigenous Languages*, pages 61–76.

Payne, E. M. (2006). Non-durational indices of Italian geminate consonants. *Journal of the International Phonetic Association*, 36(1):83–95.

Pearce, M. D. (2007). *The interaction of tone with voicing and foot structure*. PhD thesis, University College London.

Peng, L. (1992). *A unified theory of tone-voice*. PhD thesis, University of Arizona.

Pennington, M. (2005). *The Phonetics and Phonology of Glottal Manner Features*. PhD thesis, Indiana University.

Perkell, J. (1969). *Physiology of speech production.* MIT Press.

Perkell, J., Guenther, F., Lane, H., Matthies, M., Perrier, P., Vick, J., Wilhelms-Tricarico, R., and Zandipour, M. (2000). A theory of speech motor control and supporting data from speakers with normal hearing and with profound hearing loss. *Journal of Phonetics*, 28:233–272.

Perkell, J., Matthies, M., Lane, H., Guenther, F., Wilhelms-Tricarico, R., Wozniak, J., and Guiod, P. (1997). Speech motor control: Acoustic goals, saturation effects, auditory feedback, and internal models. *Speech Communication*, 22:227–250.

Peterson, G. E. and Lehiste, I. (1960). Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, 32:693–703.

Pickett, V. (1959). *The grammatical hierarchy of Isthmus Zapotec.* PhD thesis, University of Michigan.

Pierrehumbert, J. and Talkin, D. (1992). Lenition of /h/ and glottal stop. In *Papers in laboratory phonology 2: Gesture, Segment, Prosody*, pages 90–117. Cambridge University Press.

Port, R. F. (1979). Influence of tempo on stop closure duration as a cue for voicing and place. *Journal of Phonetics*, 7:45–56.

Port, R. F. and Dalby, J. (1982). Consonant/vowel ratio as a cue for voicing in English. *Perception and Psychophysics*, 32:141–152.

Powell, J. and Woodruff, F. (1976). *Quileute Dictionary.* University of Idaho, Moscow, Idaho.

Premsrirat, S. (1996). Phonological characteristics of So (Thavung), a Vietic language of Thailand. *Mon-Khmer Studies*, 26:161–178.

Premsrirat, S. and Malone, D. (2003). Language development and language revitalization in asia. SIL International, Mahidol University.

Prince, A. and Smolensky, P. (1993). Optimality theory: constraint interaction in generative grammar. Technical Report 2, Rutgers University Center for Cognitive Science, Cambridge, MA., MIT Press.

Pycha, A. (2008). *Morphological Sources of Phonological Length.* PhD thesis, University of California, Berkeley.

R Development Core Team, Vienna, A. (2007). R: A language and environment for statistical computing [computer program]. http://www.R-project.org, R Foundation for Statistical Computing.

Raphael, L. F. (1972). Preceding vowel duration as a cue to the perception of the voicing characteristics of word-final consonants in English. *Journal of the Acoustical Society of America*, 51:1296–1303.

Remesz, O. http://en.wikipedia.org/wiki/image:larynx_external_en.svg.

Rensch, C. R. (1976). *Comparative Otomanguean Phonology.* Number 14 in Language Science Monograph. Bloomington: Indiana University.

Rensch, C. R. (1990). Phonological realignment in Lealao Chinantec. In Merrifield, W. R. and Rensch, C. R., editors, *Syllables, Tone, and Verb Paradigms: Studies in Chinantec Languages*, volume 4, pages 75–89. SIL Arlington.

Repp, B. H. (1979). Relative amplitude of aspiration noise as a voicing cue for syllable-initial stop consonants. *Language and Speech*, 22:173–189.

Ridouane, R. (2007). Gemination in Tashlhiyt Berber: an acoustic and articulatory study. *Journal of the International Phonetic Association*, 37(2):119–142.

Riordan, C. J. (1980). Larynx height during English stop consonants.

Rothenberg, M. (1981). Some relations between glottal air flow and vocal fold contact area. In Ludlow, C. L. and Hart, M. O., editors, *Proceedings of the Conference on Assessment of Vocal Pathology*, volume 11 of *ASHA Report.*

Saltzman, E. and Munhall, K. G. (1989). A dynamical approach to gestural patterning in speech production. *Ecological Psychology*, 1:333–382.

Sawashima, M., Hirose, H., and Yoshioka, H. (1978). Abductor (PCA) and adductor (INT) muscles of the larynx in voiceless sound production. *Annual Bulletin, Research Institute of Logopedics and Phoniatrics*, 12:53–60.

Schein, B. and Steriade, D. (1986). On Geminates. *Linguistic Inquiry*, 17(4):691–744.

Shipp, T. and McGlone, R. (1971). Laryngeal dynamics associated with voice frequency change. *Journal of Speech, Language, and Hearing Research*, 14:761–768.

Silva, D. J. (1992). *The Phonetics and Phonology of Stop Lenition in Korean.* PhD thesis, Cornell University.

Silverman, D. (1997a). Laryngeal complexity in Otomanguean vowels. *Phonology*, 14:235–261.

