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An Acoustic Analysis of Amharic Vowels, Plosives and Ejectives

BY

DERIB ADO JEKALE

A DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE DOCTOR OF PHILOSOPHY IN EXPERIMENTAL PHONETICS

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A Dissertation Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in Experimental Phonetics

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ABSTRACT

This research set out to study the vowels, and pulmonic and ejective stops of Amharic, a South Ethio-Semitic language spoken in Ethiopia. Data from four males and four females was recorded at the Phonetics lab established at the Akaki Campus of Addis Ababa University using the Kay CSL 4400 multisignal acquisition and analysis device.

The F0, F1, F2, F3 values of Amharic vowels in **/tVt/** context were computed and presented. The F1-F2 plot of Amharic vowels showed that the so called 'high central vowel' was not really high, but high mid, and the so called 'mid central vowel' was found to be not mid, but low mid, close to the cardinal vowel [**ɜ**]. Thus a new four-height vowel system has been proposed based on the results of this study. Amharic vowels were found longer before voiced stops than before voiceless stops, and they were longer before singletons than before geminates conforming to attested patterns in other languages. A discriminant analysis showed that F1 and F2 alone could be used to classify with 86.7% accuracy, whereas the addition of F0 and F3 values in the discriminant analysis increased it to 90 % correct classification for all subjects collapsed across genders. Using Normalized values the classification results rose to 94 %.

The acoustic analysis of stops showed that total burst duration and relative intensity came out strong in classifying stops by place of articulation. Bilabials had the highest classification results followed by velars and alveolars had the least classification results. VOT and spectral mean were the most important acoustic cues that classified voiced stops with a correct classification result of 94.9 % and voiceless stops up to 89 %. VOT alone was able to classify 81.4 % of the stops correctly. Jitter perturbation, spectral mean and voicing lag came out as relatively stronger acoustic cues that identified airstream. Nevertheless, classification using the numerical results of jitter perturbation, spectral mean and voicing lag did not produce expected results though it has been found that Amharic ejectives result in creaky phonation on the following vowel. Amharic ejectives have been found to have more characteristics of slack ejectives than of stiff ejectives.

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CHAPTER ONE

INTRODUCTION

1.1 The Language

Amharic is a South Ethio-Semitic language (Hetzron and Bender 1976) spoken in the central and northern parts of Ethiopia and in all towns of the country. It has more than 21 million first-language speakers (FDRE Population Census Commission 2010) and more than four million second-language speakers (CSA 1998), making it one of the most widely used languages in the country. Outside Ethiopia, Amharic is spoken by more than a million speakers in the diaspora in the US, by the Ethiopian-descent Israelites in Israel and elsewhere.

Amharic is the official working language of Ethiopia as well as the official language of the Amhara, the South Nations, Nationalities and Peoples, the Gambela and the Benishangual Gumuz regional states and the city administrations of Addis Ababa and Diredawa. It is taught as a subject in all the primary and secondary schools of Ethiopia while it is officially the medium of instruction at primary school level mainly in the Amhara National Regional State, in city administrations of Addis Ababa and Diredawa and in many major cities of the country.

Different studies on Amharic suggest different phonemic inventories of the language. Sumner (1957) states that Amharic has 27 consonant phonemes. Mulugeta (2001) identifies 21 consonant phonemes including the less frequent /**p**/ and /**p’**/. He states that /**tʃ**/, /**dʒ**/,/**ɲ**/, /**tʃ’**/ are derived segments, and thus are not part of the phoneme inventory. Baye (2008, 2010) however, present 30 consonant phonemes including the labialized consonants /$\mathbf{k^w}$/, /$\mathbf{g^w}$/. /$\mathbf{k'^w}$/. The phonemic inventories of Amharic consonants contain five ejectives three of which are stops (/**p’**/, /**t’**/ and /**k’**/), one is a fricative (/**s’**/) and the remaining one is an affricate (/**tʃ’**/). This phenomenon makes Amharic (and many other Ethiopian languages) a phonetically interesting language.

Table 1.1: The consonant phonemes of Amharic.

Manner of Articulation	**Airstream and modifications**	**Place of Articulation**						
		Bilabial	**Labio-dental**	**(Denti-)[1] Alveolar**	**Post-alveolar**	**Palatal**	**Velar**	**Glottal**
		vl vd	vl vd	vl vd	vl vd	vl vd	vl vd	vl
Stop	Pul Simp	p b		t d			k g	ʔ
	Pul Lab						k^w g^w	
	Glot Simp	p’		t’			k’	
	Glot Lab						$k’^w$	
Fricative	Pul Simp		f (v[2])	s z	ʃ ʒ			h
	Glot Simp			s’				
Affricate	Pul Simp				tʃ dʒ			
	Glot Simp				tʃ’			
Nasal	Pul Simp	m	n			ɲ		
Central Approximant	Pul Simp	w				j		
Lateral Approximant	Pul Simp		l					
Trill	Pul Simp		r					

Key

Pul Simp: Pulmonic simple
Pul Lab: Pulmonic labialized
Glot Simp: Glottalic simple
Glot Lab: Glottalic labialized
vl: voiceless
vd: voiced

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1 Most of the researchers used the term alveolar only and few such as Sumner (1957) used dental. Baye (2008) admits that some of the sounds grouped as alveolar could be dental. Since no experimental study has identified the sounds could be described as either dental or alveolar, and I have used the term ‘denti_ alveolar to compromise the two. However, in this paper, I have used the term ‘alveolar’ to refer to this group of consonants, mainly the stop series.

2 This phoneme is found in borrowed words from foreign languages such /**velo**/ ‘veil’ and /**villa**/ ‘villa’. In recent days the sound has found itself into the proper names of individuals such as /**fevɜn**/ ‘Feven’. In most cases /**v**/ is found in free variation with /b/ as in /**velo**/ and / **belo**/ having the same meaning ‘veil’, but in some cases there appears to be a development of contrast with /**b**/ as in /**villa**/ ‘villa’ versus /**billa**/ which means ‘knife’ unless the context makes it clear that a person is talking about a type of house. The phoneme is not included in both earlier and recent studies Leslau (1969), Mullen (1986), Baye (1994, 2008, 2010).

Most researchers (Sumner 1957, Gankin 1969 cited by Podolsky 1991, Mulugeta 2001, Baye 1994, 2008 and 2010) agree that Amharic has seven distinctive vowels.

Table 1.2: The seven vowels of Amharic (after Baye 1994, 2008 and 2010).

	Front	Central	Back
High	i	ɨ	u
Mid	e	ə	o
Low		a	

There are researchers who put the number of Amharic vowels to be three, six, seven or nine (Cohen 1970, Jušmanov 1936, Hayward 1986, Podolsky 1991). For instance Hayward (1986) insists that the vowel /ɨ/ is an epenthetic vowel and thus the actual number of the vowels is six. It is possible though to find minimal pairs that contrast /ɘ[3]/ and /ɜ/ as in ***/sɜs/*** 'gazelle' and ***/sɘs/*** 'thin / not thick'. It is also possible to see a three-way contrast in the central vowels as in ***/bɜl/*** 'say (2SgM[4])...', ***/bɘl/*** 'if I say ...' and ***/bal/*** 'husband'.

The quality of Amharic vowels is as debatable as is the number. Podolsky (1991) citing Gankin (1969) mentions that the vowels /**o**/ and /**e**/ are claimed to be always long, and /ɨ/ and /ə/ are always short, whereas the length of /**u**/, /**i**/ and /**a**/ depends on stress (Podolsky 1991:19).[5] Vowel length, however, is not phonemic in contemporary Amharic. Amharic underlying syllable structure has been argued to be CV, CVC, and CVCC (Mulugeta 2001).

[3]In the transcriptions in this study, the symbol /ɘ/ represents what has been labeled as the "high central vowel" /ɨ/ and the symbol /ɜ/ represents what has been labeled as the "mid central vowel" /ə/ as presented in Table 2. The reason for the change of the symbols for the two central vowels is explained in section 4.1.

[4] Amharc verbs inflect for gender, and thus this is the form for second person singular masculine (2SgM).

[5]The detailed summary of the research on Amharic vowels is given in the review of related literature part.

Amharic has phonemic gemination in word medial and final positions. All consonants except **/h/** and **/ʔ/** can be geminate. Amharic has been said to have phonetic stress, but the placement of stress has been a debatable issue. Mullen (1986) argues that syllable weight plays a role in the placement of lexical stress in Amharic whereas Alemayehu (1995) states that syllable weight has no role in stress assignment and claims that stress in Amharic is realized as a high pitch (Alemayehu 1987).

1.2 Statement of the Problem

There are several morphological and syntactic works on Amharic; however, the phonetics and even phonology of the language remain unexplored. There are few experimental studies on Amharic phonetics (Sumner 1957, Mantel-Nieco 1971, Hayward 2000, Abebayehu 2007, Tadesse 2007 and Nadew 2008). Sumner's (1957) study on Amharic phonetics employed the now obsolete kymograph to measure the frequency and amplitude of the sounds whereas Mantel-Nieco (1971) shows palatograms of some sounds without any explanation at all. Moreover, he used a single individual for the palatographic study, which makes it of less value in light of current standards which ask a measurement be taken from up to six individuals (Ladefoged 2003). Hayward (2000) just plotted the F2-F1 values of Amharic vowels from a single speaker of the 'Gondar variety'. Abebayehu (2007) compared the speech of a patient with flaccid dysarthria with the speech of healthy adults. His comparison of the normal and the pathological speech focused mainly on formant values and spectrographic displays of the consonants, and thus is far from a complete description. Even so, his subjects were only male individuals. Taddese's (2007) and Nadew's (2008) works suffer from flaws in the basic linguistic concepts as well as methodological problems and cannot be taken seriously.

Due to lack of experimental studies on Amharic phonetics, the places of articulation of some consonants, for instance, remain unresolved. Sumner (1957) categorizes the sounds **/l/**. **/r/**, **/s/**, **/z/**, **/n/**, **/t/**, and **/d/** as dentals in the experimental study he conducted, whereas Baye (2000) considers them as alveolars. Though research on stress in Amharic has been conducted (Mullen 1986, Alemayehu 1987, Wedekind and Wedekind 1994 and

Tadesse 2007), the placement of stress and its acoustic correlates in Amharic phonetics are still open for experimental research. The basic formant values of Amharic vowels, their duration, basic acoustic measures for the obstruents and sonorants, the nature of the labialized consonants, the issue of the glottal stop and so on remain open for experimental research to shed light on them. This study attempts to fill some of the gaps that exist in the area of phonetic research in Amharic.

1.3 Objectives of the Study

This experimental study of Amharic phonetics aims at

1. identifying the basic properties of Amharic vowels (F1, F2 and F3[6]), their fundamental frequency and relative duration in different contexts; and
2. describing the basic acoustic properties of Amharic stops.

Thus, the research tries to answer the following specific research questions.

1. What are the F1, F2 and F3 values of Amharic vowels for male and female speakers? How much can Amharic vowels be discriminated using these values?
2. What are the F0 values of Amharic vowels for male and female speakers?
3. What is the nature of the duration of each of the seven Amharic vowels?
    a. Which vowels are inherently long and which ones are short?
    b. How do Amharic vowels behave in terms of duration when they come before voiced and voiceless consonants?
    c. How do Amharic vowels behave in terms of duration when they come before geminate and nongeminate consonants?

6F1, F2 and F3 are the first second and fourth formants of a vowel.

   d. Is the duration of Amharic vowels affected by gender and position (in a wordlist and a carrier sentence)?

4. What are the basic acoustic cues that identify Amharic pulmonic and ejective stops?
   a. What acoustic cues identify different places of articulation?
   b. What acoustic cues identify voicing?
   c. What acoustic cues identify the airstream mechanism?
5. How does gender affect the different acoustic cues of Amharic stops?
6. How does position in a word (initial or intervocalic) affect the different acoustic cues of Amharic stops?
7. What do the results on Amharic vowels and stops imply for the universals proposed on vowels and stops?

1.4 Significance of the Study

This study will be helpful mainly for linguists, phoneticians and phonologists who want to work on Amharic phonetics and phonology since it gives them an objective description of the vowels and stops of Amharic. Researchers working on speech synthesis could also benefit a lot since the research will inform them about different acoustic correlates of Amharic vowels and stops. Researchers working in clinical linguistics such as those working on speech therapy can use this research as a reference to the 'normal speech' status during the study and provision of therapy of the pathological speech. It can be used as a starting point to do further research in Amharic phonetics and phonology as it not only gives answers to the questions raised but also shows areas that need independent investigations. Above all, it adds to our knowledge of the nature sounds in Amharic in particular and all languages in general.

1.5 Scope of the Study

This study is limited to the investigation of the acoustic characteristics of Amharic vowels and pulmonic and ejective stops. All the seven vowels are investigated whereas in the case of the stops, nine of the thirteen stops, excluding the glottal stop and the labialized stops, have been investigated. The glottal stop was excluded from this study due to its different acoustic characteristics compared to the other stops. The study did not include palatographic, electroglottographic and aerodynamic investigation subjects reacted negatively to the request to be involved in such investigations.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

This section presents a review of relevant literature. The literature begins by presenting the theories of speech production focusing on the production of vowels and stops. The articulatory and acoustic characteristics of vowels are then followed by the previous studies on vowels in general and Amharic vowels in particular. Following these, the articulatory and acoustic characteristics of stops are presented. Finally, previous works on stops in general and Amharic stops in particular are presented.

2.1 Theories of Speech Production

There are three theories of speech production that have been discussed widely in the phonetic literature: the source-filter theory (Fant 1960), the perturbation theory (Chiba and Kajiyama 1941, Schroeder 1967, Fant 1980), and the quantal theory (Stevens 1972). Of these three theories, the first one describes both the source and the filter whereas the last two focus on the characteristics of the vocal tract as a filter. A brief description of each of the theories is provided below.

2.1.1 The Source-filter Theory of Speech Production

The source-filter theory of speech production considers speech as a result of three processes: the generation of a source signal, the filtering of this signal with the vocal tract and the radiation of the filtered signal into the external environment. Fant states,

> This basic principle stated in electrical engineering terms implies that somewhere in the vocal tract there originates a source, constituting the raw material of the sound whilst the wave propagation through the vocal tract provides a filtering, a shaping of the raw material resulting the speech wave as defined by the pressure time wave at a certain distance from the speaker's mouth (Fant 1968:191).

This theory is said to provide the right theoretical explanation of the production of all speech sounds (Stevens and House 1961, Stevens 1989).

The source-filter theory of speech production identifies three different mechanisms of source signal generation: 1. quasiperiodic oscillation, 2. frication, and 3. transient noise excitation source (Shadle 1997). The frication and transient noise excitation should not necessarily be produced at the glottis as the source of sound could be anywhere in the vocal tract above the larynx (in addition to the known glottal source) (Liberman 1977). The quasiperiodic source is used in the production of voiced sounds. Friction and transient noise excitation are used mainly in the production of different types of consonants such as stops, fricatives, affricates and approximants and breathy vowels. Since this study deals with vowels and stops, the discussion of speech production is limited to the production of vowels and stops only.

2.1.1.1 Vowel Production in the Source-filter Theory

The source-filter theory of speech production (Fant 1960) states that vowels are produced with the vocal fold vibration as a source and the vocal tract as filter. The modes of phonation of the vocal folds determine the type of source signal in the production of any sound. Thus voiced vowels are produced by vibrating vocal folds, which means a quasiperiodic signal; whispered vowels are produced by a partially open and relaxed glottis which produces an aperiodic and noisy signal; and breathy voice vowels are produced by the combination of the quasiperiodic and aperiodic vibration of the vocal folds (Rosner and Pickering 1994:3). Each individual, however, does not produce the same type of glottal waveform for a given mode of phonation as there are individual differences among speakers of a language (Monsen and Engebretson 1977, Price 1989).

The vibration of vocal folds has different frequencies for different individuals and genders. Generally speaking, males have glottal vibration, referred to as a fundamental frequency (F0 hereafter) that is considerably lower than that of females. Ladefoged (2001a) states that adult males have a fundamental frequency of 80-200 Hz whereas females have up to 400 Hz of F0. For children, F0 goes up to 500 Hz (Liberman 1977). This is ascribed to the mass, length and tension of the vocal folds: men have long and massive vocal folds whereas females and children have shorter and less massive vocal folds. Smaller and less massive vocal cords are associated with a faster vibration of the vocal cords (Clark and Yallop 1995).

When the source wave passes through the vocal tract, the energy of the source is damped at certain frequencies and amplified at other frequencies. Those frequencies "*at which maximum energy will pass through*" are referred to as the centre frequencies of the formants (Liberman 1977:30). For each vowel, the vocal tract takes different shapes and the frequencies at which energy is amplified and dampened differ accordingly. As a result each vowel has its characteristic set of formant centre frequencies that separates it from other vowels. In acoustic analysis, the centre frequencies of the first three formants are very important to distinguish a vowel in question (Ladefoged 2001a, b). The centre frequency of first formant (F1 hereafter) relates to the height of the tongue and identifies whether vowels are high or low. The centre frequency of the second formant (F2 hereafter) is used to identify the backness of vowels, but for back vowels, it also has information on lip rounding (Ladefoged 2001a, b). As a result, back vowels that are rounded have lower formants than those which are not. The centre frequency of the third formant (F3 hereafter) is used to identify the degree of lip rounding, i.e. whether the vowel is round or not. The extent to which F3 shows rounding is higher for front vowels than for back vowels (Ladefoged 2001b).

The formant center frequencies of a given vowel differ due to the size of the vocal tract of a speaker (Ladefoged 2001b, Rosner and Pickering 1994). If a speaker has a small vocal tract, then the formant values will be higher. If the speaker has a long vocal tract, his formant values will be smaller. This is the result of a larger vocal tract holding a larger volume of air which vibrates slowly and a small vocal tract holding a small volume of air which vibrates faster (Ladefoged 2001b:43). Thus children produce vowels which have higher formants than the vowels produced by females and females produce vowels which have higher formant values than those produced by male speakers (Ibid).

The type of preceding and following consonants also has an effect in changing the formant frequency values. Ladefoged and Maddieson (1996) presented data from Choi(1991) and showed that the assimilatory effects of the semivowels /**j**/ and /**w**/ lowers F1, whereas uvular and pharyngeal consonants result in vowels having higher F1 due to their lowering effect (Ladefoged and Maddieson 1996:286-287). Dialectal variations (be it sociolectal or regional) also have effects on the formant values, and in many cases can have effects similar to those that are seen between two different languages (Rosner and Pickering 1994).

On the other hand, for a given vowel in a certain word, the rate of speech and other momentary variations could cause minor variations in the formant values, and hence could not be considered to be potential causes of variations of formant values (Rosner and Pickering 1994).

The articulatory to acoustic mapping of vowel features was studied by Lindblom and Sundberg (1971). They conclude that (1) F1 increases as the jaw opening grows larger, and as the tongue approximates the pharyngeal cavity; (2) F1 decreases as the tongue approximates the palate; (3) F2 increases as the tongue approximates the palate,when the tongue shape is modified to create constrictions in the vocal tract, and when there is less rounding; (4) F2 decreses as the tongue approximates the pharynx and when the vowel is rounded (Lindblom and Sundberg 1971).

2.1.1.2 Stop Production in the Source-filter Theory

For a stop (other than a glottal stop) to be produced, there should be a closure somewhere in the vocal tract. The number of closures varies as per the type of airstream used. For simple pulmonic stops, there will be just one closure at the glottis (for the glottal stop) or at any of the possible places of ariculation in the supralaryngeal tract. Double stops such as / **p**/and /**g͡b**/ involve two obstructions in the supralaryngeal tract. For stops produced by glottalic airstream, there are two closures: one at the glottis and another at the supralaryngeal tract. For stops produced by velaric airstram, there are two cosures: one at the velum and another somewhere in the vocal tract. The source-filter theory of speech production is best explained taking the case of simple pulmonic stops.

The source for the production of stops is the transient noise excitation that is created by the total closure of the vocal tract by the articulators (Shadle 1997). The compressed air behind the closure will be released into a burst creating a turbulent noise which is transient in nature. Most stops have a burst lasting between 10 and 50 ms (Fry 1979). This burst will have its own spectral shape due to the resonance characeristics of the vocal tract.

2.1.2 The Perturbation Theory of Speech Production

The perturbation theory of speech production (Chiba and Kajiyama 1941) explains that the formant frequencies are determined by the constrictions in the vocal tract and in doing so the kinetic energy that is found at the points of maximum velocity and the potential energy found at the points of maximum pressure play very important roles. Johnson (2003: 110) summarizes it as follows.

> If the vocal tract is constricted at the point of high kinetic energy (velocity maximum), air particle movement is impeded, and consequently the frequency of the movement decreases; while, on the other hand, if the vocal tract is constricted at a point of high potential energy (pressure minimum), air particle movement is enhanced, and consequently, the frequency of the movement increases.

Two rules of thumb have been derived from this relationship, and they have different applications for each of the formants. The rules are "*Constriction of the vocal tract near a point of maximum velocity lowers the formant frequency*" whereas "*constriction of the vocal tract near a point of maximum pressure raises the formant frequency,*" (Johnson 2003: 110). Using a uniform tube to calculate resonance frequencies, Chiba and Kajiyama (1941) state that maximum velocity is found at the lips for F1, the lips and pharynx for F2, and the lips, the soft palate and the pharynx for F3. They also established that the point of maximum pressure has minimum velocity and vice versa. So taking a low back vowel, its F1 will be high because the constriction is located near the pharyngeal cavity where there is minimum velocity, meaning maximum pressure. The F2 of the same vowel will be lower than it will be in a vocal tract configuration with no constriction because the constriction happens near the pharyngeal cavity where there is maximum velocity, meaning low pressure.

In the perturbation theory, constrictions in the vocal tract are calculated taking the analogy of a uniform tube. If there is a small perturbation of a uniform tube at some point, one or more formants could be affected differently. Schroeder (1967) concludes that it is possible to affect only one formant at a time by having a small perturbation of the area of a uniform tube. Heinz (1967) showed that it is possible to calculate the formant frequencies of area perturbations for non-uniform or arbitrary area functions. In later developments, the relationship between formant frequency variations of any given formant and small local spatial variations has been worked out (Fant 1975, 1980).

2.1.3 The Quantal Theory of Speech

The quantal theory of speech was proposed by Stevens (1972). The theory states that there is a quantal relationship between the articulators' action and the acoustic signal. It explains that in certain regions of the vocal tract, large acoustic changes are results of small articulator displacement while small changes in the acoustic signal may be related to large changes in other cases of articulator placement. In other words, there are regions of stability where the acoustic signal, for instance, formant values of vowels, remain relatively stable even when there is a large change in the articulatory configuration. In another region, small changes in the articulatory movement will result in a bigger change of formant values.

The quantal theory of speech has implications for the type of speech sounds that languages prefer. Accordingly, in the vowel systems of the languages of the world, /**i**/, /**a**/ and /**u**/ are described as the most preferred vowels.[7]

2.2 Articulatory and Acoustic Description of Vowels

The production of vowels involves no significant obstruction of airstream in the vocal tract (Ladefoged 2001a). Thus, articulatory description of vowels bases itself on the height of the body of the tongue, the part of the tongue that rises above the normal rest position (the

[7] This is not the only reason why these vowels are preferred. Perceptual contrast and articulatory extremity would lead to the same preference.

front-back position) and the condition of the lips (degree of lip rounding) (ibid). Based on the height of the tongue, vowels are classified as high, high-mid, low-mid and low or just high, mid and low depending on the distribution of vowels in the vowel space of the language in question. Vowels are classified as front, central or back depending on the part of the tongue that rises above the normal rest position. Thus, the traditional terms high versus low, front versus back and rounded versus unrounded are most widely used parameters for most vowel systems of the languages of the world (Ladefoged and Maddieson 1996).

The representation of vowel height has been one of the points of discussion for phoneticians. Chomsky and Halle (1968) recognize three heights of vowels- high, mid and low. The cardinal vowels of Jones (1956) have four heights - high, high-mid, low-mid and low. Lindau (1978) in her summary of the features of vowels around the world also concluded that four vowel heights are enough to account for all contasts in any given language. The IPA's (2005) representation of reference vowels suggests seven vowel heights. Ladefoged and Maddieson (1990, 1996) however argue that no language utilizes the seven distinct heights and suggest there could be a maximum of five vowel heights in a language. On the contrary, the three-level distinction of vowel backness, namely front, central and back have been a point of agreement among phoneticians.

In acoustics, vowels are best identified by their formant centre frequencies. In the articulatory-to-acoustic mapping of vowel features, different acoustic properties represent the height and backness of vowels. One way of representing height is using F1 centre frequencies (Ladefoged and Maddieson 1990, 1996, Ladefoged 2001a, b). Another way of representing height is using the diffrence between F1 and F0 as studies in perception of openness of vowels showed (Traunmüller 1981).

The acoustic representation of the front-back distinction, however, has two different approaches. Ladefoged and Maddieson (1990, 1996) hold that the front-back distinction of vowels is best captured by the difference of the F1 and F2 (F2-F1). Many phoneticians, including Ladefoged himself, use F2 only instead of the difference of the F1 and F2 (F2-F1)

(Hillenbrand, et al. 1995, Ladefoged 2001b, Gordon and Maddieson 2004). Ladefoged (2001b) however differs in one aspect: he uses a non-linear (mel) scale of the F2 representation.

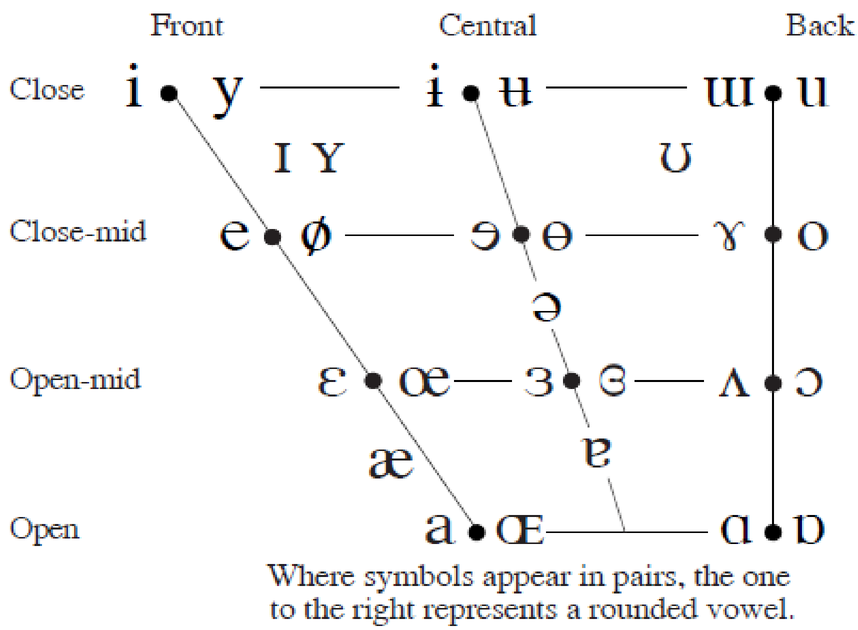

Fig. 2.1: The IPA (2005) vowel chart.

In the drawing of vowel chart using the formant values, F1 is plotted on the vertical axis and F2 is plotted on the horizontal axis. The origin of the plot is put at the top right of the plot so that when one goes from left to right and from bottom to top the F2 and F1 values decrease. As an illustration, Fig. 2.2 presents an F1-F2 plot of the seven Amharic vowels.

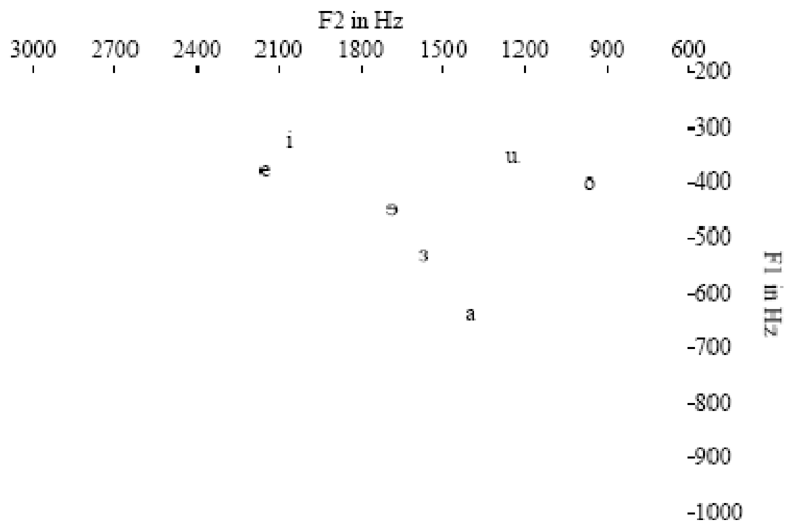

Fig. 2.2: F1-F2 plot of the seven Amharic vowels, data taken from a 46 year old male native speaker of Amharic. The vowels were recorded in /**t** V **t**/ context.

One point that should be noted in the comparison of the IPA vowel chart and the F1-f2 plot is that the IPA vowel chart is produced as a reference and is based on equidistant classification of height and backness. The acoustic/auditory hapezoid is not based on equidistant classification of height and backness, but depending on actual formant values. Thus a complete match is not expected between the articulatory and acoustic representations of the vowel system.

2.3 Previous Studies on Vowels

One of the earliest acoustic studies on vowels is that of Peterson and Barney (1952). They recorded ten vowels of the American English vowels in /**h**V**d**/ context from 76 speakers (men, women and children) and reported mean values of F0, F1, F2 and F3 values. They also plotted F2 versus F1 and showed points of overlap of formant values. Their results show that there is some overlap between [**ɛ**] and [**ɝ**], [**ɝ**] and [**ʊ**], [**ʊ**] and [**u**], and [**ɑ**] and [**ɔ**]. They also reported that children had higher formants followed by women and then men.

Hillenbrand et al. (1995) replicated Peterson and Barney's (1952) study of vowels with a more elaborated procedure which Peterson and Barney (1952) lacked. Hillenbrand et al.

(1995) tried to control dialectal differences and included duration measurements. They reported that the vowels occupy similar position in the F2-F1 plot of both Peterson and Barney and their own data; however, there were differences in average formant values and the degree of overlap among adjacent vowels. The duration of the vowels measured in a wordlist were two-thirds longer than those measured in connected speech as reported by Black (1949) but had strong correlation (r=0.91) with the connected speech data. Men had shorter duration of vowels than both children and women. The F0 values differ in few Hz's for men and women from that of Peterson and Barney (1952), but children showed a difference of 26 Hz lower than the results for children in Peterson and Barney (1952). They reported that formant values taken from the static state alone resulted in poor discrimination results compared with that of Peterson and Barney (1952) whereas including duration and spectral change information increased the accuracy of discrimination.

2.4 Previous studies on Amharic Vowels

Most of the studies that have been conducted on Amharic vowels are impressionistic. Gankin (1969), Mulugeta (2001) and Baye (1994, 2008 and 2010) agree that Amharic has seven vowel phonemes (see Fig. 1.1).

Cowley et al. (1976) also agree that Amharic has seven vowels, but use the symbols **/ə/** for the 'high central vowel' and claim that what Baye (1994, 2008 and 2010) calls the 'mid central vowel' is a low-mid front vowel and thus use the symbol **/ɛ/**. The choice of appropriate phonetic symbols for the two central vowels has been a source of confusion for a long time. There are also studies that put the number of Amharic vowels less than or greater than seven. Hetzron (1964) and Hayward (1986) claim that the highest central vowel **/ɨ/** is not phonemic and as it is used as an epenthetic vowel. Cohen (1970) adds the vowel **/ɔ/** as an independent vowel though it only comes as a variant of **/ə/** when it comes after **/w/**.

Few experimental studies have been conducted on Amharic vowels. The first experimental study that can be cited for Amharic vowels is that of Sumner (1957). Sumner (1957), taking a single male subject, measured the duration of Amharic vowels in different contexts using the electrokymograph and reported the following results. On the vowels of Amharic, Sumner agrees that there are seven vowels: /**o**/, /**a**/, /**i**/, /**u**/, /**ɛ**/, /**je**/ and /**ə**/. (He considered /**e**/ to be /**je**/). He also represented /**ɜ**/, the first order vowel or schwa with /**ɛ**/ and /**ɘ**/, the so called high central vowel with /**ə**/. He reported that Amharic vowels were longer before simple consonants than before geminates, and the longest vowel in all contexts was /**o**/ followed by /**je**/, /**a**/, /**i**/, /**ɜ**/, /**u**/, and /**ə**/.

Abebayehu (2007)[8] conducted a study on Amharic vowels in his attempt to describe Amharic vowels produced by a person with flaccid dysarthria. Abebayehu reported the following values of F1, F2 of six male speakers who speak the Addis Ababa variety.

Table 2.1: Mean formant values of Amharic vowels (Abebayehu 2007: 23).

Vowel	F1	F2
i	271	2145
e	423	1965
ɨ	312	1483
ä[9]	466	1502
a	696	1255
o	378	1010

[8] The number of tokens, procedure and the phonetic environment in which the vowels were put are not described, and thus cannot be commented on.

[9] Abebayehu (2007) used this symbol instead of the schwa [**ə**], and refers to it as the mid central vowel.

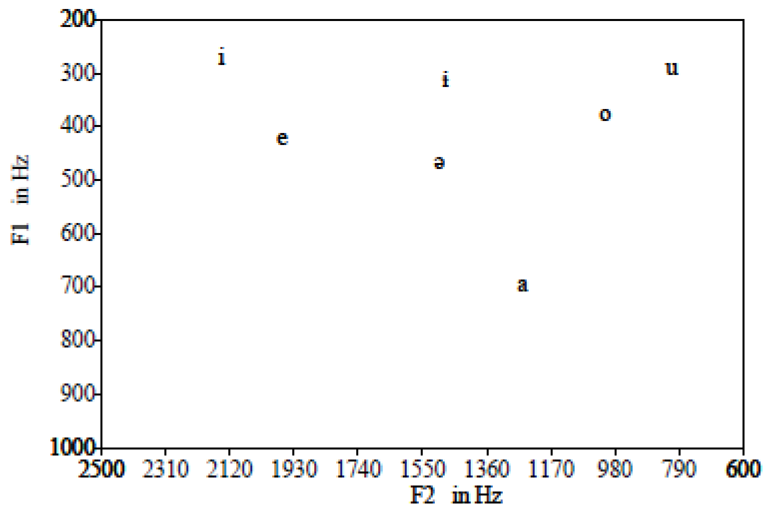

Fig. 2.3: F1-F2 plot of Amharic vowels (Average of six male speakers, Ababeyehu 2007: 23).

The F1-F2 plot of the mean formant values of the vowels reported by Abebayehu (2007) are very close to the articulatory description of the Amharic vowel presented in Fig. 1.1.

Hayward (2000:151) presented an F1-F2 plot of a single male Amharic speaker speaking the Gondar variety. She took monosyllabic words and plotted the average of four tokens for each vowel.

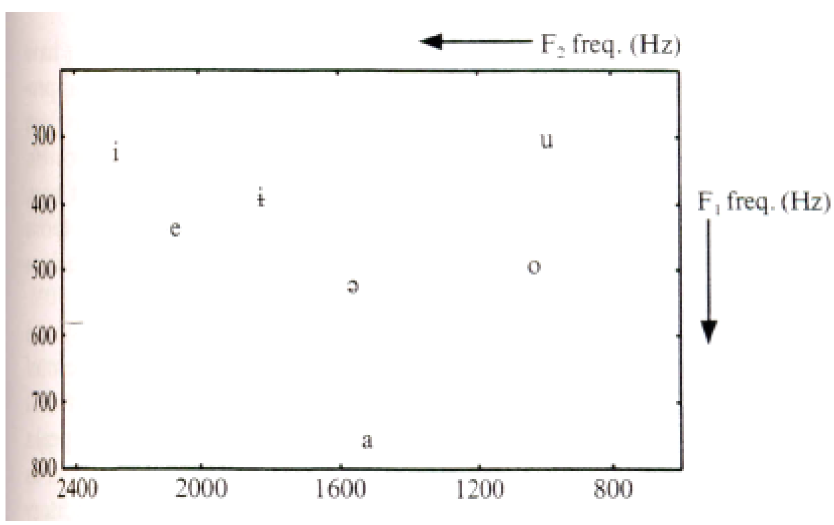

Fig. 2.4: F1-F2 plot of a male Amharic speaker of the Gondar variety (Hayward 2000: 151).

As it can be seen in the above figure, her plots have some slight differences with that of Abebayehu (2007) : [**o**] has higher F1 and [**a**] has lower F2 than they have in Abebayehu (2007)

Nadew (2008) recorded 800 tokens of the seven Amharic vowels from 12 Amharic speakers and analyzed them using Colea (a speech analysis interface developed in Matlab) to use the formant values as an input for his formant-based speech synthesizer. He used a wrong filter order in extracting the formants, and thus his results could not be considered for discussion.[10]

In this study, I have used the symbol **/ɘ/** for **/ɨ/** (what has been described as the high central vowel in earlier studies) and the symbol **/ɜ/** for **/ə/** (what has been described as the mid central vowel in earlier studies) for Amharic vowels for reasons that are explained in Section 4.1.

2.5 Articulatory and Acoustic Characteristics of Pulmonic and Ejective Stops

Stops can be produced in three airstream mechanisms: the pulmonic, glottalic and velaric airstreams. Thus, the description of how stops are produced differs as per the airstream mechanism involved. In this study, only the pulmonic and glottalic airstreams are considered because Amharic stops are produced using these two airstream mechanisms.

Stops produced by the pulmonic airstream mechanism, in terms of articulation, are defined as sounds that are produced by a complete closure of the air passage in the vocal tract mainly in the oral cavity (Ladefoged 1975, Laver 1994). In glottalic stops, specifically ejectives, there will be a simultaneous closure of the glottis, which will be followed by the raising of the larynx (Catford 1977), which results in a high oral pressure at the release of the closure.

[10] For instance he reported an average F1 value of 907 Hz for the high front vowel [**i**], but this value is appropriate only for low vowels. Nevertheless, he reported that 88.85 % of all the vowels synthesized were recognized by listeners.

Depending on whether there is a simultaneous velic closure or not, then, the stops are classified as oral stops (when there is velic closure) and nasal stops (when there is velic opening) (ibid). Most phoneticians use the term stop to refer to the oral stops and the term nasal to refer to the nasal stops (Ladefoged 2001a: 10). Pulmonic stops have been described to include trills, flaps and taps (Laver 1994). In this study, the term stop will refer to only the oral stops, and even so excluding the trills, taps and flaps.

The articulation of a stop sound has three phases: the onset or closing, closed and release or offset phases (Laver 1994:205). The onset phase refers to the state at which articulators move towards closing the air passage. The closed phase refers to the moment that starts with a complete closure of the air passage by the articulators up to the moment at which the articulators move back opening the air passage. The final phase, the release (offset) phase, starts at the moment the air that has been held up by the closure starts to move as soon as the articulators open the air passage. During this final stage, the release is accompanied by a kind of plosion in the vocal tract, but this plosion may or may not be audible (Catford 1968). The term 'plosive' is used to refer to stops due to this plosion that occurs during the release phase.

There are eight places of articulation, which are place neutral, for stops[11]: labial, dental, alveolar, palatal, velar, uvular, epiglottal and glottal (Laver 1994: 206). Labial, alveolar and velar places of articulation are the most common places for stop production in the languages of the world (Laver 1994).

Stop articulations are also made using the glottalic and velaric airstream mechanisms in addition to the common pulmonic airstream mechanism. Ejectives and implosives are those

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[5] There are also displaced stop articulations such as liguo-labial, labio-dental, and there are also double stop articulations. For details, see Laver, 1994.

stops made with a glottalic airstream mechanism whereas clicks are stops produced with velaric airstream mechanism (Ladefoged 2001a).

In terms of the laryngeal setting, stops can be produced as voiceless unaspirated, voiceless aspirated, modally voiced, breathy (murmur), slack voice, stiff voice and creaky voice (Laver 1994, Ladefoged and Maddieson 1996).

In acoustics, the description of stops bases itself on different parameters. During the closure stage, the spectrogram of both pulmonic and ejective stop consonants shows absence of energy except voiced stops, which show voice bars at the lower frequencies. The release or burst of stops is seen as transient energy that lasts for a short period of time, which is followed by aspiration and frication depending on the type of voicing investigated in a given language. Both pulmonic and ejective stops have bursts that have high energy concentrations in all frequency ranges depending on place of articulations.

In addition to these different phases, when followed by vowels, each stop has a different pattern of F1 and F2 transitions to the next vowel, and these transitions are also different for each of the vowels that follow the same stop.

2.6 Previous Acoustic Studies on Stops

Stops are one of the most studied classes of speech sounds. Extensive experimental studies have been conducted to identify the acoustic characteristics of stops and attempts have been made to identify acoustic cues that identify different places and manners of articulation among stops. The following section presents the different acoustic cues studied for stop classification.

2.6.1 Durational Measurements of Stops

Different durational aspects of stops have been measured in the quest to identify the acoustic cues that identify different types of stops.

Closure duration: This is the duration of the consonant before the burst or release. In Danish, for instance, labial stops had the longest closure duration followed by velars and alveolars in monosyllabic words (Fisher-Jørgensen 1964). Falc'hun (1951) found that the closure for the voiced bilabial stop was longer than for the voiced alveolar and velar stops in intervocalic position in Breton. In the same study, the voiceless bilabial stop had a shorter closure than the voiceless alveolar and velar stops. In other languages closure duration was found to have no role in identifying the different manners of stops as reported by McDonough and Ladefoged (1993) in Navajo, Warner (1996) in Inguish and Wysocki (2004) in Georgian.

Stathopoulos and Weismer (1983) found a pattern [**p**] > [**t**] > [**k**] and [**b**] > [**d**] > [**g**] in terms of closure duration for English stops in nonsense words. Maddieson (1997) cites Ren (1985), Elert (1964) and Vagges et al. (1978) in Chinese, Swedish and Florentine Italian respectively, and reports that the pattern was the same though the stops studied were not in the same environments for all the languages mentioned.

On the other hand, Byrd (1993), on her study of stops in the TIMIT database, found the pattern [**p**] > [**k**] > [**t**] and [**b**] > [**g**]> [**d**] in terms of closure duration for English. This finding shows that there are cases where the coronal stops have shorter duration than both the velar and bilabial stops.

Two explanations are given for the effect of place on closure duration. The first one is connected to the pressure in the cavity behind the closure. Larger cavity means longer time for the pressure to build and reach equilibrium while smaller cavity means a shorter time to build pressure and reach equilibrium. This suggests stops produced in the front part of the mouth will have longer closure duration than those produced at the back of the mouth (Maddieson 1997).

Another factor explained to have effect on closure duration is the compressibility of the articulators. Maddieson adds,

> Bilabials are formed by closure between two soft surfaces which undergo a good deal of compression as they contact, velars involve contact between two somewhat compressible articulators–the tongue back and the soft palate, whereas dentals and alveolars involve a hard surface on one side of the contact. When the upper articulator is a yielding surface, there is likely to be a less rapid rebound from the ballistic movement that creates the contact, just as a ball bounces back more rapidly from a hard surface than a soft one (1997:631).

However, the patterns may differ because of considerations of different positions for stops, language specific issues and other factors which affect duration (Maddieson 1997:631).

The closure of stops can be totally voiceless, partially voiced or totally voiced, specifically after vowels. In the case, the voiced part of the closure as well as the percentage of the voiced part of the closure to the total closure can be considered separately to identify stops into different categories. In Georgian, Vicenik (2008) found that ejective stops had longer duration of voicing into the closure than aspirated stops, but short duration of voicing into the closure than voiced stops had. This can be easily understood from the articulators' mechanism. For voiceless aspirated stops, the vocal folds are fully spread. For ejectives the glottis has to be closed, so some voicing will continue while the pressure drop runs out so that the vocal cords are shut tightly. For voiced stops the speaker will make an effort to keep the pressure drop alive.

Voice onset time: This refers to the duration of the part of the stop from release of the closure up to the onset of voicing or vibration of vocal folds. Because voicing may start before the burst in voiced stops, they can have negative voice onset time (VOT hence forth) while voiceless stops have positive VOT since the measurement starts from the stop burst up to the onset of voicing of the following vowel. Lisker and Abramson (1964) found that VOT helped to distinguish between stops in different languages, specifically in isolated words. Since then a lot of studies have been conducted on the VOT of stops, both pulmonic and glottalic, and interesting results have been found. VOT values have been found to be longer for ejectives than for voiceless unaspirated pulmonic stops but shorter than for voiceless aspirated pulmonic stops. In Witsuwit'en, Wright and Davis (2002) found a mean VOT of 59 ms for /**tʰ**/, 33 ms for /**t'**/ and 18 ms for /**t**/.

The contrast of VOT values due to place of articulation has been one of the well-known findings in various languages. One finding on VOT values is the increasing VOT values as one goes from front to back in the oral cavity (Fischer- Jørgensen 1954, Peterson and Lehiste 1960, Keating et al. 1980, Crystal and House 1988, Stathopoulos and Weismer 1983 and Ren 1985)[12].

Several explanations have been provided to account for the increasing VOT values as one goes from front to back in the oral cavity. The following factors have been summarized by Cho and Ladefoged (1999:213).

- *The volume of the cavity behind the point of constriction: The relatively smaller volume of the supralaryngeal cavity behind the closure for velar stops causes a greater pressure, which will take longer to fall and allow an adequate transglottal pressure for the initiation of the vocal folds vibration.*
- *The volume of the cavity in front of the point of constriction. The relatively greater mass of the contained air in front of velar stops causes a greater obstruction to the release of the pressure behind the velar stop, so that this pressure will take longer to fall, resulting in a greater delay in producing an adequate transglottal pressure.*
- *The movement of articulators. A faster articulatory velocity (e.g., the movement of the lower lip as compared to the tongue dorsum) allows a more rapid decrease in the pressure behind the closure and thus a shorter time before building up an appropriate transglottal pressure.*
- *Extent of articulatory contact area. The more extended contact area in laminal dental and velar stops results in a slower release because of the Bernoulli Effect pulling the articulators together. Because the articulators come apart more slowly, there is a longer time before an appropriate transglottal pressure is produced.*
- *Change of glottal opening area (for voiceless aspirated stops). The glottal opening area after the release will decrease less rapidly for the velar than for the alveolar or labial stop because the intraoral pressure drops more slowly for the velar stop.*

[12]These researches are presented as cited by Anderson and Maddieson (1994) and Cho and Ladefoged (1999).

- *Temporal adjustment between closure duration and VOT. There is a trade-off between the closure duration and the VOT so that there is a fixed duration of vocal fold opening.*

Voicing lag: It is the duration of stops starting from the onset of the burst up to the onset of voicing of the following vowel. For voiceless stops, voicing lag is the same as VOT, but for voiced stops, it may not be the same as VOT as voiced stops often had lead VOT as voicing can start before the burst. Thus while VOT values could be negative or positive for voiced stops, voicing lag values are always positive.

Amplitude rise time: Unlike voicing lag and VOT the amplitude rise time is measured for the vowel following a stop. Amplitude rise time refers to how fast the vowel reaches its local peak amplitude after vowel onset. Among other acoustic characteristics, amplitude rise time has been used to classify ejectives as slack and stiff: slack ejectives having slow rise time whereas stiff ejectives having fast amplitude rise time (Kingston 1985). Russell (1997) citing Munro and Nearey (1988) and Darwin and Pearson (1981) reported that rise time was found as a distinguishing acoustic cue between /**p**/ and /**b**/ in French and voiced and voiceless stops in English respectively.

2.6.2 Burst Spectral Shape Measurements

Burst spectral shape differences have been used to identify place differences among stops in the same language as well as between stops of different languages. According to Fant (1960), stops have different spectral shapes based on the front cavity beyond the point of obstruction, and this means that the burst spectra gives us information on the size and shape of the vocal tract area in front of the obstruction. Blumstein and Stevens (1979) reported that labial, alveolar and velar stops have different spectral shapes. Forrest et al. (1988) presented a numerical way of expressing spectral shapes and identified four important measures of the spectrum to be important in the study of burst spectral shapes: the spectral mean frequency, spectral standard deviation, skewness and kurtosis. Spectral mean measures the average frequency on which energy is concentrated. Spectral standard deviation measures the spread of the frequency around the mean. Skewness measures to what extent the distribution is symmetrical. Kurtosis measures how peaked the spectrum is.

Stoel-Gammon at al. (1994) used the four spectral measurements and tried to differentiate between alveolar and dental stops. Comparing American English and Swedish stops, they found that American English stops had smaller standard deviations and higher kurtosis than Swedish stops, meaning that American stops had more compact and peaked spectra than Swedish stops.

2.6.3 Amplitude and Intensity Measurements[13]

There are different amplitude and intensity measurements that are made to see the difference between stops of different manners. The following are some of the common measures used in analyzing stop sounds.

Burst amplitude/intensity: This measurement refers the amplitude/intensity of the stop burst relative to the following vowel. In their research on English stops, Keating et al. (1980) stated that alveolars had an early amplitude peak after release of closure while the peak of velars occurred later on in English. Because of the high subglottal pressure, which is twice than for pulmonic stops, ejective stops are described to have greater amplitude in the stop burst (Ladefoged and Maddieson 1996).

Relative burst amplitude/intensity: This refers to the amplitude/intensity of the stop burst relative to the amplitude of the following vowel. Earlier studies used the root mean squared (henceforth RMS) amplitude of the burst divided by the RMS amplitude of the vowel, and this was expressed in a ratio. A study conducted on Malayalam by Jongman et al. (1985) reported that alveolar stops had a louder burst than dental stops had. They also claimed that it is possible to use relative amplitude to differentiate inter- as well as intra-language

[13] Amplitude and intensity are different but related measures. Amplitude is the energy of a sound wave present, or the magnitude of maximum disturbance of the air during one cycle of a periodic wave, known as peak deviation. Intensity is the power present over an area. Thus, intensity is the amplitude over time over an area.

differences between stops, but also reported individual speakers showed differences in the number of tokens they identify as dentals or alveolars.

Absolute dB rise from vowel onset to vowel maximum: This measure is conducted on the vowel following a stop. It is the difference between the peak amplitude/intensity and the onset amplitude/intensity of the vowel after the stop. The peak considered for this type of study is the left most peak, also called the local peak. Russel (1977) reported that in Mam at dental, velar and uvular places, absolute dB rise differentiated glottalic from pulmonic stops: at all the places mentioned, the vowels following glottalic stops had large absolute dB rise than those following pulmonic stops.

2.6.4. Voice/Phonation/ Measurements

In languages which contrast stops having different phonation types such as aspirated and unaspirated or airstream mechanisms such as pulmonic and glottalic, different measures that help to see the mode of phonation are employed. These include F0 and jitter measurements.

F0: The F0 of the following vowel has been found to be one of the acoustic cues differentiating voiceless from voiced stops and ejectives from pulmonic stops. Two types of F0 studies have been used in the experimental investigation of stops.

One F0 measurement is the F0 at the vowel onset. Maddieson (1997) states that there is a universal tendency for F0 of vowels following voiceless stops to be higher than the F0 of vowels following voiced stops. Different factors are said to have the combined effects of lowering F0 after voiced consonants and raising F0 after voiceless consonants: "*lowered larynx position, aerodynamic effects of a supraglottal constriction, and devoicing strategies that involve tensing the vocal folds*" (Maddieson 1997:629). Maddieson claims that, "In no case F0 be higher after a voiced consonant than after a voiceless one" (Ibid).

In Witsuwit'en, Wright et al. (2002) found that male and female speakers had different patterns on F0 values of vowels after ejectives. For males, the vowels had their F0 raised by

8 Hz whereas for females, the vowels after ejectives had their F0 lowered by 22 Hz. In Georgian, Vicenik (2008) reported the same results, i.e. women had lower F0 at the onset of the vowel following ejectives while men had higher F0 on the vowel onset following ejectives.

Another measure of F0 is the F0 perturbation[14], which is the difference between the onset and the middle F0 of the vowel following a stop. This measure is conducted to normalize individual differences.

Jitter: It is a voice measurement that shows how periodic the sound wave is. This is the average absolute difference between consecutive periods, divided by the average period. The most common jitter measurement is what is known as the local jitter and is usually expressed as percentage (Boersma and Weenink 2010). The local jitter is defined as the relative mean absolute second-order difference of the point (= the first order difference of the interval process). For modal voice the jitter is low, but for creaky voice the jitter becomes higher. Jitter can be measured at the onset of the vowel following a stop consonant. To normalize individual differences, jitter perturbation (= Δ jitter) is measured as the difference between the jitter at the onset and middle of the vowel following a stop consonant. In many languages, vowels preceded by voiceless unaspirated stops have been found to have lower jitter perturbation values, whereas vowels preceded by ejectives and voiceless aspirated stops have been found to have higher jitter perturbation values (Wright et al. 2002, Ham 2007. Warner (1996) found that vowels following ejectives had aperiodic component that is several periods long on the onset.

2.7 Amharic Stops

Amharic has both voiceless and voiced pulmonic stops plus three ejective stops. It also has a series of labialized velar stops in addition to the simple stops. The following table shows the stops of Amharic.

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[14] It is also possible to represent F0 perturbation with ΔF0, change in the F0 of the vowel onset and middle following a stop.

Table 2.2: Inventory of Amharic stops.

