SOME ACOUSTIC CHARACTERISTICS OF WORD INITIAL PULMONIC AND GLOTTALIC STOPS IN MAM

by

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Abstract

Mayan languages are well known for their widespread use of contrasts beween pulmonic and glottalic stops. However, the phonetic properties that characterize these sounds and distinguish these contrasts have not been widely documented. The few acoustic studies conducted so far suggest that a variety of strategies are operative both cross-linguistically and across speakers to maintain the linguistically significant properties of what are termed "glottalic stops".

This thesis documents some acoustic characteristics of word initial pulmonic and glottalic stops in Mam, a Mayan language. Fifteen pairs of contrasting pulmonic and glottalic word initial stops, recorded in a sentence frame, from the speech of fourteen native speakers from one community (seven women and seven men), were analyzed according to three speech parameters: VOT, three amplitude envelope characteristics of voice onset abruptness of following vowels, and the fundamental frequency of following vowels.

Although pulmonic and glottalic stops differ in mean VOT at all places of articulation for this group of speakers, they do not differ according to any absolute range of values. Both bilabial and uvular glottalic stops are characterized by lengthy prevoicing. Velar and dental ejectives have longer VOT than corresponding pulmonic stops. VOT for pulmonic stops increases with place of articulation from front to back, as expected. There is no systematic variation for glottalic stops with vowel environment. The difference between pulmonic and glottalic stops may be best described as a difference between simultaneous or successive onset, rather than any absolute difference in VOT.

Greater amplitude rise time, a steeper rise in dBs, and a larger amplitude ratio from vowel onset to peak generally distinguish vowels after bilabial and dental glottalic stops from vowels after pulmonic stops in this data. Vowels after all glottalic consonants are characterized by a non-abrupt or gradual voice onset. Vowels after bilabial and dental pulmonic stops are characterized by an abrupt onset.

The data show a difference in Fo perturbation after glottalic stops in men's and women's speech. Women speakers have consistently lower Fo after glottalic stops than after pulmonic stops. Men have lower Fo at voice onset after velar and uvular glottalic stops, but after all glottalic stops tend to have a higher Fo by the peak amplitude of the vowel. This may indicate a different production strategy for men and women speakers. However, speakers generally show a rising Fo after glottalic stops and a flat or falling Fo after pulmonic stops.

Analysis of VOT, abruptness of onset, and Fo inflection of following vowels provide some useful first measures of the differences between pulmonic and glottalic stops. These findings contribute to a more complete description of the phonetic characteristics of these phenomena using data from a language that has not been previously acoustically investigated.

Dedication

for John

Acknowledgements

Almost everyone in the Linguistics Department of Simon Fraser University, most of Huixoq', and certainly everyone in my family has been instrumental in my actually finishing this thesis. Thank you all. Specifically, thanks to Tom Perry who encouraged my field work, Wyn Roberts who inspired and provoked, Zita McRobbie who painstakingly supervised all drafts, Murray Munro who helped critically at all stages, and John Esling who has added new insights. Cliff Burgess contributed immeasurably with editing the first painful drafts, as did Maya, Anna and John who first persuaded me I had a thesis. Thanks to John, to Maya, to Anna, to Jennifer, who have each given me their own inspiration and support.

Thanks to my fellow grads and mutual supporters who were all vital to graduate school survival, especially for discussions over the years with Janine Toole and Trude Heift, Xinchun Wang and Kyoung-Ja Lee, Peter Muntigl and Baoning Fu. Carol is the departmental pilot of theses into their final harbour. Nothing gets there without her assistance. Thanks to Georgina Carlson for help in many ways.

I also recognize the help provided by the Dr. Tai Wan Kim Memorial Graduate Scholarship in Language and Linguistics which helped fund the field work in Guatemala.

The data in this thesis is only available due to the critical involvement of the native speaker consultant, Alejandro Ruiz. He has been living in Canada for the last ten years, part of the Mayan diaspora displaced by the terrorism and killings perpetrated on the Mayas in Guatemala especially and horrifically during the 1980s. For the past five years we have worked together on Mam. To Alejandro, chjonte. I have also benefited from discussions with Lix Lopez here and in Guatemala. Chjonte Lix.

Especially, I thank the people of Huixoq'. To the project participants, to the children who escorted our every moment, to Vitalicia and Clara Luz who coached everyone in the project procedure and coached me in Mam, to Juana who taught me Mam and cooked too many tortillas, to the Ruiz family for hospitality, to Irma for stories, to everyone in Huixoq': chjonte cheey.

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Foreword
A Contract

This research was made possible by an extraordinary event: the return of Alejandro Ruiz to Huixoq'. To be a Mayan community activist in Guatemala in the 1980's, working for such things as drinkable water or a school in the village, meant prison, torture and almost certain death. To return after escape was to face those terrors again. Alejandro's survival and return was a miracle in Huixoq'. Because he was a hugely respected figure in the community, and because the initial recordings were carried out in his family home, gutted by the war, under his aegis,[1] his sanction gave this project unimaginable credibility in the community.

Alejandro was critically involved in all stages of this project. He was involved in preparing the materials for my fieldwork in Guatemala. He officiated at the initial recording sessions in Guatemala, explaining the purpose of the project and the procedure. He verified the correctness of the tokens during analysis. As a result, a community of people trusted in this work. Consequently, the following clarification, which was formulated in agreement with him, is vital to the assumed contract between me as researcher and the community which provides this data and owns this language.

The purpose of this project is to describe the sounds of Mam. Specifically:

1: to record for analysis a corpus of data which is representative of the language as it is spoken by the people in Huixoq', San Pedro Necta Aldea, Guatemala;

2: to record only sounds which native speakers judge to be correct productions of their language and;

3. to record these sounds in words which are carefully and respectfully translated under the guidance of (trilingual) native speakers who own this language and are its authorites.

The native speaker consultant and I are both committed to as much

[1] This happened in the kitchen which had been seized for a lookout by the notorious "defence patrols", or on the coffee drying patio where coffee is dried for export at a pittance to the growers, or in the communal bedroom where we, the gringos, were given the two best planks to sleep on and some family members accommodated us by sleeping on the floor.

control by native speakers as we can arrange to avoid misrepresentations of this language by nonnative speakers. Naturally, all inadequacies and errors of analysis are mine.

Chapter 1
Introduction

Mam shares with many of the indigenous languages of the Americas the extensive use of glottalic consonants. These sounds are describable as being produced with two different air stream mechanisms: the pulmonic and glottalic. They are similarly understood by the native speaker consultant, who describes these sounds by the directionals: /tz'ex/, that is, the air approaches and passes out past the speaker, and /tz'oqx/,the air approaches and passes inwards (into) the speaker. We can translate this parsimoniously as ejective and implosive respectively.

This thesis is an exploration of some of the acoustic attributes of ejectives and implosives in Mam, a Mayan language, as well as how they contrast with the corresponding pulmonic stops. The study is based on data from recordings of fourteen speakers, seven men and seven women.

1.1 PREVIOUS STUDIES ON GLOTTALIC CONSONANTS

Earlier studies have reported a variety of phonetic manifestations for glottalic consonants from ejectives and implosives to sequences of glottal stops with following continuants, or to various degrees of "laryngealization", subsumed as different voice qualities or phonation types. Recent research on the phonetic characteristics of these sounds suggests even greater cross-linguistic and inter-dialectal variation (Lindau 1982, Kingston 1985, Pinkerton 1986). Such studies however, are few in number, dissimilar in design and interested in a variety of theoretical questions. They have rarely attempted systematic comparison of the same parameters. Some data on the characteristics of glottalic consonants come from studies mainly interested in establishing types of linguistic universals (Greenberg 1970, Campbell 1973, Pinkerton 1986), or pursuing theories of tonogenesis (Hyman 1973, Hombert 1978). Very few studies, however, have gathered data from more than one or a few speakers - with the notable exception of Lindau's (1984) study on implosives in Niger-Congo languages and Hausa and ejectives in Hausa and Navajo, or Pinkerton's (1986) study of five Quichean languages. As a result, generalizations about universals or attempts to establish physiological or aerodynamic explanations for these phenomena so far rest on extremely limited data from few speakers.

This thesis therefore, focuses on documenting some phonetic aspects of these sounds as they occur in one language, Mam, as they are actually used by one community of speakers today, based on a representative sample of speech data from that community.

Both the analysis of field data and the design of research projects, however, partly depend on some working assumptions about what will be found. This section attempts to make those assumptions explicit.

1.2 SOME ASSUMPTIONS

A primary assumption is that meaningful distinctions are made by speakers through physiological means. These differences in production will have some acoustic consequences that are heard and perceived as different, or distinguished, by hearers in their speech community. We do not know what these differences are for all languages. We may have expectations of what they might be for any one language based on what seem to be differences in other languages which use similar contrasts. These expectations will provide a set of "first measures".

Therefore, expectations about these possible differences at least partly depend on how we think these sounds are made. If the acoustic consequences do not seem to verify this view, then such findings would suggest a rethinking of the model of production. That enterprise remains outside the scope of this thesis.

1.2.1 The classic model

Many studies of the phonetic characteristics of glottalic consonants take as a point of departure Catford's (1939) model on the classification of stop consonants. Catford extended Beach's (1938) work on Hottentot (cited in Catford 1939) to a description of the production of all sounds based on the source of the initiatory power; that is, the lungs, the glottis or the velum. This has been widely cited (Greenberg 1970, Painter 1978, Nihalani 1986, Ingram & Rigsby 1987). I refer to this as the classic model hereafter. The production of glottalic stops, that is, ejectives and (voiceless) implosives, is assumed to involve the compression of a completely closed air chamber formed by three articulatory gestures: the glottis is closed, an oral closure is formed and the velo-pharyngeal port is closed. In the production of ejectives, the larynx then is jerked upwards, decreasing the volume of contained air and increasing its pressure. It is the syncopated timing of the oral and glottal releases that syllable initially creates the classic acoustic scenario of a strong release burst, then a period of silence, followed by an abrupt vocal onset for ejectives (Catford 1977, Ladefoged 1971, Stevens 1977, McDonough and Ladefoged 1993).

According to this model, the production of voiceless implosives involves the creation of the same three closures as the ejective stop, but then the larynx is lowered, creating a rarefaction of the enclosed body of air. Upon release of the oral closure, external air flows into the oral cavity.

However, the production of both voiced stops and voiced implosives is different. The first requirement for voicing is a pressure differential between the subglottal air and the supraglottal air[1]. If a speaker makes an oral closure and attempts to continue voicing, this difference in pressure between supraglottal and subglottal air pressure will be equalized in about two glottal cycles, assuming a normal rate of (male) phonation of 100Hz [2]. However, both voiced stops and voiced implosives normally have much longer durations of voicing during closure. Therefore, it is supposed that the speaker employs some strategy to expand the enclosed cavity. The most common manoeuvre is lowering the larynx thus expanding the pharyngeal cavity. This increases the pressure drop across the glottis, and slows the rate at which the supraglottal air pressure builds up. This facilitates voicing.

In the classic model this cavity expansion gesture produces a voiced implosive, because as Hockett (1955) described: "even though some air is passing north through vibrating vocal cords the chamber above... is being rarefied"(p. 35). Ladefoged, however, challenged this explication in his phonetic investigations of African languages in which he called the action of the lowering larynx similar to a "leaky piston", allowing some upward flow of air. This largely counteracts the rarefaction effect from the cavity expansion. Ladefoged (1975) heard the difference between implosives and voiced stops instead in "the peculiar quality of the sound (which) arises from the complex

[1] The transglottal pressure drop is minimally 2cm H_2O (Catford 1977:73).
[2] See Boyle's Law again to compute the volume and pressure relation (Catford 1977:74).

changes in the shape of the vocal tract and in the vibratory pattern of the vocal cords"[3] (p. 133) rather than in the initiator or direction of airflow.

The classic model met another challenge in a recent study by Kingston (1985). Using data from three speakers of Tigrinya and one of Quiche plus a simulation study based on that data, he argued that the volume decrease and pressure increase available from the laryngeal closure and raising gesture in the classic ejective is inadequate to generate the observed pressure differences. Kingston claimed that the increased glottal resistance created by constricting the glottis far outweighed any possible increase in pressure generated by subsequently raising the larynx, and that the pressure did not increase markedly in the production of ejectives. In fact pressure increase was far greater in the production of voiceless stops where the higher rate of airflow was more effective than the compression gesture of larynx raising. The movement of the larynx was also poorly coordinated with the observed variations in pressure. Kingston argued that the increase in pressure which has been recorded in ejective stops must come from other articulatory manoeuvres, together with tensing of the vocal tract. He proposed that all types of ejectives involve medial compression.[4] He left open the issue of how this medial compression is achieved, citing a discussion by Laver (1980) on creaky voice that suggests involvement of the false vocal cords.

1.2.2 Physiological and acoustic correlates of glottalic stops

One source for modeling the production of glottalic consonants is the existing literature on the production of glottal stops[5] which can be assumed to be produced by the firm glottal closure of glottalic stops. This involves medial compression[6] with almost invariably some degree of supralaryngeal

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[3] He attributes this quality probably to the decrease in frequency of all the formants, extending through the whole syllable (1964:13).

[4] Using evidence from the overlap in VOTs of "tense" and "lax" stops in Korean as well as contrasts in how Fo correlates with VOT in Quiche and Tigrinya, Kingston (1985) argued that stiffening of the vocal cords is independent of medial tension.

[5] For the most complete description of the intrinsic muscular coordination required at adduction, before release and the triggering mechanism at vocal onset for the production of [ʔ] see Fujimura (1979).

[6] Medial compression involves activity of the lateral crico-arytenoid muscles.

constriction.[7]

The production of creaky voice also involves medial compression according to Steven's (1988) model for "pressed or glottalized phonation", during which the vocal folds are thicker than for modal or breathy phonation (p.361). Pressed phonation in fact involves slackening of the vocal fold cover. This phonation is heard in the vicinity of [ʔ] in English. In discussion after this particular paper, Hirano reported little activity of the vocalis muscle in creaky voice. He assumed that tight closure is achieved by "muscles outside the larynx", that is, the lateral cricoarytenoids, the lateral part of the thyroarytenoid and the thyropharyngeal muscle (cited in the discussion following Stevens 1988 presentation, p. 371). Esling (p.c.) adds the obliques and (by extension) the aryepiglottic folds. It appears "medial compression" is itself a somewhat cavalier term to describe the fine adjustments of a three dimensional structure.

The literature on supraglottal constriction is extensive since Catford (1964) noted the upper larynx constriction with the epiglottis in the production of "ligamental voice".[8] Gauffin (1977) noted the sphincter action of the larynx in producing the "reduced protective closure" found in [ʔ] and a concommitant lowering of Fo that results from the "larynx tube constriction". The complete convergence of the false vocal cords (i.e. the ventricular folds) is shown in photographs of the word final glottal stop in Fukienese in a study by Sawashima and Hirose (1983) and in photographs of a strong glottal stop in a study by Esling (1984).[9] Fischer-Jørgensen also notes ventricular constriction with vocalis muscle peaks and raised lateral cricoarytenoid (LCA) activity in the production of stød in Danish (1989). She notes that LCA activity lowers F0 in creaky voice.

In the production of ejectives and implosives then we may expect, as with the production of glottal stop, a greater degree of medial compression

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7 See Moore and von Leden (1958) for observations against the involvement of the ventricular bands in vocal fry and for medial compression only by internal laryngeal structures.

8 For a physiological description of the involvement of the aryepiglottic folds in enhancing medial compression, see Honda (1983).

9 Esling (1984) noted the similar configuration (increasing participation of ventricular folds) of glottal stop with harsh or ventricular voice.

with concommitant supraglottal constriction at the level of the ventricular folds and the structures of the epilarynx. This particular coordination of gestures will have certain expected acoustic results.

Klatt and Klatt (1989) isolated 48 potential acoustic cues to voice quality variations.[10] An almost opposite acoustic effect to what was seen with breathy voice can be expected in most parameters for the addition of medial compression, (what they termed a glottal-stop onset). Vowels with glottal-stop onset are associated with a rapid fall of Fo (over 30 ms), a vowel amplitude which is 6 dB less than modal voice quality and a reduced open quotient[11] of about 30% around the vicinity of the glottal stop. Therefore, there is less acoustic loss (Stevens 1988), reduced amplitude of the first harmonic, narrowed bandwidth of formants and decreased low frequency losses (Klatt and Klatt 1988). The formants are therefore said to be sharply tuned. The possible acoustic results of supralaryngeal constriction[12] could be an increase in the bandwidth of the formants and an attendant decrease in amplitude from the increased damping of the wave. Language specific gestures coordinated to produce the linguistic contrasts available from glottalic stops could therefore produce a variety of acoustic outputs.

Meanwhile, abandoning phonetic prediction and looking upstream, so to speak, from the recorded field data on glottalic obstruents, a variety of phonetic (acoustic) effects have been recorded. These tend to report the characteristics of glottalic stops as much in the characteristics of the following vowel as in the momentary acoustic cue of the stop burst itself (Ladefoged 1975, Kingston 1985 on Korean). Specific acoustic parameters typically involve a difference in voice onset time from the specific coordination of oral and glottal events required to produce ejectives or implosives, some difference in abruptness of vowel onset from the sudden release of the medial compression and a variety of recorded effects on Fo of the following vowel.

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[10]Of the ten acoustic parameters associated specifically with breathy voice, which was the focus of their study, only two had a statistically significant correlation with perception: the degree of aspiration at the level of F3 and the relative amplitude of H1. All relevant cues, however, were preferred for judgements of naturalness.

[11]The open quotient is the ratio of time the glottis is open compared to the time when the folds are closed in any glottal cylce (Klatt & Klatt 1989).

[12] Esling suggests this could also be termed pharyngealization with larynx raising (p.c.).

The three parameters of VOT, abruptness of onset, (the amplitude envelope characteristics of the following vowel) and the Fo of the following vowel comprise the three "first measures" for these sounds in Mam. This thesis will look at only these three possible acoustic effects to see both how they characterize these types of stops and whether they distinguish pulmonic from glottalic stops in Mam. A summary of the research on each of these parameters as it is recorded for glottalic stops in other languages is included in each of the relevant chapters.

An analysis of such data, including data from women's speech (traditionally underrepresented) as well as men's speech, offers new insights into old questions about how speakers make linguistic distinctions between pulmonic and glottalic stops, how these ways vary within groups of speakers, and specifically, contributes to describing one aspect of how people talk in Mam.

1.3 MAM

Mam, a Mayan language of the Guatemalan highlands, presents a phonetic case study in many of the linguistic varieties of "glottalization". England (1983) reports implosives, ejectives, phonemic vocal creak and allophonic glottal stops as well as a falling tone in the environment of glottal stop after long vowels. Mam also has breathy offsets for long vowels and paralinguistic use of falsetto voice quality (observable in my own field recordings). Mam, with other Mayan languages, provides counterexamples to several of Greenberg's (1970) generalizations. Mam has a uvular implosive, but has ejectives at more forward places of articulation. Glottalic stops occur syllable finally as well as syllable initially.

1.3.1 Background

Mam is spoken by about 800,000 people[13] in the northwestern highlands of Guatemala. It is part of the Mamean branch of the Eastern Mayan languages, most closely related to Teco, Ixil and Aguacatec (England 1983).[14] There are three divisions of Mam: Northern Mam, Southern Mam, and Western Mam. This thesis looks at data drawn from the village of

[13] This number was provided by personal communication from Lix Lopez, a recognized spokesperson for the Mam speaking Maya group in Guatemala.

[14] For an analysis of phonological regional variations and similarities in Mam, see England (1990).

Huizoq'. This variety is termed San Pedro Necta Mam by the native speaker consultant, (SPN Mam) and is a dialect of Northern Mam.

There are about two hundred and fifty people living in the village of Huixoq'. Almost all people in the village also speak Spanish as a result of the government policy called *castelanizasion,* whereby children in the rural areas are given an education (if they can afford not to work) up to grade six in Spanish. Because buses pass regularly along the treacherous roads through the highland villages, people make frequent day trips to Huehuetenango or visit families or markets in other villages or towns where Spanish is often spoken due to the mutual nonintelligibilty[15] of neigbouring dialects or languages.

1.3.2 The consonant system

The consonant inventory of SPN Mam is divided into two types: seven[16] pulmonic voiceless stops that contrast with seven glottalic stops, plus a glottal stop.[17] Mam has bilabial, dental,[18] velar, and uvular simple stops and dental, alveopalatal and retroflex affricates. For each pulmonic stop there is a glottalic contrast. There is also a set of four fricatives, one of which is strongly retroflex and labialized[19]. Each appears word initially, medially and finally. Word final pulmonic stops are characterized by a heavy degree of aspiration or affrication. The bilabial and uvular glottalic stops are implosive. The dental glottalic stop is most often ejective but occasionally implosive. It has marginal use, as in other Mayan languages. [20]

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15 According to England (1983) there is reduced but possible interinteligibility between the three branches of Mam.

16 The standard reference on Mam is England (1983). Her complete grammar documents another Northern Mam dialect, Ixtahuacan Mam, which has a consonant system of eight plain and eight "glottalized" stops.

17 This is the standard description. I have argued elsewhere (work in progress) for another contrastive glottal stop word finally with different phonetic properties. It may be prosodically motivated by open light syllables or it may be a phonemically contrastive glottal stop. This glottal stop involves a much greater degree of supralaryngeal constriction. If it is not phonemically contrastive with plain glottal stop then it must contrast with laryngealization.

18 Although England reports an alveolar contrast for Mam, the native speaker consultant for this study does not accept productions of an alveolar stop. He clearly demonstrates an apicodental articulation.

19 Labialization is a very obvious feature of Mam retroflex sounds and extends to paralinguistic uses, eg. as a directional pointing gesture.

20 /t'/ is noted as marginal in Teco (Kaufman 1969) and is elsewhere recorded as rarely used in Cakchiquel (thanks to Wyn Roberts for this source).

Canby (1994) points out that "in Guatemala even alphabets are controversial" (p. 336). There are several systems of orthography in use in Guatemala and none of them officially recognized by the Mayan organizations yet, although the Academia de Lenguas Mayas is working towards a uniform system for all Mayan languages. In his thesis I will use, following England (1983), the system devised by Terence Kaufman for the Proyecto Linguistico Francisco Marroquin (PLFM). The contrastive set of pulmonic and glottalic obstruents in Mam is:

The PLFM orthography

pulmonic	p	t	tz	ch	tx	k	q	'
glottalic	b'	t'	tz'	ch'	tx'	k'	q'	

These represent the following IPA symbols:

pulmonic	p	t	t͡s	t͡ʃ	t͡ʂʷ	k	q	ʔ
glottalic	ɓ	t'	t͡s'	t͡ʃ'	t͡ʂʷ'	k'	ʛ	

The speakers of SPN Mam in Huixoq' use the post-aleveolar affricate /ch/ whereas the speakers of some other northern Mam dialects use the palatal /ky/.

A few minimal pairs of plain and glottalic stops at the same place of articulation, written in the PLFM orthography, indicate the contrastive function of plain and glottalic stops in Mam. Although absolute minimal pairs are few due to the consonant heavy structure of Mam words, there is a heavy functional load for all contrasts, with the exception of /t'/.

/paa/ bag	/b'aa/ mole
/kaa/ grinder	/k'aa/ sour drink
/ko'j/ lion	/k'o'j/ delicious
/qo/ let's go	/q'o/ squash

1.4 THE RESEARCH PROJECT METHOD

1.4.1 The Data

An extensive word set was initially elicited from the native speaker consultant to represent all word initial and word final glottalic and pulmonic stops of Mam in each vowel environment. This was the original data set of 350 tokens. Next, we chose 162 words to represent all word initial and word final stops in Mam. We took this set to Guatemala [21] where each participant was recorded saying these 162 words, as well as taped in natural conversation. From this data fourteen contrasting pairs of word (or syllable) initial pulmonic and glottalic stops from the set of 162 tokens provided the bulk of the data for analysis. They were chosen to most closely approximate contrastive minimal pairs. These include contrasting tokens of the bilabial pulmonic stop and bilabial implosive, the dental pulmonic stop and dental ejective (or implosive), the velar pulmonic stop and velar ejective and the uvular pulmonic stop and uvular implosive, in all vowel environments. This final word list is in Appendix 1.

1.4.2 The Participants

Thirty three speakers in the village of Huixoq', San Pedro Necta Aldea, in northwestern Guatemala were recorded in Guatemala, in July 1995, saying the contrasting word pairs from the complete data set in a natural sentence frame:

q-xe'ltz'n ma'n jun jool..... *I'm going to say the word ...*

All participants spoke the same dialect of Mam. [22] From the 33 speakers, recordings of 14 adult speakers, seven women and seven men, aged 19 to 65 years, were selected for acoustic analysis based on clarity of the recording, (i.e., with least background noise) and most natural and clear voice production by the speaker, at a normal speaking rate. These speakers are numbered in the text as F2 to F8 for the women and M1 to M7 for the men. All participants were given an honorarium comparable to honoraria offered

[21] There seemed to be a lull in the climate of oppression that summer for the first time and many displaced Mayas ventured a return to visit families and homes accompanied by sympathetic protective observers.

[22] In Guatemala there are very great dialectal differences from village to village. People from just over the hill would use palatalizations, different vowel length, or variations of glottal stop or word final implosives etc. Alejandro Ruiz verified the appropriateness of the speakers for this dialect.

to participants in other SFU research projects.

1.4.3 The Equipment

The complete data set from the native speaker consultant was recorded in the SFU phonetics lab for preliminary analysis. Audio recordings were subsequently made in Huixoq', Guatemala, using a Marantz tape recorder and a hand-held unidirectional microphone. The recordings were made in the quietest conditions that were feasible in field conditions. The utterances were subsequently digitized at 20 kHz, with 16 bits resolution on the SFU Phonetics Department computer, and analyzed with the Signalyze 3.12 program.

1.4.4 The Procedure

After the explanation and introduction during the first week by the native speaker consultant, as described in the prologue, I continued to record participants. This was achieved using my survival Mam, interspersed with even less proficient Spanish and, as always, with the active help of the children who had already participated or who quickly figured out the procedure. I showed the participants a set of flash cards written in both one of the current orthographies for Mam and a translation in Spanish which they could read from. These were developed with the consultant and many participants read from them in the Mam orthography. I also asked in Mam for these words. This is the area where there is the most opportunity for researcher/native speaker foulup. Consequently, after digitizing, any questionable data was again either verified by the native speaker consultant as representing the contrasts intended, or discarded if judged by him to be unclear, faulty in production, or ambiguous in meaning. When one of these utterances was rejected, it was replaced by another token from the same speaker using the same word initial stop, if available and judged acceptable. The data set used in the field was sufficiently large to allow this.

The data set is incomplete in several ways. The contrast of /t/ and /t'/ is rare, as noted, and we did not manage to collect some contrasts, eg./ ti:t'i/ /ta:t'a/, until after field work was completed. Others were never collected, eg. /te:t'e/. The words for contrasts between /ke/ and /k'e/, /qu/ and /q'u/, in the elicited lexemes may be archaic and were not understood by all speakers. Any tokens of dental stops which were palatalized or otherwise affricated for any reason were also removed. Thus some of the data is necessarily missing.

Vowel length is phonemic in Mam (England 1983). Unfortunately the data set does not match all types of vowel environment. However, wherever possible, I paired the contrastive word initial pulmonic and glottalic stops with the same short or long vowel and open or closed syllable.

The whole set, however, represents a broad range of both male and female speakers from one dialect area and a fairly complete set of the sound contrasts for this community of speakers today.

Chapter 2
Voice Onset Time

Lisker and Abramson's 1964 study isolated voice onset time (hereafter VOT), or the acoustic results of differences in the coordination of oral and glottal gestures, as the sole parameter required to distinguish almost all the stops of the languages they surveyed. The classic model, reviewed in Chapter 1, also portrays a time-varying coordination of oral and glottal closure, subsequent air compression or rarefaction, followed by oral release and delayed glottal release. Abramson (1977) and Stevens (1977) say this syncopation of oral and glottal gestures results specifically in a delayed VOT. Stevens associated this with the laryngeal configuration which results in "substantial pressure increase" from the closed glottis, constricted vocal folds, and raised larynx (p.277).

This chapter looks at VOT to see if it does in fact distinguish pulmonic from glottalic stops in Mam as expected from the model, and in accordance with the findings of Lisker and Abramson for distinguishing other types of stops in most languages. It will be shown that on average pulmonic and glottalic stops differ in VOT at all places of articulation in Mam. However, there is considerable overlap, indicating that VOT does not completely distinguish these categories.

In the first section, a summary of the literature is presented as it relates to the acoustic measurement of VOT in glottalic consonants. The measurements are taken from the original literature if available, or if not, are estimated by measuring spectrograms in these articles where this was possible, as noted and summarized in Table 2.1. Two issues are addressed. The first is the extent of speaker variation. The second is the type of uvular implosive. The second section includes a summary of the procedures, types of measures, and the results from analyses of VOT in Mam. These include the VOT characteristics of both types of stops, and the differences in VOT between the two types of stops. It also looks at variation according to vowel environment.

2.1 PREVIOUS STUDIES ON VOT AFTER GLOTTALIC STOPS

The following section provides a brief survey of the literature on the VOT after glottalic consonants. These findings are summarized below by language, roughly in chronological order of the relevant publications. Earlier results cited in Catford (1977) are included in the table, without summary in the text, for comparative purposes. Estimated values are noted in footnotes.

2.1.1 Ejectives

Nez Perce

Aoki (1970) recorded "about 0.1 sec" of silence for /t'/ and /k'/ after an abrupt closure in Nez Perce, a Sahaptian language spoken in northcentral Idaho, southeastern Washington and northeastern Oregon. His data was drawn on measurements from one female speaker (1970).

Chipewyan

Hogan (1976) used two different measures of VOT[23] across eleven vowel environments with data from one speaker of Chipewyan, an Athabascan language spoken in Cold Lake, Alberta. Hogan found a significant difference in pre-silence durations (closure period intervocalically) between high and low vowel environment: duration being longer for high vowel contexts. The difference in post-release VOT before high and low vowels, however, was not significant. VOT measures from burst release to vowel onset varied from 86.3 to 147.3 ms for /t'/ and from 88.4 ms to 124.2 ms for /k'/.

Hogan's second duration measure of pre-release silence was designed to test Greenberg's (1970) presumed hierarchy for favored places of articulation, following Wang and Haudricourt (cited in Greenberg, 1970), which assumed that the degree of ease in compressing a smaller cavity is greater than that for compressing a larger cavity - with the attendant prediction that VOT for dentals will be longer than for velars (Hogan, op.cit.). This was not supported by Hogan's data.

Quiche

In her first study of Quiche languages, Pinkerton reported a significantly longer VOT for glottalized stops in K'ekchi (Quiche) than for their "non-glottalized counterparts" (1978:S93). Her more extensive 1986

[23] Two measures were required to distinguish VOT of stops and affricates in his data. These were the difference between durations from the point of release to vowel onset and the difference between the end of the transient or fricative noise segment to the vowel onset.

study, using twenty-seven male speakers of five Quichean languages[24], found an average VOT of 45 ms for ejectives, i.e. for /t'/, /k'/, and /q'/.

Tigrinya and Quiche

From Kingston's exhaustive study of "glottal events"[25], measurements of VOT for ejectives can be estimated from spectrograms of one token of /t'/ and /k'/ from one speaker each of Tigrinya (Ethiopian) and Quiche (Maya). Alveolar ejectives in Tigrinya thus have about 70ms VOT, velar ejectives about 85 ms VOT, while in the Quiche data, alveolar ejectives and velar ejectives have 30 ms and 35 ms VOT respectively (Kingston 1985:170).

Gitksan

Ingram and Rigsby (1987) compared what they termed the "lenis" word initial ejective stops of Gitksan, (a language from the Skeena River valley of British Columbia) with what they termed the "fortis" and clearly ejective stops of Chipewyan, Athabascan, according to four phonetic features: VOT, Fo of the following vowel, intensity of release, and type of vowel onset (1987, after Kingston, 1985). Chipewyan ejectives had an average VOT of 100 ms, (from Hogan's 1976 study) while Gitksan ejectives had an average VOT of 89.2 ms. These were [t', k', k^{j}', k^{w}',q']. Because the standard deviation of 31.3 for the "lenis" (Gitksan) stops overlaps the range of the "fortis" (Chipewyan) stops, I suggest that the fortis/lenis distinction seems questionable, at least on the basis of VOT.

Wickstrom (1974) reported an average value of 0.1 seconds (100 ms) of silence after the abrupt onset of glottalic stops in Gitksan for one speaker of Gitksan, with a range of 0.04 to 0.1 sec. I was not able to ascertain VOT any more exactly from spectrograms of this data.

Navajo

A comparison of the three-way contrasting consonant system of Navajo showed overlap of the VOT of ejectives with the slightly longer VOT of aspirated stops (McDonough and Ladefoged (1993). VOT of glottalized coronal was 108 ms (SD 31), whereas VOT of aspirated coronal stops was 130 ms (SD 29). The VOT of glottalized velar stops was 94 ms (SD 21), whereas

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24 See fn 36.

25 Kingston calls the two types of ejectives "tense" and "lax", "for convenient reference", without claiming a theoretical basis for the terminological distinction (1986:166).

VOT of aspirated velar stops was 154 ms (SD 43). Both the VOT of the aspirated (t=10.62, p=.0001) and glottalized series (t=6.94, p=.002) are significantly different from the unaspirated stop series and have a smaller but significant difference from each other (t=3.36, p=.002) (p.154). This difference was not significant in the affricate aspirated and glottalized series. The VOT for voiceless aspirated stops was found to be twice as long as those reported by Klatt for English[26]. Because the VOT was therefore roughly the same for the aspirated glottalized contrast, McDonough and Ladefoged (1984) argue that it is the fricative interval of the voiceless stop and the quality of the onset to the following vowel[27] that are their salient characteristics.

Estimates from one spectrogram in Lindau's study (1982) show VOT of about 75ms for velar ejectives in Navajo.

Hausa

Estimates from spectrograms by Lindau (1982) of Hausa, a Chaddic language spoken in Nigeria, show VOT of about 33 ms after /k'/, less than the 50 ms measured by Meyers (1972) and the 50-60 ms reported by Ladefoged (1964).

Montana Salish

There are no contrasts of VOT in Montana Salish according to Flemming and Ladefoged's (1994) acoustic and aerodynamic study of three native speakers. However, ejectives show considerable "glottal lag" with 65 ms (SD 21) for alveolar ejectives, 86 ms (SD 26) for velar ejectives, and 81ms (SD 21) for uvular ejectives.

Ingush

Warner's recent (1996)[28] study on ejectives in Ingush, a northeast Caucasian language, based on analysis from one speaker, records average VOT for ejectives of 45.1 ms, varying as expected with place of articulation and before high vowels, in agreement with findings reported by Hogan (1976). The data included [t'], and [k'] in three vowel environments, and three tokens of

[26] Klatt (1975) reports average VOT for voiced stops in English of 18ms (range11-35) and average VOT for voiceless aspirated stops of 61ms, cf. Lisker and Abramson (1964)

[27] They note that usually ejectives begin with an "immediate sharp onset of the vowel formants" (p.161), discussed further in Chapter 3, Section 3.1.

[28] Thanks to Zita McRobbie for bringing this recent conference paper to my attention.

[p'], all in a high vowel environment. Whereas VOT of ejectives in Ingush belongs to what has been termed by some as "lenis" glottalic stops, Warner demonstrates that the resulting higher Fo of the following vowels belongs to what has been categorized as "tense" glottalic stops. She concludes that binary typologies are a methodological artefact of previous research comparing only two languages in each study, and suggests that more extensive cross-linguistic data disproves the adequacy of such binary divisions.

Table 2.1 summarizes the comparative data on VOT for ejectives in a number of languages. Sources are noted as well as the number of speakers involved in each study.