Silverman, D. (1997b). *Phasing and Recoverability.* Outstanding Dissertations in Linguistics. Routledge.

Silverman, D. (2002). The diachrony of labiality in Trique and the functional relevance of gradience and variation. In Goldstein, L., Whalen, D. H., and Best, C. T., editors, *Laboratory Phonology 8: Varieties of Phonological Competence.* Mouton de Gruyter.

Silverman, D., Blankenship, B., Kirk, P., and Ladefoged, P. (1994). Phonetic structures in Jalapa Mazatec. *UCLA Working Papers in Phonetics*, 87:113–130.

Slis, I. H. and Cohen, A. (1969). On the complex regulating the voiced-voiceless distinction i. *Language and Speech*, 12:80–102.

Smith, C. L. (1995). Prosodic patterns in the coordination of vowel and consonant gestures. In Connell, B. and Arvaniti, A., editors, *Phonology and Phonetic Evidence: Papers in laboratory phonology 4*, chapter 15, pages 205–222. Cambridge University Press.

Stevens, K. N. (2000). *Acoustic Phonetics.* MIT Press, first edition.

Stevens, K. N. (2002). Toward a model for lexical access based on acoustic landmarks and distinctive features. *Journal of the Acoustical Society of America*, 111(4):1872–1891.

Stevens, K. N. and Blumstein, S. E. (1981). The search for invariant acoustic correlates of phonetic features. In Eimas, P. D. and Miller, J. L., editors, *Perspectives on the study of speech*, pages 1–38. Lawrence Erlbaum, Hillsdale, NJ.

Stevens, K. N. and Hanson, H. M. (1995). Classification of glottal vibration from acoustic measurements. In Fujimura, O. and Hirano, M., editors, *Vocal Fold Physiology: voice quality control.* Singular Publishing Group, San Diego, California.

Stevens, K. N. and Keyser, S. J. (1989). Primary features and their enhancement in consonants. *Language*, 65:81–106.

Stevens, M. and Hajek, J. (2004). Comparing voiced and voiceless geminates in Sienese Italian: what role does preaspiration play? In *Proceedings of the 10th Australian International Conference on Speech Science & Technology*, pages 340–345. Macquarie University, Sydney, Australian Speech Science & Technology Association, Inc.

Stoakes, H., Fletcher, J., and Butcher, A. (2007). An acoustic study of Bininj Gun-Wok medial stop consonants. In Trouvain, J. and Barry, W. J., editors, *Proceedings of the 16th International Congress of Phonetic Sciences*, pages 869–872, University of Saarbrücken.

Story, B. H. and Titze, I. R. (2002). A preliminary study of voice quality transformation based on modifications to the neutral vocal tract area function. *Journal of Phonetics*, 30:485–509.

Suárez, J. A. (1973). On Proto-Zapotec Phonology. *International Journal of American Linguistics*, 39:236–249.

Summers, W. V. (1987). Effects of stress and final consonant voicing on vowel production: articulatory and acoustic analysis. *Journal of the Acoustical Society of America*, 82:847–863.

Sundberg, J. (1979). Maximum speed of pitch changes in singers and untrained subjects. *Journal of Phonetics*, 7:71–79.

Sundberg, J., Andersson, M., and Hultqvist, C. (1999). Effects of subglottal pressure variation on professional baritone singers' voice sources. *Journal of the Acoustical Society of America*, 105:1965–1971.

Svantesson, J.-O. (1989). Tonogenetic mechanisms in northern Mon-Khmer. *Phonetica*, 46:60–79.

Svantesson, J.-O. and House, D. (2006). Tone production, tone perception, and Kammu tonogenesis. *Phonology*, 23:309–333.

Swadesh, M. (1947). The Phonemic Structure of Proto-Zapotec. *International Journal of American Linguistics*, 13:220–230.

Tang, K. E. (2008). *The Phonology and Phonetics of Consonant-Tone Interaction.* PhD thesis, UCLA.

Thongkum, T. (1988). Phonation types in mon-khmer languages. In Fujimura, O., editor, *Vocal Physiology: voice production, mechanisms and functions*, pages 319–333. Raven Press, Ltd.

Thongkum, T. (1991). An instrumental study of chong registers. In Davidson, J., editor, *Essays in Mon-Khmer Linguistics in Honor of H. L. Shorto*, pages 141–160. London: School of Oriental and African Studies.

Thurgood, G. (2002). Vietnamese and tonogenesis. *Diachronica*, 19(2):333–363.

Titze, I. R. (1994). *Principles of Voice Production.* Prentice-Hall, Englewood Cliffs, NJ.

Titze, I. R. and Talkin, D. (1981). Simulation and interpretation of glottographic waveforms. In Ludlow, C. L. and Hart, M. O., editors, *Proceedings of the Conference on Assessment of Vocal Pathology*, volume 11 of *ASHA Report.*

Traill, A. (1985). *Phonetic and Phonological Studies of the !Xóõ Bushman.* Helmut Buske Verlag, Hamburg.

Traill, A. and Jackson, M. (1987). Speaker variation and phonation types in tsonga nasals. *UCLA Working Papers in Phonetics*, 67:1–29.