Airstream	**Voice**	**Place**			
		Bilabial	Alveolar	Velar	Glottal
Pulmonic	Voiceless simple Voiceless labialized	p	t	k kʷ	ʔ
	Voiced simple Voiced labialized	b	d	g gʷ	
Ejective	Voiceless simple Voiceless labialized	P’	t’	k’ k’ʷ	

Of the 13 stops of Amharic, [**p**] and [**p’**] are found in loan words: /**p**/ mainly from English and perhaps from Italian as well and /**p’**/ from Greek. The bilabial stop [**b**] always has a very weak burst when preceded by a vowel. All the stops except [**ʔ**] can occur as geminate in word intervocalic and final positions. Amharic has, as can be seen from Table 2.2, three ejectives, only two of which have a high frequency of occurrence. Thus, except for the glottis, there is a three-member contrast in the bilabial, alveolar and velar places of articulation.

2.7.1 Previous Works on Amharic Stops

Very few acoustic and aerodynamic studies have been conducted on Amharic. Sumner (1957) conducted an experimental study on Amharic on a single speaker using the electrokymograph. His data show that, among stops, [**t’**] was the longest followed by [**k’**], [**k**], [**g**], [**t**], [**b**], [**d**] respectively. This shows that the ejectives had longer duration than the voiceless pulmonic stops and the voiceless stops had longer duration than the voiced stops.

Demolin (2001) studied both acoustic and aerodynamic characteristics of stops and fricatives, comparing the pulmonic and ejectives ones. According to Demolin (2001), ejective stops had higher amplitude burst than pulmonic stops.[15]

[15]Details of the results could not be presented here because I was unable to find the full text of the article.

CHAPTER THREE
METHODS AND PROCEDURES OF THE STUDY

3.1 Methodology

3.1.1 Selection of the Language

Amharic was selected for this phonetic investigation purposefully because a study like this on Amharic, the functionally dominant language in the Ethiopian context, and for which there is a lot of morphological and syntactic literature, will make it available for various technology related purposes such as text-to-speech translation[16], speech synthesis and speech recognition.

3.1.2 Selection of Subjects

This study will focus mainly on the Addis Ababa variety of Amharic because, if the results of this study are to be applied in speech synthesis, text to speech or speech to text translation, it has to be on the variety that is mainly used in the media and official business. Thus, native speakers of Amharic from Addis Ababa were selected. The selection of subjects was purposeful because random selection of subjects could have caused collection of wrong data in cases where subjects have various speech defects (either in the articulatory or perceptual apparatus). The subjects selected were therefore those who did not have any history of speech disorder, who had normal speaking and listening habits of Amharic, who were mother tongue speakers of Amharic, who did not speak any other Ethiopian language besides Amharic, and who had not lived outside Addis Ababa at all. Four male and four female subjects between 22 and 34 years of age were selected for the purpose of this

[16] Text-to speech translation can be done without making speech analysis in the approaches that are not rule based.

study, which is beyond the minimum requirement of three male and three female speakers (Ladefoged 2003).

3.2 Stimuli

The subjects were presented with word and sentence lists containing real and nonsense Amharic words written in the Ethiopic script. For the purpose of studying the acoustic characteristics, mainly F0, F1, F2, F3 and spectral shapes of Amharic vowels, the following contexts were used.

1. Real words: /**t** V **t**/ i.e. between the consonant /**t**/.
2. Nonsense-words: /**t** V **t**/ i.e. between the consonant /**t**/. The nonsense words are made with the sound /**t**/ followed by each of the seven vowels as it appears in the Amharic alphabet.[17] The /**t** V **t**/ context was arrived at by doubling each character. If we take an instance, for the first vowel, the nonsense word will be /**tɜtɜ**/.
3. In a carrier sentence containing the real words. /**jəh k’al̞**__________ **nɜw**/ ‘This word is __________.’
4. In a carrier sentence containing the nonsense words: /**jəh k’al̞**__________ **nɜw**/ ‘This word is __________. ’

The duration of Amharic vowels was measured in different contexts: before voiced and voiceless stops, before singletons and geminates. Thus, real words that contrast vowels before voiced and voiceless stops as well as geminates and singletons were selected. All the words were recorded both in a wordlist and a carrier sentence.

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[17] The Amharic alphabet for /**t**/ runs as follows:

ተ	ቱ	ቲ	ታ	ቴ	ት	ቶ
tɜ	**tu**	**ti**	**ta**	**te**	**tə**	**to**

So the subjects were presented with the following nonsense words: /**tɜtɜ**/, /**tutu**/, /**titi**/, /**tata**/, /**tete**/, /**tətə**/, /**toto**/. Based on the order in which the vowels appear in the alphabet, /**ɜ**/ is called the first order vowel, /**u**/ is the second order vowel and the list goes on up to /**o**/, which is the seventh order vowel.

Table 3.1: List of Amharic words used in the analysis of the duration of Amharic vowels before and after voiceless and voiced consonants.

/t-t/		**/t-b/**	
Word	**Gloss**	**Word**	**Gloss**
/tɜtɜwɜ/	'it was left'	**/tɜbaj /**	bug'
/abetuta/	'complaint'	**/səntu bat/**	'how many of the calves(part of leg)'
/titɜr/	'stamp'	**/tibi/**	'tuberculosis'
/tatari/	'hard working'	**/tabot/**	'ark'
/tetanɜs/	'tetanus'	**/əntebe/**	'Entebbe'
/tətɜw/	'let her leave (it)'	**/təbəs/**	'she would be more ---'
/total/	'name of company'	**/mɜto bər:/**	'one hundred Birr'
/b-t/		**/d-d/**	
Word	**Gloss**	**Word**	**Gloss**
/bɜtɜra/	'in turn (turn by turn)'	**/səndɜdo/**	'thick plaiting reed'
/bute/	'name of a person'	**/dudba/**	'heavy rain'
/bitɜw/	'if he leaves(it)'	**/dida/**	'dump'
/batɜle/	'busy'	**/lɜgɜdade/**	'name of a place'
/betɜl/	'name of a place'	**/dedo/**	'name of a place'
/bətɜw/	'if I leave (it)'	**/afɜndəda/**	'she having bent forwards'
/botaw/	'the place',	**/əndod/**	'phytolaca dodecandra' (a plant whose fruit is used as detergent or soap)'

Six of the seven vowels of Amharic were put in wordlists and sentences containing each of the vowels in a context of before a singleton and a geminate consonant.[18]

Table 3.2: Singleton and geminate words used in the analysis of the duration of Amharic vowels.

Word	**Gloss**	**Word**	**Gloss**
/gɜdɜbu/	'the limit'	**/gɜd:ɜbu/**	'they made a dam'
/dubaj/	'Dubai'	**/dub:alɜ/**	'name of a person'
/dibaba/	'name of a person'	**/bib:al/**	'if it is said so..'
/adaba/	'name of a place'	**/dab:a/**	'skin of cattle'
/dəbən/	'beer (accusative case),	**/dəb:ən:/**	'to become furious'
/gosa/	'clan'	**/gos:əm/**	'hit the drum'

For the purpose of studying the acoustic characteristics of Amharic pulmonic and ejective stops, each stop was placed in word-initial and word-medial positions preceded and

[18] The vowel /**e**/ is not included in this study because real words contrasting a geminate and singleton consonant after /**e**/ couldn't be thought of by the time of data collection. However, it is possible to have this vowel in real words before geminates, such as in /***ses:ɜnɜ***/ 'he has fornicated' and before singletons, such as in /***k'esu***/ 'the priest'. The problem was to find the vowel before consonants that differ only in gemination.

followed by the low central vowel /**a**/. All the stimuli consisted of real words. It was not possible to find real words that contain the two bilabial stops /**p**/ and /**p'**/ at the medial position in the same context by the time of the data collection, and thus it was not possible to see these stops in word medial positions. Though, phonemically /**b**/ appears in word medial position, its phonemic realization did not show any clear and audible burst, and as a result it was excluded in the word medial position. The following words were used to collect the data on the stops.

Table 3.3: List of words used in the analysis of initial and intervocalic stops.

Word initial position		**Intervocalic position**	
Word	**Gloss**	**Word**	**Gloss**
/bada/	'not relative or kin'	-	-
/parti/	'party'	-	-
/p'ap':as/	'bishop'	-	-
/taza/	'shelter'	**/atamo/**	'drum'
/daɲ:a/	'judge'	**/adal/**	'name of a place and a tribe'
/t'ara/	'roof'	**/at'ana/**	'log used for construction purposes'
/gara/	'mountain'	**/akal/**	'body'
/kar:a/	'large knife'	**/agasɜs/**	'horse'
/k'ana/	'taste'	**/ak'arɜ/**	'made somebody's stomach upset'

3.3 Recording

All the recordings were made at the Phonetics Laboratory established at the Akaki Campus of Addis Ababa University. Each subject was seated on a chair near the microphone stand holding the Sennheiser e-815 dynamic microphone. The recordings were made on the CSL 4400 hard drive attached to a computer with a sampling rate of 44100 Hz and quantization of 16 bits. The microphone was placed approximately 10 cm from the mouth of the subjects. The wordlist and sentences were prepared in the Ethiopic script in Amharic so that the subjects would not have any difficulty in reading them. The wordlist and carrier sentence were prepared in such a way that one word or carrier sentence appears in three different places. Each subject was given the wordlist and sentences and was allowed time to practice. Whenever there was a problem in reading during the practice session, the researcher would ask the subject to repeat and correct it. This usually happened when there was a word which contains a consonant that can be either geminate or nongeminate because the Amharic writing system does not mark gemination. Thus, the researcher had to make clear to the subjects which words should be read with gemination and which ones should be read without gemination so that the intended phonetic environment would be achieved. The subjects were told to read the lists in normal speed and a trial recording was made for each subject to make them accustomed to the recording environment. Two repetitions of each item in the wordlist and the carrier sentence were recorded.

3.4 Analysis Procedures

3.4.1 Vowels

The data recorded for the analysis of vowels was downsampled to 11025 Hz with the CSL 4400 software package and analyzed with Praat version 5.1.23 by Boersma and Weenink(2010) and CSL 4400 by Kay Elemetrics (now Kay Pentax). F0, F1, F2 and F3 were extracted at the middle of the vowel manually using Praat with the following parameters. For males, 0.01 seconds of window length and 0.01 time steps, maximum frequency 5000 Hz with the Burg method[19]. For females 0.01 seconds of window length and 0.01 time steps, maximum frequency 5500 Hz with the Burg method. F0 was extracted at the middle of the vowel with the autocorrelation method, which is recommended for intonation research (Boersma and Weenink 2010). In order to do that, first all the downsampled speech signals were analyzed with the Burg method with the stated parameters and the result was extracted in a text form. Then the formant values of the signal closest to the middle point were recorded on a spreadsheet for further statistical analysis. Spectral analysis was done using CSL 4400 by centering a 20 ms hamming window at the middle of the vowel. An FFT analysis with 256 points was conducted to get the spectral shape of each vowel.

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[19] The Burg method automatically computes the number of poles to be twice the maximum number of formants given in the settings. The algorithm is as presented by Anderson (1978) and Press et al. (1992).

The duration of Amharic vowels before voiceless and voiced stops was measured in the following contexts: between two voiceless stops /**t-t**/, between a voiceless stop and a voiced stop /**t-b**/, between a voiced stop and a voiceless stop /**b-t**/and between voiced stops /**d-d**/. The vowels were put in real Amharic words that contain these contexts. The recordings were made by putting the target vowels in both isolate wordlists and carrier sentences.

The duration of each vowel was extracted manually by investigating the spectrogram and waveform and formant traces of each vowel. The beginning of each vowel was taken to be the beginning of a regular waveform where the formants start stably. This is straightforward for a vowel that is preceded by a voiceless stop. For a vowel preceded by a voiced stop, however, since the burst also has some regular-like wave just before the vowel starts, it was not straightforward. A preliminary auditory investigation by the researcher showed that this burst contains the major perceptual cue of the consonant preceding the vowel. Thus, the beginning of the vowel was taken to be the point where the formants start to be stable. The end of the vowel was taken to be the end of the regular waveform of the wave and the start of the point where formants cease stable. Whether the following consonant is voiceless or voiced, there was some voicing even after the vowel ended, and thus the pitch tracing was not used as a means to identify the end of the vowel.

Once the boundaries were located, the duration was recorded in ms, i.e. taking the first three decimal places on the Praat window used in the durational measurement. So a vowel that has a duration of 0.120899 seconds will be recorded as having 120 ms. This was done to simplify the statistics computation. Each vowel was measured four times in each of the four contexts for both males and females, two of which were in the isolated wordlists and the other two were in a carrier sentence that has been used in the recoding of acoustic data for the formant analysis.

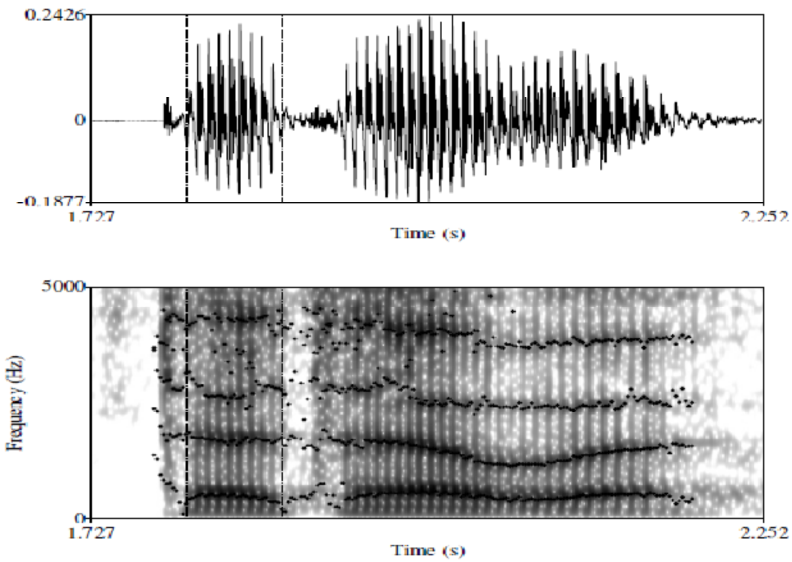


Fig. 3.1a: Duration extraction for a vowel preceded by a voiceless stop. The duration of the vowel in the /**t-t**/ and /**t-b**/ context. The vowel's duration is marked by the two vertical lines.

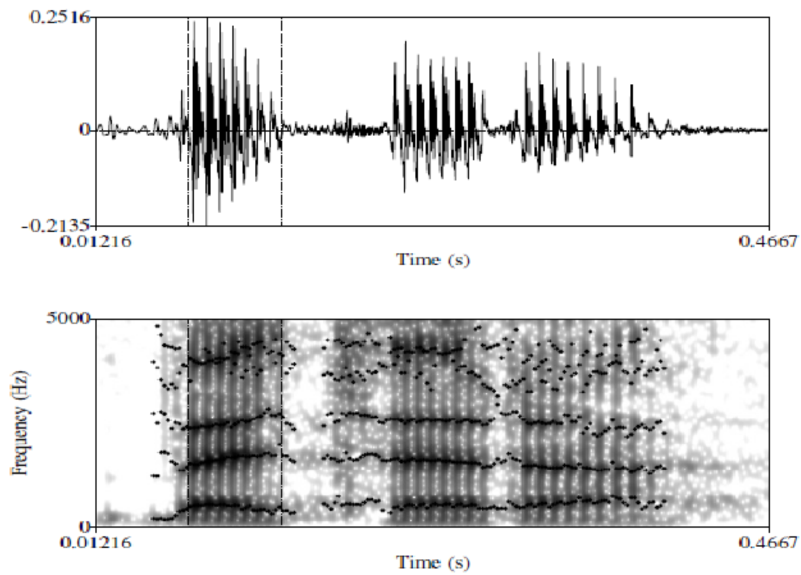


Fig. 3.1b: Duration extraction for a vowel preceded by a voiced stop. The duration of the vowel in the /**b-t**/ and /**d-d**/ context. The vowel's duration is marked by the two vertical lines.

In the analysis of vowel duration before voiceless and voiced stops, sixteen tokens of each of the vowel (two repetitions in each of the four contexts in a wordlist and carrier sentence were used). The number of tokens analyzed for vowel duration in this study was 784: 336 of females (three females * two repetitions * eight contexts [four wordlist and four carrier sentence]) and 448 of males (four males * two repetitions * eight contexts (four wordlist and four carrier sentence). The data from a fourth female speaker was not included in the analysis because her vowels were very short and locating the boundaries was quite difficult specifically for the vowels [**u**] and [**ɘ**].

In the analysis of vowel duration before geminate and nongeminate consonants, four repetitions of each of the six vowels for each subject in the wordlist and in the carrier sentence were analyzed. Data was recorded from four males and four females. The total number of tokens analyzed was 768: four repetitions * six vowels * two contexts (geminate and nongeminate) * two frames (wordlist and carrier sentence) * eight subjects.

3.4.2 Pulmonic and Ejective Stops

The recorded data had a sampling rate of 44,100 Hz and quantization of 16 bits. Because of some constant band of noise around 14 KHz, the frequencies above 14 KHz could not be utilized. As a result, the data was resampled at 22,050 Hz for analysis.

The following measurements were taken for Amharic stops in order to get answers to the questions in Section 1.3 of the introductory chapter.

a) Durational measurements: total duration (intervocalic stops only), VOT (initial stops only), voicing lag, closure duration (intervocalic stops only), duration of the voiced portion of the closure (intervocalic stops only), duration of the voiceless portion of the closure (intervocalic stops only), percentage of voiced part of the closure to the total duration (intervocalic stops only), burst duration and intensity rise time of the vowel following the stops.
b) Burst spectral measurements: spectral mean, spectral standard deviation, skewness and kurtosis.
c) Intensity measurements: RMS intensity of the stop burst, relative intensity (vowel maxim- stop burst),

d) Voice/phonation measurements: F0 (at the onset and middle of the vowel following the stop), F0 perturbation, jitter (at the onset and middle of the vowel following the stop) and jitter perturbation.

Duration measurements were made using Praat (version 5.1.23) by Boersma and Weenink (2010). Closure duration was measured from the offset of the previous vowel to the onset of the burst on the spectrogram. The voiced part of the closure was measured when there was a voiceless gap just before the burst in intervocalic stops; otherwise, specially for voiced stops, the total closure and the voiced closure had the same value. Voicing lag was measured from the onset of the burst marked by the sudden rise in the amplitude of the waveform up to the onset of the regular wave of the vowel where the voicing pulse starts. This was supported by time aligned spectrographic display and formant contour. For the pulmonic stops this is also the time when the second formant of the following vowel is in a steady state. Whenever there was a creaky part of the vowel before the modal voicing starts, the beginning of the vowel was taken to be the starting point of the steady state of the second formant. Thus, the creaky part was excluded from voicing lag measurement. VOT and voicing lag were the same for voiceless stops.

VOT and voicing lag for ejectives was measured from the onset of the oral release up to the onset of the following vowel, but following the procedure that was used for voiceless pulmonic stops was difficult because Amharic ejectives showed different patterns. In very few cases, the oral and glottal release happened simultaneously and the beginning of the following vowel was clear even though the vowel in most of the cases started with creaky voice. In most of the cases though, the glottal release happened several milliseconds after the oral release and it was followed by a creaky wave which was then followed by a vowel which started with creaky phonation. Thus, the VOT and voicing lag were measured excluding the creaky part and considering the latter as part of the following vowel.

As for voiced stops, VOT was measured from the onset of the burst to the beginning of voicing. The voiced stops in Amharic had both lead as well as lag VOT. Thus those that had lag VOT were measured in the same way as voiceless stops since the VOT value is positive and has the same value as voicing lag. Those voiced stops which had a lead VOT had to be measured differently. Thus the VOT was measured from the beginning of the stop up to the burst, and the VOT value was recorded as negative. For word initial stops, VOT had either positive value, which is the same as voicing lag, or negative value, when there was voicing before the burst.

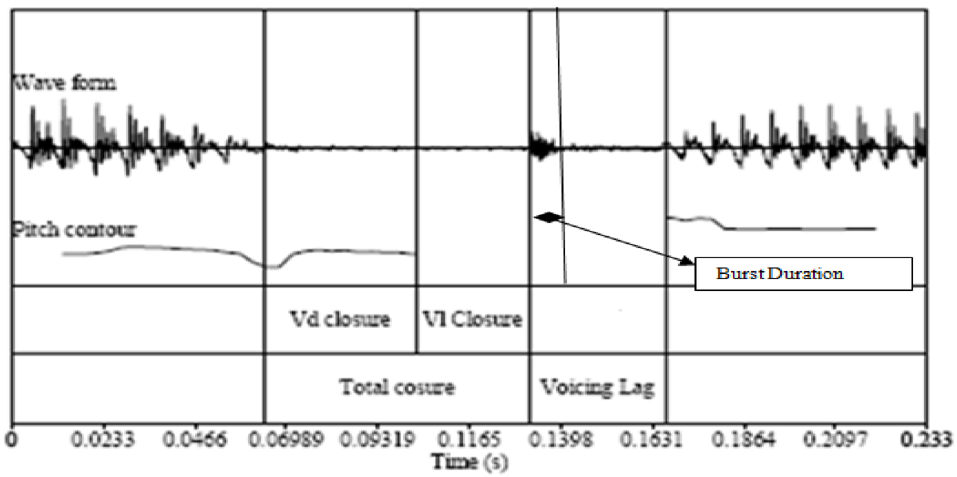


Fig. 3.2a Increments in the durational measurements of voiceless and voiced stops in intervocalic position.

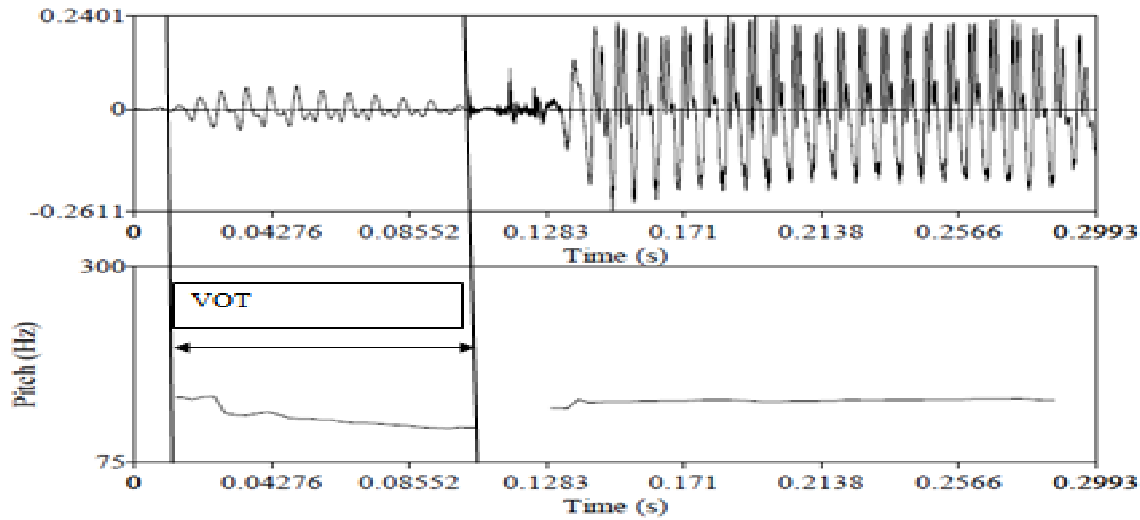


Fig. 3.2b Increments in the durational measurements of voiced stops with lead VOT.

Burst duration was measured as the difference between the burst offset and onset. The burst onset was marked by a sharp increase in waveform amplitude and burst offset was marked by a sharp drop in the waveform amplitude. The spectrum was used to aid in identifying the burst duration, as it shows the burst as having a very concentrated energy distribution compared to the frication phase after the offset.

Intensity measurements were made using CSL 4400 and Praat software packages. Overlaid energy contour was drawn over the spectrogram display of a waveform of the word containing the target stop. RMS intensity of the burst was calculated at the onset of the burst, to make it simultaneous with the spectral mean, spectral standard deviation, skewness and kurtosis measurements. The RMS intensity was calculated over a 5 ms frame length and 5 ms frame advance on CSL 4400. Relative burst intensity was measured as the difference between the maximum amplitude of the following vowel and the maximum amplitude of the stop burst. Both RMS intensity and the relative burst intensity were calculated over a 5 ms frame length and 5 ms frame advance on CSL 4400. The numerical results from CSL energy contour window were extracted and the maximum value nearest to the point in time of the maximum energy peak was taken for both the vowel and the stop burst to get the relative burst intensity. Relative burst intensity was then calculated as the difference between the local peak intensity and the vowel onset intensity. Absolute intensity was measured using Praat by placing the cursor on the vowel onset and local peak, then reading the intensity values on screen and entering them to the dataset.

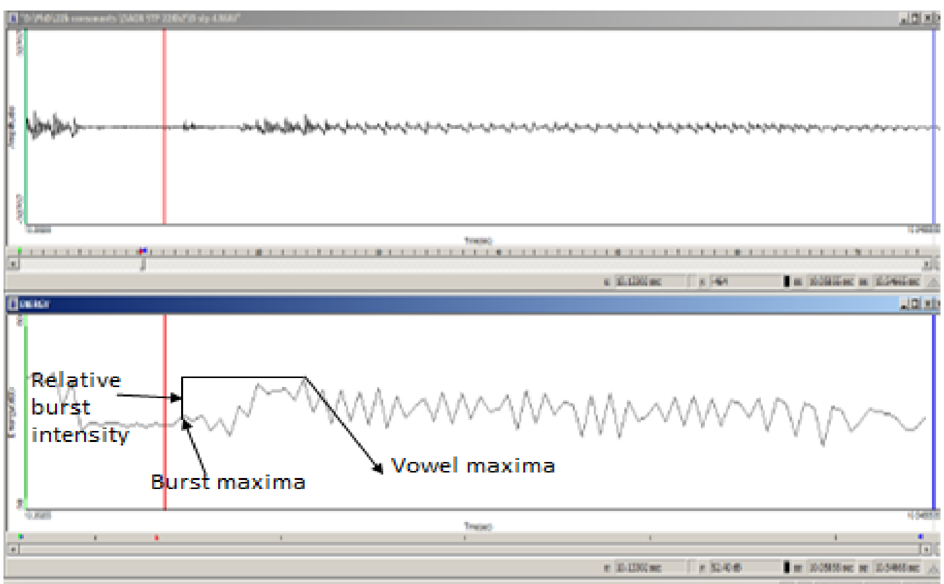


Fig. 3.3a: Increments in the relative burst intensity measurement using CSL 4400 time-aligned waveform and energy displays.

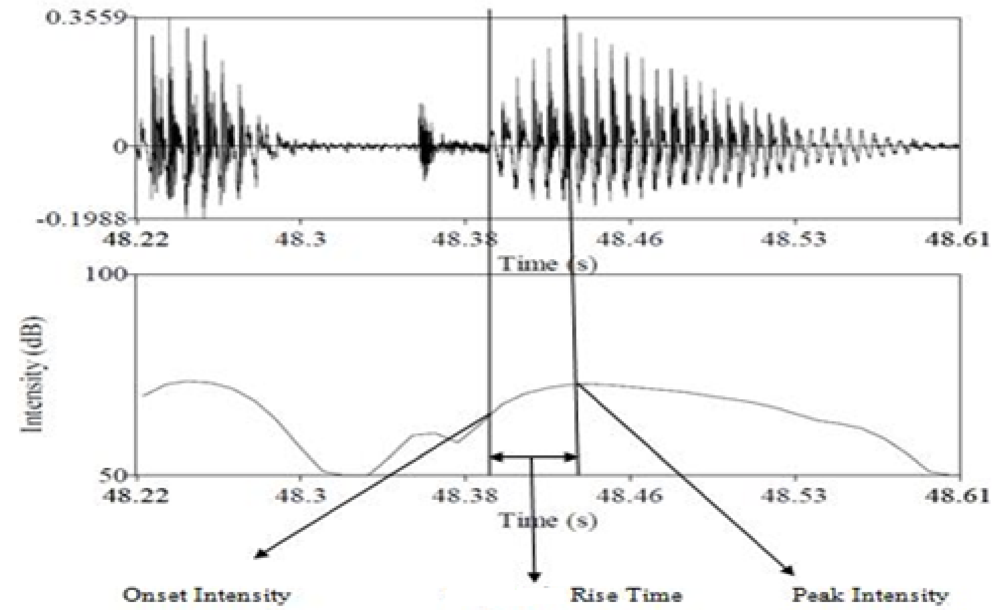


Fig. 3.3b: Increments in rise time and absolute increase in intensity measurements on vowels following Amharic stops.

Spectral measurements were made with the CSL 4400 software package with a 6 ms hamming window (128 points) by placing the cursor at the onset of the burst on the spectrogram. A 6 ms window was chosen because a fair amount of stops in Amharic had burst duration not more than 6 ms and more window length would have meant inclusion of the friction part after the burst in the spectral energy analysis. The signal was pre-emphasized by a factor of 0.9 to boost the intensity of higher frequencies. The standard deviation of spectral energy distribution, skewness and kurtosis were extracted from the numerical results of the FFT spectral analysis.

Voice measurements were made using Praat. F0 was measured at the onset of the vowel marked by the steady state of the second formant and/or the start of the regular wave and pulse mark, and at the middle of the vowel taking a 30 ms hamming window each. To enhance the measurements for voice research, the cross correlation method was used as recommended by the authors (Boersma and Weenink 2010). F0 perturbation was calculated by subtracting the middle F0 value from the onset F0 values of the vowel following the stop.

Jitter as a means of voice measurement was made simultaneously with the F0 measurements using the same parameters, i.e. a 30 ms hamming window at the onset and middle of the vowel. Jitter perturbation was calculated as the difference between the onset jitter and middle jitter of the vowel following the stop. Jitter values were read from the Praat voice report and entered to the dataset. The jitter measure conducted refers to the average absolute difference between consecutive periods, divided by the average period.

3.5 Statistical Analysis

The statistical analysis was made using SPSS version 16. Whenever applicable, mean, standard deviation (SD hereafter) of the different groups based on gender, position, place, airstream and voicing were calculated. To check whether the group results could be confirmed by individual results, individual results were also computed. To check whether there were significant differences between the means of different variables and groups, a paired sample t-test (vowel duration in different contexts) and univariate analysis of variance were conducted. Whenever there was a need to see the contribution of variables and groups in statistically significant differences, Scheffe post-hoc test was used. Discriminant analysis was performed for both vowels and stops. Discriminant analyses involving three and more variables were conducted using the step-wise method and discriminant analyses involving one or two variables were conducted by entering all independents together. All the discriminant analyses were made taking 70 % of the data in question as a model. The discussion on discriminant analyses is based on the values obtained by the cross-validation method, in which the cases used to create the model were excluded in the classification. A Lobanov transformation (z-transformation), which is the most popular normalization method, was used to see the results after speaker normalization.

CHAPTER FOUR

RESULTS

4.1 Results on Vowels

4.1.1 F0, F1, F2 and F3

Group patterns

As stated earlier, F0 and formant values were extracted for each vowel in nonsense and real words, both in a list and carrier sentence contexts. Sixteen tokens of each of the seven vowels were analyzed for all four of the male and two of the female consultants. For the rest of the two female consultants, a total 16 tokens of the vowel [**u**] (eight tokens from W1[20] and eight tokens from W4) and six tokens from the vowels [**a**], [**e**], [**i**], [**ɘ**] (1 from each of [**a**] and [**e**] and two from each of [**i**] and [**ɘ**] from W4) were discarded because they had very short duration and the formants were not clear. The following tables show the average and standard deviation of the F0, F1, F2 and F3 values of the seven Amharic vowels.

Table 4.1a: F0, F1, F2 and F3 Values of Amharic vowels: male speakers.

Vowels	F0	SD of F0	F1	SD of F1	F2	SD of F2	F3	SD of F3
a	111	11	623	62	1384	101	2398	159
e	115	9	380	35	2081	124	2762	177
ɜ	114	9	519	45	1610	66	2544	159
i	116	9	295	24	2192	140	2891	292
ɘ	117	11	380	25	1736	96	2562	114
o	115	10	421	59	1060	96	2328	147
u	115	11	324	25	1295	188	2416	165

[20] W1, W2, W3, and W4 refer to the four female subjects whereas M1, M2, M3 and M4 refer to male subjects.

Results on Vowels

Table 4.1b: F0, F1, F2 and F3 value-s of Amharic vowels: female speakers.

Vowel	**F0**	**SD of F0**	**F1**	**SD of F1**	**F2**	**SD of F2**	**F3**	**SD of F3**
a	218	15	770	56	1610	81	2867	241
e	228	14	454	26	2507	115	3129	170
ɜ	226	12	660	60	1973	111	3003	152
i	235	14	337	30	2599	90	3274	191
ɘ	236	9	451	30	1982	92	2999	85
o	230	10	447	23	1195	122	2799	107
u	234	11	397	69	1524	244	2786	189

The data shows that F0 values were quite close to each other and there was no significant difference between the vowels both for male and female speakers. The F0 values for females were twice or more as large as the F0 for males, which is quite expected from the physiology of males and females. The SD of F0 values are quite similar too: they range between 9-11 for males and 9-15 for females.

The data shows that F2 values differ significantly for females than for males, which is evidenced by greater standard deviations of F2 for females than for males. The formant values of Amharic vowels also show that the vowel [**u**] had very scattered F2 values for both males and females, few of them having very high F2 values that could result in labeling [**u**] as a central vowel. This is clearly seen from the following scatter plots.

Fig. 4.1 shows that the ellipses drawn around two SDs of the mean formant centre frequencies slightly overlap for male speakers for [**i**] and [**e**], [**e**] and [**ɘ**], [**ɜ**]and [**a**]. For the female subjects, the only overlap seen is [**u**] with [**ɘ**] and [**o**] because [**u**] is centralized in many tokens as a result of the preceding consonant, i.e. [**t**]. This was also true for the vowels of the male subjects.

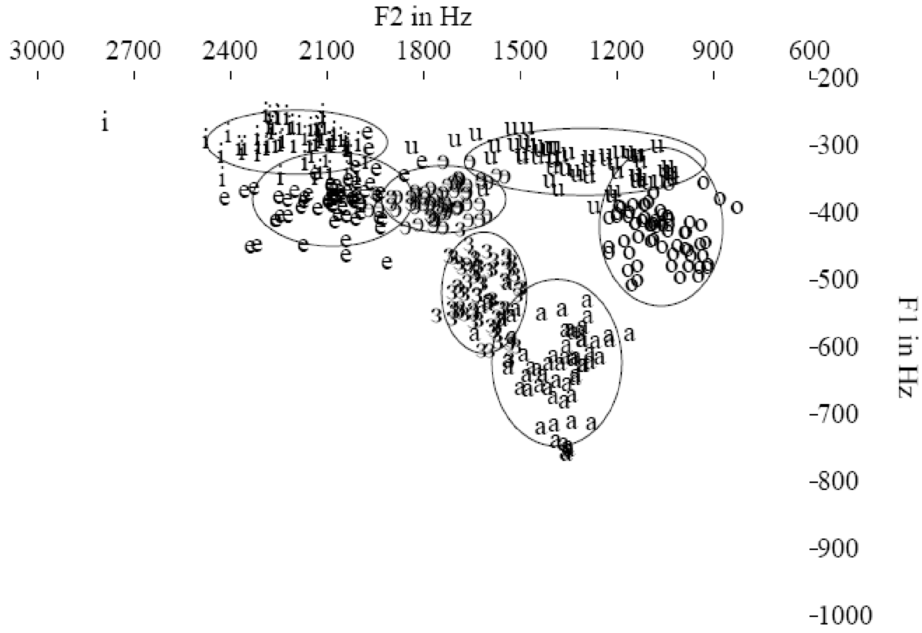


Fig. 4.1a: F1-F2 plot of Amharic vowels: males, no. 4, 64 tokens of each vowel: ellipse enclosing two standard deviations from the mean.

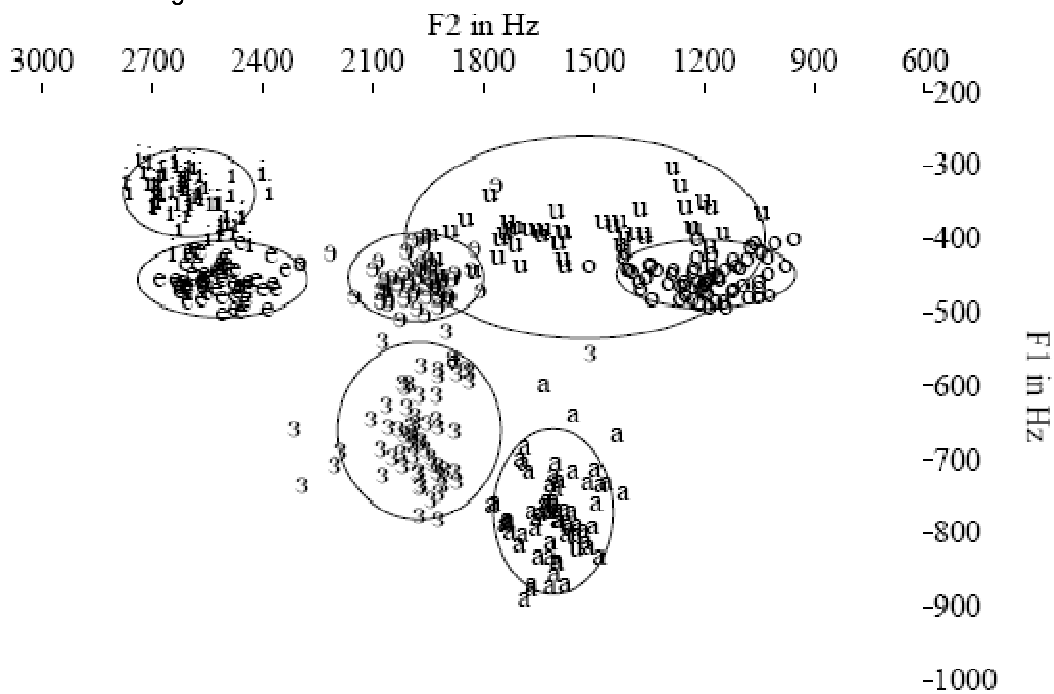


Fig. 4.1b: F1-F2 plot of Amharic vowels: females, no. 4, 64 tokens of each vowel except [**u**] that has 48 tokens: ellipse enclosing two standard deviations from the mean.

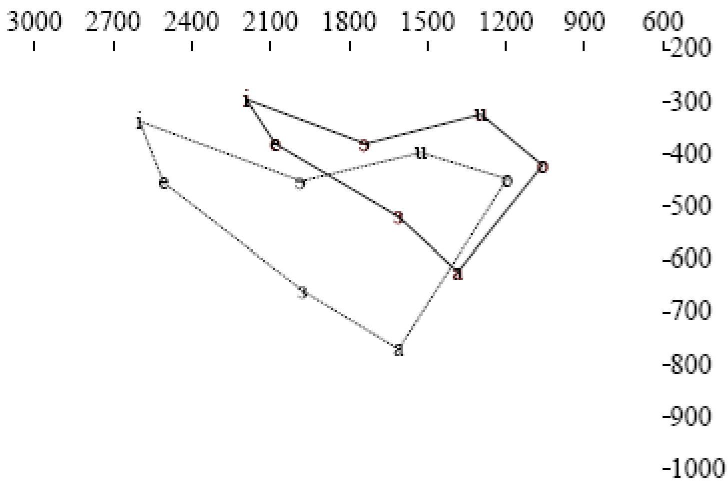


Fig. 4.2: F1-F2 plot of the mean centre formant frequencies of Amharic vowels: solid lines connect the vowels of males and dotted lines connect females' vowels.

Formant plots for individual subjects are given below. The formant plots for each of the subjects are presented taking the mean formant values.

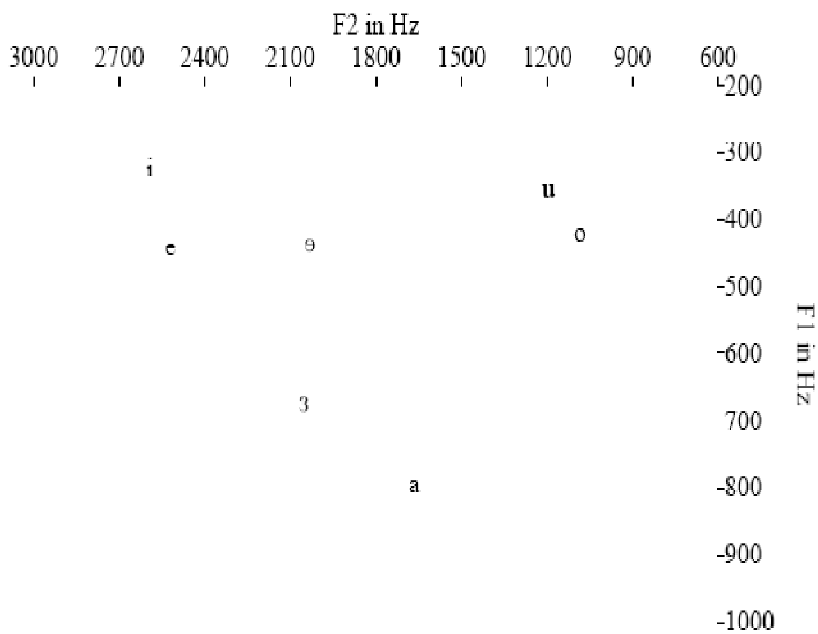


Fig 4.3a: F1-F2 plot for female subject W1.

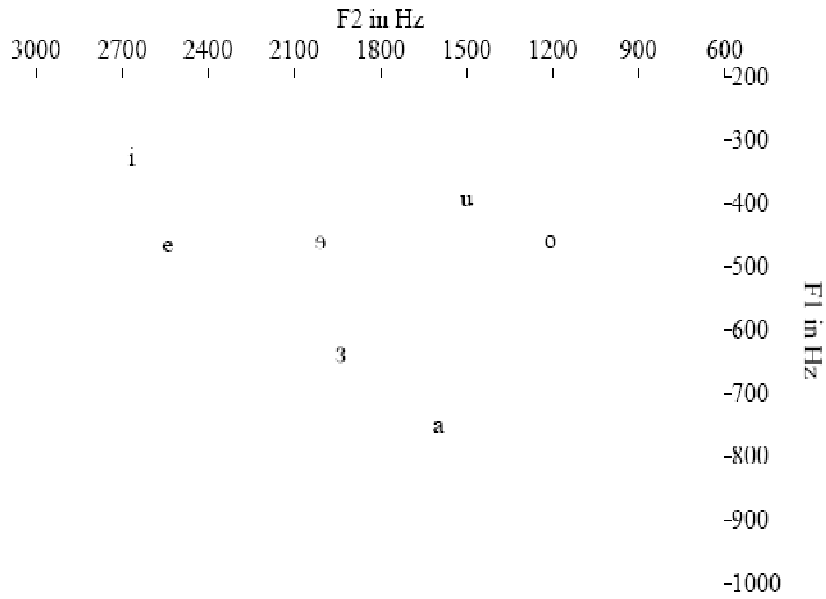


Fig 4.3b: F1-F2 plot for female subject W2.

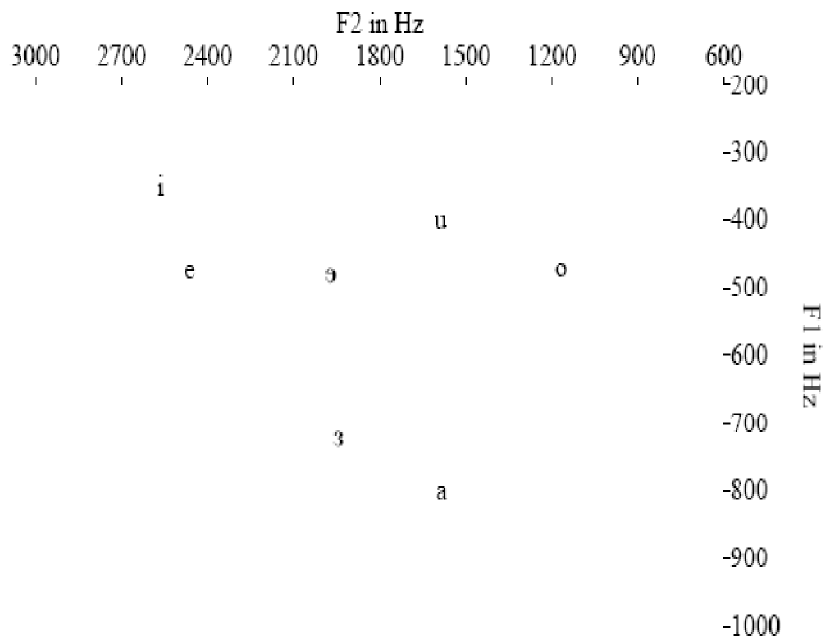


Fig 4.3c: F1-F2 plot for female subject W3.

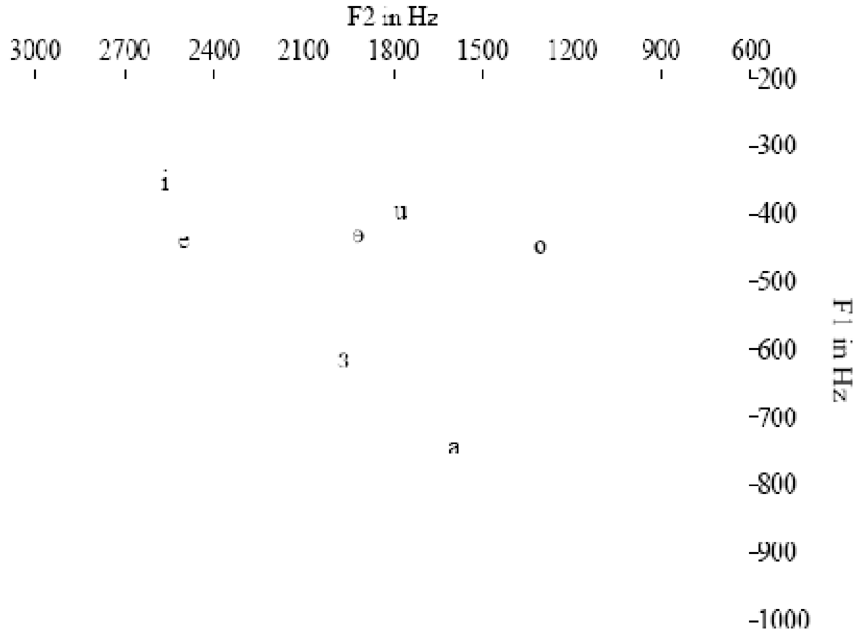


Fig 4.3d: F1-F2 plot for female subject W4.

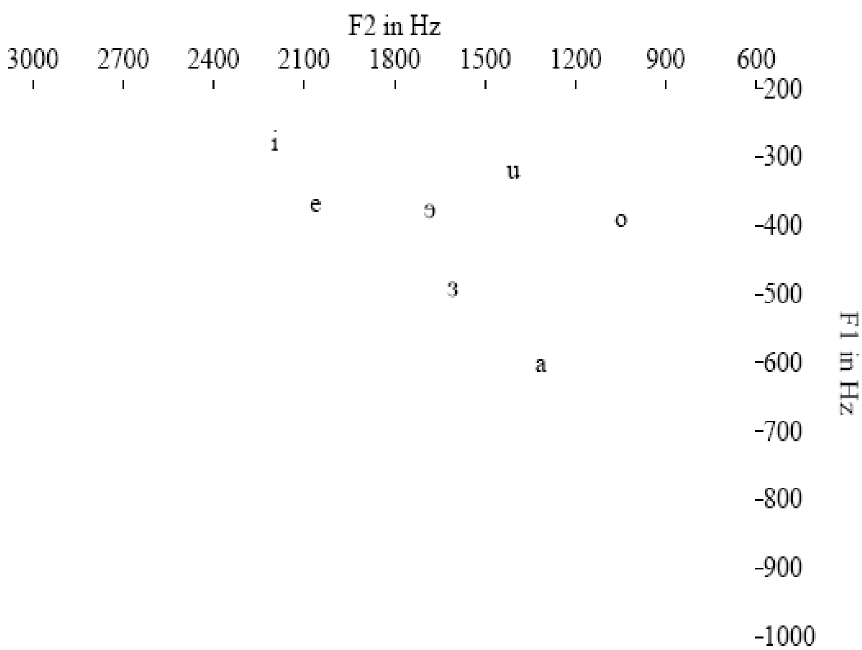


Fig 4.3e: F1-F2 plot for male subject M1.

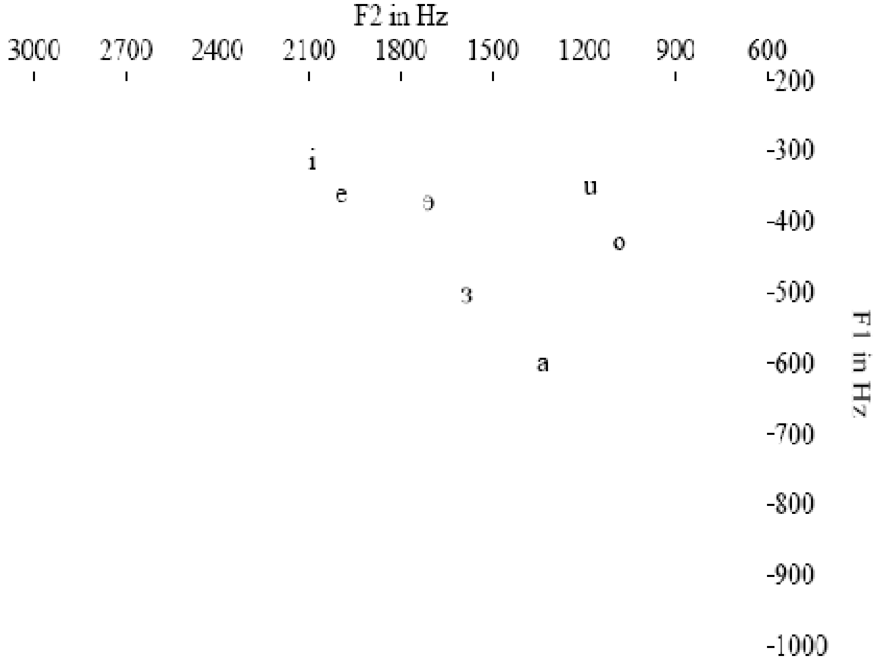


Fig 4.3f: F1-F2 plot for male subject M2.

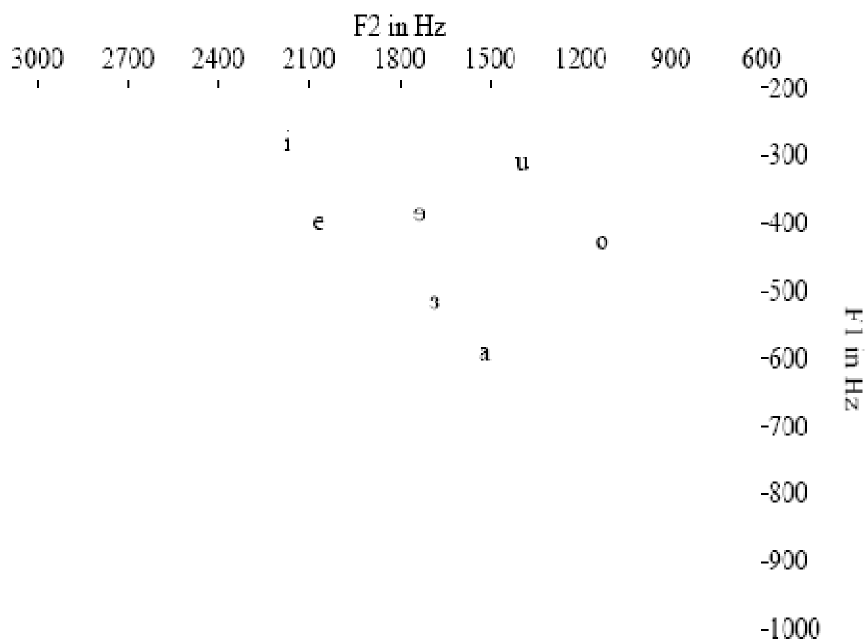


Fig 4.3g: F1-F2 plot for male subject M3.

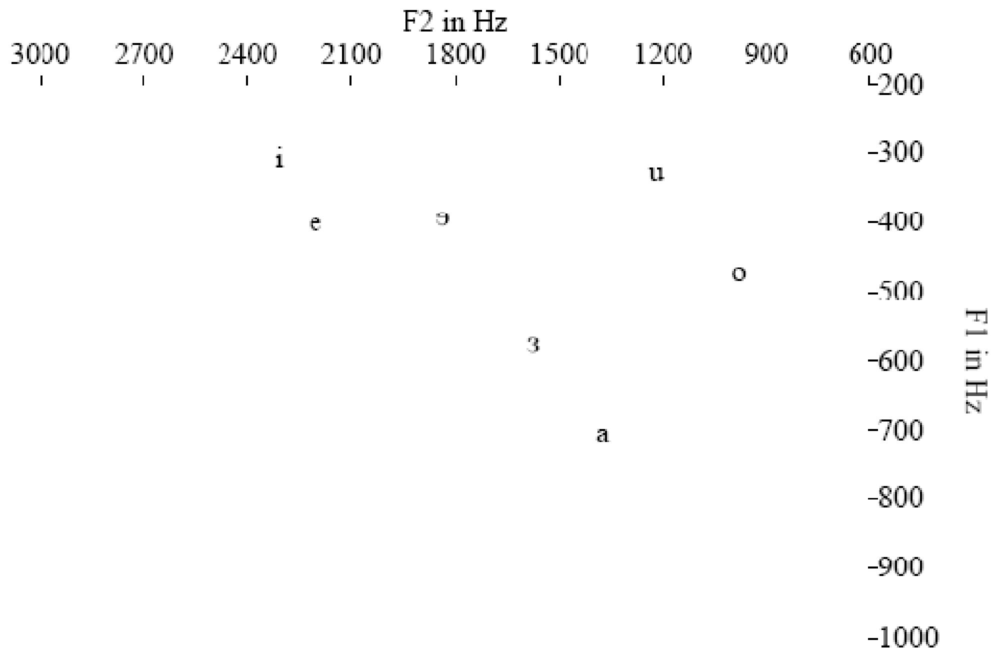


Fig 4.3h: F1-F2 plot for male subject M4.

