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THE PHONETICS OF FORTIS AND LENIS CONSONANTS IN ITUNYOSO TRIQUE

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This paper discusses the phonetic properties of the fortis–lenis distinction in San Martín Itunyoso Trique (Oto-Manguean). Discussions of the fortis–lenis contrast in related languages argue that it may instead be considered a geminate–singleton contrast. However, lenis obstruents are frequently realized with voicing and spirantization. These phenomena have led other researchers to argue against reanalyzing "fortis–lenis" contrasts as consonant length contrasts. In the first of two experiments, I show that the primary phonetic correlate of the fortis–lenis contrast in Itunyoso Trique is duration. Fortis obstruents are additionally realized with a glottal spreading gesture, which is absent in lenis obstruents. In the second experiment, I show that durational changes, due to speech rate, account for variable patterns of spirantization and partial voicing. Abstract features of articulatory effort are not necessary to account for the phonetic variation in lenis obstruents in Trique. This analysis argues in favor of considering the consonantal contrast in Trique as one based on consonant length and glottal features. The findings are discussed in relation to gestural models of speech production and to patterns within other Oto-Manguean languages.

[KEYWORDS: Oto-Manguean, phonetics, fortis, lenis, lenition]

1. Introduction. Descriptions of Trique languages (Oto-Manguean: Mixtecan) discuss a FORTIS–LENIS contrast among consonants (Hollenbach 1977; 1984 and Longacre 1952). In Chicahuaxtla Trique (ISO code: trs), for instance, fortis sonorants are longer than lenis ones, while fortis obstruents are "voiceless and slightly lengthened" and lenis obstruents vary from voiced to voiceless (Hollenbach 1977 and Longacre 1952). In many Oto-Manguean languages, the terms FORTIS and LENIS are used to refer to consonants which differ phonetically in consonant length (geminate–singleton), voicing, or in strength of articulation. In Zapotec languages (ISO code: zap), FORTIS and LENIS may be used as cover terms for what might be better described as a phonological length contrast (Jaeger 1983 and Avelino 2001). While some research argues against such an analysis (Bauernschmidt 1965 and Nellis and Hollenbach 1980), in many descriptions, the phonetic nature of this contrast simply goes unexplained.

The goal of this paper is to explain the phonetic nature of the fortis–lenis contrast in the Trique variant spoken in San Martín Itunyoso (ISO code: trq). The paper examines the contrast using both acoustic and electroglottographic (EGG) data. Among all consonants, the difference between fortis and lenis contrast is primarily realized by changes in consonant duration, while for

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obstruents, preaspiration is a significant correlate of the fortis series. No acoustic correlate of increased articulatory strength (amplitude, formant transition) is shown to be a significant correlate of the contrast. Furthermore, variable patterns of voicing and spirantization among lenis obstruents are shown to be correlated with stop closure duration. Even though lenis obstruents are voiceless and unaspirated, they undergo a pattern of PASSIVE VOICING when their duration is shortened (Westbury and Keating 1986, Jansen 2004, and Stevens and Hajek 2004). Given this observation, I argue that fortis (long) obstruents are phonologically specified with a [+SPREAD GLOTTIS] feature, while lenis (short) stops are laryngeally unspecified, surfacing as voiced when their closure duration is short enough to permit passive voicing. In Itunyoso Trique, variable voicing and spirantization in lenis obstruents is predictable solely based on consonant duration.

In the remainder of **1**, I provide a short discussion of the phonetics and phonology of fortis–lenis contrasts and discuss the phonology of this contrast in Itunyoso Trique. In **2**, I discuss the method and results from an acoustic study investigating the fortis–lenis contrast in Itunyoso Trique. In **3**, I discuss the method and results from a study using EGG (electroglottography) to investigate the timing of passive voicing processes in obstruents and an acoustic study examining variable patterns of spirantization. I discuss the conclusions reached from both experiments in **4** with respect to descriptions of fortis–lenis contrasts in other Oto-Manguean languages. Variable patterns of lenition in Trique are discussed as processes of coarticulatory overlap and articulatory undershoot from a gestural phonetic perspective.

1.1. Fortis–lenis in Trique. There are three Trique variants, all spoken in the southern part of the geographical region known as the Mixteca baja, in the state of Oaxaca, Mexico (Josserand 1983). The Copala Trique variant (ISO code: trc) is spoken by approximately 25,000 people in and around San Juan Copala, with an additional 5,000 speakers elsewhere (Lewis 2009 and Instituto Nacional de Estadística y Geografía 2005). The Chicahuaxtla Trique variant is spoken by approximately 3,240 people in the town of San Andrés Chicahuaxtla and nearby towns as well (Instituto Nacional de Estadística y Geografía 2005). The Itunyoso variant is spoken by approximately 1,345 people in the town of San Martín Itunyoso (Instituto Nacional de Estadística y Geografía 2005). Prior to my own work, there had been no linguistic work done on this variant. All Trique variants have a reasonable degree of mutual intelligibility, though Copala Trique has lower intelligibility (54%) with Chicahuaxtla Trique than Itunyoso Trique does (87%) (Lewis 2009).

Lexical morphemes in Trique may be monosyllabic, disyllabic, or trisyllabic, with disyllables comprising the largest set. Nominal morphology is restricted to either a genitive prefix or a classifier for noun type (animal, edible green, etc.). Verbal morphology consists of aspectual prefixation and either a causative or detransitivizing prefix. Most words may be followed by a personal enclitic (even conjunctions and adverbs), marking pronominal arguments in the phrase. Most phonological contrasts in the language are restricted to the final syllables of morphemes (DiCanio 2008 and Hollenbach 1984). With the exception of words with personal enclitics, this position is usually also word-final. While the permissible onset clusters vary among the different Trique variants, the only possible syllable codas are in the final syllables of morphemes, consisting of either /h/ or /ʔ/.

Like most of the other phonological contrasts, the fortis–lenis contrast in all Trique variants is restricted to word-final syllables. However, the contrast is qualitatively different in monosyllabic words than in the final syllable of polysyllabic words. According to Longacre (1952:63), the fortis consonants in Chicahuaxtla Trique 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." Fortis sonorants are longer than lenis ones, which Longacre indicates with a length diacritic. Hollenbach (1977) echoes Longacre's observation on this variant, stating that fortis obstruents are voiceless and slightly lengthened while lenis obstruents vary from voiced to voiceless. In a recent study, Edmondson (2007) proposes that while duration distinguishes the fortis and lenis consonants in the language, there is some qualitative evidence showing a difference in what he calls "overall effort."

In Copala Trique, the fortis–lenis contrast is limited to the obstruent series (Hollenbach 1977; 1984). Hollenbach observes that fortis stops are voiceless, slightly lengthened, and unaspirated. Lenis stops are voiced fricatives between vowels but vary from voiced to voiceless (stops) 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].[1]

The consontantal inventory of Itunyoso Trique is given in tables 1 and 2. The fortis–lenis contrast in Itunyoso Trique spans most of the consonant inventory, yet there is no fortis–lenis contrast among glottalized sonorants, /p/, /r/, or among pre-nasalized stops. Impressionistically, the fortis consonants seem longer than lenis consonants. Yet, in isolation, both fortis and lenis stops are voiceless, making it is difficult to perceive any differences in duration. Such differences are best perceived when the contrast occurs in sentential contexts, which will be shown in the phonetic study below. In sentential contexts, lenis onsets are occasionally voiced. Table 3 shows the

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[1] While the fortis–lenis contrast in Copala Trique does not include sonorants, Hollenbach (1984) 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, e.g., Muller (2001).

TABLE 1
ITUNYOSO TRIQUE PLAIN CONSONANT INVENTORY

	Bilabial	Dental	Alveolar	Post-Alveolar	Palatal	Retroflex	Velar	Labialized Velar	Glottal
Plosive	*p*	*t, tː*					*k, kː*	*kʷ, kʷː*	*ʔ*
Pre-nasalized plosive	*mb*		*nd*				*ŋg*	*ŋgʷ*	
Affricate		*ts*		*tʃ, tʃː*		*ʈʂ, ʈʂː*			
Nasal	*m, mː*		*n, nː*						
Pre-stopped nasal			*cn*						
Tap			*ɾ*						
Fricative	*β, βː*	*s*		*ʃ*					*h*
Approximant					*j, jː*				
Lateral approximant			*l, lː*						

TABLE 2
ITUNYOSO TRIQUE GLOTTALIZED CONSONANT INVENTORY

	Bilabial	Alveolar	Palatal	Velar
Pre-nasalized plosive		*ʔnd*		*ʔŋg*
Nasal	*ʔm*	*ʔn*		
Trill		*ʔr*		
Fricative	*ʔβ*			
Approximant			*ʔj*	
Lateral approximant		*ʔl*		

TABLE 3
ITUNYOSO TRIQUE FORTIS–LENIS CONTRASTS

Contrast	Word	Gloss	Contrast	Word	Gloss
/t/	*toh*^{53}	‘little, more’	/tː/	*tːo*^{34}	‘grinding stone’
/k/	*kãh*^{5}	‘naked’	/kː/	*kːãh*^{3}	‘sandal’
/kʷ/	*kʷi*^{3}	‘day, sun’	/kʷː/	*kʷːeh*^{3}	‘pus’
/tʃ/	*tʃĩʔ*^{2}	‘elder male’	/tʃː/	*tʃːiʔ*^{4}	‘ten’
/ʈʂ/	*ʈʂĩh*^{3}	‘spiny plant’	/ʈʂː/	*ʈʂːĩʔ*^{3}	‘grass’
/m/	*mã*^{3}	‘this, that’	/mː/	*mːãh*^{4}	‘fat’
/n/	*na*^{2}	‘the past’	/nː/	*nːa*^{3}	‘bed’
/β/	*βeh*^{2}	‘to beat (intr.)’	/βː/	*βːe*^{34}	‘maguey cactus’
/l/	*li*^{23}	‘small’	/lː/	*lːih*^{3}	‘child’
/j/	*jo*^{3}	‘in front of’	/jː/	*jːoʔ*^{3}	‘year’

fortis–lenis contrast in Itunyoso Trique. Fortis consonants are indicated with a length diacritic. The tonal transcription conventions here differ from those in DiCanio (2008; 2010). Instead, I use the Mesoamerican custom of treating tone /1/ as high and /5/ as low.