Tumtavitikul, A. (2004). A stroboscopic study of the register distinction in Chong. In *Proceedings of the 15th International Congress of the Phonetic Sciences*, Barcelona.

Ungsitipoonporn, S. (2001). A Phonological Comparison between Khlong Phlu Chong and Wang Kraphrae Chong. Master's thesis, Institute of Language and Culture for Rural Development, Mahidol University.

van Alphen, P. M. and Smits, R. (2004). Acoustical and perceptual analysis of the voicing distinction in Dutch initial plosives. *Journal of Phonetics*, 32:455–491.

Van Bael, C., Baayen, H., and Strik, H. (2007). Segment deletion in spontaneous speech: A corpus study using mixed effects models with crossed random effects. In *Proceedings from Interspeech 2007*, Antwerp, Belgium.

Watkins, J. (2002). *The Phonetics of Wa: Experimental phonetics, Phonology, Orthography, and Sociolinguistics*, volume 531. Pacific Linguistics.

Wayland, R. and Jongman, A. (2003). Acoustic correlates of breathy and clear vowels: the case of Khmer. *Journal of Phonetics*, 31:181–201.

Westbury, J. R. (1983). Enlargement of the supraglottal cavity and its relation to stop consonant voicing. *Journal of the Acoustical Society of America*, 73:1322–1336.

Westbury, J. R. and Keating, P. A. (1986). On the naturalness of stop consonant voicing. *Journal of Linguistics*, 22:145–166.

Wetzels, W. L. and Mascaró, J. (2001). The typology of voicing and devoicing. *Language*, 77(2):207–244.

Whitehead, R. W., Metz, D. E., and Whitehead, B. H. (1984). Vibratory patterns of the vocal folds during pulse register phonation. *Journal of the Acoustical Society of America*, 75:1293–1297.

Wolf, C. G. (1978). Voicing cues in English final stops. *Journal of Phonetics*, 6:299–309.

Xu, C. and Xu, Y. (2003). Effects of consonant aspiration on Mandarin tones. *Journal of the International Phonetic Association*, 33:165–181.

Yip, M. (1980). Some fragments of the tonal phonology of Mandarin. *Cahiers de Linguistique - Asie Orientale*, 7:47–57.

Yip, M. (1993). Tonal Register in East Asian Languages. In Van der Hulst, H. and Snider, K., editors, *The Phonology of Tone: The Representation of Tonal Register*. Mouton de Gruyter.

Yip, M. (2002). *Tone*. Cambridge Textbooks in Linguistics. Cambridge University Press.

Zec, D. (1988). *Sonority Constraints on Prosodic Structure*. PhD thesis, Stanford University.

Zhang, J. (2001). *The Effects of Duration and Sonority on Contour Tone Distribution - Typological Survey and Formal Analysis*. PhD thesis, UCLA.

Zhang, J. (2004). The role of contrast-specific and language-specific phonetics in contour tone distribution. In Hayes, B., Kirchner, R., Kirchner, R. M., and Steriade, D., editors, *Phonetically-based Phonology*. Cambridge University Press.

Appendix A

Stimuli Used in Phonetic Experiments

(1) ni^{3}ʔja^{32} mo^{4}li^{43} tʃãʔ^{1} nã^{3}
see.1sg mole tasty here
‘I see good mole here.’

(2) kwa^{3}ni^{32} ʔniʔ^{1} ni^{3}ja^{32}
today be.salty food
‘Today, the food is salty.’

(3) kwa^{3}ni^{32} ka^{3}ʔmi^{32} snã^{4}ʔãh^{4}–niʔ^{2} ni^{3}gjãh^{5}
today PERF.speak.1sg language-1.du Tlaxiaco
‘Today I spoke Trique in Tlaxiaco.’

(4) kwa^{3}ni^{32} ka^{1} βiʔ^{1} ŋgwi^{31}–tʃa^{1}na^{1}
today POT.die.3sg person–female
‘Today, a woman will die.’

(5) ni^{3}ʔja^{32} ttʃiʔ^{2} nu$^{3\mathrm{h}}$ta^{1} nã^{3}
see.1sg ten tamales here
‘I see ten tamales here.’

(6) kwa^{3}ni^{32} βa^{32} ru^{2}miʔ^{2} nã^{3}
today be dark here
‘Today, it is dark here.’

(7) kwa^{3}ni^{32} tʃãʔ^{3} ŋgwi^{31}–tʃa^{1}na^{1} nã^{3}–ũh^{1}
today scold person–female prox–1.sg
‘Today, this woman scolded me.’

(8) ni^{3}ʔja^{32} ka^{3}ɣaʔ^{3} nã^{3}
see.1sg bottle/metal here
‘I see a bottle here.’

(9) ni^{3}ʔja^{32} tu^{3}neʔ^{3} u^{4}ruh^{4} nã^{3}
see.1sg tail donkey here
‘I see the donkey’s tail here.’

(10) ni^{3}ʔja^{32} si^{4}kiʔ^{4} nã^{3}
see.1sg gum here
‘I see the gum here.’