Table 2.1

Comparison of VOT in ms of word initial ejectives in some languages (Standard deviations in brackets)

Language	# sp.s	p'	t'	k'	q'	average	Source
Navajo	7		108 (31)	94 (21)			McD and L. '84[29]
Navajo	9			75			Lindau '84[30]
Mont. Salish	3		65 (21)	86 (26)	81 (21)		F.L. &T. '94[31]
Hausa	12			33			Lindau '84
Hausa	?[32]			50-60			Ladefoged '53
Hausa	1			40			Meyers '72
K'ekchi	?			97 (38)	92 (38)		L & M '86[33]
Ingush	1			50		45.1	Warner '96
Chechen	?					70	Catford '77
Chechen	?					7-33	K &N unpubl.[34]
Dargi	?					16- 60	Gaprindashvili '66[35]
Nez Perce	1					100	Aoki '70
Chipewyan	1		86-147	88-124			Hogan
Gitksan	2					89.2 (31.3)	Ingram & R '87
Gitksan	1					100	Wickstrom '74
Tigrinya	3		70	85			Kingston '85

29 McDonough and Ladefoged (1984).

30 VOTs from Lindau '84 were estimated from a spectrogram of one speaker.

31 Flemming, Ladefoged and Thomason (1994).

32 Ladefoged (1953) only reported that his data was from one or a few speakers for all languages but Hausa.

33 Ladefoged and Maddieson, cited in Fleming and Ladefoged (1994).

34 Kingston and Nichols, cited in Warner (1996:1528).

35 Gaprindashvili, cited in Catford (1977).

Quiche	1	30	35		Kingston '85
5 Quiche lang.s	27			45	Pinkerton '86[36]
Abkhaz	?			12	Catford '77
Kabardian	?			28	Catford '77
Avar	?			100	Catford '77

2.1.2 Implosives

The duration of voicing in implosives tends to be shorter than in the corresponding voiced stops. For example, Nihalani (1986) reports that in the Sindhi data based on his own speech, duration of voicing of the implosives was 52% to 81% of that of the "explosives". Lindau gives histograms of only comparative closure durations in comparing Hausa to four Niger Congo languages, noting that Hausa has a shorter closure duration than the Niger Congo languages (Lindau 1982).

2.1.3 Discussion of related issues

Voiced versus voiceless uvular implosives

The Preview of the IPA handbook notes that "voiced uvular implosives do not occur in any well known language" (Nolan 1995, p. 19). This analysis of VOT in Mam will show that the majority of tokens are prevoiced for this community of speakers. However, a variety of phonetic manifestations of uvular implosives are used: from zero VOT, to aperiodic creak, to fully prevoiced implosives.

Speaker variation

There is considerable variation noted in the phonetic accounts of implosive production. Pinkerton (1978) noted two productions of [ɓ] in free variation: (one with) a voicing lead and (one with) a zero VOT (p. S93). Voicing duration and type of glottalic stop also frequently vary by place of articulation. Pinkerton (1986) found longer periods of prevoicing for bilabial and alveolar implosives in Quiche, but a positive voice onset time for uvulars. These are voiceless implosives in Quiche. A significant finding of Pinkerton's study was the degree of cross-dialect (and possibly individual) differences. For example, in her data, one (Tactic) Pocomchi speaker produced voiceless implosives at the bilabial, alveolar and uvular place of articulation

36 Of the 27 male speakers, 15 spoke K'ekchi and 3 each spoke the other 4 Quiche languages.

but velar ejectives. Another (San Cristobal) Pocomchi speaker produced bilabial and velar implosives but alveolar and uvular ejectives for the same tokens. The variation between implosive or ejective production seemed here to vary by dialect although Pinkerton also mentions the difference in ages of speakers. Pinkerton's data supported Campbell's (1973) counterexamples to Greenberg's (1970) hypothesis on universal co-occurence constraints between types of glottalic stops and place of articulation.[37] Pinkerton suggested that a possible confounding factor could be the age of the speakers and that language change could possibly be involved.

The data from Mam presented here however, indicates that even individual speakers may vary in which type of glottalic stop they produce in different tokens. This suggests that the extent of variation between different phonetic realizations of glottalic stops extends beyond language or dialect to individual speakers themselves.

Table 2.2 summarizes the duration of prevoicing in implosives where noted in the literature for some languages.

Table 2.2

Estimated voicing in ms for word initial implosives in some languages

Language	nr sp.s	bilab	dental /retroflex	palatal	velar	uvular	Source
Sindhi	1	6	8	10	9		Nihalani '86
Quiche	3	-80				20	Pinkerton '86
Pocomchi	3	30				20	"
Cakchiquel	3	-30				20	"
Kekchi	15	-30				20	"
Tzutujil	3	-30				20	"

One other problematic set of implosives are those of Lendu which are arguably two sets of voiceless and voiced implosives.[38]

37 Greenberg proposed a universal preference of implosives for front places of articulation and ejectives for back, predicting any language with an implosive at any place would have only implosives farther forward. Pinkerton subsequently supported the proposal by Gelkrelidze and Sherman (cited in Pinkerton 1986), that it was the voicing feature that was favoured by front positions and voicelessness by back.

38 For an evaluation of this argument see Demolin (1995).

2.1.4 Summary

The literature and the Tables 2.1 and 2.2 above indicate a wide variation in VOT cross-linguistically, especially for ejectives. This corroborates Catford's (1977) claim that the interval of silence from oral to glottal release appears to be language specific. What is not as clear is how this range of various VOTs varies cross-linguistically with non-glottalic stops. How do speakers distinguish pulmonic and glottalic stops according to VOT?

This study looks specifically at VOT after pulmonic and glottalic stops in Mam.

2.2 RESULTS FROM MAM

2.2.1 Analysis #1

2.2.1.1 Procedure

Measurements of VOT were taken on the expanded wave-form from the end of the burst to the onset of voicing, taking the beginning of the first glottal pulse after the consonant release as the onset of voicing. This is following Kirk et al. who note they could find no other satisfactory procedure (1984).[39] Prevoicing was measured from the waveform before the burst of the oral release, where visible, or from more than two formants representing the full resonance of the vowel, visible in the wide band spectrogram. Spectrograms are printed from the separate window from the Signalyze 3.12 Program with an expanded wave form.

Without comparative airflow data as was used by Pinkerton (1986), and Flemming and Ladefoged (1994), it is not possible to determine whether, for example, all the dental tokens with zero onset or the one dental token with lengthy prevoicing are actually implosive, or if they are possibly unaspirated stops and one voiced stop. At any rate, the results for dentals are first reported separately as ejectives and (possible) implosives. Later the data for dental ejectives and implosives are pooled for all speakers and termed "glottalic dentals".

2.2.1.2 Types of measures

I analyzed the data in three ways, summarized according to each place of articulation:

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39 This was with respect to avoiding "transitions" into vowels.

i.The means and standard deviations of the voice lag or prevoicing duration, that is VOT, after both pulmonic and glottalic stops in Mam. A positive number indicates a positive VOT, a negative value indicates a period of prevoicing. Tables 2.3-2.7 summarize these results in ms for all speakers by place of articulation.

ii. Histograms. The third measure shows the overall distribution of VOT. The histograms in Figures 2.1 to 2.4 show the distribution of VOTs for pulmonic and glottalic stops in Mam by each place of articulation, for all speakers. The format is modified from Lisker and Abramson (1964) in which each line represents the percentage of tokens belonging to the category whose values of VOT fall within a 10ms interval shown along the x-axis. The x-axis is marked in 10ms intervals in either direction from the reference point of zero onset time: values to the left representing prevoicing or minus VOT and values to the right representing voice lag or positive VOT values. The percentages represent all the tokens for all fourteen speakers of the complete data set: i.e. one token from each speaker for all the bilabials, dentals, velars and uvular contrasts in each vowel environment where available.

iii.T-tests. The t-tests provide a measure of the statistical significance of the difference betwen two sets of VOT after pulmonic and glottalic stops. The t-tests also give the mean difference in VOT between pulmonic and glottalic stops. A difference is assumed to be statistically significant at an alpha level of p= <.01. Because of the number of t-tests used, the most conservative p level was adopted for this data. The actual p value is also given.

Table 2.3
means, SD and range of VOT in ms for pulmonic and implosive bilabial stops for all speakers (total tokens=69)

Type of stop	$\bar{x}$	SD	Range
pulmonic bilabial	4.3	4.6	-5 to 20.5
implosive bilabial	-27.5	26.9	-96 to 10.9

Table 2.4
means, SD and range of VOT in ms for pulmonic and ejective dental stops for all speakers (total tokens=20)

Type of stop	$\bar{x}$	SD	Range
pulmonic dental	2.7	6.2	-20.5 to 9.6
dental ejective	45.6	48.6	6.1 to 160.5

Table 2.5
means, SD and range of VOT in ms for pulmonic and implosive dental stops 4 speakers (based on 4 tokens only)

Type of stop	$\bar{x}$	SD	Range
pulmonic dental	3.4	2.7	0 to 6.5
dental implosive	-13.5	26.9	-53.9 to 0

Table 2.6
means, SD and range of VOT in ms for pulmonic and glottalic velar stops for all speakers (total tokens= 44)

Type of stop	$\bar{x}$	SD	Range
pulmonic velar	19.2	14.9	-11 to 53.8
velar ejective	39.8	31.8	0 to132

Table 2.7
means, SD and range of VOT in ms for pulmonic and glottalic uvular stops for all speakers (total tokens = 47)

Type of stop	$\bar{x}$	SD	Range
pulmonic uvular	25.3	18.9	-6 - 101
uvular implosive	-17.6	22.8	-91 - 27.5

2.2.1.3 Results

Analysis of this data indicates that the difference in VOT between pulmonic and glottalic stops is statistically significant for all places of articulation. However, the means and standard deviations indicate there is considerable overlap of values, varying with place of articulation. The distribution of VOT does not fall along any absolute range of values that can distinguish pulmonic and glottalic stops according to VOT, in contrast to the findings for the eleven languages surveyed by Lisker and Abramson (1964).

Bilabials

The results indicate that the bilabial contrast is between a voiceless unaspirated pulmonic stop and an implosive with considerable prevoicing or else a stop with zero to 10ms voice onset.

Pulmonic bilabial voiceless stops have an average voice lag for all speakers of 4.3 ms with a standard deviation of 4.6, which is virtually a voicing onset synchronized to oral release.[40] The range of durations goes from one prevoiced token to one with a voice lag of 20.5 ms with only light aspiration.

Bilabial implosives have an average prevoicing of 27.5 ms with a larger standard deviation of 26.9 ms and a range from 96 ms of prevoicing to one token with a positive voicing lag of 10 ms.

The histogram in Fig. 2.1 indicates the degree of overlap around the zero VOT reference point. Out of 70 tokens of voiceless bilabial pulmonic stops, 90% fall within the first 10ms period and an additional 7.1% in the next 10ms period. For these stops, therefore, 97.1% of all tokens fall within the first 20 ms or the within the period of time that would be perceived as a synchronized oral and glottal gesture.

The bilabial implosives have a much wider range, with 29% of the 69 tokens falling within -40 ms to -20 ms and 20% having a VOT of zero to +10 ms. While the VOT for bilabial implosives is skewed to the left of zero onset and the VOT for pulmonic bilabial stops is focused around zero, there is some overlap at that very point for both types. Several speakers have overlap of VOT of voiceless pulmonic and voiced implosive stops at zero ms VOT, i.e. a voice onset synchronized with the oral release for both types of stops. Other speakers use a distinctively prevoiced onset with syncopated oral release for implosives. So for some speakers the "peculiar quality" of these implosives, as mentioned by Ladefoged (1975), resides elsewhere than in the characteristic of the voice onset time.

The t-test gives a signficant difference between pulmonic and glottalic

[40] Events occuring less than 25ms apart are perceptually indistinguishable, i.e. are heard to be simultaneous (Stevens and Klatt 1974).

stops for all speakers of 31.9 ms, (t(68)= 9.7, p=.0001).

The degree of overlap indicates that while individual speakers may have a significant difference in VOT between bilabial pulmonic and bilabial implosive stops, that difference cannot be represented as any particularly distinct value or set of values that distinguish pulmonic from glottalic dental stops for all speakers.

Dentals

i. The results indicate that the dental contrast is between a voiceless unaspirated dental pulmonic stop, and a dental ejective, or a dental stop with zero to 10 ms voice onset.

Pulmonic voiceless dental stops have an average voicing lag of 2.7 ms with a standard deviation of 6.2. The range of values from -20.5 to 9.6 ms includes one speaker's token with significant prevoicing and others representing a synchrony of voice onset with oral release. The dental ejectives have an average VOT of 45.6 ms with a standard deviation of 48.6 ms and a range of 6.1ms to 160.5 ms.

The dental implosives have a mean VOT of -13.5 ms and a range of 0 to -53.9 ms. Three speakers used a synchronized glottal and oral release while one speaker used a lengthy prevoicing.[41] Obviously means and averages for the dental implosives are not very significant based on only 4 tokens.

ii. Using all the data from ejectives and implosives pooled, the histogram in Fig 2.2 shows a narrow range of VOT for voiceless dental pulmonic stops, with 96.4% of 28 tokens falling within 10 ms of zero onset.

For the pooled glottalic dental ejective or implosive stops 37.5% of 24 tokens also fall within the first 10 ms period after zero onset and an additional 8.3% at 10 to 20 ms of VOT. Therefore, 45.8% fall within 20 ms of zero onset, or what would be perceived as a synchronized oral and glottal onset.

iii. The mean difference in VOT of pulmonic and glottalic dental stops is 42 ms, (t(19)= -4.2, p=.0005).

Overall then, mean differences and averages in this data indicate that differences in VOT are highly significant. The standard deviations and range in values, however, suggest that for at least some speakers, particularly with

41 This token with slightly diminishing amplitude of the prevoicing is followed by several cycles of aperiodic glottal pulsing.

the /tu/ and /t'u/ contrast, the difference in VOT between pulmonic and glottalic stops is insufficient to distinguish them, while for other speakers a strategy of delayed voice onset may be a distinct cue. As with the bilabial contrast, while individual speakers may have a significant difference in VOT between pulmonic and glottalic dental stops, that difference cannot be represented as a particular value or set of values that distinguish pulmonic from glottalic dental stops for all speakers.

Velars

The results indicate that the velar contrast is between a voiceless pulmonic stop and an ejective with zero to delayed VOT, with considerable overlap in VOT values.

i. Voiceless velar stops have an average VOT for all speakers of 19.2 ms with a standard deviation of 14.9 and a range from -11 ms to 53.8 ms. This is a longer VOT than after bilabial or dental voiceless pulmonic stops, as expected (see section 2.2.1.3 below). Despite this period of aspiration the average VOT of glottalic velar stops for all speakers is twice as long as pulmonic velar stops at 39.8 ms (SD 31.8) with a range from zero to 132 ms.

ii.The histogram in Fig 2.3 shows 28.9% of the 45 tokens for the pulmonic velar stop have a VOT within 10 ms of zero onset and an additional 26.7% within 10 to 20 ms of zero onset. So 55.6% of tokens have a VOT within 20 ms of zero onset time, indicating a perceptual synchrony of oral and glottal release. Two tokens (4.4%) have prevoicing while 40% of the tokens have a possibly perceptible degree of voicing lag spread over an 80 ms range.

By comparison the velar ejectives have a greater range of VOT values. Out of 44 tokens, about 30% have a VOT within 20 ms of zero onset. So, although the difference in VOT between pulmonic and ejective stops is still statistically significant, the extent of overlap indicates that VOT does not robustly distinguish these types of stop for many speakers. It is very clear from the histogram that while individual speakers may have a significant difference in VOT between velar pulmonic and velar ejectives, that difference cannot be represented as any different ranges of values.

iii.The mean difference of VOT between pulmonic and ejective velar stops is -20.4ms (t(43)= -4.2, p=.0001), but again the range and SD indicate considerable overlap of pulmonic and glottalic VOT.

Uvulars

The results indicate that the uvular contrast is between a voiceless aspirated pulmonic stops and most often a voiced implosive.

i. The mean VOT for voiceless pulmonic uvular stops for all speakers is 25.3 ms with a standard deviation of 18.9, slightly longer than for corresponding velar stops, and with a range of from -6 to 101 ms. Word initial uvular pulmonic stops are heavily aspirated in Mam giving a distinctively contrastive sound to the unmistakable resonance of the voiced implosive.

The mean VOT for all speakers for the uvular glottalic stop is -17.6 ms with a standard deviation of 22.8. The extensive range in values once again suggests a variety of speaker strategies.

The histogram in Fig. 2.4 shows a wide range in VOT for both pulmonic and glottalic uvular stops in Mam. However, pulmonic and glottalic stops are more clearly separated by VOT for the uvulars with less overlap than the velar contrasts. For pulmonic uvular stops, the largest proportion of tokens, 30.8%, falls in the 11 to 20 ms period and an additional 15.4% at zero to 10 ms. So, 46.2% fall within the first 20 ms of zero onset, while 78.9% of the 52 tokens fall within zero to 40 ms of VOT.

The uvular implosives have a clear peak with 38.4% of 52 tokens within -30 ms of zero onset. The distribution around the peak is relatively even but with a tail skewed to the left of pulmonic uvular stops. So while the histogram indicates some degree of overlap in VOT, the means and SDs with the skewed distribution to the left for uvular implosives suggests that VOT distinguishes pulmonic from glottalic uvular stops more robustly for most speakers than it does for velars. However, again there is no difference in the absolute values for VOT that distinguish pulmonic from implosive uvular stops.

iii.The mean difference between VOT of pulmonic and glottalic uvular stops is 44.1 ms, (t(46)= 9.7, p=.0001).

2.2.1.4 Discussion of some related issues

Speaker variation between implosives/ejectives

Dental glottalic stops

Robertson et al (1969), quoted in Campbell (1973), suggest that dentals in Mam are in the process of change from ejective to implosive. England (1983) reports that whether they are implosive or ejective depends on the speaker. The results from this data indicate that the production of dentals varies in all respects: between tokens and within any token, across speakers and within speaker productions.

For example, some speakers use a short lag in some tokens with a long lag and ejective for other tokens. Again, without airflow data, it is challenging to determine if some tokens are ejective or implosive. The spectrograms in Figures 2.5 and 2.6, show two different tokens from one speaker of /t'ut'n/ *soft/squishy* and /t'o'n/ *you give* with different phonetic realizations. The token/t'ut'n/ in Figure 2.5, from Speaker F4, has a short lag. For /t'o'n/ in Figure 2.6, the same speaker uses what may be a voiceless implosive with three formants clearly resonating after the burst followed by a period of very low amplitude, low frequency energy before any audible vibration. Something similar to this may have led to the occasional claim in the literature of a "voiced ejective", cited but discounted by Henton et al (1992) as requiring air pressures comparable to wind instrument playing. However, several tokens of glottalic sounds in this data show indications of voicing at the stop release followed by some period of silence and then full glottal pulsing. Various articulatory possibilities could account for such apparent voicing - including the syncopated creaky vibration of different parts of the vocal cords.

The spectrograms in Figures 2.7 and 2.8 show two tokens from Speaker F5, who used zero onset for /t'ut'n/, which is possibly implosive, and a clearly ejective dental with 74.4 ms VOT for /t'o'n/. So where there is variation in type of glottalic stop, some speakers may exploit all possibilities. In other words, the categories of ejective versus implosive do not isolate how even individuals speak.

This data, therefore, does not corroborate other studies which claim that speakers use only one kind of glottalic stop, i.e. ejective or implosive, for all productions of that type, although types may vary across speakers and across communities (Lisker and Abramson 1964, Pinkerton 1986). Variation in production of glottalic dental stops in this data also seems to extend to within the speech of individual speakers.

This data indicates a shift towards implosives or voiced dental stops in the high vowel environment, /t'u/. The majority, 60% of tokens of the dental glottalic contrast, however, are realized as ejectives, at least with a positive VOT, though there is some variation in the speech of some speakers as is seen in the standard deviations in Tables 2.4 and 2.5.

Uvular glottalic stops

Speaker variation is also evident in variation between implosives and ejectives with uvular glottalic stops. Any speaker who used a positive VOT with uvular glottalic stops in this data set, also used a prevoiced, implosive production in other tokens with word initial uvular glottalic stops.

VOT and frication

The slightly higher VOT means of pulmonic velar and uvular stops over the bilabial and dental pulmonic stops, seen in Table 2.6 and Table 2.7, reflect the slower response time of the articulators involved in velar and uvular stops. As noted, pulmonic velar and uvular stops are typically produced with considerable frication extending up to the vowel onset. Ladefoged and Traill (1984) attributed this frication to slower articulatory movement. This tendency for delayed onset is in accordance with what Ladefoged and McDonough (1975) termed "the universal phonetic tendency for velar stops to have a longer VOT than stops at more anterior positions" (p. 154). The wider extent of contact with the back of the tongue and the velum or, farther back, the uvula, and slower response time of the tongue dorsum than is available from the more rapid articulation available for bilabial and dental stops contribute to this delay (Lisker and Abramson 1964, Stevens and Klatt 1974, Klatt 1975).

Voiced uvular implosives in Mam

As noted above, Nolan (1995) claims that "voiced uvular implosives do not occur in any well-known language" (p. 9). However, the results of this data indicate that most speakers have some kind of voiced implosive, though the range of VOT indicates a variety of strategies. The spectrograms in Figures 2.9-2.10 exemplify two different strategies for two voiced implosives in /q'o/ *squash* and /q'a/*fire*. Speaker F6 uses a voiced implosive with 25 ms of prevoicing for /q'o/, showing the increase in amplitude and periodicity characterizing any classically voiced implosive. The period of prevoicing shows resonances up to the 4th Formant before the onset of regular voicing, a considerable degree of resonance. Speaker F5 has a creaky voiced implosive with only low frequency resonances apparent for /q'a/. This damped (creaky) onset may be required to hear an implosive. The native speaker consultant appears to require a considerable period of damped low frequency onset to avoid ambiguity. It is possible that because of the extended contact of the uvular closure, which must also involve adduction to the back of the velo-pharyngeal port, uvular implosives require an extended period of release. Categorical distinctions of consonant release versus vowel transition do not seem here to be particularly revealing.

2.2.2 Analysis #2

Although the t-tests with mean differences show a significant difference in VOT for all places of articulation, the ranges and standard deviations indicate varying amounts of overlap. Also, although the differences may be statistically significant, the t-tests do not indicate whether the differences might be perceptually significant, that is, if speakers can hear such differences. Consequently, I re-organized the data according to the absolute difference in VOT for each speaker between the pulmonic and glottalic contrasts at each place of articulation in the same vowel environment according to percentages of tokens in again a 10ms period. This was designed to see how absolute differences in VOT distinguish the two types of stops.

2.2.2.1 Results

The histograms in Figures 2.11-2.14 show the distribution of differences.

Bilabials

Fig 2.11 shows the distribution of differences in VOT for bilabials has two tendencies. One peak is centred on zero difference with 23.2% of 69 tokens within zero to 10ms difference in VOT and an additional 7.2% of tokens from 11 to 20ms VOT. So 30.4% tokens fall within 20ms difference of each other in VOT. The other peak of difference in VOT is centred at 30-40ms with a diminishing distribution to the right having longer VOT. If a difference in more than 40ms in VOT is salient, then the majority of bilabial contrasts have a possibly perceptible difference in VOT between pulmonic and glottalic stops.

Dentals

Because the difference between pulmonic and glottalic dental stops is skewed to negative values the glottalic stops obviously tend to have a longer VOT. However, 25% of the 24 tokens have a VOT difference of zero to -10 ms while 16.7% have a difference of zero to +10 ms, showing that 41.7% have within plus or minus 10 ms difference. Although the data set is very small with only 24 contrasts, the histogram in Fig. 2.12 indicates once again an appearance of two different strategies used by speakers: one with less than 20 ms difference in VOT used in about 44% of these tokens and one with a greater than 20 ms difference in VOT used in about 56% of the tokens.

Velars

Perhaps due to the considerable degree of aspiration there is a clustering of values of VOT in either direction of zero. Within the roughly 50% of tokens centred around zero difference, almost half of the tokens are divided between glottalic tokens with VOTs longer than pulmonic and pulmonic tokens with VOTs longer than glottalic, i.e. 20% have longer glottalic stops and 27.3% have longer pulmonic stops. All fall within 20ms of each other. The histogram in Fig 2.13 shows another peak with 20.5% of tokens centred around a 30 ms difference. With this distribution any difference in VOT, either positive or negative, could be random. Only a minority of tokens of the velar contrast, about 32%, have a difference in VOT of over 30ms. VOT therefore is less than a robust cue for this group of speakers, if it is available as a cue at all.

Uvulars

As shown in Figure 2.14, a smaller proportion, 23.5%, of tokens for the uvular contrast fall within a range of 10 to 20 ms difference in VOT and another 6% fall within the same range with the opposite direction of difference, that is, the pulmonic stops are longer than the glottalic. It appears that a difference of more than 20ms in VOT is available to distinguish about 70% of the contrasts for this group of speakers.

2.2.2.2 Discussion

This analysis presents the data according to what might be available for perceptually significant distinctions, without yet knowing what those criteria might be. However, it is known from perceptual studies that a boundary of around 17 to 20 ms is a categorical difference in human perception. The human auditory system has temporal limits to resolving two successive pure tones. Such sounds more than 20 ms apart are heard as successive. Pure tones less than 20 ms apart cannot be temporally distinguished. What we do not know, however, is how much difference in VOT between non-contiguous speech tokens might be perceptible. Warner noted the difference in VOT between ejective and pulmonic stops in Ingush was 19 ms "(which might) not be enough to serve as a major perceptual cue" (1996, 1525). It is unlikely that listeners compare sounds on the basis of 20 ms differences separated randomly in time. Therefore, without perceptual data, it is premature to assess how available these differences are for linguistic distinctions. Also, Summerfield and Haggard (1977) found that distinctions based on VOT may be less acute at larger absolute increases, that is, that perceptual acuity of VOT differences is greatest at "simultaneity-successivity thresholds". Consequently, I suggest that listeners probably do not make distinctions on the basis of absolute differences in VOT by ms between tokens but make some kind of global assessment of abruptness or gradual onset based on which cover a range of onset durations.

I assume that the difference of more or less than 20 ms provides a sort of aural landmark for listeners, permitting a global assessment of sounds as having only simultaneous or successive onset. However, the extent of VOT overlap and the range of absolute differences between pulmonic and glottalic stops in this data suggest that specifically VOT must be only one of several cues available to Mam listeners.

2.2.3 Experiment #3: VOT by vowel environment

The tendency for VOT to be longer before high vowels has been variously noted (Fischer-Jorgensen, 1964, Ohala, 1975, cited in Laver, 1994). Klatt (1975) found that VOT is 15% longer in English before higher vowels than mid or low vowels, p=<.01 (p. 691), increasing generally with lower F1 frequency of following vowel. Klatt noted that this is consistent with the phonological rule in Japanese of devoicing high vowels between voiceless obstruents. Both physiological and perceptual reasons have been argued for this tendency[42]. Doing research on trading relations between acoustic phonetic cues in synthesized speech, played to speakers of British English, Summerfield and Haggard (1977) also showed that VOT varies inversely with degree of vocal tract constriction, or VOT trades "elegantly" with F1 frequency (p. 443). In other words, the F1 onset frequency is an acoustic cue to stop perception which "trades" with VOT as a cue. This suggests systematic variation of VOT with vowel environment for voicing perception.

Although Hogan (1976) reports a longer pre-silence duration before high vowels there is no other mention in the literature on glottalic stops for variation of VOT, other than Warner (1996) who claims VOT is longer before high vowels in Ingush "as is usual cross-linguistically" (p. 1525). Consequently the data from Mam was examined to see if it would corroborate this apparently universal tendency.

The averages for each vowel environment for both bilabial and uvular implosives and velar and dental (mostly) ejectives were compared. Although data is missing for dental glottalic stops in /a/, /e/, and /i/ environment, and velar ejectives in the /i/ context, data from the native speaker consultant was added for the purpose of preliminary comparison. While uvular implosives in the /u/ environment were not included in the other analyses as the pulmonic uvular /qu/ was missing, in this case the pooled values for the uvular implosives /q'u/ were added for analysis here.

The line chart in Fig 2.15 shows these tendencies for mean values of each type of stop based on data from all speakers and additional data from one speaker for /t'a,t'e, t'i, k'i/. The x-axis in the following figure is the vowel environment and the y-axis represents the VOT of bilabial and uvular implosives and dental and velar ejectives.

42 See Summerfield and Haggard (op.cit.) for some explication of these.

Despite the limited data, it is clear that from the comparisons available there is no systematic variation with vowel environment for these speakers. Velar ejectives do not vary from the /a/ to /e/ and rise only slightly to /i/ environment.[43] Dental and velar ejectives vary in the opposite direction, with velar ejectives increasing VOT in the higher vowel environment /o/ to /u/ while dental ejectives decrease VOT from /o/ to /u/. While bilabial and uvular implosives both decrease in duration of prevoicing from the pre- /a/ environment to the higher vowel /e/, they vary in the opposite direction for the high vowel /i/ environment. The bilabial implosive seems to maintain a longer period of prevoicing than the uvular implosive in the /a/, /e/, and /i/ vowel environments in corollary agreement with Greenberg's 1970 predictions on possible voicing duration of larger versus smaller cavities, but the tendency does not extend to the /o,u/ environment.

Such random variation might argue for such distinctions being "learned" rather than physiologically constrained, with this distinction not being linguistically salient in Mam. At any rate, preliminary analysis of this somewhat incomplete data does not support any systematic variation of VOT with vowel environment after glottalic stops.

2.2.5 Summary

In this data, a difference in VOT, that is, a production strategy to either syncopate or synchronize oral and glottal release is available for some of the pulmonic/ glottalic distinctions. Over all tokens there is a statistically significant difference with longer VOT after the majority of ejectives and longer periods of prevoicing before the majority of implosives. It does not however distinguish both types of stops according to any absolute values of VOT, as suggested for other types of stops. It does not distinguish all pulmonic and glottalic stops or the velar distinction at all reliably. It appears to be more extensively used by speakers to realize a distinction between implosives and pulmonic stops than to realize a distinction between ejectives and pulmonic stops.

The values for average VOT with standard deviations in brackets are summarized in Table 2.9 with the results for dental ejectives and implosives

43 This is based on a token from one speaker only.

entered separately.

Table 2.8
Summary of VOT for word initial glottalic stops in Mam

Language	# of speakers	/ɓ/	/t'/	/k'/	/ʠ/
Mam	14	-27.5 (26.9)	45.6 (48.6) -13.5 (26.9)	39.8 (31.8)	-16.5 (23)

The analysis of the data summarized in this chapter, shows considerable variation both between speakers in one community and within the speech patterns of individual speakers.

A majority of pulmonic/glottalic contrasts differ according to simultaneous or successive onset. I suggest that this is one cue to a distinction based on abrupt versus non-abrupt onset. Because a proportion of stops do not differ in VOT, or by this cue to abruptness, it is apparent that this is only one cue in a possible constellation of phonetic cues available to speakers and listeners.

This analysis suggested looking at the findings on other acoustic cues according to whether they might be distinguishable by such a global property. Consequently, I analysed the raw data on amplitude and Fo similarly.

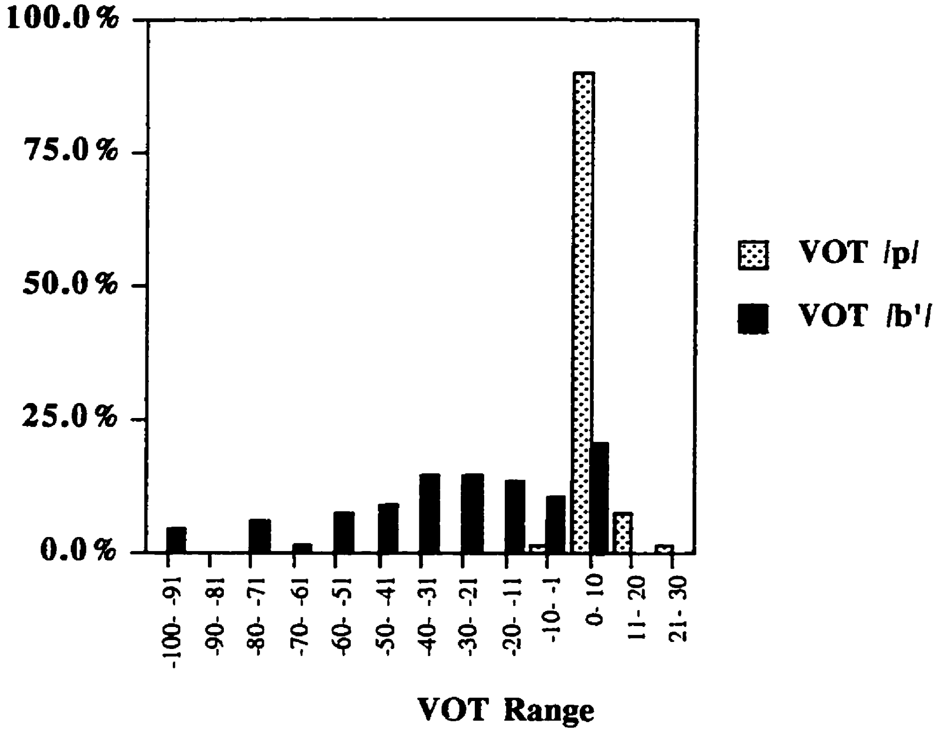

Fig.2.1
Distribution of VOT for word initial pulmonic and implosive bilabial stops for 14 speakers

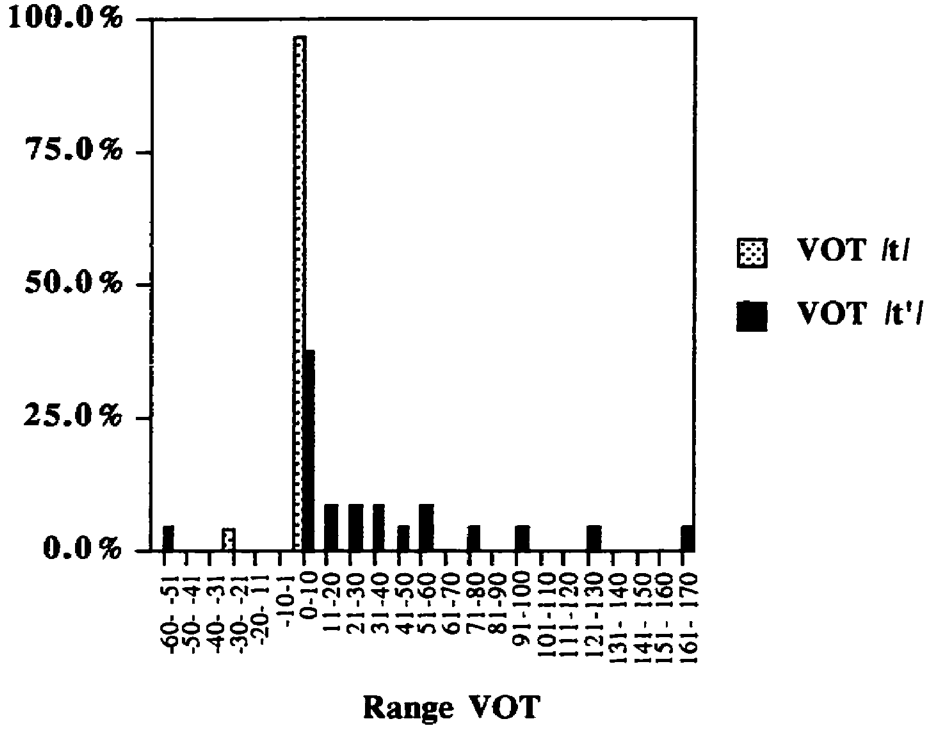

Fig 2.2
Distribution of VOT for word initial pulmonic and glottalic (ejective or implosive) dental stops for 14 speakers

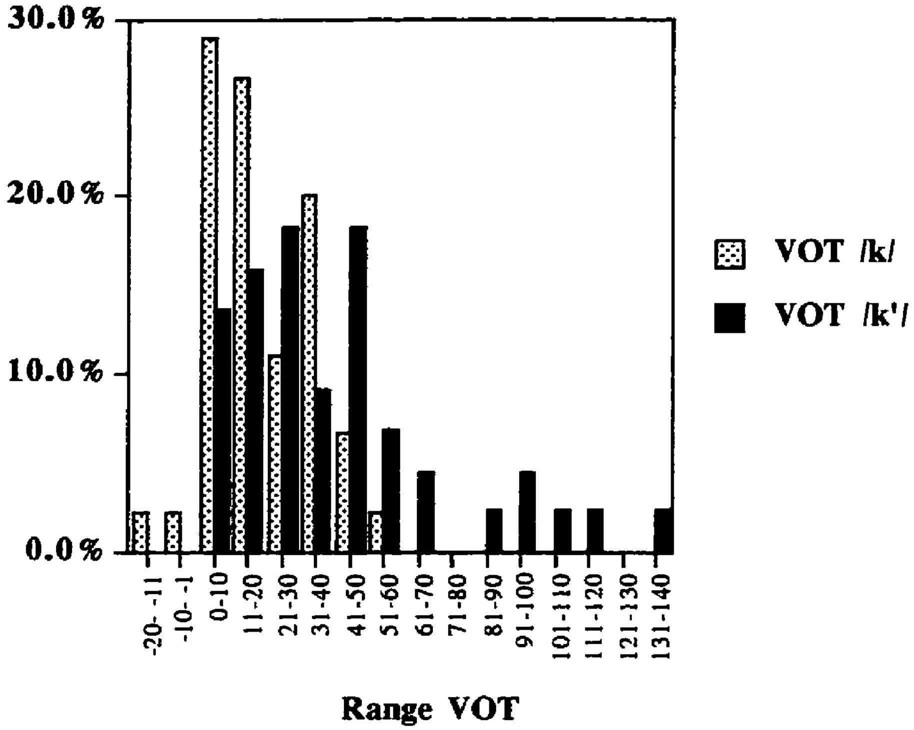

Fig 2.3
Distribution of VOT for word initial pulmonic and ejective velar stops
14 speakers