The fortis–lenis contrast in polysyllabic words is qualitatively different from the contrast discussed above in monosyllabic words. First, for all Trique variants, only obstruents show a fortis–lenis contrast word-medially. Second, in Itunyoso and Copala Trique, the lenis series is realized as voiced fricatives, not as shortened stop variants. Third, for all Trique variants, there are relatively few words which contrast lenis obstruents in ultimas of polysyllabic words. Within a small Itunyoso Trique dictionary consisting of 1,826 words collected since 2004, where 1,100 words are monomorphemic, we observe few words with lenis variants in word-medial position. Yet many words with fortis variants occur in word-medial position.[2] This data is shown in table 4. For all Trique variants, lenis obstruents occur freely in non-final syllables but seem to be very restricted in final syllables. There is a near-complementary

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[2] Voiced fricatives normally appear in Spanish loanwords, in accordance with Mexican Spanish phonology.

TABLE 4

	Contrast	Frequency in Word-Medial Position
Dental	/t/	76/1100
	/ð/	1/1100
Post-alveolar	/tʃ/	41/1100
	/ʃ/	2/1100
Velar	/k/	112/1100
	/ɣ/	5/1100
Labialized velar	/kʷ/	35/1100
	/ɣʷ/	1/1100

distribution between fortis and lenis obstruents in polysyllabic words. The former occurs word-medially, while the latter occurs word-initially.

1.2. Defining "strength." A phonological debate over the features FORTIS and LENIS has existed since the work of Jakobson, Fant, and Halle (1961), who considered certain articulations to be produced with greater articulatory energy. At the time, articulatory energy was broadly defined to include such phonetic properties as aspiration and spirantization, e.g., [tʰ] is strong but [ð] is weak. Malécot (1966) attempted to provide some phonetic grounding for differences in articulatory energy between consonants. He concluded that the "intra-buccal air pressure impulse" was the primary correlate of force of articulation, where stops [p] and [t] were produced with greater intra-buccal air pressure than stops [b] and [d].[3]

From early on, the debate over [fortis] and [lenis] consonants in phonology depended closely on the notion that distinctive features were grounded in articulatory or acoustic phonetics. This notion of featural grounding has extended to current work in phonology and phonetics (Zsiga 1997 and Steriade 2001). For instance, Zsiga mentions that place and ATR features always involve a specific articulatory gesture, such as lip constriction for the feature [LABIAL]. These specific gestures, here called PRIMARY ARTICULATIONS, may produce one or many acoustic effects in the speech signal. For instance, a voicing gesture usually results in a stop having lower amplitude, shorter duration (if voicing is to be sustained for aerodynamic reasons), and a lower amplitude burst. These acoustic effects are predictable from an underlying, primary gesture. If we consider distinctive features to correspond to such primary articulations, then contrasts which involve unambiguously stronger articulations will be phonologically [fortis].

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[3] Yet Malécot did not consider that differences in voicing would have significantly contributed to the lower oral pressure and amplitude values that he observed.

There are three phonetic correlates which unambiguously reflect a stronger primary articulation. First, one expects stronger articulations to involve greater constriction between two articulators (Fougeron and Keating 1997, Keating et al. 2000, and Lavoie 2001). The only articulation that can be responsible for this is greater muscular tension between the articulators. Second, one expects stops to have louder bursts if they are produced with greater muscular tension. Articulators with more muscular tension will close and release more quickly, causing burst intensity to increase (Debrock 1977 and Kohler 1984). Related to this is the fact that increased stiffness among articulators will result in more abrupt formant transitions into and out of a consonant and faster falling and rising intensity contours (Debrock 1977). Thus, one usually expects consonants with increased articulatory strength to be abruptly timed relative to the surrounding segments. While differences in the constriction degree of consonants are usually measured using articulatory measures (e.g., electropalatography [Lavoie 2001]), both burst amplitude and formant and intensity transitions can be measured acoustically.

Throughout this paper, the term STRENGTH is used phonetically in reference to articulations which unambiguously reflect greater articulatory effort. The terms FORTIS and LENIS are used phonologically to refer to the distinctive features which are used to distinguish contrasts.

1.3. Theoretical motivation. Inasmuch as distinctive features are independent, the phonetic properties for features like [fortis] or [tense] should be at least partially distinct from those for laryngeal features. They should also be distinct from those associated with underlying length contrasts. However, most studies discussing [fortis] and [tense] features do not distinguish between phonetic characteristics deriving precisely from durational or glottal timing differences and characteristics which are more independently controlled for strength.

In their analysis of Cajonos Zapotec (ISO code: zad), Nellis and Hollenbach (1980) argue in favor of a fortis–lenis contrast as opposed to one based on voicing or length. They argue that analyzing fortis and lenis consonants in terms of length or voicing does not explain patterns of spirantization, devoicing, place assimilation, or preceding vowel lengthening (also found in Guelavia Zapotec [ISO code: zab] [Jones and Knudson 1977]). Yet in later phonetic studies on related Zapotec languages, researchers conclude that duration and glottal timing are the most robust correlates of the fortis–lenis contrast (Jaeger 1983, Avelino 2001, and Leander 2008). Phonetic characteristics, such as spirantization and devoicing, may instead be incidental by-products from changes in phonetic duration or glottal timing. If this is true, then one expects the phonetic cues to strength to be closely correlated with such changes.

The current phonetic study examines the fortis–lenis contrast in Itunyoso Trique in an attempt to answer the following two questions: What are the phonetic properties distinguishing the contrast? And to what extent do these properties account for variable patterns of voicing and lenition? This investigation is not only relevant for the description and comparative phonology of Oto-Manguean languages but also for our general understanding of strength in phonological systems. Investigating the phonetic implementation of this contrast evaluates the degree to which strength is used. If the contrast involves differences in strength, this would suggest that the contrast uses the phonological feature [tense] or [fortis]. If, however, all the phonetic properties can be fully explained by standard phonetic features such as duration or glottal timing, then a phonological feature like [tense] or [fortis] would be unnecessary. Also, patterns of lenition and variable voicing may be directly related to durational or glottal timing differences. If this is the case, it argues that such patterns do not require an abstract featural specification like [fortis], as per Nellis and Hollenbach (1980). If this is not the case, such an abstract featural view would be sustained.

2. Experiment 1: acoustic study of fortis–lenis contrast.

2.1. Method.

2.1.1. Stimuli and speakers. The stimuli for this experiment consisted of 40 monosyllabic words contrasting obstruents and sonorants. The obstruents investigated here were: /t/, /tː/, /tʃ/, /tʃː/, /ʈʂ/, /ʈʂː/, /k/, /kː/, /k^w/, and /k^{w}ː/. Two voiced continuant contrasts were investigated: /n/, /nː/, /β/, /βː/.[4] 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^{2}ʔja^{23}___ 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 /23/. 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 six times for a total of 240 repetitions per subject, a total of 1,920 tokens. Of these, 1,734 were used. Sentences produced with disfluencies were discarded and not analyzed. There were sampling differences in the number of tokens used for each comparison. These are given in table 5. To correct for the differences in sample size, the reported measurements in this study weighed each comparison equally. Analysis of variance tests were verified with a post-hoc Tukey's HSD (Honestly Significant Difference) test, which adjusts for differences in sample size (Baayen 2008).

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[4] The bilabial fricative /β/ patterns as a glide in Itunyoso Trique (DiCanio 2008).

TABLE 5

Comparison	Sample Size Used in Study
/t/–/tː/	365
/k/–/kː/	92
/kʷ/–/kʷː/	116
/tʃ/–/tʃː/	336
/ʈʂ/–/ʈʂː/	137
/n/–/nː/	434
/β/–/βː/	254

Eight speakers were recruited for the investigation, four female and four 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. Seven of the speakers were bilingual in Spanish and Trique. The oldest, female speaker spoke only Trique but understood Spanish at an intermediate level. 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, U.S.A. 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 my primary consultant, who acted as an interpreter. The stimuli were read aloud in Trique either by me or my consultant as a prompt for the participant. The participant then spoke each stimulus sentence six times in a row.

2.1.2. Procedure. Participants spoke into a unidirectional dynamic handheld microphone that I maintained at a comfortable distance. Recordings were made directly onto my Apple iBook G4 computer using a 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. Some participants' acoustic data contained a low-frequency harmonic at 61 Hz. This was particularly noticeable in low-signal amplitude recordings where participants did not speak loudly. These data were high-pass filtered with a lower cutoff frequency of 65 Hz prior to segmentation. The duration and amplitude extraction scripts used the unfiltered recording, however.