(11) ni^{3}ʔja^{32} tʃã^{1} nu$^{3\mathrm{h}}$ta^{1} nã^{3}
see.1sg eleven tamales here
‘I see eleven tamales here.’

(12) ni^{3}ʔja^{32} si^{4}sno^{43} tʃa$^{1\mathrm{h}}$kã^{1} nã^{3}
see.1sg man tall here
‘I see a tall man here.’

(13) kwa^{3}ni^{32} ka$^{2\mathrm{h}}$ka^{2} ŋgwi^{31}–tʃa^{1}na^{1}
today POT.burn.3sg person–female
Today, a woman will burn.

(14) kwa^{3}ni^{32} ka^{2}ka^{2} tu^{2}ʔβe^{2} nu^{3}ta^{1}
today expensive tamal
‘Today, tamales are expensive.’

(15) kwa^{3}ni^{32} βa^{32} tʃa$^{3\mathrm{h}}$ka^{3} neh^{4}
today go.1sg Yucunicoco tag
‘Today, I am going to Yucunicoco, eh?’

(16) kwa^{3}ni^{32} βa^{32} tʃi^{3}ne^{3} neh^{4}
today go.1sg San.Isidro.de.Morelos tag
‘Today, I am going to San Isidro de Morelos, eh?’

(17) ni^{3}ʔja^{32} stĩ^{4} nã^{3}
see.1sg fingernail here
I see a fingernail here.

(18) βa^{2} na^{4} ni^{3}kĩʔ^{4} si^{3}–pa^{4}lah^{4}
be long.time be.standing.3sg Gen-shovel.1sg
'My shovel is very old.'

(19) ni^{3}ʔja^{32} jo^{32} li^{43} nã^{3}
see.1sg sugarcane small here
'I see a small sugarcane here.'

(20) kwa^{3}ni^{32} ta^{3}ni^{43} na$^{3\text{h}}$to^{32}
today lower.1sg banana
'Today, I lower (put down) the banana.'

(21) kwa^{3}ni^{32} ni$^{4\text{h}}$ka^{43} na$^{3\text{h}}$to^{32} βa^{32}
today carry.1sg banana go.1sg
'Today, I take away the banana.'

(22) ni^{3}ʔja^{32} ti^{3}ni^{32} nã^{3}
see.1sg nopal here
'I see a nopal (cactus) here.'

(23) ni^{3}ʔja^{32} ni$^{3\text{h}}$ka^{32} ŋgwi^{31} nã^{3}
see.1sg spouse person here
'I see the spouse of the person here.

(24) ni^{3}ʔja^{32} tʃo^{32} nã^{3}
see.1sg comal here
'I see a comal here.'

(25) ni^{3}ʔja^{32} tʃa^{31} ŋgwi^{31} nã^{3}
see.1sg head person here
'I see the head of the person here.'

(26) na^{3}na^{4} ni^{31} βa^{32}
little.while night go.1sg
'In a little while at night, I will go.'

(27) kwa^{3}ni^{32} joh^{13} ka^{2}mi^{32} nã^{3}
today be.light/fast car here
‘Today, the car is light.’

(28) ni^{3}ʔja^{32} ne^{3}nih^{1} nã^{3}
see.1sg ground.cooked.bean here
‘I see cooked ground bean here.’

(29) kwã^{3} tʃa$^{1\mathrm{h}}$kãh^{1} toh^{3} ri^{3}ã^{32}–sih^{3}
day.before.yesterday be.tall.1sg little face–3.sg.masc
‘The day before yesterday, I was a little bit taller than him.’

(30) ni^{3}ʔja^{32} tʃu^{2}βih^{2} nu$^{3\mathrm{h}}$ta^{1} nã^{3}
see.1sg twelve tamales here
‘I see twelve tamales here.’

(31) kwa^{3}ni^{32} tʃa$^{2\mathrm{h}}$kah^{2}–si^{3}–ũh^{3}
today get.married–3.sg.masc–3.sg.fem
‘Today, he got married to her.’

(32) ni^{3}ʔja^{32} jãh^{3} nã^{3}
see.1sg paper here
‘I see paper here.’

(33) ni^{3}ʔja^{32} ku^{3}rih^{3} nã^{3}
see.1sg salamander here
‘I see a salamander here.’

(34) tʃu^{3}βe^{3} la$^{3\mathrm{h}}$kah^{3} βĩ^{3} tã^{4}–reʔ^{1}
dog skinny be CLF.anim–2.sg
‘Your animal is the skinny dog.’

(35) kwa^{3}ni^{32} tʃãh^{4} ŋgwi^{31} nã^{3}
today PERF.push person this
‘Today, these people were pushing.’

(36) kã^{2}ʔã^{2} skwe^{4}la^{43} rah^{4} a^{2}kwa^{3}ni^{32}
POT.go.1sg school want.1sg today
‘I want to go to the school today.’

(37) ni^{3}ʔja^{32} ska$^{4\mathrm{h}}$tah^{4} ni^{3}kah^{2}
see.1sg cuñado spouse.1sg
‘I see my spouse’s cuñado.’

(38) ni^{3}ʔja^{32} ʔnih^{35} nã^{3}
see.1sg corn here
‘I see corn here.’