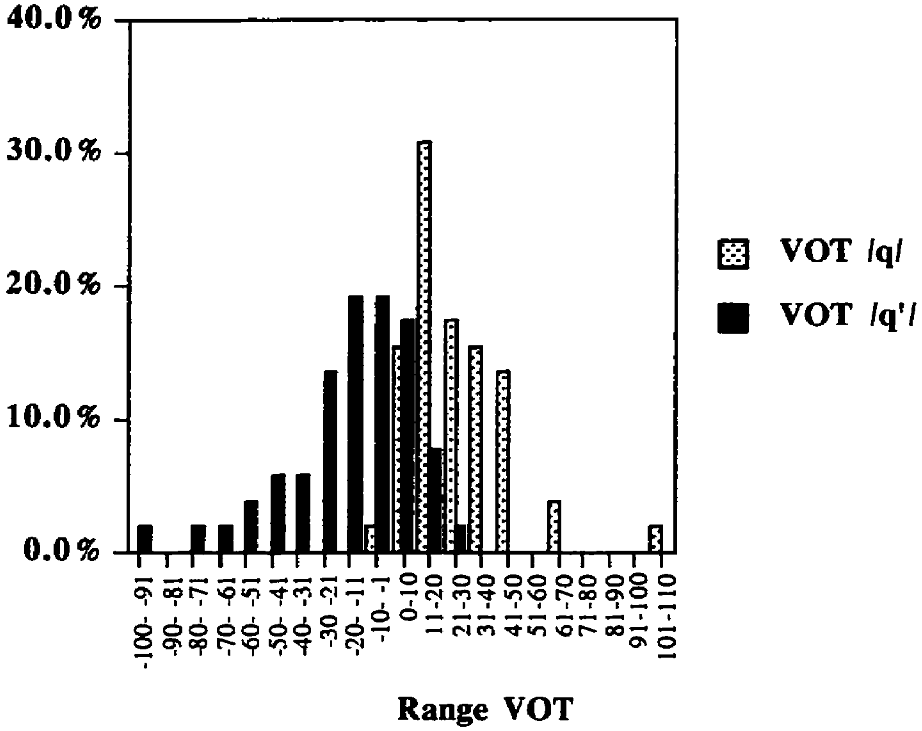

Fig. 2.4
Distribution of VOT for pulmonic and implosive uvular stops for 14 speakers

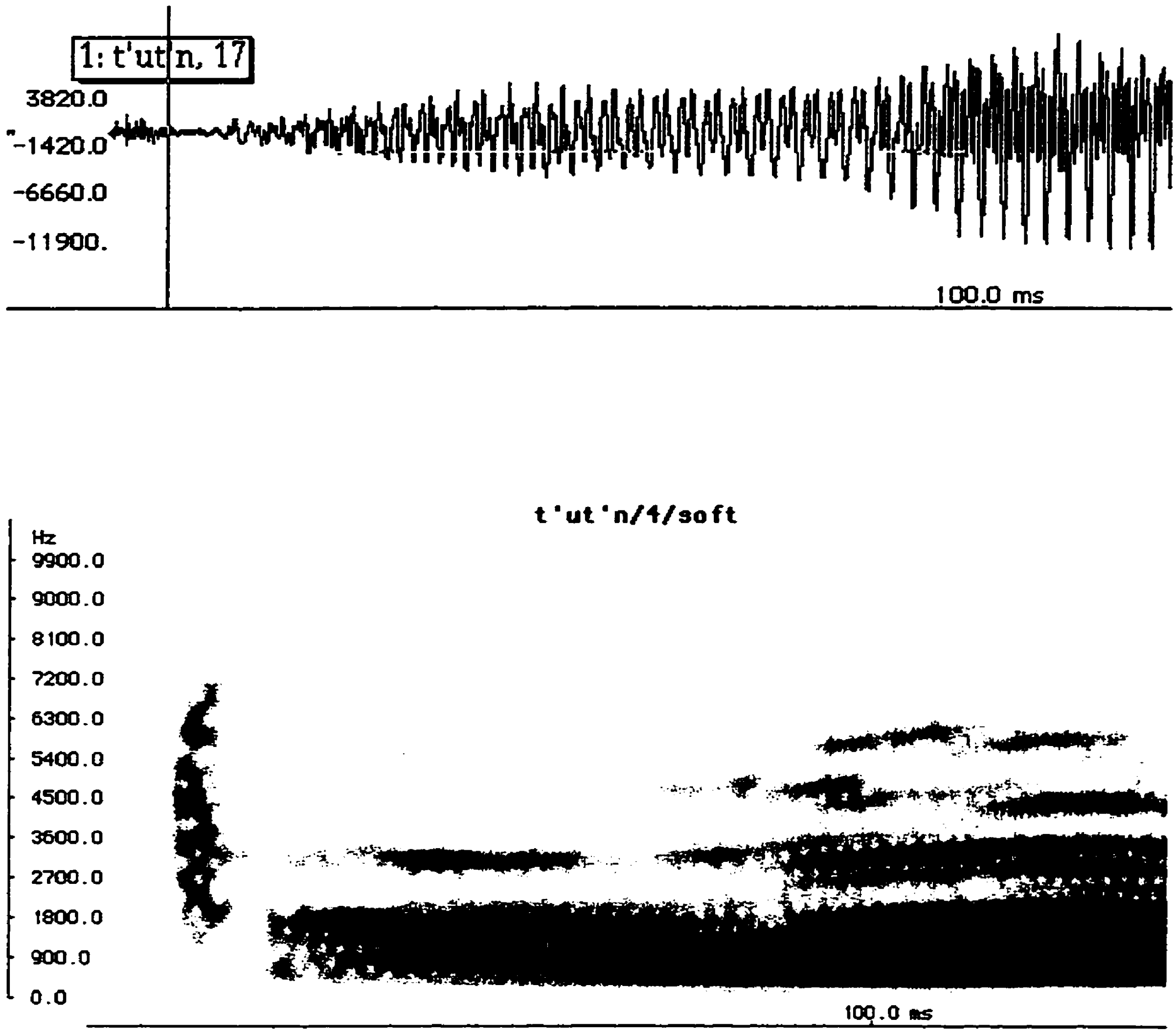

Fig 2.5
Spectrogram of /t'ut'n/ (*squishy*)
Speaker F4

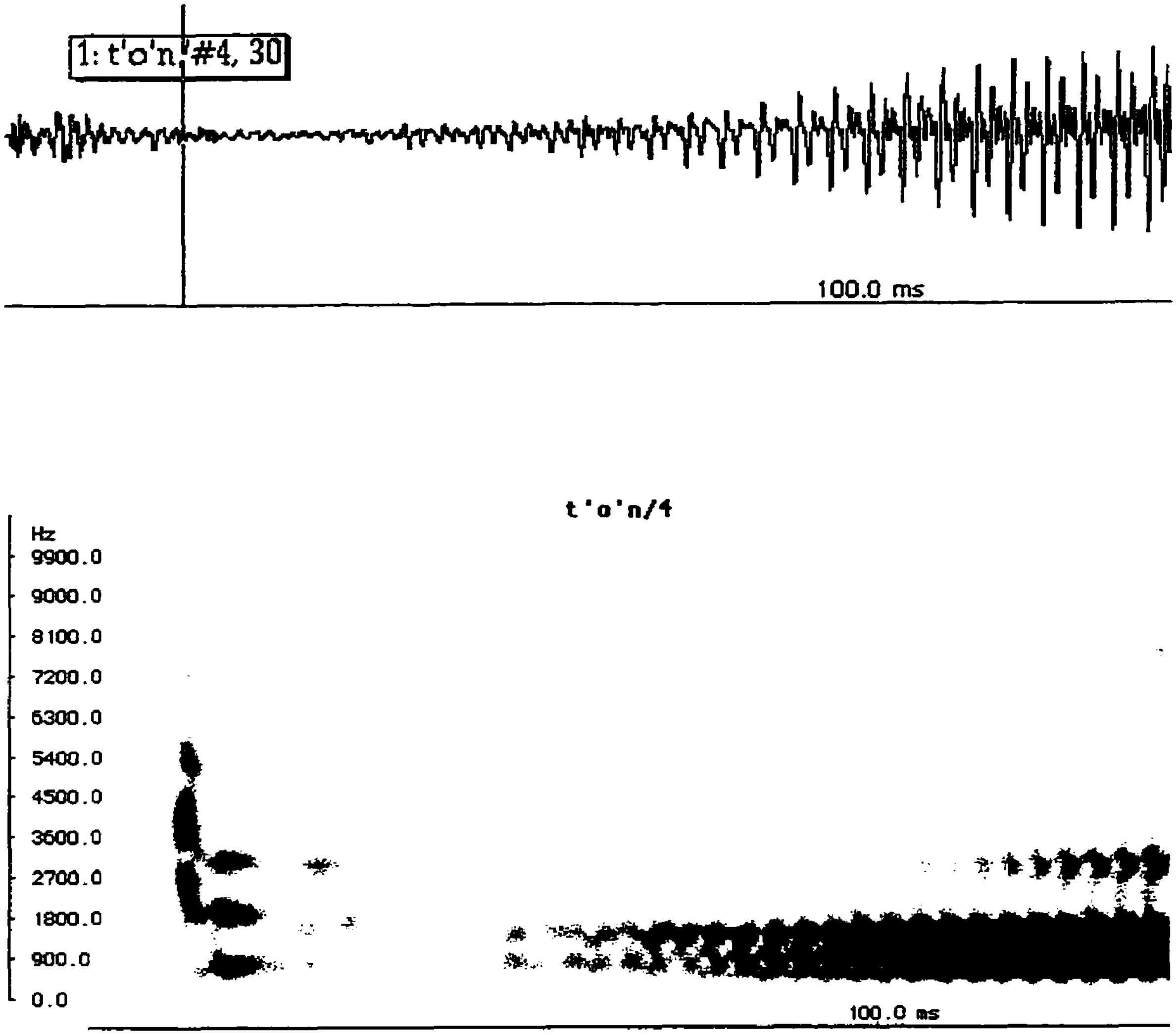

Fig 2.6
Spectrogram of /t'o'n/ (*you give*)
Speaker F4

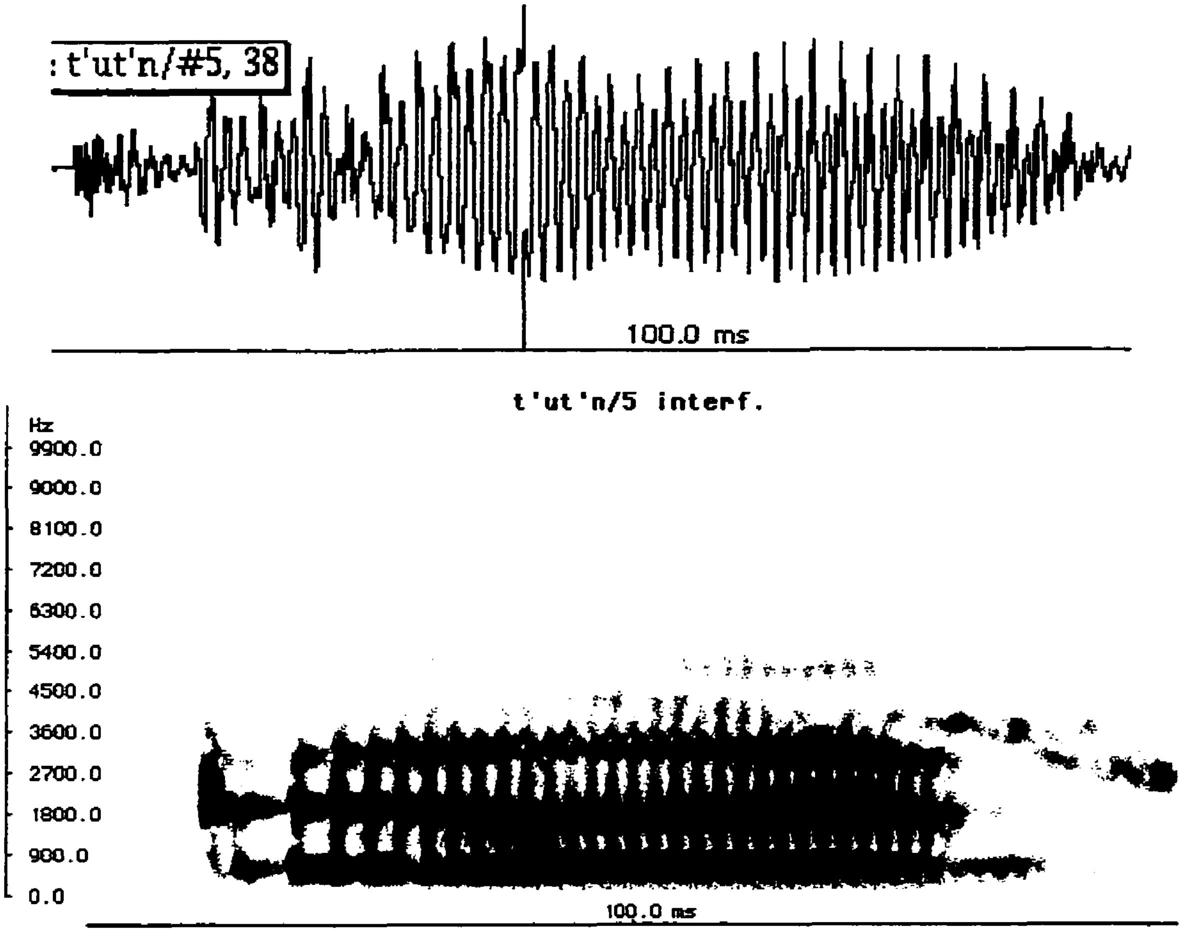

Figure 2.7
Spectrogram of /t'ut'n/ *squishy*
Speaker F5

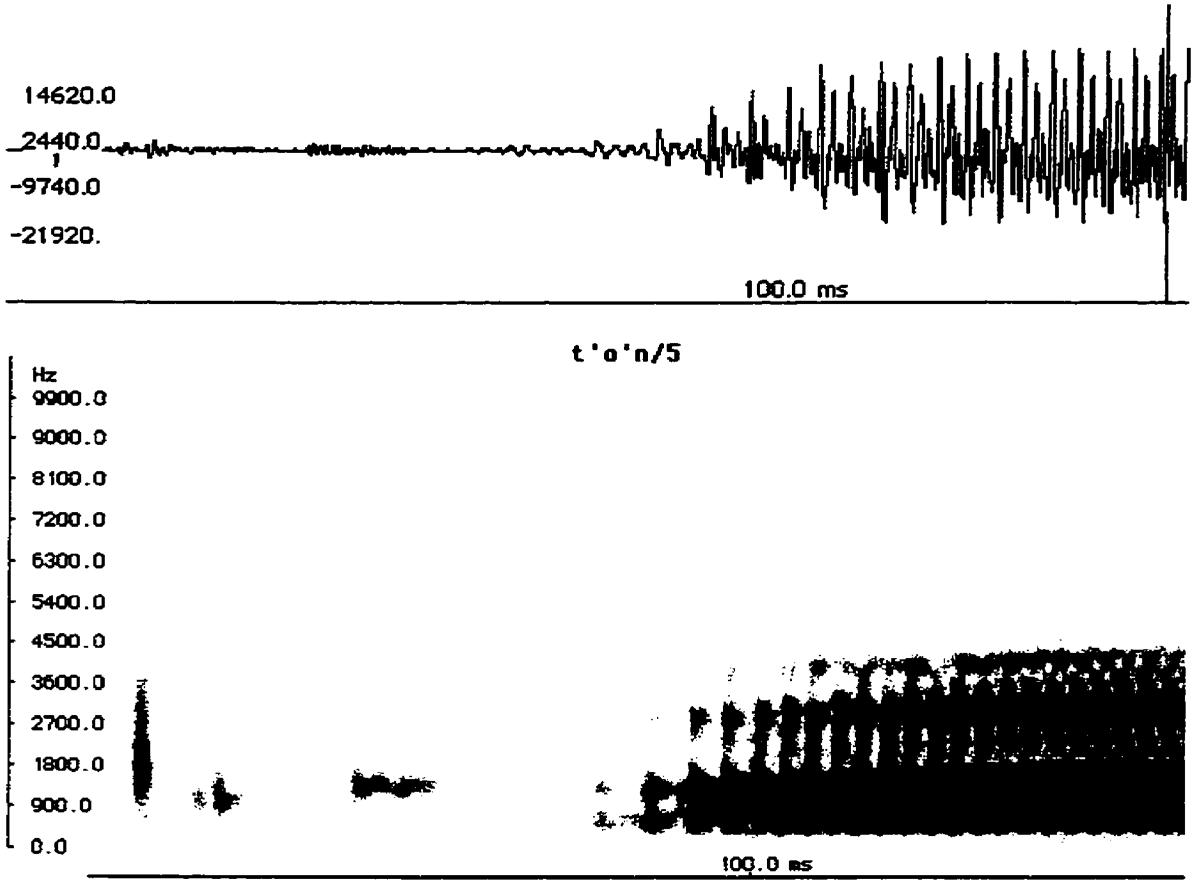

Figure 2.8
Spectrogram of /t'o'n/ *squishy*
Speaker F5

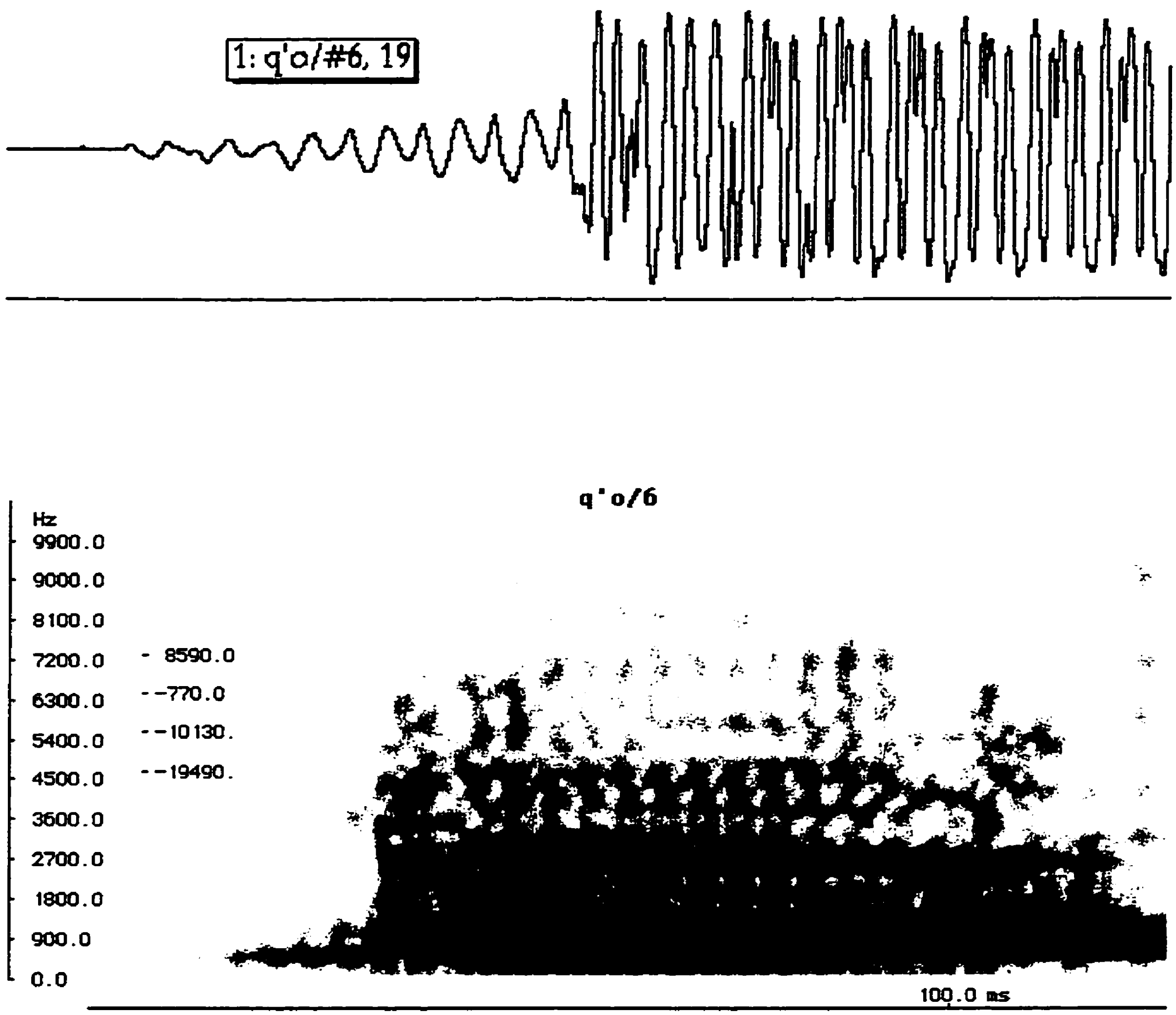

Fig 2.9
voiced uvular implosive /q'o/ *squash*
speaker F6

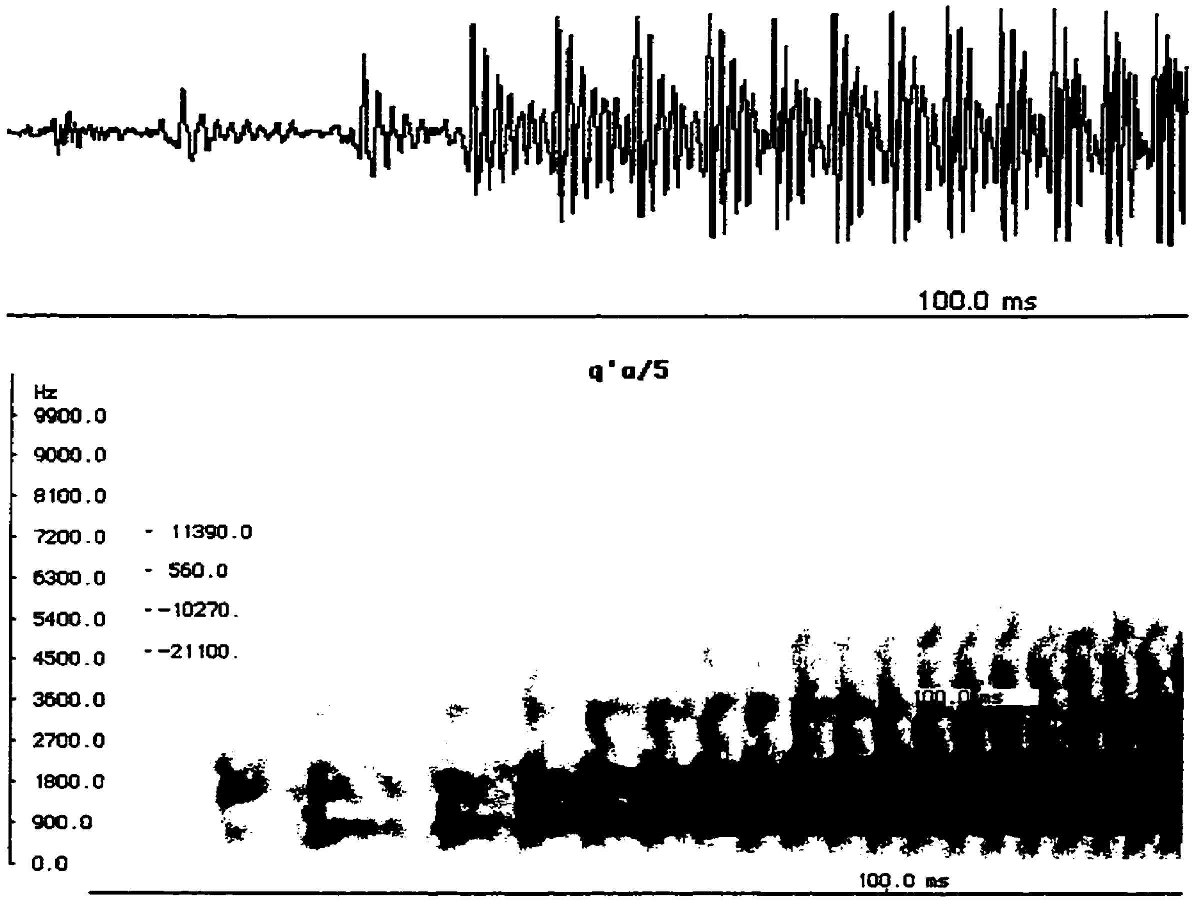

Fig 2.10
voiced creaky implosive /q'a/ *fire*
Speaker F5

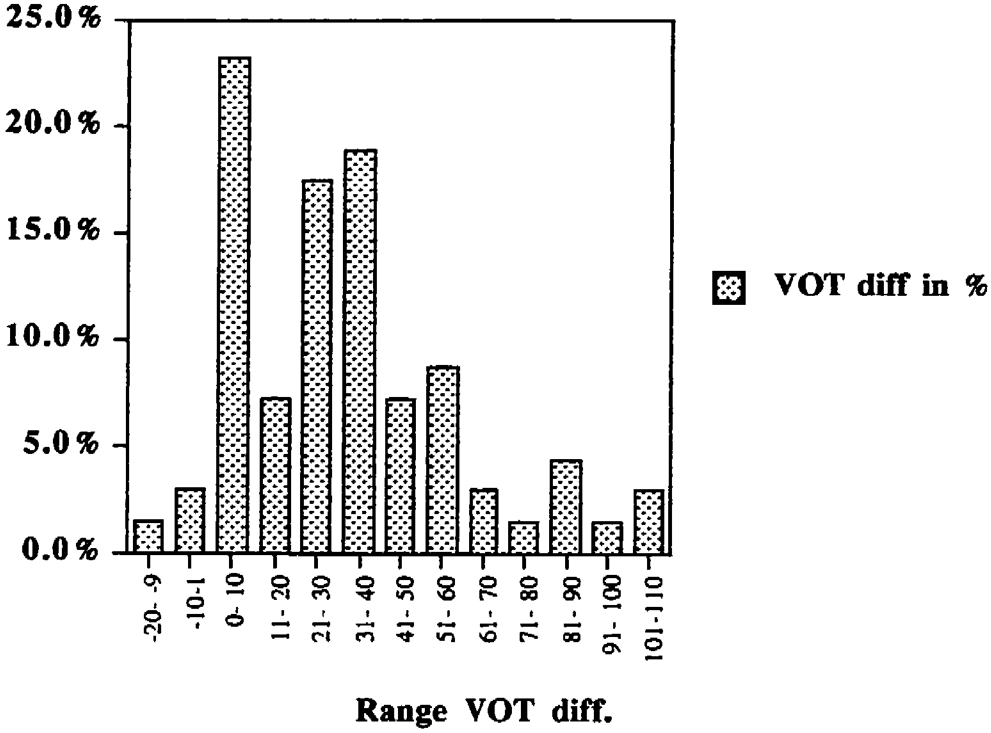

Fig 2.11
Distribution of absolute difference in ms of VOT between pulmonic and implosive bilabial stops

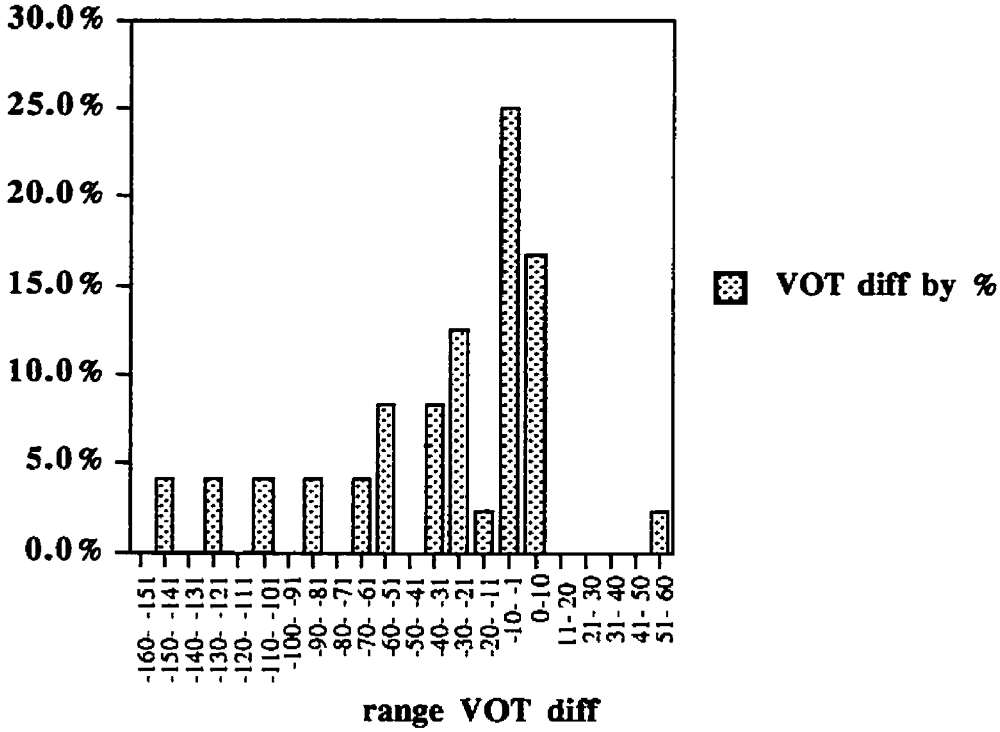

Fig 2.12
Distribution of absolute difference in ms of VOT between pulmonic and all glottalic dental stops

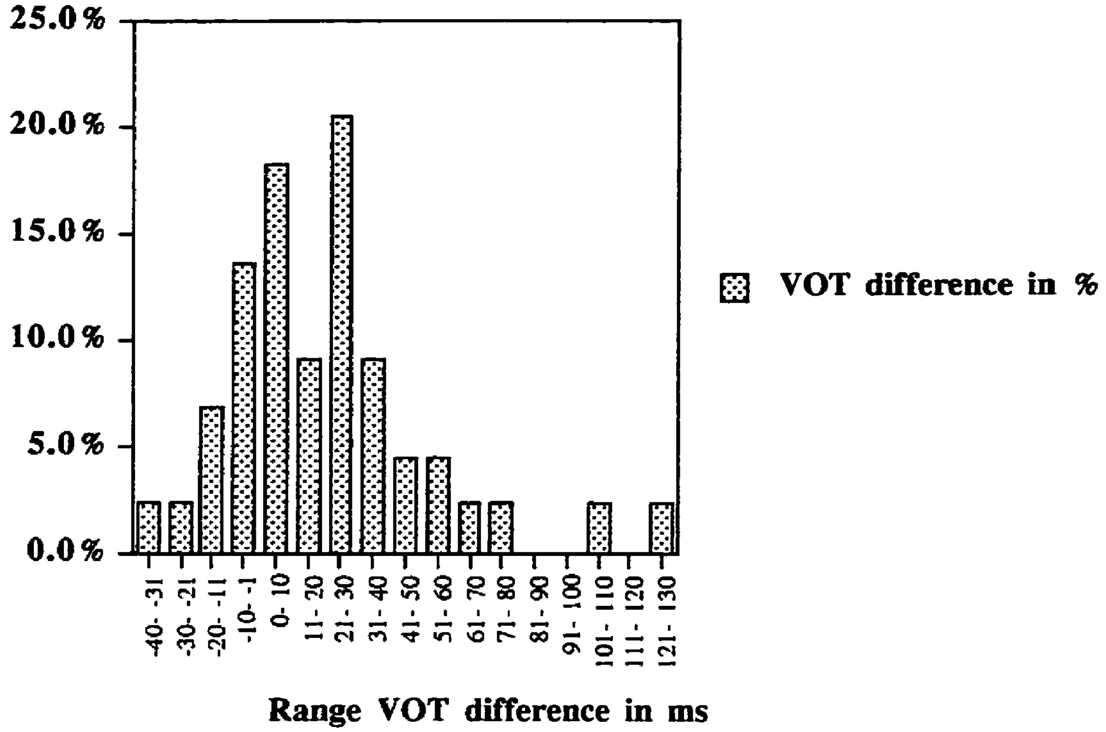

Fig 2.13
Distribution of absolute difference in ms of VOT between pulmonic and ejective velar stops

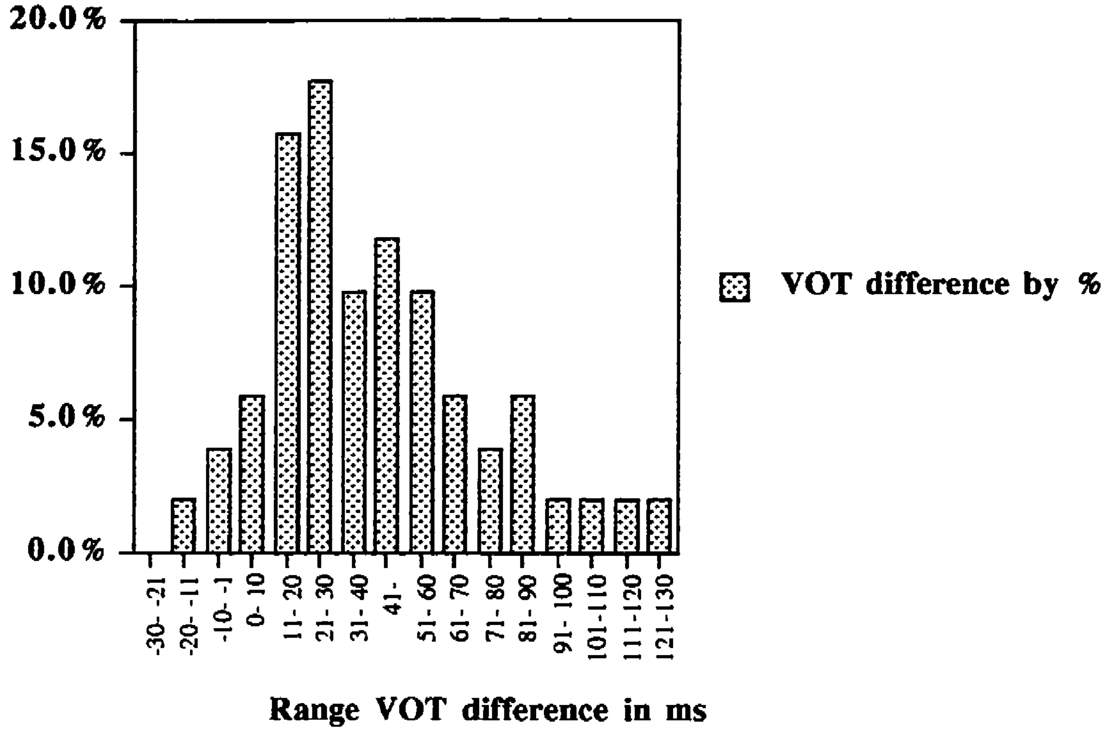

Fig 2.14
Distribution of absolute difference in ms of VOT between pulmonic and implosive uvular stops

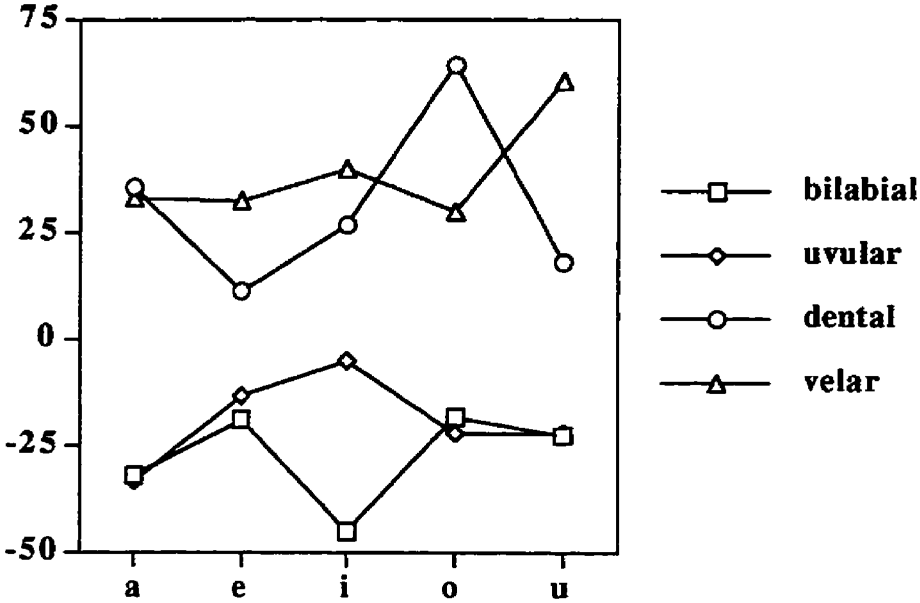

Fig 2.15
line chart of VOT in ms according to vowel environment
for 14 speakers
one speaker only for / t'a, t'e, t'i, k'i/

Chapter 3

Vowel amplitude characteristics after pulmonic and glottalic stops in Mam

This chapter includes a brief summary of the literature and the terminology on voice onset types as they relate to the amplitude characteristics of glottalic stops. I describe three measures of abruptness which are used to distinguish pulmonic from glottalic stops in this study. Section 3.2.3.1 summarizes the specific format used to analyze the data. Section 3.2.3.2. gives the results of comparing the amplitude rise time of vowels after pulmonic and glottalic stops and comparing the absolute dB rise of vowels after pulmonic and glottalic stops. These are summarized for each place of articulation. The results of the comparison of the ratios of amplitude onset to peak after pulmonic and glottalic stops follow. Finally the results are summarized and assessed. The figures which accompany the text are appended to the chapter end.