The phonetic characteristics which unambiguously characterize stronger articulations are those which reflect greater constriction degree or constriction velocity (DiCanio 2008, Keating et al. 2000, and Maddieson 1999). In this investigation, two measures were used which reflect strength of articulation: burst amplitude and the speed of formant trajectory. A total of six acoustic measures were examined in this investigation. For stops, durational measures

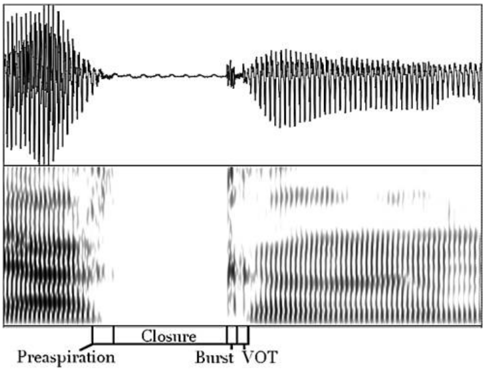

FIG. 1.—Obstruent duration measurements. Context: [ni^{2}ʔja^{23} kːə̃^{3} nə̃^{3}] ‘I see squash here’.

were made for preaspiration, closure, burst, and VOT. Preaspiration here is defined as the duration of glottal frication which preceded the stop closure for plosives and affricates. Non-durational measures consisted of relative burst amplitude and formant trajectory. A waveform with a corresponding spectrogram for the word /k:ã^{3}/ ‘squash’ is shown in figure 1, illustrating the durational measures. The procedure used for the non-durational measures is given in the sections corresponding to the measures.

2.2. Results: duration.

2.2.1. Obstruents. Spectrograms illustrating the difference between fortis and lenis /t/ are shown in figure 2. 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 3.

Each of the duration measures was statistically analyzed separately using a repeated measures analysis of variance (ANOVA) with two within-subjects factors, Type (fortis vs. lenis) and Onset (/t/, /tʃ/, /ʈʂ/, /k/, /k^{w}/), and with Speaker as an error term. In each of these analyses, except for frication duration and VOT, stops were grouped with affricates. For closure duration, the main effect of Type was significant (F[1,7] = 25.13, $p < 0.01$). The average closure duration for fortis obstruents was 113.5 ms (sd = 24.7), while lenis closures averaged 72.9 ms (sd = 23.3); however, these values include the affricate data. Table 6 illustrates the durational differences by obstruent manner.

The Onset main effect was also significant (F[4,27] = 8.12, $p < 0.001$). As seen in figure 3, 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

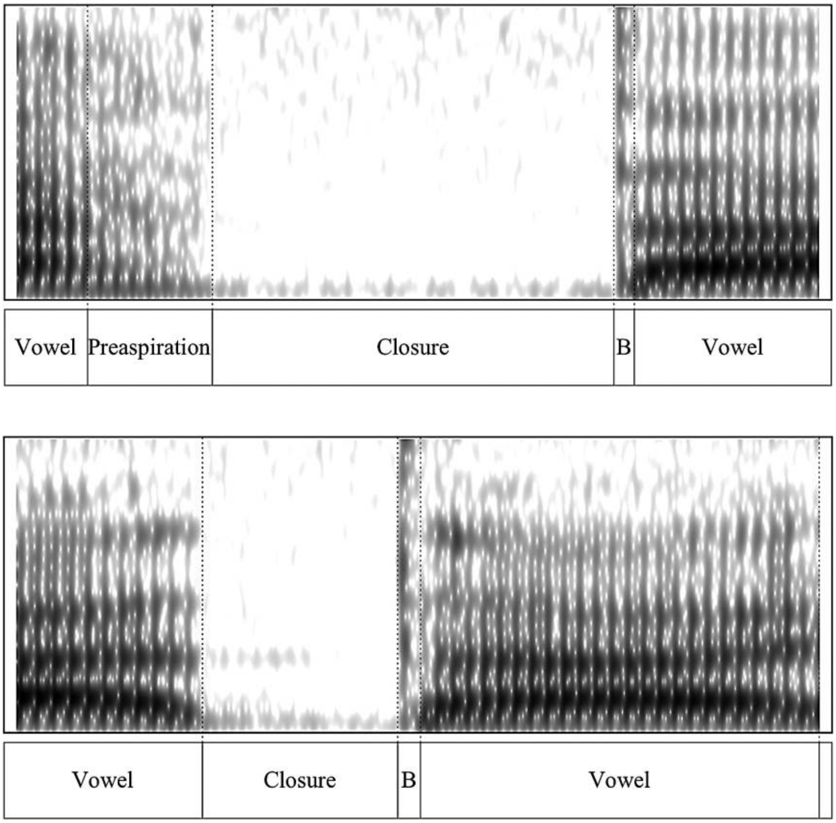

FIG. 2.—Acoustic differences between obstruents /tː/ (above) from the word [tːa^3] ‘field, plain’ and /t/ (below) from the word [ta^3] ‘that’. Both spectrograms show windows of identical duration.

differences among stops and the more marginal differences between the affricate types is reflected in such an interaction. Tukey’s post-hoc pairwise comparisons were made to test the significance of Type on closure duration between the fortis and lenis variants for each obstruent place of articulation. Closure duration as a function of type was significant for obstruents /t/, /ʈʂ/, /k/, and /k^w/ ($p < 0.001$) but not for the post-alveolar affricate /tʃ/. 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 × Onset interaction showed that burst duration as a function of place of articulation

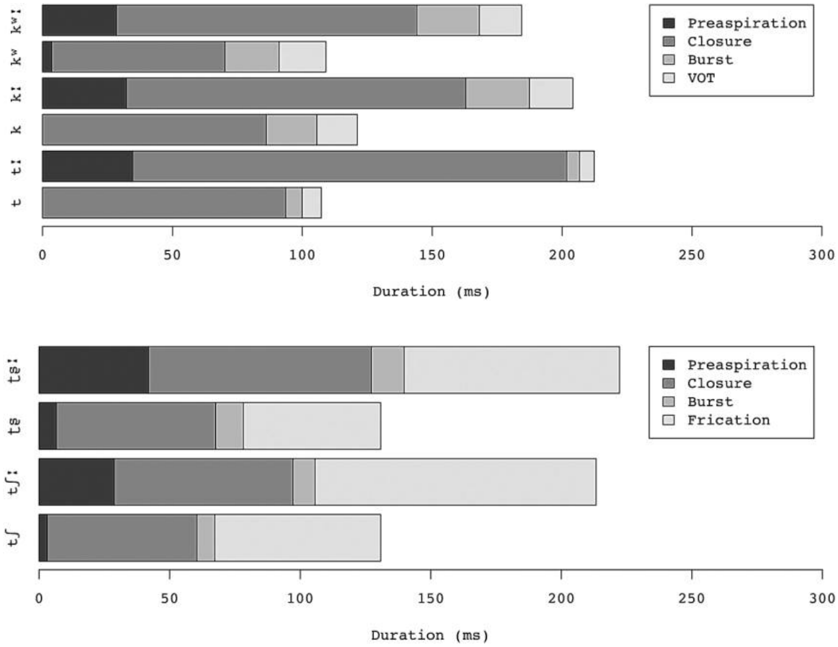

FIG. 3.—Fortis–lenis obstruent duration.

TABLE 6
ITUNYOSO TRIQUE FORTIS–LENIS OBSTRUENT DURATION DATA

Stops	Closure	Burst	VOT	Total Duration
Lenis	82.1 ms	15.6 ms	13.7 ms	111.4 ms
	24.8 sd	6.2 sd	7.9 sd	
Fortis	137.8 ms	17.8 ms	12.9 ms	168.5 ms
	25.1 sd	9.2 sd	8.0 sd	
Affricates	**Closure**	**Burst**	**Frication**	**Total Duration**
Lenis	59.2 ms	8.8 ms	58.1 ms	126.1 ms
	21.0 sd	7.6 sd	19.7 sd	
Fortis	76.9 ms	10.6 ms	95.1 ms	182.6 ms
	24.1 sd	7.5 sd	20.6 sd	

was significant for all obstruent comparisons, e.g., /t/ vs. /k/, /k/ vs. /tʃ/, etc. ($p < 0.001$), except for the comparison /k/ vs. /k^{w}/. These onset effects reflect the tendency for more posterior articulations to be realized with longer burst durations than more anterior ones. Yet as 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.

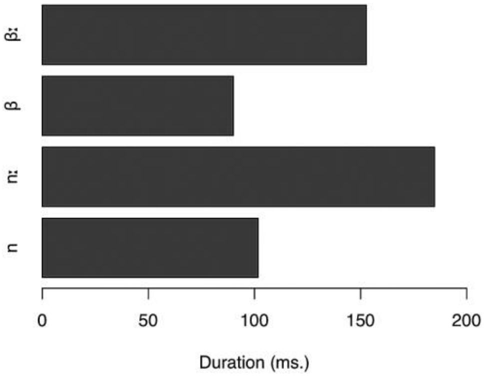

FIG. 4.—Fortis–lenis sonorant duration.