(39) ni^{3}ʔja^{32} tʃu$^{3\mathrm{h}}$tãh^{5} nã^{3}
see.1sg fly here
‘I see a fly here.’

(40) ni^{3}ʔja^{32} tʃa$^{3\mathrm{h}}$kah^{5} nã^{3}
see.1sg pig here
‘I see a pig here.’

(41) ni^{3}ʔja^{32} jãh^{4} nã^{3}
see.1sg dirt here
‘I see dirt here.’

(42) ni^{3}ʔja^{32} toh^{13} ni^{3}ya^{32}
see.1sg little.bit food
‘I see a little food.’

(43) kwa^{3}ni^{32} jeh^{13} a$^{4\mathrm{h}}$tah^{4}–sih^{3} ri^{3}ã^{32}–reʔ^{1}
today yes say–3sg.masc face–2sg
‘Today he told you “yes”.’

(44) ni^{3}ʔja^{32} kkweh^{32}–stah^{13} nã^{3}
see.1sg vegetable.green–mustard here
‘I see mustard greens here.’

(45) kwa^{3}ni^{32} a$^{3\mathrm{h}}$ka^{1} tʃa^{31} βeʔ^{3}
today leak head house
‘Today, the roof is leaking.’

(46) ni^{3}ʔja^{32} tʃa$^{3\mathrm{h}}$ko^{3} ni$^{3\mathrm{h}}$koʔ^{1} nã^{3}
see.1sg honey.wasp.larva be.hanging here
‘I see a honey wasp larva hanging here.’

(47) ni^{3}ʔja^{32} tʃu$^{3\,\mathrm{h}}$ku^{3} nã^{3}
see.1sg animal here
‘I see an animal here.’

(48) ni^{3}ʔja^{32} kkã^{3} nã^{3}
see.1sg squash here
‘I see a squash here.’

(49) nã^{3}ʔã^{3} kã^{3}–tʃah^{4}–sih^{3}
burn.3sg tube–head–3sg.masc
‘His throat is burning (hurting).’

(50) ni^{3}ja^{32} ta^{3} tʃah^{4}
food this eat.1sg
‘I am eating this food.’

(51) ni^{3}ja^{32} tah^{2} tʃah^{4}
food rich eat.1sg
‘I am eating tasty food.’

(52) ni^{3}ʔja^{32} ja$^{3\,\mathrm{h}}$tu^{1} nã^{3}
see.1sg jicara here
‘I see a bowl here.’

(53) ni^{3}ʔja^{32} tʃu^{3}a$^{4\,\mathrm{h}}$tu^{43} nã^{3}
see.1sg billygoat here
‘I see a billygoat here.’

(54) ni^{3}ʔja^{32} tta^{3} nã^{3}
see.1sg field here
‘I see the field here.’

(55) ni^{3}ʔja^{32} tto^{32} nã^{3}
see.1sg metate here
‘I see the metate here.’

(56) ni^{3}ʔja^{32} ka$^{4\,\mathrm{h}}$to^{4} nã^{3}
see.1sg shirt here
‘I see the shirt here.’

(57) ni^{3}ʔja^{32} tto^{31} nã^{3}
see.1sg milk here
‘I see the millk here.’

(58) βa^{4}su^{43} ttah^{35} ri^{3}ã^{32} me^{4}sa^{43}
glass be.on face table
‘The glass is on top of the table.’

(59) kwa^{3}ni^{32} ka^{2}ʰto^{2} ri^{3}ã^{32} nna^{3}
today POT.sleep.1sg face bed
‘Today, I am sleeping on the bed.’

(60) ni^{3}ʔja^{32} ŋgwi^{31}–tʃa^{1}na^{1} ka^{1}ʰtĩ^{1} ni^{3}kĩʔ^{3} nã^{3}
see.1sg person–female skinny stand.3sg here
‘I see the skinny woman that is (standing) here.’

(61) ni^{3}ʔja^{32} ʈʂuh^{3} nu^{32} nã^{3}
see.1sg kettle be.inside here
‘I see a kettle inside here.’

(62) ni^{3}ʔja^{32} ʈʈʂuh^{3} nu^{32} nã^{3}
see.1sg egg be.inside here
‘I see an egg inside here.’

(63) ni^{3}ʔja^{32} tʃeh^{3}–tʃa^{1}na^{1} ni^{3}kĩʔ^{3} nã^{3}
see.1sg nun be.standing.3sg here
‘I see a nun standing here.’

(64) kwa^{3}ni^{32} kã^{3}ʔã^{32} tʃeh^{32}–kã^{1}ʔã^{1} mã^{3}
today PERF.go.1sg side–go distal
‘Today, I went down that road.’

(65) a^{3}ʔjoh^{3} ka^{2}ʰtʃih^{2} ta^{3}ʔni^{32}
tomorrow POT.grow.3sg son.1sg
‘Tomorrow my son will grow.’

(66) ni^{3}ʔja^{32} kkweh^{32} nu^{32} nã^{3}
see.1sg vegetable.green be.inside here
‘I see a vegetable green inside here.’