3.1 PREVIOUS STUDIES

3.1.1 The terminology on voice onset

One assumption of the classic model of the production of glottalic stops, (reviewed in Chapter 1), is that vowels following glottalic stops will have an abrupt onset. Catford (1977) and Ingram & Rigsby (1987) report that the vowels after these stops have an abrupt onset.[44] The syncopated glottal release phase in the production of glottalic stops is associated with a sudden release of the considerable medial compression. Peters, Boves and van Dielen (1986) note that after this sudden release, vowel amplitude quickly reaches its maximum value. This can be assumed to be an auditory correlate of medial compression.

Terminologies for types of voice onset, were based on both the physiological criteria of medial compression and the auditory criteria of amplitude buildup.[45] Koike, Hirano and von Leden (1967), and Werner-Kukuk and von Leden (1970) termed a firm glottal closure as well as a rapid rise in amplitude, a "hard" vocal onset. A "soft" attack has a smooth rise in

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[44]An abrupt onset can also be assumed from Ladefoged's (1971) description of glottalic stops starting with [ʔ] .

[45] For a summary of the literature since 1866 on vocal initiation, see Werner-Kukuk and von Leden (1970).

intensity (p. 114). Flege (1982) contrasted hard onset, which starts from a firmly closed glottis, with soft onset, which starts from the more gentle approximation of the vocal folds, involving the Bernoulli effect. Esling (1996) associates the first with a more tightly closed laryngeal sphincter and the second with a simple glottal closure.

The terms hard and abrupt are therefore roughly synonymous, as are soft and gradual. However, they tend to be used in different contexts. Hard or soft onset (also "attack") summarize an articulatory gesture or physiological condition that matter to the literature on vocal pathology or singing technique. Abrupt or gradual vocal onset describe the same articulatory gesture or physiological condition that matter to linguistic distinctions. They refer in both cases to the auditory characteristics of the rise in amplitude of the vowel or to particular laryngeal muscular coordinations. In this thesis I refer to the characteristics of the vowels after pulmonic or glottalic stops as having abrupt or non-abrupt (gradual) vocal onset. These terms refer here specifically to the three amplitude envelope measures (see section 3.2.1 below).

3.1.2 Previous studies on voice onset and glottalic stops

Many phonetic accounts of vowel onset after glottalic stops simply report, or expect, a "sharp onset".

Navajo

Lindau (1982) reports that vowels after /k'/ in Navajo start with a "sharp large amplitude".

McDonough and Ladefoged (1993) report that vowel formants after all ejectives other than the lateral ejectives in Navajo, i.e. /t', k', k'ʷ, ts, tʃ/, "start with sharp onset". The lateral ejective in this study showed an additional spike on the spectrogram between release and vowel onset. McDonough and Ladefoged point out that in this case the glottal closure was released and re-made (p. 161).

Montana Salish

Vowels after glottalic stops "begin abruptly" in Montana Salish, based on the mean of five utterances of /p'/ by three speakers (Flemming and Ladefoged 1994, p. 18).

Gitksan

Wickstrom (1974) reported an abrupt onset for pre-glottalized continuants in Gitksan, seen in the "straight edge..on the leading edge of the frequency envelope" (p.73).

Rigsby and Ingram (1990) record "a gradual rather than abrupt vowel onset" after many pretonic glottalized obstruents in Gitksan (p 261). They claim that the main distinguishing characteristic of glottalic stops in Gitksan is the (low) amplitude of the vowel onset[46], and argue that these sounds are not actually ejective or implosive in the sense of movement up or down of the larynx. They quote Montler (1986)'s recent work on Saanich, on the apparently perceptibly elusive nature of glottalic obstruents in some Amerindian language (cited in Rigsby & Ingram 1990) and argue for a tense/lax distinction after Kingston's (1984) typological division. However, Ingram and Rigsby (1987) did not find their own "index of the abruptness of vowel onset" actually distinguished pulmonic from glottalic stops in their study of two Gitksan speakers[47] (p.145). They attribute this to either speaker variation or language shift.

Quiche and Tigrinya

Kingston (1984) noted a "gradual voice onset with slow rise to maximum amplitude" by one speaker of Quiche (p. 166). He distinguished ejectives of "the Tigrinya type as 'tense' and the Quiche type (as) 'lax'...(using the terms) for convenient reference" (p. 166/167). This convenient reference has now perhaps grown beyond his intentions, (see Ingram and Rigsby (1987) above). This is the way of convenient solutions.

Ingush

Warner (1986) found a slow rise in the amplitude of the following vowel in Ingush, using data from one speaker (p.1527).

English listeners

Finally, in a recent and related study of some acoustic cues for intervocalic glottal stops, Hillenbrand and Houde (1996), in their perceptual

[46] The low amplitude is also accompanied by creaky voice (Rigsby &Ingram 1990).

[47] Their index of abruptness measured the proportion of the amplitude of the third glottal pulse to the maximum vowel amplitude. See Section 3. for a discussion on various measures of abruptness.

experiments with natural and synthesized speech, found an amplitude dip "is usually sufficient to cue the presence of a glottal stop" (p. 1188).

3.1.3 Summary

Whereas the classic model, as well as descriptions of types of voice onsets might lead us to expect a sudden increase in amplitude after glottalic stops, the existing literature on the characteristics of vowels after glottalic stops reports some differences in the amplitude characteristics of voice onset. Some researchers have leaped to further distinctions of tense and lax types with as yet uncertain acoustic properties. It was noted in Chapter 2, (Section 2.1. that Warner (1996) warned against binary comparisons of languages because they result in possibly spurious binary typologies. Earlier, Henderson (1977) warned against the search for phonological features at all before "*first* a thorough investigation- articulatory, acoustic and perceptual- into what is actually happening" (p.259). It still needs to be done.

The data from Mam give an opportunity to investigate systematically the amplitude characteristics of vowels after pulmonic and glottalic stops for a representative group of speakers of one community. The following sections look at the amplitude envelope characteristics of vowels after pulmonic and glottalic stops in Mam to see if in fact abruptness of onset, or one of its amplitude envelope measures, does distinguish these contrasting types of sounds in this data.

3.2 AMPLITUDE CHARACTERISTICS OF PULMONIC AND GLOTTALIC STOPS IN MAM

This analysis looks at three amplitude envelope indicators of the type of voice onset: the rise time in amplitude, the absolute rise in decibels, and the ratio of vowel onset amplitude to peak vowel amplitude. Initially the choice of these indices was serendipitous if not arbitrary. This is how amplitude is measured in various other studies, as noted below.

This thesis will suggest that all these indicators distinguish pulmonic from glottalic stops in Mam to some extent. They most robustly distinguish bilabial and dental pulmonic from glottalic stops. However, the analysis will show that the more global properties of non-abruptness and steep amplitude rise, derivable from these indices, specifically and robustly characterize vowels after glottalic stops in this data.

3.2.1 Three amplitude envelope measurements of abruptness

3.2.1.1 Amplitude rise time

The duration in milliseconds of the rise in amplitude from voice onset to the first peak amplitude of the vowel is a general measure of gradual versus abrupt onset. A short duration suggests that onset starts at close to maximum amplitude or reaches it rapidly. The peak amplitude was determined by the first (left-most) maximum in the amplitude envelope which was followed by a smaller amplitude. The peak amplitude therefore did not necessarily correspond to the vowel maximum amplitude.

Amplitude rise time was isolated by Munro and Nearey (1988) as a cue to distinguishing /p/ /b/ contrasts in French. They found that category judgements of /b/ tokens correlated with rise slope.

Darwin and Pearson (1981) used rise time differences in synthetic stop contrasts and found that they cued the voicing distinction for English listeners.[48]

Peters, Boves and van Dielen (1986) established the log rise time of the amplitude as a preferred cue for abruptness judgements of isolated vowels; that is, the log rise time measure is more robust than the slope of the amplitude envelope. They computed the value of 10% of the maximum value and 90% of the maximum as a reliable measure of the amplitude rise time, by rejecting extreme values at onset and peak.

Warner (1996) avoided using the "rise time of the power curve" due to the extent of variation in power of the following vowels in her data on Ingush and seems to have used the slope instead. She used the first order differential for a comparable measure of how fast the amplitude rises. The difference between vowels after pulmonic voiceless stops and after ejectives was statistically significant using this measure.

Koike et al. (1967) call the measurement of the rise time of the amplitude (from voice onset to a steady phonation) "the simplest and most reliable acoustic technique...to measure the quality of vocal onset" (p. 179). Koike et al. define a hard attack as a duration of 7-51ms of amplitude rise,

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48 Thanks to Murray Munro for bringing this to my attention.

which gives a practical measure for abruptness. I have used this measure of abruptness to classify the Mam data on amplitude rise time.

3.2.1.2 The absolute dB rise from onset to vowel maximum

I also measured the absolute difference in dB from vowel onset to first vowel maximum to see if and how it distinguishes pulmonic from glottalic stops in this data. This was determined as in amplitude rise at the first left-most peak in the amplitude envelope. The absolute decibel rise from vowel onset to first vowel maximum measures the amount of change in intensity.

Fischer- Jørgensen (1989) cites earlier studies giving differences in absolute intensity of about 6 dB for stød in Danish, or a steeper rise in amplitude for words with stød (p. 13). These findings were not confirmed by her. She reported, rather, a significant decrease in absolute intensity in the second part of the syllable with stød.

I found no handy guide in the literature for a specific measure to relate dB rise to abruptness, as was found for the amplitude rise time. Given the large variation in absolute rise in amplitude among the tokens, I have arbitrarily taken a division of less than 5 dB or more than 5 dB as a conservative estimate to distinguish a comparatively level amplitude from a steep rise in amplitude.

3.2.1.3 The ratio of vowel onset to vowel peak amplitude

I also used the ratio of the values of the onset amplitude to the peak vowel amplitude (determined as above for the amplitude rise time) as an indirect measure of the degree of the change from onset to peak amplitude. A ratio close to one suggests the amplitude level is relatively uniform.

Lindau (1982) used a ratio of two amplitudes from the middle to the end of the period of closure during implosives in several languages to indicate the amount of cavity expansion, or degree of implosion.

A ratio is often used for data where degrees of absolute difference would not be comparable, such as with different signal strength, variations within and between speaker productions, or different vowel environments, with intrinsically different strength. Ingram & Rigsby (1987) use a ratio of the release burst to vowel maximum in their contrasting set of stops "to normalize the data for arbitrary variations" (p.135).

3.2.2 Procedure

Data from the fourteen Mam speakers were analyzed for three indicators of abruptness of voice onset following contrasting pairs of pulmonic and glottalic stops. The three indicators were computed from the RMS amplitude envelope with a 40 ms window width for dB differences from 1, using the Signalyze 3.12 program for the ratio and absolute dB rise. The results are summarized below in Sections 3.2.3, 3.2.4 and 3.2.5.

The determination of vowel onset is arbitrary. I chose wherever the wave form indicates the onset of regular glottal pulsing after the stop release as the moment of vowel onset, (see also Chapter 2, Section 2.2.1.1 for related discussion). In the case of ejectives, usually defined as voiceless, the moment of vowel onset coincides with voice onset. In the case of voiced implosives, voice onset obviously precedes vowel onset. The end of the rise is the first plateau of amplitude or the vowel peak, whichever comes first, as mentioned earlier.

The duration of amplitude rise time is thus an artifact of the choice of starting point. If native speakers are somehow attuned to a gestural timing score then vowel onset is not necessarily either physiologically or perceptually equivalent to voice onset for any type of stop (cf Flege 1982). In addition, listeners may attend to amplitude changes after the highly salient release burst rather than to the moment of vocal onset. In the absence of perceptual tests, however, the start of regular glottal pulsing provides a convenient and intuitively satisfying starting point from which to measure abruptness.

A line indicates the first glottal pulse, or the point of vowel onset in the wave form in Figure 3.1 for /paa/*bag*, and /b'aa/*mole*, speaker M5.

3.2.3 Analysis of amplitude rise time

3.2.3.1 Types of measures

I analyzed the data according to three types of measures, as used in Chapter 2. These are:

i. The means, standard deviations and range of values for the duration in rise time of vowels after pulmonic and glottalic stops, summarized in Tables 3.1 to 3.4.

ii. The distribution of the amplitude rise time for vowels after pulmonic and glottalic stops in Mam. The histograms in Figures 3.2, 3.5, 3.7, and 3.10 show these distributions.

iii. T- tests. The t-tests provide a measure of the statistical significance of the difference between the two sets of rise times after pulmonic and glottalic stops. As several tests were performed, a conservative p level of 0.01 was adopted, as for VOT. The histograms in Figure 3.3, 3.6, 3.8, and 3.11 show the distribution of these differences between contrasting tokens. The analyses are computed from the raw data and presented in graph form in the histograms. Values to the right of zero indicate that the amplitude rise time is greater for vowels after glottalic stops. Values to the left of zero indicate that amplitude rise time is greater after pulmonic stops. Values close to zero indicate no difference in rise time between vowels after pulmonic and glottalic stops.

The three measures are organized by numbered subsections, i., ii., and iii., by each place of articulation.

3.2.3.2 Results

The overall tendency is for pulmonic stops to be followed by a faster rise time in intensity than the slower rise time in intensity after the ejective and implosive stops. Vowels after pulmonic stops, therefore, tend to have a more abrupt onset than vowels after glottalic stops in this data, as measured by the amplitude rise time (i.e., less than 50ms of rise time: see Section 3.2.1 above). However, there is considerable overlap of amplitude rise time for vowels after pulmonic and glottalic stops and variation exists according to place of articulation. The difference in rise time between pulmonic and glottalic stops is statistically significant only for bilabials and dentals. Rise time after glottalic stops is more than 20 ms longer than after pulmonic stops for about 71% of bilabials and 70% of dental contasts but only 36% of velars and 39% of uvulars. However, when the data for pulmonic and glottalic stops is analyzed separately, it is clear that vowel onset is gradual after glottalic stops at all places of articulation.

Table 3.1

mean value, SD and range of rise time of amplitude in ms. after pulmonic and implosive bilabial stops

Type of stop	$\bar{x}$	SD	range
pulmonic bilabial	36.9	14.9	17.9 - 88.1
bilabial implosive	77.5	33.9	5.4 -176.2

Table 3.2

mean value, SD and range in rise time of amplitude in ms. after pulmonic and glottalic dental stops

Type of stop	$\bar{x}$	SD	range
pulmonic dental	38.9	16.8	19.7 - 84.6
glottalic dental	74	29.2	25.1 - 129.2

Table 3.3

mean value, SD and range in rise time of amplitude in ms after pulmonic and ejective velar stops

Type of stop	$\bar{x}$	SD	range
pulmonic velar	60.4	27	19.7 - 84.6
velar ejective	70.3	30.5	31 - 170

Table 3.4

mean value, SD and range of rise time of amplitude in ms after pulmonic and implosive uvular stops

Type of stop	$\bar{x}$	SD	range
pulmonic uvular stop	51.5	23.2	23.4 - 106.1
uvular implosive	63.1	23.4	32.2 - 115.8

Bilabials

i. The mean value of rise time after pulmonic bilabial stops is 36.9 ms with a standard deviation of 14.9. The mean duration rise time of vowels after glottalic bilabials is 77.5 ms with a standard deviation of 33.9.

ii. The histogram in Figure 3.2 shows the distribution of the durations of amplitude buildup from vowel onset to vowel maximum for vowels after both pulmonic and glottalic bilabial stops. Vowels after pulmonic stops are distributed mostly at a range of 30-40ms of amplitude rise time. The duration of rise time is less than 50ms for 87.1% of 70 pulmonic bilabial tokens, that is they have an abrupt onset, using the Koike et al. (1967) abruptness measure.

The vowels after the bilabial implosive stops have a wider range in amplitude rise time: only 17.5% have an abrupt onset whereas 82.5% have more than 50 ms of amplitude rise time. However, the histograms also indicate considerable overlap.

iii. The distribution of differences between vowel amplitude rise times after pulmonic and glottalic bilabial stops is shown in Figure 3.3. The range of values on both sides of zero indicates that to some extent the difference in rise time can fall either way. For 10% of the contrasts, vowels after glottalic stops have a shorter rise time than after pulmonic stops. However, for the majority of bilabial contrasts, vowels after bilabial implosives have a longer rise time than after pulmonic bilabial stops. Glottalic stops are followed by a rise time which is 20-150 ms longer than the rise time after pulmonic stops for 71% of the 69 contrasts.

A t-test shows a statistically significant difference in the rise time of amplitude between vowels after pulmonic and glottalic bilabial stops. The mean rise time after bilabial implosives is 40.9 ms longer than after corresponding bilabial pulmonic stops ($t(68)=-9.1$, $p=.0001$).

An example of contrasting types of abrupt and non-abupt onset after pulmonic and glottalic stops respectively is shown in the wave form and amplitude envelope in Figure 3.4 in the tokens /pen/*fence* and /b'ee/*road* , Speaker F7. The wave form after the implosive has a much more gradual buildup in intensity. This is contrasted with the amplitude envelope of the vowel after the pulmonic stop, which rises dramatically.

Dentals

i. The mean rise time of vowels after pulmonic dental stops is 38.9 ms from onset to vowel maximum. The mean rise time of glottalic dental stops is 74 ms. Standard deviations of rise time after both bilabials and dentals are less than the spread between rise time after pulmonic and glottalic stops.

ii. The histogram in Figure 3.5 shows the distribution of the durations of amplitude buildup from vowel onset to vowel maximum for vowels after both pulmonic and glottalic dental stops. Although 75% of 28 tokens of pulmonic dental stops have an abrupt onset, using the Koike (1967) measure of abruptness, another 25% have 51 to 90 ms of amplitude rise time, overlapping the range for vowels after glottalic stops.

The vowels after the dental glottalic stops tend to be distributed to the right of the values for vowels after pulmonic stops and have a wider distribution of values, with 83% of the tokens having an amplitude buildup greater than 50 ms, i.e. they have a gradual onset.

iii. The distribution of the differences between vowel amplitude rise times after pulmonic and glottalic dental stops is shown in Figure 3.6. Once again, the range indicates that the difference in rise time can to some extent fall either way. Vowels after pulmonic stops have 10-40 ms longer rise time than after glottalic stops for 12.6% of 24 contrasts. However, for 70.8% of the tokens, the difference in rise time after glottalic dental stops is 21-90 ms longer than after pulmonic stops, that is, vowels after glottalic dental stops have a longer rise time than after pulmonic dental stops.

A t-test shows a statistically significant difference in the amplitude rise time between vowels after pulmonic and glottalic dental stops. The mean difference in amplitude rise time after glottalic dental stops[49] is 34.7 ms longer than after corresponding pulmonic dental stops, ($t(23)=-5.5$, $p=.0001$).

Velars

For velar contrasts between pulmonic and glottalic stops, there is the smallest absolute difference between rise times, the largest standard deviation, and the widest range of values over all tokens. However, the tendency is for a longer amplitude rise time after velar ejectives than after velar pulmonic stops.

i. The mean rise time of vowels after pulmonic velar stops is 60.4 ms with a standard deviation of 27 ms and a range from 19.7 ms to 84.6 ms. The mean rise time of vowels after glottalic velar stops is 70.3 ms with a standard deviation of 30.5 ms and a range from 31 to 170 ms.

49 This includes both ejectives and implosives glottalic stops. Most dental glottalic stops are ejectives in this data.

ii. The histogram in Figure 3.7 shows the extent of the overlap of amplitude buildup for velars after 45 tokens of pulmonic velar stops and 44 tokens of velar ejectives. The central tendencies are only slightly staggered for the velar contrast, with the ejective amplitude rise time shifted slightly to the right of the pulmonic velar stops. However, when the raw data is again divided acording to the Koike et al. (1967) abruptness measure, i.e. greater than or less than 50 ms rise time, a distinction is clearer. Vowels after pulmonic velar stops are divided between abrupt (42.2%) and non-abrupt (57.8%). Vowels after glottalic stops have a non-abrupt onset for 75% of 44 tokens.

iii. The distribution of differences between vowel amplitude rise times after pulmonic and glottalic velar stops is shown in Figure 3.8. The almost evenly split range of values on both sides of zero indicates that the difference in rise time between velar contrasts can fall either way. The amplitude rise time is longer after pulmonic velar stops than after velar ejectives for 43.3% of 44 contrasts. The amplitude rise time is 20-120 ms longer after velar ejectives than after pulmonic velar stops for 36.3% of the tokens. So voice onset appears to be abrupt either way.

A t-test of the difference in rise time between vowels after pulmonic and ejective velar stops gives a difference that is not statistically significant. The mean difference in rise time for vowels following velar ejectives is 10.9 ms longer than after corresponding pulmonic velar stops, ($t(43)=-2.2, p=.0349$).

An example of contrasting types of abrupt and non-abrupt onset after velar pulmonic and glottalic stops is shown in the wave-form and amplitude envelope below in Figure 3.9 for the tokens /ku'x/ *gone down* and /k'u'x/ *stomach,* Speaker M1. The vowel after the ejective has a much more delayed buildup in amplitude than the vowel after the pulmonic velar stop. This is despite the amplitude dip after the pulmonic stop, presumably with the onset of creaky voice in the second half of the vowel.

Uvulars

i. The mean rise time of vowels after pulmonic uvular stops is 51.5 ms with a standard deviation of 23.2 ms. The mean rise time of vowels after the uvular implosives is 63.1 ms with a standard deviation of 23.4 ms. The ranges for pulmonic stops (23.4 ms- 106.1 ms) and implosives (32.3 ms-115.8 ms) almost completely overlap.

ii. The histogram in Figure 3.10 shows the distribution of the amplitude rise times from vowel onset to vowel maximum for vowels after both pulmonic and glottalic uvular stops. Despite the overlapping ranges, the histogram indicates a shift to a longer amplitude rise time for vowels after implosives than after pulmonic stops. A higher proportion of vowels after pulmonic stops have a shorter amplitude rise time,that is 56.8% of 52 tokens of vowels after pulmonic stops have a buildup of 21-50 ms, whereas only 28.9% of vowels after implosives have an amplitude buildup of less than 50 ms. The rise time of vowels after uvular implosives centres around 50 to 70 ms rise time.

iii. The distribution of differences between vowel amplitude rise times after pulmonic and glottalic uvular stops is shown in Figure 3.11. Once again, the difference in rise time for uvulars could be either way. The amplitude rise time is longer after pulmonic uvular stops than after the uvular implosives for 32.5% of the 49 pairs of contrasts. The rise time is 21-110 ms longer after uvular implosives than after uvular pulmonic stops for 39.2% of the 49 pairs.

A t-test of the difference between vowels after pulmonic and implosive uvular stops gives a difference that is not statistically significant. The mean rise time of vowels after uvular implosives is 9.9 ms longer than after pulmonic uvular stops, ($t(46)=-1.9$, $p=.0588$).

3.2.3.3 Discussion

The results, summarized in Tables 3.1 to 3.4, indicate that amplitude rise time after all pulmonic stops increases in duration roughly according to place of articulation, or from front to back. Rise time increases from about 40 ms after dental pulmonic stops to 50 ms for uvulars and about 60 ms after velars. This shift in values for pulmonic stops with place of articulation is consistent with what is seen in other languages from front to back in VOT, (see Chapter 2, Section 2.2.1.3 for a discussion of this) as well as in the VOT data from Mam, (see Chapter 2, Tables 2.3 to 2.7). However, the rise time for uvular implosives and velar ejectives is actually slightly shorter than for bilabial implosives and dental ejectives or implosives. Consequently, the difference between the pulmonic and glottalic stops shrinks for velars and uvulars. Possibly some increased tension involved in the production of glottalic stops of the vocal tract walls or glottal mechanism may increase the efficiency of the articulation, accounting for the shorter time.

Amplitude rise time robustly distinguishes pulmonic and glottalic stops at the bilabial and dental place of articulation. Although vowels after velars and uvulars tend to have a delayed rise in amplitude in comparison with vowels after pulmonic stops, the difference is not statistically significant.

However, when the data is organized according to whether the onset can be termed gradual or abrupt, that is, according to Koike et al.'s (1967) measure of more or less than 50 ms of amplitude rise time, then vowels after all glottalic stops show a consistent tendency to gradual onset, whereas vowels after only bilabial and dental pulmonic stops have a clearly abrupt onset. There is no clear tendency after velar and uvular pulmonic stops. Slightly more velars are followed by a gradual onset. Slightly more uvulars are followed by an abrupt onset.

Table 3.5 below summarizes the results according to whether stops are followed by an abrupt or gradual onset. This clarifies that a majority of all glottalic stops have a gradual onset. Pulmonic stops cannot be as systematically described by this criterion.

Table 3.5

Percentage of tokens with abrupt or gradual voice onset after pulmonic and glottalic stops

	Pulmonic stops		Glottalic stops	
	% Abrupt	% Gradual	% Abrupt	% Gradual
bilabial	87.1	12.9	17.5	82.5
dental	75	25	16.7	83.3
velar	42.2	57.8	25	75
uvular	55.8	44.2	28.9	71.1

3.2.4 Analysis of absolute dB rise

The absolute change in dB from onset to first vowel peak, or first amplitude plateau, is perhaps the most direct measure of what is termed a "steep rise" in amplitude, or conversely, an amplitude decrease. The previous results indicate that there is a difference in the duration of the amplitude rise time between pulmonic and glottalic stops, and that the increase is greater after glottalic stops. The question remains as to how much of an amplitude change in absolute decibels this represents.

3.2.4.1 Types of measures

The types of measures are the same as for the analysis of amplitude rise time in Section 3.2.3.1.

Tables 3.6-3.9 summarize the results with means, standard deviations, and range in values for all tokens of the dB rise after pulmonic and glottalic stops in Mam, from vowel onset to vowel maximum amplitude.

The histograms in Figures 3.12, 3.14, 3.16, and 3.18 represent the distribution of the dB rise from vowel onset to first vowel peak after both pulmonic and glottalic stops, at all places of articulation. The divisions along the x-axis are in 1dB units.

T-tests provide a measure of the statistical significance of the difference between the two sets of dB rise after pulmonic and glottalic stops. They are reported at an alpha level of 0.01. Figures 3.13, 3.15, 3.17, and 3.19 summarize the distribution of these differences. The analyses are computed from the raw data and presented in graph form in the histograms. Values to the right of zero indicate that the dB increase is greater for vowels after glottalic stops. Values to the left of zero indicate that dB increase is greater after pulmonic stops. Values close to zero indicate no difference in dB increase between vowels after pulmonic and glottalic stops.

3.2.4.2 Results

The absolute dB difference from vowel onset to first vowel peak distinguishes vowels after pulmonic and glottalic stops in this data. There is a significantly larger absolute increase in dB for vowels after glottalic stops at all places of articulation.

However, an analysis of the range and differences between pulmonic and glottalic stops indicates that absolute rise in dB more robustly distinguishes the bilabial and dental contrasts than the velar and uvular contrasts. There is a larger absolute increase in dB for 88.1% of bilabial and 87.5% of dental pulmonic and glottalic contrasts whereas just over one half, or 52% of velar ejectives, and 56% of uvular implosives, have a larger than 1 dB increase than corresponding pulmonic stops. A further analysis, based on less than or more than a 5 dB increase in vowel amplitude after all pulmonic and glottalic stops, shows that pulmonic stops vary with place of articulation whereas glottalic stops at all places of articulation tend to be followed by a steep rise in amplitude.

Table 3.6
means, standard deviations, and range of absolute rise in dBs after pulmonic and glottalic bilabial stops in Mam

Type of stop	$\bar{x}$	SD	Range
pulmonic bilabial	4.6	2	.9- 13.1
glottalic bilabial	9.6	4.5	2.4- 23

Table 3.7
means, standard deviations, and range of absolute rise in dBs after pulmonic and glottalic dental stops in Mam

Type of stop	$\bar{x}$	SD	Range
pulmonic dental	4.4	1	2.8- 5.9
glottalic dental	10.3	4.7	3.2- 16.3

Table 3.8
means, standard deviations, and range of absolute rise in dBs after pulmonic and glottalic velar stops in Mam

Type of stop	$\bar{x}$	SD	Range
pulmonic velar	7.1	2.6	3- 14
glottalic velar	9.5	5	3.3- 21.9

Table 3.9
means, standard deviations, and range of absolute rise in dBs
after pulmonic and glottalic uvular stops in Mam

Type of stop	$\bar{x}$	SD	Range
pulmonic uvular	5.9	2.1	1.6- 11.5
glottalic uvular	8.6	3.7	1.8- 17.2

Bilabials

i. The mean dB rise after pulmonic bilabial stops in this data is 4.6 dB with a standard deviation of 2 dB and a range from .9 dB to 13.1 dB. The mean dB rise after glottalic bilabial stops is 9.6 dB with a standard deviation of 4.5 and a range from 2.4 to 23 dB.

ii. The histogram in Figure 3.12 shows the distribution of the dB rise of vowels after both pulmonic and glottalic bilabial stops. Vowels after pulmonic bilabial stops have a peak at 4 dB, with a 3 to 5 dB increase from vowel onset to vowel maximum for 65.7% of tokens. Vowels after glottalic bilabial stops have a peak at 8 dB and a wider range of values. Only 13% of tokens overlap the central tendency of vowels after pulmonic stops, i.e. with under 5 dB increase.

The majority of vowels after glottalic bilabial stops have a greater increase in absolute dB than vowels after pulmonic stops. The dB rise is less than 5 dB after 78.6% of the pulmonic stops and more than 5 dB after 21.4% of the pulmonic stops. Conversely, the dB rise is less than 5 dB after just 16.6% of the bilabial implosives and more than 5 dB after 83.3% of the bilabial implosives.

iii. The distribution of the differences in dB rise between vowels after pulmonic and implosive bilabial stops is represented in the histogram in Figure 3.13. The difference in dB rise was greater after pulmonic stops than after glottalic stops for just 11.9% of the contrasts. There was a difference of only plus or minus 1 dB for 10 contrasting pairs, or, 14.6% of bilabial contrasts. However, vowels after the implosives have an increase greater than 1dB more than after pulmonic stops for 77.9% of the tokens and an increase equal to or greater than 5 dB more than after pulmonic stops for 53.2% of the implosives. This indicates a considerably larger increase in amplitude after the bilabial implosives than after the pulmonic bilabial stops.

A t-test shows a statistically significant difference in dB rise betweeen vowels after pulmonic and implosive bilabial stops. The mean amplitude increase after bilabial implosives is 5 dB more than after pulmonic voiceless bilabial stops, $t(68)=-8.5$, $p=.0001$.

Dentals

i. The mean dB rise after pulmonic dental stops in this data is 4.4 dB with a standard deviation of 1 dB and a range from 2.8 to 5.9 dB. The mean dB rise after glottalic dental stops is 10.3 dB with a standard deviaton of 4.7 dB and a range from 3.2 to 16.3 dB increase.

ii. The histogram in Figure 3.14 shows the distribution of the dB rise of vowels after both pulmonic and glottalic dental stops. Vowels after pulmonic dental stops all fall within 3 to 6 dB of increase. Vowels after glottalic dental stops have a wider range that overlaps the values for pulmonic stops and extends well beyond, peaking at 9 to 11 dB increase. Using the classifier of greater or less than 5 dB, it is clear that a majority of pulmonic dental stops, (78.6%), are followed by a rise of less than 5 dB whereas a majority of glottalic dental stops, (83.3%), are followed by a rise of more than 5 dB.

iii. The distribution of the difference in dB rise between vowels after pulmonic and glottalic dental stops is shown in the histogram in Figure 3.15. The difference in dB rise was greater for 12.5% of vowels after pulmonic dental stops than after glottalic dental stops. The difference is within 1dB for an additional 4.2% of the contrasts. The majority of contrasts, or 87.5%, have a larger dB increase after glottalic stops. The difference in dB rise is 10 dB or more after glottalic stops than after pulmonic stops for 25% of the contrasts . This indicates a considerably larger increase in amplitude after glottalic dental stops than after pulmonic dental stops.

A t-test shows a significant difference in dB rise between vowels after pulmonic and glottalic dental stops. The mean increase in amplitude after all glottalic dental stops is 6.1 dB more than after pulmonic dental stops, $t(23)= -6.2$, $p=.0001$.

Velars

i. The mean dB rise of vowels after pulmonic velar stops in this data is 7.1 dB with a standard deviation of 2.6 dB and a range from 3 to 14 dB increase. The mean dB rise of vowels after glottalic velar stops is 9.5dB with a standard deviaton of 5 dB and a range from 3.3 to 21.9 dB increase.

ii. The histogram in Fig 3.16 indicates the extent of overlap in values for absolute dB increase of vowels after velar pulmonic and glottalic stops. The central tendencies are almost coterminous with only a slight tail of lower values for vowels after pulmonic stops and a longer tail of higher dB values for vowels after glottalic stops. Using the classifier of greater or less than 5 dB, only 18.8% of pulmonic velar stops are followed by a rise of less than 5 dB whereas 81.2% are followed by a rise of more than 5 dB. Vowels after velar ejectives have less than 5 dB rise for 22.3% of tokens whereas 77.7% of ejectives are followed by a rise of more than 5 dB.

iii. The distribution of the differences in dB rise between vowels after pulmonic and ejective velar stops is shown in the histogram in Fig 3.17. The values are more evenly distributed around zero for this data with the central tendency centred around zero to one dB difference, suggesting an imperceptible difference. However, the tail slightly skewed to the right also indicates some higher values after glottalic stops. The dB increase is greater after pulmonic stops for 25.1% of the contrasts and greater after the ejective stops for 52.4% of the contrasts.

A t-test shows a just significant difference in dB rise between vowels after pulmonic and ejective velar stops. The mean dB rise after velar ejectives is 2.5 dB more than after pulmonic velar stops, ($t(43)= -2.9$, $p=.0059$).

Uvulars

i. The mean dB rise of vowels after pulmonic uvular stops in this data is 5.9 dB with a standard deviation of 2.1 dB and a range from 1.6 to 11.5 dB increase. The mean dB rise of vowels after glottalic uvular stops is 8.6 dB with a standard deviaton of 3.7 dB and a range from 1.8 to 17.2 dB increase.

ii. The histogram in Fig 3.18 gives the distribution of the dB rise of vowels after both pulmonic and implosive uvular stops. It shows the tendency for a higher dB rise after uvular glottalic stops than after pulmonic stops. The dB rise of 21.2% of vowels after uvular implosives exceeds any values after pulmonic uvular stops. However, the histogram also shows the considerable overlap of the central tendencies.