For VOT, the main effect of Onset (but not Type) was significant (F[4, 28] = 10.77, $p < 0.001$). Tukey's post-hoc pairwise comparisons showed that VOT varied significantly between alveolar and velar places of articulation ($p < 0.01$) but not between /k/ vs. /k^w/. The average VOT values for the alveolar stops were 6–7 ms, while velar and labiovelar stops had average values between 16–18 ms.

For the affricates, the main effect of Type (but not Onset) was significant for frication duration. Fortis affricates has significantly longer frication duration than lenis affricates (F[1, 5] = 354.9, $p < 0.001$). Frication duration did not differ among the lenis affricates, but the fortis post-alveolar affricate had significantly longer frication duration than the retroflex affricate, as indicated by a significant interaction between Type × Onset (F[1, 7] = 38.3, $p < 0.001$). The average difference in frication duration between the lenis and fortis post-alveolar 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 to 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 post-alveolar series is distinguished mostly by frication duration.

2.2.2. Sonorants. For both sonorants that were examined, lenis variants had substantially shorter closure duration than did fortis variants. The average duration of lenis /n/ was 101.7 ms, while fortis /nː/ was 184.8 ms. The average duration of lenis /β/ was 90.0 ms, while fortis /βː/ was 152.7 ms. A bar plot of the differences is shown in figure 4.

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/, /β/), and Speaker as an error term. 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

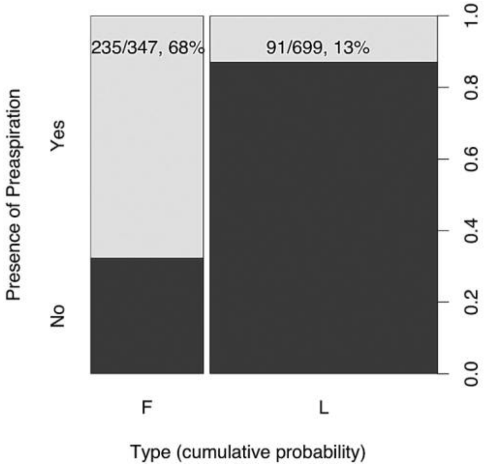

FIG. 5.—Probability of preaspiration on obstruents as a function of Type: **F**ortis vs. **L**enis.

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 ($p < 0.001$). Taking global duration as a measure, the durational ratio between lenis and fortis stops was 1:1.51, while the ratio between affricates was 1:1.45. The ratio for sonorants was greater, at 1:1.76. However, fortis obstruents are frequently preceded by a short period of preaspiration, which would add to their overall duration.

2.2.3. Preaspiration. Aspiration noise was observed preceding stops and affricates in much of the data. This preaspiration often resulted in a short duration of breathiness on the vowel preceding the fortis or lenis obstruent, as shown in figure 2. In this figure, we observe clear formant structure on the vowel preceding the lenis stop but breathiness preceding the fortis one. Two separate statistical analyses were made to evaluate the possible relevance of this preaspiration. In the first investigation, I considered Type and Onset as fixed effects and Speaker as a random effect using a generalized linear mixed model. This method evaluates whether the likelihood of preaspiration (rather than its duration) varied significantly as a function of Type and Onset. In the second investigation, a repeated measures ANOVA was used with Type and Onset as factors and with Speaker as an error term. This evaluates whether the average DURATION of preaspiration varied significantly.

The probability data are shown in figure 5. Preaspiration was much more frequent on fortis tokens (68%) than on lenis tokens (13%). The main effect of Type was significant (z value = –9.0, $p < 0.001$). Onset (the place of articulation of the stop or affricate) was also found to be significant, but only for alveolar stops (z value = –5.4, $p < 0.001$), where the fortis variant

TABLE 7
Likelihood and Duration of Preaspiration
by Place of Articulation

Consonant	Fortis–Lenis	Probability of Preaspiration	Duration of Preaspiration
/t/	L	2.7%	39.3 ms
/t:/	F	43.2%	34.7 ms
/k/	L	0.0%	n.a.
/k:/	F	87.0%	37.2 ms
/kʷ/	L	12.8%	27.4 ms
/kʷ:/	F	74.0%	38.3 ms
/tʃ/	L	17.5%	17.9 ms
/tʃ:/	F	84.1%	34.2 ms
/ʈʂ/	L	30.2%	21.7 ms
/ʈʂ:/	F	100.0%	41.9 ms

was realized with preaspiration least often. Table 7 provides the data on the likelihood of preaspiration along with its average duration for each obstruent.

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 and Speaker as an error term 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) was significant. The relevance of preaspiration for fortis obstruents is examined further in **3**, where the more fine-grained details of glottal timing are evaluated using electroglottography.

2.3. Results: measures of strength.

2.3.1. Burst amplitude. Two measures of strength were considered in this study: burst amplitude and formant transition speed. Relative burst amplitude was defined as the difference between the maximum amplitude on the following vowel and the maximum amplitude during the burst duration, $A_R = A_{burst} - A_{vowel}$. It is well known that higher vowels have greater amplitude than lower vowels (Lehiste and Peterson 1959 and Fónagy 1966). In order to control for the height of the following vowel, a repeated measures analysis of variance was run with maximum vowel amplitude as the dependent factor and vowel quality (/i/, /e/, /a/, /o/, /u/, /ə̃/) as the independent factor. Speaker was treated as an error term. Vowel quality was significant (F[4, 25] = 4.4, p < .01**). However, a post-hoc Tukey's HSD test revealed that the only significant differences in vowel amplitude occurred for comparisons between /ə̃/ and the non-high vowels (/e/, /o/, /a/), between the low vowel /a/ and the high vowels (/i/, /u/), and between the vowel /i/ and the mid vowels (/e/, /o/). With the exception of the /tʃ/–/tʃ:/ contrast, no fortis–lenis obstruent contrast contained vowels with significantly different amplitude. In the case of the post-alveolar affricate contrast, the vowel amplitudes were significantly different across the fortis–lenis pair, e.g., /tʃa^{31}/ ‘head’ vs. /tʃːih^{4}/ ‘ten’. Post-alveolar affricate tokens were omitted from this measure. Where visible bursts were obscured or missing in the data, burst amplitude was not measured.

Relative burst amplitude was statistically analyzed using a repeated measures ANOVA with Type and Onset as factors and Speaker as an error term. The main effect of Type (F[1, 1] = 0.71, p = .55) was not significant, but the main effect of Onset was (F[3, 17] = 5.9, p < .01*). This finding reflected the fact that velar stops had greater burst amplitude than all other obstruents (/t/, /ʈʂ/, /kʷ/). There was a near-significant interaction between Type and Onset (F[3, 19[= 2.5, p = .09). This reflected the fact that there were differences in the effect of Type for different Onsets. Fortis velar stops had greater burst amplitude than lenis velar stops, but lenis alveolar stops had greater burst amplitude than fortis alveolar stops. This data is shown in figure 6.

Individual comparisons between fortis and lenis obstruents revealed that the lenis series actually had GREATER amplitude bursts than the fortis series for the /t/–/tː/ and /kʷ/–/kʷː/ contrasts, but the fortis series had greater amplitude bursts than the lenis for the /k/–/kː/ contrast. The presence of greater amplitude in the LENIS series for two of the obstruents suggests that amplitude is not used as a consistent correlate in distinguishing the fortis–lenis contrast in Itunyoso Trique. A separate statistical model was used to determine what contributed to differences in relative burst amplitude. The main effects of Closure duration and Preaspiration duration were tested. A repeated measures ANOVA with Speaker as an error term did not find either of these effects to be significant. Burst amplitude in Itunyoso Trique varies with obstruent place of articulation but is not used to distinguish fortis and lenis obstruents.

2.3.2. Formant transition. Formant trajectory was measured on the vowel preceding the target consonant. As vowel devoicing damps formant amplitude, only those tokens without preaspiration were examined. Since a majority of the fortis affricates, fortis velars, and fortis labialized velars had preaspiration, I was only able to examine formant trajectory differences for alveolar stops, which tend to be produced with the least preaspiration. 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.

Acoustic boundaries were hand-labeled. 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. For the bilabial glide, the acoustic boundaries were determined by taking the midpoint between maximal F1 values in the VC or CV transition. All measures were made using a set of scripts written for Praat (Boersma and

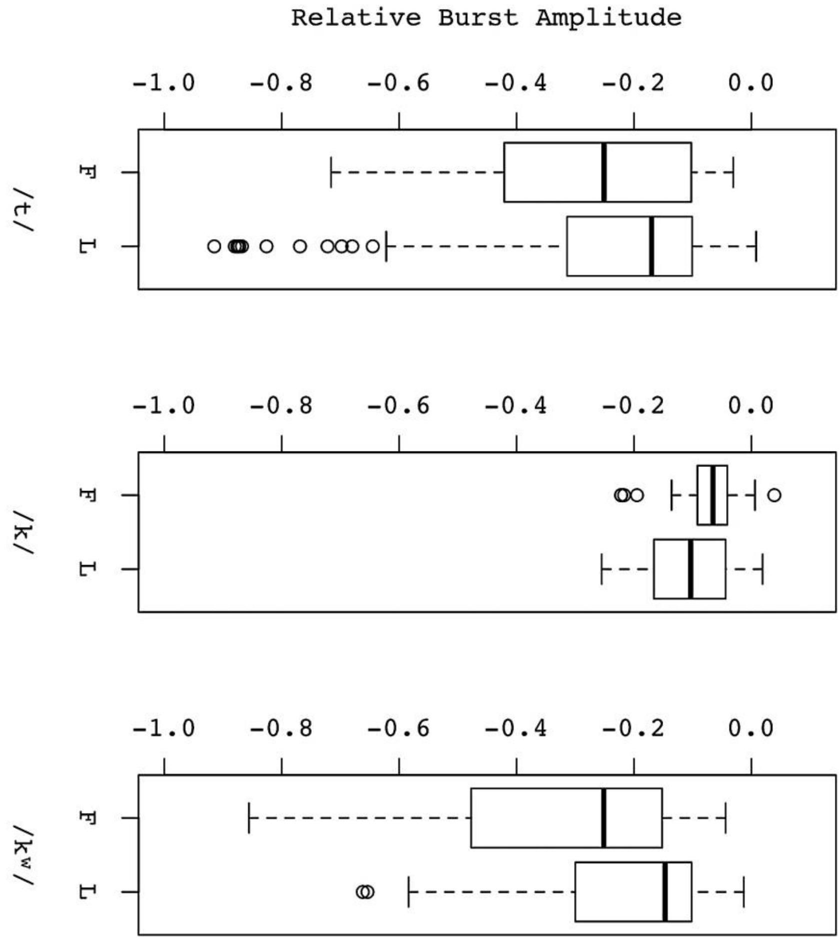

FIG. 6.—Relative burst amplitude by type and onset.