(67) kwa^{3}ni^{32} βa^{2} si^{3} kweh^{2} ri^{3}ã^{32} tʃi^{3}ŋga^{4}
tomorrow be indef. POT.jump.3sg face fence
‘Tomorrow, someone will jump over the fence.’

(68) ni^{3}ʔja^{32} kkweh^{3} mã^{4} ra^{3}ʔ^{3}–reʔ^{1}
see.1sg pus LOC.be hand–2sg
‘I see pus in your hand.’

(69) ni^{3}ʔja^{32} ββih^{1} na^{3}ʰto^{1} nu^{32} nã^{3}
see.1sg two tamales be.inside here
‘I see two tamales that are inside here.’

(70) ni^{3}ʔja^{32} ββeh^{35} nu^{32} nã^{3}
see.1sg straw.mat be.inside here
‘I see the straw mat that is here.’

(71) kwa^{3}ni^{32} βeh^{4} ni^{4}mãh^{3}
today beat heart.1sg
‘Today my heart is beating.’

(72) kwa^{3}ni^{32} na^{1}ʰka^{1} ββe^{4} nu^{32} nã^{3}
today collect.1sg hair here
‘Today I am collecting (sweeping up) the hair here.’

(73) ni^{3}ʔja^{32} ββeh^{3} nã^{3}
see.1sg cave here
‘I see the cave here.’

(74) ni^{3}ʔja^{32} ββe^{32} nã^{3}
see.1sg maguey.cactus here
‘I see the maguey cactus here.’

(75) ni^{3}ʔja^{32} jah^{32} nu^{32} nã^{3}
see.1sg flower be.inside here
‘I see the flower inside here.’

(76) ni^{3}ʔja^{32} jah^{3} nu^{32} nã^{3}
see.1sg ash be.inside here
‘I see the ash inside here.’

(77) ni^{3}ʔja^{32} jjeh^{3} nu^{32} nã^{3}
see.1sg stone be.inside here
‘I see the stone inside here.’

(78) kwa^{3}ni^{32} βa^{2} nneh^{1} ja^{3} ka^{4}neh^{3}
today be naked when PERF.bathe.1sg
‘Today, when I was bathing, I was naked.’

(79) kwa^{3}ni^{32} nniʔ^{2} ra^{43}–sih^{3}
today disgust be.central.to–3sg
‘Today, he is making a mess.’

(80) ni^{3}ʔja^{32} nnãh^{32} nu^{32} nã^{3}
see.1sg cigarette be.inside here
‘I see the cigarette inside here.’

(81) kwa^{3}ni^{32} nne^{2} ŋgwi^{31}–tʃa^{1}na^{1}
today lie.3sg person-female
‘Today, the woman is lying.’

(82) ni^{3}ʔja^{32} nneʔ^{3} nu^{32} nã^{3}
see.1sg mecate be.inside here
‘I see the mecate inside here.’

(83) ni^{3}ʔja^{32} nne^{3} nu^{32} nã^{3}
see.1sg plow be.inside here
‘I see the plow inside here.’

(84) ni^{3}ʔja^{32} nnãh^{3} nu^{32} nã^{3}
see.1sg bag be.inside here
‘I see the bag inside here.’

(85) ni^{3}ʔja^{32} tʃi^{3}nãh^{5} nu^{32} nã^{3}
see.1sg loom be.inside here
‘I see the loom inside here.’

(86) ni^{3}ʔja^{32} ru^{4}ne^{43} nu^{32} nã^{3}
see.1sg avocado be.inside here
‘I see the avocado inside here.’

(87) ni^{3}ʔja^{32} nne^{32} nu^{32} nã^{3}
see.1sg water be.inside here
‘I see the water inside here.’

(88) ni^{3}ʔja^{32} ru^{3}ne^{32} nu^{32} nã^{3}
see.1sg bean be.inside here
‘I see the bean inside here.’

(89) ni^{3}ʔja^{32} nne^{31} nu^{32} nã^{3}
see.1sg meat be.inside here
‘I see the meat inside here.’

(90) βa^{2} ʔβi^{1} na$^{3\mathrm{h}}$to^{1}
be raw/unripe banana
‘The banana is unripe.’

(91) βa^{2} ʔjo^{2} jo^{3}ʔoh^{5}
be humid land/ground
‘The ground is humid/moist.’

Appendix B

Praat scripts used for analyzing phonetic data

B.1 Duration Extraction Script

```
#Extraction of durations from textgrids.
#Saves the duration data as a text file with the name of the file and the interval
name.
#Copyright Christian DiCanio, UC Berkeley, 2/2008

form Extract Durations from labelled points
sentence Directory_name: /Directory/
sentence Objects_name: Filename
sentence Log_file Logname
positive Labeled_tiernumber tiernumber
sentence Interval_label label
positive Analysis_points_time_step 0.005
positive Record_with_precision 1
endform

Read from file... ’directory_name$”objects_name$’.aiff
soundID = selected(“Sound”)

Read from file... ‘directory_name$’‘objects_name$’.TextGrid
textGridID = selected(“TextGrid”)
num_labels = Get number of intervals... labeled_tier_number
```

```
select ‘soundID’
plus ‘textGridID’
Extract intervals where... labeled_tier_number no “is equal to” ‘interval_label$’

durID = selected (“Sound”)
objID = selected (“Sound”, -1)
for i from durID to objID
select ‘i’
dur = Get total duration
fileappend ‘directory_name$’‘log_file$’.txt ‘objects_name$’‘tab$’
‘interval_label$’‘tab$’‘dur’‘newline$’
endfor
select all
Remove
```