The formant plots of individual subjects show the same results to that of the group patterns. For all subjects, [**ɘ**] is lower than [**u**] and has relatively similar height with that of [**e**] though it is slightly higher than [**e**] for five of the eight subjects.

In the next sections, the front, central and back vowels are discussed separately.

4.1.1.1 Front Vowels

The vowel [**i**] is the highest and the most front vowel in Amharic for both males and females. It has the lowest F1 and highest F2 values. The F1 and F0 values of the vowel [**i**] show that it is clearly a high vowel. Stevens (1998:266) states that a high vowel has F1 values within the range of 250-350 Hz, and the F1 value is within 100-200 Hz of the F0. The vowel [**i**] had F1 values 295 Hz and 337 Hz for males and females respectively, and the F0 was 116 Hz and 235 Hz for males and females respectively. The spectral shape of a high vowel is expected to have "*only a narrow and shallow low-frequency dip in the spectrum below the first spectral peak*" (Stevens 1998:264). As it is presented in Fig. 4.5a-b, both male and female speakers produce [**i**] with such a spectral shape.

The vowel [**e**] is higher and more advanced than the cardinal vowel [**e**]. This vowel is not /**je**/ as described by Sumner (1957). In the /**t**V**t**/ context that has been used to analyze the formants of Amharic vowels, it is a clear monophthong vowel. Two instances of this vowel, one from a male speaker and another from a female speaker, are presented in Fig. 4.4. As can be seen in Fig 4.4, the vowel [**e**] is clear monophthong and not preceded by any glide.

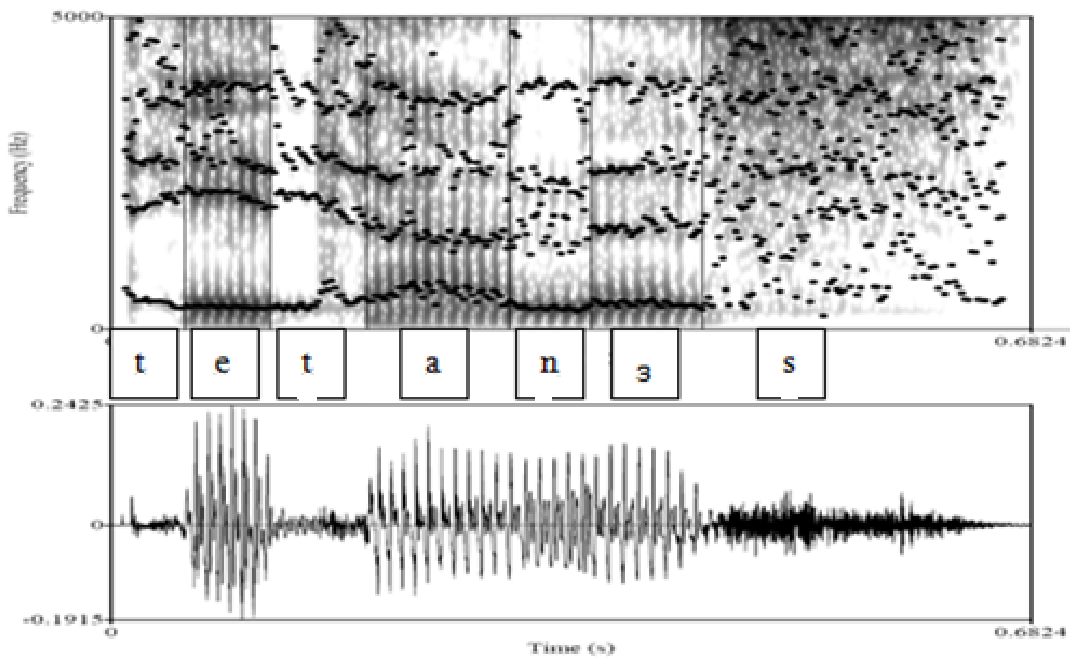


Fig. 4.4a: Spectrum and waveform of the word /**tetanʒs**/: male speaker.

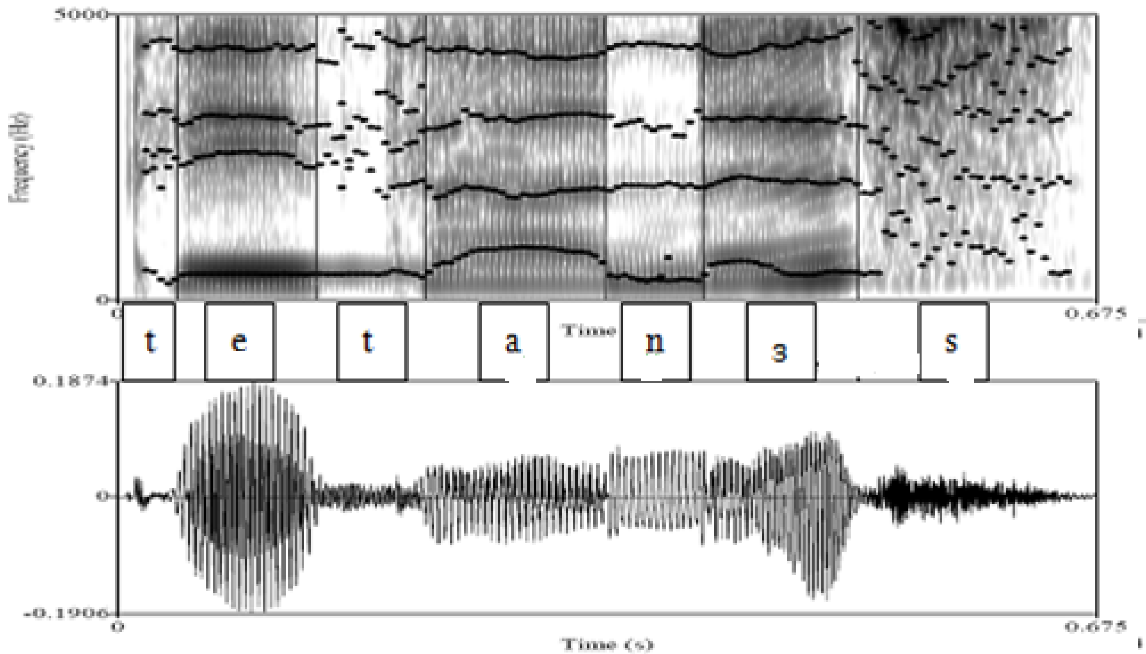


Fig. 4.4b: Spectrogram and waveform of the word /**tetanɜs**/: female speaker.

The spectral shape of the vowels [**i**] and [**e**]are presented in Fig 4.5-4.6. Since [**e**] is close to the high vowel, its spectral shape has a component of a low frequency dip after the first spectral peak, but not as low as the one for [**i**].

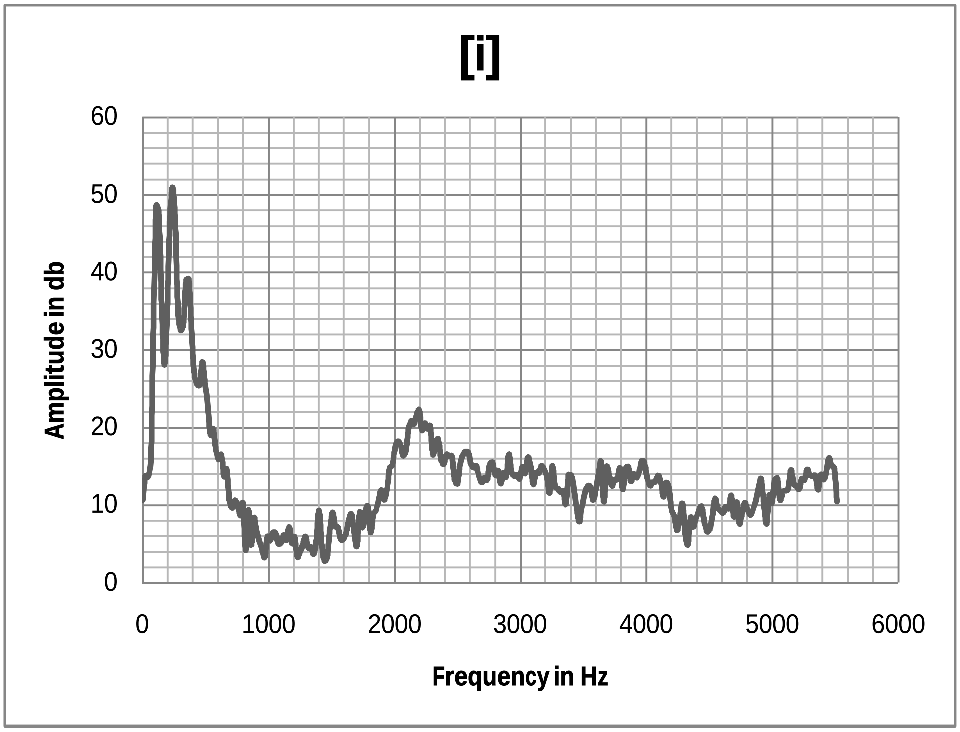


Fig. 4.5a

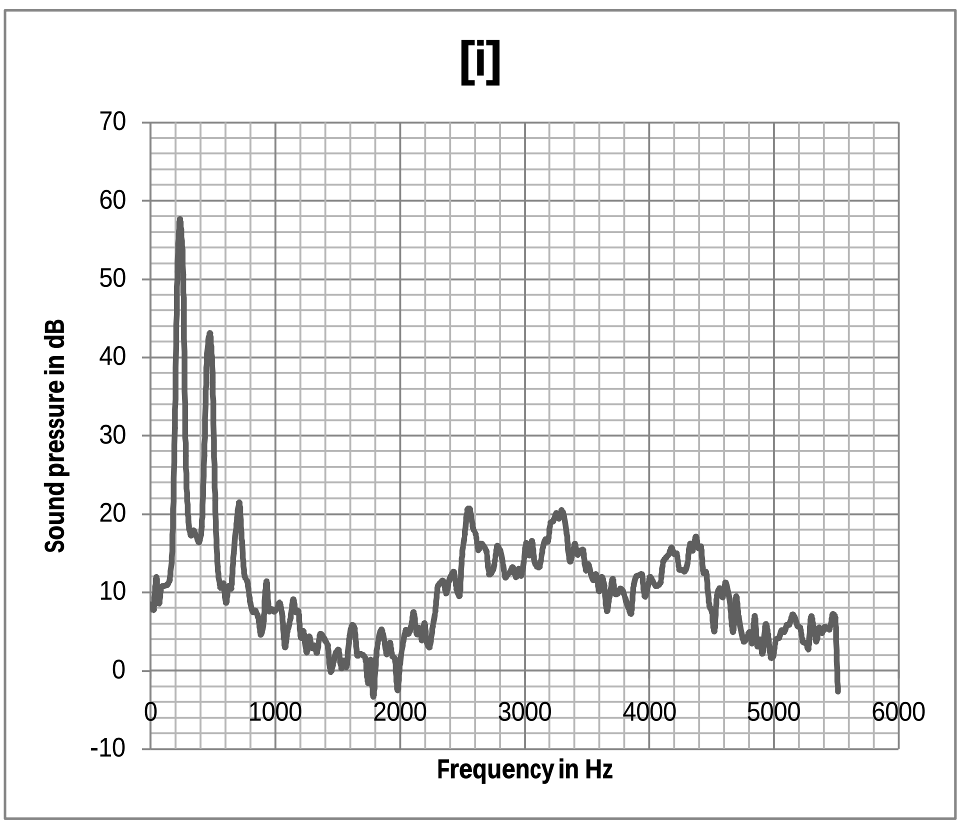


Fig. 4.5b

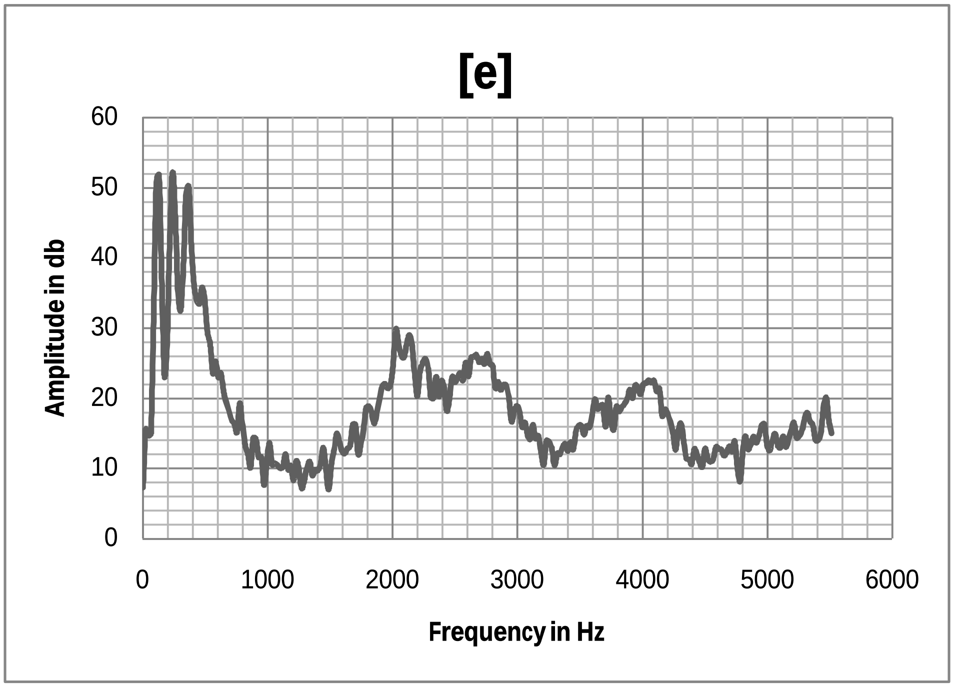


Fig. 4.6a

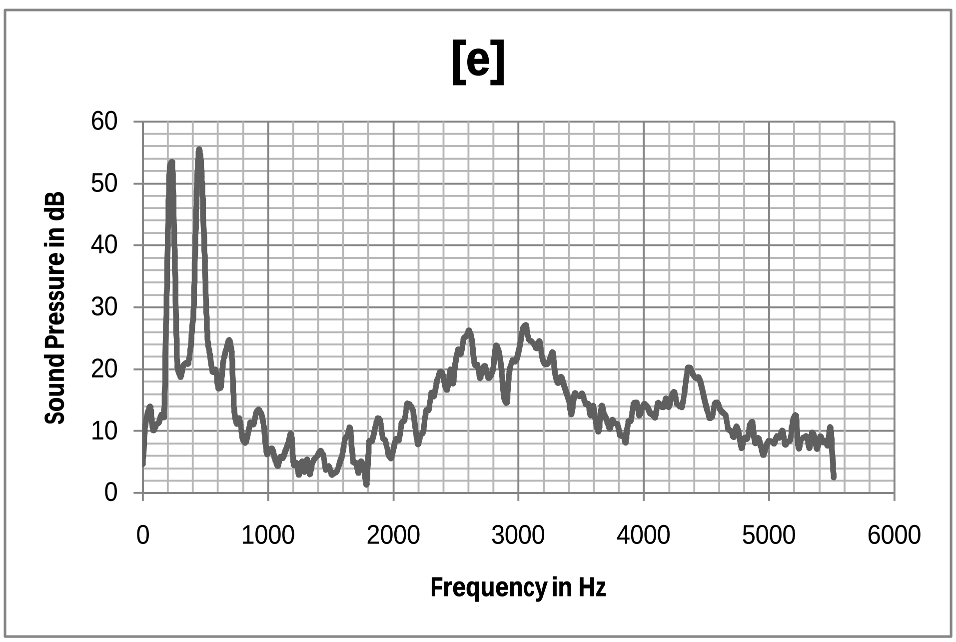


Fig. 4.6b

Fig. 4.5-4.6: Spectral shapes of the front vowels of Amharic. In each figure the first one (a) is average spectrum of the vowel from male speakers (b) is average spectrum of the vowel from female speakers. FFT spectrum results were extracted from 16 tokens of each vowel using a 20 ms window centered at the middle of each vowel using CSL 4400.

4.1.1.2 Central Vowels

There are three central vowels in Amharic. The lowest central vowel is quite low and has been represented by [**a**] in earlier studies (Sumner 1957, Mulugeta 2001). Some scholars consider this vowel to be low back (Ullendorff 1955, Cohen 1970). In this study it has been found to be central.

The two remaining central vowels have been a point of difference for a long time. Cowley et al. (1976) consider what has been labeled as [**ɜ**] to be [**ɛ**] and [**ɘ**] to be [**ə**]. I hold that the Amharic 'mid central' vowel is closer to [**ɜ**] than it is to [**ɛ**] or [**ə**] as it is lower than [**ə**]. Using [**ɛ**] instead of [**ɜ**] would also give an impression that it is a front vowel. The F1-F2 plots in Fig.4.1-2 show that the vowel is central, but lower in position than that of the schwa vowel. Nevertheless, it is also possible to use the symbol [**ä**] as is most widely employed by Europeans and even prominent Amharic grammarians such as Baye.

The highest central vowel, that has been labeled as [**ɘ**], is close to the IPA vowel [**ɘ**] both in quality and distance than it is to [**ɨ**]. For males, the average F1 values for [**e**] and [**ɘ**] are the same. I choose the symbol [**ɘ**] for this central vowel of Amharic, and I claim that it is not high but high-mid, at least for the Addis Ababa variety, which is the focus of this study. Thus, I will use the symbols [**ɜ**] and [**ɘ**] for the two central vowels in spite of the fact that the latter one has been used rarely in Amharic. The following are spectral shapes of these three vowels.

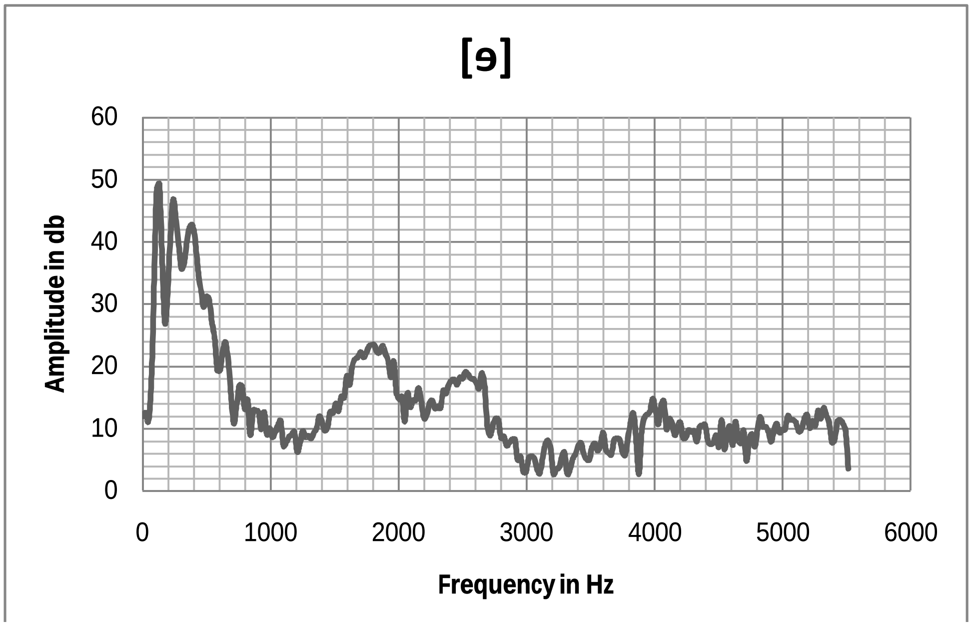


Fig. 4.7a

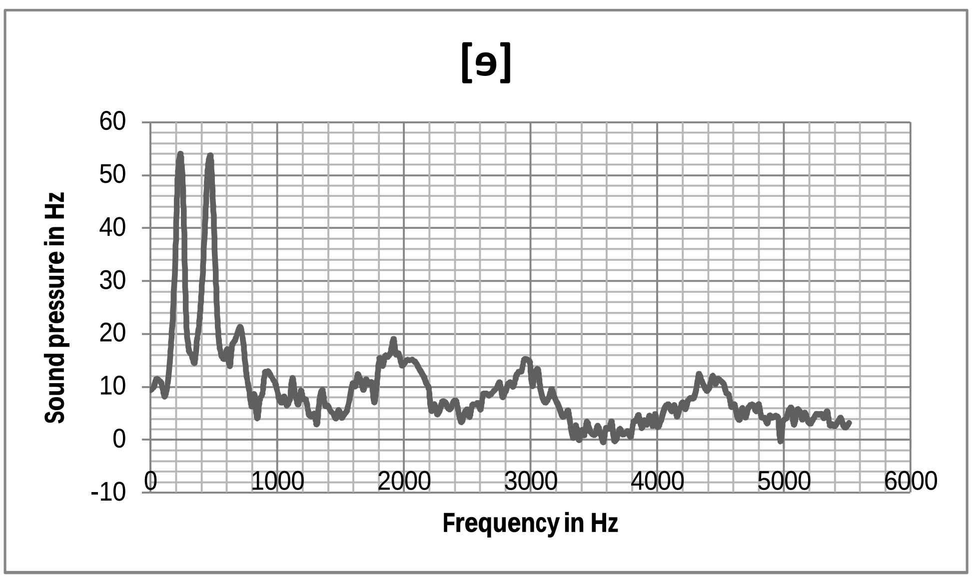


Fig. 4.7b

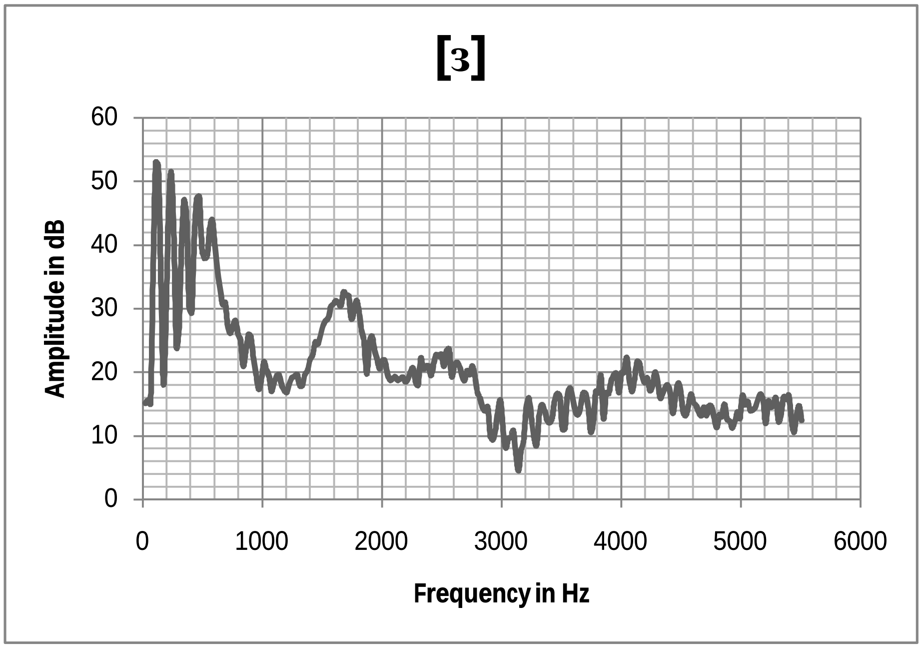


Fig 4.8a

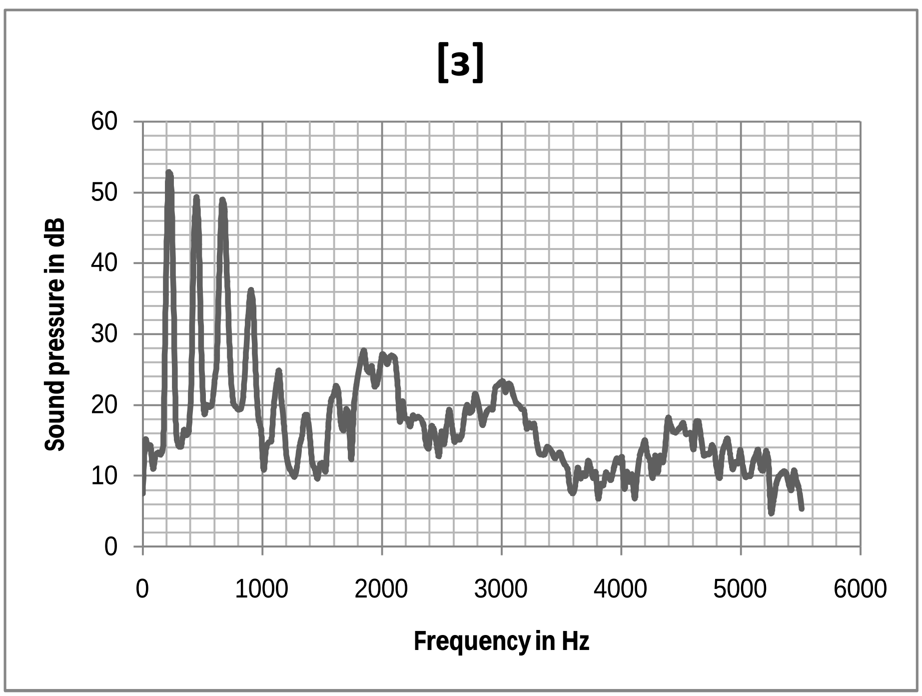


Fig. 4.8b

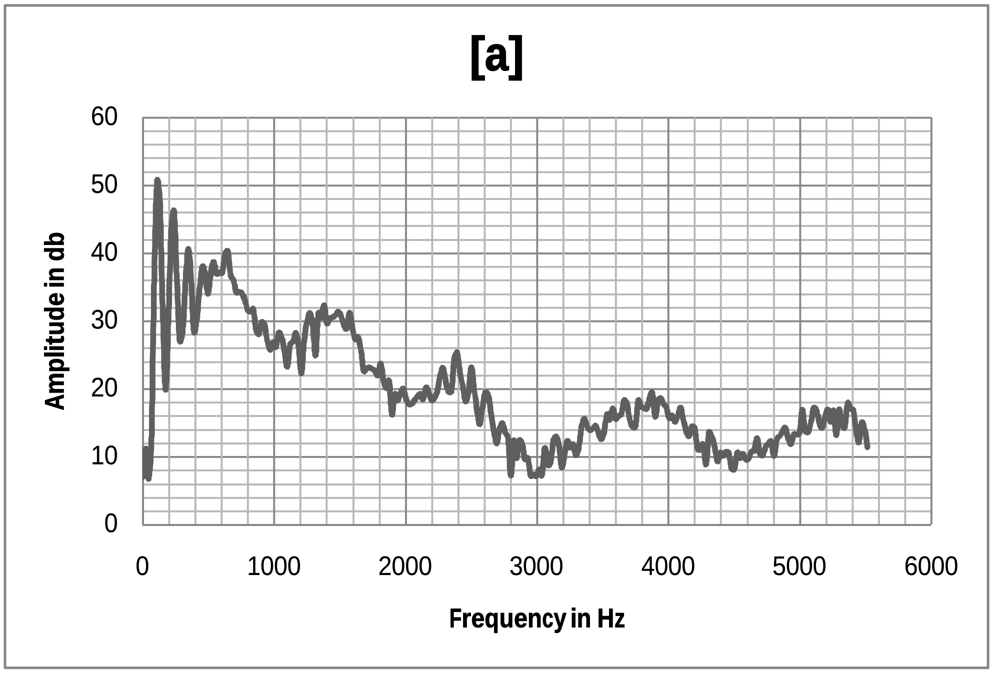


Fig. 4.9a

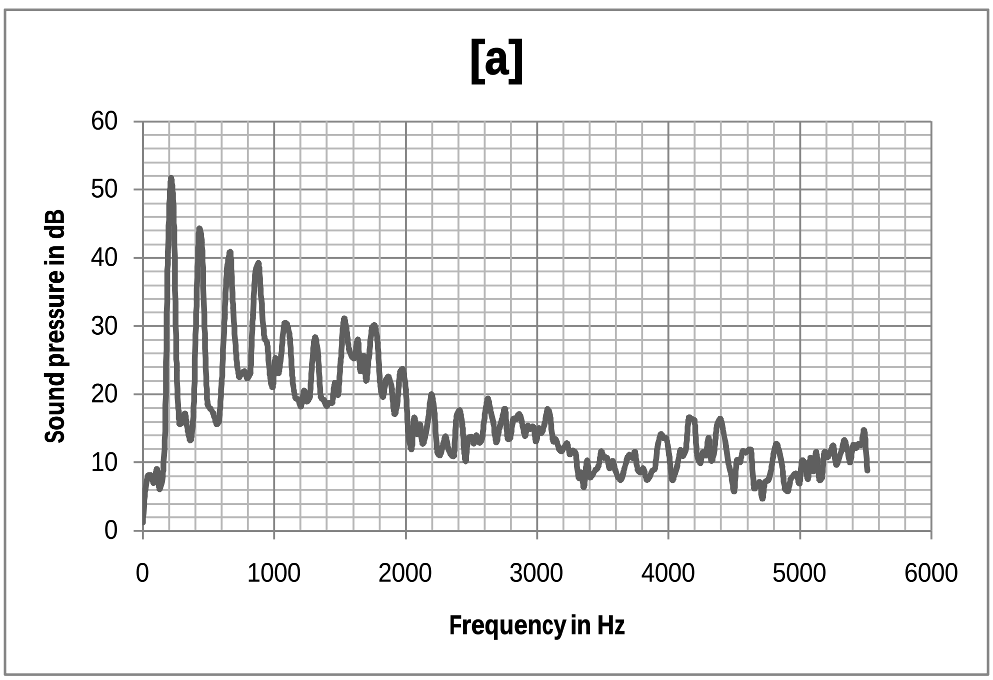


Fig. 4.9b

Fig. 4.7-4.9: Spectral views of the central vowels of Amharic. In each figure the first one (a) is average spectrum of the vowel from male speakers (b) is average spectrum of the vowel from female speakers. FFT spectrum results were extracted from 16 tokens of each vowel using a 20 ms window centered at the middle of each vowel using CSL 4400.

4.1.1.3 Back Vowels

There are two back vowels in Amharic. The high back vowel has been represented by [**u**]. This vowel is centralized for most of the subjects. It is almost centralized for one male and one female subjects. Earlier studies found that when vowels are preceded by alveolar consonants, they become more centralized. Rosner and Pickering (1994) reproduced the results of Stevens and House (1963) in ERB rate and showed that when vowel formants are measured in CVC contexts, the formants centralize compared to the formant values taken from vowels in isolation. Of all the vowels, [**u**] was the most affected vowel and the most affecting consonants were postdentals, which include alveolars. The Amharic vowel [**u**] was found to be more centralized, perhaps due to the same effect[21]. The vowel [**o**] is closer to the cardinal vowel [**o**] and is in high-mid position. The following are spectral views of the back vowels.

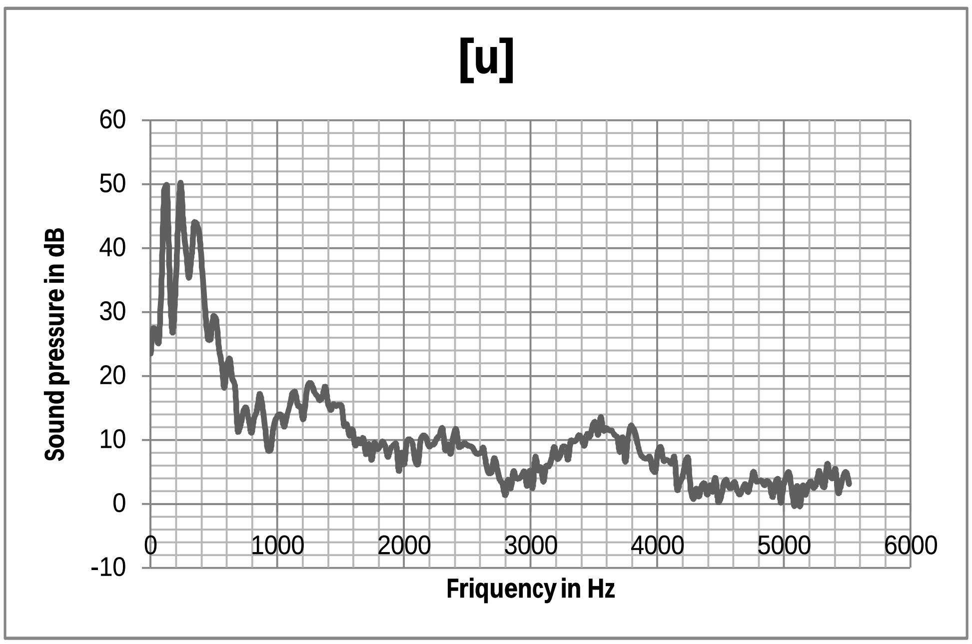


Fig. 4.10a

[21] To verify this claim, a separate analysis was conducted on Amharic vowels in **bVb** contex by recording the data from one of the male subjects. The results showed that [**u**] was not centralized in the /**b**V**b**/context.

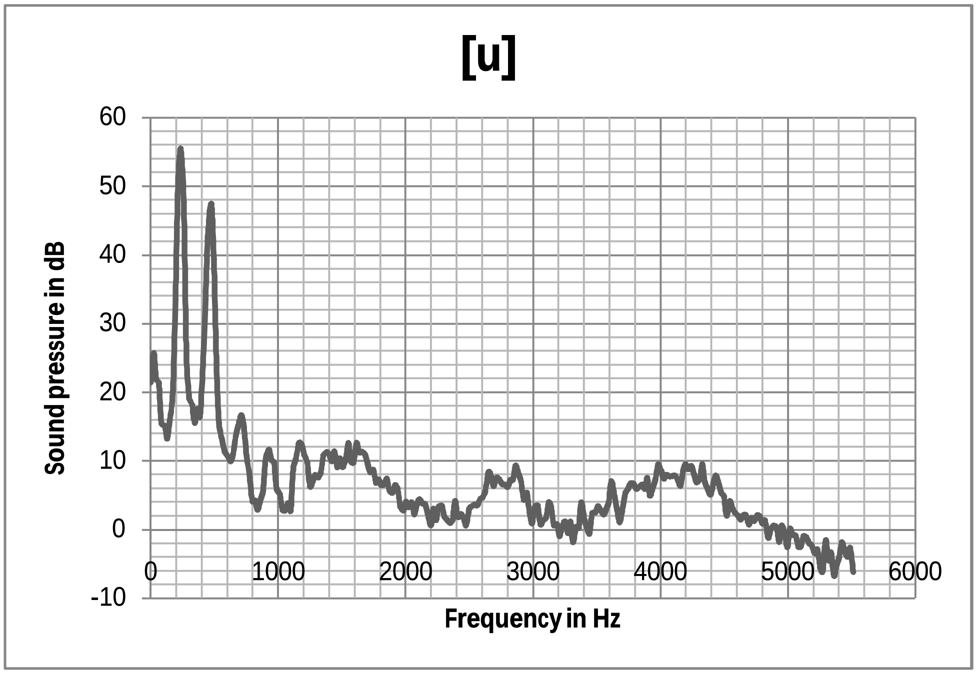


Fig. 4.10b

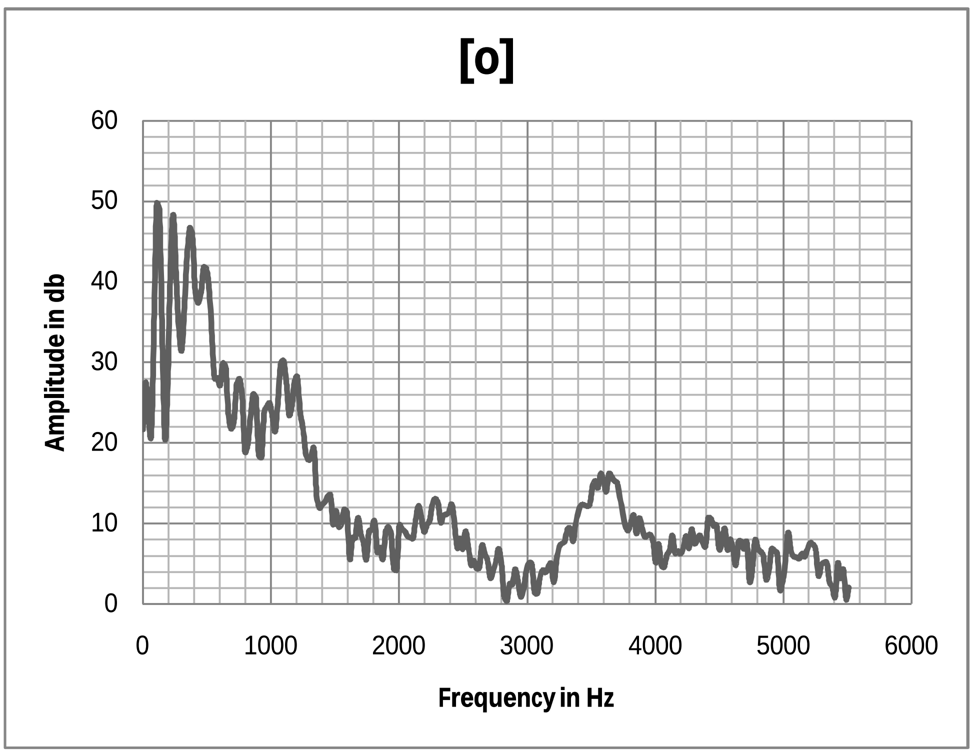


Fig. 4.11a

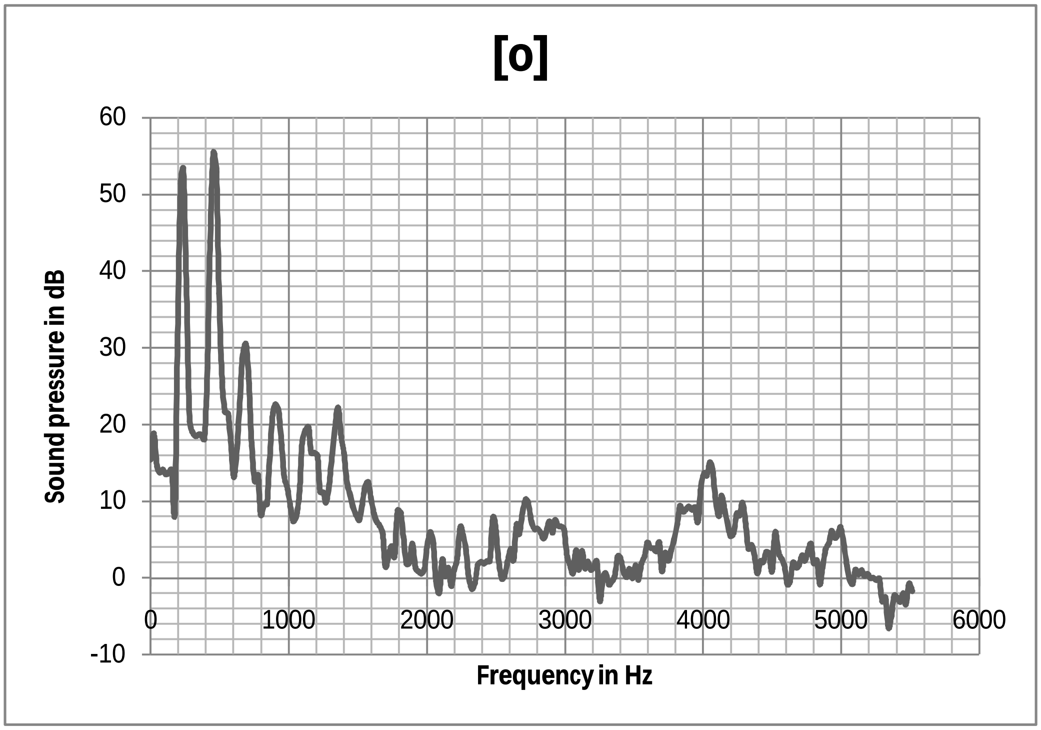


Fig. 4.11b

Fig. 4.10-4.11: Spectral shapes of the back vowels of Amharic. In each figure, the first one (a) is average spectrum of the vowel from male speakers, and (b) is average spectrum of the vowel from female speakers. FFT spectrum results were extracted from 16 tokens of each vowel using a 20 ms window centered at the middle of each vowel using CSL 4400.

4.1.1.4 Degree of Lip Rounding

In terms of the formant frequencies, the degree of lip rounding is explained by F3 for front vowels and F2 for back vowels (Ladefoged 2001 a, b). The F3 values obtained for each vowel shows the following facts: for front vowels, [**e**] has lower F3 than [**i**]; for back vowels, [**o**] has lower F2 than [**u**]. For central vowels, the F2 values go lower in the order [**ɘ**], [**ɜ**], [**a**]. This is supplemented by the pictures of the lip taken from a female speaker. The vowels with lower F2 or F3 values show more open and round lip position.

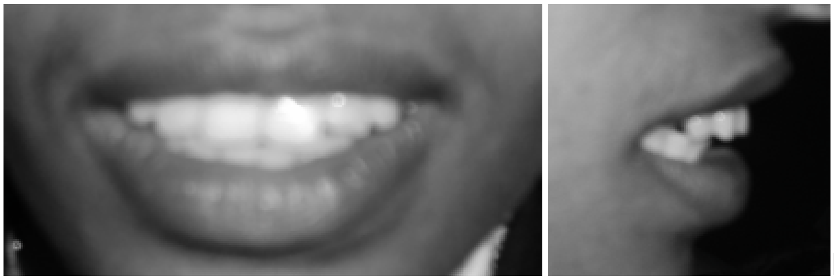


Fig. 4.12a [**i**]


Fig. 4.12b [**e**]

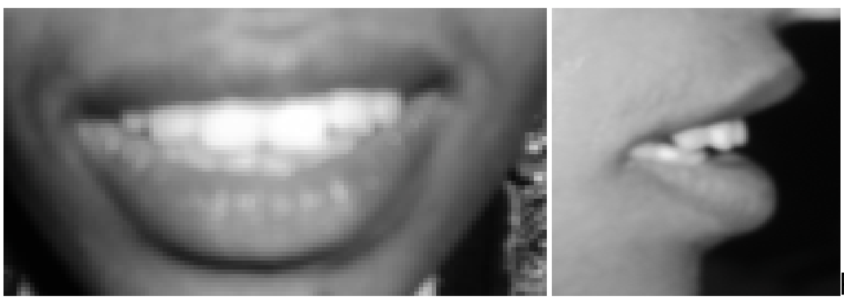


Fig. 4.12c [**ɘ**]

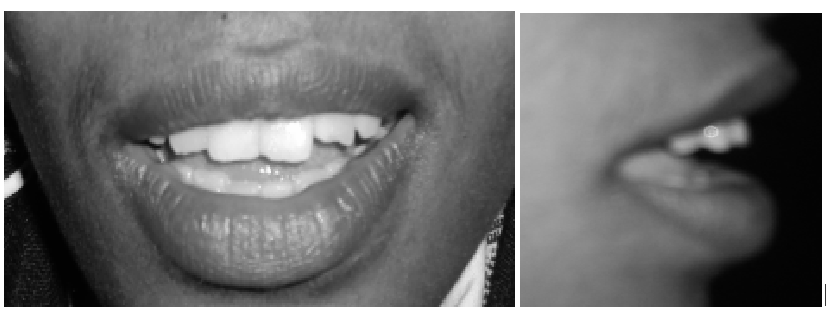


Fig. 4.12d [**ɜ**]


Fig. 4.12e [**a**]

Fig. 4.12f [**u**]

Fig. 4.12g [**o**]

Fig. 4.12a-g: Front and side views of the lips in the production of Amharic vowels by a female speaker.

Of the seven vowels, [**u**] had a very strong rounding feature, which is explained by the lips being very tightened to make a small spherical shape as seen in Fig. 4.12f. The F2 values, however, could not be employed to consider the rounding feature because there are no unrounded back vowels that can be compared to [**u**] and [**o**]. In addition,

Individual Patterns

Individual differences within the same gender were seen for F1 and F3 values only. Even for F1, the individual differences occurred for male subjects only at $p<0.05$, and Fisher's LSD test revealed that this difference occurred between subjects M4 and M1. F3 values showed significant differences between subjects within the same gender for both male and female subjects. The differences between subjects for females were significant at $p<0.005$, and this occurred between the subjects F3 versus subjects W1 and W2. For male subjects, the individual difference was significant at $p<0.01$, and it happened between subject M2 versus subjects M1 and M3.

4.1.2 Duration of Amharic Vowels

4.1.2.1 Average Duration of Vowels

Before going to the different contexts, the average duration of each of the vowels was computed both in wordlists and a carrier sentence both for males and females. It was found that the vowels of females were quite longer than male's vowels in a range of 15-20 ms.[22]

For both males and females, [**a**] was the longest vowel followed by [**o**] and then by [**e**]. The vowel [**u**] was the shortest vowel. Gankin's (1969) claim that the vowels [**o**] and [**e**] are always long is only partially confirmed since it is [**a**] which had the longest duration and [**o**] and [**e**] were the second and third long vowels in terms their mean duration.

Amharic partially conforms to the results of earlier results which showed that "*Other factors being equal, a high vowel is shorter than a low vowel*" (Lehiste 1970:18). This fact has been a ested in languages such as English (House and Fairbanks 1953 and Peterson and Lehiste 1960), Danish (Fischer-Jørgensen 1955), German (Maack 1949), Spanish (Navarro Tomás 1966, Swedish (Elert 1964) and Thai (Abramson 1962)[23]. The longer duration of the low vowels has been accounted for by the longer duration that the movement of the articulators takes in the production of the low vowels. Nevertheless, the vowel [**e**] is longer than [**ɜ**], and [**i**] is longer than [**ɘ**] in Amharic, showing the phonetic universal proposed is not absolute. The results for Amharic are presented in the following figures.

[22] Various explanations could be proposed for this result, including cultural effects or female's speech tending to be clearer etc. Nevertheless, this could only be a speculation and a separate study would bring the desired explanations.

[23] All these studies were cited by Lehiste (1970).

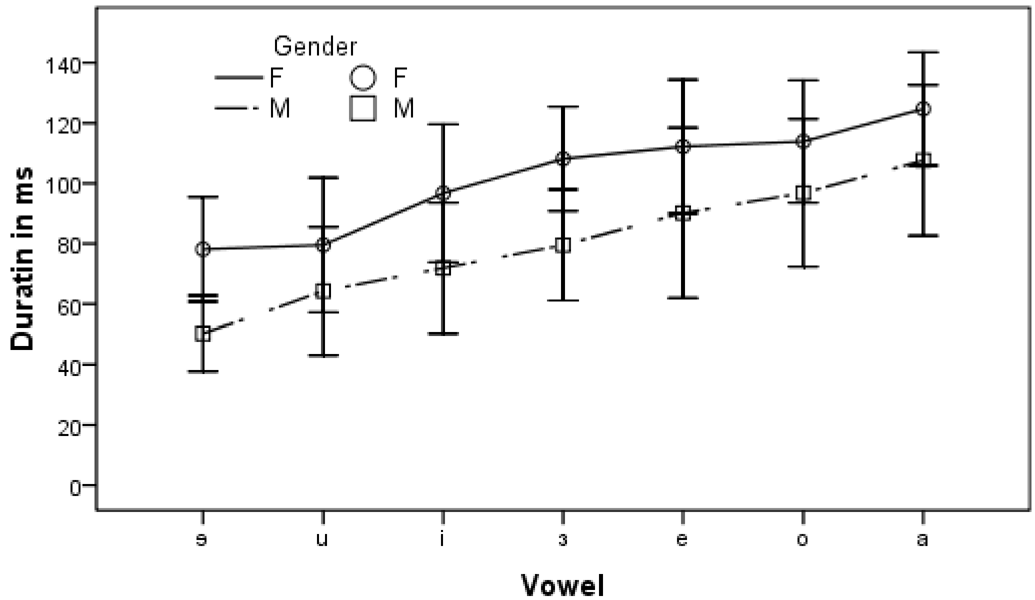


Fig. 4.13: Average duration of Amharic vowels of male and female subjects. Error bars represent plus or minus one SD from the mean .

4.1.2.2 Duration of Vowels before Voiceless and Voiced Consonants

Group Patterns

Amharic vowels were found to be longer when they come before voiced consonants than when they come before voiceless consonants as is the case for the majority of languages in the world. The effect of the voice of the following consonant was significant in Amharic, f(1, 775)= 58.35 (p<0.001). Both gender and position (in a wordlist or a carrier sentence) had significant) effects on the values, f(1, 775)=119.8 (p<0.001) for gender and f(1, 775)= 32.2 (p<0.001). (For this reason, the results are presented in figures separately for the two genders and the two positions (in a wordlist and in a carrier sentence). The results in Fig. 4.14- show that all of the vowels of Amharic were longer before the voiced stops than they were before the voiceless stop. For males, the difference of the duration between each vowel before voiceless and voiced stops varied between 7-63 ms and for females the duration difference varied between 3-44 ms.

There were two sub-contexts in which the duration of vowels before voiceless and voiced stops were examined. The first was in the sub-context **/t – t/** and **/t – b** / environments (Fig. 4. 14a).The second sub-context was in **/b – t/** and **/d – d/** environments (Fig. 4.14b). The two sub-contexts differ in the preceding consonant. When the preceding consonant was a voiced stop, the duration of five of the seven vowels was consistently longer before voiced cosonants than before voiceless consonants. Two of the vowels [**u**] and [**ɘ**] showed shorter duration before [**t**] than before [**d**] for both male and female subjects. The ratio of the average duration of vowels before the voiceless stop to the average duration of vowels before voiced stops for Amharic (taking both males and females, and both in a wordlist and in a carrier sentence irrespective of the voiced the consonant preceding the vowel) is 2.5:3, which is higher than the 2:3 ratio of the average duration of vowels before voiceless consonants to the average duration of vowels before voiced consonants for American English that was reported by Peterson and Lehiste (1960).

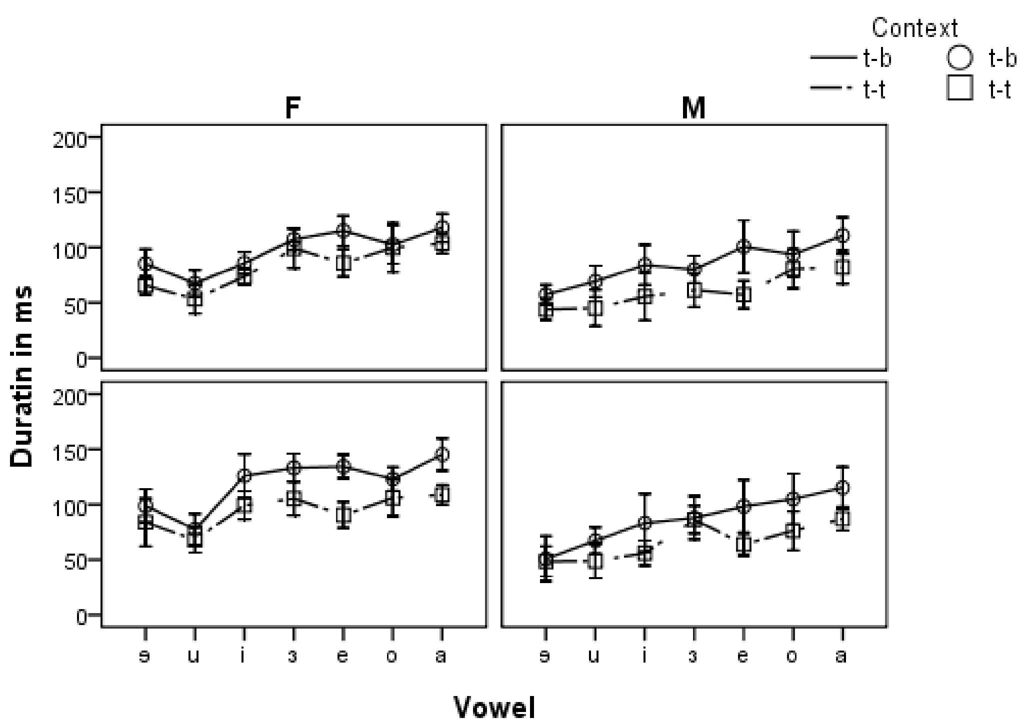


Fig. 4.14a: Duration of Amharic vowels before voiced and voiceless stops: upper panel – vowels in a wordlist, lower panel - vowels in a carrier sentence.