Once again, using the classifier of more or less than 5 dB of increase separates the effect of dB rise for pulmonic stops and uvular implosives. Vowels after pulmonic stops have less than 5 dB rise for 42.3% of tokens whereas 67.7% of vowels after pulmonic stops have a rise of more than 5 dB. However, vowels after uvular implosives have less than 5 dB rise for only 19.2% of tokens whereas uvular implosives are followed by more than 5 dB rise in amplitude for 80.8% of the tokens.

iii. The distribution of the differences in dB rise between vowels after pulmonic and implosive uvular stops is shown in the histogram in Figure 3.19. As with the results for the velar contrasts, the values are more evenly distributed around zero for this data. An even larger proportion of contrasts are centred around plus or minus 1 dB with 22.9% of the contrasts. The dB rise is greater after pulmonic uvular stops than after glottalic uvular stops for 20.9% of the contrasts. The dB rise is greater after glottalic stops than after pulmonic stops for 56.2% of the contrasts.

A t-test shows a significant difference in dB rise between vowels after pulmonic and implosive uvular stops. The mean amplitude increase after uvular implosives is 2.6 dB more than after pulmonic voiceless uvular stops, ($t(46)=-4$, $p=.0002$).

3.2.4.3 Discussion

The index of absolute rise in dB distinguishes pulmonic from glottalic stops at all places of articulation. This difference is least robust at the velar place of articulation. The histograms show the considerable extent of overlap in absolute dB rise for velars and uvulars. However, a larger increase in amplitude characterizes vowel onset after glottalic stops.

Table 3.10 below summarizes the results according to whether stops are followed by a level or steep rise in amplitude. This format indicates more clearly that vowels after pulmonic stops vary with place of articulation, whereas vowels after glottalic stops tend to have a steep rise in absolute amplitude at all places of articulation. So, whereas absolute dB rise in amplitude only distinguishes bilabial and dental pulmonic and glottalic stops, a steep rise in amplitude characterizes all glottalic stops.

Table 3.10
Percentage of tokens with level or steep amplitude rise after pulmonic and glottalic stops

	Pulmonic stops		Glottalic stops	
	% Level	% Steep	% Level	% Steep
bilabial	74.2	25.8	13	87
dental	78.6	21.4	16.7	83.3
velar	18.8	81.2	22.3	77.7
uvular	42.3	57.7	19.2	80.8

The greater absolute increase in amplitude after all glottalic stops may be the acoustic result of a heavily damped creaky voice onset in many cases. However, not all speakers use a creaky voice onset. So, whether creaky or regular in glottal pulsing, the tendency is for vowels after glottalic stops to start from a low amplitude, followed by a gradual but steep rise.

However, two questions remain.

First, given the very large increase in dB from onset to vowel peak, some measure is required to judge whether this change is audible. Darwin and Pearson (1982) found that voicing is heard to onset in synthetic English stops from any level 20 dB down from the vowel steady state amplitude. Only one token had an increase of over 20 dB. Therefore, I assume that the differences in this data can be heard.

Second, given the range in dB differences, we need to know if they are distinguishable to listeners. Fant (1970) established that listeners can make minimal distinctions in dBs from .5 dB to 5 dB. He also reported that a rise in 10 dB effectively doubles the loudness sensation. Therefore, I assume the differences in dB rise in this data are perceptible to listeners. The differences after glottalic stops must double in loudness from onset to vowel peak. I suggest that this change in intensity may make such sounds more "prominent" to listeners than sounds with no change in intensity.

3.2.5 Analysis of Ratios

Finally, I used the measure of the ratio of amplitude onset to vowel maximum to see if it would provide another means of distinguishing pulmonic stops from glottalic stops in Mam. Table 3.11 summarizes the mean values for the ratio of vowel onset to vowel maximum for pulmonic and glottalic stops at all places of articulation.

Table 3.11
the mean value and SD of the amplitude ratios for pulmonic and glottalic stops

Type of stop	$\bar{x}$	SD
bilabial pulmonic	1.08	.08
bilabial implosive	1.14	.09
dental pulmonic	1.06	.05
all glottalic dental	1.16	.1
velar pulmonic	1.11	.04
velar ejective	1.15	.09
uvular pulmonic	1.09	.05
uvular implosive	1.12	.06

Table 3.5 shows a larger ratio for glottalic stops at all places of articulation, indicating a greater difference in amplitude between onset to vowel peak. The differences are statistically significant only for the bilabials, dentals and velars. The bilabial difference is significantly different at $t(68)=-4.8$, $p=.0001$. The dental contrast is also significantly different at $t(23)= -4.5$, $p=.0002$. The velar contrast difference is just significant at $t(43)=-2.8$, $p=.0071$, and the uvular contrast is not significant at $t(46)=-2.5$, $p=.0179$. Therefore, this index of abruptness, which is measured by the ratio of amplitude difference from onset to vowel peak, most robustly distinguishes bilabial and dental pulmonic and glottalic stops for this data.

3.3 SUMMARY

Three measures of abruptness were tested to distinguish all pulmonic from glottalic stops in Mam. A longer rise time in the amplitude of the following vowel with a concommitant larger change in absolute dBs during that buildup, reflected in a larger ratio, all tend to characterize glottalic stops in Mam. A shorter rise time to the target amplitude and a smaller change in intensity of the following vowel tend to characterize the pulmonic stops in Mam. Whereas the three measures of abruptness all robustly distinguish bilabial and dental pulmonic stops from glottalic stops there is considerable overlap in values for velars and uvulars. Although pulmonic stops vary with place of articulation, glottalic stops at all places of articulation tend to be followed by a non-abrupt vowel onset and a steep rise in amplitude.

In summary, vowels after pulmonic stops tend to have a more abrupt onset and level amplitude than vowels after glottalic stops, based on three indices of abruptness. Vowels after glottalic stops tend to have a non-abrupt onset with steep rise in amplitude.

Analysis of this data suggests that the production of glottalic stops in Mam does not reflect a classic view of firm glottal closure with considerable medial compression, followed by sudden burst with abrupt vowel onset. In fact the tendency is for an opposite strategy, involving a more delayed amplitude onset of the following vowel and a larger absolute difference in amplitude after glottalic stops. Further perceptual work is required to elucidate how speakers may coordinate or weigh these cues. I suggest that some global property of non-abruptness of onset, based on a rise time of over 50ms and a steep rise in amplitude of over 5 dB, appears to characterize glottalic stops in Mam.

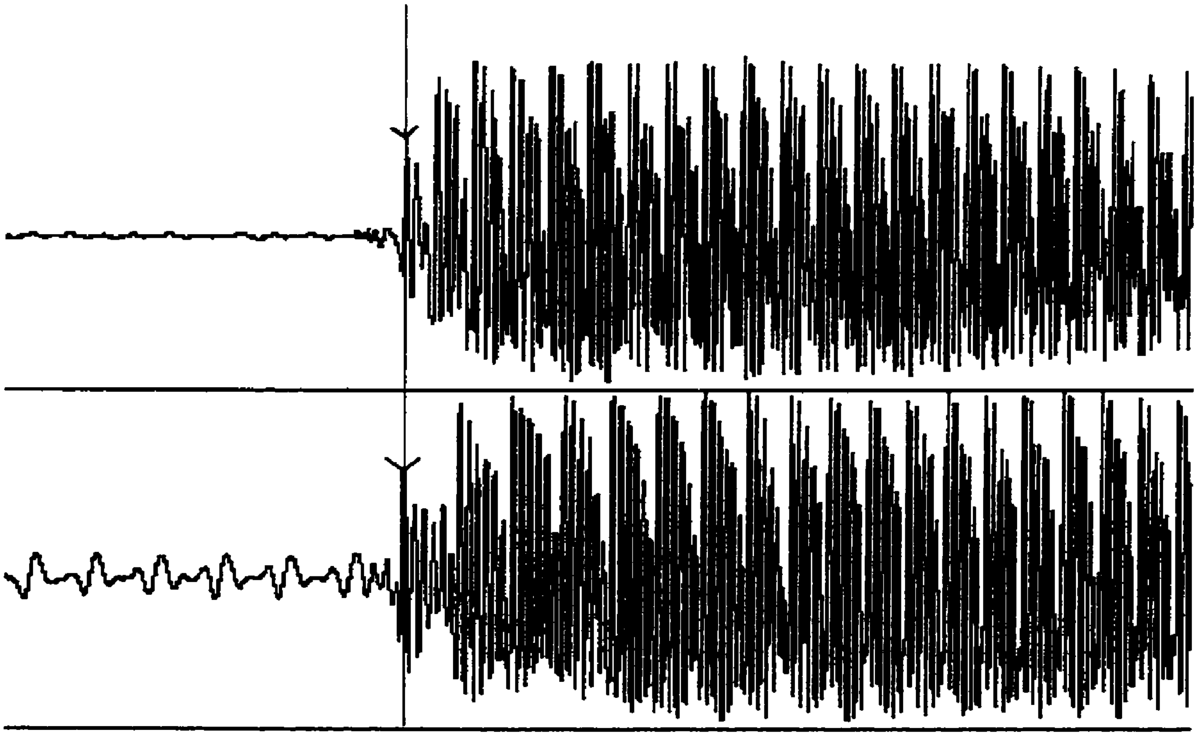

Fig 3.1
Wave-form showing vowel onset for /paa/ and /b'aa/, Speaker M5

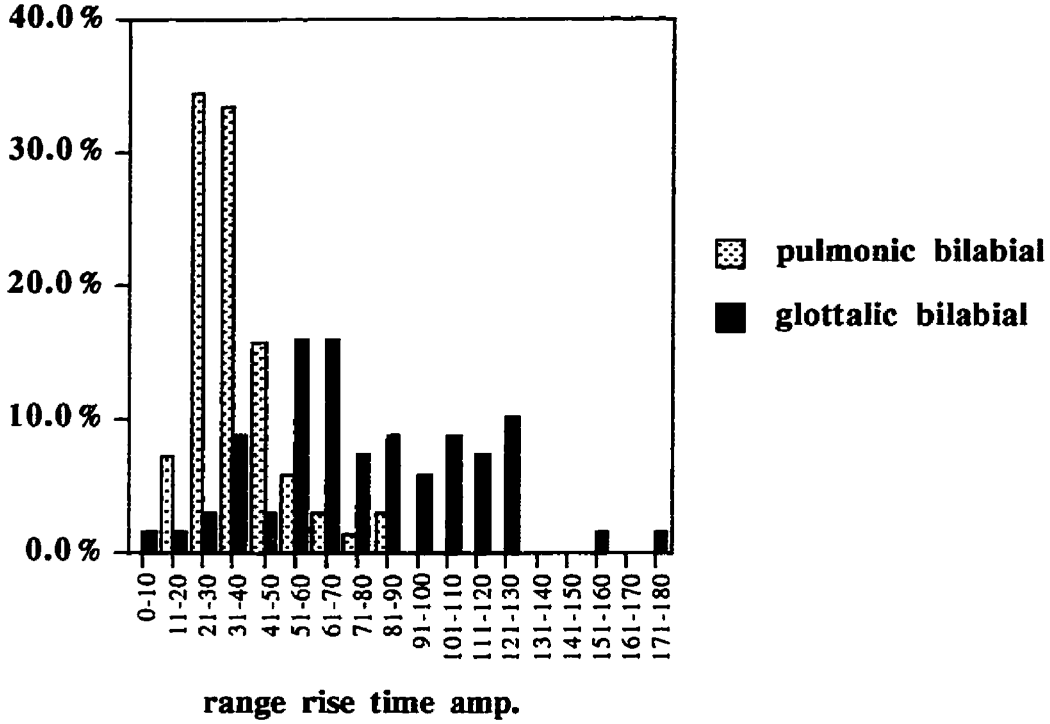

Figure 3.2
The distribution of the amplitude rise times after pulmonic and implosive bilabial stops in ms

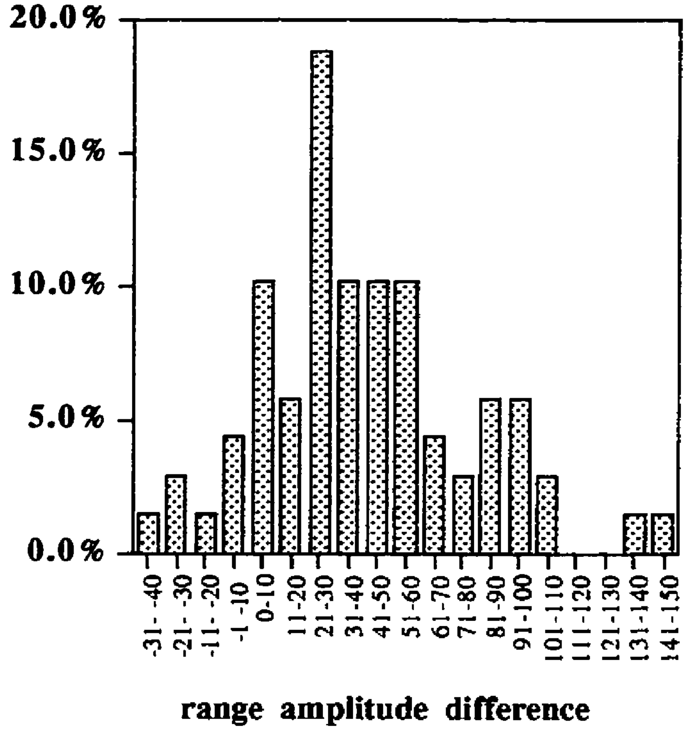

Figure 3.3
The distribution of differences between vowel amplitude rise times after pulmonic and implosive bilabial stops in ms

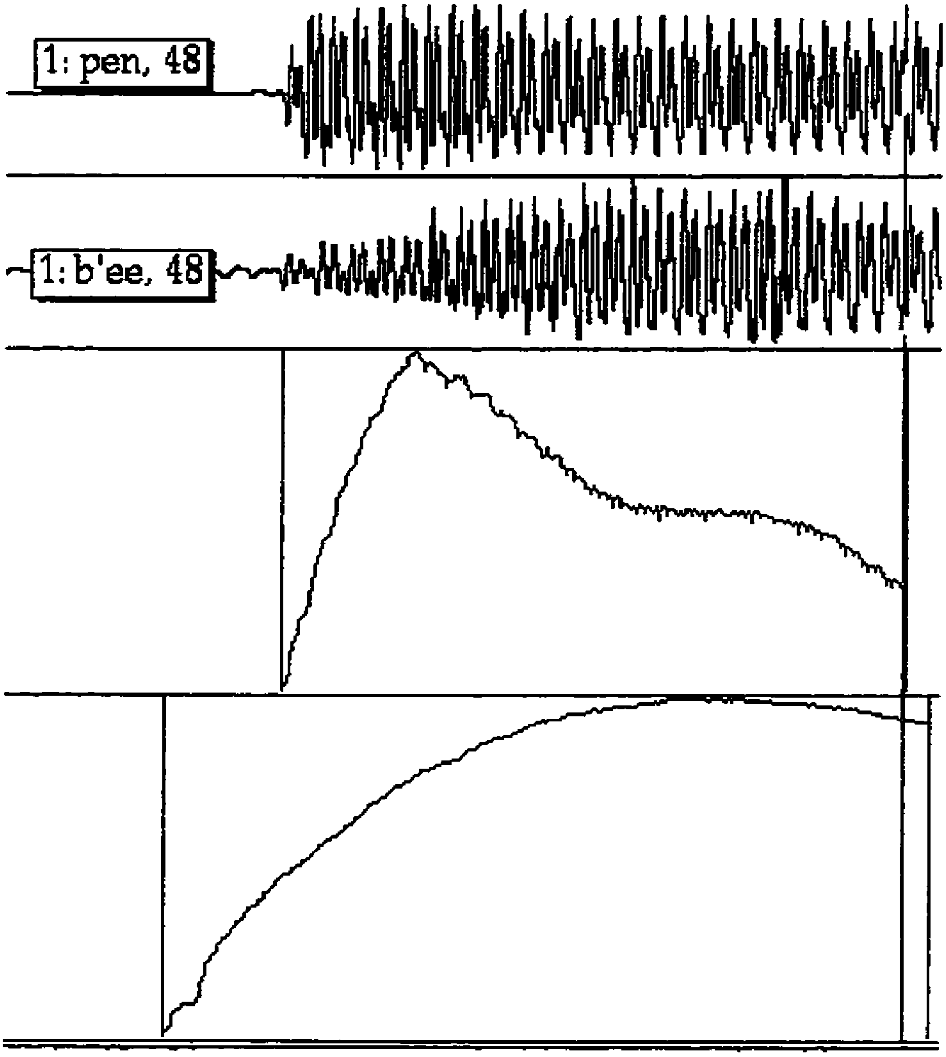

Figure 3.4
Abrupt and non-abrupt voice onset after bilabial pulmonic and implosive stops
Speaker F6

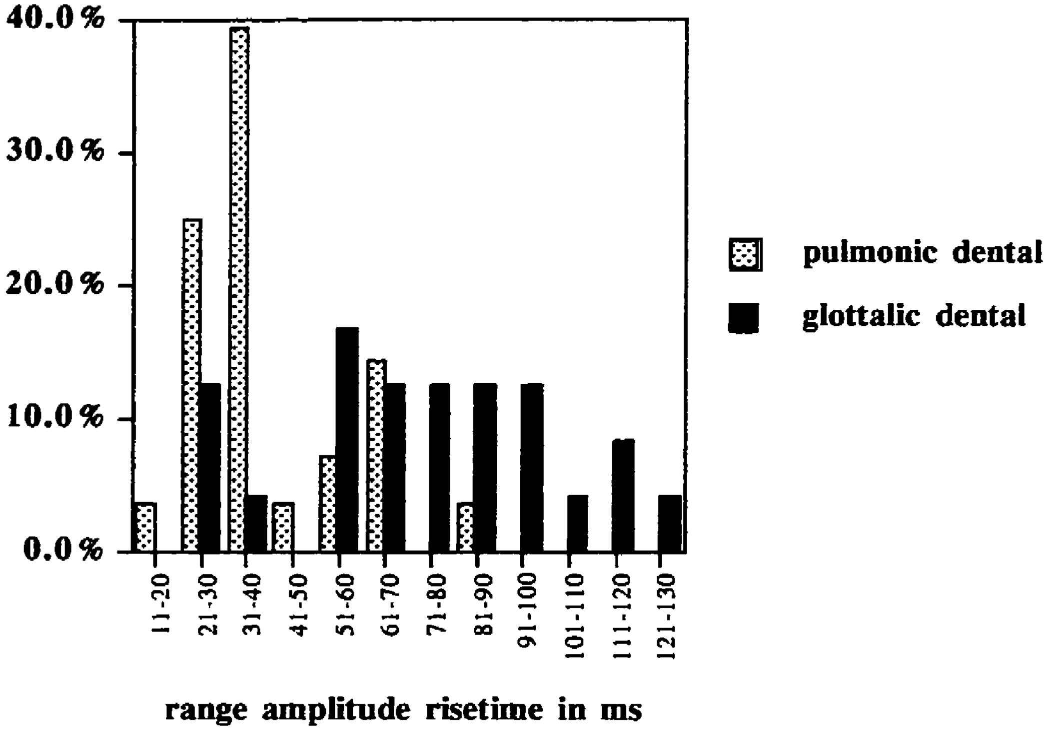

Figure 3.5
Distribution of the vowel amplitude rise times after pulmonic and glottalic dental stops in ms

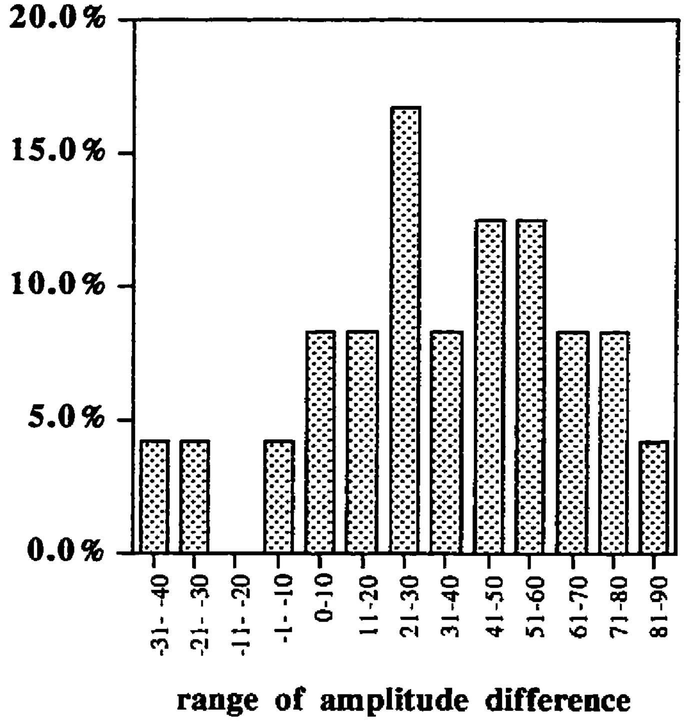

Figure 3.6
The distribution of the differences between vowel amplitude rise times after pulmonic and glottalic dental stops in ms

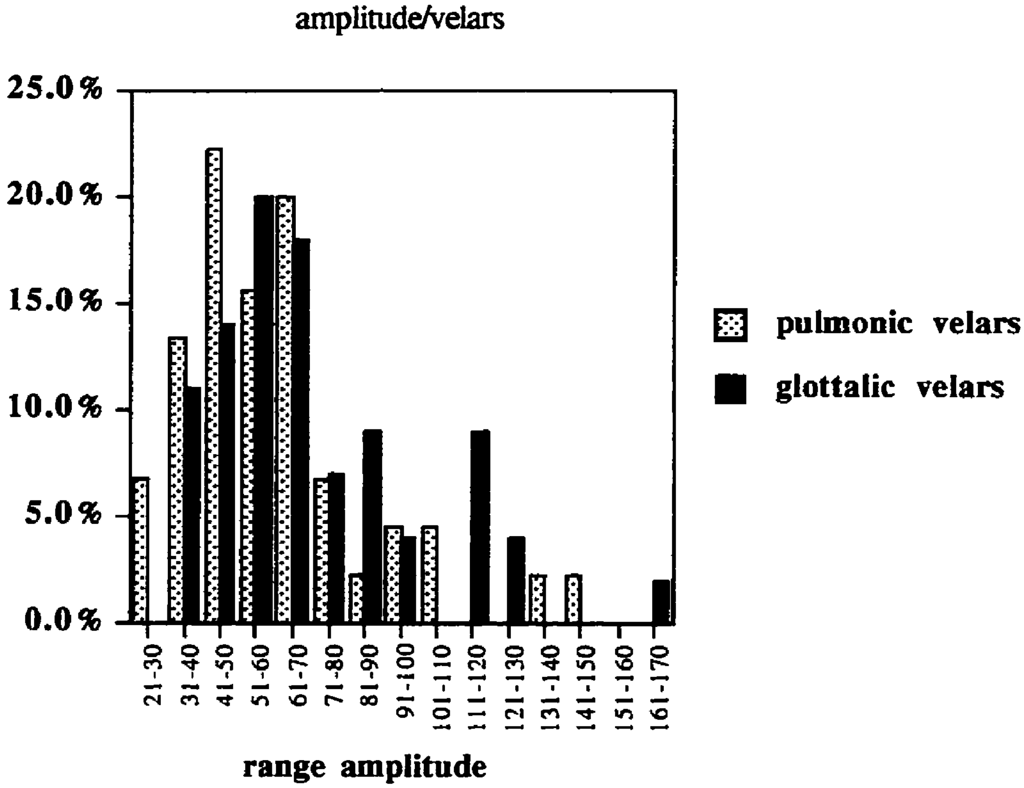

Figure 3.7
The distribution of vowel amplitude rise times after pulmonic and ejective velar stops in ms

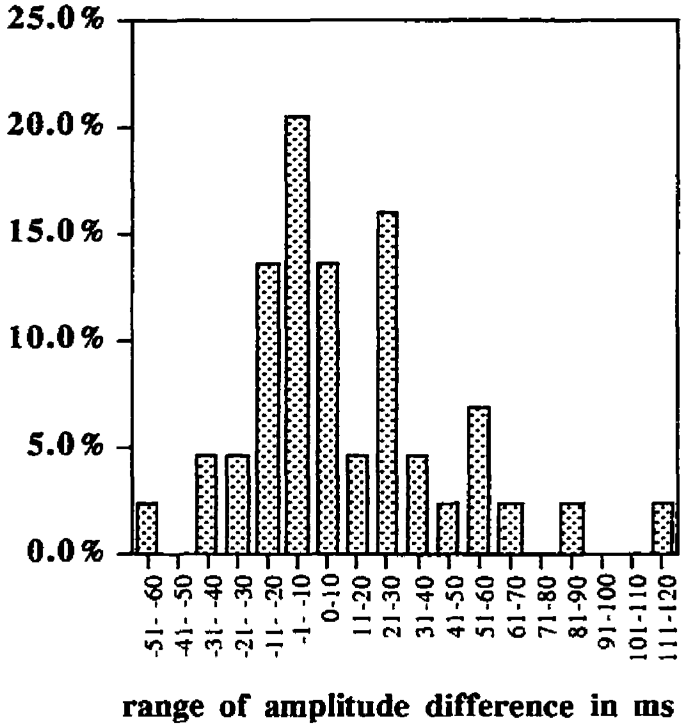

Figure 3.8
The distribution of the differences between vowel amplitude rise times after pulmonic and ejective velar stops in ms

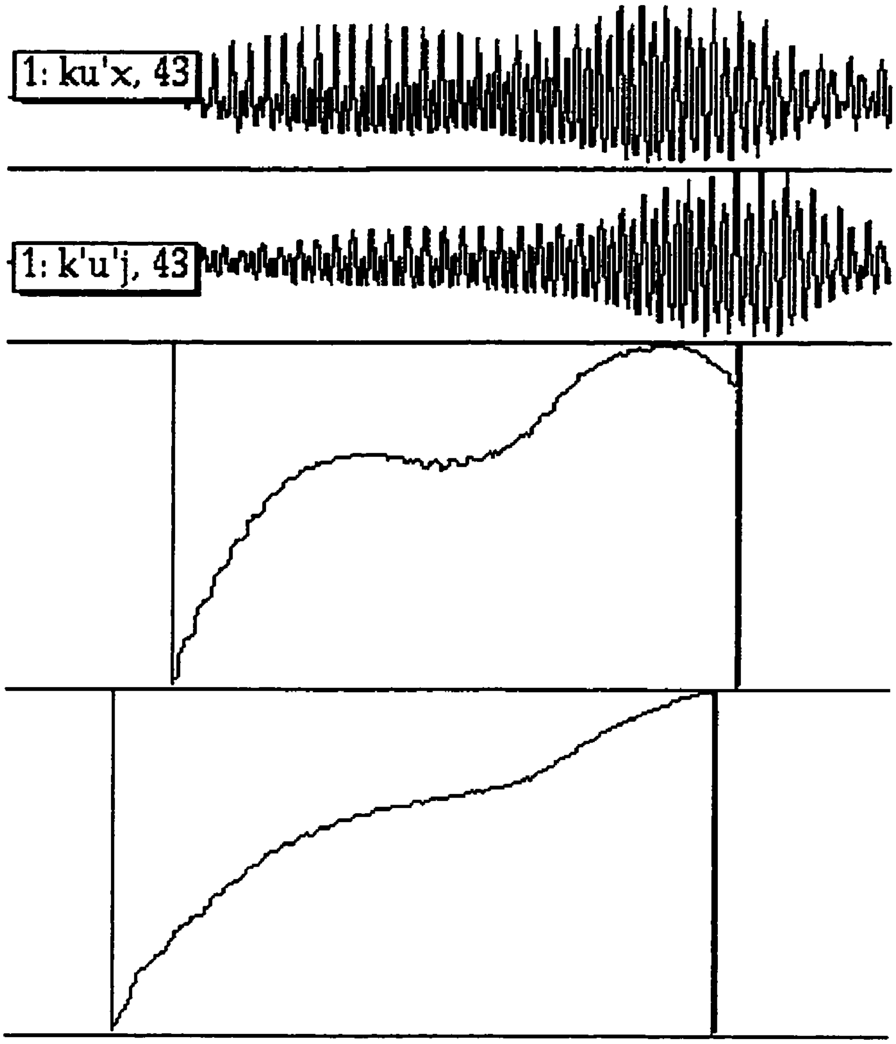

Figure 3.9
Abrupt and non-abrupt vowel onset after velar pulmonic and ejective stops
Speaker M1

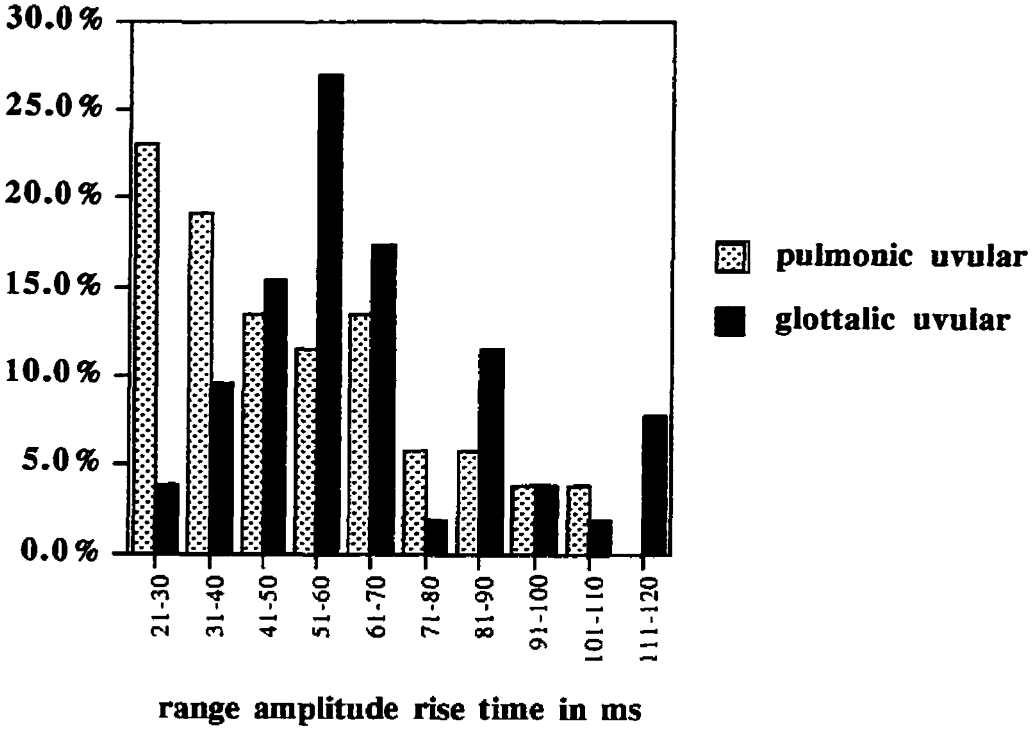

Figure 3.10
the distribution of vowel amplitude rise time after pulmonic and implosive uvular stops in ms

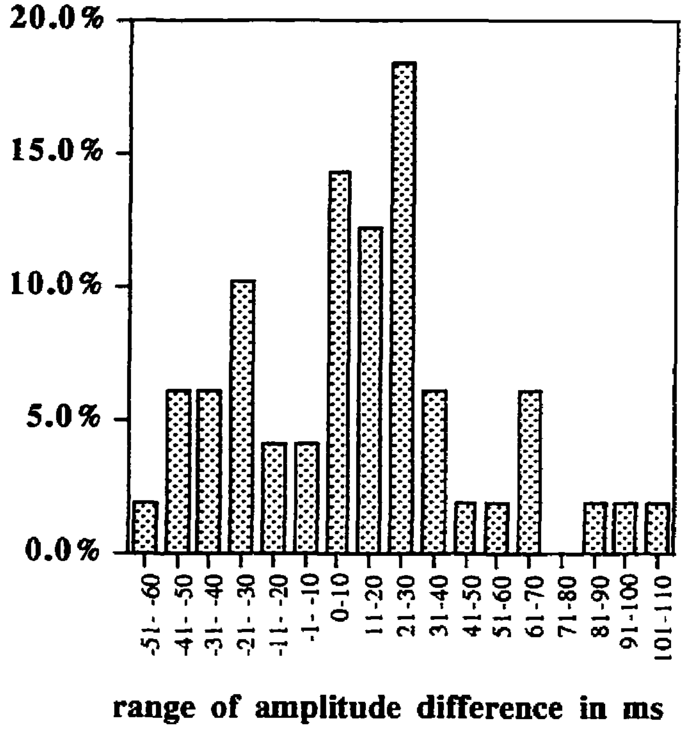

Figure 3.11
The distribution of the differences between vowel amplitude rise times after pulmonic and glottalic uvular stops in ms

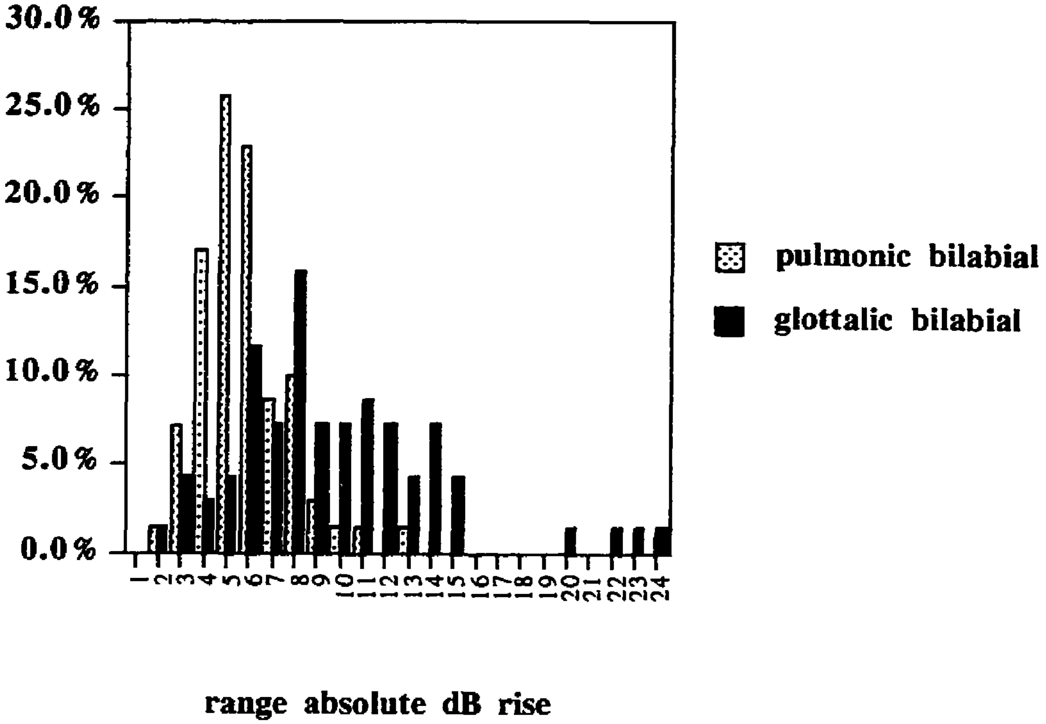

Fig 3.12
The distribution of dB rise of vowels after pulmonic and implosive bilabial stops

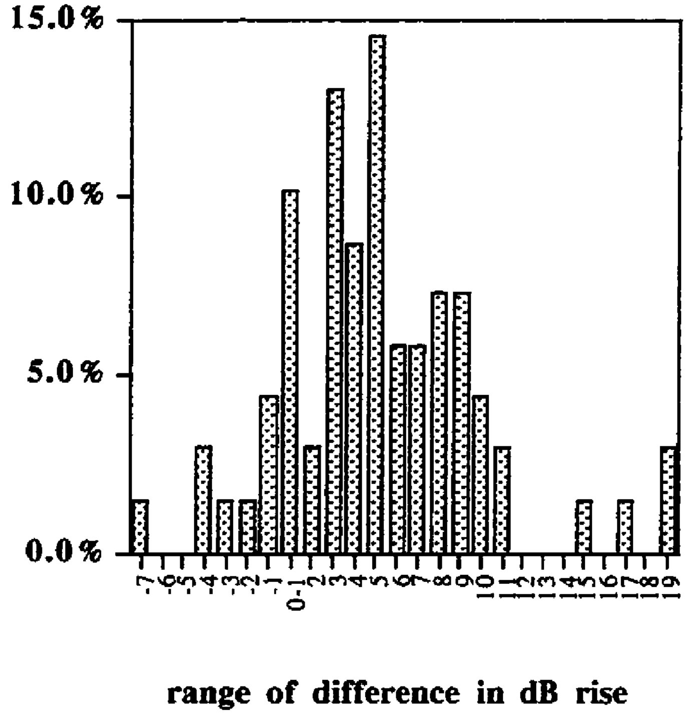

Figure 3.13
The distribution of differences in dB rise between vowels after pulmonic and implosive bilabial stops