B.2 Pitch Extraction Script

```
# Extract_pitch_averages
# Ronald Sprouse, 10/2005
# Modified by Christian DiCanio, 2007

# Extract array of pitch values in labeled region and computer averages
# over every numintervals in the duration of the region. Write results to
# a text file.

numintervals = 10
#Number of intervals you wish to extract pitch from.

form Extract pitch data from labelled points
sentence Directory_name: /Directory/
sentence Objects_name:
sentence Log_file
positive Labeled_tier_number 1
positive Analysis_points_time_step 0.01
positive Record_with_precision 1
comment From sound to pitch:
positive Pitch_analysis_time_step 0.005
positive Minimum_pitch 75
positive Maximum_pitch 300
endform
```

```
#If your sound files are in a different format, you can insert that format instead of aiff below.
Read from file... ‘directory_name$’‘objects_name$’.aiff
soundID = selected(“Sound")

To Pitch... pitch_analysis_time_step minimum_pitch maximum_pitch
pitchID = selected(“Pitch")

Read from file... ‘directory_name$’‘objects_name$’.TextGrid
textGridID = selected(“TextGrid")
num_labels = Get number of intervals... labeled_tier_number

fileappend ‘directory_name$’‘log_file$’.txt label‘tab$’start‘tab$’end
for i to numintervals
fileappend ‘directory_name$’‘log_file$’.txt ‘tab$’‘i’
endfor

fileappend ’directory_name$”log_file$’.txt ’newline$’

# for storage of pitch data
for i to num_labels
select ‘textGridID’
label$ = Get label of interval... labeled_tier_number i
if length(label$)
select ‘textGridID’
start = Get starting point... labeled_tier_number i
end = Get end point... labeled_tier_number i
interval = (end-start)/numintervals
intvl_num = 1
position = start
fileappend ‘directory_name$’‘log_file$’.txt ‘label$’‘tab$’‘start’‘tab$’‘end’‘tab$’
while position <= end
total = 0
number = 0
while position < start + intvl_num * interval
select ‘textGridID’
select ‘pitchID’
hertz = Get value at time... position Hertz Linear
if hertz = undefined
# do nothing
else
total = total + hertz
number = number + 1
```

```
endif
position = position + analysis_points_time_step
endwhile
average = total / number
if total = 0
average$ = “NA"
else
average$ = fixed$(average, record_with_precision)
endif
if intvl_num = numintervals
fileappend ‘directory_name$’‘log_file$’.txt
... ‘average$’
else
fileappend ‘directory_name$’‘log_file$’.txt
... ‘average$’‘tab$’
endif
intvl_num = intvl_num + 1
endwhile
fileappend ‘directory_name$’‘log_file$’.txt ‘newline$’
endif
endfor
```