Weenink 2008). The acoustic data were resampled at 16 kHz prior to formant estimation. The script divided the vowel's duration into ten chunks of equal duration and extracted mean F1, F2, and F3 frequencies across the duration of each chunk. The method followed here permitted simple comparison of formant trajectories because duration was normalized. The vowel preceding the fortis consonant was always /a/; i.e., verb stimuli were excluded from this measure.

Both absolute formant values and changes in formant values were examined. F1, F2, and F3 values are plotted in figure 7. Time is normalized here because there were no significant differences in the duration of vowels preceding fortis

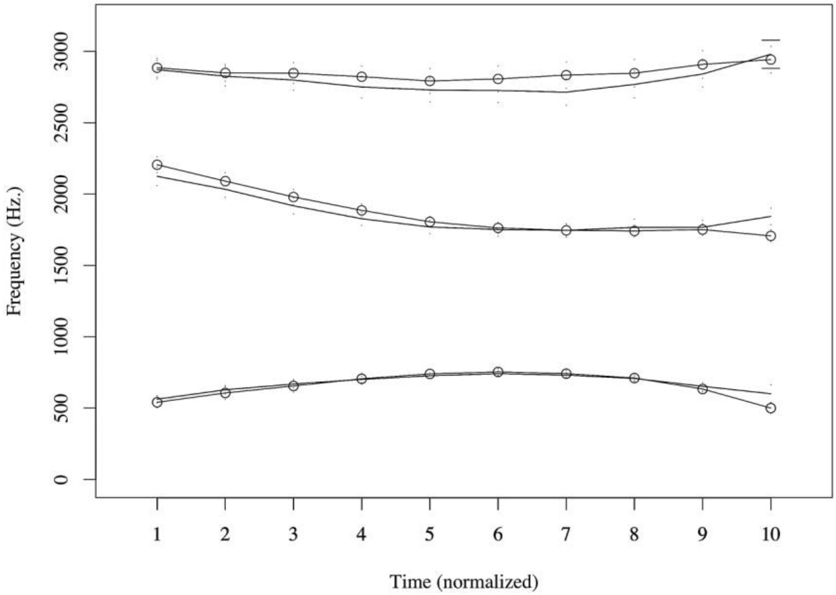

FIG. 7.—Formant values on vowel preceding /t/ and /tː/.

and lenis /t/. The vowel duration preceding each consonant was roughly the same: 149.0 ms before /tː/ and 156.7 ms before /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 figure 7, 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/. 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. However, 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 /tː/ 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 /tː/ but 1706.7 Hz preceding the lenis /t/. 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). There was no change in vowel quality preceding the lenis and fortis stops.

Two measures of formant trajectory were examined using a repeated measures 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, rather than simply its value, was faster preceding the fortis stop. Speaker was treated as an error term. 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, at least 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.

2.4. Interim summary. Among the acoustic correlates of the fortis–lenis contrast investigated for the obstruent data, closure duration and the presence of preaspiration were significant. Durational differences between fortis and lenis sonorants were similar to the durational differences between the obstruents. For sonorants, the durational ratio was 1:1.76. For obstruents, once preaspiration is taken into account, the durational ratio was 1:1.7 for stops and 1:1.61 for affricates. These ratios were very similar to durational differences found among languages with contrastive consonant length (Ladefoged and Maddieson 1996 and Ham 2001), where geminate consonants are between 1.5–3 times longer than singleton consonants. The acoustic measures of articulatory strength, adjusted burst amplitude, and differences in the formant trajectory of the preceding vowel do not distinguish between fortis and lenis obstruents. The fortis–lenis contrast in Itunyoso Trique is mainly realized by differences in duration, with an early glottal adduction (spreading) gesture in the case of fortis obstruents. The result of this glottal spreading is a short period of preaspiration preceding the consonant.

3. Experiment 2: acoustic and electroglottographic study of lenition patterns. Two variable patterns typify the fortis–lenis contrast in Oto-Manguean languages: voicing and spirantization. Lenis obstruents are frequently found to be variably voiced or spirantized (Nellis and Hollenbach 1980 and Jaeger 1983). While the acoustic evidence in **2** above does not show any differences in articulatory strength between fortis and lenis consonants, it is possible that more abstract phonological constraints may account for these variable patterns. For instance, if lenis consonants, regardless of variability in phonetic duration, are realized with voicing or spirantization, this would argue that such patterns are independent from durational properties. In this case, abstract features like [tense], [LAZY], or [Minimize Effort] may be responsible for the patterns. However, if such patterns follow directly from the durational properties of the fortis and lenis consonants, there is no need to posit an abstract level of articulatory strength. Variable voicing and variable spirantization were investigated in Itunyoso Trique with this particular hypothesis in mind.

3.1. Spirantization. In order to investigate patterns of spirantization, I used the acoustic data given in **2** above. All obstruents (stops and affricates) were coded for whether they were produced as fricatives throughout their duration or were realized with a stop closure. The two spectrograms shown in figure 8 illustrate the lenition patterns observed in the Trique data. The first example illustrates the realization of the affricate /tʃ/ as [ʃ], while the second shows an affricate realization. The spirantized example shows some changes in acoustic intensity (quick rise time) approximating those found in affricates, but it lacks closure.

3.1.1. Effect of duration. To evaluate what factors are responsible for spirantized realizations, I considered "total obstruent duration" and Onset as fixed effects and Speaker as a random effect using a generalized linear mixed model. This method evaluated whether the probability of spirantization varied significantly as a function of obstruent duration and place of articulation. The effect of obstruent duration was significant (z value = –2.5, $p < 0.05$), but not the effect of place of articulation. The scalar factor of duration was replaced with the phonological factor Type (fortis–lenis) in a separate model which was then compared to the first model. However, neither the factor of Type nor Onset in the second model was significant. Raw total duration, rather than phonological status, correlated with patterns of spirantization. When the duration of the obstruent was shorter, spirantization was more likely to occur. When it was longer, it did not occur.

Given that lenis obstruents are shorter than fortis obstruents, more lenis tokens than fortis tokens were realized with incomplete closure. Yet even in these cases, incomplete closure was not very frequent. Of the lenis tokens, 83/699 (11.9%) were realized with incomplete closure, while only 5/347 (1.4%) of the fortis tokens were realized with incomplete closure. Almost all of the tokens realized as fricatives were affricates.[5] However, as shown in **2** above, the affricates had the shortest closure duration among all obstruents

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[5] Only one case of a spirantized lenis [t] occurred, as [ð].

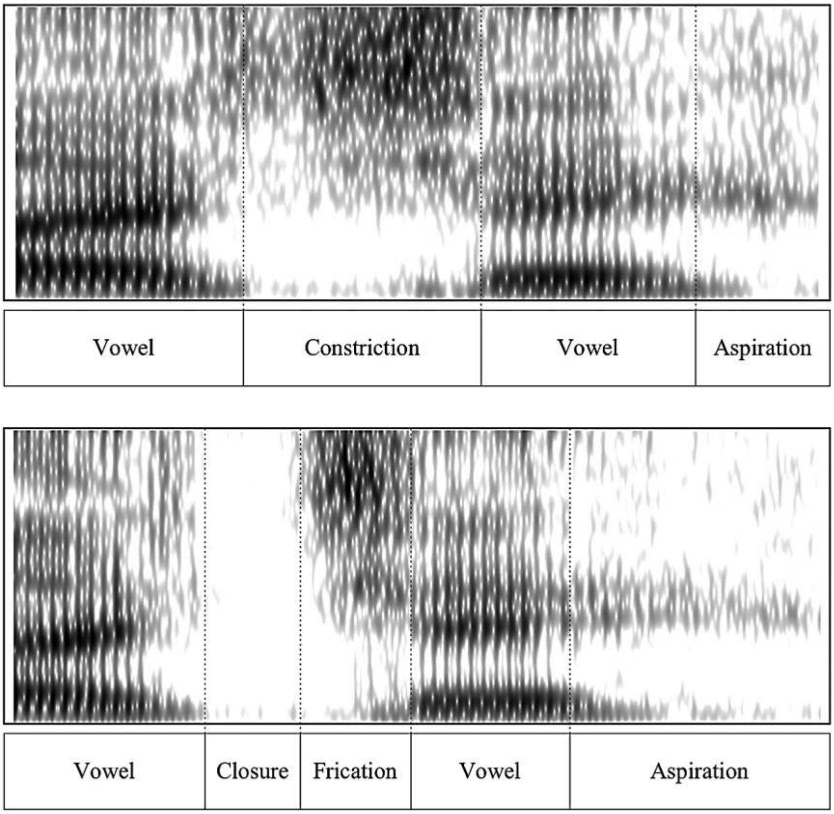

FIG. 8.—Two instances of the word /tʃeh^{34}/ ‘path’ from the same speaker.

in Itunyoso Trique. Since any change in their total duration would result in an even shorter duration for closure, it is unsurprising that affricates would undergo spirantization more frequently than stops.