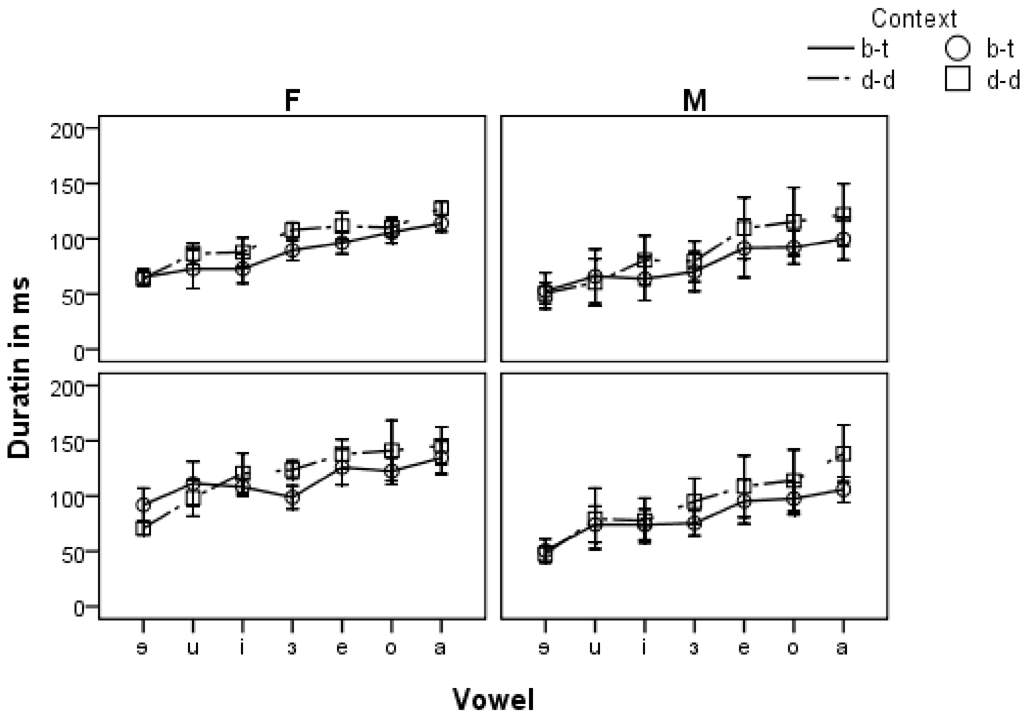


Fig. 4.14b: Duration of Amharic vowels before voiced and voiceless stops: upper panel – vowels in a wordlist, lower panel - vowels in a carrier sentence.

To investigate how significant these duration differences were, a paired sample t-test was conducted. The results are summarized in Table 4.2.

The results from the univariate analysis showed that five of the seven vowels showed significant differences in length due to the voice of the stop that comes after them. Only two vowels, [ə] and [**u**], which had the opposite pattern showed no significant differences of duration at all. Generally, it can be concluded that Amharic vowels tend to be longer before voiced consonants than before voiceless consonants, but they were significantly longer when the preceding consonant is voiceless.

Results on Vowels

Table 4.2: Level of statistical significance of the duration differences between vowels that come before voiceless and voiced stop in Amharic (α<0.05).

Vowel	Male, List	Male, Sentence	Female, List	Female, Sentence
a	f(1, 30)=17.66, p<0.001	f(1, 30)=11.46, p=0.002	f (1,22)=12.48, p=0.002	f (1,22)=10.76, p=0.003
e	f(1, 28)=7.93, p=0.009	f(1, 29)=10.98, p=0.002	f (1,22)=14.04, p=0.001	f (1,22)=19.38, p<0.001
ɜ	Not Significant	f(1, 30)=6.2, p=0.019	f (1,22)=28.33, p<0.001	f (1,22)=7.85, p=0.01
i	f(1, 30)=5.04, p=0.032	f(1, 30)=5.04, p =0.003	f (1,22)=10.07, p=0.004	f (1,22)=9.64, p=0.005
ɘ	Not Significant	Not Significant	Not Significant	Not Significant
o	f(1, 30)=8.18, p =0.008	f(1, 30)=4.93, p =0.034	f (1,22)=5.13, p=0.034	Not Significant
u	Not Significant	Not Significant	Not Significant	f (1,22)=4.49, p=0.046

The effect of preceding stops on the duration of vowels was also compared. The results show that three of the seven vowels ([**a**], [**e**], [**o**]) for males and only one of the seven vowels, i.e.[**u**]) for females were consistently longer when they come after a voiced stop than when they come after a voiceless stop. The rest of the vowels ([**i**], [**ɜ**], [**ɘ**] and [**u**] for males and [**a**], [**e**], [**o**], [**i**], [**ɜ**], [**ɘ**] for females) showed inconsistent results. These results show that voice of preceding consonants in Amharic cannot be considered as a cue to the duration of a vowel following it.

Individual Patterns

Individual differences within the same gender were significant for male subjects only f (3, 438)=3.97, p<0.001. Scheffe post-hoc test showed that the differences were between subjects M4 and all the rest three male subjects at p<0.001. The individual patterns confirmed the group patterns. Of the seven subjects, only one female subject had the vowel [**ɜ**] longer before a voiceless stop than before a voiced stop when the consonant preceding the vowel was a voiceless stop. When the consonant preceding the vowel was a voiced stop, one male subject and all female subjects had the vowel [**ɘ**] longer before voiceless stops than before voiced stops. Two male and all female subjects had the vowel [**u**] longer before voiceless stops than before voiced stops. This also confirms the group results. The only exception to the group results was the case of a female subject who had the vowel [**o**] and a male subject who had the vowel [**ɜ**] in addition to the two vowels [**ɘ**] and [**u**] longer before voiceless stops than before voiced stops.

4.1.2.3 Duration of Vowels before Singletons and Geminates

Group Patterns

Amharic vowels were found to be longer before nongeminates than before geminates. There were exceptions in the patterns of the duration of Amharic vowels before geminates and singletons, as presented in Fig. 4.15. For male subjects, [**i**] had higher mean duration before a geminate consonant than before a singleton both in the wordlist and in the carrier sentence. The vowel [**o**] of male subjects also had higher mean duration before a geminate consonant than before a singleton in the carrier sentence.

In general, the effect of consonant length on the duration the preceding vowel was significant $f(1, 757)=49.36$ ($p<0.001$) irrespective of whether the vowels were in a wordlist or in a carrier sentence. A univariate analysis of variance conducted for each of the six vowels showed that three vowels for males and other three vowels for females had significant differences as it is presented in Table 4.3.

A separate analysis was conducted to see the effect of consonant length in a wordlist and in a carrier sentence for separate genders. It was found that vowels in a wordlist had significant differences in duration when they come before geminate and nongeminate consonants: for females $f(1, 188)=42.62$ ($p<0.001$) and for males $f(1,187)=7.18$ ($p=0.008$). Vowels in a carrier sentence showed differences in duration before geminate and nongeminate consonants only for female subjects, $f(1, 187)=27.53$ ($p<0.001$).

Results on Vowels

The results in Fig. 4.15 show that, females had longer vowels in all contexts than males had, and the difference was significant, f(1-757)=19.5 (p<0.001). A GLM univariate analysis of variance for individual vowels showed that the significant differences happened on the duration of the three central vowels only: **[ɜ]**- f(1, 123)=32.09(p=0.001); **[ɘ]**- f(1,124)=12.08(p=0.001) and **[a]** - f(1, 125)=3.95 (p=0.049).

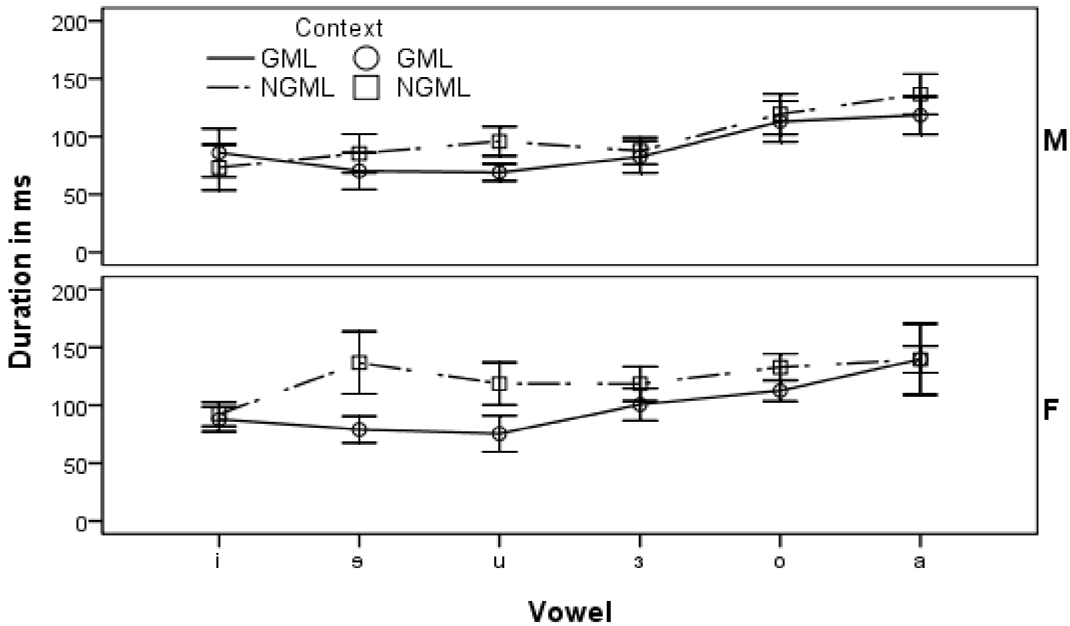


Fig.4.15a: Duration of six Amharic vowels before nongeminate and geminate consonants: vowels in a wordlist. Error bars indicate plus or minus one SD from the mean.

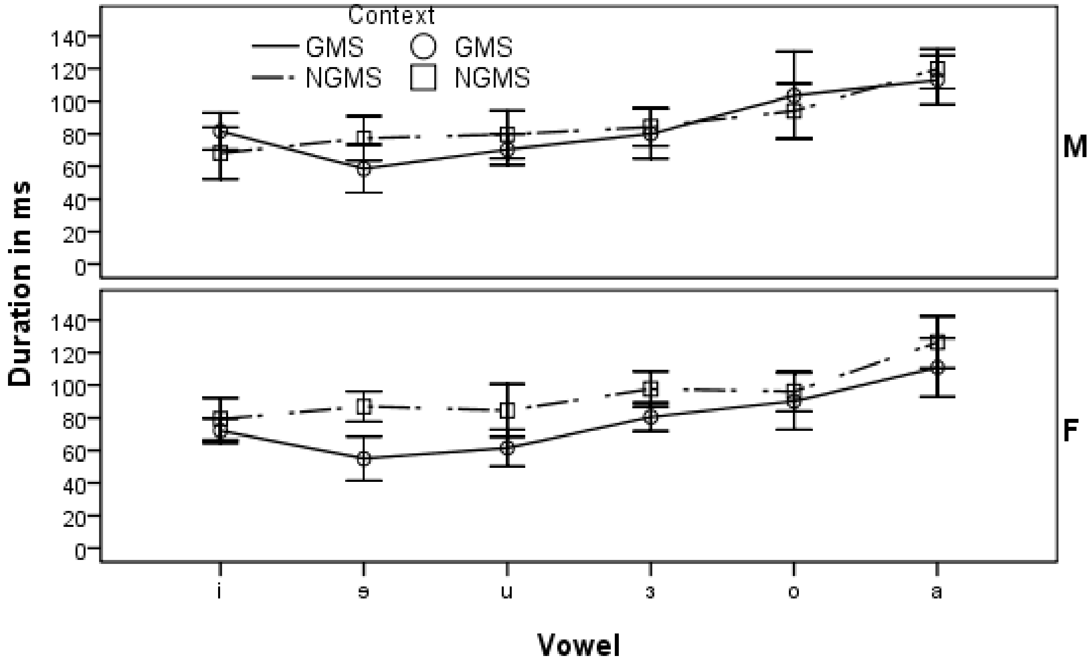


Fig.4.15b: Duration of six Amharic vowels before nongeminate and geminate consonants: vowels in a carrier sentence. Error bars indicate plus or minus one SD from the mean.

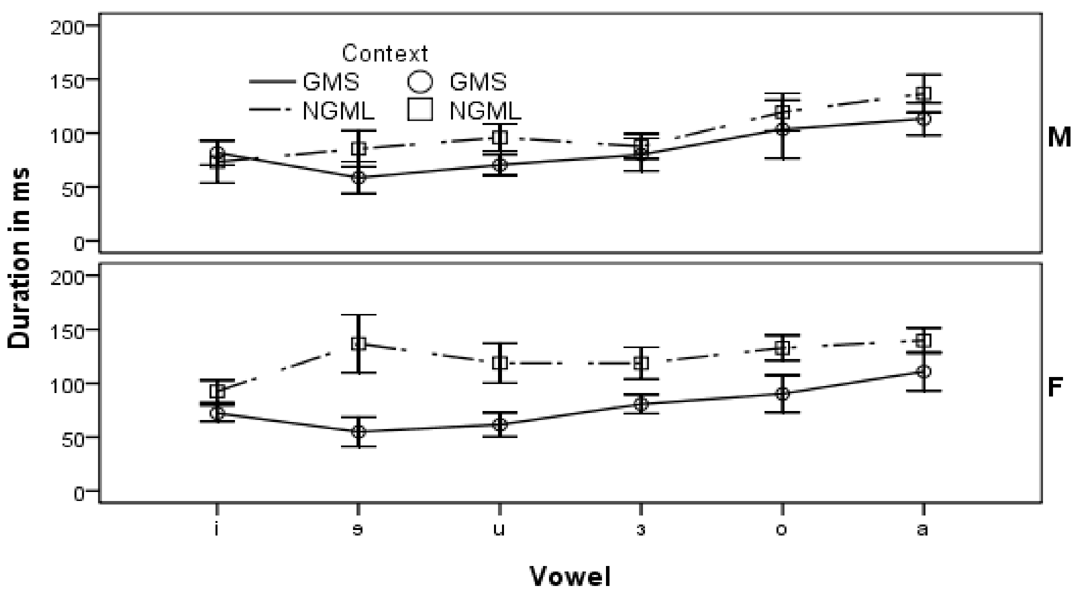


Fig.4.15c: Duration of six Amharic vowels before geminate consonants in a carrier sentence and nongeminate consonants in a wordlist. Error bars indicate plus or minus one SD from the mean.

Key to context

NGML- before a nongeminate consonant in wordlist *GML-before geminate consonant in wordlist*

NGMS- before a nongeminate consonant in a carrier sentence *GMS-before a nongeminate consonant in a carrier sentence*

Table 4.3: Level of statistical significance of the differences in duration of vowels when they come before a nongeminate and a geminate consonant. The statistical significance shows the result of a univariate analysis of variance conducted for each vowel but collapsing vowels in a wordlist and vowels in a carrier sentence.

Vowel	Males	Females
ɜ	Not Significant	f(1, 0)=18.47, p<0.001
u	f(1, 62)=32.64, p<32.64	f(1, 61)=41.19, p<0.001
i	f(1, 61), p=0.004[24]	Not Significant
a	Not Significant	Not Significant
ɘ	f(1, 60)=17.07, p<0.001	f(1, 62)=49.19, p<0.001
o	Not Significant	f(1, 61)=7.11, p=0.01

Individual Patterns

Individual differences were not significant for female subjects. Male subjects however had differences which were significant, f (3, 379) =6.98 (p<0.001). The significant differences were between subject M4 versus M1 and M3 at p<0.005 when tested by Scheffe post-hoc test. The individual patterns agree with the group results. For female subjects, all vowels had longer mean duration when they came before nongeminate consonants than when they came before geminate consonants, and his pattern was confirmed by a minimum of three of the four female subjects. The results for male subjects also confirmed the group pattern seen in the case of vowels in the wordlist. The vowels of at least three of the four male subjects had longer mean duration when they came before nongeminate consonants than when they came before geminate consonants. The exceptional case of the vowel [**i**] was also the same in the individual results. Three of the four subjects had the opposite pattern for vowel [**i**] compared to the rest of the vowels. The vowels [**u**] and [**ɜ**] had only one and two subjects out of the four male subjects conforming to the group patterns.

[24] Remember here that the pattern is the opposite of the rest of the vowels for male subjects.

4.1.3 Discriminant Analysis

4.1.3.1 Results on Discriminant Analysis Using F1 and F2 Values

General Results

The results on the discriminant analysis using F1 and F2 values only show that more than 84% of the cases were correctly classified: 87.0 % of selected original grouped cases, 84.4 % of unselected original grouped cases and 86.7 % of selected cross-validated grouped cases were classified correctly. Both F1 and F2 had significant contribution to the difference in variance (Wilk's Lambda < 0.001). Nevertheless, F2 accounted for 87.1 % and F1 accounted for 12.9 % of the difference in variance. The result found in Amharic has higher classification values than found for American English vowels reported by Peterson and Barney (1952) (74.9%) and Hillenbrand et al. (1995) (68.2 %). The classification result for each of the vowels is presented in Table 4.4. The results for each of the vowels show that [**o**] had higher classification rate than all the rest of the vowels while [**u**] had the lowest classification rate.

Table 4.4: Classification results of Amharic vowels using F1 and F2 values for all subjects collapsed across genders.

Cases		**Vowel**	**Predicted Group Membership**							**Total**
			ɜ	**u**	**I**	**a**	**e**	**ɘ**	**o**	
Cases Selected	Original %	**ɜ**	84.9	5.8		5.8		3.5		100.0
		u		66.2				21.6	12.2	100.0
		i			90.3		9.7			100.0
		a	7.9			89.9			2.2	100.0
		e	1.1		3.2		82.1	13.7		100.0
		ɘ	1.1	4.6			1.1	93.1		100.0
		o		1.1					98.9	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**I**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	84.9	5.8		5.8		3.5		100.0
		u		66.2				21.6	12.2	100.0
		i			89.2		10.8			100.0
		a	7.9			89.9			2.2	100.0
		e	1.1		4.2		81.1	13.7		100.0
		ɘ	1.1	4.6			1.1	93.1		100.0
		o		1.1					98.9	100.0

Results on Vowels

		Vowel	ɜ	u	I	a	e	ɘ	o	Total
Cases Not Selected	Original %	ɜ	80.5	4.9		7.3		7.3		100.0
		u		67.6				18.9	13.5	100.0
		i			90.6		9.4			100.0
		a	7.7			89.7	.0		2.6	100.0
		e			15.6		75.0	9.4		100.0
		ɘ		7.7			2.6	89.7		100.0
		o		2.8					97.2	100.0

Results by Gender

The results of the discriminant analysis by gender showed increased rates of classification as expected. For female subjects, 93.9 % of selected original grouped cases, 92.1 % of unselected original grouped cases and 93.2 % of selected cross-validated grouped cases were classified correctly. For male subjects, 93.1 % of selected original grouped cases, 87.6 % of unselected original grouped cases and 92.2 % of selected cross-validated grouped cases were classified correctly. The results for each vowel are presented in Table 4.5.

The results of each vowel for female and male speakers show that for females, the front vowels [**i**] and [**e**] had higher classification results, but for males the back vowels [**o**] and [**u**] had higher classification results.

Table 4.5a: Classification results of Amharic vowels using F1 and F2 values: results for female subjects.

Cases		**Vowel**	**Predicted Group Membership**							**Total**
			ɜ	u	i	a	e	ɘ	o	
Cases Selected	Original %	ɜ	93.2			2.3		2.3	2.3	100.0
		u		67.7				12.9	19.4	100.0
		i			100.0					100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		2.1					97.9	100.0

		Vowel	з	u	i	a	e	ɘ	o	Total
	Cross-validated %	з	90.9			4.5		2.3	2.3	100.0
		u		67.7				12.9	19.4	100.0
		i			100.0					100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		4.3					95.7	100.0
Cases Not Selected	Original %	Vowel	з	u	i	a	e	ɘ	o	Total
		з	94.7					5.3		100.0
		u		68.8				12.5	18.8	100.0
		i			93.3		6.7			100.0
		a	4.5			95.5				100.0
		e					100.0			100.0
		ɘ		4.3				95.7		100.0
		o		6.2					93.8	100.0

Table 4.5b: Classification results of Amharic vowels using F1 and F2 values: results for male subjects.

Cases		Predicted Group Membership								
Cases Selected	Original %	**Vowel**	з	u	I	a	e	ɘ	o	**Total**
		з	90.5			7.1		2.4		100.0
		u		95.3				4.7		100.0
		i			91.5		8.5			100.0
		a	12.8			87.2				100.0
		e			4.2		93.8	2.1		100.0
		ɘ	2.1				4.2	93.8		100.0
		o							100.0	100.0
	Cross-validated %	**Vowel**	з	u	I	a	e	ɘ	o	**Total**
		з	90.5			7.1		2.4		100.0
		u		95.3				4.7		100.0
		i			89.4		10.6			100.0
		a	12.8			87.2				100.0
		e			8.3		89.6	2.1		100.0
		ɘ	2.1				4.2	93.8		100.0
		o							100.0	100.0

		Vowel	ɜ	u	i	a	e	ɘ	o	Total
Cases Not Selected	Original	ɜ	77.3			18.2		4.5		100.0
		u		85.7				14.3		100.0
		i			94.1		5.9			100.0
		a	17.6			82.4				100.0
		e	6.2				87.5	6.2		100.0
		ɘ					12.5	87.5		100.0
		o							100.0	100.0

Results after Speaker Normalization

Speaker normalization was conducted and the normalized values were used for discriminant analysis. The results were significantly higher than it was found for collapsed genders but almost similar to the results found for separate genders. The results show that 94.8 % of selected original grouped cases, 94.1 % of unselected original grouped cases and 94.5 % of selected cross-validated grouped cases were classified correctly.

Table 4.6: Classification results of Amharic vowels using F1 and F2 values: results using normalized values.

Cases		Vowel	Predicted Group Membership							Total
			ɜ	u	i	a	e	ɘ	o	
Cases Selected	Original %	ɜ	96.5					2.3	1.2	100.0
		u		82.4				8.1	9.5	100.0
		i			97.8	.0	2.2			100.0
		a	5.6			94.4				100.0
		e	1.1		4.2		92.6	2.1		100.0
		ɘ					1.1	98.9		100.0
		o		1.1					98.9	100.0
	Cross-validated %	Vowel	ɜ	u	i	a	e	ɘ	o	Total
		ɜ	96.5					2.3	1.2	100.0
		u		82.4				8.1	9.5	100.0
		i			97.8		2.2			100.0
		a	5.6			94.4	.0			100.0
		e	1.1		4.2		92.6	2.1		100.0
		ɘ					2.3	97.7		100.0
		o		2.2					97.8	100.0

		Vowel	ɜ	u	i	a	e	ɘ	o	Total
Cases Not Selected	Original %	ɜ	97.6					2.4		100.0
		u		81.1				10.8	8.1	100.0
		i			96.9	.	3.1			100.0
		a	2.6			97.4				100.0
		e	3.1		3.1		90.6	3.1		100.0
		ɘ		5.1				94.9		100.0
		o							100.0	100.0

Classification results for each vowel showed that except for [**u**], all Amharic vowels had more than 90 % correct classification.

4.1.3.2 Results on Discriminant Analysis Using F1, F2 and F3 Values

General Results

Using a step-wise method, the discriminant analysis using F1, F2 and F3 values for all subjects collapsed across genders showed no significant classification results from the results obtained using F1 and F2 values only: 86.3 % of selected original grouped cases 86.3 % of unselected original grouped cases and 86.2 % of selected cross-validated grouped cases were classified correctly. However, the contribution of F2 and F1 changed a little while F3 contributed very little though the contribution was significant (Wilk's Lambda <0.001). F2 accounted for 83.7 %, F1 16.1 % and F3 0.02 % of the difference in variance. The classification results for each of the vowels are presented in Table 4.7.

Table 4.7: Classification results of Amharic vowels using F1, F2 and F3 values for all subjects collapsed across genders.

Cases			Predicted Group Membership							
		Vowel	ɜ	u	i	a	e	ɘ	o	Total
Cases Selected	Original %	ɜ	83.7	3.5		5.8		5.8	1.2	100.0
		u		64.9				21.6	13.5	100.0
		i			89.2		10.8			100.0
		a	9.0			91.0				100.0
		e	1.1		5.3		82.1	11.6		100.0
		ɘ	1.1	3.4			2.3	93.1		100.0
		o		3.3					96.7	100.0

Results on Vowels

		Vowel	ɜ	u	i	a	e	ɘ	o	Total
	Cross-validated %	ɜ	83.7	3.5		5.8		5.8	1.2	100.0
		u		63.5				21.6	14.9	100.0
		i			89.2		10.8			100.0
		a	9.0			91.0				100.0
		e	1.1		5.3		82.1	11.6		100.0
		ɘ	1.1	3.4			2.3	93.1		100.0
		o		3.3					96.7	100.0
Cases Not Selected	Original %	Vowel	ɜ	u	i	a	e	ɘ	o	Total
		ɜ	80.5			9.8		9.8	.0	100.0
		u		73.0				13.5	13.5	100.0
		i			90.6		9.4			100.0
		a	7.7			89.7			2.6	100.0
		e			6.2		81.2	12.5		100.0
		ɘ		5.1			5.1	89.7		100.0
		o							100.0	100.0

Similar to the classification results using F1 and F2 values only, this classification also resulted in higher classification results for [**o**] followed by [**ɘ**], [**a**], [**i**], [**ɜ**], [**e**] and finally [**u**].

Results by Gender

The discriminant analysis using F1, F2, and F3 yielded almost similar results by gender. For females, 92.9 % of selected original grouped cases, 92.1 % of unselected original grouped cases and 92.2 % of selected cross-validated grouped cases were correctly classified. For males, 93.1 % of selected original grouped cases, 87.6 % of unselected original grouped cases and 92.2 % of selected cross-validated grouped cases were correctly classified. The results for individual vowels are presented in Table 4.8.

Table 4.8a: Classification results of Amharic vowels using F1, F2 and F3 values: female subjects

Cases		Vowel	Predicted Group Membership							Total
			ɜ	**u**	**i**	**a**	**e**	**ɘ**	**o**	
Cases Selected	Original %	**ɜ**	93.2			2.3		2.3	2.3	100.0
		u		64.5				12.9	22.6	100.0
		i			100.0					100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		6.4					93.6	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	90.9			4.5		2.3	2.3	100.0
		u		64.5				12.9	22.6	100.0
		i			97.8		2.2			100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		6.4					93.6	100.0
Cases Not Selected	Original %	Vowel	**ɜ**	**u**	**I**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	94.7					5.3	.0	100.0
		u		68.8				12.5	18.8	100.0
		i			93.3		6.7			100.0
		a	4.5			95.5				100.0
		e					100.0			100.0
		ɘ		4.3				95.7		100.0
		o		6.2					93.8	100.0

Table 4.8b: Classification results of Amharic vowels using F1, F2 and F3 values: male subjects

Cases		Predicted Group Membership								
Cases Selected	Original	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	90.5			7.1		2.4		100.0
		u		95.3				4.7		100.0
		i			91.5		8.5			100.0
		a	12.8			87.2				100.0
		e			4.2		93.8	2.1		100.0
		ɘ	2.1				4.2	93.8		100.0
		o							100.0	100.0
	Cross-validated	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	90.5			7.1		2.4		100.0
		u		95.3				4.7		100.0
		i			89.4		10.6			100.0
		a	12.8			87.2				100.0
		e			8.3		89.6	2.1		100.0
		ɘ	2.1				4.2	93.8		100.0
		o							100.0	100.0
Cases Not Selected	Original	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	77.3			18.2		4.5		100.0
		u		85.7				14.3		100.0
		i			94.1		5.9			100.0
		a	17.6			82.4				100.0
		e	6.2				87.5	6.2		100.0
		ɘ					12.5	87.5		100.0
		o							100.0	100.0

The results for each of the vowels for male and female speakers showed the same results to those results found using F1 and F2 values for discriminant analysis: higher classification results of the front vowels [**i**] and [**e**] for females and the back vowels [**u**] and [**o**] for males.

Results after Speaker Normalization

There were not significant differences in classification results using the normalized values in the discriminant analysis with the results found for gender split classifications: 95.0 % of selected original grouped cases, 94.1 % of unselected original grouped cases and 94.6 % of selected cross-validated grouped cases were correctly classified. However, compared to the results for collapsed genders, these results were higher. Once again, [**u**] had a significantly lower classification result than all the remaining six vowels.

Table 4.9: Classification results of Amharic vowels using F1, F2 and F3 values: results using speaker normalized values.

Cases			Predicted Group Membership							
		Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
Cases Selected	Original %	**ɜ**	96.5					2.3	1.2	100.0
		u		82.4				8.1	9.5	100.0
		i			97.8		2.2			100.0
		a	5.6			94.4				100.0
		e	1.1		3.2		93.7	2.1		100.0
		ɘ					1.1	98.9		100.0
		o		1.1					98.9	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	96.5					2.3	1.2	100.0
		u		82.4				8.1	9.5	100.0
		i			97.8		2.2			100.0
		a	6.7			93.3				100.0
		e	1.1		3.2		93.7	2.1		100.0
		ɘ					2.3	97.7		100.0
		o		1.1					98.9	100.0
Cases Not Selected	Original %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	97.6					2.4		100.0
		u		81.1				10.8	8.1	100.0
		i			96.9		3.1			100.0
		a	2.6		.	97.4				100.0
		e	3.1		3.1		90.6	3.1		100.0
		ɘ		5.1				94.9		100.0
		o							100.0	100.0

4.1.3.3 Discriminant Analysis Using F0, F1, F2 and F3 Values

General Results

The contribution of F0 in accounting for the difference of variance was very minimal not significant. This is expected as the vowels of Amharic did not show any significant difference in their F0 values. Still F2 accounted for 70.2 % and F1 accounted for 29.5 % of the difference in variance. The role of F2 decreased while the role of F1 increased in this discriminant analysis. Using F0, F1, F2 and F3 values, 91.5 % of selected original grouped cases, 88.8 % of unselected original grouped cases and 90.5 % of selected cross-validated grouped cases were correctly classified. Compared to the classification results using F1, F2 and F3 values, the classification results obtained using F0, F1, F2 and F3 values were higher. The results for each of the vowels are presented in Table 4.10.

Table 4.10 Classification results of Amharic vowels using F0, F1, F2, and F3 values for all subjects collapsed across genders.

Cases			Predicted Group Membership							
		Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
Cases Selected	Original	**ɜ**	89.5			5.8		3.5	1.2	100.0
		u		75.8				9.1	15.2	100.0
		i			93.4		6.6			100.0
		a	9.1			90.9				100.0
		e	1.1		1.1		92.6	5.3		100.0
		ɘ	1.2				1.2	97.6		100.0
		o		3.3					96.7	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	89.5			5.8		3.5	1.2	100.0
		u		74.2				9.1	16.7	100.0
		i			89.0		11.0			100.0
		a	9.1			90.9				100.0
		e	1.1		1.1		92.6	5.3		100.0
		ɘ	1.2				2.4	96.5		100.0
		o		3.3					96.7	100.0

Results on Vowels

		Vowel	ɜ	u	i	a	e	ɘ	o	Total
Cases Not Selected	Original %	**ɜ**	85.0			10.0		5.0		100.0
		u		67.7				16.1	16.1	100.0
		i			93.8		6.2			100.0
		a	10.3			89.7				100.0
		e	3.1		9.4		84.4	3.1		100.0
		ɘ		2.6				97.4		100.0
		o							100.0	100.0

The results of the classification of each vowel showed that still [**o**] and [**ɘ**] had the highest classification results and [**u**] had the lowest classification results.

Results by Gender

The cumulative role of F2 and F1 in accounting for the difference in variance remained the same, but F2 accounted for 67.9 % for female and 68.7 % for male speakers whereas F1 accounted for 31.9 % for female and 31.2 % for male speakers. Thus, what were observed were a decrease in the contribution of F2 and an increase in the contribution of F1 in accounting for the difference in variance as more variables are included in the discriminant analysis.

The classification results show that there was no significant difference in classification values when compared to the classification results obtained using F1, F2 values and F1, F2 and F3 values. For female speakers, 92.9 % of selected original grouped cases, 92.1 % of unselected original grouped cases and 92.2 % of selected cross-validated grouped cases were correctly classified. For male speakers, 94.8 % of selected original grouped cases, 84.4 % of unselected original grouped cases and 93.8 % of selected cross-validated grouped cases were correctly classified.

Results on Vowels

Table 4.11a: Classification results of Amharic vowels using F0, F1, F2 and F3: results for female subjects

Cases		Vowel	Predicted Group Membership							Total
			ɜ	u	i	a	e	ɘ	o	
Cases Selected	Original %	ɜ	93.2			2.3		2.3	2.3	100.0
		u		64.5				12.9	22.6	100.0
		i			100.0					100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		6.4					93.6	100.0
	Cross-validated %	Vowel	ɜ	u	i	a	e	ɘ	o	Total
		ɜ	90.9			4.5		2.3	2.3	100.0
		u		64.5				12.9	22.6	100.0
		i			97.8		2.2			100.0
		a	4.8			95.2				100.0
		e	2.1				97.9			100.0
		ɘ					2.6	97.4		100.0
		o		6.4					93.6	100.0
Cases Not Selected	Original %	Vowel	ɜ	u	i	a	e	ɘ	o	Total
		ɜ	94.7					5.3	.0	100.0
		u		68.8				12.5	18.8	100.0
		i			93.3		6.7			100.0
		a	4.5			95.5	.0			100.0
		e					100.0			100.0
		ɘ		4.3				95.7		100.0
		o		6.2					93.8	100.0

Results on Vowels

Table 4.11b: Classification results of Amharic vowels using F0, F1, F2 and F3: results for male subjects

Cases		Vowel	Predicted Group Membership							Total
			ɜ	**u**	**i**	**a**	**e**	**ɘ**	**o**	
Cases Selected	Original %	**ɜ**	95.2			4.8				100.0
		u		97.1				2.9		100.0
		i			97.8		2.2			100.0
		a	6.5			93.5	.0			100.0
		e			10.4		87.5	2.1		100.0
		ɘ	2.2				4.3	93.5		100.0
		o							100.0	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	92.9			7.1				100.0
		u		97.1				2.9		100.0
		i			97.8		2.2			100.0
		a	6.5			93.5				100.0
		e			10.4		83.3	6.2		100.0
		ɘ	2.2				4.3	93.5		100.0
		o							100.0	100.0
Cases Not Selected	Original %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	76.2			19.0		4.8		100.0
		u		80.0				20.0		100.0
		i			94.1		5.9			100.0
		a	23.5			76.5				100.0
		e	6.2		6.2		81.2	6.2		100.0
		ɘ		6.2			12.5	81.2		100.0
		o							100.0	100.0

Though not exactly the same results were found, still the classification results of each of the vowels for male and female speakers showed comparable results with the results found in the discriminant analysis using F1 and F2 as well as F1, F2, and F3 values. For female speakers, the vowels which had higher classification results were [**e**] and [**i**], but for males [**o**] and [**i**]. But still [**u**] also had the highest classification rate since it had only 0.06 %

difference with [**i**]. Female speakers had the vowel [**u**] with the lowest classification results whereas male speakers had the vowel [**e**] with the lowest classification results.

Results after Speaker Normalization

The results obtained using z-transformed values of the four parameters are presented in Table 4.12.

Table 4.12: Classification results of Amharic vowels using F0, F1, F2 and F3: results using speaker normalized values.

Cases			Predicted Group Membership							
		Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
Cases Selected	Original %	**ɜ**	96.5					2.3	1.2	100.0
		u		81.8				7.6	10.6	100.0
		i			96.7	.	3.3			100.0
		a	5.7			94.3				100.0
		e	1.1		3.2		94.7	1.1		100.0
		ɘ					1.2	98.8		100.0
		o		1.1					98.9	100.0
	Cross-validated %	Vowel	**ɜ**	**u**	**i**	**a**	**E**	**ɘ**	**o**	Total
		ɜ	96.5					2.3	1.2	100.0
		u		81.8				7.6	10.6	100.0
		i			96.7		3.3			100.0
		a	5.7			94.3				100.0
		e	1.1		3.2		94.7	1.1		100.0
		ɘ					1.2	98.8		100.0
		o		1.1					98.9	100.0
Cases Not Selected	Original %	Vowel	**ɜ**	**u**	**i**	**a**	**e**	**ɘ**	**o**	Total
		ɜ	95.0			2.5		2.5		100.0
		u		80.6				12.9	6.5	100.0
		i			96.9		3.1			100.0
		a	5.1			94.9				100.0
		e	3.1		3.1		90.6	3.1		100.0
		ɘ		5.1				94.9		100.0
		o							100.0	100.0

Results on Vowels

The classification results after speaker normalization showed slightly higher classification results than the results without normalization (for collapsed genders). Using the normalized values, 95.0 % of selected original grouped cases, 93.6 % of unselected original grouped cases and 95.0 % of selected cross-validated grouped cases were correctly classified. Once again, [**u**] had the least classification results.

4.1.3.4 Discriminant Analysis Using Separate Values

The normalized values of each of the four variables were entered in a discriminant analysis to see the contribution of that they make in the classification of Amharic vowels. Conforming to results found in earlier studies, the contribution of F2 was higher followed by F1 and F3. The discrimination power F0 was very minimal as it can be seen in Table 4.13.

Table 4.13: Classification of Amharic vowels by separate variables using speaker normalized values.

Variable	Percentage of Correct Classification		
	Selected original grouped cases	Unselected original grouped cases	Selected cross-validated grouped
F2	66.5	65.6	66.2
F1	59.5	63.7	56.7
F3	39.8	35.2	39.8
F0	20.8	18.5	20.8

4.2 Results on Pulmonic and Ejective Stops

The results on the different measurements on pulmonic and ejective stops are provided in this section. Duration measurements are presented first, followed by intensity measurements, then spectral shape measurements, and finally voice measurements. The result in each variable is presented in two categories: group and individual patterns. The focus is on group results, and individual patterns are presented to see how much individual patterns confirm group patterns and see whether individual differences could account for group patterns or not. In cases where the group results show no significant effects, individual patterns are not presented. At the end of the section, the results of the discriminant analyses taking the significant cues for place, voice and airstream are presented.

4.2.1 Results on Duration Measurements

4.2.1.1 Total Duration

Group Patterns

Total duration was measured for the sake of having general information about the duration of Amharic stops. It was measured for six of the nine stops investigated in this study. The three bilabial stops were not included in the total duration measurement as total duration was measured only in intervocalic position. The result is presented in Fig 4.18.

The results on total duration measurements show that females had longer duration of stops than males, by an average of 22 ms. The same results were obtained earlier on the vowels of Amharic. For all the stops measured, the duration of stops produced by females was 1.23-1.63 times longer than the stops produced by males. These differences in duration due to gender were significant, $f(1, 329)=82.04$ ($p<0.001$) when the means were compared by a GLM univariate analysis.

For both males and females, both at alveolar and velar places, voiced stops had the lowest mean duration. The contrast between ejectives and pulmonic was not straightforward as values differed for the two genders. For males, voiceless pulmonic stops had longer duration than ejectives at both places. For females, the differences in total duration between ejectives and voiceless pulmonic stops were not consistent in the alveolar and velar places of articulation: ejectives had longer mean duration at alveolar place while shorter mean duration at the velar place of articulation.

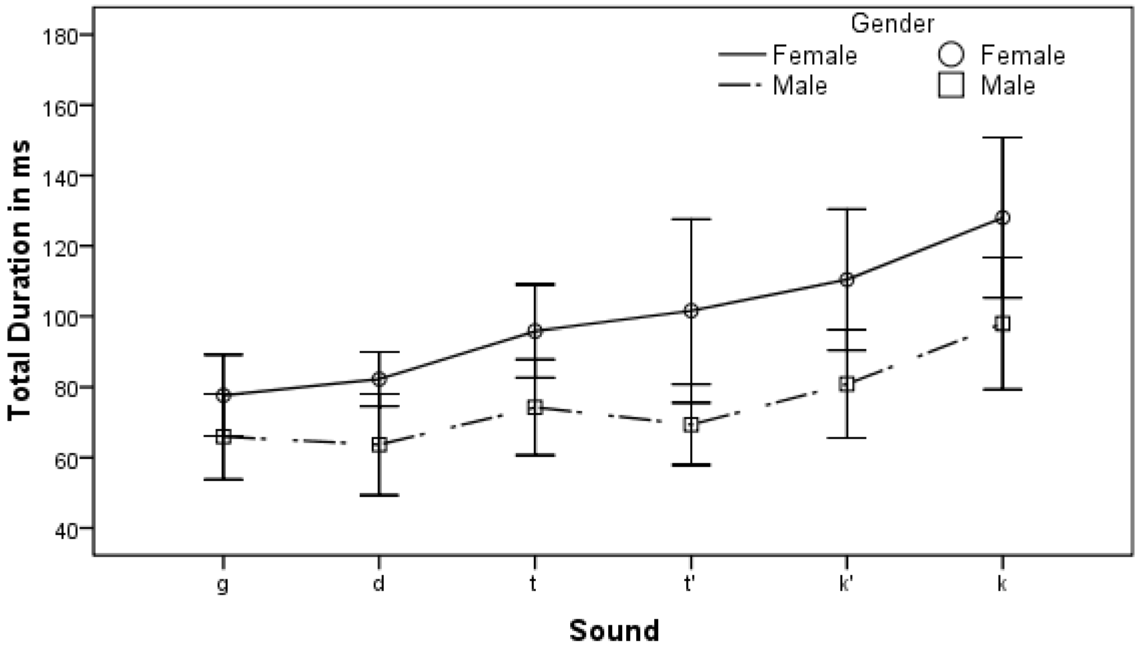


Fig. 4.16: Mean total duration of Amharic stops. Error bars represent plus or minus one SD from the mean.

The effect of place on mean total duration was significant for both genders, but not for all voices and airstream mechanisms. For males, the significant differences were for voiceless pulmonic stops, $f(1, 580)=30.86$ ($p<0.001$) and for voiceless ejective stops $f(1, 56)=10.59$ ($p=0.002$). For females, the significant differences occurred for voiceless ejective stops only, $f(1, 550)=41.32$ ($p<0.001$). For males, all the pulmonic and ejective stops had a consistent pattern: velars had longer mean total duration than alveolars. For females, this pattern did not work for the voiced stops as the mean duration of the voiced velar stop was lower than that of the mean total duration of the alveolar stop. The median value for the voiced stops, however, is the same as those of the males' mean values - the voiced velar stop having higher median value than the alveolar voiced stop. Females' voiceless stops, both pulmonic and ejective, showed longer mean total duration at the velar place than at the alveolar place. For both genders, the voiced stops did not show statistically significant difference in total duration due to place.

Individual Patterns

The duration of sounds showed significant differences across subjects of the same gender. For females, the level of significance was $f(3, 173)=12.08$ ($p<0.001$), and for males it was $f(3, 150)=9.47$ ($p<0.001$). The differences were between subjects for females were between subject W3 and the rest of the subjects ($p<0.001$ with W1 and W2, $p=0.008$ with W4) when tested by Scheffe post-hoc test. For males, subject M3 showed a significant difference with the rest of the three male subjects ($p<0.001$ with M1 and M2, $p=0.005$ with M4) ($p<0.001$) on Scheffe post-hoc test.

4.2.1.2 Closure Duration

Group Patterns

The results on the closure duration measurement are summarized in Fig. 4.19. The results on closure duration measurements show that, like total duration, female values were higher than male values, the difference being significant, $f(1, 350)=194.45$ ($p<0.001$).

The effect of place on the closure duration of Amharic was not consistent across the three groups of stops (voiced, voiceless pulmonic and voiceless ejective) and the two genders. The stops produced by males showed that velars had higher mean closure duration than alveolars in the same voice and airstream category, as it can be seen in the results of total duration. The differences were statistically significant for voiceless ejectives, $f(1, 56)=10.59$ ($p=0.002$) and for voiceless pulmonic stops, $f(1, 58)=30.86$ ($p<0.001$). The differences between the voiced stops were not statistically significant. The stops produced by females had some differences with the ones produced by males. Female's voiced alveolar stops had longer closure duration than the voiced velar stops had as opposed to males' voiced velar stops having longer closure duration than their voiced alveolar stops had, and this was the case for the median values as well. For the voiceless series, the results are the same as the ones for males, but with the differences being statistically significant only for the voiceless pulmonic stops, $f(1, 55)=41.32$ ($p<0.001$).

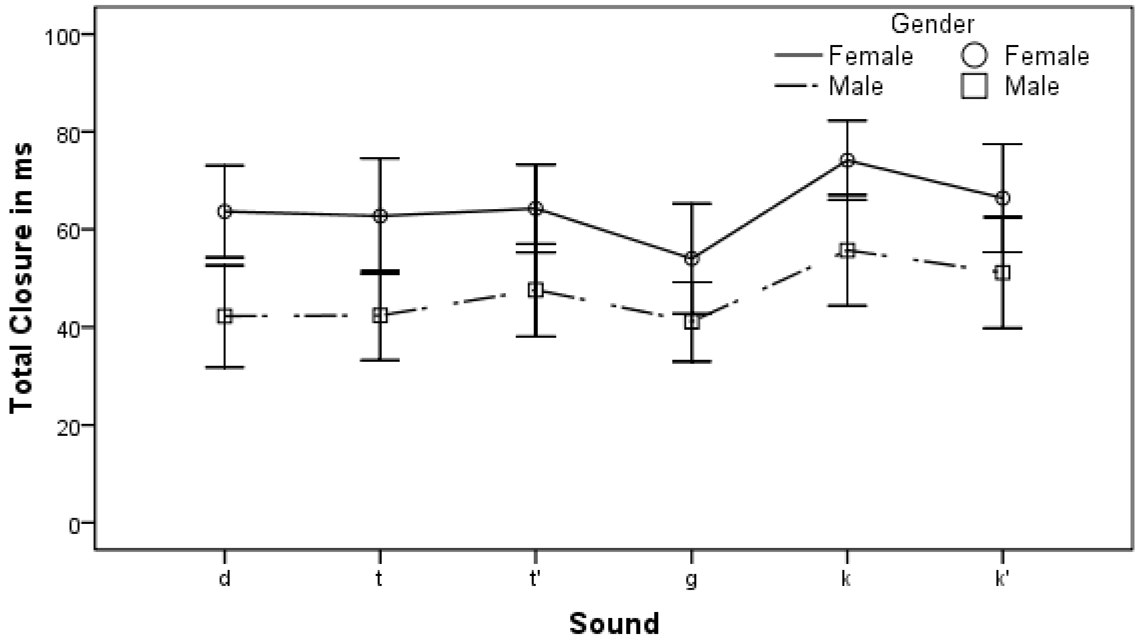


Fig. 4.17: Mean total closure of Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

The effect of voice was consistent across the two places of articulation: voiced stops had shorter closure than voiceless stops, and the difference was significant for both genders and all places: f(1, 85)=17.44(p<0.001) for alveolar stops by females; f(1, 88)=88.65(p<0.001) for velars by females; f(1, 75)=5.38 (p=0.023) for alveolars by males and f(1, 75)=24.08 (p<0.001). The effect of airstream was not consistent across the two places of articulations.

4.2.1.3 Voiced Closure

Group Patterns

The results on the measurement of the duration of the voiced part of the closure are presented in Fig. 4.18.

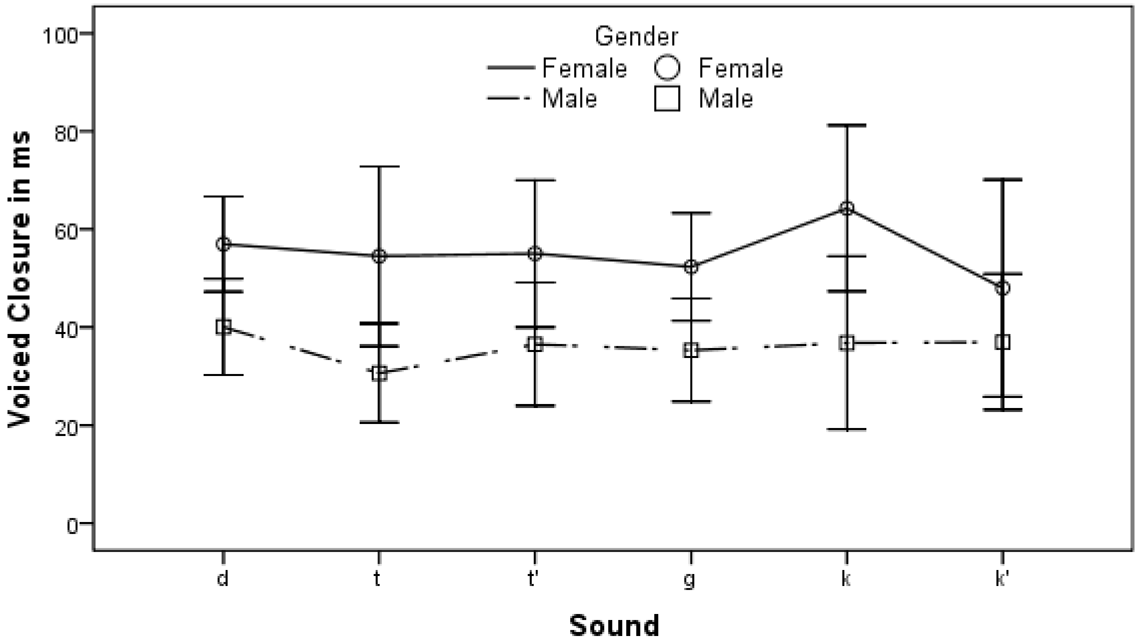


Fig. 4.18: Mean duration of the voiced part of the closure of Amharic stops. Error bars represent plus or minus one SD from the mean.

The results show that males' stops had shorter voiced closure than females' stops, and this was significant, f(1, 295)=113.57 (p<0.001). Place and voice had no significant and systematic effect on voiced closure duration. The effect of airstream was also not consistent: the results for male and female subjects show opposite patterns. Because there was no systematic and significant effect of place, voice or airstream on the duration of the voiced part of the closure, it is not necessary to discuss the individual patterns here.

4.2.1.4 Percentage of Voiced Closure to Total Closure

Group Patterns

The percentage of the duration of voicing into the stop closure to the mean total closure duration gave some systematic difference among Amharic stops, as the results in Fig. 4.19 show. Voiceless stops in Amharic conform to the pattern found by Byard (1993): alveolars had shorter voicing into the closure than velars.

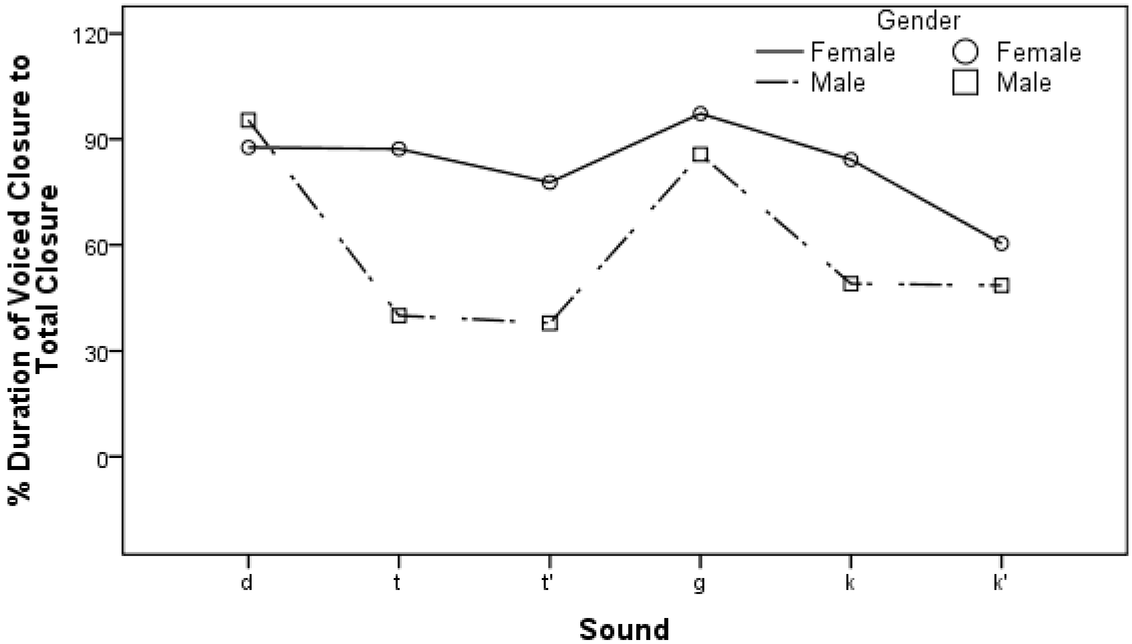


Fig. 4.19: Percentage of the duration of the voiced part of the closure to the total closure.

The results of the percentage of the mean duration of voicing into the stop closure to the mean total closure duration show that voiced stops had the highest percentage followed by voiceless pulmonic stops and finally by the voiceless ejectives. The effect of voice was significant, $f(1, 178)=12.79$ ($p=0.001$) for females and $f(1, 170)=73.73$ ($p<0.001$) for males.

The differences between the stops on the mean duration of voicing into the stop closure to the mean total closure duration due to gender were significant, $f(1, 350)=41.63$ ($p<0.001$), with stops produced by the female subjects having higher percentage than the stops produced by male speakers except for [**d**].

The effect of airstream was significant for female subjects only, $f(1, 170)=14.68$ ($p<0.001$) though for both genders, ejectives stops had lower values than their voiced and voiceless counterparts. Place of articulation showed no systematic effect. Thus, the percentage of duration of the voicing into the closure to duration of the total closure showed whether the stops were voiceless or voiced.

Individual Patterns

Since the duration of the closure as a whole or the duration of the voiced part of the closure in ms did not show any pattern for the groups considered, only the percentage of the mean duration of voicing into the stop closure to the mean total closure duration, which showed significant differences for groups, is discussed here.

Individual differences were significant for female subjects only, $f(3, 176)=6.01$ ($p=0.001$). Scheffe post-hoc test revealed that the differences occurred between subjects W4 and W1 ($p=0.002$) and W4 and W2 ($p=0.024$).

The individual results show that the voiced stops had the highest percentage of the voiced part of the closure duration to the total duration, as expected. But even so, subjects W1 and W4 did not conform to this pattern. The voiceless stops also showed the pattern ejectives having lower percentage of the voiced closure to the total closure duration (for 80% of the voiceless stops by five of the eight subjects).

4.2.1.5 Voiceless Part of the Closure

Group Patterns

The results on the voiceless part of the closure duration measurements are presented in Fig. 4.20. The results presented here include cases which had voicing all the way through the closure as 0 ms voiceless closure.