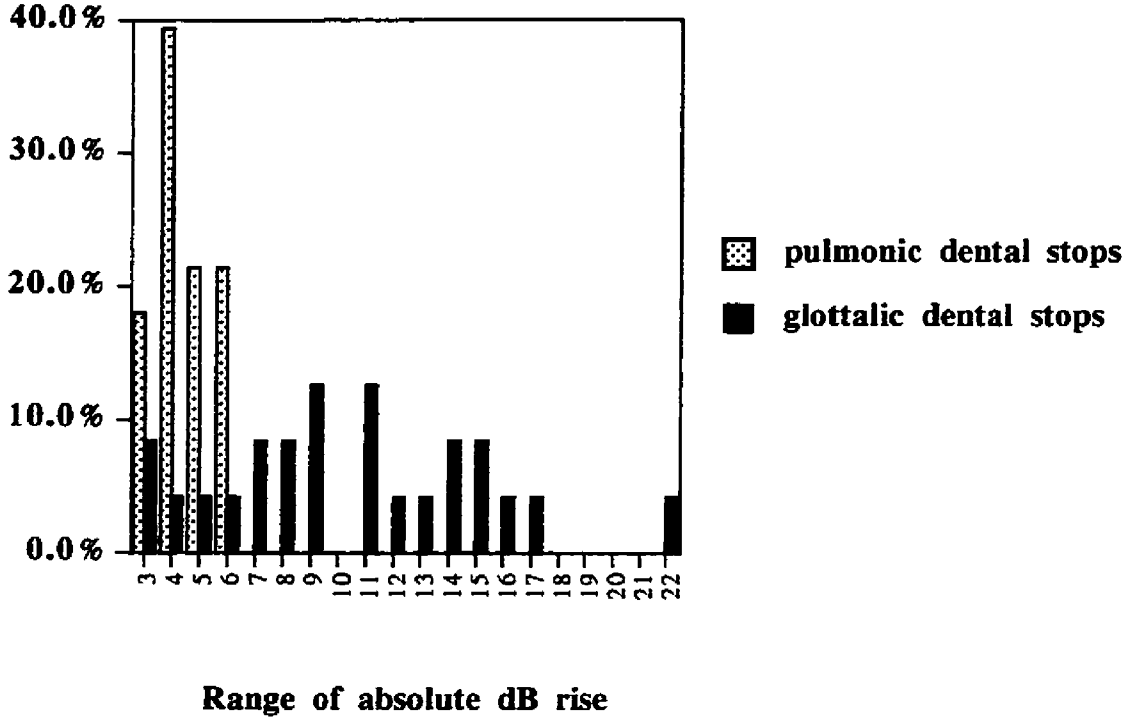

Fig 3.14
The distribution of dB rise of vowels after pulmonic and glottalic dental stops

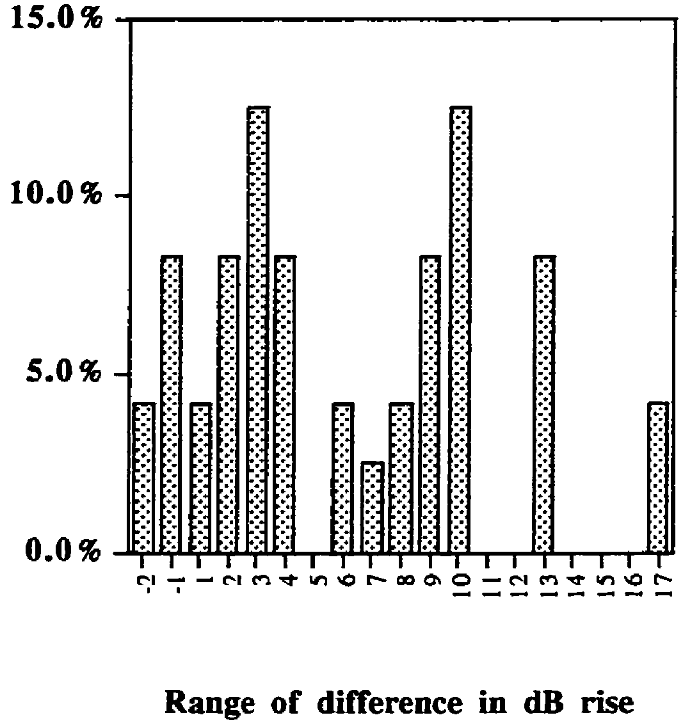

Figure 3.15
The distribution of the differences of dB rise between vowels after pulmonic and glottalic dental stops

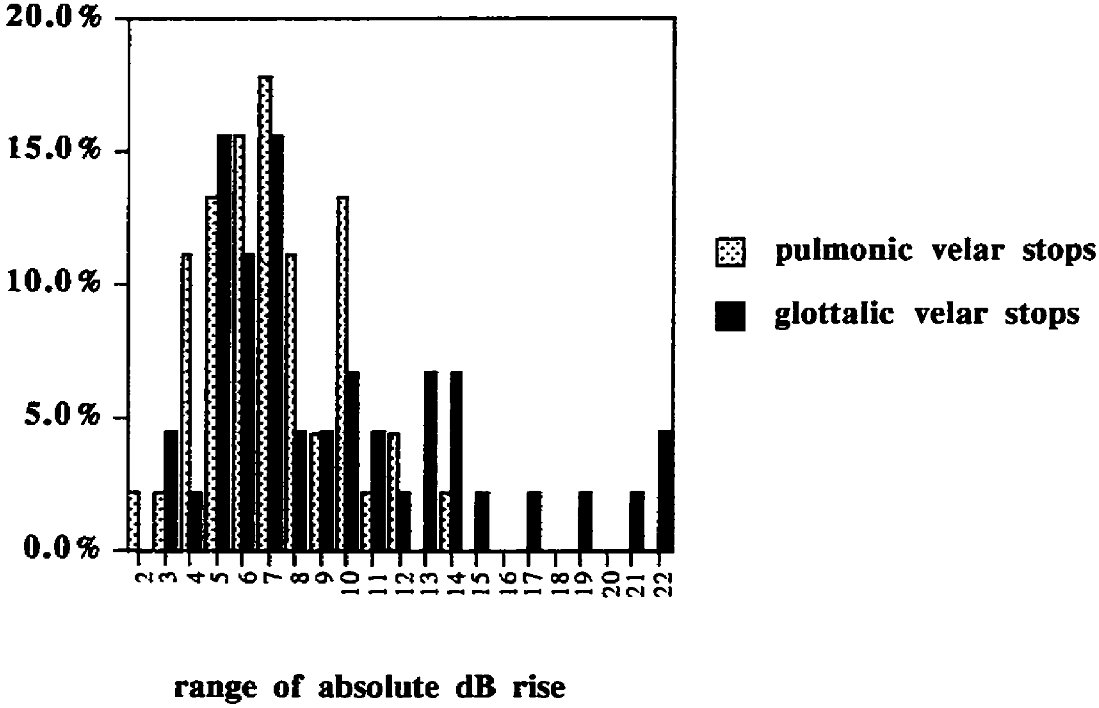

Figure 3.16
The distribution of dB rise of vowels after pulmonic and ejective velar stops

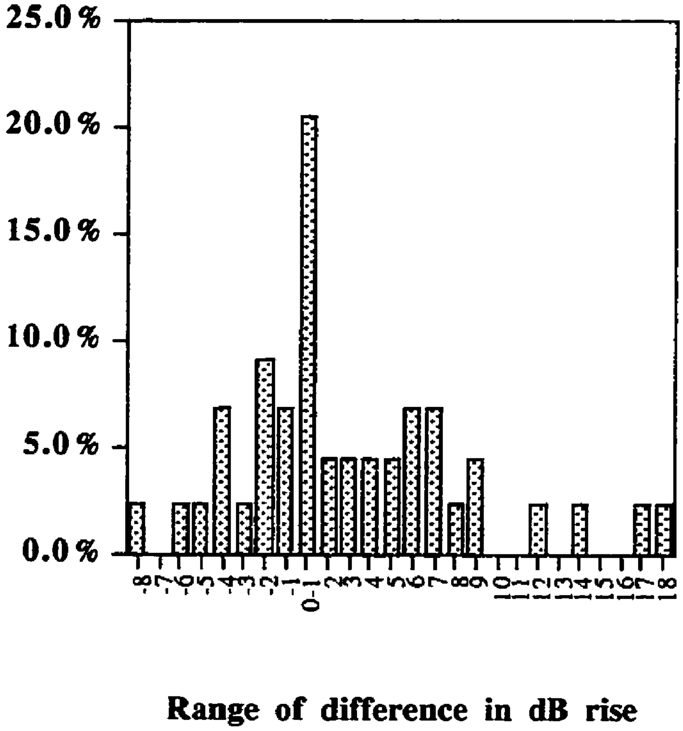

Figure 3.17
The distribution of the differences in dB rise between vowels after pulmonic and ejective velar stops

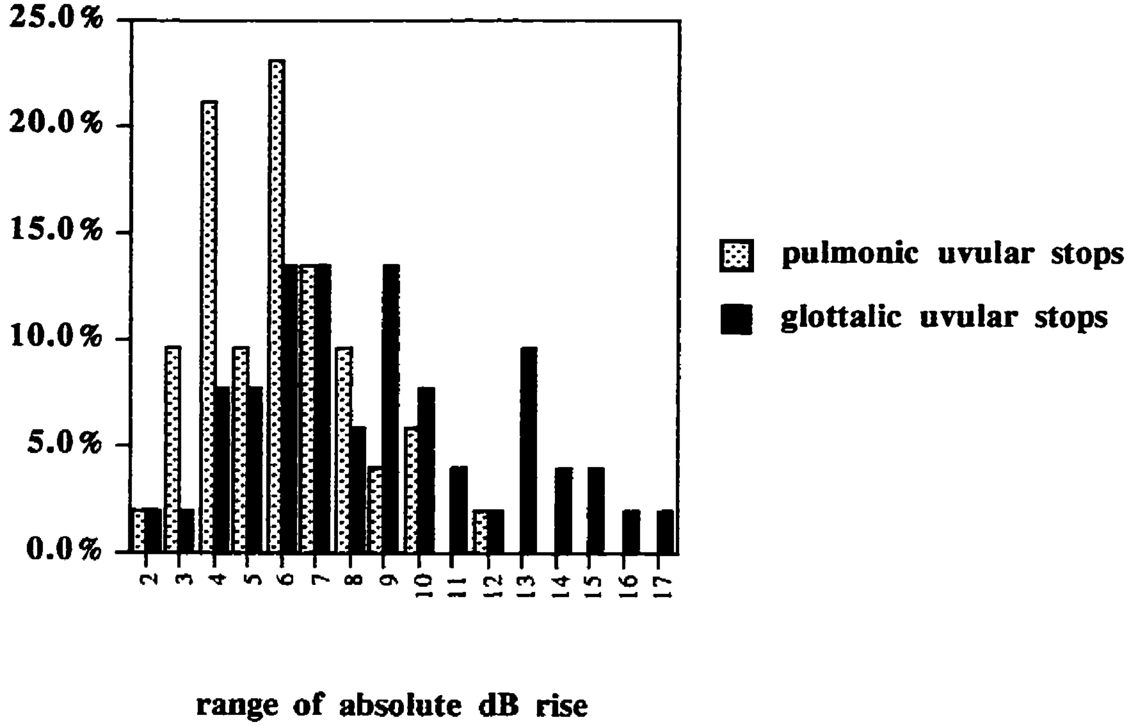

Fig 3.18
The distribution of dB rise of vowels after pulmonic and glottalic uvular stops

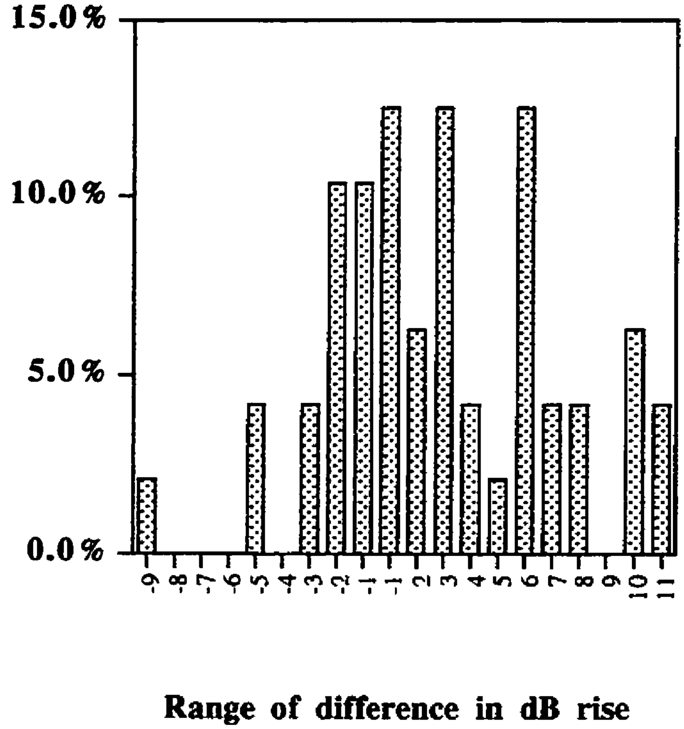

Figure 3.19
The distribution of the differences in dB rise between vowels after pulmonic and implosive uvular stops

Chapter 4

The effect of the pulmonic-glottalic contrast on fundamental frequency

4.1 THE LITERATURE ON FO PERTURBATION

Many studies have drawn an association between the type of stop and the Fo of preceding or following vowels. A difference in Fo is assumed to be a cue to voicing distinctions. House and Fairbanks (1952), Lehiste and Peterson (1961), and others (summarized in Hombert 1978), found that vowels after voiceless stops have a higher Fo than vowels after voiced stops. Haggard, Ambler and Callow (1969) reported that a low rising pitch was the cue for voiced stops in English and French versus a falling pitch after voiceless stops. This became known as the rise-fall dichotomy (Ohde 1984) after Lea's (1973) hypothesis that "a rise in Fo at vowel onset marks a preceding voiced consonant, and a fall in Fo marks an unvoiced consonant" (p. 49). Abramsonand Lisker (1985) note this effect while calling it secondary to VOT as a voicing cue. However, both Silverman (1984) and Ohde (1984) did not replicate these results. They found that all stops are followed by a fall in Fo, although the absolute Fo is higher after voiceless stops.

Fo perturbation due to the voiced/voiceless distinction was thought to lead to subsequent reanalysis by listeners of intrinsic Fo cues of preceding stops in the development of tones in some languages (Maspero 1911, Karlgren 1926, Haudricourt 1954, Beach 1938, Hyman and Schuh 1974, cited in Hombert, Ohala and Ewen, 1977).

There is a less systematic report on the effect of glottalic stops on Fo, apart from the early literature on tonogenesis. However, a survey of the literature on glottalic stops gives some idea of the variation.

4.1.1 Previous studies on the effect of ejectives and implosives on Fo

Nez Perce

Aoki (1970) reported "a lowering of frequency" during glottalized continuants in Nez Perce based on two speakers (p. 68). He did not record the Fo after glottalized stops in Nez Perce.

Hausa

Meyers (1972) found a variety of pitch effects in Hausa. Ejectives had irregular Fo effects and a "wide scatter of pitch at transition" (p. 49). However, she found all vowels after "the glottalized approximant", [ʔ], had a rising contour (p. 57).

Although Lindau (1982) reports some aperiodicity, or jitter, in vowels after ejective /k'/ in Hausa, she did not note any other Fo effect, other than that vowels after pulmonic stops had a more periodic onset.

Lindsey et al. (1992) found more Fo effect at stop onset than stop offset in Hausa but that glottalic consonants are "generally associated with a decrease in... (Fo)" with the greatest effect for laryngealized consonants, then ejectives, and then voiced consonants. (p. 523).

Chipewyan

Hogan (1976) did not find a systematic effect of Fo with glottalic stops in Chipewyan, though he found 30% of vowels after ejectives began with a "very low fundamental frequency ... (resembling) vocal creak' (p. 278).

K'ekchi, Quiche

Pinkerton (1978) reports that Fo is lower after glottalized consonants in K'ekchi than after corresponding non-glottalized stops. She found an exception to this only when the vowel in question preceded uvular stops, in which case the pitch remained the same.

Gitksan

In Ingram and Rigsby's (1987) study, Fo rose in the speech of one speaker from a creaky range to modal voice within "the first five or six glottal cycles", and fell in the speech of the other "to normal values within the first three cycles" (p. 136). They argued, as with their data on VOT (see Chapter 2, Section 2.1.1) for a tense/lax distinction, while also attributing speaker differences between their two talkers to "language shift" (p. 137).

Montana Salish

Flemming and Ladefoged's (1994) record "a marked lowering" of Fo during glottalized continuants and pharyngeals in Montana Salish. They note higher Fo with high vowels, but do not distinguish for consonant type.

Tigrinya and Quiche

As discussed above, Kingston (1985) also found a different perturbation effect in vowels after ejectives in Tigrinya versus Quiche.[50] Fo of vowels

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50 This was the study used by Ingram and Rigsby to propose a typological fortes/lenis distinction.

following ejectives was elevated in Tigrinya, whereas the Fo of vowels following ejective was depressed in Quiche (see p. 166 for his summary chart).

Ingush

Warner finds that Fo after ejectives in Ingush is "audibly higher" with the pitch raising effect continuing for several periods into the vowel, i.e. 221.4 Hz compared to 195.2 Hz in corresponding voiceless stops at five to seven periods into the vowel (Warner 1996:1526). She found that pitch rises toward the middle of the vowel after pulmonic voiceless stops in Ingush, and falls after ejectives, based on the speech of one talker.

Lendu

Tones are raised on vowels after voiced implosives in Lendu (Demolin 1995) corresponding to expectations from the literature on tonogenesis. Demolin claims that Fo is very high during the prevoicing phase of voiceless implosives (sic) in Lendu and that this high Fo may extend into the vowel, though she notes an opposite effect, of lowered frequency, after the voiceless palatal implosive and voiced implosives.

Sindhi

Painter's (1978) study reports that implosives raise pitch up to 150 ms after release in Sindhi. He attributes this to the lower supraglottal airpressure during implosives, with attendant increase in pressure drop, although this would hardly explain the same effect with ejectives.

Nihalani (1986) found a steep fall in the Fo curve during implosives in Sindhi but did not record the post consonantal effect.

Siswati

Wright and Shryock (1993) looked systematically at the effect of implosives on pitch in siSwati for the first 90 ms of the following vowels, taking an Fo measurement every 10 ms. This gave a very reliable picture of the pattern of Fo declination in siSwati after all types of stops. They found that Fo consistently starts at a lower level after bilabial implosives than after voiceless stops in siSwati, contrary to the literature on tonogenesis already cited. This effect was reliable in a high and low tone environment.

They attributed this Fo lowering to a possible effect from larynx lowering, which overrides factors such as stiff folds or increased pressure drop across the vocal folds specifically in the production of implosives in this language. However, their larynx lowering explanation is arguable, given data from Kingston (1985), (see below).

4.1.2 A discussion of the literature

Consonant related Fo perturbation has been explained by two hypotheses: i. the aerodynamic hypothesis and ii. the vocal cord tension hypothesis.[51]

i.Ladefoged (1967) argued that the production of voiced stops involves a gradually increasing oral air pressure and concommitant reduction in trans-glottal airflow during the stop phase. This reduced pressure drop reduces Fo after a voiced stop. An opposite effect from increased transglottal airflow raises Fo after voiceless stops.

ii. Halle and Stevens (1971) argued that it is the increased vocal cord tension involved in the production of voiceless stops that causes the rise in Fo and, conversely, slack cords that result in lowered Fo. Hirose et al. (1972) and Hirose, Lisker and Abramson (1973), in their electromyographic study of /p/, /b/ and /ɓ/, however, found no difference in cricothyroid activity in any of these stops. (The cricothyroid is usually associated with Fo regulation).

Ohala, in various works (see Hombert et al. 1979 for a survey) developed the vertical tension hypothesis, which associated voiceless stops with a raised larynx and voiced stops with a lowered larynx. Ohde's (1984) account of the similar Fo patterning of voiceless aspirated and voiceless unaspirated stops also argued for a vocal cord tension hypothesis.

A considerable literature supports this. Larynx raising was generally correlated with higher Fo by Lindqvist (1969), Lehiste (1970), Ohala (1972), Painter (1978) and Laver (1980). Larynx lowering was associated with lowered Fo by through activity in the strap muscles, specifically the sternohyoid (Ohala 1972, cited in Ohde 1984, Hirose et al. 1972) .[52] Honda (1983) associated upward larynx displacement with a pull on the position of the hyoid bone through

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51 See Hombert et al. (1979) and Ohde (1984) for a more extended explanation of these two hypotheses.

52 However, sternohyoid activity is not considered to "cause" the lowering, as it is seen subsequent to Fo change (Sawashima & Hirose 1973, Honda 1983) .

the genioglossus and geniohyoid muscles (Honda 1983).[53] He points out that the evolutionary change in human anatomy has resulted in a greater separation of the tongue and the larynx than the closer approximation in animals. However, some vestigial interconnections still link larynx height with tongue movements.

If a raised larynx has an effect of raising pitch it would be assumed that pitch after ejectives (which involve larynx raising) would be significantly higher while if a lowered larynx lowers pitch we should expect the pitch after implosives to be lower. Interestingly, evidence from studies on glottalic stops suggested otherwise.

In tonogenesis, Greenberg (1970) noted that implosives patterned with voiceless stops in their effect on tonogenesis as Kingston (1985) found for their effect on tone spreading. That is, both ejectives and implosives raise pitch in the following vowel, or, fail to lower pitch.[54] Matisoff (1972) and Mazaudon (1977) both report that in Lolo-Burmese the "glottalized" series led to the development of a higher tone (cited in Hombert et al. 1979). This effect was also seen in development of rising tone in Vietnamese, Chinese, and high tone in Lolo-Burmese after loss of previous glottal stop (Hombert et al. 1979).

The assumption of a correlation between larynx height and Fo also met a serious challenge from Kingston (1985). Kingston showed in his study of three Tigrinya speakers that in the speech of one subject[55], Fo and larynx moved in opposite directions: that is, the speaker had low Fo with raised larynx and a high Fo with lowered larynx. He recycled the argument that if pitch after implosives is in fact higher, although the larynx is depressed, then larynx height cannot correspond to Fo. The corollary is his observation that pitch after ejectives in Quiche is lower, although the larynx is clearly raised, as seen from Pinkerton's (1980) data on increased oral air pressure during

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53 However, cf Zawadzki and Gilbert for evidence of the role of the jaw position in regulating Fo, rather than the hyoid bone (1989)

54 Painter explained the rise in pitch after lowered larynx in implosives as a result of the increase in airflow generated by the decrease in supraglottal pressure, in distinction to a lowered larynx in singing, where the glottis does not close before lowering, and thus causes no decrease in supraglottal pressure (1978).

55 The vowel environments are only recorded orthographically as /a/ .

ejectives. He argues that Fo differences must result from shifts in vocal fold tension, that "vocal fold stiffness is an independently manipulated parameter (of larynx movement)" (p. 175).

Meyers (1972) pointed out, in an account of tone in Hausa, that the long delay between the release of the oral closure in ejectives and the onset of voicing could have a very different effect of the pitch of the following vowel. Voicing may not start until the larynx has resumed its previous position. For instance, Hogan (1972) found little evidence of any formant transitions in vowels after glottalic stops in Chipewyan. Only 24% of vowels had any trace of F2 or F3 transition. He assumed the vocal tract had sufficient time (average VOT was 130.3 ms) to "assume the configuration for the following vowel" (p. 277). This assumption could extend to the larynx position also.

Other studies concentrated on the effect of larynx raising and lowering with differences in the frequencies of the formants. In their study on a trained and untrained singer, as well as from synthesized stimuli, Sundberg and Askenfelt (1988) saw the effect of raised larynx mostly in the raised formant frequencies.[56] The effects of Fo are obviously controlled differently in sung rather than spoken sounds, but previous research has largely emphasized the "effects on the formant frequencies ... from shortening/lengthening of the pharynx cavity" rather than Fo effects (Sundberg 1976, p 39).

4.1.3 Summary

This brief summary of previous studies indicates that glottalic consonants vary in their effect on Fo of following vowels among languages. The evidence does not seem to support so far either the assumption that the production of implosives with its lowered larynx will automatically lower pitch or the predictions from tonogenesis that would associate them with raised pitch. Different coordinations of glottal and supraglottal gestures, as well as different glottal configurations used in the production of implosives and ejectives (i.e., tightly closed glottis, or looser approximation of cords without longitudinal tension), may result in quite different Fo effects. Kingston (1985) has suggested that Fo contours may not be "generalizable" across languages (p. 234). At any rate the only generalization that holds so far

[56] They also noted an effect on the amplitude of the fundamental with a lesser effect on vibrato amplitude.

seems to be Lindau's (1982) conclusion that "languages ... differ in the way they maintain distinction between (glottalic) stops and corresponding ... plosives" (p. 74).

The data from Mam allows a detailed assessment of the effect of glottalic stops on the following vowel, comparing the speech of men and women, and individual speakers. The following sections will summarize the results on the Fo effects of glottalic stops on following vowels in Mam.

4.2 RESULTS FROM MAM

The following analysis shows a difference in the Fo patterns in the speech of men and women talkers when taken over a trajectory of three measures, apart from the expected natural difference in ranges. Generally, speakers showed a significantly lower Fo at the first glottal pulse after glottalic stops than after pulmonic stops. However, the measures at 5th glottal pulse and 100 ms (or 50 ms for short vowels) differed for male and female speakers.

However, despite these differences in absolute Fo between pulmonic and glottalic stops, or even whether Fo is higher or lower than after corresponding pulmonic stops, the data indicates speakers tend to exhibit a characteristic rising contour after glottalic stops and a flat or falling contour after pulmonic stops. This may provide a more reliable indicator of glottalic stops in Mam across male and female speakers than absolute Fo differences.

4.2.1 Procedure

Mam has a variety of vocal "qualities" which are used phonemically, (see Chapter 1). The most extensively used contrast to a modal voice quality is vocal creak. Fujimura (1988) pointed out some inherent problems in analyzing creaky voice, which has subharmonics of considerable amplitude. A pitch extraction program cannot distinguish the fundamental from the subharmonic one half its frequency, in fact "missing the entire point... by draw(ing) a smooth contour connecting the two" (p. 377). He suggested the possibility of using a "frequency split factor" (p. 377) which would compute the ratio of the amplitude of the subharmonic to the fundamental, or else a very narrow band spectrogram. Ultimately, I found the most reliable and available method was simply to compute the Fo from the expanded wave-form, measuring from peak to peak of the glottal pulses, that is the period of the glottal pulse, using the feature of the reciprocal of the duration, which is provided by the Signalyze 3.12 program.

The wave-form was measured at three places to estimate the extent of the effect of the consonants on the following vowel: at the first glottal pulse, at the fifth glottal pulse, and a third measurement at 100 ms into the vowel or, in short vowels, at 50 ms, or vowel peak. The fifth glottal pulse measure indicates whether the Fo trajectory is initially rising or falling at the voice onset phase. The third measurement at 100 ms for long vowels or 50 ms for short vowels is, obviously, variable in time, and is largely an attempt to establish the Fo of the basic vowel quality, or target Fo of the word.

Figure 4.1 is a sample wave-form of the token /k'aa/ Speaker M7. It shows the point of the first glottal pulse after the ejective /k'/, readily apparent here. Figure 4.2 is a wave-form of the bilabial implosive /b'ii/ *name* Speaker F2. It indicates the somewhat arbitrary business of determining the first glottal pulse (of vowel onset) if voicing during the stop is not to be included. I used the point where more than two vowel formants were visible from the spectogram wherever the wave-form defied division. The values for what is the moment of vowel onset, especially for implosives, therefore, must be judged as approximate in this data. The direction of change is probably more reliable than any absolute Fo value based on an arbitrary choice of vowel onset. Given that, the very large differences in Fo between some contrasts, (eg. differences with a significance level of $p=.0001$), mitigate against some degree of error.

4.2.2 Measures

I analyzed the data according to three types of measures, summarized for female or male speakers. They are first organized by place of articulation. Finally results are also given for the pooled data of all pulmonic and glottalic stops for female and male speakers.

These measures are:

i. The means and standard deviations (in parentheses) of Fo after pulmonic and glottalic stops, at three different times: first glottal pulse, fifth glottal pulse and at 100ms for long vowels, or 50ms for short vowel, (see Section 4.2.1 for elaboration).

ii. T- tests. The t-tests provide a measure of the statistical significance of the difference between the two sets of Fo after pulmonic and glottalic stops. The t-tests also provide the mean differences between values after pulmonic and glottalic stops. A positive value indicates the values are higher after pulmonic stops. A minus value indicates the values are higher after glottalic stops. All results are reported as significant at an alpha level of 0.01.[57]

iii. The means and standard deviations (in parentheses) of the difference in Fo between the first glottal pulse and the fifth glottal pulse. A positive value indicates a drop in Fo. A minus value indicates a rise in Fo.

iv. Line charts. The line charts in Figures 4.3 to 4.8 represent visually the relative difference between Fo after pulmonic and glottalic stops at the three different times. They show the shrinking difference in Fo over time and the extent of difference by female and male speakers.

The results of i and iii. are summarized in Tables 4.1 to 4.10.

The following results answer several questions:

What is the effect of both pulmonic and glottalic stops on the Fo of the following vowel? This is summarized in the subsections numbered i.

How do pulmonic and glottalic stops differ in this effect? This is summarized in the subsections numbered ii.

How far does any pitch perturbation extend into the vowel? This is analyzed with three different measures from voice onset to vowel peak.

What is the Fo trajectory after each type? The difference between voice onset and the fifth glottal pulse gives the direction of Fo change, or its trajectory, summarized in subsection iii.

What are the variations of Fo after pulmonic and glottalic stops by gender, by individual speaker, or by vowel environment? These results are summarized under their respective headings.

4.2.3 Results

4.2.3.1 Female speakers

4.2.3.1.1 Results by place of articulation

bilabials

The Fo after bilabial implosives is lower than after bilabial pulmonic

[57] I used the most conservative alpha level for this data to make any claims of data being significant. I also report the actual probability level.

stops. The difference is statistically significant at first and fifth glottal pulse. This tendency persists to vowel peak. The Fo level remains remarkably level after pulmonic bilabial stops whereas the Fo rises steeply after bilabial implosives.

Table 4.1 summarizes means and standard deviations of Fo after pulmonic and implosive bilabial stops for female speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel) with the change in Fo from first to fifth glottal pulse, (g.p.= glottal pulse).

Table 4.1
Means and SD.s of Fo after pulmonic and implosive bilabial stops at three times, for female speakers, in Hz.

Type of stop	$\bar{x}$	SD
pulmonic bilabial: first g.p.	257	28.4
bilabial implosive: first g.p.	192.3	53.2
pulmonic bilabial: fifth g.p.	257.2	28.2
bilabial implosive: fifth g.p.	234.8	31.3
pulmonic bilabial: 100 ms	262.4	31.6
bilabial implosive: 100 ms	251.9	29.4
pulmonic bilabial: 1st g.p. - 5th g.p.	.1	3.3
bilabial implosive: 1st g.p. - 5th g.p.	-42.5	43.3

i. The mean Fo after pulmonic bilabial stops at first glottal pulse is 257 Hz (28.4). The mean Fo of vowels after glottalic bilabials at first glottal pulse is 192.3 Hz (53.2).

The mean Fo after pulmonic bilabial stops at fifth glottal pulse is 257.2 Hz (31.3). The mean Fo of vowels after glottalic bilabials is 234.8 Hz (31.3).

The mean Fo after pulmonic bilabial stops at 100 ms is 262.4, (31.6). The mean Fo of vowels after glottalic bilabials at 100 ms is 251.9, (29.4).

ii. A t-test shows a statistically significant difference in the Fo between vowels after pulmonic and glottalic bilabial stops at first glottal pulse and at fifth glottal pulse. The difference is not significant at 100 ms. At first glottal pulse the mean difference in Fo is 64.9 Hz, ($t(34)=7.3$, $p=.0001$). At fifth glottal pulse the mean difference in Fo is 22.4Hz (t(34)=3.9, p=.0005). At 100ms the difference is 10.5 Hz , (t(34)=1, p=.0438).

iii. The mean difference in Fo from first glottal pulse to fifth glottal pulse after pulmonic bilabial stops is .1 Hz, (3.3). The mean difference in Fo from first glottal pulse to fifth glottal pulse after bilabial implosives is -42.5 Hz (43.3).

dentals

The Fo is lower at first and fifth glottal pulse after glottalic dental stops than after pulmonic dental stops. The Fo is higher by vowel peak after glottalic stops than after pulmonic stops. These differences are not significant, however, for dentals. The data shows that the Fo level remains remarkably level after pulmonic dental stops whereas it rises steeply after dental glottalic stops.

Table 4.2 summarizes means and standard deviations of Fo after pulmonic and glottalic dental stops for female speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), with the change in Fo from first to fifth glottal pulse, (g.p.= glottal pulse).

Table 4.2
Means and SD.s of Fo after pulmonic and glottalic dental stops at three times, female speakers, in Hz.

Type of stop	$\bar{x}$	SD
pulmonic dental: first g.p.	264.3	33.8
glottalic dental: first g.p.	199.4	100.9
pulmonic dental: fifth g.p	257.7	31.9
glottalic dental: fifth g.p.	237.5	55.4
pulmonic dental: 100 ms	253.7	28.3
glottalic dental: 100 ms	275.6	38.5
pulmonic dental: 1st g.p.- 5th g.p.	6.6	1.9
glottalic dental: 1st g.p.- 5th g.p.	-39	58.2

i. The mean Fo of vowels after pulmonic dental stops at the first glottal pulse is 264.3 (33.8). The mean Fo of vowels after glottalic dental stops is 199.4 (100.9).

The mean Fo of vowels after pulmonic dental stops at the fifth glottal pulse is 257.7 (31.9). The mean Fo of vowels after glottalic dental stops at the fifth glottal pulse is 237.5 (55.4).

The mean Fo of vowels after pulmonic dental stops at the 100 ms is 253.7 (28.3). The mean Fo after glottalic stops at 100 ms is 275.6 (38.5).

ii. A t-test does not give a statistically significant difference in the Fo between vowels after pulmonic and glottalic dental stops. At first glottal pulse the mean difference in Fo after pulmonic and glottalic dentals is 68.9Hz ($t(11)=2.7$, $p=.021$); that is, at voice onset the mean Fo after pulmonic stops is 68.9 Hz higher than average Fo after the glottalic stop. At fifth glottal pulse the mean difference in Fo is 23.4Hz ($t(11)=1.9, p=.0845$). By 100ms the difference is -19.1 Hz ($t(11)=-1.9, p=.0822$), that is, the vowel is 19Hz higher after the glottalic stops than the pulmonic dental stops. Although these differences approach the significant differences of the bilabial contrast, the much smaller sample size (of only eleven dental contrasts) may account for the lack of significance here.

iii. The mean difference in Fo from first glottal pulse to fifth glottal pulse after pulmonic dental stops is 6.6 Hz, (1.9). The mean difference in Fo from first glottal pulse to fifth glottal pulse after glottalic dental stops is -39 Hz (58.2).

velars

The Fo of vowels after velar ejectives is significantly lower than after pulmonic velar stops at voice onset. This difference shrinks rapidly by fifth glottal pulse. The Fo tends to remain level after pulmonic stops whereas there is a considerable rise in Fo after the ejectives.

Table 4.3 summarizes means and standard deviations of Fo after pulmonic and velar ejective stops for female speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), and the change in Fo from first to fifth glottal pulse,(g.p.=glottal pulse).

Table 4.3

means and SD.s of Fo after pulmonic and ejective velar stops at three times, for female speakers, in Hz.

Type of stop	$\bar{x}$	SD
pulmonic velar: first g.p.	276.9	37.7
velar ejective: first g.p.	215.7	56.7
pulmonic velar: fifth g.p.	272.8	44.8
velar ejective: fifth g.p.	252.5	49.2
pulmonic velar: 100 ms	262.7	53.9
velar ejective:100 ms	256.4	47.8
pulmonic velar: 1st g.p.- 5th g.p.	4.1	19.4
velar ejective: 1st g.p.- 5th g.p.	-46.1	85.7

i. The mean Fo of vowels after pulmonic velar stops is 276.9 Hz (37.7). The mean Fo of vowels after velar ejectives at the first glottal pulse is 215.7 Hz (56.7).