B.3 Spectral Tilt Extraction Script

```
# Extracts mean formant values, H1, H2, and spectral tilt measures.
# dynamically across an duration defined by the textgrid.
# The number of interval values extracted is equal to numintervals below.
# Writes results to a textfile.
# Christian DiCanio, 2007 – revised 2008 to include output amplitude values.

numintervals = 10
#Number of intervals you wish to extract pitch from.

form Extract Formant data from labelled points
sentence Directory_name: /Directory/
sentence Objects_name:
sentence Interval_label
sentence Log_file
positive Labeled_tier_number 1
positive Analysis_points_time_step 0.005
```

```
positive Record_with_precision 1
comment Formant Settings:
positive Analysis_time_step 0.005
positive Maximum_formant 5000
positive Number_formants 3
positive F1_ref 500
positive F2_ref 1475
positive F3_ref 2450
positive F4_ref 3550
positive F5_ref 4650
positive Window_length 0.005
comment Pitch Settings:
positive Pitch_floor 75
positive Pitch_ceiling 400
endform

maxf =maximum_formant

# If your sound files are in a different format, you can insert that format instead
of wav below.
# Resampling done for LPC analysis.
Read from file... ‘directory_name$’‘objects_name$’.aiff
soundID_bf = selected(“Sound")
select ‘soundID_bf’
Resample... 16000 50
soundID = selected(“Sound")
select ‘soundID’
Read from file... ‘directory_name$’‘objects_name$’.TextGrid
textGridID = selected(“TextGrid")
num_labels = Get number of intervals... labeled_tier_number

fileappend ‘directory_name$’‘log_file$’.txt label‘tab$’
for i to numintervals
fileappend ‘directory_name$’‘log_file$’.txt ‘i’F1‘tab$’‘i’F2‘tab$’‘i’F3‘tab$’
fileappend ‘directory_name$’‘log_file$’.txt ‘i’H1hz‘tab$’‘i’H2hz‘tab$’
fileappend ‘directory_name$’‘log_file$’.txt ‘i’H1-H2‘tab$’‘i’H1dB‘tab$’

‘i’H2dB‘tab$’‘i’H1-A1‘tab$’‘i’A1dB‘tab$’‘i’H1-A2‘tab$’‘i’A2dB
‘tab$’‘i’H1-A3‘tab$’‘i’A3dB‘tab$’
endfor
fileappend ‘directory_name$’‘log_file$’.txt ‘newline$’

for i to num_labels
select ‘textGridID’
```

```
label$ = Get label of interval... labeled_tier_number i
if label$ = interval_label$
fileappend ‘directory_name$’‘log_file$’.txt ‘objects_name$’‘tab$’
intvl_start = Get starting point... labeled_tier_number i
intvl_end = Get end point... labeled_tier_number i
select ‘soundID’
Extract part... intvl_start intvl_end Rectangular 1 no
intID = selected(“Sound")
To Pitch (ac)... ‘analysis_points_time_step’ ‘pitch_floor’ 15 no 0.03 0.45 0.01 0.35 0.14 ‘pitch_ceiling’
invl_pitch = selected(“Pitch")
chunkID = (intvl_end-intvl_start)/numintervals

for j to numintervals
#Getting formants and frequency boundaries 10% away from them. Writing to data file.

select ‘intID’
Extract part... (j-1)*chunkID j*chunkID Rectangular 1 no
chunk_part = selected(“Sound")
form_chunk = To Formant (burg)... 0 5 ‘maxf’ ‘window_length’ 50
formantID_bf = selected(“Formant")
Track... ‘number_formants’ ‘f1_ref’ ‘f2_ref’ ‘f3_ref’ ‘f4_ref’ ‘f5_ref’ 1 1 1
formantID = selected(“Formant")
f1 = Get mean... 1 0 0 Hertz
f1_a = f1-(f1/10)
f1_b = f1+(f1/10)
f2 = Get mean... 2 0 0 Hertz
f2_a = f2-(f2/10)
f2_b = f2+(f2/10)
f3 = Get mean... 3 0 0 Hertz
f3_a = f3-(f3/10)
f3_b = f3+(f3/10)
if j = numintervals
fileappend ‘directory_name$’‘log_file$’.txt
... ‘f1’‘tab$’‘f2’‘tab$’‘f3’
else
fileappend ‘directory_name$’‘log_file$’.txt
... ‘f1”tab$’‘f2’‘tab$”f3’
endif
select ‘intID’
select ‘formantID_bf’
select ‘formantID’
Remove
```

#Getting H1 and H2 values by extracting pitch values. Then getting the frequency
#boundaries 10% away from them. Writes H1 and H2 measures to data file.

```
select ‘invl_pitch’
h1hz = Get mean... (j-1)*chunkID j*chunkID Hertz
h1hz_a = h1hz-(h1hz/10)
h1hz_b = h1hz+(h1hz/10)
h2hz = h1hz*2
h2hz_a = h2hz-(h2hz/10)
h2hz_b = h2hz+(h2hz/10)
if j = numintervals
fileappend ‘directory_name$’‘log_file$’.txt
...‘tab$’‘h1hz’‘tab$’‘h2hz’
else
fileappend ‘directory_name$’‘log_file$’.txt
... ‘tab$’‘h1hz’‘tab$’‘h2hz’
endif
```

#Converting each chunk in interval to a long term average spectrum. Then queries the maximum amplitude within a frequency region specified by the frequency boundaries around H1, H2, F1, F2, and F3. The difference between these maxima is a measure of spectral tilt which is then written to the data file.

```
select ‘chunk_part’
To Ltas... 100
ltasID = selected(“Ltas")
h1db = Get maximum... h1hz_a h1hz_b None
h2db = Get maximum... h2hz_a h2hz_b None
a1db = Get maximum... f1_a f1_b None
a2db = Get maximum... f2_a f2_b None
a3db = Get maximum... f3_a f3_b None
h1_h2 = h1db - h2db
h1_a1 = h1db - a1db
h1_a2 = h1db - a2db
h1_a3 = h1db - a3db
if j = numintervals
fileappend ‘directory_name$’‘log_file$’.txt
... ‘tab$’‘h1_h2’‘tab$’‘h1db’‘tab$’‘h2db’‘tab$’‘h1_a1’‘tab$’‘a1db’‘tab$’
‘h1_a2’‘tab$’‘a2db’‘tab$’‘h1_a3’‘tab$’‘a3db’‘newline$’
else
fileappend ‘directory_name$’‘log_file$’.txt
... ‘tab$’‘h1_h2’‘tab$’‘h1db’‘tab$’‘h2db’‘tab$’‘h1_a1’‘tab$’‘a1db’‘tab$’
‘h1_a2’‘tab$’‘a2db’‘tab$’‘h1_a3’‘tab$’‘a3db’‘tab$’
```

```
endif
select ‘ltasID’
Remove
endfor
select ‘intID’
Remove
select ‘invl_pitch’
Remove
else
#do nothing
endif
endfor
select all
Remove
```