The results show that the effects of place and airstream were not significant and systematic for both genders. Gender differences were not consistent for all sounds.

The effect of voice was significant, $f(1, 349)=65.54$ ($p<0.001$), with voiceless stops having longer voiceless closure than voiced stops.

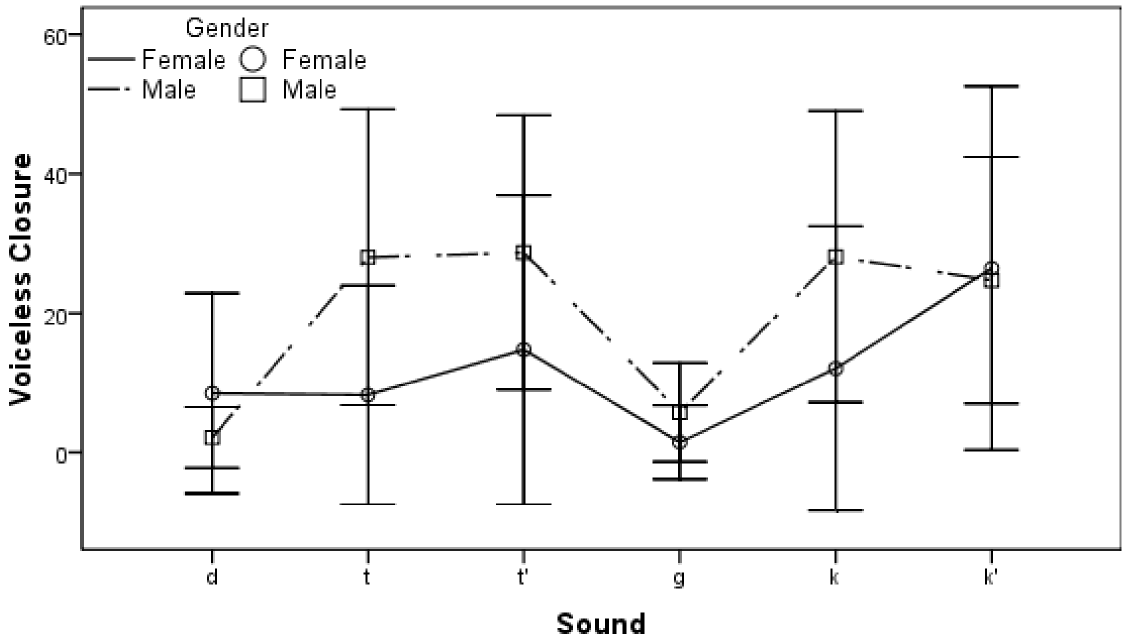


Fig. 4.20: Mean duration of the voiceless part of the closure of Amharic stops.

The general pattern in the mean duration of the stops of Amharic is repeated in the distribution of the cases that have voiceless closure. The results show that voiceless stops had voiceless closure in more than half of the cases where as the voiced stops had voiceless closure in less than 30 % of the cases measured for closure duration. The gender difference in the percentage of cases which had voiceless part in the closure show differences for two genders.

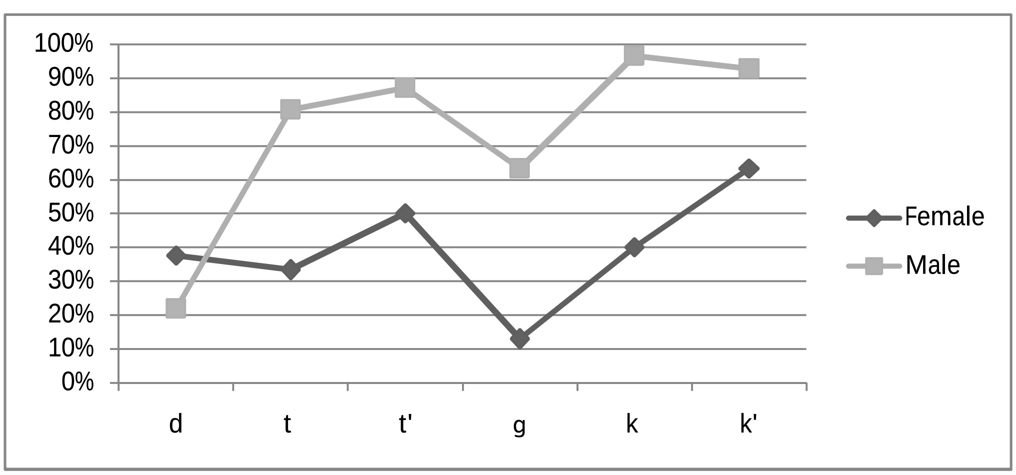


Fig. 4.21: Percentage of cases with voiceless closure for Amharic stops: separate genders.

Fig. 4.21 shows that there were more cases of stops with voiceless part of the closure for males than for females except for [**d**]. For females, [**d**] had more cases with voiceless part in the closure than [**t**] did. The results show that the only consistent pattern was that voiceless stops had more cases with the closure having a voiceless section than voiced stops, which is the same as the results found on mean voiceless closure duration.

Individual Patterns

Individual differences were significant only for female subjects, $f(3, 68)=4.07$ ($p=0.01$). The significant differences occurred between subjects W1 and W3 at $p<0.05$ on Scheffe post-hoc test. The individual patterns confirm that voiceless stops had longer voiceless closure than voiced stops (except subject W4 who had longer mean voiceless closure for [**d**] than for all alveolar and velar voiceless stops).

4.2.1.6 Burst Duration

Group Patterns

Results on the burst duration measurements of Amharic stops are presented in Fig. 4.22.

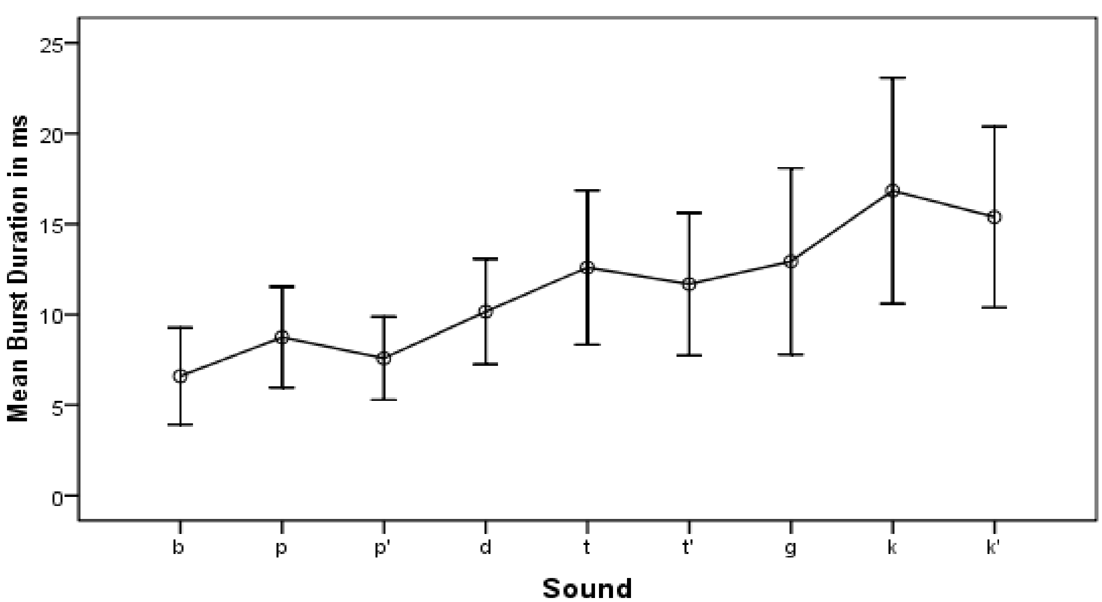


Fig. 4.22: Mean burst duration of Amharic stops. Error bars represent plus or minus one SD from the mean.

The results showed that there were no systematic and significant differences in burst duration due to the gender of the speaker. There were also no systematic and significant differences in burst duration due to the position of the stop in question.

The results on burst duration of Amharic stops showed that there were significant differences in burst duration between the three places of articulation for stops, $f(2, 743)=117.22$ ($p<0.001$). Velars had the longest duration followed by the alveolars and then the bilabials, which is a front-to- back order. Scheffe post-hoc test showed that all the differences between the three places were significant ($p<0.001$).

In all the three places of articulation, voiceless pulmonic stops had the longest burst followed by voiceless ejective stops and then by voiced pulmonic stops. The effect of airstream was not statistically significant, but the effect of voice was significant, $f(1, 744)=36.12$ ($p<0.001$).

Individual Patterns

Individual differences in the same gender showed significant differences only for female subjects, $f(3, 377)=5.46$ ($p=0.001$). Scheffe post-hoc test showed that the differences were between W3 and the rest of the subjects: $p=0.004$ with W1, $p=0.024$ with W2 and $p=0.046$ with W4. W3 had higher values for seven of the nine stops measured for burst duration.

The individual results confirm the effect of place on burst duration results: seven of the eight subjects for ejectives, and six of the eight subjects for the voiceless and voiced pulmonic stops each had confirmed the group results as they had mean burst duration in the order velar > alveolar > bilabial.

Individual results of burst duration about the effect of voice and airstream show that half of the subjects at alveolar and bilabial places and six of the eight subjects at the velar place had the same result as that of the group pattern: voiceless pulmonic > ejective > voiced pulmonic.

4.2.1.7 VOT

Group Patterns

The results of VOT measurements of Amharic stops are presented in Fig. 4.23.

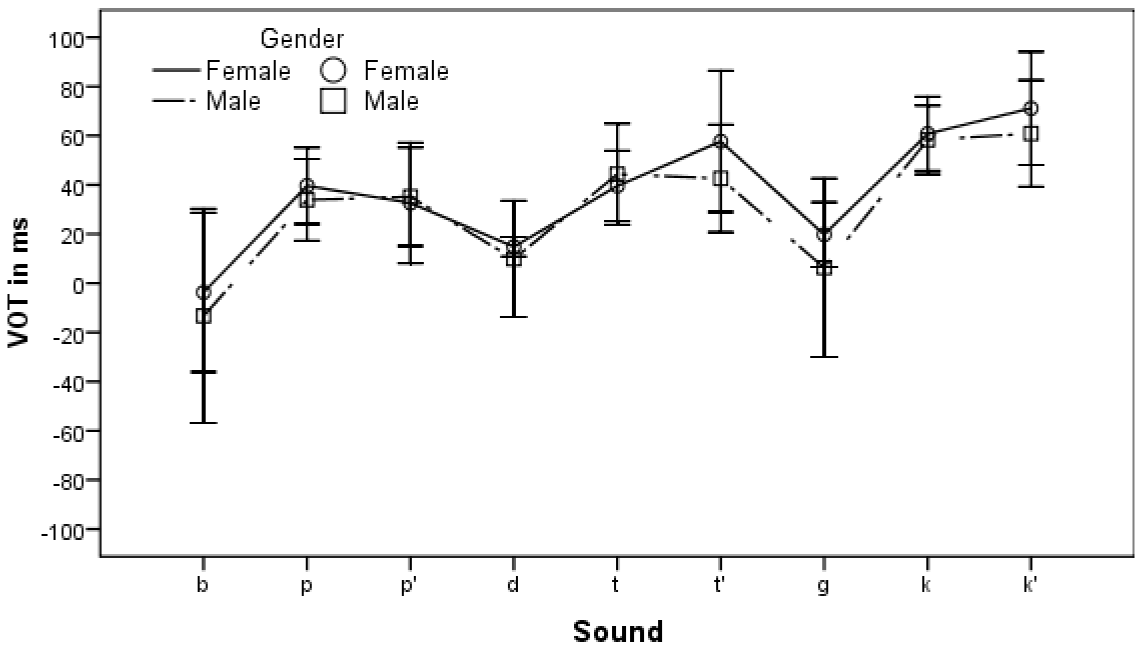


Fig. 4.23: Mean VOT of Amharic stops for female and male subjects. Error bars represent plus or minus one SD from the mean.

The VOT measurement results showed that Amharic stops had lead as well as lag VOT when they occurred word initially. When the data was looked into closely, of 135 voiced stops measured for VOT, 25 (18.5 %) had a closure that had voice before the burst. But as to the individual patterns, one of the male subjects alone accounted for 13 (52 %) of the stops with lead VOT, while other five subjects shared the remaining 48 %. Two subjects did not produce any voiced stop with lead VOT at word initial position. Looking at the lead VOT values only for voiced stops, it was found that [b] accounted for 13 (52 %) of the lead VOT cases whereas [**d**] and [**g**] accounted for the remaining 48 %.

Gender had no statistically significant effect on VOT values. The voiced versus voiceless distinction is clearly seen from the VOT measurements, i.e. voiceless stops having far longer VOT than voiced stops, and this was significant, $f(1, 416)=241.87$ ($p<0.001$). The difference between mean VOT values of voiceless and voiced stops collapsed across genders and places of articulation was 42 ms. Place also had a significant effect on the VOT values of Amharic stops, $f(2, 415) = 22.19$ ($p<0.001$). A front to back increase in VOT was found in Amharic when the mean VOT values of all the sounds in the three places of articulation were computed and compared as it is illustrated in Fig. 4.24. However, this pattern could not be seen for voiced stops of male subjects and for voiceless stops of female subjects.

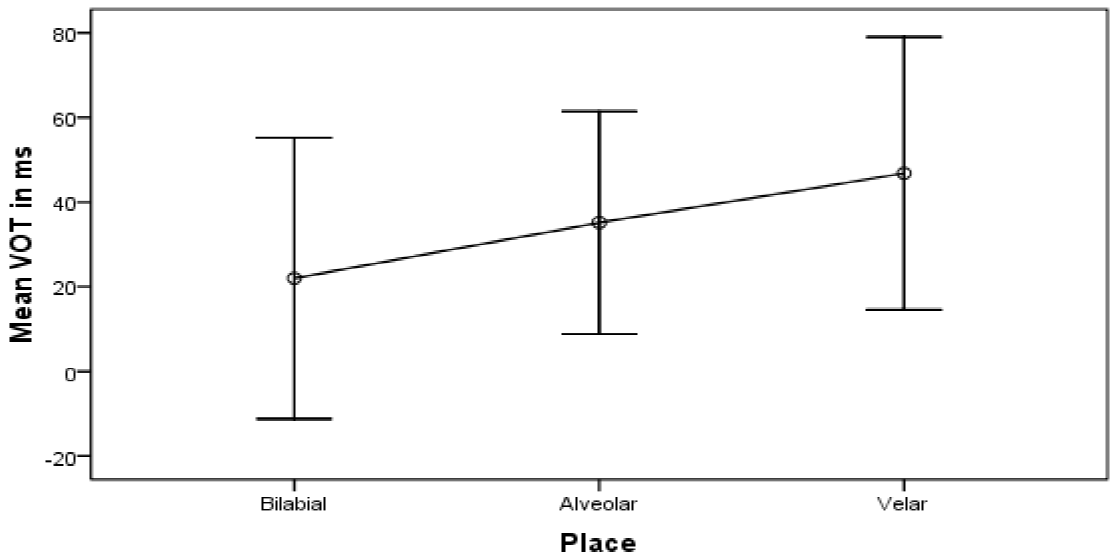


Fig. 4.24: Mean VOT of Amharic stops by place of articulation. Error bars represent plus or minus one SD from the mean.

Airstream differences were also reflected on VOT values, the difference being significant, $f(1, 416)=55.44$ ($p<0.001$). Ejectives had longer VOT than voiceless pulmonic stops at alveolar and velar places. The voiceless pulmonic bilabial stop had a longer VOT than the bilabial ejective in contrast to the alveolar and velar places.

Individual Patterns

VOT value differences were statistically significant only for females, $f(3, 206)=6.62$ ($p<0.001$). The differences between females were checked further with Scheffe post-hoc test, and it was found that subjects W4 versus W1, W2 and W3, W1 versus W4, and W2 versus W4 at $p<0.05$.

Comparison of mean VOT values of subjects within the same gender showed that subjects M3 and W3 had lower VOT values for all sounds except [k’] for subject M3. Note that M3 is the subject who produced 43% of the total lead VOT cases of voiced stop.

The group results showing the effect of place on VOT were confirmed by the individual results. All subjects had produced stops with mean VOT greater for velars, followed by alveolars and bilabials, conforming to the front to back hierarchy. However, close inspection of the mean VOT for each of the voiced pulmonic, voiceless pulmonic and ejective stops showed that there were individual differences. Subject W2 produced ejective stops with higher mean VOT at alveolar place than at bilabial place; subjects M3, M4 and W4 produced voiceless pulmonic stops with higher mean VOT at alveolar place than at bilabial place; and subject M2 produced voiced pulmonic stops with more mean VOT at alveolar place than at bilabial place.

4.2.1.8 Voicing Lag

Group Patterns

To exclude the lead VOT and see the positive values only, voicing lag (positive VOT) was computed for all the stops. For voiceless stops, voicing lag is equal VOT. For voiced stops however, the values of voicing lag are all positive, and thus significantly different from VOT values. Voicing lag was computed both for initial and intervocalic stops.

The results on the voicing lag measurements of Amharic stops are presented in Fig. 4.25. They show that there are differences in voicing lag due to position, gender, place and voice. Nevertheless, all differences were not significant at the same level.

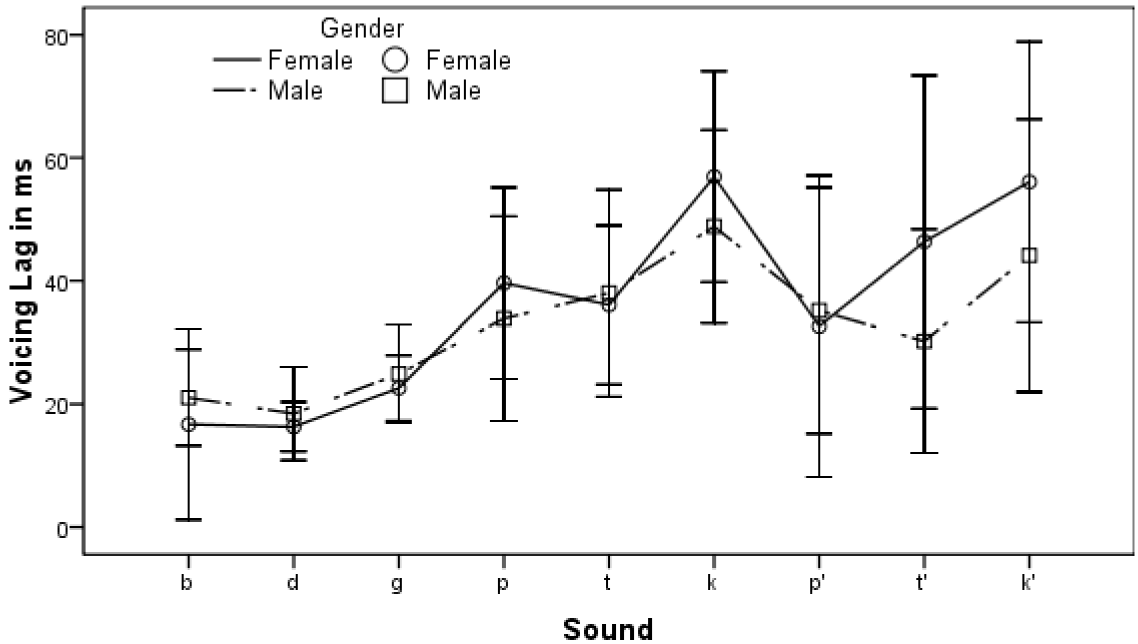


Fig. 4.25: Mean voicing lag of Amharic stops for female and male subjects. Error bars represent plus or minus one SD from the mean.

Statistically speaking, gender had a marginally significant effect on voicing lag values, f(1, 746) =7.48 9 (p=0.033), but the effect was not uniform for all places and voices. When the results were split for each stop, significant differences occurred only for three of the nine stops. In initial position, females had significantly longer voicing lag for [**k**]. In intervocalic position, stops had significantly longer mean voicing lag for females than for males for [**t'**] and [**k'**] and [**k**].

Mean values of voicing lag for stops had significant differences due to place, f(2, 745)=31.94, (p<0.001). Scheffe post-hoc test revealed that velars had significant difference from bilabials and alveolars for both genders. In terms of mean voicing lag values, the trend is velars > alveolars > bilabials though voiced pulmonic stops had velar > bilabial > alveolar pattern for both genders at word initial position. Mean values of all the stops categorized into the three places of articulation shows that the difference in voicing lag of alveolars and bilabials was not significant.

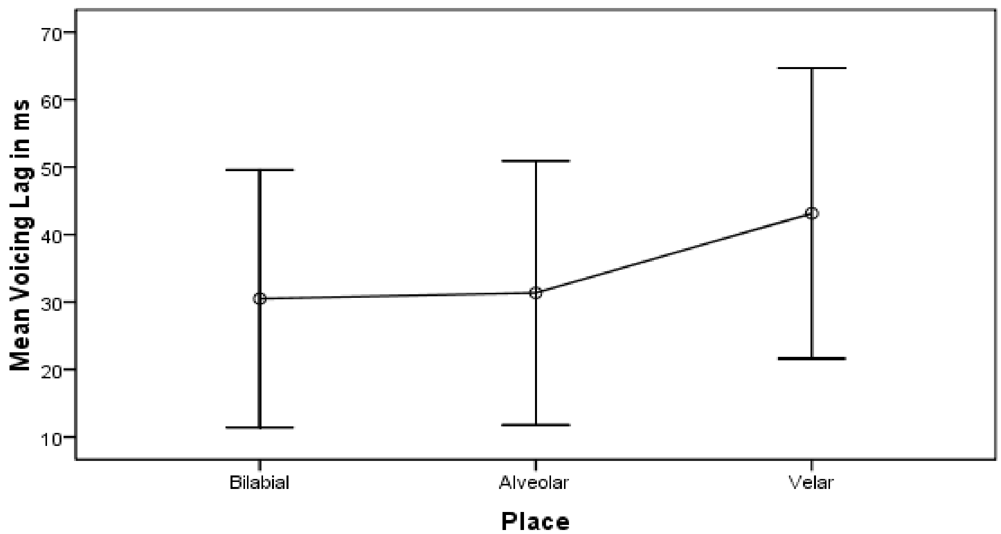


Fig. 4.26: Mean voicing lag of Amharic stops by place of articulation.

Position had effect on voicing lag, f(1, 746)=19.8 ($p<0.001$). Initial stops had longer voicing lag than intervocalic stops, specially for the voiceless series irrespective of airstream.

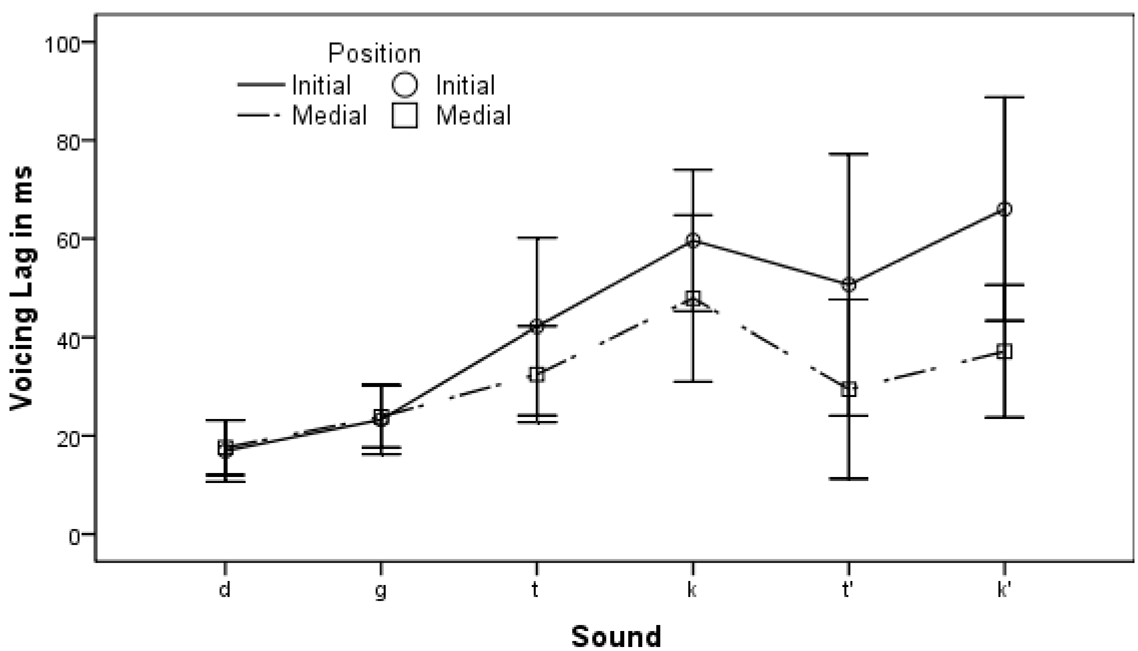


Fig. 4. 27: Mean voicing lag of Amharic stops by position. Error bars represent plus or minus one SD from the mean.

There was no systematic difference between the voiceless pulmonic stops and ejectives of Amharic in terms of mean voicing lag values. Mean values were not consistent across gender, position and place. Even when all the stops were categorized into voiceless pulmonic , voiced pulmonic and ejective, the difference in mean voicing lag between the two types of voiceless stops (as seen in VOT values) is insignificant; it is only a little more than 1 ms as can be seen from the following figure.

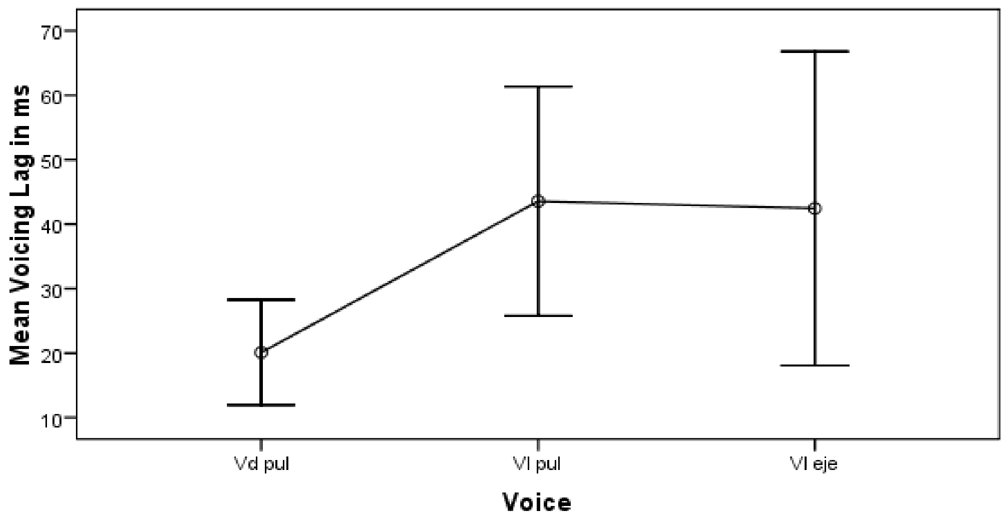


Fig. 4.28: Mean voicing lag of Amharic stops by voice and airstream. Error bars represent plus or minus one SD from the mean.

Thus, it is clear here that voicing lag cannot be considered as a significant acoustic cue to identify the airstream mechanism in Amharic voiceless stops. The effect of voice, however, was clear in the voicing lag values: voiced stops had shorter voicing lag values than voiced stops. As the data shows, voiceless stops had more than twice the duration of the voicing lag of voiced stops on average.

Individual Patterns

Individual differences were significant for female subjects, $f(3, 83)=13.41$ ($p<0.001$) but not for male subjects. Scheffe post-hoc test showed that subject W4 had significant differences with W1 and W2, and subject W3 had significant differences with W3 and W1, all at $p<0.001$. The comparison of mean voicing lag values of subjects showed that four of the eight subjects confirmed the group results showing velar > alveolar > bilabial for both the pulmonic and ejective stops. Three of the subjects had the pattern velar > bilabial > alveolar for the voiced pulmonic and four of the eight subjects had the pattern velar > bilabial > alveolar for the voiceless pulmonic. Thus, these individual results show insignificant differences between the alveolar and bilabial stops' voicing lag values conforming to the group patterns.

4.2.1.9 Rise Time

Group Patterns

The results in the intensity rise time of the vowel following Amharic stops are summarized in Fig. 4.29.

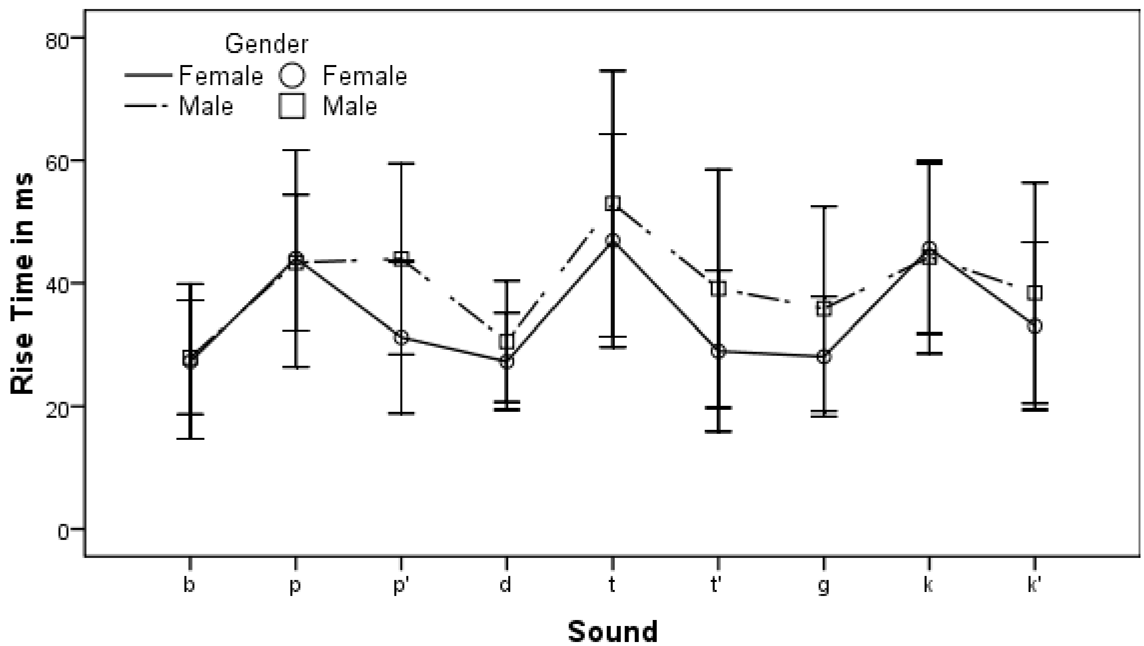


Fig. 4.29: Mean rise time of vowels following Amharic stops. Error bars represent plus or minus one SD from the mean.

Male values on the intensity rise time measures were longer than that of females', except for [**p**] and [**k**], and this was statistically significant, f(1, 737)=16.97 (p<0.001). Though male values were longer in both word initial and intervocalic positions, the differences in the rise time of the vowel following Amharic stops were significant at word initial position only. Of the nine stops investigated word initially, three of them, [**b**], [**t**] and [**k**] showed visible differences while the rest of the stops showed significant differences. The greatest mean differences between male and female values of rise time appeared on the three ejective stops in word initial position.

The results on the rise time show no significant and systematic differences due to place of articulation. The effect voice was significant, f(1, 737)=93.78 ($p<0.001$). In all places, vowels preceded by voiceless stops in general had longer rise time than vowels preceded by voiced stops.

The effect of airstream was visible, but not statistically significant. The mean values show that the vowels preceded by ejectives had shorter rise time than the vowels preceded by voiceless pulmonic stops but longer rise time than the vowels precede by voiced stops.

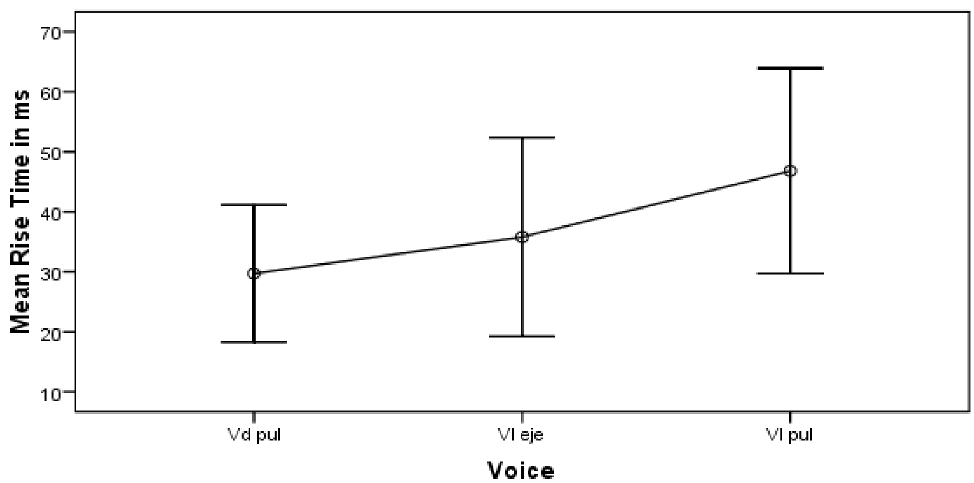


Fig. 4.30: Mean intensity rise time of vowels following pulmonic and ejective stops. Error bars represent plus or minus one SD from the mean

The results also showed that stops resulted in longer rise time of the following vowel when they occurred in initial position than when they occurred in intervocalic position, and this was significant, f(1, 374)=64.68 ($p<0.001$). The only sound that did not show difference in the rise time of the following vowel was [**d**]. Fig. 4.31 presents the intensity rise time of vowels following Amharic stops in initial and intervocalic positions.

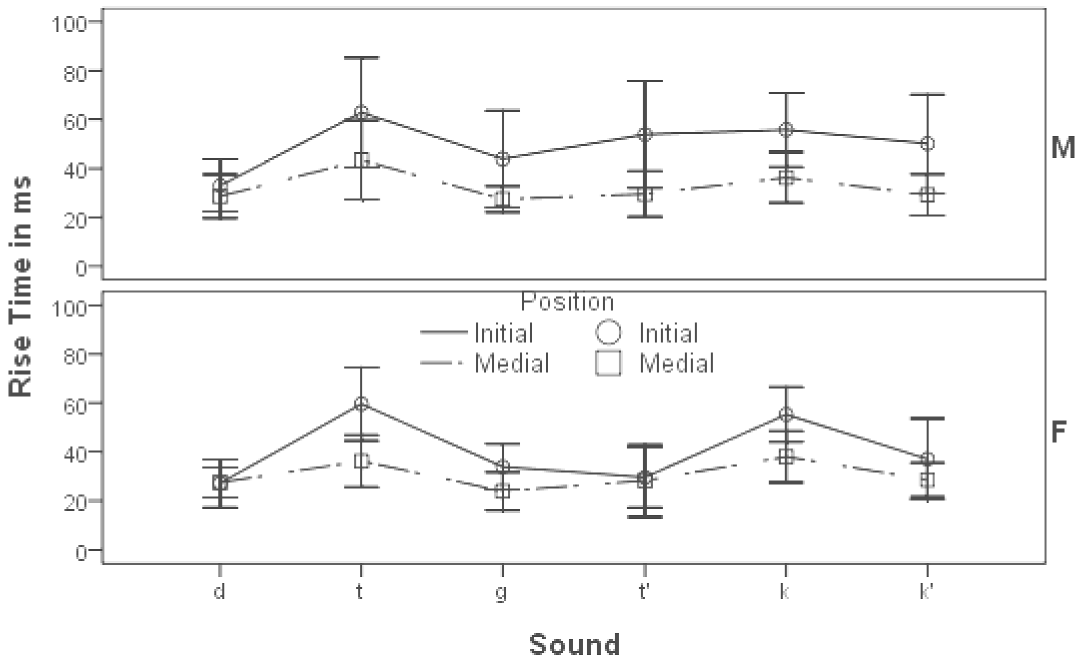


Fig. 4.31: Mean intensity rise time of vowels following stops in initial and intervocalic positions. Error bars represent plus or minus one SD from the mean.

Figure 4.31 clearly shows that Amharic stops had longer intensity rise time in the following vowel when they appeared in word initial position than when they appeared in intervocalic position. This is expected as there is more pressure buildup during the production of initial consonants than medial consonants.

Individual Patterns

A GLM univariate analysis of variance showed that there were significant differences between individuals in the same gender: f(3, 359)=5.41 (p=0.001) for females and f(3, 372)=5.14 (p=0.002) for males. Scheffe post-hoc test showed that for female subjects there were significant differences between subjects W1 and W2 (p=0.017) and W2 and W3 (p=0.004). For males, it was between M3 versus M1 (p=018) and M2 (p=0.16).

The pattern of intensity rise time concerning the voiceless pulmonic and ejective stops confirmed the group results. Except for subject M2, vowels preceded by ejectives had lower intensity rise time than vowels preceded by voiceless pulmonic stops. The intensity rise time of vowels preceded by voiced pulmonic stops and ejectives could not be determined based on individual results as three of the eight subjects (one male (M3) and two females (W1 and W2)) had similar pattern to the group results whereas 3 males (M1, M2, M4) and two females (W3 and W4) had higher intensity rise time for vowels that were preceded by ejective stops than those that were preceded by voiced pulmonic stops. Nevertheless, this difference seems insignificant considering that voiced and voiceless stops are separated more clearly based on other acoustic cues such as VOT and voicing lag than the intensity rise time. The most significant result here is that vowels preceded by ejective stops had shorter rise time than vowels preceded by voiceless pulmonic stops.

4.2.2 Results on Intensity Measurements

4.2.2.1 RMS Intensity

Group Patterns

The burst intensity values of each of the stops measured are summarized in Fig. 4.32. The burst RMS intensity values show that there were differences due to gender: for all stops, females had louder bursts than males. The differences between male and female values were statistically significant, f(1, 745)=88.1 (p<0.001).

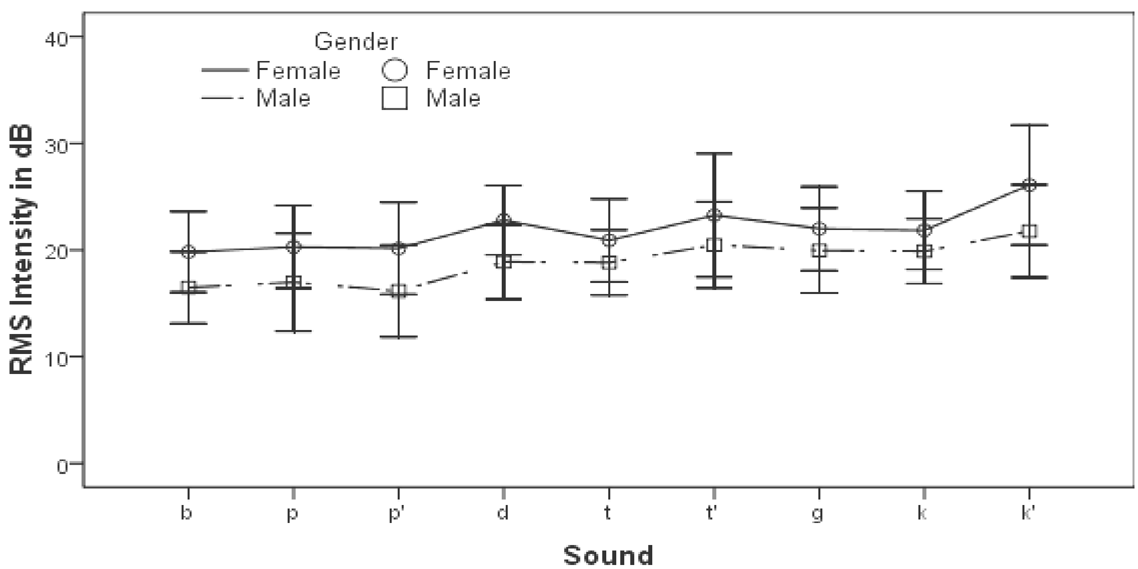


Fig. 4.32a: Mean burst RMS intensity of Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

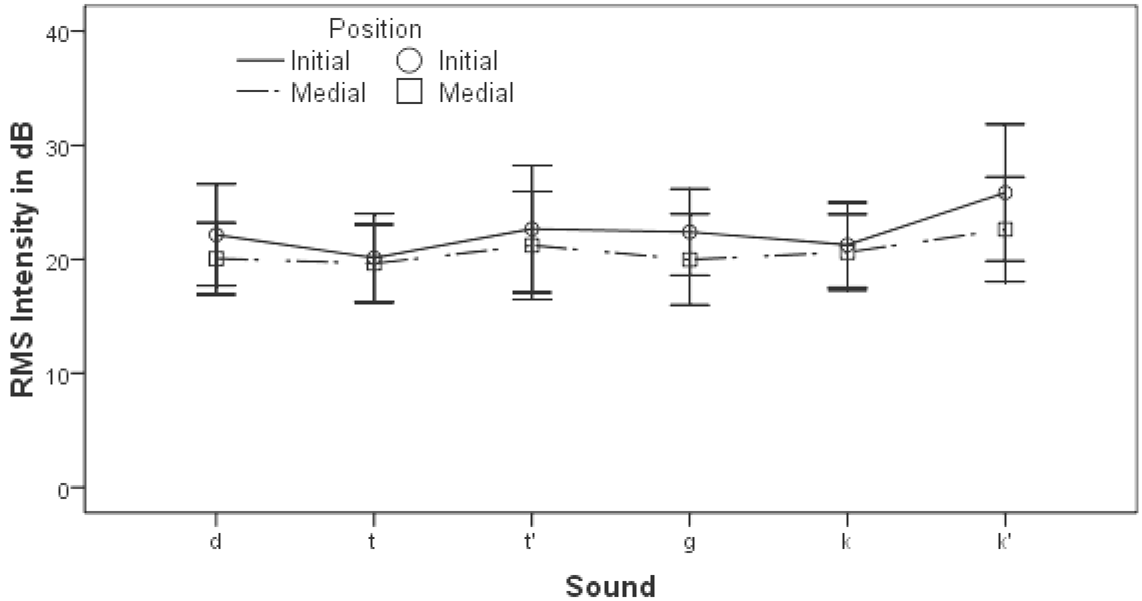


Fig.4.32b: Mean burst RMS intensity of Amharic stops by position. Error bars represent plus or minus one SD from the mean.

Position also had effect on burst intensity values: initial stops had louder bursts than intervocalic stops. The difference between the RMS intensity of initial and intervocalic stops was not statistically significant.

The effect of place was significant, $f(2, 744)=28.93$ ($p<0.001$). Velars had louder bursts than alveolars, which in turn had louder bursts than bilabials. Scheffe post-hoc test showed that Bilabial versus alveolar and velar was significant at $p<0.001$ and alveolar versus velar was significant at $p=0.006$. .

Voice had no significant effect on RMS intensity values of the burst of Amharic stops. However, the effect of airstream was found significant on RMS values, $f(1, 745)=27.56$ ($p<0.001$). Ejective stops had louder burst RMS intensity than voiceless pulmonic stops, specifically for alveolar and velar places. At bilabial place, the ejectives had lower burst intensity than the pulmonic stops had.

Individual Patterns

The individual mean comparisons showed that there were statistically significant differences between subjects of the same gender: for females, $f(3, 378)=31.97$ ($p<0.001$) and for males, $f(3, 361)=16.03$ ($p<0.001$). Scheffe post-hoc showed that for females, subject W3 had significant differences with subjects W1 and W2 at $p<0.001$, with W4 at $p=0.008$. Subjects W1 and W2 had significant differences at $p=0.004$. For males, M1 had significant differences with the rest of the three male subjects at $p<0.001$. Individual patterns confirmed the group results showing that at alveolar and velar places, ejectives had louder bursts than pulmonic stops. The exception was one female subject, W2, who had higher burst for the alveolar ejective than for the voiceless pulmonic stop. At bilabial place, six of the eight subjects had louder burst for the voiceless pulmonic stop than for the ejective, and the remaining two subjects (W3 and M3) had the opposite.

Individual patterns regarding place showed that ejectives came out strong in confirming the pattern velar > alveolar > bilabial. Six of the eight subjects (all females and two males) had this pattern. For voiceless pulmonic stops, only two male and two female subjects confirmed the group results. Voiced stops had five subjects (three males and two females) confirming the group results.

4.2.2.2 Relative Burst Intensity

Group Patterns

Relative burst intensity was measured as a difference between the maximum intensity of the following vowel and the maximum intensity of the burst, and was measured in dB. The results are summarized in Fig. 4.33.

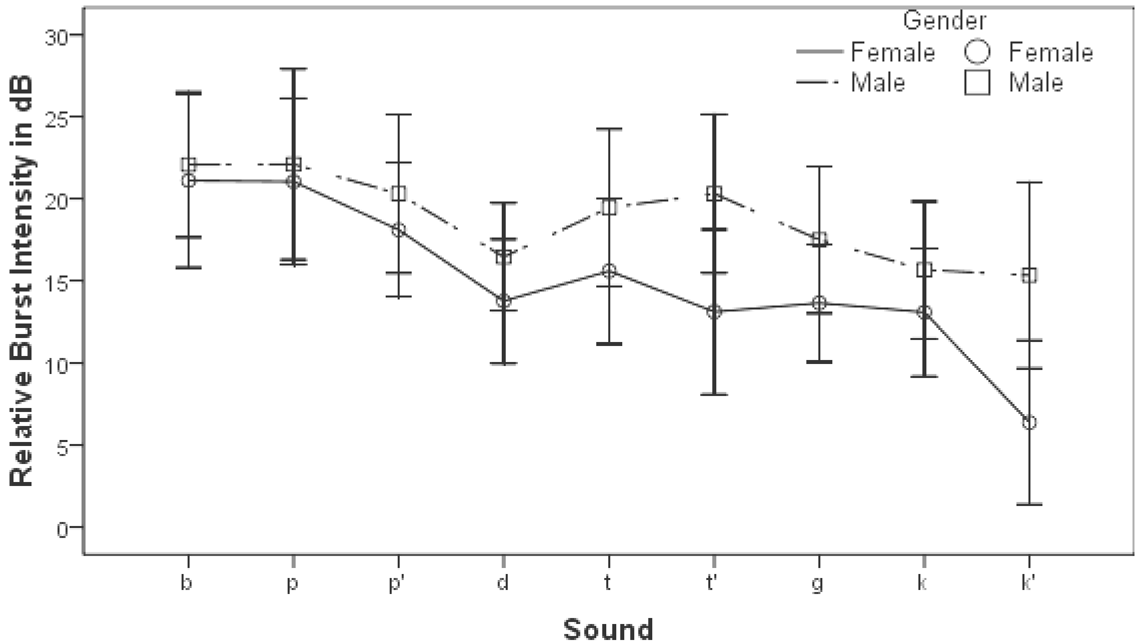


Fig. 4.33a: Mean relative burst intensity of Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

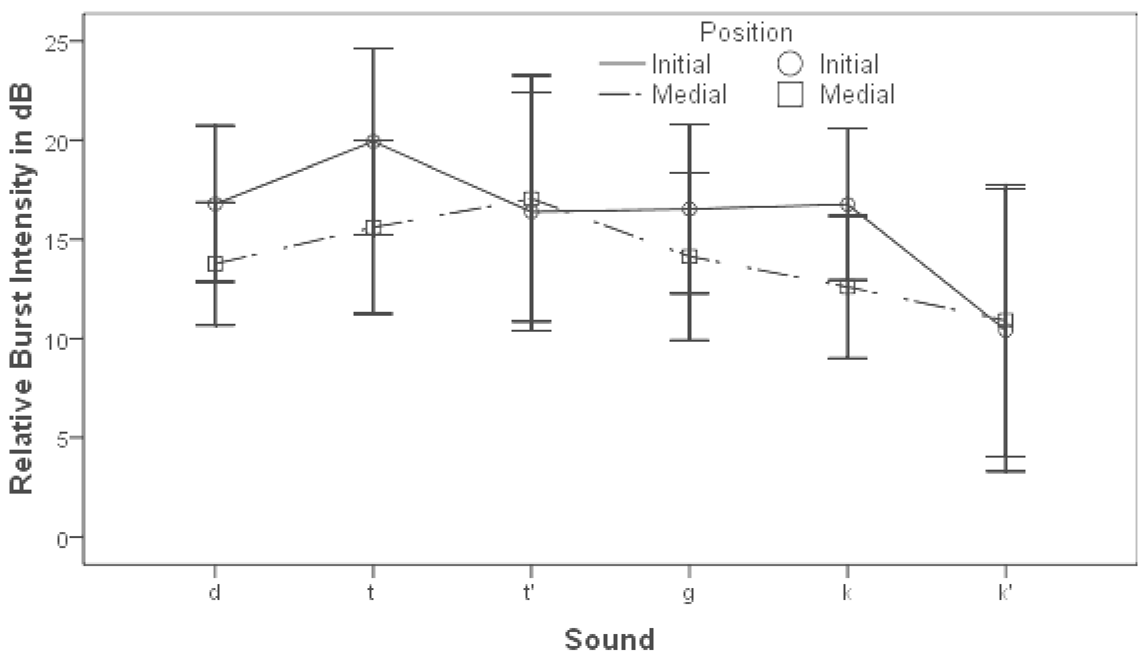


Fig. 4.33b: Mean relative burst intensity of Amharic stops by position. Error bars represent plus or minus one SD from the mean.

Mean values for male and female subjects show that the relative burst intensity values of the stops produced by males were greater than those for females in all cases, and these differences were significant, f(1, 740)=124.65 (p<0.001). This means the stops produced by females had more intense burst than the ones produced by males.

The effect of position was also seen on the relative burst intensity values: initial stops had higher relative intensity values than intervocalic stops, specially for the pulmonic stops. The difference due to position was significant, (1, 740)=69.24 (p<0.001). This result cannot be interpreted as medial pulmonic stops having more intense burst than initial pulmonic stops because RMS intensity showed the opposite. The two ejective stops ([**t’**] and [**k’**]) showed the opposite, i.e., they had greater mean relative burst intensity when they occurred in intervocalic position than when the occurred word initially.

In terms of place, voiceless bilabials had the highest relative burst intensity values whereas velars had the lowest relative burst intensity values. This means velars had the most intense burst followed by alveolars and finally by bilabials. The difference in relative burst intensity due to place was significant, f(2, 739)=82.76 (p<0.001). Voiced stops, however had a pattern bilabial > velar > alveolar in terms of relative burst intensity results, but the median values show the same pattern as voiceless stops: bilabials > alveolars > velars. Thus, it could be generalized here that in terms of relative burst intensity Amharic stops have the pattern bilabials > alveolars > velars, which is the bursts becoming more intense as one goes from front to back in the oral cavity.

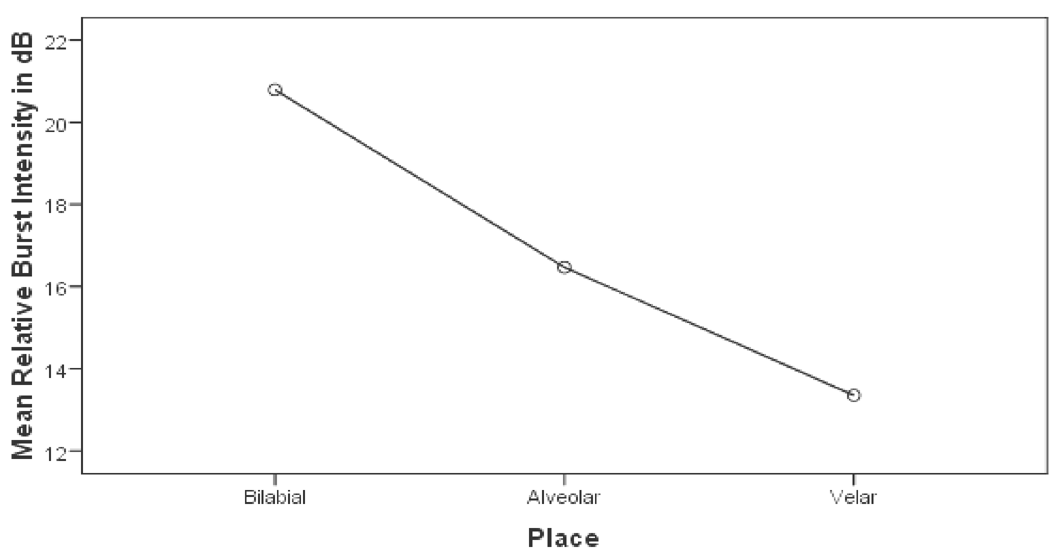


Fig. 4.34: Mean relative burst intensity of Amharic stops by place of articulation.

Voice did not show consistent effect on relative burst intensity across different places of articulation, but airstream did. In all the three places, ejective stops had lower relative burst intensity than that of the voiceless pulmonic stops, the difference being significant at p<0.001. This shows that Amharic ejective stops had louder bursts than the pulmonic voiceless stops, which was stronger by two dB.