3.1.2. Effect of speech rate. Speech rate frequently causes predictable changes in segment duration (Solé 2007). While the speakers who produced the words in this study were not specifically instructed to change their speech rate, speech rate did vary naturally throughout each of the recording sessions. For each set of carrier sentences corresponding to a particular elicited word, the duration of each syllable was measured (using a script). The average duration of all the syllables within this set was divided by the total duration of the syllables, resulting in a rate measure (syllables/second) for each word in the recording session. This measure of rate was then treated as a fixed effect in a generalized linear mixed model, along with “total obstruent duration.” Speaker was treated as a random effect.

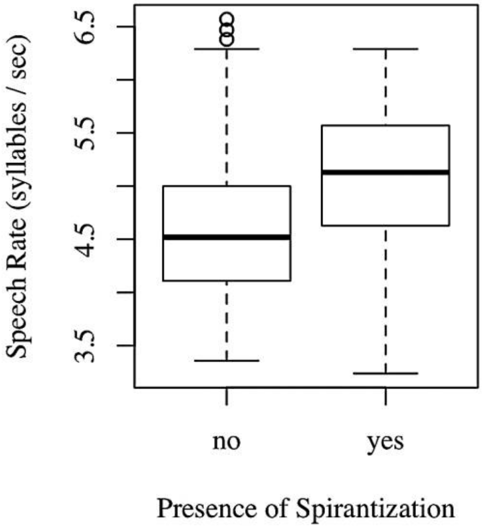

FIG. 9.—Effect of speech rate on spirantization.

Speech rate was found to be significant (z value = –2.01, $p < 0.05$ *). When speech rate increased, speakers were more likely to spirantize short duration affricates. A graph of the rate difference is shown in figure 9. Forms with a spirantized variant were produced in contexts where the speech rate was approximately 5 syllables/sec, while forms without spirantization were produced in contexts where the speech rate was approximately 4.5 syllables/sec. There was no significant difference in rate between contexts with fortis consonants and those with lenis consonants or between contexts where different onset types were elicited. This was a general pattern of speech rate variability. The effect was not particularly strong, but it suggests that slight changes in speech rate cause spirantization. An increase in speech rate causes durational windows for segments to shorten. This results in the lack of a complete closure for certain obstruents. Durational changes due to speech rate account for the observed patterns, not abstract phonological categories like FORTIS or LENIS.

3.2. Variable voicing. Similar to other Oto-Manguean languages, lenis obstruents in Itunyoso Trique are occasionally voiced. What accounts for this variable pattern? If variable patterns of voicing or partial voicing in lenis obstruents are related to differences in closure duration, then one would anticipate only obstruents with shorter closure duration to contain more voicing than obstruents with longer closure duration.[6] If, however, these patterns are

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[6] Sensitive to aerodynamic constraints on voicing which asymmetrically affect consonants at different places of articulation (Ohala 1983).

simply related to categorical differences in articulatory effort, then one would anticipate voicing patterns to be less predictable from durational differences and simply derive from categorical differences.

In order to investigate the relationship between patterns of voicing and duration, electroglottography (EGG) was used. With an electroglottograph (laryngograph), sensors are placed on opposite sides of the speakers neck, adjacent to the thyroid cartilage (just beneath the Adam's apple). Weak electrical current passes through the sensors. When the vocal folds are closed, more of the current can pass through the neck. When the vocal folds are open, less passes through. It is possible to use EGG 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, and Heinrich et al. 2004). The presence of EGG maxima and minima indicates that there is glottal vibration. The advantage to using an electroglottograph in lieu of acoustic recordings is that the EGG signal is unaffected by acoustic disturbances in field recordings. Voicing can be difficult to measure from an acoustic signal when such disturbances occur.

3.2.1. Method. Four subjects, three male (speakers B, C, J) and one female (speaker M) participated in the study. EGG data were acquired using a Laryngograph model portable electroglottograph recorded directly onto my Apple iBook G4 computer. Recordings were made at the same time as the acoustic recordings. An M-Audio MobilePre® USB preamplifier was used as an audio interface. The data consisted of the set of words with fortis and lenis obstruents used in **2** above. Praat version 4.6 (Boersma and Weenink 2008) was used to record all data. All data were sampled at 44.1 kHz.

Phonetically speaking, voicing is not categorical. Short duration voicing may spread from preceding voiced segments onto following segments or vice versa. If enough voicing spreads over from the preceding context (in this case, the final vowel on the word preceding the obstruent), the obstruent may be completely voiced. This gradual pattern of voicing was examined here. Three main patterns were observed in the obstruent data, representing three glottal timing possibilities. Devoicing occurred prior to closure, it coincided with closure, or it occurred during closure. A fourth possibility also occurred: complete voicing throughout the duration of closure. However, only six words were observed to have voicing throughout the closure in the data. These were lumped together with the pattern where voicing occurred during the closure.

When voicing ceased prior to oral closure, the duration between the point of voicing cessation and the onset of consonant closure was labeled "Vo" (Voice Offset Time). When oral closure was timed exactly to coincide with devoicing, no additional labels were necessary. When voicing ceased after oral closure was achieved, this was labeled as "V.term" (Voice Termination Time). This effectively measured the duration of the oral closure that was voiced.

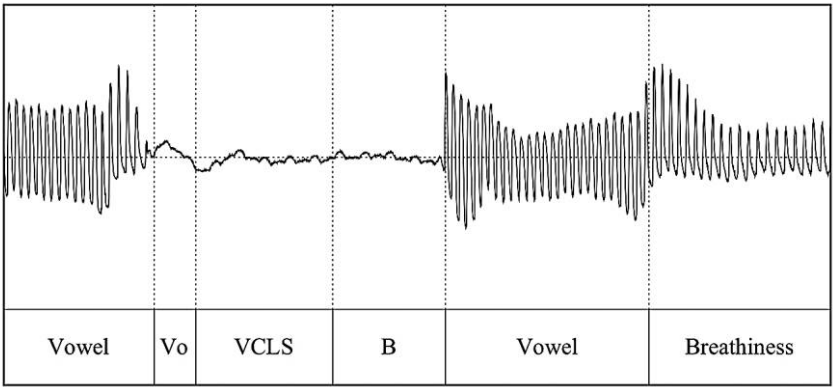

FIG. 10.—Voice offset time (Vo), devoicing prior to closure.

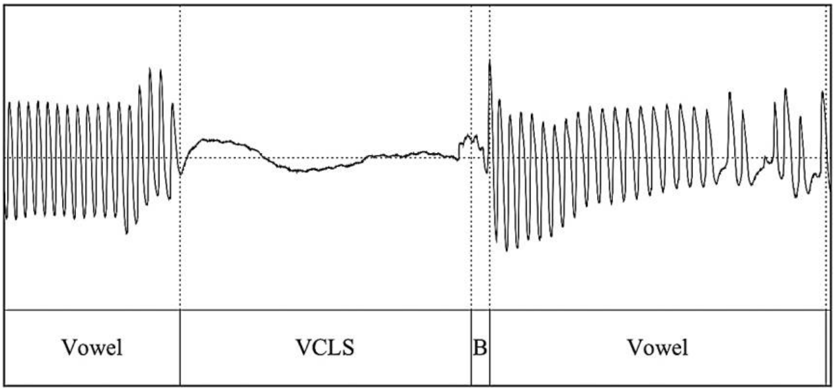

FIG. 11.—Devoicing coincidental with oral closure.

For the case of consonants which were fully voiced, "V.term" was equivalent to the full duration of the consonant. The four possibilities are represented in figures 10–13. These labeling methods followed a similar procedure used in Jansen (2004).

In figure 10, oral closure occurs at the boundary between "Vo" and "VCLS." The label "B" represents the combined burst and VOT duration. Note, however, that there is no voicing in the laryngographic signal during the duration labeled "Vo." Here, devoicing began before closure. This is the pattern during preaspiration. In figure 11, voicing ceases simultaneously with the moment of consonant closure, shown at the boundary labeled "VCLS." If closure occurred within 5 ms or less of the cessation of voicing, the token was

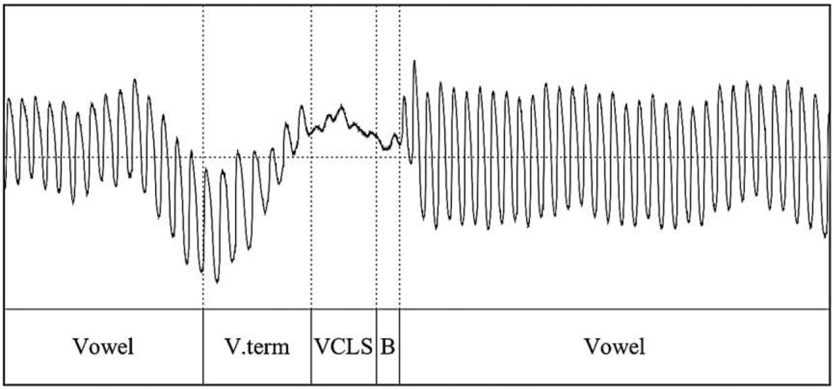

FIG. 12.—Voice termination time (V.term), devoicing following closure.