The mean Fo of vowels after pulmonic velar stops at the fifth glottal pulse is 272.8 Hz (44.8). The mean Fo of vowels after velar ejectives at the fifth glottal pulse is 252.5 Hz (49.2).

The mean Fo of vowels after pulmonic velar stops at 100 ms is 262.7 Hz (53.9). The mean Fo of vowels after velar ejectives at 100 ms is 256.4 (47.8).

ii. A t-test shows a statistically significant difference in the Fo between vowels after pulmonic and velar ejectives at the first glottal pulse. The mean difference is 57.3Hz ($t(21)=6.3$, $p=.0001$); that is, the average Fo after pulmonic velar stop is 57.3 Hz higher than after glottalic stop. The difference is not statistically significant at fifth glottal pulse, where the mean difference is 20.3Hz ($t(22)=2.5, p=.0206$), or at 100 ms where the mean difference is 6.3Hz($t(22)=1, p=.3496$).

iii. The mean difference in Fo from the first glottal pulse to the fifth glottal pulse after pulmonic velar stops is 4.1 Hz (19.4). The mean difference in Fo from the first glottal pulse to the fifth glottal pulse after velar ejectives is

-46.1 (85.7).

uvulars

The Fo of vowels after uvular implosives is lower than after pulmonic uvular stops at voice onset and by the fifth glottal pulse.The Fo difference shrinks, or the vowel returns to normal Fo target value by 100 ms. The results indicate that the Fo level remains remarkably level after pulmonic uvular stops whereas the Fo rises steeply after uvular implosives.

Table 4.4 summarizes means and standard deviations of Fo after pulmonic and uvular implosive stops for female speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), with change in Fo from first glottal pulse to fifth glottal pulse, (g.p.=glottal pulse).

Table 4.4
means and SD.s of Fo after pulmonic and implosive uvular stops at three times, for female speakers, in Hz.

Type of stop	$\bar{X}$	SD
pulmonic uvular: first g.p.	271.3	25.9
uvular implosive: first g.p.	214.8	76.1
pulmonic uvular fifth g.p.	269.4	22.8
uvular implosive: fifth g.p.	250.4	50.8
pulmonic uvular: 100 ms	272.1	38.5
uvular implosive: 100ms	260.7	40
pulmonic uvular: 1st g.p.- 5th g.p.	2.7	14.1
uvular implosive: 1st g.p.-5th g.p.	-38	52.7

i. The mean Fo of vowels after pulmonic uvular stops at first glottal pulse is 271.3 Hz (25.9). The mean Fo of vowels after uular implosives at first glottal pulse is 214.8 Hz (76.1).

The mean Fo of vowels after pulmonic uvular stops at fifth glottal pulse is 269.4 Hz (22.8). The mean Fo after uvular implosives at fifth glottal pulse is 250.4 Hz (50.8).

The mean Fo of vowels after pulmonic uvular stops at 100 ms is 272.1

Hz (38.5). The mean Fo after uvular implosives at 100 ms is 260.7 Hz (40).

ii. A t-test shows a statistically significant difference in the Fo between vowels after pulmonic and implosive uvular stops at first glottal pulse and at fifth glottal pulse. The difference is not significant at 100 ms. At first glottal pulse the mean difference in Fo is 61.9Hz ($t(20)=5.2$, $p=.0001$); that is, at voice onset the mean Fo after pulmonic uvular stops is 60.7 Hz higher than after uvular implosives. At fifth glottal pulse the difference is 21.7 Hz , ($t(20)=3.3, p=.0035$). At 100 ms the difference is 13.2 Hz, ($t(20)=1.9, p=.0713$).

iii. The mean difference in Fo from first glottal pulse to fifth glottal pulse after pulmonic uvular stops is 2.7 (14.1). The mean difference in Fo from first glottal pulse to fifth glottal pulse after uvular implosives is -38 (57.2).

4.2.3.1.2 Pooled results for female speakers

This section summarizes the Fo tendencies after pulmonic and glottalic stops at all places of articulation. Summarizing the results from the pooled data at all places of articulation indicates a global tendency for each type of stop which could be an available cue for linguistic distinction. These are further discussed in Sections 4.2.4.1 (Differences in the speech of men and women) and 4.2.4.2 (Similarities in the speech of men and women).

The Fo of vowels after all glottalic stops from the pooled data for women speakers is significantly lower at voice onset and by the fifth glottal pulse. The Fo after glottalic stops approaches that of vowels after pulmonic stops by 100 ms. The difference shrinks, therefore, from vowel onset to the vowel target where the vowel after glottalic stops has returned to normal Fo target. Over the pooled data the Fo trajectory after pulmonic stops remains almost level, whereas it rises after glottalic stops.

Table 4.5 summarizes the results for the pooled data from all places of articulation of Fo after all pulmonic and glottalic stops for women speakers with means, standard deviations and the range in values of Fo.

Table 4.5
means, SD.s and range in values of Fo after all pulmonic and glottalic stops for female speakers, at three times, in Hz

Type of stop	$\bar{x}$	SD	Range
pulmonic stops: first g.p.	276.9	37.7	209.4 to 361.5
glottalic stops: first g.p.	215.7	56.7	49.8 to 380
pulmonic stops: fifth g.p.	263.9	32.9	214 to 393.8
glottalic stops: fifth g.p.	243.5	45	72.8 to 373
pulmonic stops: 100 ms	262.7	53.9	190.1 to 408
glottalic stops: 100 ms	256.4	47.8	175 to 400.9
pulmonic stops: 1st g.p.- 5th g.p.	2.7	14.1	-32 to 69.9
glottalic stops: 1st g.p.-5th g.p.	-38	57.2	-380 to 80

i. The mean Fo for female speakers of vowels after pulmonic stops for the pooled data at first glottal pulse is 276.9 Hz (37.7) with a range from 209.4 to 361.5. The mean Fo for female speakers of vowels after glottalic stops for the pooled data at first glottal pulse is 215.7 Hz (56.7) with a range from 49.8 to 380 Hz.

The mean Fo for female speakers of vowels after pulmonic stops for the pooled data at fifth glottal pulse is 263.9 Hz (32.9) with a range from 214 to 393.8. The mean Fo for female speakers of vowels after glottalic stops for the pooled data at fifth glottal pulse is 243.5 Hz (45) with a range from 72.8 to 373 Hz.

The mean Fo for female speakers of vowels after pulmonic stops for the pooled data at 100 ms is 262.7 Hz (53.9) with a range from 190.1 to 408. The mean Fo for female speakers of vowels after glottalic stops for the pooled data at 100 ms is 256.4 Hz (47.8) with a range from 175 to 400.9 Hz.

ii. T-tests of the pooled data for women speakers give a statistically significant difference between all pulmonic and all glottalic stops at first and fifth glottal pulse. The difference is not significant at 100 ms. Glottalic stops are 62.9 Hz lower than pulmonic stops at first glottal pulse ($t(89)=10.6$, p=.0001), and 22.1 Hz lower at fifth glottal pulse (t(90)= 5.9, p=.0001) for women speakers in this data. Vowels after glottlic stops are 6.1 Hz lower at 100 ms but this difference is not significant (t(90)=1.8, p=.0795).

i.i.i. Female speakers have a mean fall in Fo from the first glottal pulse to the fifth glottal pulse after all pulmonic stops of just 2.7Hz (SD 14.1). Female speakers have a mean rise in Fo from the first glottal pulse to the fifth glottal pulse after all glottalic stops of 38 Hz (SD 57.2).

4.2.3.2 Male speakers

4.2.3.2.1 Results by place of articulation

Bilabials

There is no significant difference in Fo after pulmonic and glottalic bilabials for male speakers in this data at any of the three times measured. There is only a slight tendency for the Fo to be lower after glottalic stops at voice onset and to rise above corresponding values after pulmonic stops at fifth glottal pulse and 100 ms. There is a tendency for Fo to rise after implosives and to fall after pulmonic stops.

Tables 4.6 summarizes means and standard deviations of Fo after pulmonic and implosive bilabial stops for male speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), with the change in Fo from first glottal pulse to fifth glottal pulse, (g.p.= glottal pulse)

Table 4.6
Means and SD.s of Fo after pulmonic and implosive bilabial stops at three times for male speakers, in Hz

Type of stop	$\bar{x}$	SD
pulmonic bilabial: first g.p.	170.1	27.8
bilabial implosive: first g.p.	164.1	39.9
pulmonic bilabial: fifth g.p.	169.2	28.1
bilabial implosive: fifth g.p.	171.5	33.7
pulmonic bilabial: 100 ms	164.5	28.9
bilabial implosive: 100 ms	170	26.1
pulmonic bilabial: 1st g.p. -5th g.p.	.9	5.4
bilabial implosive: 1st g.p.- 5th g.p.	-7.3	13.5

i. The mean Fo for male speakers after pulmonic bilabial stops at the first glottal pulse is 170.1 Hz (27.8). The mean Fo after bilabial implosive stops at the first glottal pulse is 164.1 (39.9).

The mean Fo after pulmonic stops at fifth glottal pulse is 169.2 (28.1). The mean Fo after bilabial implosives at fifth glottal pulse is 171.5 (33.7).

The mean Fo after pulmonic stops at 100 ms is 164.5 (28.9). The mean Fo after bilabial implosive stops at 100 ms is 170 Hz (26.1).

ii. A t-test gives no significant difference in Fo between vowels after pulmonic and glottalic stops for male speakers in this data. At first glottal pulse the difference is 5.4 Hz ($t(33)=1$, $p=.3183$. At fifth glottal pulse the difference is -2.9 Hz ($t(33)=-.6$, $p=.5552$). At 100 ms the difference is -6.2Hz ($t(33)=-1.5$, $p=.1437$).

iii. The mean difference in Fo from first glottal pulse to fifth glottal pulse after pulmonic stops is .9 Hz (5.4). The mean difference in Fo between first glottal pulse and fifth glottal pulse after implosives is -7.3 Hz (13.5).

Dentals

The Fo of vowels after glottalic dental stops is only slightly lower than after pulmonic dental stops at voice onset for male speakers. By vowel peak the difference is equivalent in the other direction, that is, Fo is as much higher after glottalic stops as it was lower at first glottal pulse. The results indicate a pitch drop after pulmonic dental stops and a slight pitch rise after glottalic dental stops.

Table 4.7 summarizes means and standard deviations of Fo after pulmonic and dental glottalic stops for male speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), and change in Fo from first glottal pulse to fifth glottal pulse, (g.p.= glottal pulse).

Table 4.7
Means and SD.s of Fo after pulmonic and dental glottalic stops at three times for male speakers, in Hz.

Type of stop	$\bar{x}$	SD
pulmonic dental: first g.p.	183.2	37.8
glottalic dental: first g.p.	179.4	71.4
pulmonic dental: fifth g.p.	175.7	32.8
glottalic dental: fifth g.p.	182.8	55.4
pulmonic dental: 100 ms	173.5	30.8
glottalic dental: 100 ms	187.8	51
pulmonic dental: 1st g,p,-5th g.p.	6.8	12.2
glottalic dental: 1st g,p,-5th g.p.	-3.5	28.8

i. The mean Fo for male speakers after pulmonic dental stops at first glottal pulse is 183.2 Hz (37.8). The mean Fo after glottalic dental stops at first glottal pulse is 179.4 Hz (71.4).

The mean Fo after pulmonic dental stops at fifth glottal pulse is 175.7 Hz (32.8). The mean Fo after glottalic dental stops at fifth glottal pulse is 182.8 Hz (55.4).

The mean Fo after pulmonic dental stops at 100 ms is 173.5 Hz (30.8). The mean Fo after glottalic dental stops at 100 ms is 187.8 Hz (51).

ii. A t-test does not give a statistically significant difference in Fo between vowels after pulmonic and dental glottalic stops, though there is a tendency for the Fo to rise to a higher pitch after glottalic stops than after pulmonic stops by fifth glottal pulse and vowel peak. At first glottal pulse the mean difference in Fo is 4.6Hz,($t(14)=.3$, $p=.7367$. At fifth glottal pulse the difference is -7.1 Hz, ($t(14)=-.7$, $p=.5527$). At 100ms vowels the difference is -15.2Hz , ($t(14)=-2$, $p=.0618$.

iii. The mean difference between first and fifth glottal pulse after pulmonic stops is 6.8 Hz (12.2). The mean difference from first to fifth glottal pulse after glottalic stops is -3.5 Hz (28.8).

Velars

The Fo of vowels after velar ejectives is significantly lower than after pulmonic velar stops only at voice onset for male speakers. The tendency is for vowels after velar ejectives to begin at a lower pitch than after pulmonic stops, and to rise slightly above the pitch of vowels after pulmonic stops by the vowel target.

The results indicate the pitch trajectory falls after pulmonic velar stops and rises after the ejectives.

Table 4.8 summarizes means and standard deviations of Fo after velar pulmonic and ejective stops for male speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel), with the change in Fo from first to fifth glottal pulse, (g.p.= glottal pulse).

Table 4.8
Means and SD.s of Fo after pulmonic and ejective velar stops at 3 times for male speakers, in Hz

Type of stop	$\bar{x}$	SD
pulmonic velar: first g.p.	187.7	38.4
velar ejective: first g.p.	165.5	53.5
pulmonic velar: fifth g.p.	175.6	32.8
velar ejective; fifth g.p.	179.5	48.5
pulmonic velar: 100 ms	165.3	28.6
velar ejective: 100ms	171.6	43.4
pulmonic velar: 1st g.p.- 5th g.p.	12.1	20.1
velar ejective: 1st g.p.- 5th g.p.	-14	15.5

i. The mean Fo for male speakers after pulmonic velar stops at first glottal pulse is 187.7 Hz (38.4). The mean Fo after velar ejective at first glottal pulse is 165.5 Hz (53.5).

The mean Fo after pulmonic velar at fifth glottal pulse is 175.6 Hz (32.8). The mean Fo after velar ejectives at fifth glottal pulse is 179.5 Hz (48.5).

The mean Fo after pulmonic velar stops at 100 ms is 165.3 Hz (28.6).

The mean Fo after velar ejectives at 100 ms is 171.6 (43.4).

ii. A t-test gives a statistically significant difference in Fo between pulmonic and ejective velar stops at the first glottal pulse only. After that, the difference is for a higher pitch after glottalic stops, but not significantly. At the first glottal pulse the mean difference in Fo between velar pulmonic and glottalic stops is 20.8Hz (t(21)=3, p=.0062). At the fifth glottal pulse the mean difference in Fo is -4.8Hz,(t(21)=-.7, p=.4996, or an almost random difference. At 100 ms the mean difference in Fo is -7.8Hz,(t(21)=-1.3, p=.2228.

iii. The mean difference in Fo from first to fifth glottal pulse after pulmonic velar stops is 12.1 Hz (20.1). The mean difference after velar ejectives is -14 Hz (15.5). This indicates a falling pitch after pulmonic stops and a rising pitch after glottalic velar stops.

Uvulars

The Fo of vowels after uvular implosives is lower than after pulmonic uvular stops at vowel onset for male speakers. The Fo rises rapidly to a value just above the Fo after pulmonic stops by the fifth glottal pulse and vowel peak. There is a slight fall in Fo after the pulmonic stops and a much larger rise in Fo after the uvular implosives.

Table 4.9 summarizes means and standard deviations of Fo after uvular pulmonic and implosive stops for male speakers at three times: first glottal pulse, fifth glottal pulse and at 100ms (or 50ms for short vowel),and the change in fo from first to fifth glottal pulse, (g.p.= glottal pulse).

Table 4.9

means and SD.s of Fo after pulmonic and implosive uvular stops at three times for male speakers, in Hz.

Type of stop	$\bar{x}$	SD
pulmonic uvular: first g.p.	183.3	20.9
uvular implosive: first g.p.	149.1	31.7
pulmonic uvular: fifth g.p.	170.6	25.1
uvular implosive; fifth g.p.	171.4	40.9
pulmonic uvular: 100 ms	169.4	29.4
uvular implosive: 100 ms	172	39.5
pulmonic uvular: 1st g.p.- 5th g.p.	7.8	14.3
uvular implosive:1st g.p.- 5th g.p.	-22.3	34.6

i. The mean Fo of vowels after pulmonic uvular stops at first glottal pulse is 183.3 Hz (20.9). The mean Fo of vowels after uvular implosives at first glottal pulse is 149.1 (31.7).

The mean Fo of vowels after pulmonic uvular stops at fifth glottal pulse is 170.6 (25.1). The mean Fo of vowels after uvular implosives at fifth glottal pulse is 171.4 Hz (40.9).

The mean Fo of vowels after pulmonic uvular stops at 100 ms is 169.4 Hz (29.4). The mean Fo of vowels after uvular implosives at 100 ms is 172 Hz (39.5).

ii. A t-test gives a statistically significant difference in Fo between vowels after pulmonic and implosive uvular stops at the first glottal pulse. The difference is not significant at fifth glottal pulse or 100 ms. At first glottal pulse the mean difference is 32.7Hz, ($t(25)=5.7$, $p=.0001$). At fifth glottal pulse the mean difference is -2Hz, ($t(25)=-.4$, $p=.6694$). At 100 ms the mean difference is -4.4Hz, ($t(25)=-.8$, $p=.4066$). This indicates that the pitch after uvular implosives starts at a lower value than after pulmonic stops but tends to rise above the corresponding values after pulmonic stops by the vowel target.

iii. The mean difference from first glottal pulse to fifth glottal pulse after pulmonic uvular stops is 7.8 Hz. The mean difference between first and fifth glottal pulse after uvular implosives is -22.3 Hz. This indicates a small fall after pulmonic stops and a larger rise after implosives.

4.2.3.2.2 Pooled results for male speakers

The Fo is significantly lower at voice onset after glottalic stops than after pulmonic stops for male speakers based on the pooled data. At fifth glottal pulse the trajectory of the Fo change after glottalic stops for male speakers has approached the pitch of the vowel after the corresponding pulmonic stop; that is, there is no significant difference between vowels after pulmonic or glottalic stops. By 100ms into the vowel the Fo after glottalic stops is higher than after pulmonic stops.

The Fo trajectory has a slight fall after pulmonic stops and a larger rise after glottalic stops.

Table 4.10 summarizes the means, standard deviations and range in values for Fo after all pulmonic and glottalic stops for male speakers at voice onset, fifth glottal pulse and by 100ms into the vowel, or vowel peak, and the difference in Fo from first to fifth glottal pulse. The values for all places of articulation are pooled.

Table 4.10

Means, SD.s and range in values of Fo after all pulmonic and glottalic stops at three times for male speakers, in Hz.

Type of stop	$\bar{x}$	SD	Range
pulmonic: first g.p.	179.8	31.1	127.3 to 294
glottalic: first g.p.	162.8	47.7	85.3 to 319.6
pulmonic: fifth g.p.	172.1	28.9	122.3 to 242
glottalic: fifth g.p.	175.6	42.6	116 to 275.6
pulmonic: 100 ms	167.4	29	113.6 to 239.7
glottalic: 100 ms	173.7	38.3	105.5 to 282.7
C/difference 1st g.p - 5th g.p.	7.8	14.7	-16 to 64.3
C'/difference 1st g.p - 5th g.p.	-12.3	24.5	-121.2 to 28.8

i. The mean Fo of vowels after pulmonic stops for the pooled data at first glottal pulse is 179.8 Hz with a range from 127.3 to 294 Hz. The mean Fo of vowels after glottalic stops for the pooled data at first glottal pulse is 162.8 Hz with a range from 85.3 to 319.6 Hz.

The mean Fo of vowels after pulmonic stops for the pooled data at fifth glottal pulse is 172.1 Hz with a range from 122.3 to 242 Hz. The mean Fo of vowels after glottalic stops for the pooled data at fifth glottal pulse is 175.6Hz with a range from 116 to 275.6 Hz.

The mean Fo of vowels after pulmonic stops for the pooled data at 100 ms is 167.4 Hz with a range from 113.6 to 239.7 Hz. The mean Fo of vowels after glottalic stops for the pooled data at 100 ms is 173.7 Hz with a range from 105.5 to 282.7 Hz.

ii. T-tests of the pooled data for male speakers show a mean difference between all pulmonic and glottalic stops at first glottal pulse of 16.1 Hz ($t(96)=4.4, p=.0001$), at fifth glottal pulse a mean difference of -3.7Hz ($t(96)=-1.2, p=.235$), and at 100ms a mean difference of -7.5 Hz ($t(96)=-2.8, p=.0067$).

iii. The mean difference from first glottal pulse to fifth glottal pulse after pulmonic stops for the pooled data is 7.8 Hz (14.7). The mean difference from first glottal pulse to fifth glottal pulse after glottalic stops for the pooled data is -12.3 (24.5). This indicates a small fall in Fo after pulmonic stops and a larger rise in Fo after glottalic stops.

4.2.4 Discussion

Klatt and Klatt (1988) pointed out that women's and children's speech has been "somewhat neglected.. in the history of speech analysis"(p. 620). They attribute this to two factors: the higher Fo of women's (and children's) voices making formant frequency analysis less easily readable, and the possibility of source/tract interactions, which make women's voices less amenable to an all-pole model. Not surprising, therefore, the literature does not abound in systematic and comparative analyses by gender of speaker, beyond a few large scale studies, mostly on Fo.

In this data the effects of pulmonic and glottalic stops on the Fo of following vowels differed in the speech of men and women. The results presented above and in the line charts to follow indicate that they vary along several parameters: the type of stop (that is, pulmonic or glottalic), the place of articulation, the duration of difference, to some extent the vowel, and in the absolute pitch range used. These differences are summarized below. Men and women, however, do not differ in the Fo trajectory after all pulmonic and glottalic stops. Men (with the exception of one speaker) and women in this data share a characteristic flat or falling Fo after pulmonic stops and a rising Fo after glottalic stops. This is discussed below.

4.2.4.1 Differences in the speech of men and women

Women have a systematically lower Fo after all glottalic stops at all places of articulation at voice onset. Bilabials and dentals are not well distinguished by Fo for men at voice onset, though velar ejectives and uvular implosives are. The difference in Fo betwen pulmonic and glottalic stops is preserved by women by fifth glottal pulse, whereas for male speakers the difference now appears random or to have converged. By 100 ms or vowel peak women have no discernible difference in Fo after either pulmonic or glottalic stops. They have converged or differ either way. By 100 ms or vowel peak, male speakers have a tendency to higher Fo after the glottalic stops, though the values remain close.

The line charts in Figures 4.3 to 4.8 present graphically these differences. The results are organized according to the minimal pairs which contrast pulmonic with glottalic stops: that is, by word. Figure 4.3 indicates a clear distinction in Fo between the lower Fo after glottalic stops and higher value after pulmonic stops for women speakers at first glottal pulse. Figures 4.4 and 4.5 show the shrinking difference by 5th glottal pulse and the overlapping values at 100 ms. Figure 4.6 shows a smaller difference difference between pulmonic and glottalic stops at first glottal pulse for male speakers than for women speakers. Only the velar ejective and uvular implosive are clearly separated by Fo from the pulmonic counterparts. There is almost no difference between pulmonic and glottalic bilabials. By the fifth glottal pulse, the difference between pulmonic and glottalic stops appears random, except for the /to, t'o/ contrast. By 100 ms, the mean Fo after glottalic stops is higher than after pulmonic stops, or has converged with it.

Fo range for men and women speakers

The absolute rise in Hz of Fo after glottalic stops is much larger for women speakers than for male speakers. After glottalic stops men's Fo starts at a value which is closer to the comparable value after pulmonic stops and rises to a value slightly above it. The results indicate that men and women vary in the comparative differences in Fo after pulmonic and glottalic stops and in the extent of the difference.

I only examined the extent of the Fo spread for men and women speakers in Mam at voice onset, after pulmonic and glottalic stops. Other research based on normal range values, such as Klatt and Klatt (1989), conclude that the average Fo of women speakers is 1.7x the average Fo of male speakers. Hillenbrand et al (1995) present one of the few templates available for values of fundamental frequencies and formant frequencies based on measurements of the speech of 45 men, 48 women and 46 children. They show average Fo values over all vowel environments from 121 Hz to 143 Hz for male speakers and from 210 Hz to 235 Hz for women.

The Mam data summarized above indicates that a wide pitch range is exploited linguistically by speakers of Mam, with considerable overlap between men and women. The largest range for all speakers in this data occurs at vowel onset after glottalic obstruents.

Women have a range over all tokens and all speakers of 49.8 Hz to 380 Hz while male speakers have a range of 82.6 Hz to 301.6 Hz. The absolute range of women speakers overlaps that of male speakers and extends above by about 80 Hz, (or about a major third).

Although the data on English and Mam are not strictly comparable, it would appear that speakers of English use a relatively limited portion of the possible pitch range of the human vocal instrument. However, the mean Fo remains about 100 Hz higher for women than men in both Mam and English. This suggests that in Mam speakers modify the natural resonating frequency of the vocal instrument with two gender-specific strategies: creak and tenseness, to exploit a larger range Fo possibilities for linguistic purposes. It seems the use of creak, and whatever production strategy is used alternatively by men, is a great democratizer of F0 across the genders for this community of speakers.

Figure 4.9 shows the distribution of women's and men's ranges at voice onset in Mam. The histogram indicates how women's voices overlap all values for male speakers at first glottal pulse, although the central tendencies remain about 100 Hz apart.

Mam is a language where creaky voice is phonemic for all speakers, and men and women also use a falsetto phonation for both paralinguistic uses, [58] and possibly phonemic distinctions. This particular data set does not include any tokens of falsetto, and the word initial stops do not involve creak to the same extent as is involved with creaky vowels. A more complete examination of Fo range in Mam would include data from both falsetto, (what England (1983) decribed as a high falling tone) and phonemic vocal creak, which is used extensively in the last half of vowels. Consequently the range in Fo in this data can be assumed to be largely the effect of perturbations from the word initial stops, rather than a complete account of Fo range in Mam.

Vowel effect

Both female and male speakers show a similar tendency according to vowel, with the expected increase of Fo with high vowels. The difference in Fo with vowel environment is the same after pulmonic stops as after glottalic stops, although the absolute values are lower after glottalic stops. One exception is that for male speakers /u/ has the same high Fo after both pulmonic or glottalic stops. Male speakers also have a slightly higher mean Fo for /o/ than /i/ after both pulmonic and glottalic stops. Absolute values are highest for /u/ and /i/ after both plain and glottalic consonants for female speakers. There is a difference in the relative height of /u/ for women speakers after pulmonic and glottalic stops.

This suggests that Fo is not only varying with raised or lowered larynx. The line charts in Figures 4.3 to 4.8 and the data show that Fo is initially lowered after both ejectives and implosives, that is, after both raised and lowered larynx. However, the line charts in Figures 4.10 to 4.11 show that there is an additional effect from vowel environment on Fo. For women, there is an additional rise in Fo with vowels with a low F1, that is, high vowels. For men this difference is not as systematic.

58 See also Brown and Levinson (1978) on the male use of falsetto in Tzeltal.

Summary of differences

In conclusion, there seem to be differences in the speech of men and women that are both impressionistically audible and acoustically measurable in terms of Fo. To a naive (non native speaker) listener it seems that male speakers use a contrastive phonation type which "colours" the whole word after a glottalic stop. This appears to result in a higher Fo later in the word. It is audibly apparent and can be impressionistically described as a more vigorous vocal production.

Kingston (1984) noted two possible voice qualities induced by glottal stop, or ejectives, on neighboring vowels (p. 152). He claims that glottal stop often is associated with either "tense" or creaky voice.[59] He notes that these two different voice quality strategies share similar spectral properties from other voice types (modal or breathy) and differ primarily in their fundamental frequency. The results on Mam suggest that the speech of men and women differ according to Fo patterns and may correspond to a difference in voice quality. Further investigation of the relation of the amplitude characteristics of formants compared to the fundamental might find other spectral cues which could elucidate- or discount- this difference.

While Kingston did not have data on vowels after implosives to compare with, this data supports the existence of these two different voice qualities, distinguishable largely by Fo patterns, after all glottalic stops. In this case the different strategies are used within one community of speakers, seemingly by gender.

4.2.4.2 Similarities in the speech of men and women

Fo trajectory

The results summarized above showed how the speech of men and women varies in Fo after pulmonic and glottalic stops. Despite these differences in extent of Fo change, relative Fo after either type of stop at vowel onset or vowel peak, and some variation according to place of articulation and vowel environment, there is a shared characteristic for most speakers in the Fo trajectory[60] . The mean Fo rises after glottalic stops at all places of

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[59] In his study this difference is purported to lead to tonal splits historically between language groups of Athabascan.

[60] One (older) male speaker has an atypical Fo trajectory after glottalic stops.

articulation, in all vowel environments. The mean Fo does not rise after pulmonic stops in this data. It remains level or falls. I suggest that a rising Fo contour or trajectory on following vowels may be the most robust cue for all glottalic stops in Mam.

For the women speakers, all speakers but one have higher absolute Fo after pulmonic than glottalic stops. However, for all speakers, the mean Fo trajectory rises after glottalic stops whether absolute values are higher or not. For the male speakers, there is more overlapping of the pulmonic with glottalic values. However, again, for all speakers except one, the mean Fo trajectories rise after glottalic stops, despite considerable variation in absolute values.

The line chart in Figure 4.12 represents these mean Fo trajectories of pooled values of male and female speakers at the three different times after pulmonic and glottalic stops. It is apparent that the Fo after glottalic stops rises considerably after vowel onset for female speakers. Female speakers have a lower Fo after glottalic stops at first and fifth glottal pulse but the Fo approximates Fo after pulmonic stops by the vowel target. The absolute rise in Fo is larger after glottalic stops for women speakers than for male speakers.

For male speakers, Fo at voice onset is lower after glottalic stops than after pulmonic stops, but is appreciably closer to the comparable value after pulmonic stops than for women speakers. By the vowel target, Fo has fallen after pulmonic stops and risen to a higher value after the glottalic consonants. However, for both men and women the Fo trajectory rises after the glottalic stops.

4.2.5 Summary

Fo tends to be lower after glottalic stops, both implosives and ejectives, than after pulmonic stops for all speakers but one, (Speaker M3), at first glottal pulse. The mean Fo is lower at fifth glottal pulse after glottalic stops for female speakers and approaches the same value at 100 ms. Fo tends to be higher at 5th glottal pulse for male speakers and at 100 ms approaches a significantly higher value.

The most reliable difference, therefore, between pulmonic and glottalic stops for female and male speakers is between a rising Fo trajectory after glottalic stops and a flat or falling trajectory after pulmonic stops, rather than absolute differences in Fo.

There is an additional effect with vowel height for female speakers and a tendency for male speakers to have higher Fo with high and back vowels. This effect is additional to any Fo perturbation associated with either raised or lowered larynx position.

A perceptual quibble

We still need some way of assessing how listeners might make distinctions based on the observed characteristics and differences. Some earlier perceptual research gives a few ways of predicting what kinds of differences may be available for linguistic distinctions.

Humans are not very sensitive to differences in absolute pitches. It is well known that few humans have "perfect pitch", but we all can tell if pitch is changing. Hombert et al (1979) said "our auditory system seems more efficient at detecting dynamic change in Fo rather than differences in level" (p.53). Ohde (1984) also suggested that listeners may tune to rise/fall changes rather than differences in absolute pitch. The duration of this change is also critical. Quoting research on "just perceptible differences", Meyers (1976) noted that pitch differences are perceived best over a duration of 60 ms rather than in an abrupt rise or fall (p.77). These studies, therefore, give a very preliminary way of assessing the differences in the Mam data.

A rising Fo trajectory after glottalic stops that extends from onset to vowel peak, therefore, may provide the most salient cue to distinguish these contrasting types of sounds in Mam.

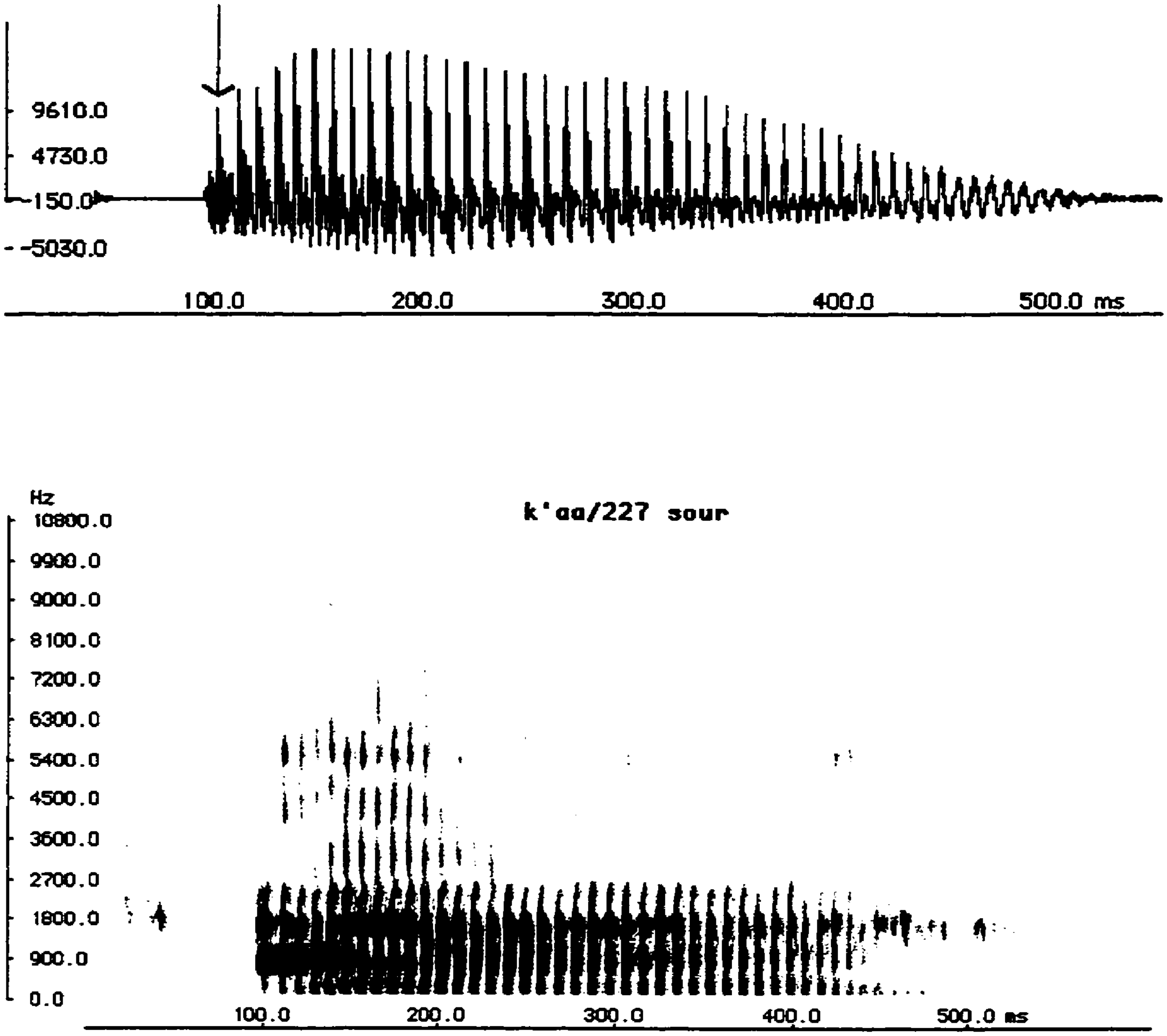

Figure 4.1
Wave-form and spectrogram of a velar ejective, showing the first glottal pulse for token /k'aa/ *sour,* by Speaker M7.