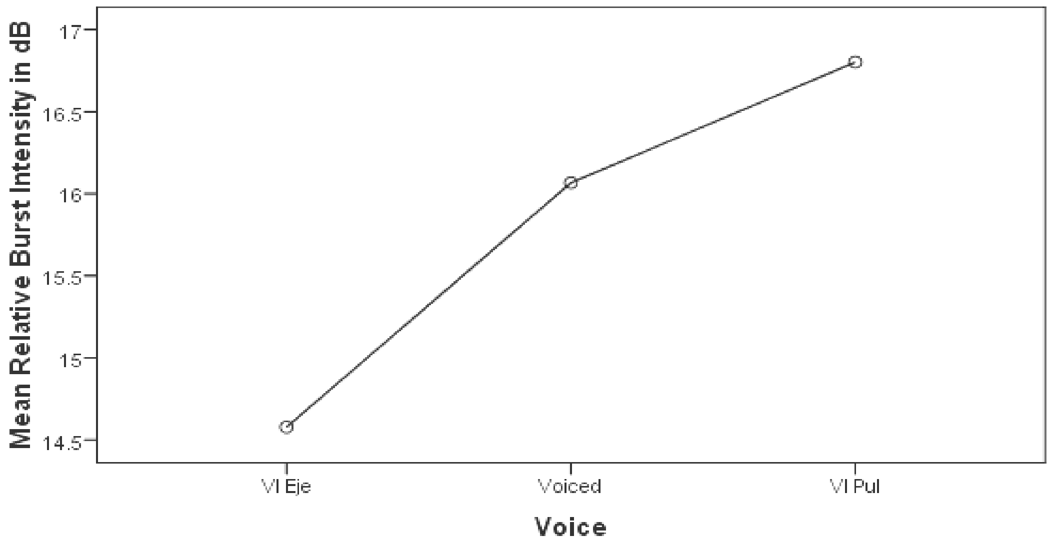


Fig. 4.35: Mean relative burst intensity of Amharic stops by voice and airstream mechanisms.

Individual Patterns

The mean values of subjects within the same gender were significant: for females, f(3, 376) =5.82 (p=0.001) and for male's f(3, 358) =31.44) (p<0.001). Scheffe post-hoc test revealed that, for females, subject W2 had significant differences with subjects W1 (p=0.007) and W3 (p=0.004) and with subject W4 at p<0.05. For males, subject M1 showed significant differences with subjects M2 and M4 (p<0.001); subject M3 showed significant differences with M2 and M4 (p<0.001) and with subject M1 (p=0.014).

The effect of place on relative burst intensity of ejectives and voiceless pulmonic stops had the pattern bilabial > alveolar > velar for five of the eight subjects. However, the gender distribution was skewed towards the females: four female subjects as compared to one male subject showed this pattern for ejectives, whereas for voiceless pulmonic stops three females and two males showed this pattern. For all subjects, velars had the lowest relative burst intensity for both types of voiceless stops. Voiced stops confirmed the group results showing that bilabials had the highest relative burst intensity (for all subjects) alveolars had the lowest relative burst intensity (six of the eight subjects, three males and three females).

The effect of airstream on relative burst intensity was not straightforward for all places. Alveolar ejectives were lower than the pulmonic stops only for three female subjects, and for three male subjects, alveolar ejectives had the highest relative burst intensity. Bilabial ejectives and velar ejective stops came out lower than their pulmonic counterparts for six of the eight subjects.

4.2.2.3 Absolute Rise in Intensity in dB

Group Patterns

The results on the difference between the local peak intensity and the onset intensity of the vowel, the absolute rise in dB, following Amharic stops are presented in Fig. 4.36.

The results showed that place, voice, airstream and gender did not have significant and systematic effects on the absolute rise in intensity values.

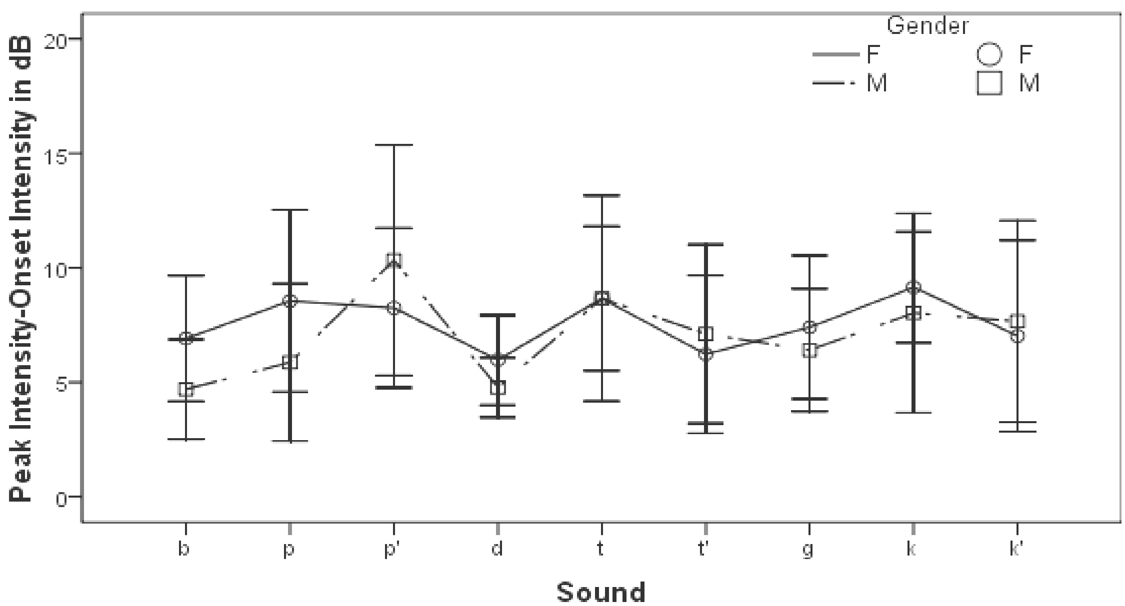


Fig. 4.36a: Mean absolute rise in intensity of vowels following Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

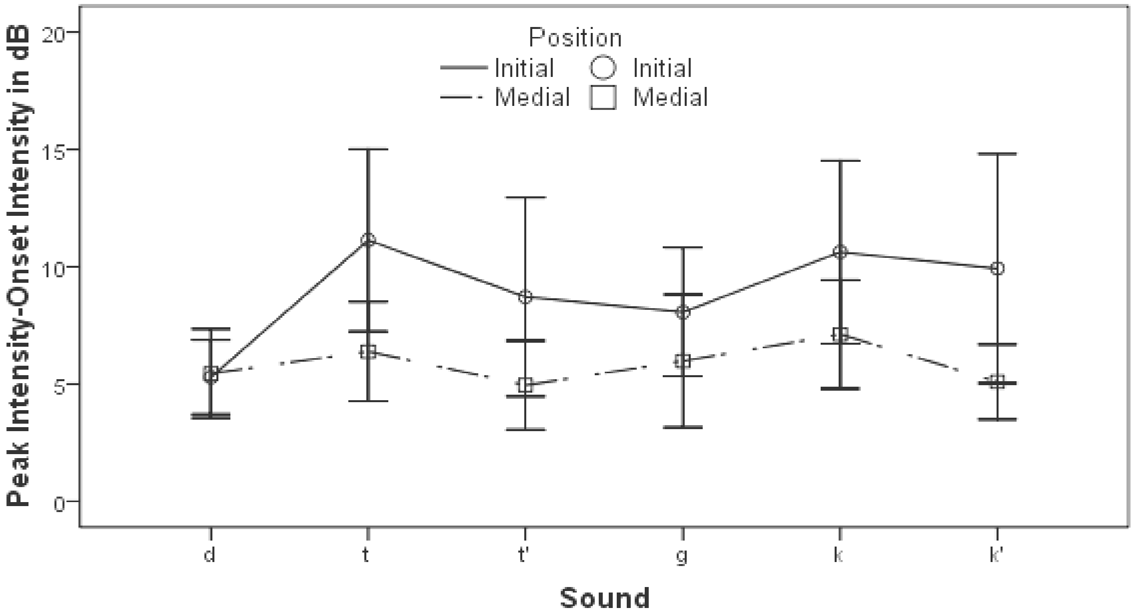


Fig. 4.36b: Mean absolute rise in intensity of vowels following Amharic stops by position. Error bars represent plus or minus one SD from the mean.

The results on the absolute rise in intensity measurements show that position, which was considered for velar and alveolar stops only, had effect on the absolute intensity values, f(1, 727)=102.72 ($p<0.001$). Vowels preceded by initial stops had higher values than vowels preceded by intervocalic stops.

Individual Patterns

The results of individuals on absolute rise in intensity measurements show that there were individual differences only for males, f(1, 366)=4.44 (p=0.004). Scheffe post-hoc test showed that the significant difference occurred between subjects M3 and M2 (p=0.005)

The effect of position on absolute rise in intensity of the vowel following Amharic stops reflected the group patterns too: the vowels produced by five of the eight subjects had higher values when they were preceded by initial stops. Three subjects had vowels preceded by intervocalic stops having higher values than vowels proceeded by initial stops for [**k**], [**k’**], [**g**] and [**d**].

4.2.3 Results on Burst Spectral Shape Measurements

4.2.3.1 Spectral Mean

Group Patterns

The spectral mean values of Amharic stops are summarized in Fig. 4.37. The Spectral mean values of Amharic stops showed differences due to gender, place, and voice. Position, however, had no effect on the mean values.

The results on the spectral mean measurements showed that female values were higher except for [**b**], and it was significant f(1, 741)=15.97 (p<0.001). When the results for each of the stops were compared, the effect of gender was significant for the alveolar stops only, f(1, 105)=52.22 (p<0.001) for [**d**], f(1,. 107)=19.07 (p<0.001) for [**t'**] and f(1, 106)=5.86 (p=0.017) for [**t**]. The effect of gender was as expected as males have larger cavities than females, which means lower spectral mean for males than for females.

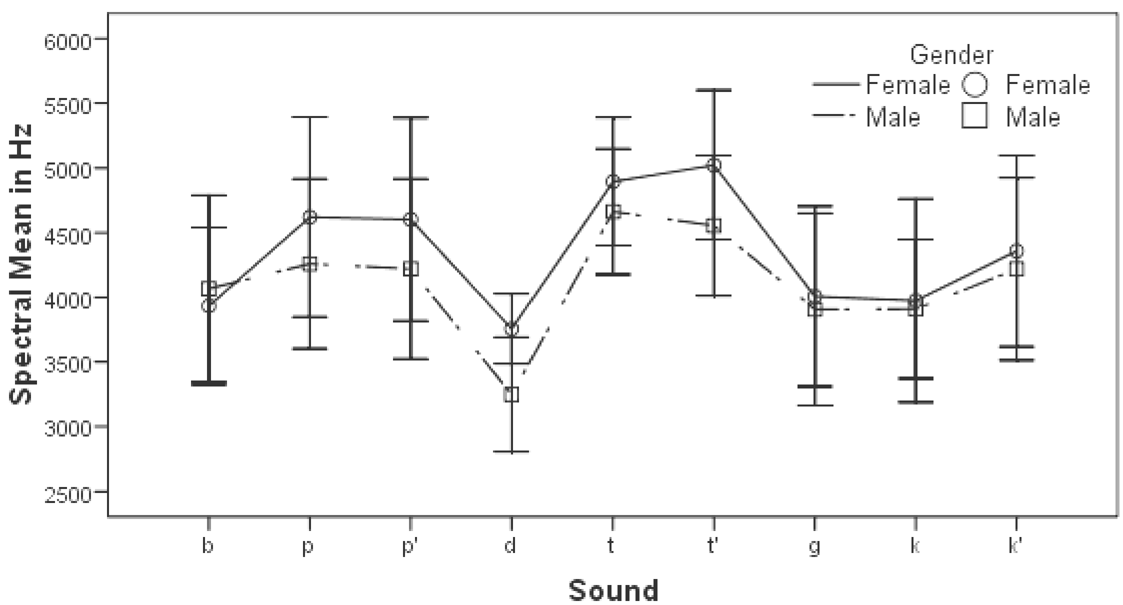


Fig. 4.37a: Mean burst spectral mean of Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

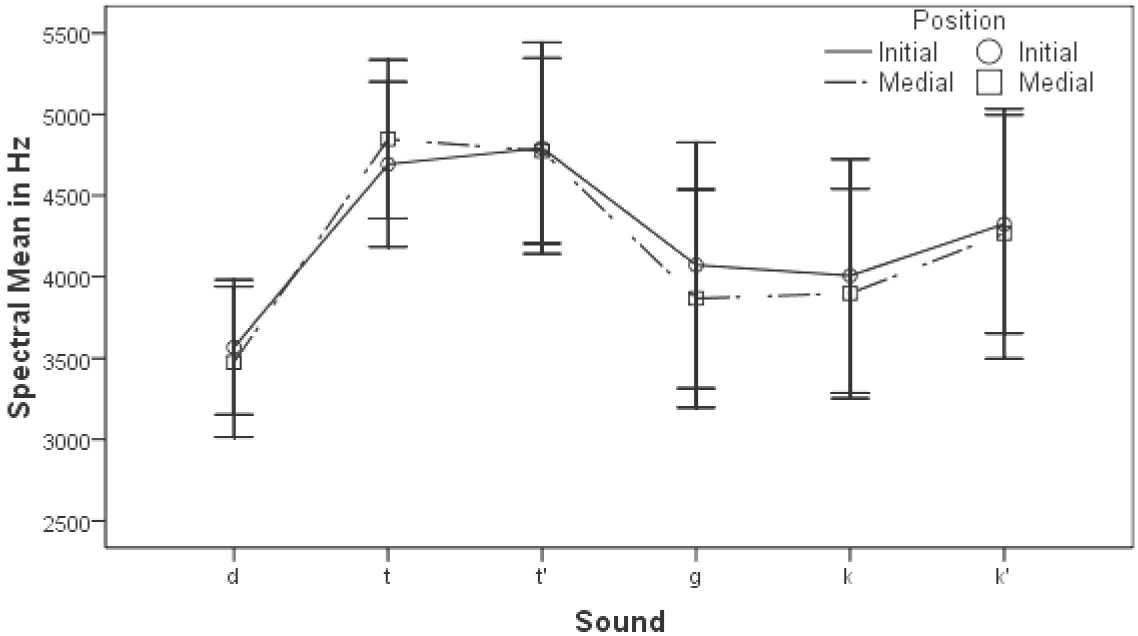


Fig. 4.37b: Mean burst spectral mean of Amharic stops by position. Error bars represent plus or minus one SD from the mean.

The effect of place on spectral mean values was significant, f(2, 740)=12.12 (p<0.001). . The major difference that was seen among places was between the velar and the rest two (bilabial and alveolar), which was significant at p<0.001 and p=0.025 when tested on Scheffe post-hoc test. Mean values for Amharic stops in general showed the pattern alveolar > bilabial > velar. However, this pattern was not reflected when the results for the voiceless ejective, voiceless pulmonic and voiced pulmonic stops were seen separately. Voiced stops had a different pattern from the general pattern. For voiced stops, the bilabial stop had the highest spectral mean followed by the velar and alveolar stops as it can be seen from Fig. 4.38.

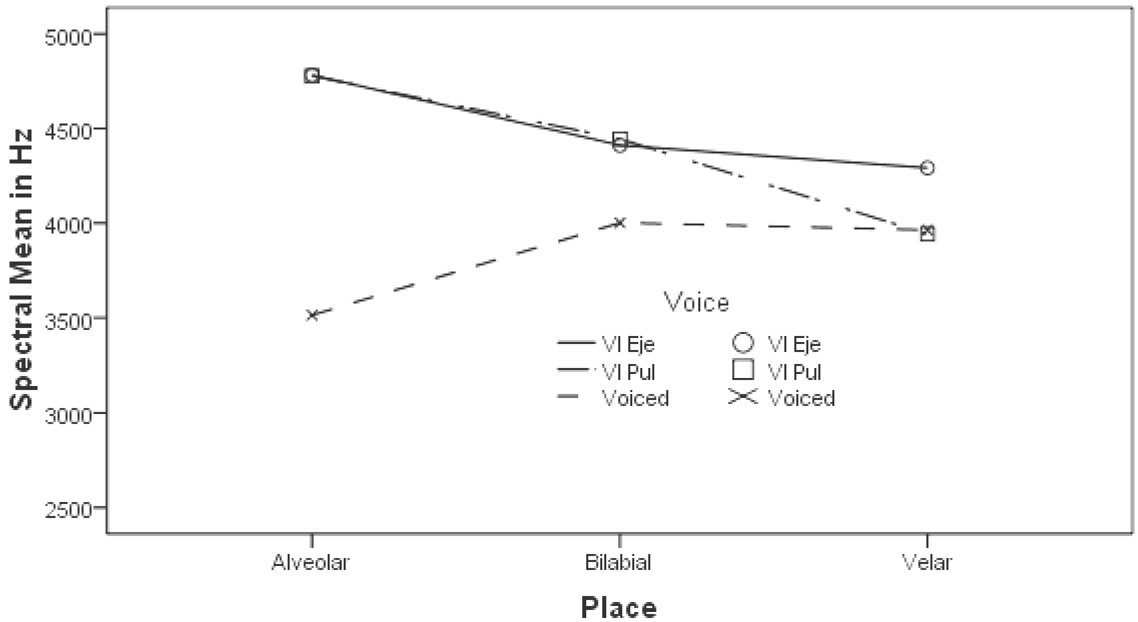


Fig. 4.38: Mean burst spectral mean of Amharic stops by place of articulation.

The effect of voice was significant, f(1, 741) =150.78 (p<0.001): voiceless stops had higher burst spectral mean than voiced stops irrespective of airstream. The effect of airstream was significant f(1, 741)=61.04 (p<0.001). Nevertheless, the effect of airstream was seen for velar stops only, f(1, 313)=16.49 (p<0.001) when the results were compared for separate places.

Individual Patterns

Within the same gender, individual differences were significant, f(3, 377)=5.84 (p=0.001) for females and f(3, 358)=4.74 (p=003) for males. Scheffe post-hoc test showed that the differences were between subjects W2 and W1 (p=0.013) and between subjects W2 and W4 (p=0.005). For males, the significant differences were between subjects M4 and (p=0.045) and between subjects M4 and M3 (p=0.007).

When the group and individual patterns were compared, only subjects W1 and M3 had the alveolar > bilabial > velar pattern for ejectives and subjects W4, M1, M2 and M4 had the alveolar > bilabial > velar pattern for voiceless pulmonic stops, showing that the spectral mean are highly dependent on individual speakers than on the group. For voiced stops, only subjects W4 and M4 had the pattern similar to the group pattern, i.e., alveolar > velar > bilabial while subjects W2, W3, M2 and M4 had the pattern bilabial > velar > alveolar.

The effect of voice was similar to the group patterns for alveolar and bilabial stops: all subjects for alveolar stops, and six and four of the eight subjects for bilabial and velar stops respectively had lower mean spectral mean values than the pulmonic and ejective voiceless stops.

The effect of airstream came out strong only for alveolar stops for all subjects showed higher spectral mean values for the ejective than for the voiceless pulmonic stop. However, only four subjects at velar place and one subject at alveolar place conformed to the group pattern that showed higher average spectral mean for ejectives than for pulmonic stops. This shows that the effect of airstream was not uniform across the three places of articulation. Thus, the spectral mean of stop bursts of Amharic seem to be highly affected by individual differences.

4.2.3.2 SD of Spectrum

Group Patterns

The results on SD of spectrum measurements are summarized in Fig. 4.39. The spectral SD values show that there were significant differences between stops due to the position in word, with five of the six stops investigated having higher SD of spectrum values in intervocalic position than in initial position. This difference was not statistically significant though.

The spectral SD values show gender had a slightly significant effect, $f(1, 738)=5.23$ ($p=0.022$); female values were higher than male values for all sounds except [**b**].

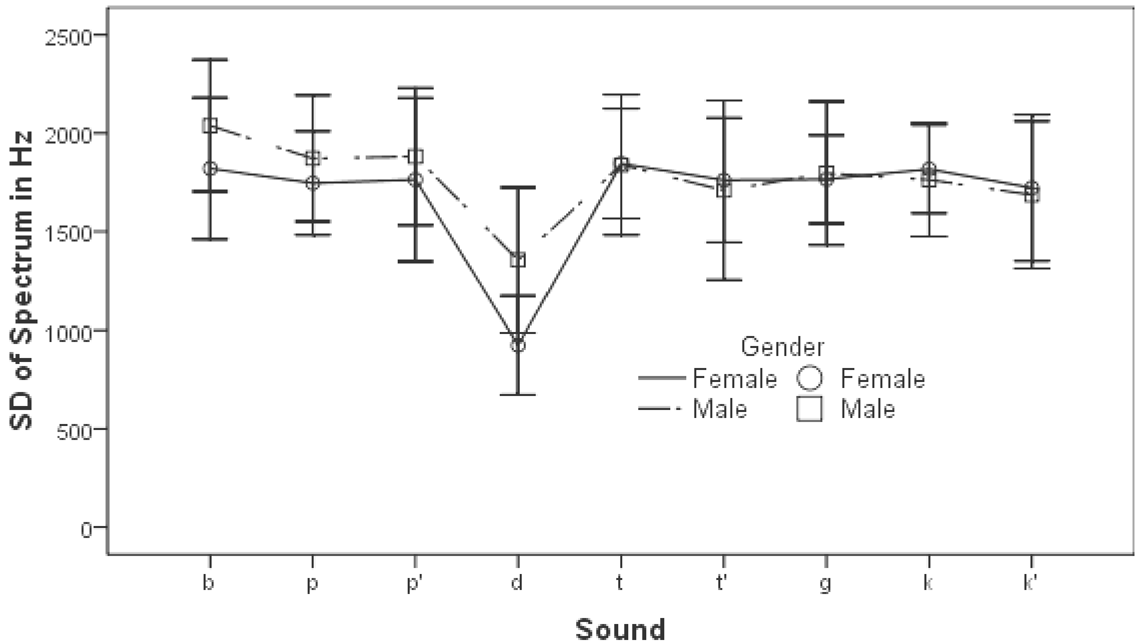


Fig. 4.39a: Mean burst spectral standard deviation of Amharic stops by gender. Error bars represent plus or minus one SD from the mean.

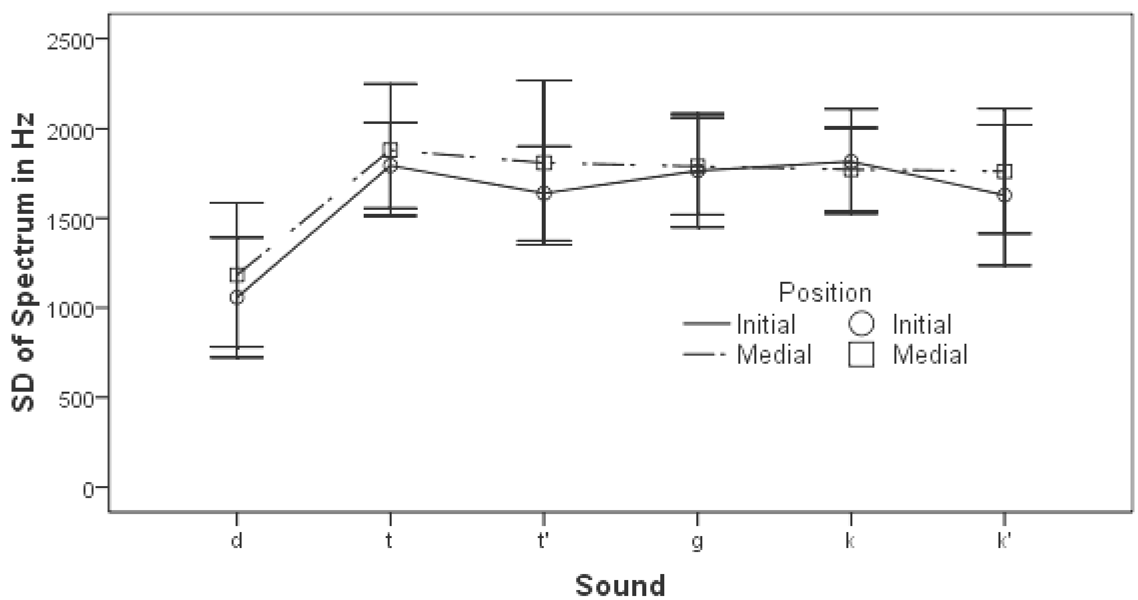


Fig. 4.39b: Mean burst standard deviation of Amharic stops by position. Error bars represent plus or minus one SD from the mean.

Place, voice and airstream did not have systematic effects on the SD of spectrum values, as can be seen in Fig. 4.40.

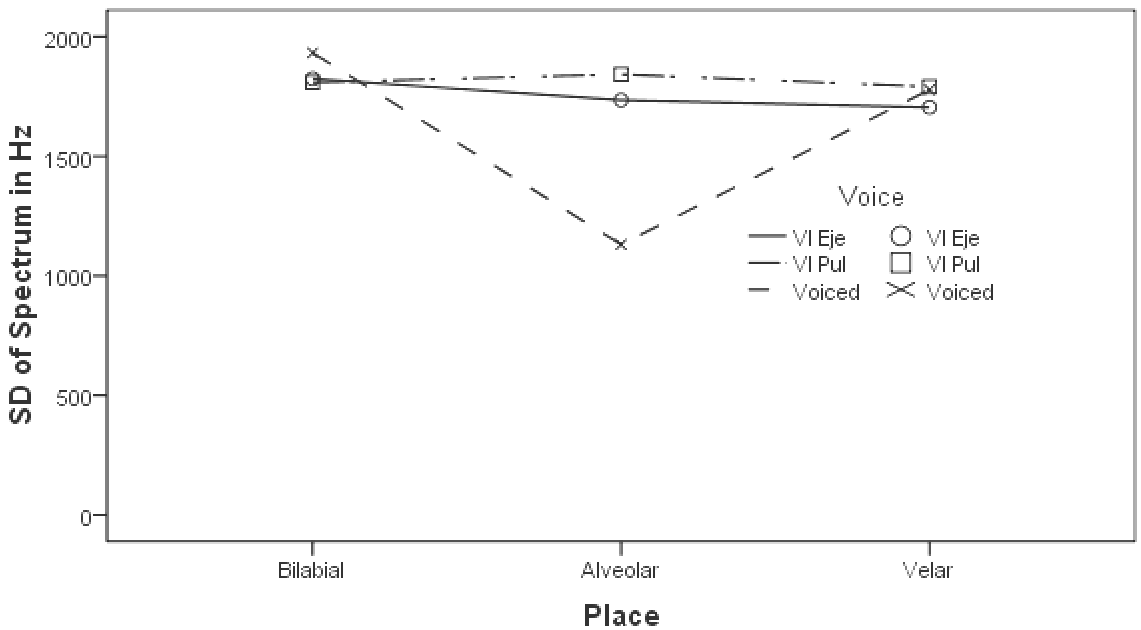


Fig. 4.40: Mean burst spectral standard deviation of Amharic stops by place of articulation, voice and airstream mechanism.

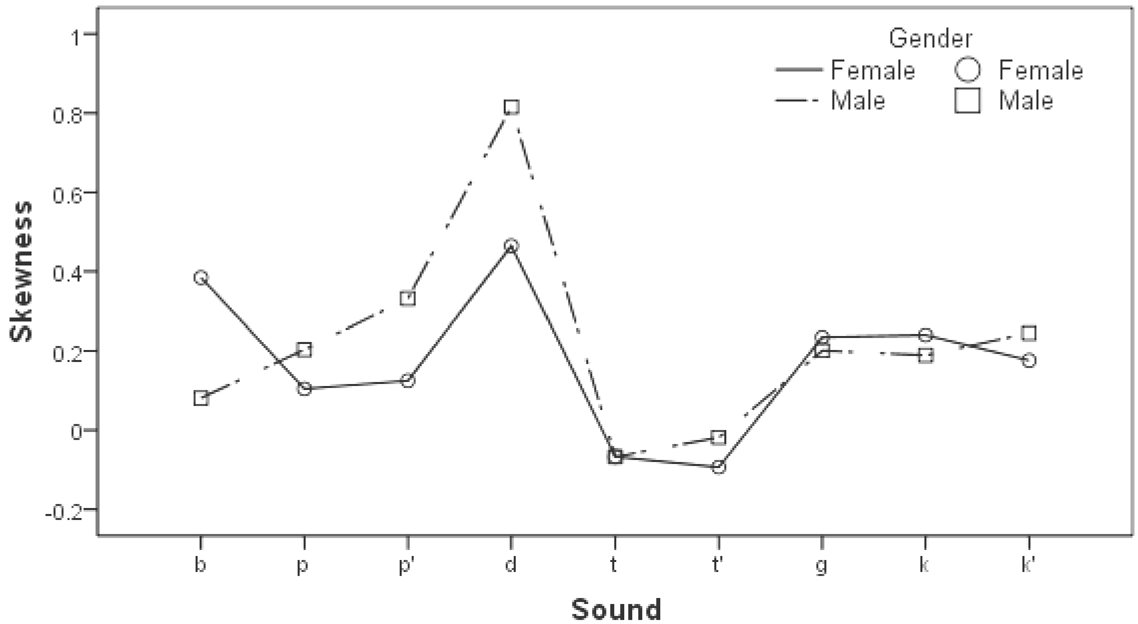
Individual Patterns

For females individual differences were not significant, but for males they were significant f(3, 356)=4.74 (p=0.003). Scheffe post-hoc test showed that the significant differences between male subjects were between subjects M1 and M3 (p=0.004). Since SD of spectrum was not systematically affected by place, voice or airstream, a detail discussion of individual is not provided here.

4.2.3.3 Skewness

Group Patterns

The results on the skewness measures of stop burst in Amharic are presented in Fig. 4.41.



4.41a: Mean burst spectral tilt of Amharic stops by gender.

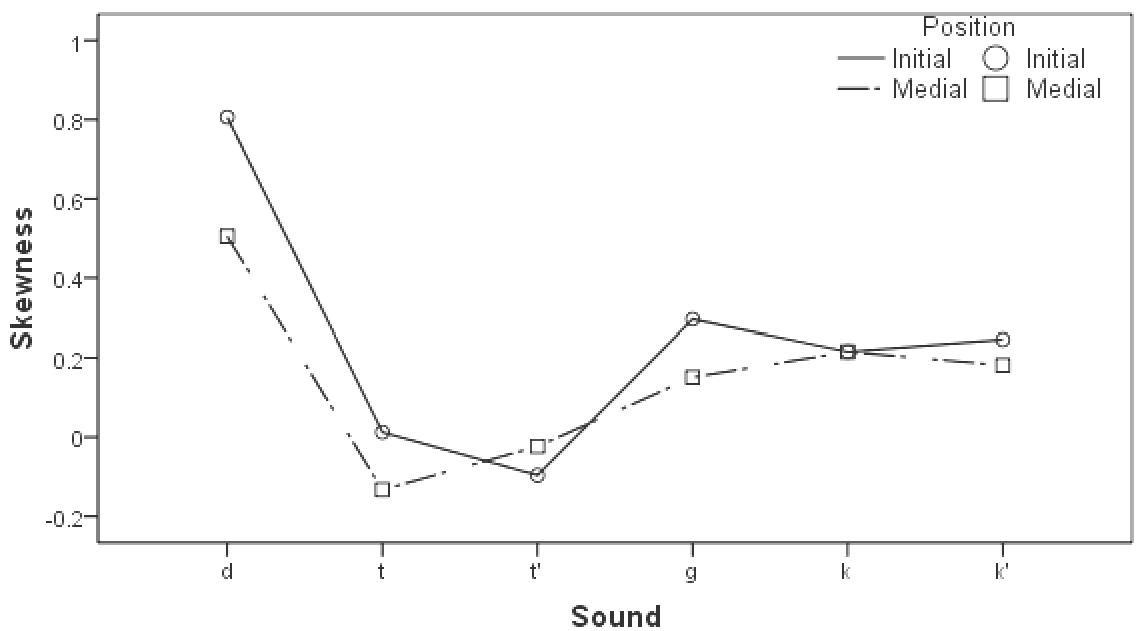


Fig. 4.41b: Mean burst spectral tilt of Amharic stops by position.

Statistically speaking, there were no significant differences between skewness measures due to the gender of speakers, place of articulation and position in a word of stops. There were, however, significant differences due to voice, f(1, 744)=44.28 (p<0.001) and airstream, f(1, 744)=9.32 (p=0.002). The differences due to voice were found to be due to the alveolar stop [**d**], which had far greater skewness than the rest of the stops. The effects of voice and airstream were not systematic across the three places of articulation: bilabial stops showed a different pattern than alveolar and velar stops in skewness values due to voice, whereas velar stops showed a different pattern in skewness values due to airstream.

Place differences show that voiceless stops, whether pulmonic or ejective, had similar pattern across places in terms of skewness in that velars had the highest skewness followed by the bilabials and then the alveolars. The pattern for voiced stops was different from the pattern for voiceless stops.

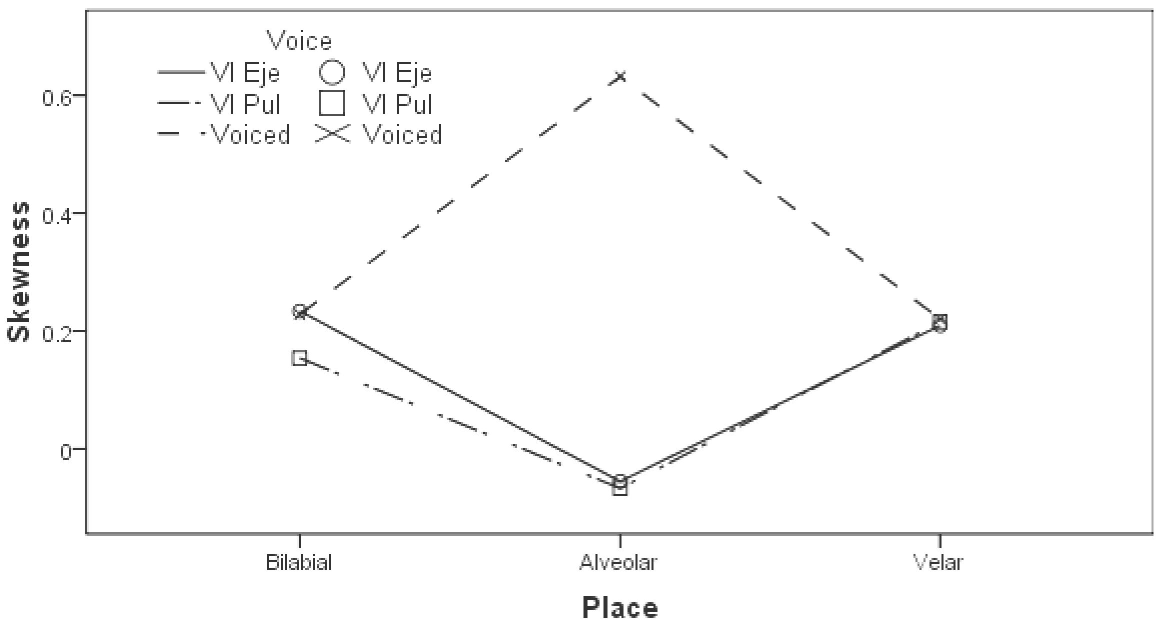


Fig. 4.42: Mean burst spectral tilt of Amharic stops by place of articulation, voice and airstream mechanism.

Except for voiceless alveolar stops, all the stops had positive spectral tilt, which means that the energy concentration was below the spectral mean, yet with different values. The voiceless alveolar stop had negative spectral tilt meaning that it had energy concentration above the spectral mean.

Individual Patterns

Individual differences within the same gender were not statistically significant. Only two subjects, one male and one female, had the pattern ejectives>voiceless pulmonic stops at all places of articulation. The rest of the subjects did not confirm this pattern at one or two of the places.

4.2.3.4 Kurtosis

Group Patterns

Results on the kurtosis measurements of Amharic stops are presented in Fig. 4.43.

The kurtosis values did not show significant differences due to gender and context. Place and voice effects were significant: f(2, 741)=35.79 ($p<0.001$) for place and f(1, 742)=111.86 ($p<0.001$) for voice. However, these differences came due to [**d**] which had far greater kurtosis values than the rest of the stops.

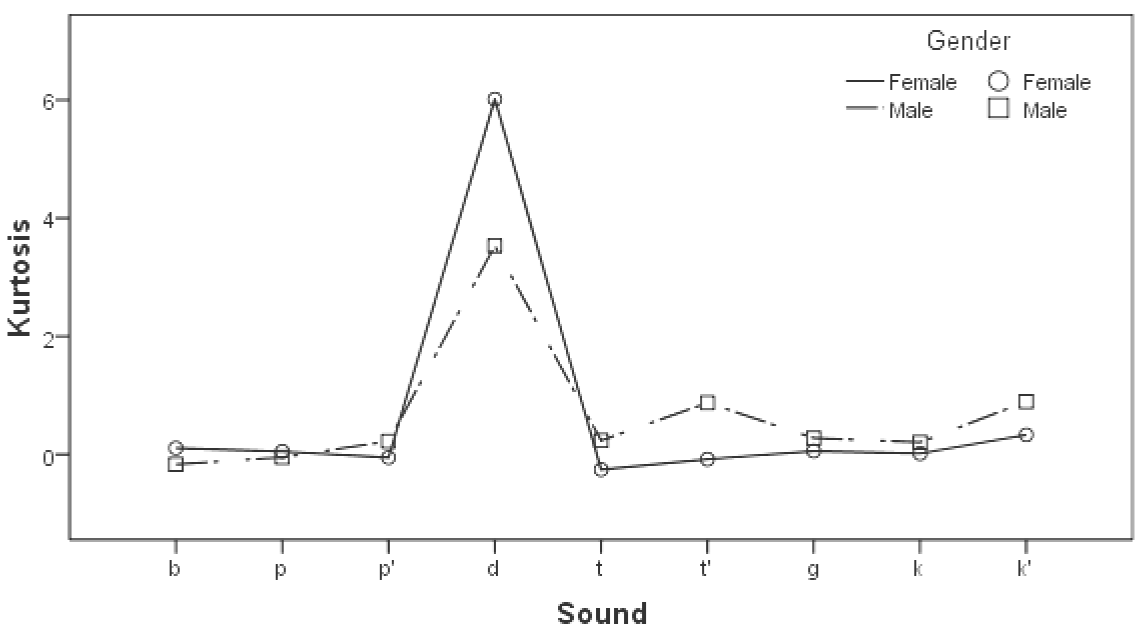


Fig. 4.43a: Mean burst spectral kurtosis of Amharic stops by gender.

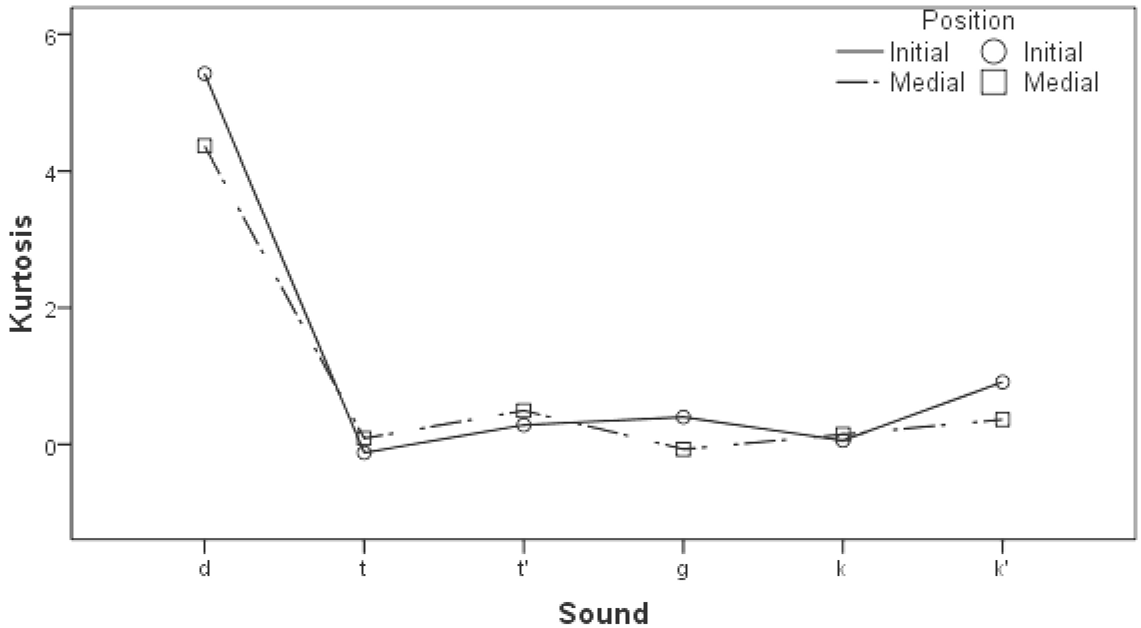


Fig. 4.43b: Mean burst spectral kurtosis of Amharic stops by position.

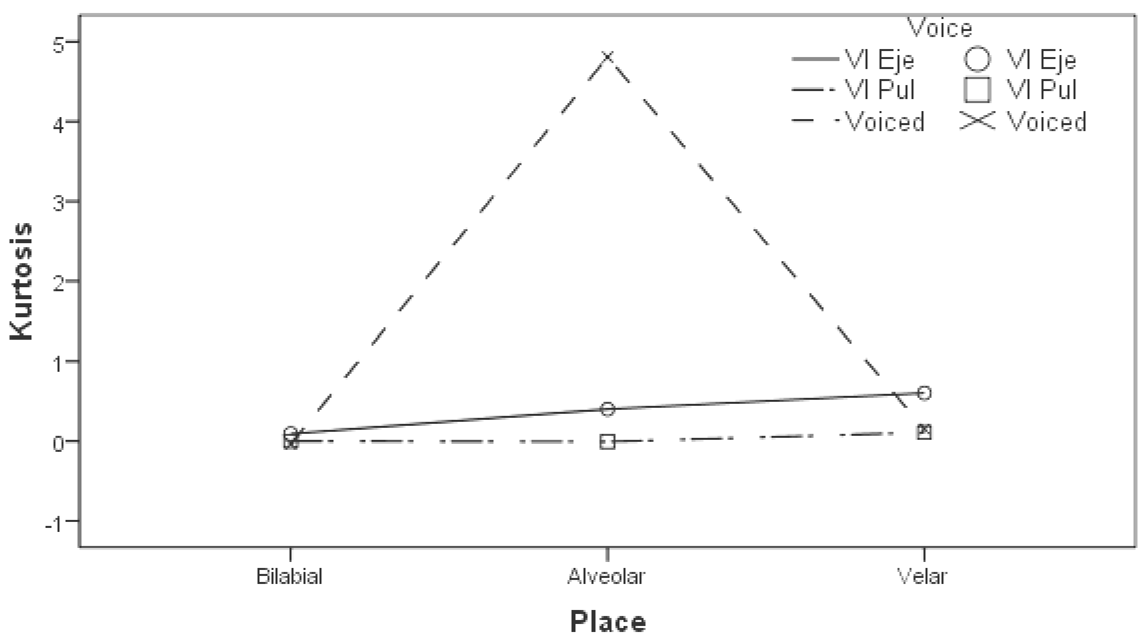


Fig. 4.43c: Mean burst spectral kurtosis of Amharic stops by place, voice and airstream.

In general, only voiceless stops showed a systematic pattern in terms of place effects: velars had the highest kurtosis values, followed by alveolars and bilabials.

Individual Patterns

Only male subjects showed significant differences within the same gender, f(3, 360)=8.58 ($p<0.001$). Scheffe post-hoc test showed that the very significant differences occurred between subjects M1 and M3 ($p<0.001$). Subjects M2 and M3, M1 and M4 had significant difference at $p<0.05$. The group patterns were confirmed by two male and two female showing higher kurtosis values for the ejectives than for the voiceless pulmonic stops at all the places, but the other two male and two female subjects had different patterns at the bilabial place of articulation, and one of the female subjects from these female subjects had a different pattern at the alveolar place as well.

4.2.4 Results on Voice Measurements

In general, voice measurements were conducted to see if there were differences in the phonation of the vowel following ejective stops compared to pulmonic stops. During the measurement of the phonation of the following vowels as manifested by the F0 and jitter, it was found that 50% of the ejectives for females and 30.53 % of males' ejectives had a clear creaky type of phonation at the onset of the following vowel for more than 10 ms, the mean value being 23 ms. Table 4.14 presents the summary of the cases and the mean duration of the creaky part of the vowel without F0 contour.

Table 4.14: Percentage and duration of the creaky part of vowels following Amharic ejectives.

Sound	Gender	Mean Duration of Creaky Part	N of Cases	Total N of Cases	Ratio of Cases to Total
k'	Female	23.7778	27	54	50.00 %
	Male	25.1875	16	51	31.37 %
	Total	24.3023	43	105	42.57 %
p'	Female	24.7273	11	23	47.82 %
	Male	23.6667	6	24	25.00 %
	Total	24.3529	17	47	36.17 %
t'	Female	21.6786	28	54	54.85 %
	Male	23.3889	18	56	34.61 %
	Total	22.3478	46	106	43.39 %
Total	Female	23.0455	66	131	50.38%
	Male	24.1500	40	131	30.53%
	Total	23.4623	106	262	45.68%

Thus in general, close to 46 % of the ejectives produced were followed by a creaky phonation which was longer than 10 ms at the onset of the vowel. No pulmonic stop was followed by a creaky vowel, and if there is a creak part on the onset of the vowel following Amharic stops, then it is an ejective stop.[25] The results reported in the voice measurements exclude the cases which had creaky phonation for more than 10 ms of the onset of the vowel following the stop.

4.2.4.1 F0 at Onset of Vowel

Group Patterns

The results on the F0 measurement at the onset of the following vowel are summarized in Fig. 4.44.

The results show that position had no effect on the F0 values. Female and male values were different as expected due to the physiological differences.

[25] From what has been observed in the course of this research, vowels followed by the glottal stop can also be be creaky at least on the onset. The results discussed in this research refer only to the vowels following

Airstream differences were apparent from the F0 values at the onset of the following vowel, specifically for females: ejectives had values less than the voiced and voiceless pulmonic stops, except for [**p’**] produced by males. For males, [**p’**] had higher F0 at the onset of the following vowel than both [**b**] and [**p**]. The difference between the F0 values for the ejective and the pulmonic stops was significant for females only, f(1, 348)=1.08 (p<0.001).

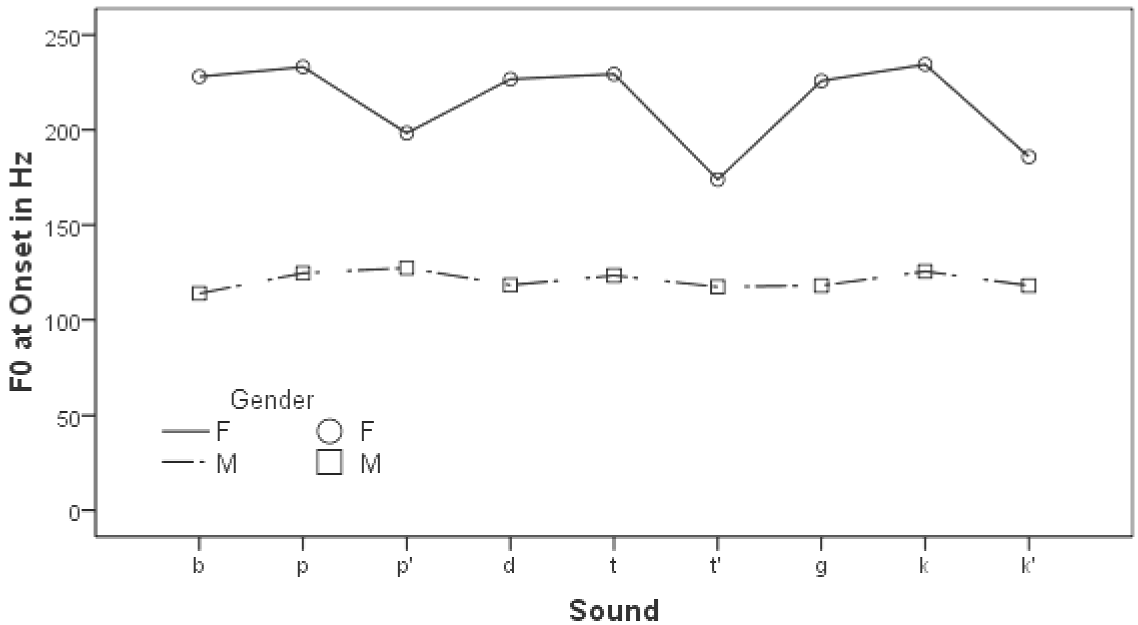


Fig. 4.44: Mean F0 at the onset of the vowel folowing Amharic stops by gender.

The effect of voice was also seen specifically for the pulmonic stops. Voiced pulmonic stops had lower F0 than voiceless pulmonic stops at the onset of the following vowel, this difference was significant only for male subjects at p<0.001 with on Scheffe post-hoc test.

Both for males and females, F0 values at the onset of the following vowel do not show significant differences for place of articulation.

Individual Patterns

There was individual differences among males, f(3, 346)=95.72 (p<0.001) and females f(3, 316)=2.85 (p=0.037). Scheffe post-hoc test showed that M1 had significant differences with M2, M3 and M4 (p<0.001) and there was a significant difference in the values of M3 and

M4 (p=0.009). For females, the only slight significant difference occurred between W2 and W4 (p=0.044).

The mean F0 values at the onset of the following vowel shows that at bilabial, alveolar and velar places, vowels followed by ejectives had lower F0 than the voiceless pulmonic stops for five, six and eight of the eight subjects respectively, a result which confirms the group patterns.

4.2.4.2 F0 at Mid of Vowel

Group Patterns

The results on the F0 measurements at the middle of the vowels following Amharic stops are presented in Fig. 4.45.

The results of the F0 measurement at the middle of the following vowel show that the effect of voice was not the same across the three places of articulation. The voiced alveolar stop had higher F0 at the middle of the following vowel than the alveolar voiceless stops, irrespective of airstream. At bilabial and velar places, the voiced stops had lower F0 at the middle of the following vowel than the voiceless stops had. The difference between voiced and voiceless pulmonic stops in terms of the F0 values at the middle of the following vowel was not statistically significant though.

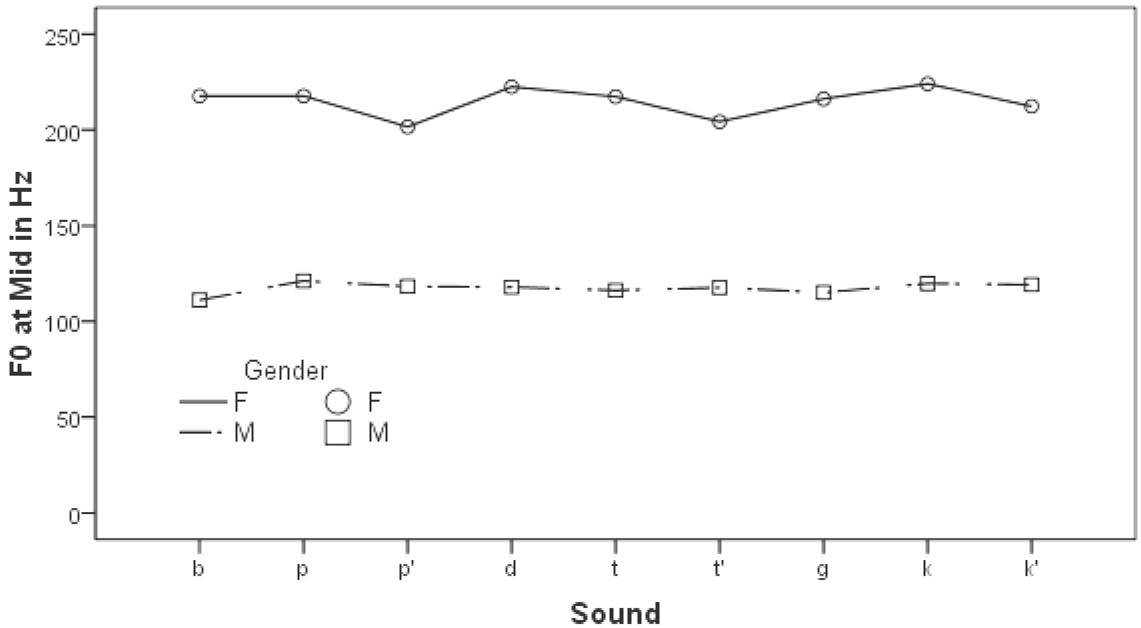


Fig. 4.45: Mean F0 at the middle of the vowel following Amharic stops by gender.

The effect of airstream was significant only for females, f(1, 322)=27.72 (p<0.001). The pattern for females showed that vowels preceded by ejectives had lower F0 at the middle than vowels preceded by voiceless pulmonic stops. Results for males, however, had the opposite pattern at alveolar and velar places. Place and voice did not show any significant differences on the F0 values at the middle of the vowel following the different stops of Amharic.

Individual Patterns

Individual differences were significant only for male subjects, f(3, 348)=79.04 (p<0.001). The differences were between subjects M1 and the rest of the male subjects, which were significant at p<0.001 on Scheffe post-hoc test.

When the individual patterns were compared, at alveolar place, six of the eight subjects (all females and two males) had higher F0 at the middle of the vowel following the voiced pulmonic stop than following the voiceless pulmonic stop. At bilabial place, six of the eight subjects (two females and all males) had lower F0 at the middle of the vowel following the voiced pulmonic stop than following the voiceless pulmonic stop. At velar place, all subjects had lower F0 at the middle of the vowel following the voiced pulmonic stop than following the voiceless pulmonic stop. Thus, the group results were also confirmed by the individual results.

4.2.4.3 F0 Perturbation

To normalize these individual differences on the F0 values of the following vowels, F0 perturbation was calculated. The results on the F0 perturbation of Amharic stops are summarized in Fig. 4.46.