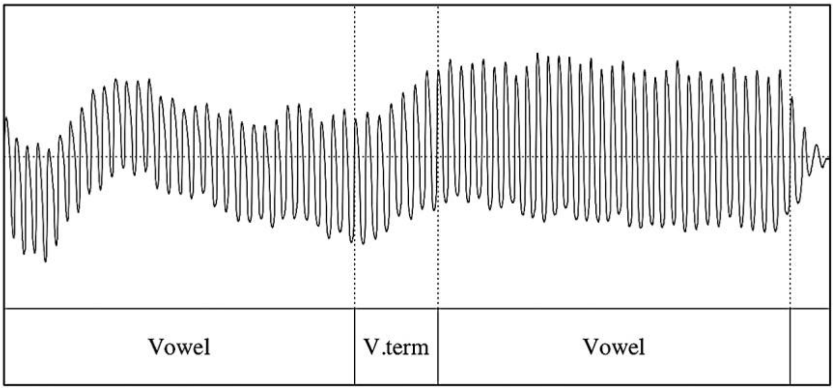

FIG. 13.—Voice termination time (V.term), no devoicing during closure.

considered to have simultaneous closure and devoicing. In figure 12, closure occurs at the boundary between "Vowel" and "V.term," but voicing continues throughout the duration marked as "V.term" and ceases between "V.term" and "VCLS."[7] This stop is partially voiced. The location of stop bursts and VOT are indicated with the label "B" from the matched acoustic signal. In figure 13, we observe that voicing does not cease during consonant closure. Both the relative frequency of these glottal timing patterns and the duration between closure and devoicing were evaluated. Data were dummy-coded for

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[7] In certain cases, voicing was characterized with symmetrical oscillations of small amplitude, a characteristic of what is called PARTIAL VOICING (Mazaudon and Michaud 2008).

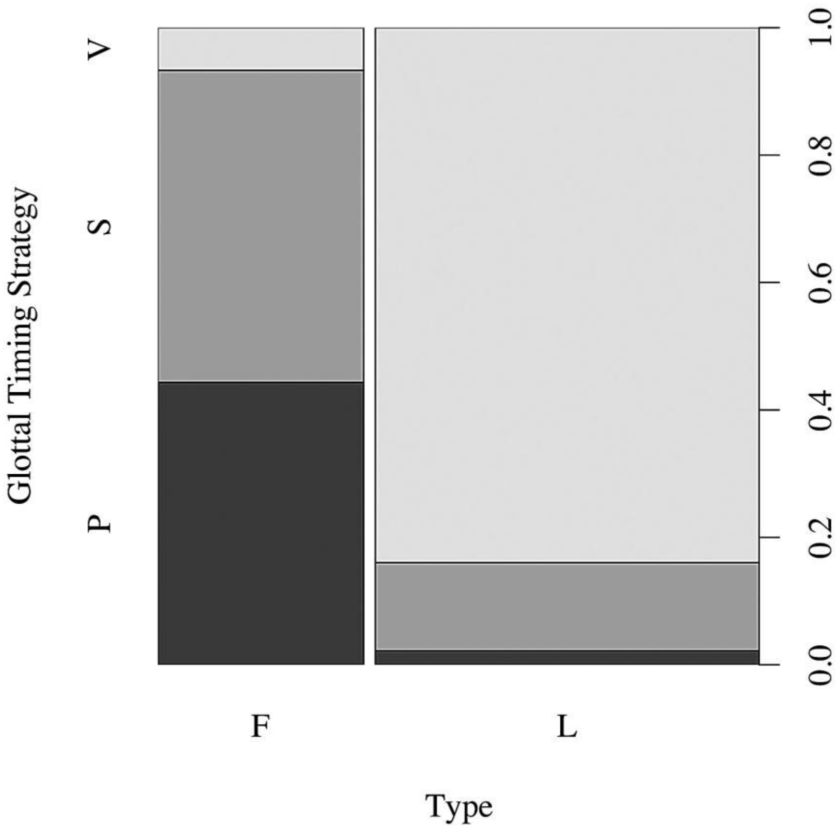

FIG. 14.—Glottal timing pattern by consonant type: P = devoicing precedes closure; S = devoicing simultaneous with closure; and V = devoicing follows closure.

the glottal timing strategy employed: **V** for patterns with any voicing during consonant closure, **S** for patterns where devoicing was simultaneous with closure, and **P** for patterns where devoicing preceded closure.

3.2.2. Results. The glottal timing strategy was tested using a generalized linear mixed effects model with Type and Onset as fixed effects and Speaker as a random effect. This statistic evaluated whether the probability of the glottal timing strategy varied significantly as a function of Type and Onset. A barplot of the probability data is provided in figure 14, where *F* represents "fortis" and *L* represents "lenis."

The main effect of Type was significant ($z = 5.72$, $p < 0.001$). Most of the lenis obstruents were realized with partial voicing during the consonant closure (304/362 = 84%). This manner of glottal timing was rare for the fortis obstruents (13/194 = 6.7%). While simultaneous closure and devoicing were common among the fortis obstruents (96/194 = 49.4%), they were 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 (for /t/, $z = 3.5$, $p < 0.001$; for /tʃ/, $z = –3.1$, $p < 0.01$; for /k/, $z = –2.2$, $p < 0.05$). This reflected a marked tendency for posterior places of articulation to be more often realized with devoicing prior to closure than more anterior places. 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. The pattern reflects a general aerodynamic constraint against voicing in more retracted obstruents (Ohala 1983; 2005).

The average duration of voicelessness prior to closure was very short for the fortis obstruents (15 ms). The average duration of voicing after closure was slightly longer for the lenis obstruents (22 ms, or 21% of the closure duration). While this amount of voicing is not dramatic and full voicing is relatively rare in lenis obstruents (at least in the elicitation session), the differences in glottal timing shed light on patterns of variable voicing in Itunyoso Trique. When we examine the effects of consonant duration, rather than phonological status, for both the fortis and lenis consonants, a more specific pattern emerges, shown in figure 15.

Differences in glottal timing do not only vary between fortis and lenis obstruents but also vary within lenis obstruents with their total duration. The results from a generalized linear mixed effects model (with total consonant duration and onset type as fixed effects and speaker as an error term) show a significant effect of duration on glottal timing strategy for the lenis obstruents ($z = –2.3$, $p < 0.05$). The same model used for fortis obstruents shows no significant effect. Thus, in figure 15, we observe that the glottal timing strategy is directly affected by the duration of the consonant for the lenis obstruents. The obstruents realized with devoicing before closure were longer than those with devoicing aligned with closure, which were longer still than obstruents realized with voicing during the closure duration. Those lenis obstruents with the longest duration of voicing during closure (resulting in full voicing) also had the shortest total duration.

3.2.3. Summary. The data here demonstrate the glottal timing differences between fortis and lenis obstruents. Fortis obstruents are most often realized with devoicing prior to or simultaneous with closure, while lenis obstruents usually have some duration of voicing that spreads into the closure. This glottal timing strategy for fortis obstruents suggests that they are produced with an active devoicing gesture. Lenis obstruents, by contrast, are partially voiced. The voicing duration varies with the total obstruent duration. Just

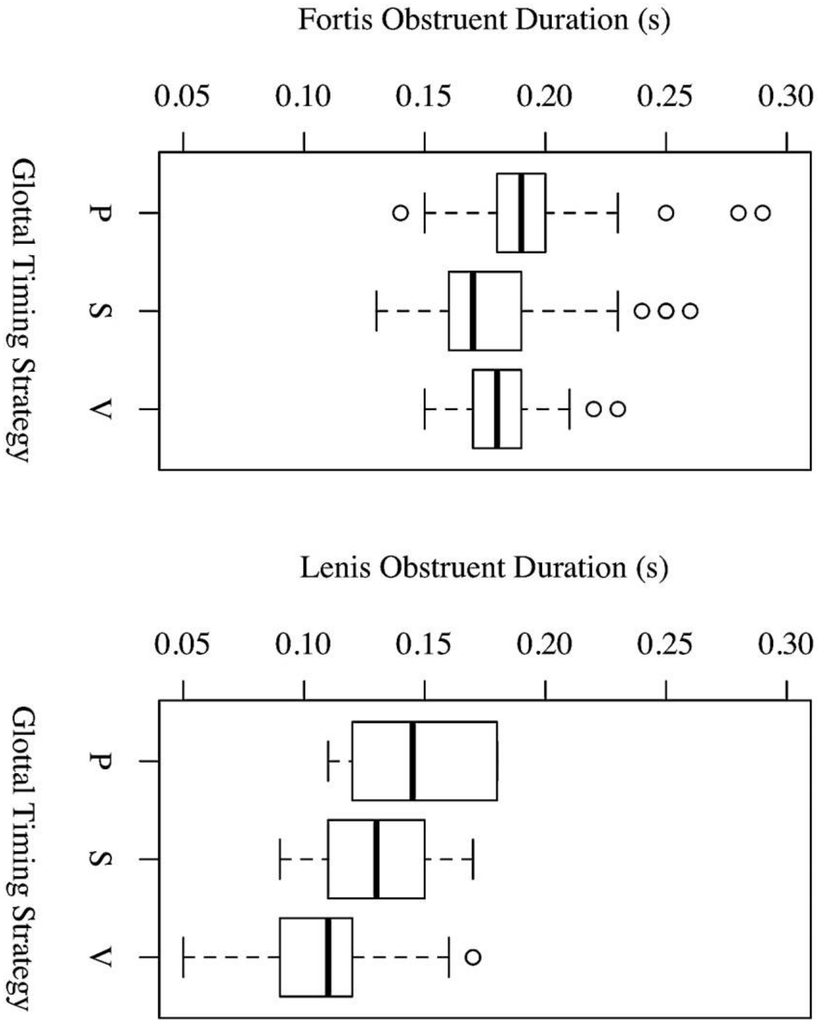

FIG. 15.—Effect of total obstruent duration on glottal timing strategy. Fortis obstruent data on left; lenis obstruent data on right.