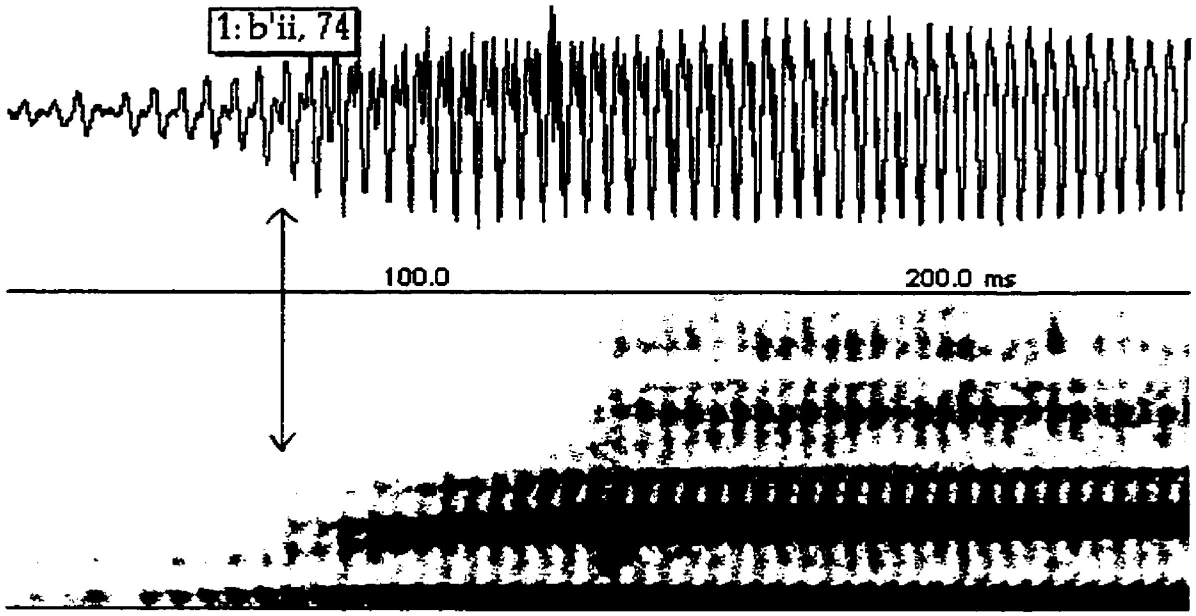

Fig 4.2
Wave-form and spectrogram for a bilabial implosive, showing the point of vowel onset. The utterance is /b'ii/ *name*, by Speaker F2.

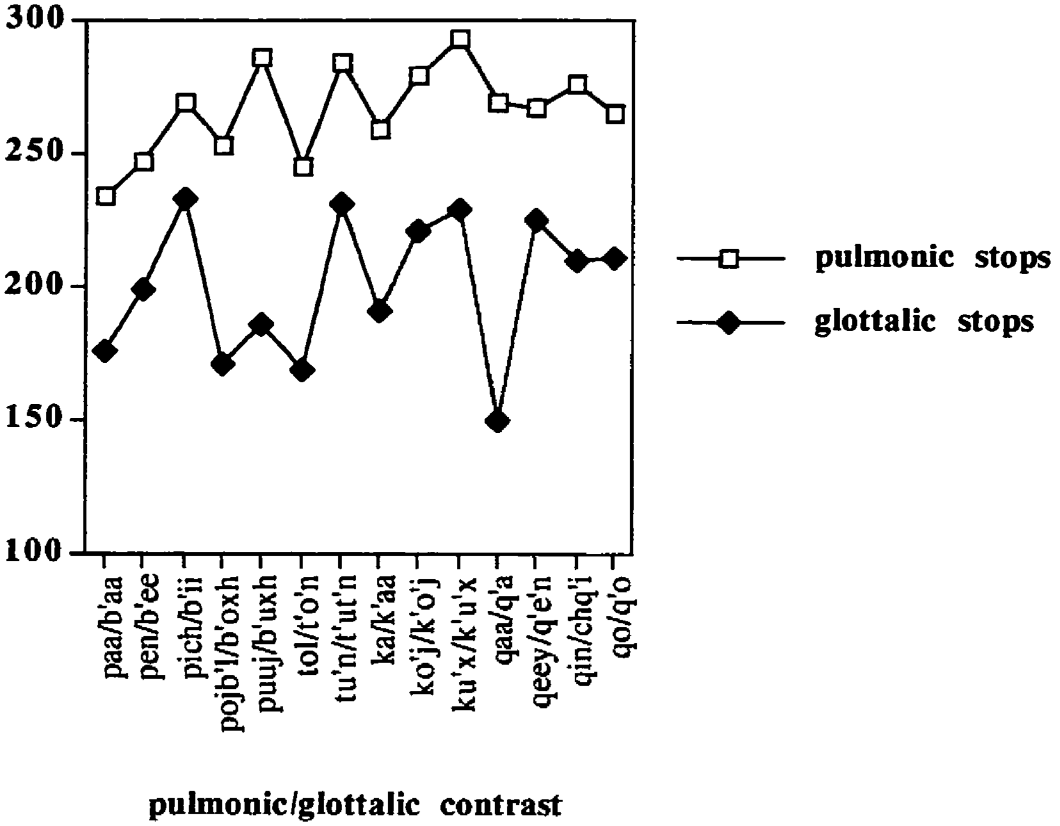

Figure 4.3
The mean Fo after pulmonic and glottalic stops at first glottal pulse, female speakers, in Hz.

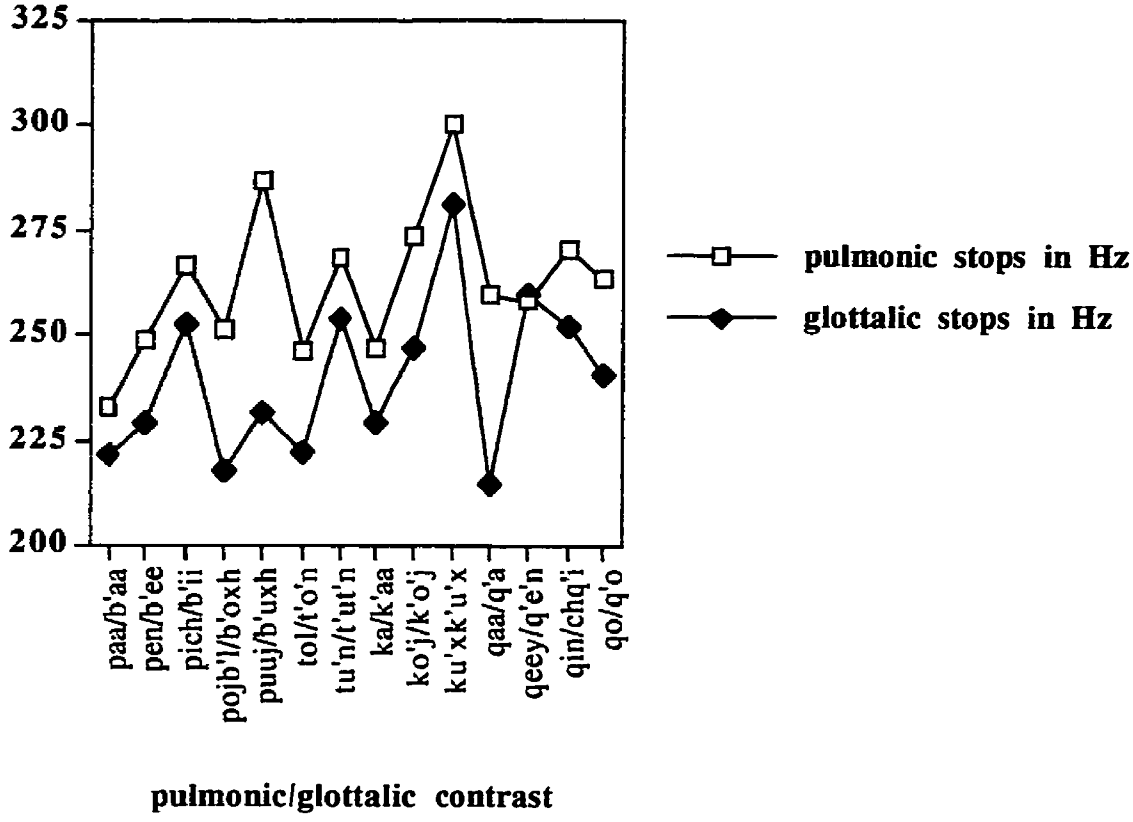

Figure 4.4
The mean Fo after pulmonic and glottalic stops at fifth glottal pulse female speakers, in Hz.

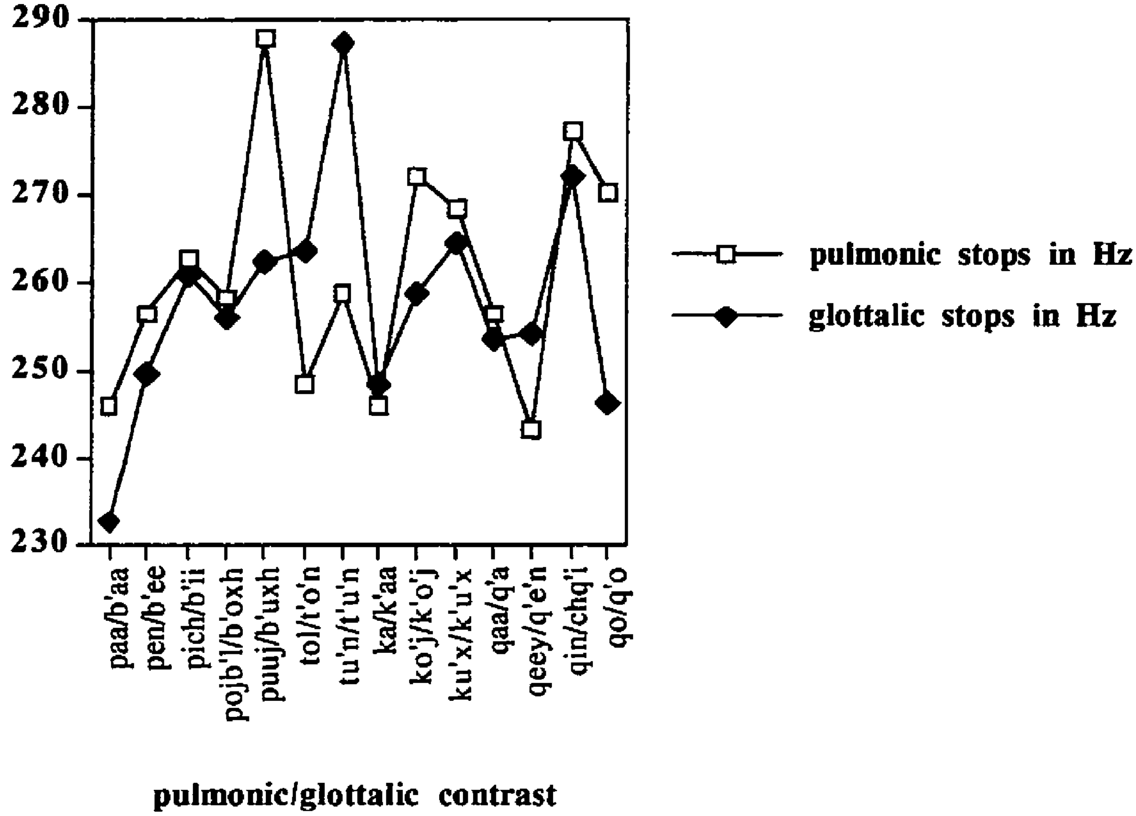

Figure 4.5
The mean Fo after pulmonic and glottalic stops at 100 ms
female speakers, in Hz.

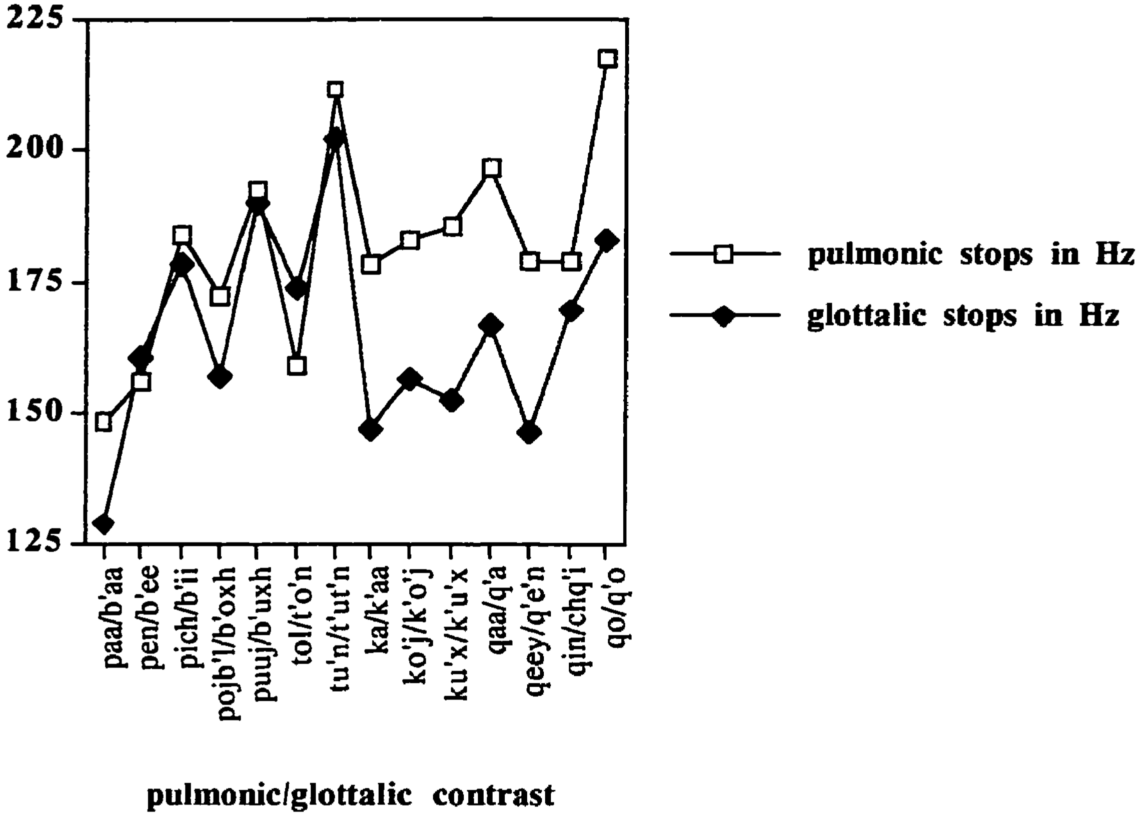

Figure 4.6
The mean Fo of pulmonic and glottalic Fo stops at first glottal pulse male speakers, in Hz.

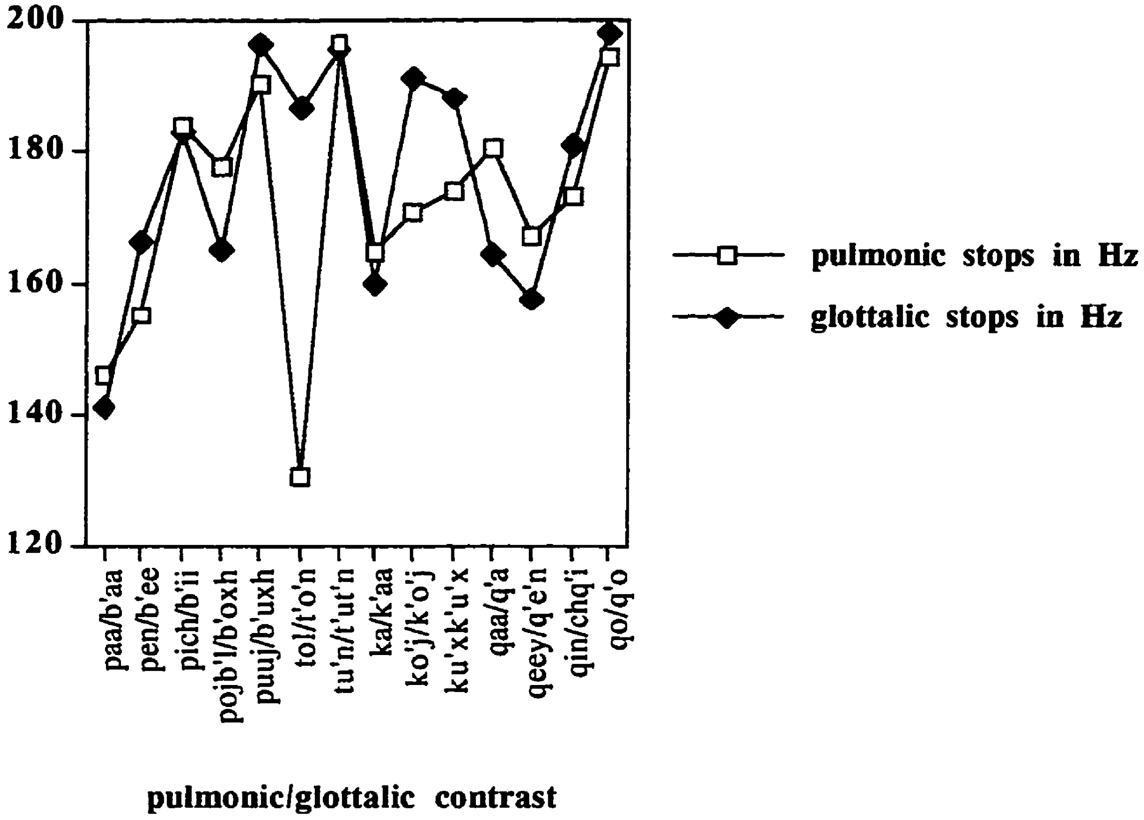

Figure 4.7
The mean Fo of pulmonic and glottalic stops at fifth glottal pulse
male speakers, in Hz.

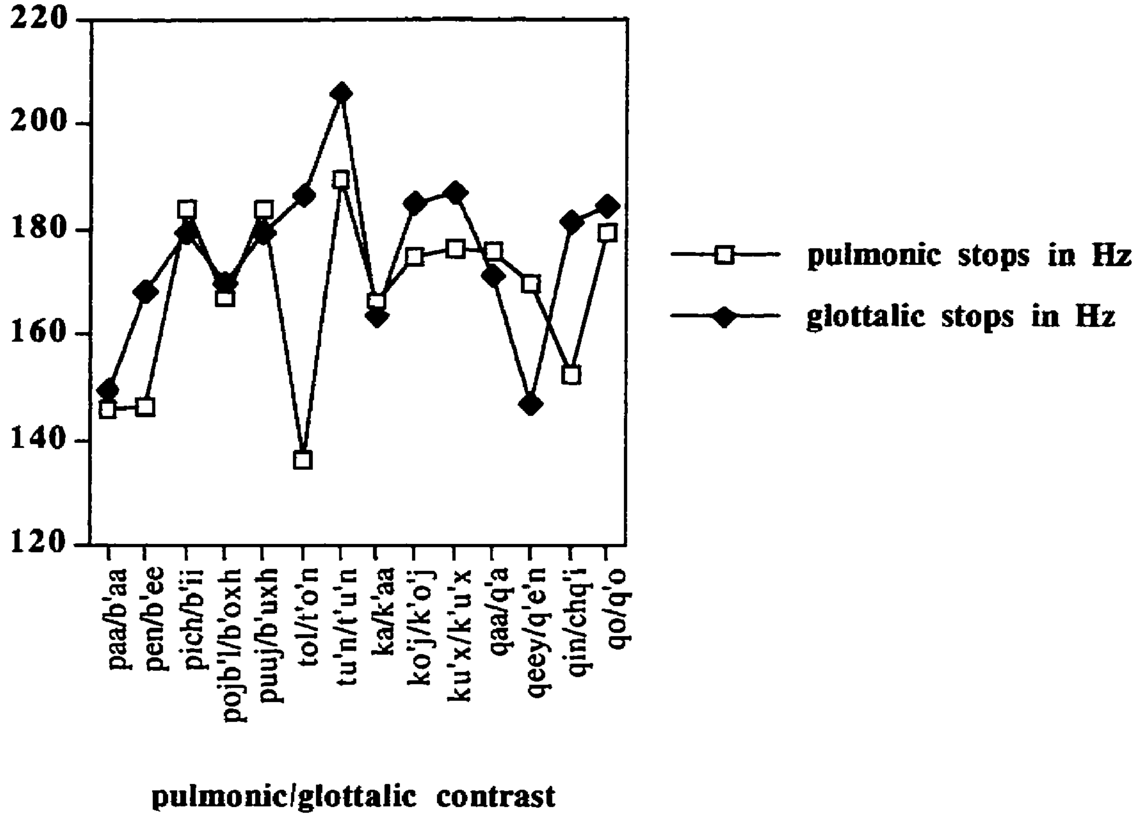

Figure 4.8
The mean Fo after pulmonic and glottalic stops at 100 ms, male speakers, in Hz.

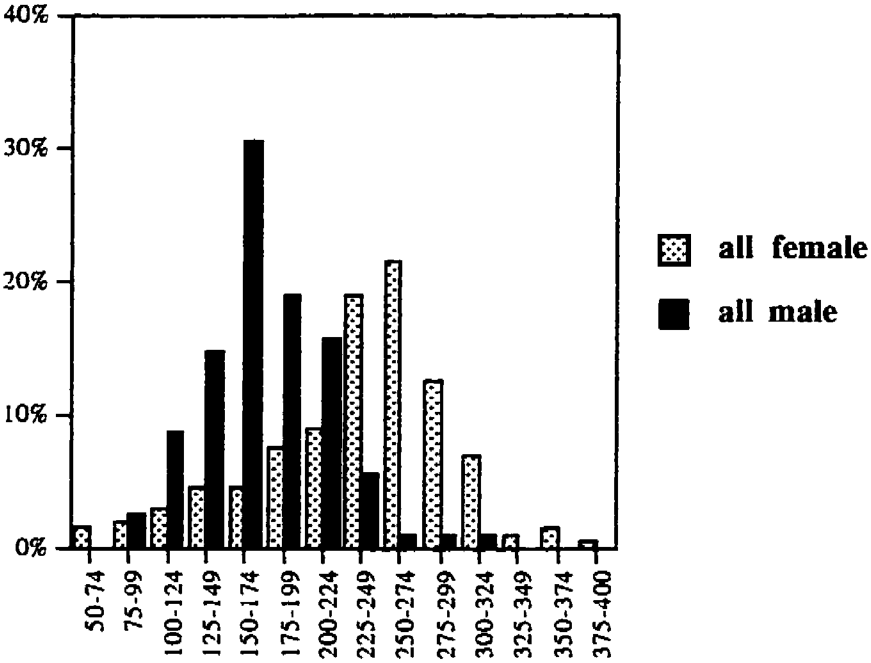

Figure 4.9

Distribution of Fo range for female and male speakers at voice onset.

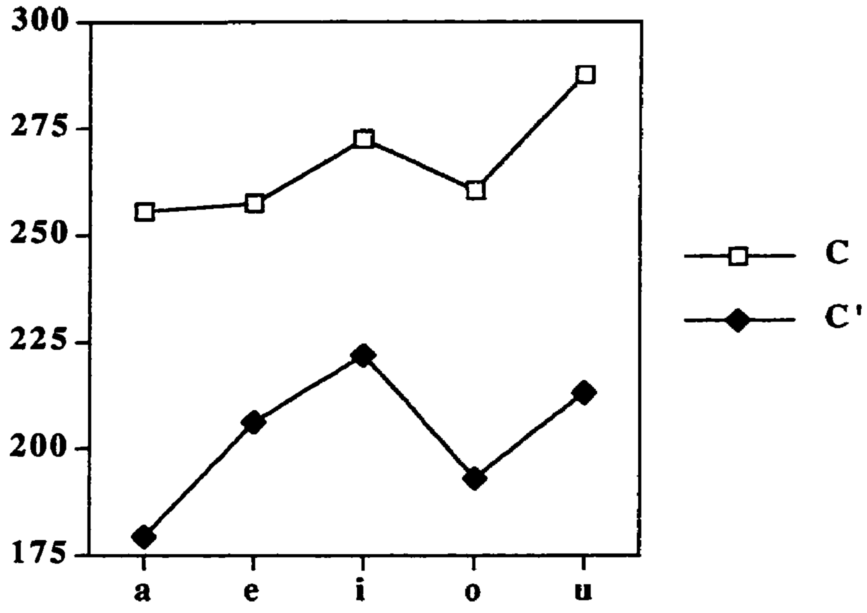

Figure 4.10
Mean Fo by vowel after pulmonic and glottalic stops, female speakers, in Hz

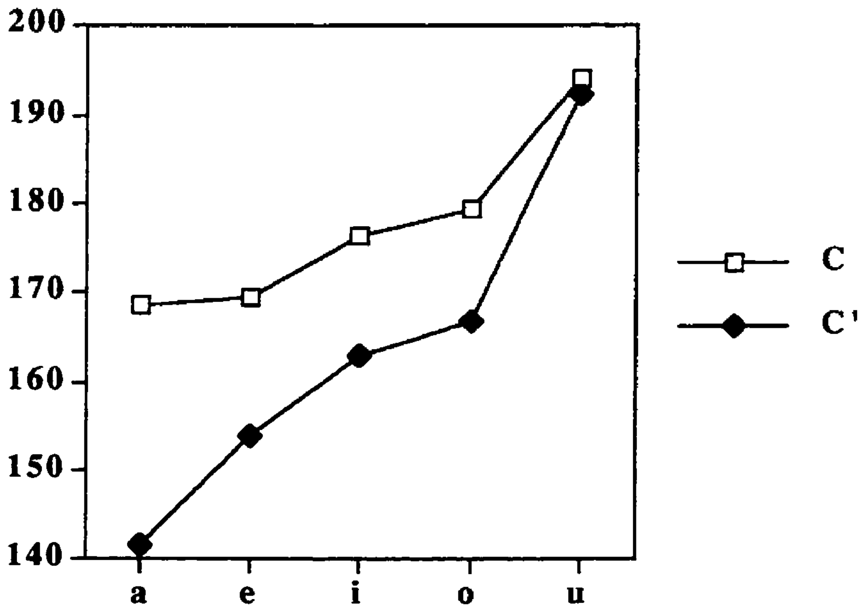

Figure 4.11
Mean Fo by vowel after pulmonic and glottalic stops, male speakers, in Hz

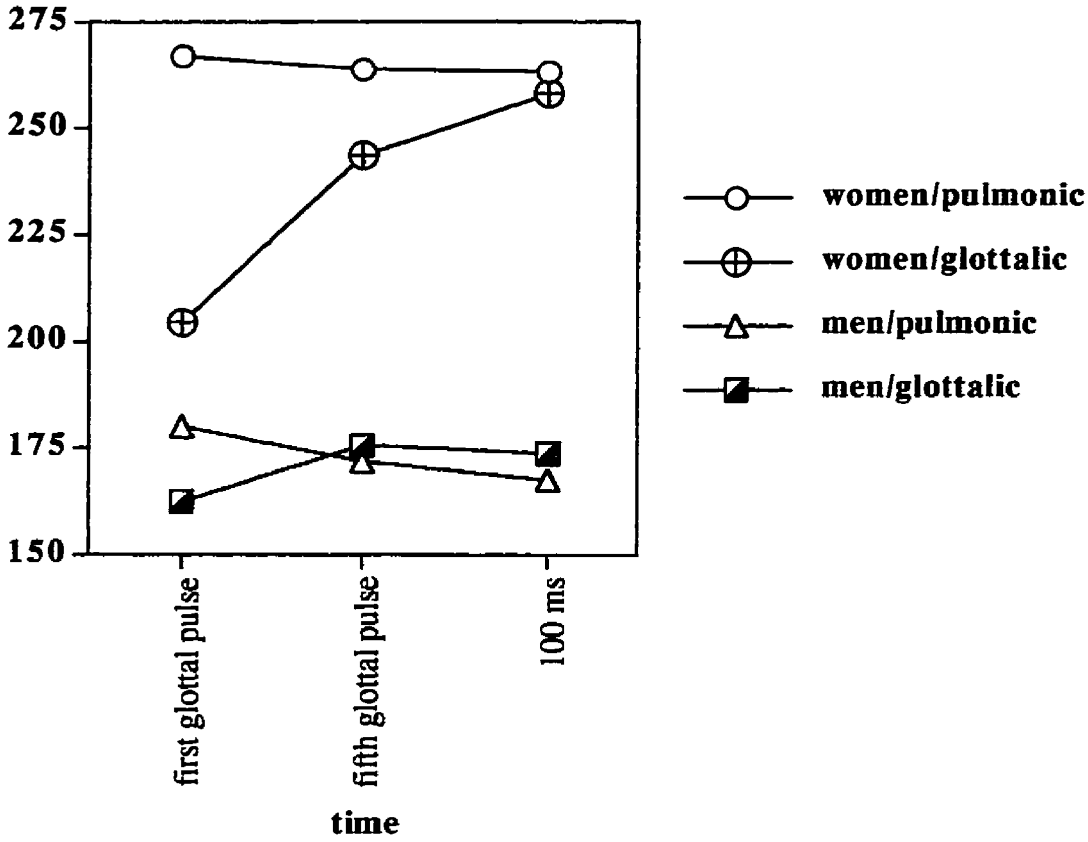

Figure 4.12
Mean Fo trajectories for all pulmonic and glottalic stops, female and male speakers, in Hz.

Chapter 5
Conclusion

In this work I have looked at some acoustic characteristics of word initial glottalic and pulmonic stops in a Mayan language, Mam, based on data from fourteen speakers from Huixoq', San Pedro Necta, Guatemala. I have looked at two broad questions:

1. What are the acoustic characteristics of pulmonic and glottalic stops in Mam, according to three acoustic parameters of VOT, amplitude and Fo?
2. How do pulmonic and glottalic stops differ in VOT, amplitude and Fo?

5.1 SUMMARY OF FINDINGS

Chapter two

I found a significant difference in VOT between vowels after pulmonic and after glottalic stops at all places of articulation. However, no absolute values of VOT distinguish the two types.

There is also considerable overlap in VOT between the two types. Glottalic stops may have lengthy prevoicing (the implosives) or positive VOT (the ejectives). However, some may have a synchronized voice onset with oral release, varying with place of articulation.

VOT increases after pulmonic stops with place of articulation from bilabials and dentals to velars and uvulars. The difference between pulmonic and glottalic stops shrinks correspondingly.

The majority of glottalic stops have a successive, or syncopated onset, whereas the majority of pulmonic stops have a simultaneous, or synchronized onset.

Chapter three

A difference in amplitude rise time distinguishes pulmonic and glottalic bilabial and dental stops. Rise time does not distinguish velar and uvular pulmonic from glottalic stops.

A larger difference in dB rise distinguishes all glottalic from pulmonic stops, most robustly for bilabial, dental and uvular stops.

A larger ratio of vowel onset amplitude to vowel peak amplitude distinguishes bilabial, dental and (just) velar glottalic from pulmonic stops.

For a majority of tokens, vowels after glottalic stops have a gradual or non-abrupt amplitude rise time with a steep rise in amplitude and a concomitant larger ratio in amplitude onset to vowel peak. Consequently, vowels after glottalic stops can be characterized by a non-abrupt onset. Vowels after pulmonic bilabial and dental stops have an abrupt onset. Vowels after velars and uvular pulmonic stops vary in onset type.

Chapter four

Fo was lower at voice onset after glottalic stops than after pulmonic stops for all speakers. However, men and women differ in the extent of Fo change and in the relative values by vowel peak.

Women have a much larger absolute rise in Fo. By vowel peak the Fo has reached the same target value as after pulmonic stops.

Men speakers have a smaller difference but still lower Fo at vowel onset after glottalic stops than after pulmonic stops. Their Fo trajectory passes above the comparable values after pulmonic stops by vowel peak.

Men and women may differ in voice quality. Women may use a more creaky phonation type, men a more tense production.

All speakers but one, however, tend to have a rising Fo trajectory after glottalic stops and a falling or level Fo trajectory after pulmonic stops.

5.2 THE OUTLOOK FOR FURTHER RESEARCH

From the findings above several questions emerge:

5.2.1 Perceptual questions

These findings have been assessed according to what we already know about how people hear differences in the acoustic signal. These ways of organizing the results appear to distinguish these sounds. But are they perceptually relevant to speakers and listeners of Mam?

How do speakers actually weigh the complex of cues which seem to characterize these sounds? Are distinctions based on the kinds of acoustic characteristics found in this work? Do listeners "trade" cues? Do listeners make distinctions between contrasting sounds by any one cue or do they have a certain global property which would be better perceptually defined as "prominence" or "abruptness"? Further studies based on a perceptual model are needed to investigate how speakers make these distinctions.

5.2.2 Speaker variation: a recommendation

These results have indicated that when a representative sample of speakers is analyzed for any speech parameter, (eg. VOT, amplitude, Fo), there is a wide range of observable results. Many previous studies, which have described the phonetic or acoustic characteristics of not well-known languages, have been based on speech from only a single speaker or a very few speakers. The variety of results found in this study suggests that results from a single speaker should be taken very provisionally until such a language is studied in all its variety, with a truly representative sample of speakers.

5.3.3 Physiological causes

How are these different types of sounds realized physiologically? These results suggest the possibility that various combinations of events may be employed in the laryngeal/suprlaryngeal mechanism to produce the consonant contrasts of pulmonic and glottalic stops. Further study is required to elucidate those events that produce the Mam that people hear and speak in Huixoq'.

Appendix #1

Word List for Mam contrastive word-initial pulmonic and glottalic stops

Pulmonic		Glottalic	
paa	*bag*	b'aa	*mole*
pen	*fence*	b'ee	*road*
pich	*toad*	b'ii	*name*
pojb'l	*hammer*	b'oxh	*armadillo*
puuj	*dust*	b'u'xh	*tattered*
tol	*owl*	t'o'n	*you give*
tu'n	*by you*	t'ut'n	*soft, squishy*
kaa	*molar/grinder*	k'aa	*sour drink*
keyixh	*fine/beautiful*	k'e'x	*resonant sound*
ko'j	*lion*	k'o'j	*delicious*
ku'x	*go south*	k'u'j	*belly*
qaa'	*our water*	q'aa	*boy*
qeey	*us*	q'e'n	*alcohol*
qin	*me*	chq'i	*wind*
qo	*let's go*	q'o	*squash*

Some additional contrasts with limited number of speakers

kixh	*fish*	k'ixhbaj	*suffering*
kotz	*gift*	k'ok	*barbed seed*
quuq	*silt*	q'uuq'	*quetzal bird*

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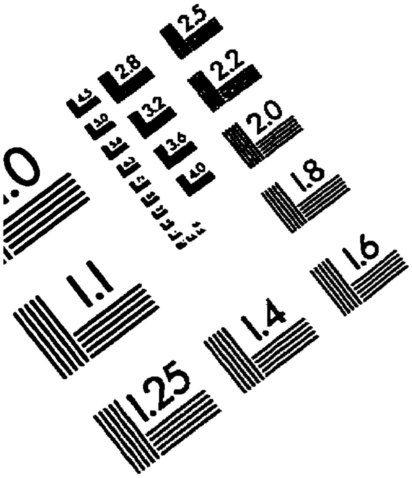

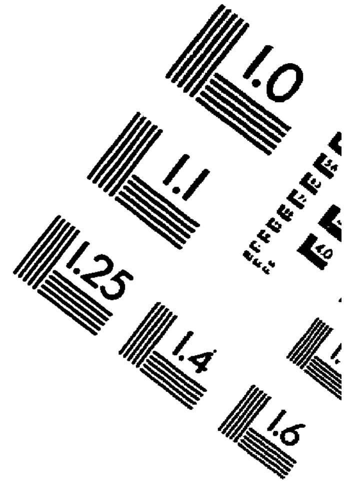

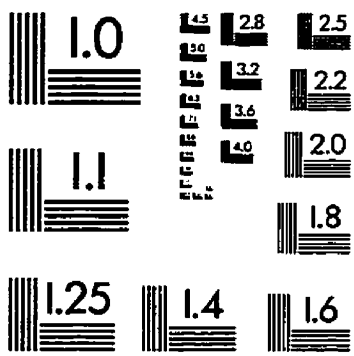

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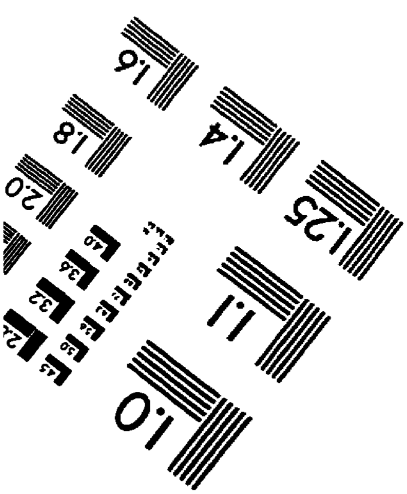

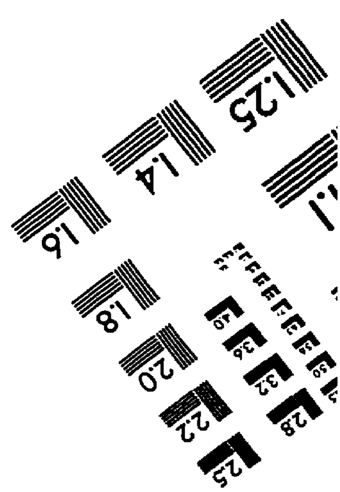

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