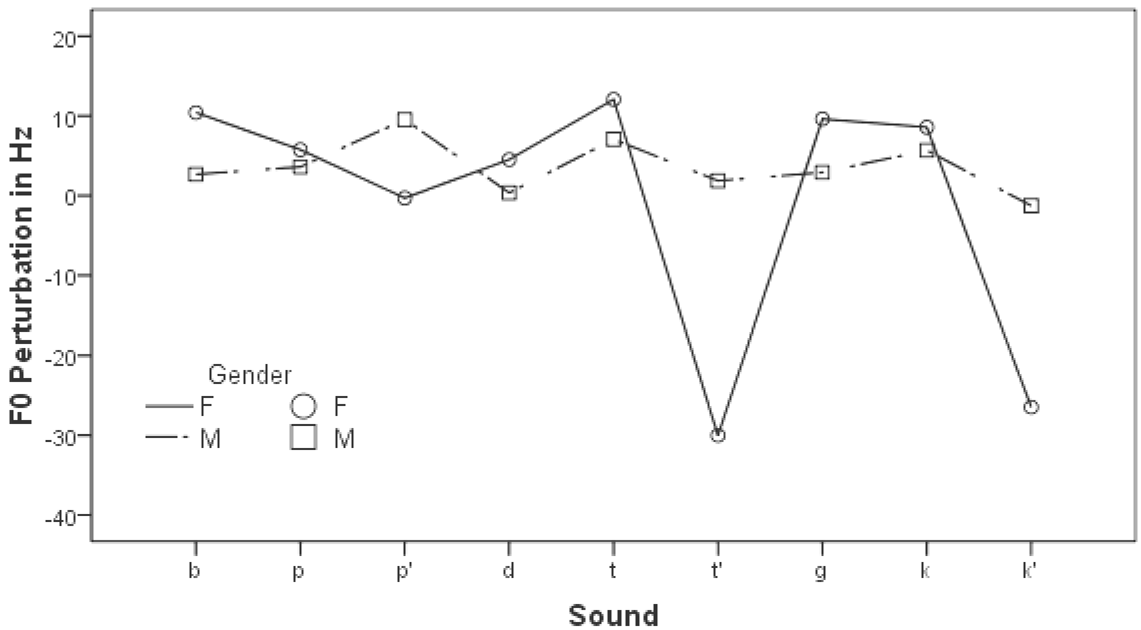


Fig. 4.46: Mean F0 perturbation of the vowel following Amharic stops.

F0 perturbation values for females were higher than males for all pulmonic stops, they were lower than males for all ejective stops. The differences in F0 perturbation due to gender was significant, $f(1, 638)=39.57$ ($p<0.001$).

The effect of airstream was significant for female subjects only, $f(1, 346)=1.15$ ($p<0.001$). The results showed that vowels followed by all ejectives had significantly lower F0 perturbation than vowels followed by the pulmonic stops for female subjects except the bilabial ejective for males. For males, vowels preceded by the bilabial ejective had higher F0 perturbation than vowels preceded by bilabial pulmonic stops. Males' vowels preceded by velar and alveolar ejectives had the same pattern as females' vowels in F0 perturbation values: they had lower values than those preceded by voiceless pulmonic stops.

Individual Patterns

Individual differences were significant for both genders: $f(3, 288)=3.82$ ($p=0.01$) for females and $f(3, 344)=15.45$ ($p<0.001$) for males. For females, the differences were between W4 and W1 ($p=0.035$). For males M3 had significant differences with the rest of the male subjects ($p\leq 0.001$).

Six of the eight subjects consistently showed that the F0 perturbation values of vowels after ejectives were lower than those vowels after pulmonic stops for alveolar and velar places of articulation. For bilabial stops, the results are divided by half. Two males and two females had lower F0 perturbation for ejectives than for voiceless pulmonic stops while the rest two males and two females had lower F0 perturbation for voiceless pulmonic stops than for ejectives.

4.2.4.4 Jitter at Onset of Vowel

Group Patterns

The results on jitter measurements at the onset of the following vowel are presented in Fig. 4.47.

The values on jitter measurements at the onset of the vowel following Amharic stops showed significant differences due to gender, $f(1, 675)=41.99$ ($p<0.001$). In eight of the nine stops, males had higher mean jitter values at the onset of the vowel after the stop.

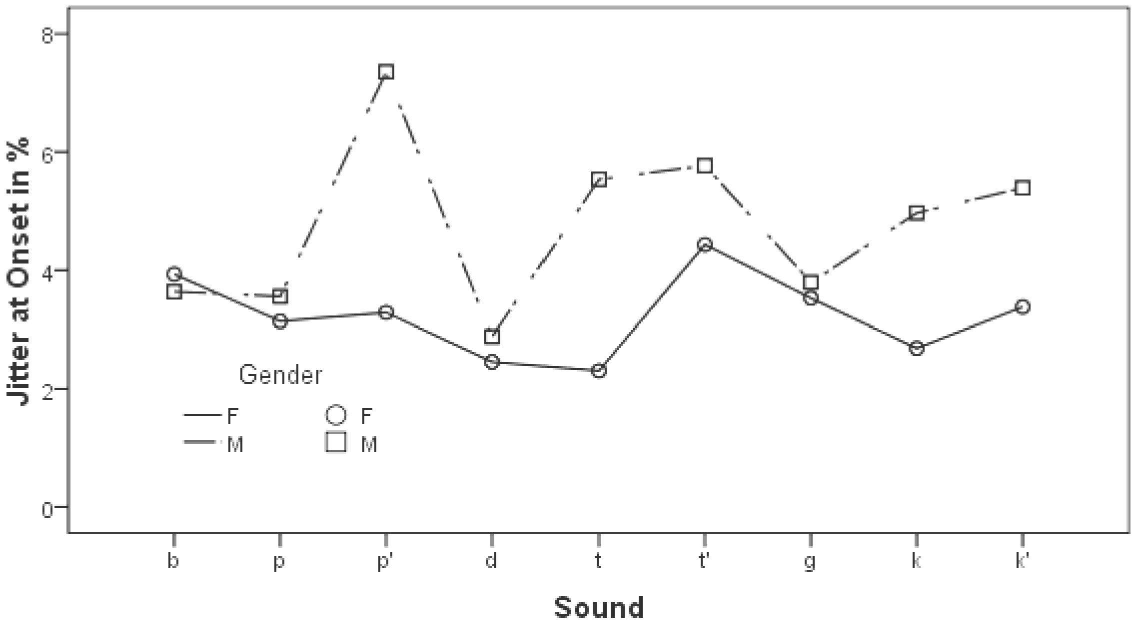


Fig. 4.47: Mean jitter of the onset of the vowel following Amharic stops.

The effect of airstream was significant f(1, 675)=28.62 (p<0.001). For all places and genders, vowels preceded by ejective stops had higher jitter at the onset than vowels which were preceded by both voiced and voiceless pulmonic stops.

Individual Patterns

Individual differences within the same gender were significant: f(3, 321)=6.36 (p<0.001) for females and f(3, 348)=5.87 (p=0.001) for males. Scheffe post-hoc test for females' values showed that the significant differences occurred between W3 and W1 (p=0.001) and W1 and W2 (p=0.027). For males, the significant differences occurred for subject M3 versus subjects M1 (p=0.01) and M4 (p=0.003). The individual patterns showed that for both males and female subjects, at the bilabial and alveolar places of articulation vowels which were preceded by ejective stops had higher jitter at the onset than vowels preceded by pulmonic stops. This was confirmed by seven of the eight subjects for each of the places. At the velar place of articulation, only one male and two female subjects, a total of three subjects confirmed the group pattern.

4.4.4 5 Jitter Perturbation

Group patterns

The general patterns showed that vowels preceded by ejectives had higher jitter perturbation than vowels preceded by voiceless pulmonic stops. The effect of airstream was significant, f(1, 668)=39.95 ($p<0.001$).

The effect of gender was significant, f(1, 668)=2433 ($p<0.001$). Mean jitter perturbation values were higher for males for six of the nine stops investigated. For male speakers, the ejective stops had higher values than that of both voiceless and voiced pulmonic stops. For female speakers, the ejective stops showed higher values than that of the voiceless pulmonic stops, but not necessarily so for voiced stops since at bilabial and velar places, voiced stops had higher jitter perturbation values than ejectives as well as the voiceless pulmonic stops. The jitter perturbation results for Amharic stops are presented in Fig. 4.48.

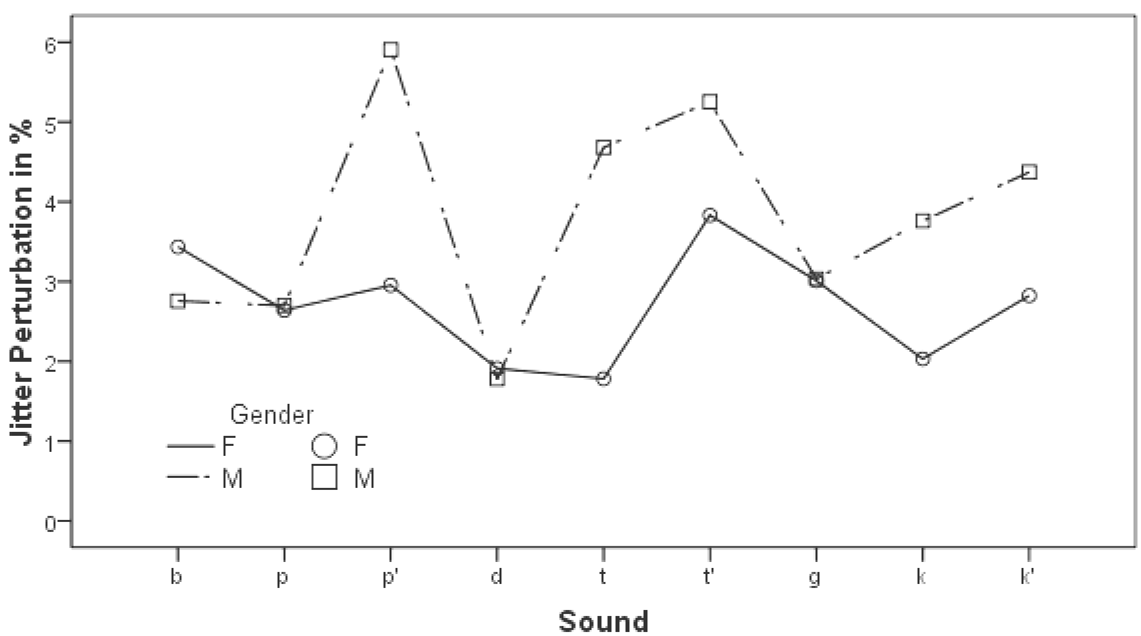


Fig. 4.48: Mean jitter perturbation of the vowel following Amharic stops.

As far as the pulmonic stops is concerned, no systematic and statistically significant difference of jitter perturbation values were recorded for voiced and voiceless pulmonic stops for both genders as male and female values go the opposite way.

Position had a significant effect on jitter perturbation: f(1, 352) =5.09 (p=0.025) for males and f(1, 322) 12.48 (p<0.001) for females. However, the general pattern that was found for male and female subjects collapsing both positions could not be conformed to by either the stops in the initial or intervocalic position of male or female subjects as presented in Fig. 4.49.

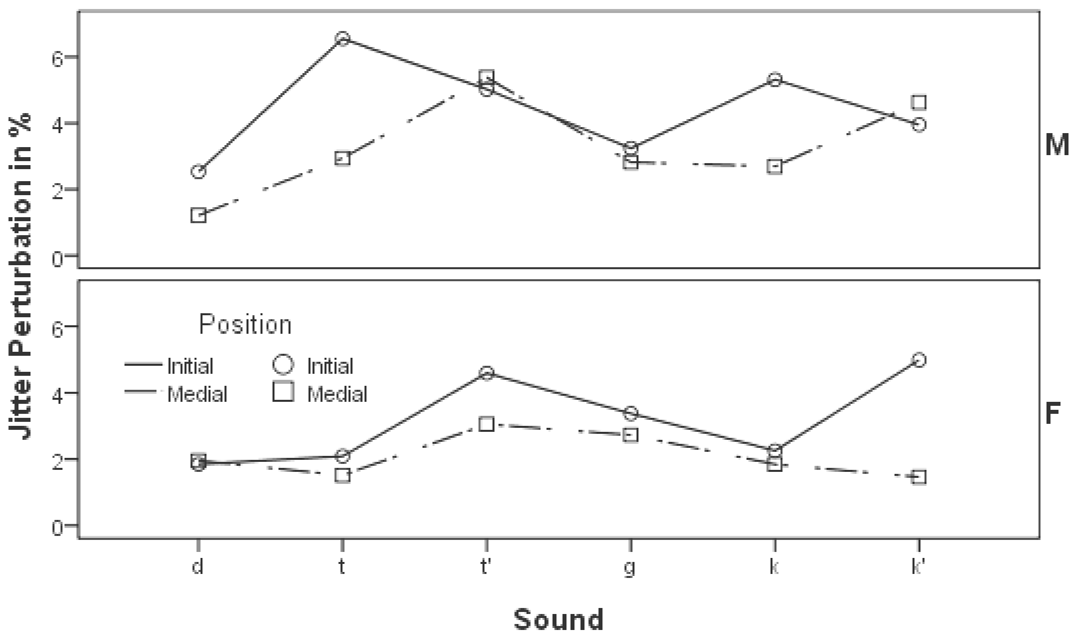


Fig. 4.49: Mean jitter perturbation of the vowel following Amharic stops by position and gender.

Individual Patterns

When the mean jitter perturbation values were compared for subjects in the same gender, the differences were significant: f(3, 320)=4.98 (p=0.002) for females and f(3, 350)=5.58 (p=0.001) for males. For females, subject W1 had significant differences with subjects W2 (p=0.029) and W3(p=0.005) on Scheffe post-hoc test. For males, subject M3 had significant differences with subjects M1 (p=0.039) and M4 (p=0.002).

The group patterns were also reflected in the individual patterns in alveolar and bilabial places as six of the eight subjects had higher mean jitter perturbation values for ejectives than for voiceless pulmonic stops. For velar stops the mean jitter perturbation values conforming to the group patterns were registered for half of the subjects.

4.2.5 Discriminant Analysis of Stops

4.2.5.1. Discriminant Analysis for Place of Articulation

The results of the different acoustic measurements of Amharic stops showed that total duration, burst duration, VOT and RMS intensity of the stop burst and relative intensity were affected by place. The first discriminant analysis was conducted to see which variables could stand out in discriminating between the three places of articulation. For this reason, the total duration measurements were not included as they were measured only for intervocalic alveolar and velar stops. The discriminant analysis conducted for both genders and positions showed that burst duration and relative intensity were significant (Wilk's Lambda <0.001). However, burst duration alone accounted for 98.5 % of the difference in variance whereas relative intensity accounted for 1.5 % of the difference in variance. The classification results show that 59.6 % of selected original grouped cases, 55.4 % of unselected original grouped cases and 58.8 % of selected cross-validated grouped cases were classified correctly. The results for each of the three places of articulation are presented in Table 4.15.

Table 4.15: Classification results for Amharic stops by place of articulation: all subjects collapsed across genders.

Cases			**Place**	**Predicted Group Membership (% of cases)**			**Total**
				Bilabial	**Alveolar**	**Velar**	
Cases Selected	Original	%	Bilabial*[26]	80.0	18.7	1.3	100.0
			Alveolar	25.6	54.3	20.1	100.0
			Velar	13.1	29.0	57.9	100.0
	Cross-validated	%	Bilabial*	78.7	20.0	1.3	100.0
			Alveolar	26.0	53.4	20.5	100.0
			Velar	13.1	29.4	57.5	100.0
Cases Not Selected	Original	%	Bilabial*	73.5	23.5	2.9	100.0
			Alveolar	29.0	49.5	21.5	100.0
			Velar	14.0	31.4	54.7	100.0

Of the three places, alveolar stops had the least classification results: more than 25 % of the alveolars were classified as bilabials and more than 20 % of them were classified as velars. Bilabials had the highest classification results (above 73 %) and the chance of bilabials being classified as velars was very little (less than 3 %). A minimum of 54.7 % of the velars were classified correctly whereas their chance of being classified as alveolars was 13 % to 14 % and their chance of being classified as alveolars was 29 and 31.4 %.

To see the discriminant power of each of the variables for all subjects collapsed across genders, separate discriminant analyses were conducted for each of the variables that were found to have been affected by place of articulation. As it can be seen from Table 4.16, burst duration and relative intensity came out as stronger indicators of place of articulation than VOT and RMS intensity, which had little more than the equal chance results.

[26] All bilabial stops were measured in word initial position only.

Table 4.16: Classification results for major variables that were used to classify Amharic stops by place of articulation: all subjects collapsed across genders.

Variable	**Classification results for place of articulation (% of cases)**		
	Selected original grouped cases (%)	**Unselected original grouped cases (%)**	**Selected cross-validated grouped cases (%)**
Burst duration	55.1	54.1	54.9
Relative intensity	50.4	46.7	50.4
VOT*	41	50.4	41
RMS intensity	37.5	40.2	37.5

A discriminant analysis was conducted separately for male and female subjects in order to see which variables could perform better for male and which variables could perform better for male subjects. The results are summarized in Table 4.17.

Table 4.17: Classification results for major variables that were used to classify Amharic stops by place of articulation: separate genders.

Variable	**Classification results for place of articulation (% of cases)**					
	Selected original grouped cases		**Unselected original grouped cases**		**Selected cross-validated grouped cases**	
	Male	Female	Male	Female	Male	Female
Burst duration	47.8	62.1	54.4	55.5	47.8	62.1
Relative intensity	44.8	50.0	46.5	49.5	44.4	49.6
VOT[27]	40.8	42.6	54.1	50	40.8	42.6
RMS intensity	46.2	37.1	45.6	34.2	45.8	37.1

Table 4.17 shows that the principal variables (burst duration and relative intensity of the burst to the following vowel) as well as the least performing variables (VOT and RMS intensity) were sensitive to gender. Looking at the selected cross-validated grouped cases only, burst duration, relative intensity and VOT had higher classification for females than they had for males. RMS intensity had the opposite pattern: it performed better for male subjects than it did for female subjects.

[27] VOT measurement was conducted for word initial stops only.

Results after Speaker Normalization

Speaker normalization was conducted using Lobanov transformation (z-transformation). These normalized values were used in the discriminant analysis for place. The results show that 63.1 % of selected original grouped cases, 63.5 % of unselected original grouped cases and 61.9 % of selected cross-validated grouped cases were classified correctly by place of articulation.

Table 4.18: Classification results for major variables that were used to classify Amharic stops by place of articulation using speaker normalized values.

Variable	**Classification results for place of articulation (% of cases)**		
	Selected original grouped cases (%)	**Unselected original grouped cases (%)**	**Selected cross-validated grouped cases (%)**
Burst duration	55.1	53.1	54.2
Relative intensity	48.6	50	48.6
VOT*	42.7	47.2	42.7
RMS intensity	44.9	43.9	44.9

Tabel 4.18 presents separate discriminant analysis using each of the variables. The results were similar with the ones found using the nonnormalized values for all subjects collapsing both genders.

4.2.5.2 Discriminant Analysis for Voice

The variables which were affected by voice were total duration, percentage of voiced closure, duration of the voiceless closure, VOT, voicing lag, burst duration, rise time and spectral mean. Of these variables, total duration was measured for alveolar and velar stops, and measurements on the closure duration (percentage of voiced closure and duration of the voiceless closure) were done for intervocalic stops only (which means for alveolar and velar places), and thus were excluded from the discriminant analysis.

The discriminant analysis for all subjects collapsed across genders showed that 90.8 % of selected original grouped cases, 87.7 % of unselected original grouped cases and 90.4% of selected cross-validated grouped cases were classified correctly. All variables were significant (Wilk's lambda <0.001) but it were VOT and voicing lag that had significant contributions in accounting for the difference of variance. The classification results of the discriminant analysis for voiced and voiceless stops are summarized in Table 4.19.

Table 4.19: Classification results for Amharic stops by voice: all subjects collapsed across genders.

Cases			**Voiced or Voiceless**	**Predicted Group Membership (% of cases)**		**Total**
				Voiceless	**Voiced**	
Cases Selected	Original	Count	**Voiceless**	89.0	11.0	100.0
			Voiced	5.1	94.9	100.0
	Cross-validated	%	**Voiceless**	88.5	11.5	100.0
			Voiced	5.1	94.9	100.0
Cases Not Selected	Original	%	**Voiceless**	80.6	19.4	100.0
			Voiced	-	100.0	100.0

The results in Table 4.19 show that the classification results were higher for voiced stops than for voiceless ones. This is mainly due to the smaller VOT values of the bilabial voiceless stops, which were classified as voiced stops.

The same analysis was conducted by splitting gender. The results showed no significant differences due to gender. For females, 89.0 % of selected original grouped cases, 78.3 % of unselected original grouped and 89 % of selected cross-validated grouped cases were classified correctly. For males, 90.4 % of selected original grouped, 86.8 % of unselected original grouped cases and 88.8 % of selected cross-validated grouped cases were classified correctly. However, there were differences in the classification results of voiceless and voiced stops: voiced stops for females and voiceless stops for males had higher classification results than their counterparts as table 4.20 shows.

Table 4.20: Classification results for Amharic stops by voice: separate genders.

Gender	Cases			Voiced or Voiceless	Predicted Group Membership: Voiceless	Predicted Group Membership: Voiced	Total
Female	Cases Selected	Original	%	**Voiceless**	84.8	15.2	100.0
				Voiced	2.1	97.9	100.0
		Cross-validated	%	**Voiceless**	84.8	15.2	100.0
				Voiced	2.1	97.9	100.0
	Cases Not Selected	Original	%	**Voiceless**	72.5	27.5	100.0
				Voiced	10.0	90.0	100.0
Male	Cases Selected	Original	%	**Voiceless**	90.9	9.1	100.0
				Voiced	10.8	89.2	100.0
		Cross-validated	%	**Voiceless**	90.9	9.1	100.0
				Voiced	16.2	83.8	100.0
	Cases Not Selected	Original	%	**Voiceless**	84.4	15.6	100.0
				Voiced	9.5	90.5	100.0

The performance of each variable was investigated by using each of them in the discriminant analysis. The results in Table 4.21 show that voicing lag and spectral mean also had resulted in higher classification results followed by rise time. Burst duration had classification results close to the chance classification result, which shows its incompetence of discrimination between voiced and voiceless consonants.

Table 4.21: Classification results for major variables that were used to classify Amharic stops by voice: all subjects collapsed across genders.

Variable	Classification results for voice (% of cases): Selected original grouped cases	Unselected original grouped cases	Selected cross-validated grouped cases
VOT	81.4	76.4	81.4
Voicing lag	74.2	75.6	74.2
Spectral mean	70.6	73.1	70.4
Rise time	66.9	57.5	66.9
Burst duration	53.4	54.5	53.4

The discriminant analysis was done separately for male and female speakers to see if there were differences between the classification results for males and females. The results are presented in table 4.22.

Table 4.22: Classification results for major variables that were used to classify Amharic stops by voice: separate genders.

Variable	Classification results for voice (% of cases)					
	Selected original grouped cases		Unselected original grouped cases		Selected cross-validated grouped cases	
	Male	Female	Male	Female	Male	Female
VOT*	80.3	83.1	77	79	80.3	81.8
Voicing lag	67.1	80.2	74.8	78.1	67.1	80.2
Spectral mean	69.5	71.6	70.6	74.5	69.5	71.5
Burst duration	60.6	51.5	64.1	49.1	60.6	51.5
Rise time	61	68.6	61.5	61.	61	68.6

As the classification results in Table 4.17 show, females had higher classification than males had. The significant differences between male and female classification results happened using, voicing lag, burst duration and rise time.

Results after Speaker Normalization

The results of the discriminant analysis using the speaker normalized values were close to the classification results obtained using the nonnormalized values: 91.2 % of selected original grouped cases, 83.2 % of unselected original grouped cases and 91.2 % of selected cross-validated grouped cases were classified correctly by voice. The classification conducted using each of the variables separately were also very close to the results found using the nonnormalized values as Table 4.23 shows.

Table 4.23. Classification results for Amharic stops by voice using speaker normalized values.

Variable	Classification results for voice (% of cases)		
	Selected original grouped cases	Unselected original grouped cases	Selected cross-validated grouped cases
VOT	82	80.5	82
Voicing lag	74	77	74
Spectral mean	70	72.6	70
Rise time	65.9	61.2	65.9
Burst duration	54.6	55.9	54.6

4.2.5.3 Discriminant Analysis for Airstream

Percentage of voiced closure, voiceless portion of the closure, burst duration, voicing lag, relative intensity, spectral mean, absolute rise in intensity, F0 perturbation and jitter perturbation were found to be affected by airstream. However, the percentage of voiced closure and the voiceless portion of the closure were measured for intervocalic stops and thus the airstream differences could not be seen for bilabial stops, which were not included in the measurement of stops in the intervocalic position. As a result, burst duration, voicing lag, relative intensity, spectral mean, absolute amplitude and jitter perturbation were used in the discriminant analysis conducted to see the potential of variables in discriminating between pulmonic and glottalic stops.

The discriminant analysis using burst duration, voicing lag, relative intensity, spectral mean, absolute rise in intensity, F0 perturbation and jitter perturbation showed that F0 perturbation was the most significant variable that accounted for most of the differences in variance of the pulmonic and glottalic stops. However, the classification results did not show higher results as expected: 82.7 % of selected original grouped cases, 77.6 % of unselected original grouped cases, 80.7 % of selected cross-validated grouped cases were classified correctly. Compared to the results found for classification by voice, the results of the classification by airstream were lower by almost 10 %. The results of the classification of Amharic stops by airstream are presented in Table 4.24.

Table 4.24: Classification results for Amharic stops by airstream: all subjects collapsed across genders.

Cases			**Pulmonic or Ejective**	**Predicted Group Membership**		**Total**
				Pulmonic	Ejective	
Cases Selected	Original	Count	Pulmonic	291	67	358
			Ejective	63	60	123
		%	Pulmonic	81.3	18.7	100.0
			Ejective	51.2	48.8	100.0
	Cross-validated	Count	Pulmonic	291	67	358
			Ejective	63	60	123
		%	Pulmonic	81.3	18.7	100.0
			Ejective	51.2	48.8	100.0
Cases Not Selected	Original	Count	Pulmonic	127	19	146
			Ejective	18	25	43
		%	Pulmonic	87.0	13.0	100.0
			Ejective	41.9	58.1	100.0

The results show that ejectives were poorly discriminated: the classification results show more than 40 % of ejectives were classified as pulmonic. Pulmonic stops, however, were classified better: a minimum of 81.7 % of the pulmonic stops were classified correctly. The explanation for the lower classification results is that the F0 perturbation (for males) and the jitter perturbation values of pulmonic and ejective stops were not statistically significant. However, it is clear from the results on voice measurements that Amharic ejectives were followed by creaky phonation in almost all cases. Thus, the discriminant analysis could have performed better if a binary value of presence and absence of creaky phonation was given instead of using the jitter perturbation measurement values.

Separate discriminant analyses were made using each of the variables. The results are presented in Table 4.25.

Table 4.25: Classification results for major variables that were used to classify Amharic stops by airstream: all subjects collapsed across genders.

Variable	Classification results for airstream (% of cases)		
	selected original grouped cases	unselected original grouped cases	selected cross-validated grouped cases
F0 perturbation	73	80.4	73
Jitter perturbation	66	65.1	66
Spectral mean	61.2	64.6	61.2
Voicing lag	59.5	63.1	59.5
Absolute rise in intensity	53.3	55.5	53.3
Burst duration	52.8	51.6	52.8
Relative intensity	51.8	49.5	51.8

The results show that spectral mean and voicing lag had almost similar classification results following jitter perturbation. Absolute intensity, burst duration and relative intensity had classification results close to 50 %, which is the chance result.

Separate gender discriminant analyses for each of the variables were conducted. The results are summarized in Table 4.26.

Table 4.26: Classification results for major variables that were used to classify Amharic stops by airstream: separate genders.

Variable	Classification results for airstream (% of cases)					
	selected original grouped cases		unselected original grouped cases		selected cross-validated grouped cases	
	Male	Female	Male	Female	Male	Female
F0 perturbation	55	85.3	56.4	87.5	55	85.3
Jitter perturbation	63.3	64.7	61.2	59.6	63.3	64.7
Spectral mean	60.2	62.5	62.7	66.4	59.8	62.5
Voicing lag	50.4	67	63.1	62.3	50.4	67
Absolute rise in intensity	58.6	52.1	65.4	54.9	58.6	52.1
Burst duration	48.6	54.2	49.5	52.7	48.6	54.2
Relative intensity	52	64.1	58.4	56.8	52	64.1

The results Table 4.26 show that there were not much differences between male and female classification results on jitter perturbation and spectral mean. On the other four variables (excluding F0 perturbation), the differences between male and female values, taking the selected cross-correlated grouped case only, was between 4 and 17 %. F0 perturbation however, was exceptional as the results for males were close to the chance result whereas the results for females were very high - more than 85 %. Females had higher classification results than males had on all variables except absolute intensity.

Results after Speaker Normalization

The results of the discriminant analysis using the speaker normalized values were quite lower than the classification results obtained using the nonnormalized values: 72.8 % of selected original grouped cases, 76.2 % of unselected original grouped cases and 71.6 % of selected cross-validated grouped cases were classified correctly by airstream. The results on obtained using each of the variables that were affected by airstream mechanism are presented in Table 4.27.

Table 4.27: Classification results of Amharic stops by airstream using speaker normalized values.

Variable	Classification results for airstream (% of cases)		
	selected original grouped cases	unselected original grouped cases	selected cross-validated grouped cases
F0 perturbation	70.9	73.5	70.7
Jitter perturbation	63.8	58.9	63.6
Spectral mean	59.8	63.2	59.8
Voicing lag	59.1	61.3	59.1
Absolute rise in intensity	52.1	54.1	48.5
Burst duration	52.8	51.6	52.8
Relative intensity	51.8	49.5	51.8

Once again, it is clear from these results that speaker normalization did not improve the classification results. In the case of the discriminant analysis for airstream, the results after speaker normalization showed lower classification results than the results without speaker normalization.

Summary of Results on Discriminant Function Analysis

Results on the discriminant analysis conducted to separate Amharic stops by place, voice and airstream show that, as expected, the voice of Amharic stops could better identified than their place of articulation or airstream mechanism.

The experiment to classify Amharic stops by place of articulation was successful particularly for bilabial stops, whereas alveolars and velars had a very marginal difference in terms of the percentage of correctly classified stops.

Voiced stops were better classified than voiceless stops as the classification results showed. One possible explanation for this may be because bilabial voiceless stops had smaller VOt values, they are likely to be wrongly classified as voiced ones, which reduces the percentage of correct classification for voiceless stops.

Classification results for airstream showed that ejectives were poorly discriminated. Though the general classification results go as high as 80 %, 40 % of ejectives were wrongly classified as pulmonic stops. It was expected that Amharic ejectives would come out with higher correct classification results because during the inspection of the sound files, for all subjects, most ejectives could be identified by the presence creaky phonation on the onset of the vowel following ejectives. The acoustic cues that are related to quality of voice, i.e. change in F0 (F0 perturbation in this study) and jitter perturbation still dominate as main cues that separate ejective stops from pulmonic ones.

The classification made using separate variables showed that females' token were better classified than male tokens. This is expected as literature shows that female speech is clearer, and thus better classified than male speech. Even in this study, it was found that females' stops and vowels were longer than males' stops and vowels, which conforms to this general trend. The biggest difference in female and male classification results was seen in the classification of ejectives using F0 perturbation: females' tokens were correctly classified by 30 % more than male tokens. This happened because F0 of vowels' onset following ejectives of female subjects were lowered nearly by half. Since females have F0 which is twice or so F0 of males, this change can bring a lot of differences between male and female values as seen in the discriminant function analysis.

Finally, speaker normalization was seen to marginally affect classification results. In most cases, it brought about higher classification results than classification results found using nonnormalized for all subjects collapsing both genders.

CHAPTER FIVE

DISCUSSION, SUMMARY AND FUTURE DIRECTIONS

5.1 Discussion on Vowels

The results show that the quality of the central vowels is quite different from the previous studies (Abebayehu 2007, Hayward 2000) which reported a high central vowel, mid central vowel and a low central vowel. According to the results in the current study, what is referred to as a high central vowel in Amharic is not really high. It is the same height as that of the mid front vowel [**e**]. I suggest that the use of the symbol [**ɨ**] for this vowel nowadays seems not appropriate based on the results of this study. Thus, I recommend and have used the symbol [**ɘ**].

The so called mid central vowel, which has been represented by [**ə**] (Hayward 2000) or [**ä**] (Abebayehu 2007) did not take the same acoustic space as the schwa vowel. Rather, it is lower and a bit advanced. There are other better candidates for representation. One option is to use [**ɛ**] as Cowley et al. (1976) did. The problem with this is that this would make readers feel that the vowel is front. I still hold that the vowel is not a front vowel, but a central one[28]. The second option is to use [**ä**]. This is customary in linguistic as well as philology works on Amharic and Geez. However, there is the central low vowel, which is represented by [**a**] and there might be confusion between the two due to form similarity. Thus, I propose the symbol [**ɜ**], which, according to the cardinal vowel representation, is closer to Amharic central vowel.

The low central vowel has always been represented by [**a**]. If we have to select the symbol close to the place where the Amharic vowel is found in the acoustic vowel space, the symbol [**a**] is appropriate. Selecting [**ɑ**] is also possible, but this means that the vowel is back, and the results show that it is not.

[28] This claim, however, needs a perceptual test to prove.

Based on the phonetic analysis conducted, it is proposed that Amharic is moving towards having a four-height vowel system as presented in Table 5.1. This is a phonetic view which ignites further phonological debate because it is also possible to argue that the language has a three vowel height phonologically, with the central vowels having a phonetically lower position.

Table 5.1: The vowels of Amharic: a new proposal.

	Front	Central	Back
High	i		u
high-mid	e	ɘ	o
Low-mid		ɜ	
Low		a	

This new vowel chart departs from earlier charts in the introduction of a new height distinction: it has four heights instead of the common three heights. The chart best describes the phonetic system, but at the same time could also be adapted as a new phonological system of Amharic vowels.

The most likely reason for Amharic developing such a different vowel system is a vowel shift that is in progress. Nowadays, a lot of languages are undergoing a vowel shift, and some have already undergone a vowel shift like the Great Vowel Shift in English. Amharic seems an addition to this list. The subjects of the study were young speakers between twenty two and thirty four years of age who were born and raised in Addis Ababa. Thus, it is likely that the height of the central vowels is being lowered by one level, and can be taken as an example of a chain shift.

This new vowel system has a number of implications for phonological universals proposed. A number of absolute and implicational universals have been proposed based on large databases (Crothers 1978 and Schwartz et al. 1997). Attempts also have been made to create models that can generate universally common vowel systems given the number of vowel in a vowel system (Liljencrants and Lindblom 1972, Lindblom 1986). While there are several universals that the new Amharic vowel system confirms, there are also numerous universals that it departs from.

Amharic has /**i**/, /**a**/, /**u**/, a universal set of vowels found in all languages (Crothers 1978). These vowels are also the preferred vowels according to the quantal theory of speech (Stevens 1972 in Johnson 2003). Amharic is perhaps moving towards having more height distinctions than it has backness distinctions, conforming to the universal proposed on height and backness distinctions (Crothers 1978, Schwartz et al. 1997). Amharic has the same number of front and back vowels and two interior vowels which are central, conforming to the preferred symmetry of the peripheral vowel systems and the preference of central vowels instead of front rounded or back unrounded from the set of interior vowels (Schwartz et al. 1997).

On the other hand, Amharic seems to moving towards having /**ɘ**/ instead of /**ɨ**/, and /**ɜ**/ instead of /**ə**/. With this new vowel system, Amharic is going to change its status as an exception instead of a language that conforms to the tendencies that Crothers (1978) presents.

- All languages with four or more vowels have /**ɨ**/ or /**ɛ**/. They generally also have /**ɔ**/.
- Languages with five or more vowels have /**ɛ**/. They generally also have /**ɔ**/.
- Languages with six or more vowels have /**ɔ**/ and also either /**ɨ**/ or [**e**], generally the former.
- Languages with seven or more vowels have /**e o**/ or /**ɨ ə**/. (The types /**ɨ ə**/ may be represented by /**y ø**/.

The vowel systems based on which the tendencies had been drawn were formulated more than 40-50 or more years ago using mostly impressionistic articulatory techniques. The vowel system of Amharic as described by Leslau (1968) was used as an input in the formulation of these and other universals on vowels. It is not claimed in this paper that the analysis conducted on Amharic provides comparable results with that of Peterson and Barney (1952) or Hillenbrand et al. (1995) due to the size of the data. However, in light of the current data, the proposals made earlier need to be revisited for two reasons. First, as languages change overtime, so should the generalizations on languages. For instance, Crothers (1978) presented the list of languages with seven vowel systems with two interior vowels, and none of the fourteen languages mentioned (including Amharic) had a high-mid central unrounded vowel **/ɘ/**. Second, we have now better experimental methods to determine the type of vowels that a language has.

The most confusing case in the discussion of Amharic vowels concerns the symbol **/ə/**. In the IPA chart it represents the mid central vowel. The intention of earlier researchers in using the symbol **/ə/** is clear as the earlier vowel charts (Leslau 1968, Baye 2010) show **/ə/** stand for what is known as schwa. However, there is a trend among philologists and linguists to (Sumner 1957, Amsalu 1987) use **/ə/** as a representation of the sixth order vowel (the high central vowel **/ɨ/** in Amharic. Indeed, such confusion has been a case in studies that look into phonological universals as well. Schwartz et al. (1997) claim that **/ə/** is one of the most common vowel and one that seems not “interact with other vowels” in the system. In the set of symbols they used to represent the set of vowels in the UPSID, **/ə/** is placed where the IPA chart places **/ɘ/**.

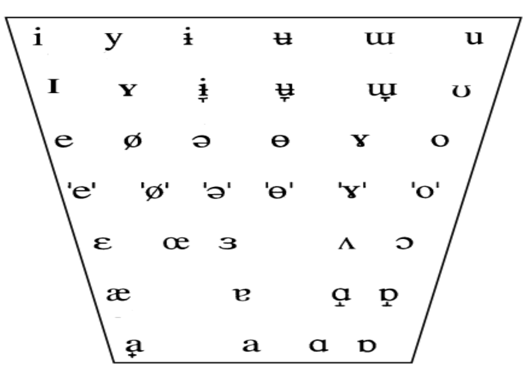


Fig. 5.1: The grid of representing the 37 vowel symbols in UPSID. The horizontal dimension represents the front-back and rounding dimensions and the vertical dimension represents the close-open (or high-low) dimension. (Schwartz et al. 1997:236)

I hold that part of this confusion comes from equating /ə/ with /ɘ/. I have doubt about the results as there possibly are two separate vowels, /ə/ and /ɘ/, which could have been considered when making generalizations about only one of them, mainly /ə/. The use of /ə/ by linguists to represent the sixth order vowel of Amharic, the one represented with /ɘ/ in this thesis, may have its source in such traditions. I hold that there should be a separate treatment of the two symbols, or a clear case of description in cases where /ə/ is used to replace /ɘ/.

Another issue regarding the use of /ə/ in Amharic is its status in other major languages of the world such as English. In many languages, /ə/ is seen as a vowel that is not stable, i.e. a form that does not exist by itself unless some phonological phenomena such as unstressed syllable exists. The vowel which it is made to represent in Amharic is a very stable and typical Amharic vowel which has the highest frequency of occurrence in the language Sumner (1957). Therefore, it is advisable to avoid such confusions by selecting a vowel that does not open a way for such misunderstanding and yet closer to the reality, which I assume is /ɜ/.

Amharic vowels were longer before voiced stops than they were before voiceless stops. This result is the same as the one found by House and Fairbanks (1953) in American English. The durational difference in vowels before voiceless and voiced consonants is a universal feature (Maddieson 1997). One explanation for this is that it happens as a result of "*a need to make a forceful gesture of closure for a voiceless consonant since the unimpeded flow of air through an open glottis provides greater resistance to the formation of oral seal*" (Maddieson 1997: 624 citing Chen 1970). What this means is that the articulators will achieve the closure in a shorter time as they move fast due to the application of more forceful gesture (Maddieson 1997). Another explanation says that listeners perceive the vowel as longer before voiced consonant due to the continuous voicing making it difficult to identify the end of the vowel (Maddieson 1997 citing Javkin 1976). Amharic is not an exception to this, and it has been found that vowels were longer before voiced consonants than before voiceless consonants.

The duration of Amharic vowels before singletons and geminates also conforms to universal features. Amharic vowels before singletons were longer than they were before geminates. This result is similar to the ones found in Amharic (Sumner 1957) and Italian (Smith 1995). One explanation for this is the need to control the duration of the larger unit such as the syllable resulting in some compromise in the duration of the segments in the unit(Smith 1995). Thus, if the consonant is long, the vowel will be short and vice versa.

5.2 Discussion on Pulmonic and Ejective Stops

The results of the various measurements show place, voice, and airstream of Amharic stops can be identified based on some acoustic cues. The discussion section presents the results which are significant and those not significant in differentiating the various categories of Amharic stops. The discussion (in Section 5.2.1) is presented based on the measurement categories in which the results have been discussed.

5.2.1 Discussion on the Results of Durational Measurements

In all durational measurements, it was found that stops in the speech of females had longer duration than stops in the speech of males.

The results show that voiceless stops had longer duration than voiced stops, and velar stops had longer duration than alveolar stops. However, the difference between ejectives and voiceless pulmonic stops was not systematic. Thus, it is clear for Amharic that total duration cannot be a valid acoustic cue to differentiate between voiceless pulmonic and ejective stops, but it could be used to identify place of articulation of stops.

The results on closure duration show that, again velars had longer duration than alveolars, with the exception of female voiced stops, and that voiced stops had shorter closure than voiceless stops. Closure duration, however, could not distinguish between pulmonic and ejective voiceless stops as the results were not consistent for the two places of articulation investigated. Amharic stops have inconsistent closure duration as the voiceless consonants conform to results found by Byrd (1993) which show coronal stops have shorter closure duration than velars, whereas the voiced stops conform to the results found in other languages such as Chinese, Swedish, Italian, and English (Ren 1985, Elert 1964, Vagges et al. 1978, Stathopoulos and Weismer 1983), which show alveolars have longer closure duration than velars.

This result confirms Maddieson's (1997:631) statement that runs, as far as duration of the closure of stops is concerned, "*It is often the case that inconsistent rankings are found even within a single language*."

The voiced part of the closure had no role to play in differentiating between places or manners of articulation.

The percentage of the mean duration of voicing into the stop closure in relation to the mean total closure duration gave some systematic difference among Amharic stops. Voiced stops had higher percentages of voiced closure than voiceless stops had, and voiceless pulmonic stops had higher percentages of voiced closure than ejective stops had. Thus, the percentage of voiced closure in relation to the total closure can be a cue for voice and airstream differences, but not for place differences in Amharic intervocalic stops.

As voiced closure, the voiceless part of the closure also showed some systematic results: ejectives had longer voiced closures than the voiceless pulmonic stops, and voiceless stops had longer voiceless closures than voiced stops. However, place effects were not consistent for voiceless and voiced stops.

The burst duration results show that velars had the longest burst followed by alveolars and then bilabials, which agrees with the results of Fleming (2007), who reported shorter duration of burst for the bilabial voiced stop than the alveolar and velar voiced stops before the alveolar central approximant in American English[29]. Voiceless consonants had longer bursts than voiced consonants; voiceless pulmonic stops had longer burst than ejective stops. Thus, place, voice and airstream are separated, based on the burst duration in Amharic.

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[29]The burst duration measurement included the friction in addition to the transient though.

VOT values of Amharic stops showed systematic differences across places and voices: velars had longer VOT followed by alveolars and then bilabials; voiceless stops had longer VOT than voiced stops. The effects of airstream differed for bilabial and the remaining two places and for the two genders. Thus, VOT as a cue to airstream differences in Amharic is weak.

An interesting finding on the VOT of Amharic stops is the presence of both lead and lag VOT for voiced stops. One third of the initial stops in Amharic had voicing before the burst, but almost half of these stops with lead VOT were produced by only one of the subjects. In addition, taking lead VOT values only, it has been found that the effect of place was not significant and not systematic. Therefore, it is clear here that the Amharic stops tend to have lag VOT. The lead versus lag VOT of Amharic stops, however, needs a separate research which can include as many subjects as possible from male, female and children with the combination of all the seven vowels.

The increasing VOT values as one goes from front to back in the oral cavity has been one of the earliest findings in phonetics research (Fischer- Jørgensen 1954, Peterson and Lehiste 1960). Amharic VOT values conform to this phonetic universal.

In terms of VOT values, these results are also in line with that of Ladefoged and Cho (2001), who reported that of the six languages (Apache, Hupa, Montana Salish, Navajo, Tlingit and Yapese) which contrast velar pulmonic and ejective stops, five of them (except Hup'a) had higher VOT[30] for the velar ejective than for the velar voiceless unaspirated stop. Ladefoged and Cho (2001) reported that there was a significant difference in VOT between the velar voiceless pulmonic stop and the velar ejective for five of the six languages (except for Hupa) and suggested that these languages may employ VOT as a supplementary cue to distinguish between the stops produced by the two airstream mechanisms, as mentioned by Stevens et al. (1986). However, though Amharic velar ejective had longer VOT than the voiceless pulmonic stop, the differences of VOT due to airstream were not significant in Amharic.

[30] Ladefoged and Cho (2001) took VOT of ejective stops to be the interval between the oral release and the glottal release.

Since VOT for ejectives is not the same as VOT for voiceless pulmonic stops, these results should be viewed with caution.

Voicing lag results did not come as strong as VOT values. Place differences were found between velar on one hand, and alveolar on the other hand, velar stops having longer voicing lag than both alveolars and bilabials. Alveolar and bilabial stops did not show significant and consistent differences. As with VOT values, voiceless stops had longer voicing lag, which was more than twice the duration of the voicing lags of voiced stops on average.[31] One aspect of voicing lag observed in Amharic stops is the fact that initial stops had longer voicing lag than intervocalic stops. A possible explanation for this is that voiceless stops tend to be more aspirated when they come in initial position than when they come in intervocalic position. Cho and Ladefoged (1999) grouped the voiceless velar stops of 18 languages into four categories based on VOT values[32]. Velar stops that had mean VOT of around 30 ms were grouped as unaspirated, those which had mean VOT of around 50 ms were grouped as slightly aspirated, those which had mean VOT of around 90 ms were grouped as aspirated and those which had mean VOT values above that, mainly above 120 or so were grouped as highly aspirated. The mean voicing lag values of Amharic voiceless stops are 36 ms for [**p**], 37 ms for [**t**] and 52 ms for [**k**]. Based on this result, Amharic voiceless stops fall into both the unaspirated ([**p**] and [**t**]) and the slightly aspirated ([**k**]) categories as per the taxonomy of Cho and Ladefoged (1999). Amharic voiceless stops have intermediate values compared to the VOT values of Hindi (Ohala and Ohala 1992). Ohala and Ohala (1992) reported that Hindi aspirated stops had a mean VOT of 84.8 ms whereas unaspirated stops had 19.4 ms. There is no phonological contrast between aspirated and unaspirated stops in Amharic. I hold that phonetically Amharic stops are slightly aspirated. Nevertheless, other acoustic measurements of Amharic voiceless pulmonic stops in different phonetic environments would be required to make a conclusive

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[31] The airstream differences are the same as for VOT values and thus do not need an independent discussion here.

[32] Cho and Ladefoged (1999) actually used VOT to classify voiceless stops. The comparison of their data with the Amharic voicing lag values is raised here because voicing lag is similar to VOT for voiceless stops.

statement on the distribution of aspirated and unaspirated allophones of the voiceless pulmonic stops of Amharic.

The final durational measurement, intensity rise time, differentiated ejectives from pulmonic stops in that vowels following ejectives took shorter time to reach their local peak intensity than the vowels following the voiceless pulmonic stops did. This contradicts with some studies such as the one on Mam by Russel (1997) who reported that vowels following ejectives had longer rise time than vowels following pulmonic stops at dental, velar and uvular places. Wright et al. (2002) also reported a slow rise time for vowels following ejectives than pulmonic stops for Witsuwit'en.[33]

The intensity rise time of vowels following voiced stops was shorter than both those followed by ejectives and voiceless pulmonic stops, showing the effect of voice on intensity rise time as well. This result conforms to the ones found by Munro and Nearey (1988) and Darwin and Pearson (1981) in French. Intensity rise time values were not affected by the place of articulation of the stops in Amharic.

5.2.2 Discussion on the Results of Intensity Measurements

The burst RMS intensity results show that female subjects had louder bursts than male subjects, and initial stops had louder bursts than intervocalic stops. The general pattern of RMS intensity in place comparisons was velar > alveolar > bilabial. Ejective stops came out quite strong, confirming the general pattern of RMS values. The effect of voice was not significant but the effect of airstream was divided between bilabials on one hand and alveolars and velars on the other. At velar and alveolar places, ejectives had louder RMS intensity than voiceless pulmonic stops, but at bilabial place, the ejective had lower RMS intensity than the voiceless pulmonic stop.

The relative burst intensity of the burst compared to the following vowel showed the same results for position comparisons. Initial pulmonic stops had higher relative burst intensity

[33] The method they used in the calculation of the rise time was different from the one used in this study. They measured rise time to the difference in energy between the vowel peak and 30 ms from the vowel onset. They expressed the rise time in dB rather than in ms.

than intervocalic pulmonic stops, but it does not mean that initial pulmonic stops had louder bursts than intervocalic pulmonic stops. Ejective stops had a different pattern at alveolar and velar places: initial ejectives had lower relative burst intensity than intervocalic ejectives.

The bilabials had higher relative burst intensity followed by alveolars and then velars, which means that velars had the loudest burst followed by the alveolars and then bilabials.

Voice did not have a consistent and significant effect on the relative burst intensity values. But, the effect of airstream on relative burst intensity measurements showed significant differences. Among voiceless stops, ejective stops had lower relative burst intensity than voiceless pulmonic stops, showing that ejectives had louder bursts than voiceless pulmonic stops. This was again an expected outcome due to the almost double pressure during the production of ejective stops (Ladefoged and Maddieson 1996).

The absolute rise in intensity of the vowel following Amharic stops was affected by airstream and position only. Vowels following initial stops had a higher increase in intensity than vowels following intervocalic stops did. Nevertheless, the interesting result here is the airstream effect: vowels preceded by ejectives had higher increase in absolute intensity than vowels preceded by voiceless pulmonic stops had.

5.2.3 Discussion on the Burst Spectral Shape

The burst spectral shape was investigated on four parameters: spectral mean, spectral standard deviation, spectral kurtosis and spectral skewness or spectral tilt.

Spectral mean values show that female values were higher than male values. The place effect on spectral mean show that alveolars > bilabials > velars in group patterns, but individual patterns and results across the two voices and airstream mechanisms do not support this. The most consistent results were voiced stops having lower spectral mean than voiceless stops, and ejectives having higher spectral mean than the voiceless and voiced pulmonic stops.

Spectral standard deviation, which is a measure of how diffuse the energy concentration is, did not show any significant effect of place, gender, voice or airstream. The spectral standard deviation as a cue of identifying the place or voice of stops was found to be insignificant in earlier researches as well (Forrest et al. 1980).

Skewness values showed that most of the Amharic stops had positive spectral tilt. The voiceless alveolar stops were the only exception to this finding. The effect of airstream was systematic: ejectives had higher spectral tilt than the voiceless pulmonic stops. Voice also showed a systematic effect in the pulmonic series: voiced pulmonic stops had higher skewness values than voiceless pulmonic stops. Initial stops had higher skewness values than intervocalic stops. The effect of place on skewness values showed that velars had higher skewness followed by bilabials and then alveolars for the voiceless stops, both pulmonic and glottalic. Among all the stops, the voiced alveolar stop had an extraordinary higher skewness values, and this was found to account for place, voice and airstream differences that seemed significant on the GLM univariate analysis of variance.

The kurtosis measurement shows that ejectives had higher kurtosis values than voiceless pulmonic stops. The voiced alveolar stop had an extraordinary higher kurtosis value among all the stops.

5.2.4 Discussion on Results of Voice Measurements

Three F0 measurements were conducted on the vowels following Amharic stops: at the onset of the vowel, at the middle of the vowel and the difference between the onset and the middle of the vowel. The general pattern was that vowels following voiced pulmonic had lower F0 values than those following by voiceless pulmonic stops, and vowels preceded by ejectives had lower F0 than vowels preceded by voiceless pulmonic stops.

For male speakers, vowels followed by the bilabial ejective had higher F0 perturbation and F0 at the onset than vowels followed by the bilabial pulmonic stops. This was quite different from the pattern seen in alveolar and velar places for males and the pattern seen for all the three places for females.

The results on F0 measurements did not conform to the results found in earlier studies in other languages. Wright, Hargus and Davies (2002) found that ejectives were followed by vowels which had lower F0 perturbation for female subjects, but with higher F0 perturbation for males. In the case of Amharic though, higher F0 perturbation was found for males only for one of the three ejective stops, that is [**p’**].

The jitter perturbation values and the jitter values at the onset of the vowels following the stops clearly show that ejectives had higher jitter perturbation than voiceless pulmonic stops. The difference between voiced and voiceless pulmonic stops, however, was not significant and not consistent for all places. These results conform to the results of Wright, Hargus and Davies (2002) who found higher jitter perturbation values for vowels following ejectives than for vowels following voiceless pulmonic stops.

5.2.5 Notes on Amharic Ejective Stops

Amharic ejective stops, compared to the voiceless pulmonic stops, had systematic differences: ejectives had lower percentage of voiced closure in relation to the total closure, longer voiced closure, shorter burst, shorter intensity rise time, lower relative burst intensity, higher absolute intensity, higher spectral mean, higher skewness or spectral tilt, higher kurtosis, lower F0 perturbation and higher jitter perturbation. The bilabial ejective had a somewhat different pattern in some of these measurements: it had lower RMS burst intensity and higher F0 perturbation (specifically for males).