as we observed with the spirantization data in **3.1** above, durational factors account for the voicing patterns.

4. Discussion.

4.1. Fortis and lenis constrasts in Oto-Manguean. The data from **2** above demonstrate that the fortis–lenis contrast in Itunyoso Trique is mainly realized via differences in duration with an additional glottal spreading gesture in the case of fortis obstruents. No evidence was found supporting the view that fortis consonants had a stronger articulation than lenis consonants. These findings are in general agreement with phonetic studies on fortis–lenis contrasts in related Zapotecan languages.

In three different Zapotec varieties, Jaeger (1983), Avelino (2001), and Leander (2008) find duration and completeness of closure to be the main correlates of the fortis–lenis distinction. For Yatée Zapotec (ISO code: zty), Jaeger (1983) concluded that duration, glottal width, and the completeness of closure were the main correlates of the fortis–lenis distinction, not articulatory strength. Voicing differences between the obstruents resulted from different glottal width parameters. Fortis obstruents were realized with fully abducted vocal folds. For Yalálag Zapotec (ISO code: zpu), Avelino (2001) argued that glottal manner features (spreading, constriction) did not characterize the fortis–lenis contrast, but VOT and duration did. The fortis–lenis contrast here involves both duration and voicing. Fricative realizations of lenis stops are implemented as a strategy "for the goal of keeping voicing in the entire segment" (Avelino 2001:47). For Ozolotepec Zapotec (ISO code: zao), Leander (2008) found that duration, both on the consonant itself and on the preceding vowel, was the strongest correlate of the fortis–lenis contrast. However, the contrast was also distinguished by concomitant changes in vowel quality resulting from vowel shortening before fortis consonants. Voicing differences distinguished fortis and lenis obstruents, but only in word-medial position. The current study obtained similar results to the previous work on Zapotecan languages: duration and glottal spreading are the most robust correlates to the contrast.

The presence of voicing and other phonetic correlates distinguishing the contrast had led researchers to reject a geminate–singleton analysis (Jones and Knudson 1977 and Nellis and Hollenbach 1980). By analyzing fortis and lenis consonants in terms of length, they argued, one could not explain patterns of spirantization, devoicing, place assimilation, or preceding vowel lengthening. The current study provides a connected explanation for variable patterns of spirantization and devoicing in lenis consonants in Itunyoso Trique. They arise from rate-related durational changes in the speech signal. The mechanism responsible for this, articulatory undershoot, is discussed further in **4.2**.

4.2. A durational account of lenition. Two optional patterns of lenition (spirantization and partial voicing) were observed within obstruent data in Itunyoso Trique. Each of these patterns correlated with durational differences in obstruents. In the case of spirantization, changes in closure duration were correlated with changes in speech rate, and lenis obstruents with shorter closure duration were more likely to be spirantized with a decrease in their total duration. Similarly, lenis obstruents were more likely to be realized with partial to complete voicing when their total duration decreased.

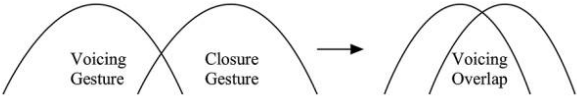

FIG. 16.—Influence of durational changes on laryngeal timing in lenis obstruents.

Both of these patterns fit neatly within a gestural model of consonant lenition (Browman and Goldstein 1986; 1990, Byrd 1996*a*; 1996*b*, Lavoie 2001, Romero 1999, and Saltzman and Munhall 1989). In such a model, patterns of reduction are accounted for by changes in the intrinsic timing of the constriction gesture and in the intergestural timing relation between adjacent gestures. As the total duration of a singleton consonant decreases, due to increases in speech rate, there is less likelihood that the tongue-tip gesture can reach its target (Byrd and Tan 1996). The mechanism responsible for this is articulatory undershoot (Byrd and Tan 1996, Gay 1981, and Lindblom 1983), the idea that when external demands (like stress, rate, or word size) cause duration to decrease, speech gestures may not reach their target articulation. In the case of stops, the movement of the tongue toward the oral constriction location in combination with oral airflow causes frication at the place of articulation.

Within this theory, laryngeal gestures may spread further into following consonants due to duration-based changes in the timing between segments. In the case of Trique, the voicing gesture on the vowel preceding an obstruent may spread into the obstruent itself, via a process of PASSIVE VOICING. 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, and 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, [ʔ͡t], 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. Fortis obstruents in Trique have such an active devoicing gesture: glottal spreading. Lenis obstruents permit voicing on the preceding vowel to spread because no devoicing gesture occurs. The effect of durational changes on both types of obstruents is schematized in figures 16 and 17.

Consonant duration is frequently affected by fast speech rate and unstressed syllables, both contexts traditionally considered LENITING. As a consequence of these durational changes, stop consonants may be realized as fricatives (Lavoie 2001 and Villafaña Dalcher 2007). In the case of Itunyoso Trique, lenis obstruents are often spirantized or undergo partial voicing.

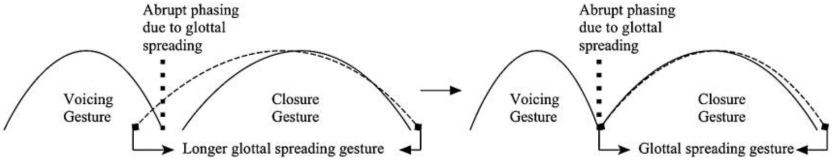

FIG. 17.—Influence of durational changes on laryngeal timing in fortis obstruents.

The crucial notion here is that the observed patterns are related to the durational magnitude of the gesture. When a gesture is shorter, there is an increased likelihood that a coarticulatory processes can span a larger proportion of the consonant. For instance, anticipatory vowel nasalization spans across a larger proportion of the vowel before a voiceless stop coda in English than before a voiced stop coda (Beddor 2009). In English, vowels are shorter before voiceless stops than before voiced stops. A coarticulatory process like anticipatory nasalization will span a greater proportion of the vowel preceding a voiceless stop because that vowel is shorter. The constant coarticulatory effect has variable effects based on the duration of the adjacent vowels. Similarly, in the variable voicing pattern in Trique, the shorter closure duration permits a greater proportion of the vowel to be voiced due to passive voicing.

5. Conclusion. Within Oto-Manguean languages and within the literature on consonant length contrasts, it is often argued that additional phonological features are necessary to explain patterns of lenition (Jansen 2004 and Nellis and Hollenbach 1980). The phonetic data from Itunyoso Trique argue that short duration consonants are not phonologically [lenis], they simply are more likely to undergo noticeable coarticulatory changes due to their shorter durational window. The patterns of lenition in lenis obstruents can be accounted for without reference to these abstract features; they are phonologically short. In contrast, long duration consonants do not undergo either variable patterns of voicing or processes of spirantization because they are phonologically long with a glottal spreading feature.

This particular finding makes predictions about phonetic patterns in other Oto-Manguean languages. Phonetic patterns in lenis obstruents, like voicing, lenition, or assimilation, ought to be limited to prosodically weak environments, such as word-medial, pre-unstressed, or phrase-final positions (Kirchner 1998 and Lavoie 2001). Consonants produced in these environments tend to be of shorter duration (Keating et al. 2000) than those produced in prosodically prominent positions. Data from Ozolotepec Zapotec suggest this to be the case. Only medial, intervocalic lenis obstruents show partial voicing (Leander 2008). The duration of obstruents in this position is shorter than their duration in word-final or word-initial position. As a result, Leander (2008:125) states, "the susceptibility of a consonant to voicing is, in part, conditioned by the consonant duration."

A purely durational, gestural account of lenition patterns in lenis consonants would also predict patterns of variable voicing or spirantization to be correlated to durational adjustments caused by speech rate. While the current study seeks to address this pattern, a more controlled context for eliciting rate-related lenition patterns is needed. It is hoped that this investigation will inspire future work testing this hypothesis. An examination of how phonetic patterns like these vary within Oto-Manguean or other American Indian languages not only reveals the nature of the phonological structure of the contrast but also informs more general theories of speech production in linguistic theory.

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