On the basis of the voice measurement values together with the inspection of waveform and spectrogram of the vowels after the ejective stops, it has become clear that Amharic ejective stops were followed by creaky voice. In almost half of the total cases, there was on average a 24 ms clear case of creaky phonation, which resulted in no F0 contour on the analysis window. The jitter perturbation values showed the same results: vowels followed by ejectives had higher jitter perturbation, which, given the spectrographic and waveform displays, is a creaky phonation. The creaky phonation of the vowels after the ejectives was clearly seen from the wave forms which had lower intensity than the modal voiced part, and which sometimes seem to have some form of irregular wave.

An interesting point in the ejectives of Amharic is the occurrence of the glottal release after the oral release. For the alveolar and velar places, 37.03 % (40 of the 108 ejective stop cases) had a mean duration of 25 ms between the oral and glottal release, which was either some kind of irregular wave or a creaky voiced burst. There were more cases of the alveolar ejective stop (43.39% of the total alveolar ejective stop cases) than the velar ejective stop cases (42.57% of the total velar ejective stop cases) which had such duration between the glottal and oral release. The bilabial ejective had a total of 36.17 % percent of the total cases a mean duration of 24 ms between the oral and glottal release. Fig. 5.2a,b show the creaky phonation of vowels following ejectives both in initial and intervocalic positions. Note the lower F0 and low intensity wave forms at the beginning of the vowel.

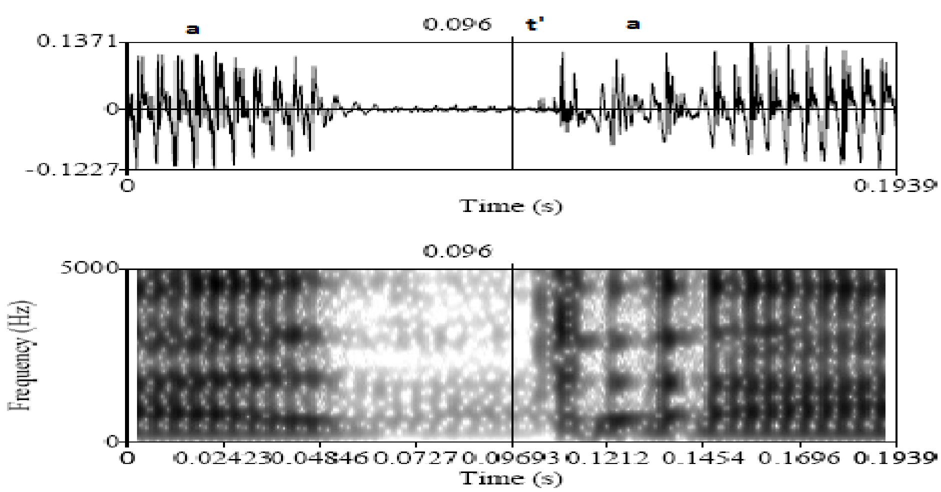

Fig. 5.2a: Waveform, spectrogram and pitch contour of ***/at'a/*** excised from the word ***/at'ana/*** 'log of wood' spoken by a female speaker.

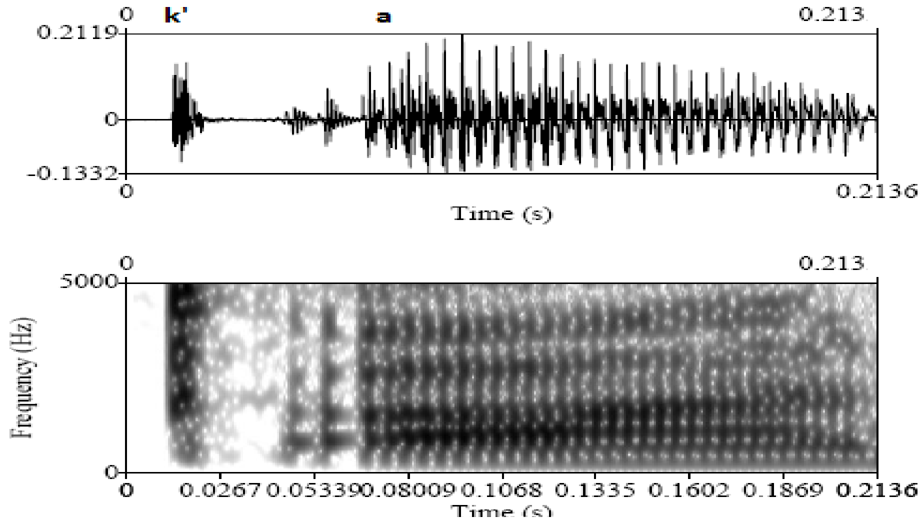

Fig. 5.2b: Waveform, spectrogram and pitch contour of **/k'a/** excised from the word **/k'ana/** 'taste' spoken by a female speaker.

5.2.5 Notes on the Typology of Amharic Stops

The stops of Amharic are among the universally preferred segments. The stops /**p t k**/[34] are found in Amharic along with their voiced counterparts. The total number of stops in Amharic is 13, which is beyond the preferred number, which is between 4 and 8 (Nartey 1979). The number of voiceless stops in Amharic is clearly greater than the number of voiced stops as there are only three voiced and seven voiceless stops.

Amharic stops do not use aspiration phonemically. Compared to what is heard in languages that contrast aspirated and unaspirated stops, Amharic stops create the impression that they are aspirated, but durational measurements showed that they are only slightly aspirated, but certainly not aspirated in the sense of languages such as Hindi.

The question of typology of Amharic ejectives based on the data needs a further look in this section. Based on the typology of Lindau (1984) and Kingston (1985), ejectives could be grouped into slack or stiff. Stiff ejectives have, among other things, intense burst, long VOT, higher F0 and fast (short) intensity rise time, and modal or tense phonation (the last three

[34] It should be noted here that the voiceless pulmonic stop /**p**/ is a phoneme found only in loan words, and that replacing this phoneme with /**b**/ or /**f**/ results only in somewhat deformed pronunciation (even so only for the Amharic speaking urban dwellers).

on the following vowel). Slack ejectives have normal burst, short VOT, lower F0 and slow (longer) intensity rise time and creaky phonation (the last three on the following vowel).

Table 5.2: Mean VOT and intensity rise time of ejectives and vowels following ejectives. Standard deviation values are indicated in brackets.

Sound	VOT	Rise Time in ms
p'	33.89 (22.14)	37.58 (15.29)
t’	50.62 (26.57)	34.72 (17.59)
k'	66.00 (22.73)	35.93 (16.23)
Total	50.17 (23.81)	37.58 (16.37)

Amharic ejective stops had intermediate VOT, normal burst, and lower F0 perturbation, the last one on the following vowel. They had, however, shorter rise time. VOT values suggest that Amharic has an intermediate value, which is the same as that of Inguish (Warner 1996), a language which has the properties of slack and stiff ejectives. Though Amharic ejectives had louder burst than their pulmonic counterparts, the difference was on average 2 dB, which shows the burst was normal. The most common acoustic cue that separated Amharic ejectives from pulmonic stops was the creaky phonation on the onset of vowel following ejectives. This was seen on stops produced by all subjects. The discriminant analysis showed that F0 perturbation, which was the manifestation of the creaky phonation, was the most discriminating acoustic cue for airstream compared to the other variables. As a result, Amharic ejective stops seem to be more of the slack kind of ejectives than stiff ones.

5.3 Summary

F0, F1, F2 and F3 values of Amharic vowels have been computed, both by gender and individual subjects. F1-F2 plots of Amharic vowels have been provided in the previous chapter. Based on the results, a new vowel chart has been proposed and the cause of the difference in this vowel chart and earlier charts of Amharic is explained as a vowel shift in progress. The implications of the new vowel chart for the phonological universals have been pointed out.

It was found that F1 and F2 alone can discriminate between Amharic vowels with up to 86.7 % of correct classification for both genders, and F2 had a higher contribution to the classification (more than 80 % of the difference in variance was due to F2). When the classification was conducted by gender, the correct classification results rose up to 93 %. The addition of F0 and F3 values in the discriminant analysis increased the classification rate to 90 % for all subjects collapsed across genders. By gender, 94.8 % of males' vowels and 91.6 % females' vowels were classified correctly. These results showed that even if there are clear differences in formant and F0 values between male and female subjects, the classification results disregarding gender differences were very high, and the contribution of gender differences did not come out strong.

The classification results of each vowel had different patterns for male and female speakers. For male speakers, the back vowels had higher classification results but for female speakers it was the front vowels that had higher classification results. Also female speakers' [**u**] was classified with the lowest correct results whereas males' [**a**] was classified with the lowest correct results, showing a contrast of high and low vowels between female and male speakers' vowels.

The results showed that the vowels [**a**] and [**o**] had longer durations whereas the vowels [**ɘ**] and [**u**] had shorter durations. All vowels had shorter durations when they came before voiceless stops whereas they had longer durations when they came before voiced stops. The vowels also had shorter duration when they came before geminate obstruents than when they came before nongeminate consonants. Comparing genders, it was found that the vowels of females had longer durations than the vowels of males. The effect of position on vowel duration showed that vowels in a wordlist had longer durations than vowels in a carrier phrase.

The results of the analysis of pulmonic and ejective stops showed that the difference in place of articulation can be captured with the following acoustic cues: total duration, burst duration, VOT, RMS intensity of the stop burst and relative intensity of the burst to the following vowel. The discriminant analysis conducted using the variables that were measured for all the stops showed that burst duration and relative intensity came out strong in classifying stops by place of articulation. Bilabials had the highest classification results followed by velars and alveolars had the least classification results. Of the four major variables that were used in the discriminant analysis, three of them, i.e. burst duration, relative intensity and VOT showed higher classification results for the stops recorded from female speakers than those of the male speakers. Concerning gender differences, only RMS intensity showed higher classification results for the stops of male speakers than for the stops of female speakers.

The variables which were affected by voice were total duration, percentage of voiced closure, duration of the voiceless closure, VOT, voicing lag, burst duration, rise time and spectral mean. The discriminant analysis using the variables measured for all the stops showed that VOT, voicing lag and spectral mean were the most important acoustic cues that classified voiced stops, with a correct classification result of 94.9 %; and voiceless stops, up to 89 %. VOT cues alone were able to classify 81.4 % of the stops correctly. The classification results of voiced and voiceless stops showed differences due to gender: the voiced stops of females and the voiceless stops of males had higher classification results than their counterparts.

The acoustic cues that were affected by airstream were burst duration, voicing lag, relative intensity, spectral mean, absolute intensity, jitter perturbation, percentage of voiced closure and the voiceless portion of the closure. All but the last two variables were used in the discriminant analysis and jitter perturbation, spectral mean and voicing lag came out as relatively stronger acoustic cues that identified airstream. However, the classification results did not clearly show that these parameters can be used to effectively classify Amharic stops into pulmonic and ejective. During the analysis, it was noted that close to half of the vowels after ejectives had a clear case of creaky voice onset that exceeds 10 ms and the creaky voiced part of the vowel had a mean duration of 23 ms. Though the measurements did not succeed in classifying ejectives and pulmonic stops with a high percentage of correct classification, it was found that Amharic ejectives result in a creaky phonation of the following vowel.

Amharic ejectives have two bursts, oral and glottal, occurring one after the other, differing in few tens of milliseconds. It has been discussed that Amharic ejectives can be categorized as slack ejectives as they exhibit most of the properties of slack ejectives.

The measurements conducted on Amharic stops did not tell much about the nature of aspiration of Amharic voiceless pulmonic stops. Voicing lag results showed that Amharic voiceless pulmonic stops could be unaspirated or slightly aspirated, but the difference in voicing lag values indicated a front-back distinction rather than a distinction between aspirated and unaspirated stops.

5.4 Future Directions

This study is just the beginning of a systematic phonetic study of Amharic phonetics in recent times. Due to financial and time constraints a lot of issues remained untouched or not covered in depth.

The central vowels of Amharic have always been the interest of linguists, and this study has come up with one more issue regarding them: the height of Amharic central vowels. There is a need to conduct a larger regional and social dialect survey on Amharic vowels to see the acoustic space these vowels take in the different regional and social dialects and investigate extent of the vowel shift that is proposed by this study.

One issue that arises from this study is the lead and lag VOT of Amharic stops. The present study is not enough to conclude once and for all that Amharic stops have either lead or lag or both types of VOT. Data from a larger group of speakers and from different regional varieties should be collected and different phonetic environments should be considered.

Another issue that needs attention is the quantification of the acoustic cues of ejectives. Ejectives in Amharic posed a problem in the analysis as the acoustic cues investigated could not stand out like the cues that identified place and voice, especially in the discriminant analysis. It was clear that if a vowel after an Amharic stop (except a glottal stop) has a creaky phonation at the onset, then, it is preceded by an ejective stop. The glottal stop, though not part of this study, was observed to have the same effect as the ejective stop. Thus, aerodynamic parameters and other acoustic measurements should be considered in the search for better objective parameters to set apart ejective stops from pulmonic stops on one hand and ejective stops from the glottal stop on the other hand. A method that combines the visible creaky phonation with additional phonation measures will give the best results in separating ejective stops from pulmonic stops.

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Appendix I: Mean and SD values of F1, F2, F3 and F0 for Amharic vowels in /t V t/ context: individual results. The group values for male and female are given as totals of each group for each vowel.

Vowel	Gender	Subject		F1	F2	F3	F0
ɜ	Female	W1	Mean	670.19	2052.06	3033.00	221.0625
			SD	56.459	179.797	80.869	5.97181
		W2	Mean	635.38	1933.69	3109.25	234.3750
			SD	51.757	57.946	109.436	9.74936
		W3	Mean	719.19	1943.06	2856.50	231.7500
			SD	33.082	42.388	177.542	10.17513
		W4	Mean	612.07	1964.27	3013.67	214.5625
			SD	38.233	66.507	100.885	10.80721
		Total	Mean	659.95	1973.41	3002.94	225.4375
			SD	60.476	111.033	152.039	12.20184
	Male	M1	Mean	489.56	1606.25	2496.12	108.8125
			SD	34.993	66.171	63.158	6.90139
		M2	Mean	500.63	1584.69	2730.81	117.6000
			SD	30.690	63.475	100.856	6.09215
		M3	Mean	512.75	1677.88	2598.19	111.0000
			SD	34.228	34.968	70.274	8.88444
		M4	Mean	572.19	1572.69	2352.31	120.7500
			SD	28.720	39.853	70.019	7.69848
		Total	Mean	518.78	1610.37	2544.36	114.4921
			SD	45.003	66.037	158.863	8.78942
ə	Female	W1	Mean	435.38	2029.38	3033.00	231.1250
			SD	21.682	103.570	77.179	9.90539
		W2	Mean	459.69	2004.75	2986.06	233.1250
			SD	16.136	69.556	51.608	8.36560
		W3	Mean	477.44	1967.12	2916.06	239.3125
			SD	14.081	79.957	64.439	7.91386
		W4	Mean	428.00	1916.93	3071.50	229.2000
			SD	37.497	75.875	56.326	8.00179
		Total	Mean	450.84	1981.56	2999.40	233.2540
			SD	30.275	91.545	84.702	9.21424
	Male	M1	Mean	374.87	1677.88	2521.94	104.9333
			SD	25.537	52.547	137.032	5.79984
		M2	Mean	369.25	1704.87	2639.75	123.6667
			SD	26.837	97.873	74.781	5.82687
		M3	Mean	383.69	1729.12	2563.06	115.5000
			SD	17.036	56.500	64.428	11.50652
		M4	Mean	391.44	1831.56	2525.00	123.3750
		Total	Mean	379.81	1735.86	2562.44	116.9516
			SD	25.453	96.330	113.900	10.80593
a	Female	W1	Mean	793.94	1664.13	2995.25	220.6875
			SD	59.818	86.274	96.311	5.58234

		W2	Mean	749.37	1596.44	2864.06	237.6250
			SD	48.755	69.513	204.357	17.34311
		W3	Mean	797.81	1583.88	2775.88	220.4375
			SD	30.087	60.229	102.714	9.20122
		W4	Mean	740.50	1594.75	2834.69	208.8125
			SD	60.061	86.089	393.023	9.44612
		Total	Mean	770.41	1609.80	2867.47	221.8906
			SD	56.242	81.080	240.821	15.08822
	Male	M1	Mean	600.69	1313.88	2218.31	101.0625
			SD	28.521	64.766	148.959	7.19693
		M2	Mean	596.37	1334.75	2496.88	114.6875
			SD	38.495	62.291	108.663	4.62916
		M3	Mean	589.88	1518.44	2502.81	109.4375
			SD	48.665	67.717	76.743	9.75684
		M4	Mean	704.56	1370.50	2376.25	119.2000
			SD	42.420	51.302	99.263	11.58324
		Total	Mean	622.88	1384.39	2398.56	110.9683
			SD	61.753	100.708	159.485	10.81362
	Male	M1	Mean	365.62	2060.88	2691.75	109.3125
			SD	24.177	61.933	209.964	8.73093
		M2	Mean	357.44	1994.44	2791.69	117.5000
			SD	31.661	88.909	146.187	5.18973
		M3	Mean	396.44	2065.50	2645.44	113.0625
			SD	35.268	90.896	64.659	11.03007
		M4	Mean	398.88	2204.56	2919.25	119.5000
			SD	27.997	141.133	118.989	7.32120
		Total	Mean	379.59	2081.34	2762.03	114.8437
			SD	34.660	124.295	176.519	9.06453
i	Female	W1	Mean	323.38	2592.06	3074.75	230.3125
			SD	30.852	117.405	184.403	6.85778
		W2	Mean	324.62	2665.62	3431.75	236.6250
			SD	15.824	52.160	80.999	14.04695
		W3	Mean	351.07	2563.60	3261.40	247.9375
			SD	28.779	70.232	122.387	6.29782
		W4	Mean	350.64	2565.36	3324.21	224.0000
			SD	26.812	71.122	152.979	9.52890
		Total	Mean	336.77	2598.23	3271.54	234.7188
			SD	28.857	90.257	191.185	12.98652
	Male	M1	Mean	277.81	2197.06	2781.69	106.2500
			SD	17.657	177.911	149.229	5.13160
		M2	Mean	313.50	2090.44	2968.38	121.2500
			SD	22.666	61.519	164.021	6.64831
		M3	Mean	280.69	2170.31	2560.75	115.2000
			SD	15.252	79.655	154.776	10.15030
		M4	Mean	307.62	2308.62	3253.06	122.5333
			SD	19.473	121.945	98.250	7.60514

		Total	Mean	294.91	2191.61	2890.97	116.2258
			SD	24.427	140.316	291.987	9.85039
o	Female	W1	Mean	419.12	1085.19	2929.81	227.1250
			SD	14.687	79.343	66.014	6.60177
		W2	Mean	456.75	1208.12	2765.62	232.9375
			SD	15.186	79.263	48.357	10.37605
		W3	Mean	469.94	1168.00	2741.69	233.8125
			SD	12.315	103.210	82.750	8.62723
		W4	Mean	444.67	1305.13	2768.13	224.4375
			SD	13.829	84.187	197.666	8.97380
		Total	Mean	447.67	1189.81	2801.84	229.5781
			SD	23.442	116.070	133.689	9.41091
	Male	M1	Mean	388.69	1048.94	2333.00	105.4375
			SD	18.456	102.863	69.738	6.67302
		M2	Mean	427.13	1084.06	2380.38	120.5000
			SD	18.970	68.340	89.178	5.00666
		M3	Mean	423.50	1127.12	2406.00	114.1333
			SD	30.596	77.059	107.555	11.50693
		M4	Mean	469.06	980.69	2193.31	119.3750
			SD	22.113	70.789	194.651	7.90675
		Total	Mean	427.09	1060.20	2328.17	114.8730
			SD	36.487	95.698	147.249	9.91820
u	Female	W1	Mean	354.12	1195.62	2909.62	236.1250
			SD	33.745	76.465	207.413	2.79987
		W2	Mean	390.62	1499.69	2770.94	231.8750
			SD	18.832	140.472	45.251	11.71822
		W3	Mean	399.93	1587.67	2819.53	241.1250
			SD	33.739	262.594	195.257	10.34005
		W4	Mean	394.75	1776.00	2611.75	222.8000
			SD	18.706	83.476	248.723	12.55919
		Total	Mean	388.09	1523.04	2782.96	233.7000
			SD	30.740	246.363	191.328	12.21282
	Male	M1	Mean	317.19	1406.25	2495.12	100.8182
			SD	23.410	196.751	207.547	8.87489
		M2	Mean	346.44	1178.31	2334.56	119.5714
			SD	13.411	126.687	53.748	5.48725
		M3	Mean	307.62	1392.62	2458.31	113.5385
			SD	20.192	154.069	69.209	10.79055
		M4	Mean	325.56	1219.31	2375.44	122.1667
			SD	24.620	161.813	214.389	7.43252
		Total	Mean	324.20	1299.12	2415.86	114.5000
			SD	24.960	188.105	164.848	11.35737

Appendix II: Mean and SD values of durational measurements: individual results. Group results based on gender given as total for each stop.

Sound	gender	Subject		Total duration in ms	Voiced Closure in ms	VOT	Voicing Lag in ms	Rise Time in ms
b	F	F1	Mean	Not measured in intervocalic position	Not measured in intervocalic position	15.17	15.17	32.50
			SD			1.941	1.941	11.041
		F2	Mean			-13.17	12.00	17.83
			SD			38.270	1.673	2.927
		F3	Mean			-20.20	26.40	34.80
			SD			45.268	31.126	18.992
		F4	Mean			2.75	13.00	24.25
			SD			20.565	2.000	4.113
		Total	Mean			-3.71	16.70	27.29
			SD			32.410	15.516	12.578
	M	M1	Mean			-2.00	20.83	25.67
			SD			35.372	5.115	8.238
		M2	Mean			22.50	22.50	32.00
			SD			9.849	9.849	12.675
		M3	Mean			-70.33	21.00	28.33
			SD			13.736	10.271	10.801
		M4	Mean			13.00	20.20	27.00
			SD			19.849	8.786	7.211
		Total	Mean			-13.29	21.05	27.95
			SD			43.551	7.830	9.260
d	F	F1	Mean	87.38	60.00	16.00	16.29	29.86
			SD	5.344	10.784	4.050	3.074	7.892
		F2	Mean	81.37	62.62	14.20	15.21	24.71
			SD	9.117	7.981	2.168	3.191	6.944
		F3	Mean	79.50	52.63	12.17	15.29	25.29
			SD	6.782	8.618	4.665	4.762	6.402
		F4	Mean	80.50	51.86	16.83	18.83	29.29
			SD	7.969	8.112	3.601	4.260	9.351
		Total	Mean	82.30	56.94	14.83	16.31	27.29
			SD	7.693	9.726	3.996	4.023	7.866
	M	M1	Mean	71.71	49.25	17.17	16.62	31.64
			SD	6.157	7.760	3.971	5.424	9.989
		M2	Mean	68.25	40.75	17.00	24.33	32.50
			SD	22.381	9.910	28.991	10.886	8.847
		M3	Mean	59.75	39.38	-11.67	17.40	27.86
			SD	12.093	6.886	30.787	4.971	8.592
		M4	Mean	49.00	30.88	18.17	16.60	30.14
			SD	5.944	4.794	8.256	6.883	11.999
		Total	Mean	63.68	40.06	9.87	18.45	30.54
			SD	14.403	9.771	23.636	7.571	9.835

g	F	F1	Mean	71.75	45.62	22.17	23.21	33.64
			SD	10.416	9.039	5.269	5.366	6.979
		F2	Mean	86.71	57.00	20.17	22.54	28.62
			SD	5.619	10.263	5.115	5.348	5.767
		F3	Mean	66.14	44.00	12.60	21.75	23.54
			SD	5.872	5.451	27.916	5.413	11.537
		F4	Mean	85.75	63.12	23.00	22.79	26.29
			SD	7.741	5.566	4.000	5.659	11.276
		Total	Mean	77.67	52.29	19.78	22.60	28.09
			SD	11.568	10.998	13.180	5.318	9.744
	M	M1	Mean	62.80	34.83	29.40	25.30	33.36
			SD	8.526	6.178	10.714	10.264	18.024
		M2	Mean	88.00	47.20	24.40	28.12	39.00
			SD	8.660	9.834	3.782	7.279	23.903
		M3	Mean	58.60	29.17	-30.83	22.82	38.75
			SD	3.286	7.731	43.751	6.838	13.686
		M4	Mean	62.50	30.50	9.17	24.30	32.00
			SD	4.041	9.815	31.378	7.334	9.165
		Total	Mean	65.94	35.33	6.32	24.92	35.86
			SD	12.142	10.471	36.279	7.958	16.636
k	F	F1	Mean	133.50	65.20	54.67	55.00	45.33
			SD	8.849	16.634	13.261	9.658	13.500
		F2	Mean	157.62	59.62	75.33	76.93	42.07
			SD	11.057	26.098	9.416	8.194	10.262
		F3	Mean	105.50	57.37	64.33	50.79	53.64
			SD	10.954	8.450	11.147	16.989	12.894
		F4	Mean	116.75	75.12	48.83	44.71	41.50
			SD	9.706	5.027	12.797	11.235	15.820
		Total	Mean	128.00	64.24	60.79	56.93	45.65
			SD	22.752	16.957	15.022	17.131	13.808
	M	M1	Mean	114.12	49.29	52.20	52.15	47.38
			SD	16.470	14.975	16.100	14.656	14.315
		M2	Mean	94.38	41.86	55.20	43.00	46.92
			SD	16.230	16.985	10.450	15.362	23.595
		M3	Mean	76.88	21.80	69.83	50.50	42.64
			SD	6.312	9.576	11.321	19.374	14.102
		M4	Mean	106.62	27.40	54.50	49.43	40.43
			SD	8.052	14.775	13.081	12.829	7.552
		Total	Mean	98.00	36.83	58.32	48.81	44.24
			SD	18.688	17.636	13.954	15.697	15.618
k'	F	F1	Mean	122.00	44.67	85.00	66.77	33.67
			SD	23.629	32.593	17.274	24.994	11.873
		F2	Mean	115.63	33.86	89.33	65.00	23.56
			SD	10.623	11.276	18.261	26.568	9.632

		F3	Mean	85.50	38.00	58.17	44.07	39.22
			SD	6.256	14.560	7.935	14.600	13.709
		F4	Mean	121.43	74.86	52.00	48.69	34.77
			SD	5.127	3.485	21.964	15.348	15.303
		Total	Mean	110.43	47.96	71.12	56.07	33.05
			SD	19.951	22.105	23.062	22.819	13.631
	M	M1	Mean	89.14	37.50	55.17	42.85	44.08
			SD	7.426	12.911	17.105	16.582	17.085
		M2	Mean	81.86	38.75	57.67	45.77	44.25
			SD	21.606	12.121	26.258	21.680	28.175
		M3	Mean	64.33	29.00	76.83	49.25	31.17
			SD	8.335	14.799	11.754	30.127	8.758
		M4	Mean	85.25	39.00	53.83	39.36	34.79
			SD	9.239	16.763	24.935	20.406	10.312
		Total	Mean	80.89	37.00	60.88	44.12	38.42
			SD	15.344	13.826	21.662	22.152	17.944
p	F	F1	Mean	Not measured in intervocalic position	Not measured in intervocalic position	39.83	39.83	48.83
			SD			11.703	11.703	12.222
		F2	Mean			60.33	60.33	30.40
			SD			9.288	9.288	19.139
		F3	Mean			25.17	25.17	45.33
			SD			3.371	3.371	21.860
		F4	Mean			33.17	33.17	49.33
			SD			7.834	7.834	14.067
		Total	Mean			39.63	39.63	44.04
			SD			15.545	15.545	17.629
	M	M1	Mean			36.17	36.17	51.80
			SD			19.260	19.260	6.648
		M2	Mean			35.17	35.17	47.50
			SD			19.250	19.250	13.172
		M3	Mean			21.17	21.17	37.00
			SD			5.742	5.742	9.778
		M4	Mean			43.00	43.00	38.50
			SD			13.957	13.957	8.019
		Total	Mean			33.88	33.88	43.35
			SD			16.625	16.625	11.052
p'	F	F1	Mean	Not measured in intervocalic position	Not measured in intervocalic position	52.67	52.67	27.50
			SD			26.417	26.417	9.268
		F2	Mean			42.67	42.67	26.83
			SD			24.985	24.985	15.158
		F3	Mean			15.00	15.00	32.00
			SD			10.020	10.020	9.618
		F4	Mean			20.17	20.17	38.67
			SD			13.045	13.045	13.231

		Total	Mean			32.62	32.62	31.22
			SD			24.471	24.471	12.354
	M	M1	Mean			39.33	39.33	45.50
			SD			24.312	24.312	11.726
		M2	Mean			28.67	28.67	50.83
			SD			20.868	20.868	17.394
		M3	Mean			41.17	41.17	26.20
			SD			22.239	22.239	8.786
		M4	Mean			31.50	31.50	50.33
			SD			13.693	13.693	11.605
		Total	Mean			35.17	35.17	43.96
			SD			19.997	19.997	15.523
t	F	F1	Mean	96.83	61.67	44.00	39.58	49.00
			SD	12.766	11.690	12.198	11.333	10.117
		F2	Mean	108.62	52.00	51.50	46.79	38.21
			SD	5.927	21.554	5.992	6.727	10.800
		F3	Mean	83.12	41.88	43.20	34.92	48.77
			SD	9.920	15.487	8.228	10.874	15.744
		F4	Mean	94.60	70.00	20.17	20.00	53.64
			SD	6.542	8.246	2.927	3.376	27.303
		Total	Mean	95.85	54.48	39.57	36.08	46.94
			SD	13.208	18.314	14.355	12.895	17.335
	M	M1	Mean	75.57	30.00	49.22	42.44	63.12
			SD	13.915	9.899	16.323	14.882	23.272
		M2	Mean	86.17	36.00	43.50	41.25	47.00
			SD	14.525	13.077	23.450	16.799	24.279
		M3	Mean	63.88	24.40	43.17	32.79	50.50
			SD	6.792	10.644	20.634	16.461	20.338
		M4	Mean	74.57	34.75	39.00	35.15	48.62
			SD	11.118	5.058	27.144	19.065	15.403
		Total	Mean	74.25	30.64	44.33	38.00	52.96
			SD	13.618	10.074	20.655	16.798	21.620
t'	F	F1	Mean	128.14	52.40	78.67	67.62	30.89
			SD	25.777	23.734	20.781	24.554	15.120
		F2	Mean	106.71	50.00	81.50	61.46	19.14
			SD	28.224	11.662	18.064	28.617	9.720
		F3	Mean	77.75	47.29	38.50	28.86	38.11
			SD	6.819	6.473	20.491	16.057	9.584
		F4	Mean	97.62	67.75	32.00	30.07	26.79
			SD	9.753	9.223	13.145	10.802	11.885
		Total	Mean	101.57	55.00	57.67	46.35	28.97
			SD	25.964	14.990	28.715	27.047	13.074
	M	M1	Mean	72.88	38.20	45.67	29.36	39.18
			SD	11.103	7.014	20.551	14.299	21.032

		M2	Mean	73.57	26.00	33.83	32.00	50.92
			SD	6.188	22.627	14.428	9.933	22.092
		M3	Mean	57.71	31.75	51.67	32.31	25.77
			SD	6.897	9.287	32.284	28.010	6.559
		M4	Mean	72.38	43.00	40.67	27.29	40.50
			SD	13.060	14.612	16.990	16.740	17.150
		Total	Mean	69.37	36.56	42.57	30.22	39.12
			SD	11.473	12.538	21.846	18.173	19.378
Total	F	F1	Mean	104.90	55.34	45.35	42.51	36.88
			SD	27.884	16.798	27.703	25.062	12.972
		F2	Mean	110.00	52.89	47.49	46.37	29.64
			SD	28.395	18.164	36.786	27.472	12.417
		F3	Mean	83.28	46.85	28.59	30.96	38.03
			SD	14.035	12.056	30.278	17.823	16.674
		F4	Mean	100.17	67.09	28.62	30.15	35.43
			SD	17.069	10.309	18.359	14.848	17.380
		Total	Mean	99.36	55.32	37.68	37.61	35.02
			SD	24.755	16.292	30.217	23.044	15.334
	M	M1	Mean	82.50	41.88	35.83	34.94	43.43
			SD	20.311	11.893	25.639	17.962	19.650
		M2	Mean	82.77	40.34	36.04	35.50	43.67
			SD	17.365	13.135	22.349	16.853	21.369
		M3	Mean	64.42	30.16	21.22	33.86	35.32
			SD	9.769	10.586	51.976	22.231	14.772
		M4	Mean	79.03	34.33	34.04	33.03	38.15
			SD	19.693	12.328	24.445	17.675	13.434
		Total	Mean	77.22	36.71	31.63	34.31	40.07
			SD	18.793	12.765	34.034	18.769	17.826

Appendix III: Mean and SD values of intensity measurements: individual results. Group results based on gender given as total for each stop.

Sound	Gender	Subject		Peak Intensity-Onset Intensity in dB	RMS Intensity in dB	Relative Burst Intensity in dB
b	Female	W1	Mean	19.2525	27.5475	76.3783
			SD	2.30939	3.24307	2.96293
		W2	Mean	21.8000	18.6217	70.5100
			SD	3.33493	3.83960	1.13081
		W3	Mean	16.2300	19.8333	70.1140
			SD	3.44632	1.10889	1.10378
		W4	Mean	20.2133	18.7433	73.8925
			SD	5.23886	6.70326	2.21518
		Total	Mean	19.8213	21.1031	72.7367
			SD	3.77883	5.30535	3.30860
	Male	M1	Mean	15.6920	18.1260	72.7583
			SD	3.70251	4.48959	3.64925
		M2	Mean	14.9500	25.5900	73.7975
			SD	1.65774	5.51952	1.05256
		M3	Mean	16.1367	22.4700	73.4950
			SD	3.14047	2.15126	3.56401
		M4	Mean	18.1033	23.4217	76.5760
			SD	3.83961	2.70560	1.29131
		Total	Mean	16.4906	22.0788	74.0757
			SD	3.35465	4.42860	3.03391
d	Female	W1	Mean	22.4593	14.1171	72.3993
			SD	2.85219	3.47878	4.42608
		W2	Mean	24.8136	11.9207	72.5936
			SD	3.08790	2.27750	1.42630
		W3	Mean	22.2157	14.1285	71.3629
			SD	2.64090	4.40119	2.42347
		W4	Mean	21.7014	14.9777	71.3421
			SD	3.71699	4.34841	1.84508
		Total	Mean	22.7975	13.7576	71.9245
			SD	3.24751	3.77253	2.76443
	Male	M1	Mean	21.2862	14.6462	71.9871
			SD	4.36311	3.87440	3.70849
		M2	Mean	16.5008	17.6525	72.8850
			SD	2.30924	3.41755	1.87662
		M3	Mean	18.3869	15.5792	74.1614
			SD	2.69891	1.98734	1.85011
		M4	Mean	19.2100	18.0338	73.5393
			SD	2.74390	2.61467	1.52308

		Total	Mean	18.8920	16.4549	73.1432
			SD	3.50033	3.28682	2.47011
g	Female	W1	Mean	20.0321	14.2771	72.6607
			SD	4.11728	3.38123	5.01506
		W2	Mean	25.9550	13.9314	72.5500
			SD	3.06981	4.24210	.98718
		W3	Mean	20.0615	15.2738	70.6846
			SD	2.86714	2.18593	1.48421
		W4	Mean	21.8343	11.1893	70.7279
			SD	2.35598	3.05200	2.02983
		Total	Mean	22.0055	13.6387	71.6572
			SD	3.93494	3.56593	2.96998
	Male	M1	Mean	21.1867	13.4475	72.3827
			SD	3.87494	3.55192	3.53488
		M2	Mean	19.8988	20.0100	73.2590
			SD	3.53625	4.41235	2.59983
		M3	Mean	18.6442	18.8300	75.8708
			SD	4.96247	3.40865	3.17514
		M4	Mean	20.1010	19.4289	73.8680
			SD	3.09269	3.68946	2.96868
		Total	Mean	19.9564	17.4936	73.9053
			SD	3.97779	4.47922	3.28072
k	Female	W1	Mean	20.9057	12.9879	73.4667
			SD	2.59471	4.77877	5.37684
		W2	Mean	25.2293	12.6136	69.5871
			SD	4.01324	2.76718	1.34688
		W3	Mean	20.5643	13.9636	70.5257
			SD	3.07557	4.12819	1.40351
		W4	Mean	20.6986	12.7500	69.4436
			SD	2.86035	3.88807	3.10176
		Total	Mean	21.8495	13.0788	70.6554
			SD	3.66877	3.88495	3.43096
	Male	M1	Mean	21.0821	14.2271	70.5300
			SD	2.80153	3.67667	4.39742
		M2	Mean	19.1817	17.3775	72.2723
			SD	2.79853	3.29640	1.72692
		M3	Mean	19.5750	15.3271	72.3071
			SD	2.48555	4.52018	2.58170
		M4	Mean	19.6314	15.9657	73.7407
			SD	3.86323	4.76275	1.85798
		Total	Mean	19.8930	15.6631	72.2749
			SD	3.04295	4.17261	2.93078
k'	Female	W1	Mean	28.7164	5.3557	74.6392
			SD	5.10382	3.72828	3.42596

		W2	Mean	28.8957	3.1971	70.9000
			SD	6.87985	3.34108	1.28508
		W3	Mean	22.9779	8.1964	70.2862
			SD	3.76235	3.30435	2.62277
		W4	Mean	25.9593	5.8664	69.7083
			SD	2.47540	3.12566	1.67497
		Total	Mean	26.6373	5.6539	71.5259
			SD	5.29747	3.74566	3.13491
	Male	M1	Mean	24.3277	10.8362	73.1217
			SD	4.07484	4.10319	3.61511
		M2	Mean	20.2675	18.1367	72.4508
			SD	4.77080	5.80803	2.13594
		M3	Mean	22.3015	13.7577	73.0475
			SD	4.57755	5.76929	3.26205
		M4	Mean	20.2300	18.5843	74.5736
			SD	2.97720	3.11609	2.22726
		Total	Mean	21.7810	15.3373	73.3494
			SD	4.35056	5.66414	2.88511
p	Female	W1	Mean	21.1517	21.5717	75.5633
			SD	.71253	2.87446	3.44029
		W2	Mean	22.6617	15.8567	69.0700
			SD	2.03355	3.63633	1.07098
		W3	Mean	14.8300	28.2025	69.7033
			SD	3.14631	1.48161	6.68101
		W4	Mean	20.9100	20.8850	73.8667
			SD	4.96508	1.61579	.93189
		Total	Mean	20.2920	21.0460	72.1804
			SD	3.87880	5.07856	4.58358
	Male	M1	Mean	17.6367	21.3833	74.1575
			SD	1.35208	1.51533	2.68109
		M2	Mean	17.4950	24.3350	73.3033
			SD	2.92250	7.00965	2.42494
		M3	Mean	11.1500	17.1480	73.3867
			SD	2.30383	3.78649	3.27249
		M4	Mean	20.9883	24.3567	74.9133
			SD	3.55376	5.48883	1.37207
		Total	Mean	16.9780	22.1020	73.9205
			SD	4.58813	5.81710	2.43055
p'	Female	W1	Mean	19.6133	20.1450	75.1800
			SD	3.66107	3.98625	2.43830
		W2	Mean	22.5217	14.0283	69.0283
			SD	4.61145	1.38122	2.80771
		W3	Mean	17.2200	19.1775	68.4140
			SD	4.46458	3.35023	1.80702

		W4	Mean	20.5950	22.0700	73.1467
			SD	3.54260	.73539	1.92316
		Total	Mean	20.1600	18.1050	71.5739
			SD	4.31075	4.08679	3.58257
	Male	M1	Mean	16.2867	20.3350	74.1733
			SD	4.18088	3.43809	3.71625
		M2	Mean	12.0350	23.9650	72.8550
			SD	2.00111	3.81131	2.92978
		M3	Mean	13.3000	16.8317	74.0020
			SD	2.35117	4.67958	1.57673
		M4	Mean	20.2617	22.5317	74.6133
			SD	3.11078	5.12865	2.75889
		Total	Mean	16.1580	20.3060	73.9070
			SD	4.30162	4.83172	2.78042
t	Female	W1	Mean	22.8438	16.2031	72.5258
			SD	3.33668	3.75857	4.71426
		W2	Mean	23.8900	12.3462	69.6677
			SD	3.11712	3.11345	1.75158
		W3	Mean	17.6236	15.1086	70.0900
			SD	3.01682	3.04677	1.31816
		W4	Mean	19.3036	19.3236	69.9664
			SD	2.06226	5.21380	2.78884
		Total	Mean	20.9139	15.5925	70.5467
			SD	3.88509	4.41955	3.03924
	Male	M1	Mean	21.5800	15.7164	72.1750
			SD	2.68821	5.07515	4.75007
		M2	Mean	17.3173	23.9927	71.9033
			SD	2.52554	4.65553	2.26408
		M3	Mean	18.3407	18.7350	71.8907
			SD	3.37014	2.07450	3.71543
		M4	Mean	17.7743	20.3636	74.3254
			SD	1.58083	3.36992	1.91674
		Total	Mean	18.8343	19.4591	72.5516
			SD	3.06302	4.79614	3.52952
t'	Female	W1	Mean	27.0864	14.7050	73.7800
			SD	4.55637	4.84388	3.84734
		W2	Mean	27.1575	9.6833	69.8814
			SD	4.71429	4.38038	3.01187
		W3	Mean	18.5614	11.9914	68.3222
			SD	4.61660	5.57522	2.61052
		W4	Mean	20.8157	15.5479	70.7264
			SD	3.94248	3.27236	2.35508
		Total	Mean	23.2663	13.1041	70.7246
			SD	5.78460	5.02187	3.40435

	Male	M1	Mean	25.9814	15.0821	70.2350
			SD	2.35418	3.23768	3.74769
		M2	Mean	17.5646	24.4223	71.4746
			SD	2.68302	3.80092	2.23823
		M3	Mean	20.0921	19.2293	73.0223
			SD	2.60471	3.64307	2.31981
		M4	Mean	18.2347	22.6220	73.9650
			SD	1.78409	2.77415	2.16633
		Total	Mean	20.4802	20.3068	72.3264
			SD	4.05224	4.84096	2.88970

Appendix IV: Mean and SD values of spectral measurements of the stop burst: individual results. Group results based on gender given as total for each stop

Sound	Gender	Subject		Spectral Mean in Hz	SD of Spectrum in Hz	Skewness	Kurtosis
b	Female	W1	Mean	4053.7500	1842.75	.5500	.1250
			SD	679.18155	353.311	.31801	.42587
		W2	Mean	3881.1667	1694.83	.2133	.0883
			SD	663.38629	75.946	.63194	.36163
		W3	Mean	3848.0000	1897.67	.4967	.3600
			SD	98.97474	405.562	.19088	.76622
		W4	Mean	3964.6667	1965.00	.3933	-.1300
			SD	959.02155	719.969	.07234	.94430
		Total	Mean	3933.7500	1820.50	.3844	.1075
			SD	607.86089	360.207	.42480	.54891
	Male	M1	Mean	4076.0000	2237.40	-.0340	-.6000
			SD	511.29884	219.195	.25284	.51682
		M2	Mean	3575.0000	2117.00	.2867	-.5300
			SD	418.08970	369.260	.12342	.46701
		M3	Mean	4038.3333	1918.33	.1767	.4467
			SD	609.60998	519.592	.45654	2.04003
		M4	Mean	4318.8333	1892.17	.0267	.0617
			SD	1013.70615	282.690	.53053	.42771
		Total	Mean	4066.6471	2038.00	.0812	-.1694
			SD	723.97056	334.711	.38313	.91920
			SD	1013.70615	282.690	.53053	.42771
		Total	Mean	4002.2121	1932.55	.2282	-.0352
			SD	663.18671	359.194	.42621	.76384
d	Female	W1	Mean	3853.2143	793.43	.4264	6.2086
			SD	317.42599	222.748	.60859	4.44638
		W2	Mean	3844.7857	966.14	.4014	5.6593
			SD	159.69210	172.171	.60781	2.92957
		W3	Mean	3701.2857	907.62	.8257	8.0562
			SD	202.16270	284.707	1.08467	4.82995
		W4	Mean	3626.6429	1025.86	.2043	4.1446
			SD	320.41502	272.716	.65087	3.37976
		Total	Mean	3756.4821	923.55	.4645	6.0141
			SD	270.56123	250.267	.77776	4.09218
	Male	M1	Mean	3491.0769	1478.31	.3054	1.1162
			SD	462.64448	230.589	.57311	1.18740
		M2	Mean	2844.7500	1247.17	.8358	3.0058
			SD	321.41028	390.825	.86974	2.61433
		M3	Mean	3117.3846	1339.92	1.1523	5.4000
			SD	297.54006	434.079	.49985	4.32884
		M4	Mean	3508.8462	1347.46	.9700	4.5577

			SD	321.69469	397.204	.90036	2.90646
		Total	Mean	3248.2745	1355.29	.8155	3.5300
			SD	443.50423	369.147	.77668	3.33637
g	Female	W1	Mean	3461.9286	1718.29	.4179	.1571
			SD	708.07556	222.578	.58716	2.15737
		W2	Mean	4620.2143	1812.36	.0050	-.4071
			SD	558.30777	181.119	.20183	.43999
		W3	Mean	4112.3077	1686.38	.2531	.5700
			SD	426.12134	298.789	.76845	1.59940
		W4	Mean	3840.9286	1839.36	.2636	-.0564
			SD	526.33705	165.859	.54947	.53342
		Total	Mean	4006.9636	1765.51	.2345	.0567
			SD	697.94062	224.396	.56514	1.38895
	Male	M1	Mean	3277.2500	1920.45	.5917	-.2708
			SD	518.84121	257.312	.43315	.90556
		M2	Mean	4365.7500	1730.12	-.0150	.1500
			SD	719.89141	270.129	.34765	.82537
		M3	Mean	3662.4167	1876.42	.1567	.0575
			SD	554.98673	405.787	.44787	1.08963
		M4	Mean	4589.6000	1596.11	-.0420	1.2990
			SD	320.34468	440.285	.57708	1.58399
		Total	Mean	3907.0952	1796.20	.2010	.2769
			SD	744.41785	364.350	.51637	1.25119
k	Female	W1	Mean	3311.0000	1891.57	.6336	.1093
			SD	725.36357	229.866	.81441	2.06095
		W2	Mean	4425.4286	1813.29	.0586	-.0864
			SD	843.02119	160.588	.67327	1.63828
		W3	Mean	4264.8571	1777.57	.1314	.2986
			SD	566.10774	308.219	.56868	1.48243
		W4	Mean	3897.2857	1786.50	.1364	-.2621
			SD	519.64254	176.204	.31235	.38461
		Total	Mean	3974.6429	1817.23	.2400	.0148
			SD	786.58291	224.564	.64572	1.49588
	Male	M1	Mean	3545.0714	1756.21	.2238	-.1379
			SD	574.14906	261.954	.34471	.95494
		M2	Mean	4039.0833	1743.42	.0775	.1708
			SD	542.45577	259.104	.45243	.76359
		M3	Mean	3989.0000	1758.14	.0850	-.0921
			SD	379.94595	193.384	.23774	.65436
		M4	Mean	4084.9286	1792.36	.3571	.8743
			SD	508.00719	418.503	.61747	2.40149
		Total	Mean	3909.9074	1763.24	.1892	.2050
			SD	537.88528	288.497	.44030	1.42733
k'	Female	W1	Mean	3868.4286	1791.23	.3643	.3821

			SD	786.70078	449.978	.90069	1.19578
		W2	Mean	4980.0000	1629.07	-.0279	.1629
			SD	725.02021	389.827	.38819	.98525
		W3	Mean	4309.5000	1675.21	.2514	.3100
			SD	475.95406	251.630	.45936	.73531
		W4	Mean	4087.1429	1720.14	.3971	.4893
			SD	541.75752	316.403	.62243	1.35304
		Total	Mean	4311.2679	1702.33	.2462	.3361
			SD	754.97428	352.832	.63031	1.06876
	Male	M1	Mean	3882.0000	1831.92	.3638	.5092
			SD	653.21997	282.044	.70987	.99653
		M2	Mean	4055.5833	1718.67	.2642	.5442
			SD	794.46362	340.245	.48260	1.73253
		M3	Mean	4208.6154	1476.62	.0631	1.4100
			SD	704.16872	366.549	.53158	1.46432
		M4	Mean	4684.0000	1716.93	.2871	1.0729
			SD	445.96516	433.022	.61948	1.60370
		Total	Mean	4219.6346	1686.00	.2450	.8942
			SD	706.05766	374.451	.58798	1.47796
p	Female	W1	Mean	4996.1667	1942.67	-.0883	-.0917
			SD	752.77923	151.674	.59617	.34822
		W2	Mean	4237.6667	1705.50	.0983	-.1433
			SD	592.54322	317.978	.39922	.65384
		W3	Mean	4594.7500	1739.50	.2850	.0875
			SD	1161.88650	179.080	.46293	1.00662
		W4	Mean	4658.7500	1517.50	.2225	.5075
			SD	564.52834	227.676	.09811	.90437
		Total	Mean	4620.8500	1745.85	.1045	.0485
			SD	772.19988	263.900	.43860	.70430
	Male	M1	Mean	4284.6667	1888.67	-.1100	.4067
			SD	887.23184	309.531	.94430	.85541
		M2	Mean	4175.8333	1715.50	.2533	.2550
			SD	507.01417	237.576	.28904	.73948
		M3	Mean	3797.2500	2216.20	.2220	-.4560
			SD	644.65979	243.547	.52742	.56554
		M4	Mean	4638.3333	1731.83	.2950	-.2400
			SD	615.46654	277.745	.27289	.46217
		Total	Mean	4259.3684	1871.55	.2035	-.0485
			SD	656.59561	320.758	.46157	.67937
p'	Female	W1	Mean	4984.3333	1953.17	-.0583	-.0300
			SD	1088.54300	453.392	.39857	.42195
		W2	Mean	4644.5000	1760.33	.0300	-.2683
			SD	143.54477	266.369	.22414	.43595
		W3	Mean	4282.7500	1605.00	.3000	-.1450

			SD	886.92066	608.191	.70697	.90002
		W4	Mean	3971.0000	1521.50	.6100	.6950
			SD	154.14928	95.459	.11314	.21920
		Total	Mean	4602.5556	1763.56	.1250	-.0544
			SD	786.02539	415.501	.44764	.58172
	Male	M1	Mean	4157.8000	1943.50	.3433	.3517
			SD	729.85492	432.483	.74350	1.18785
		M2	Mean	3453.0000	2158.50	.1150	-.6700
			SD	585.48441	171.827	.43134	.07071
		M3	Mean	4216.8000	1827.50	.4200	.6467
			SD	527.84534	416.718	.93409	2.42531
		M4	Mean	4530.6667	1760.60	.3033	-.0333
			SD	759.42970	149.834	.37163	.29871
		Total	Mean	4220.1667	1881.37	.3315	.2225
			SD	696.49334	348.800	.65492	1.45244
t	Female	W1	Mean	4958.0769	1655.31	-.0554	-.1562
			SD	315.79884	287.723	.36963	.48945
		W2	Mean	4867.8462	1887.54	-.1269	-.4492
			SD	508.09101	280.814	.37127	.31779
		W3	Mean	4979.0000	1937.14	-.1143	-.1793
			SD	501.70525	267.858	.40867	.88788
		W4	Mean	4749.5455	1904.36	.0500	-.2527
			SD	654.20797	194.409	.39433	.49874
		Total	Mean	4895.8431	1845.59	-.0671	-.2580
			SD	494.76246	279.259	.38079	.59194
	Male	M1	Mean	4922.7143	2041.57	-.1021	-.7179
			SD	407.99329	176.706	.30438	.35419
		M2	Mean	4708.3636	1887.00	-.2918	-.0382
			SD	559.97451	267.189	.39230	.60282
		M3	Mean	4356.2143	1416.17	.0436	1.5029
			SD	393.06942	256.485	.60255	1.49786
		M4	Mean	4675.1429	1961.93	.0336	.1343
			SD	452.86504	345.131	.61001	1.67915
		Total	Mean	4663.1887	1839.22	-.0672	.2349
			SD	485.58082	356.337	.50358	1.43623
t'	Female	W1	Mean	5235.3077	1503.00	-.2207	.6236
			SD	467.98903	238.471	.61868	1.57209
		W2	Mean	5113.2500	1701.33	-.0017	-.4058
			SD	431.05581	187.782	.40640	.45749
		W3	Mean	4984.4286	1985.57	-.2429	-.4064
			SD	569.94436	279.796	.42577	.51666
		W4	Mean	4786.5714	1847.00	.1043	-.1850
			SD	726.38586	323.690	.41877	.85364
		Total	Mean	5022.8679	1761.37	-.0935	-.0819

			SD	575.81598	315.964	.48791	1.03909
	Male	M1	Mean	4848.2857	1665.21	.0179	.1614
			SD	656.77340	216.156	.44710	.96999
		M2	Mean	4760.6154	1877.54	-.3031	.1575
			SD	653.39530	475.057	.46721	1.07578
		M3	Mean	4338.0714	1359.93	-.1079	2.7671
			SD	275.66687	449.360	.60682	3.15269
		M4	Mean	4306.8667	1931.33	.2787	.3487
			SD	290.38001	436.836	.68126	2.21080
		Total	Mean	4555.3571	1709.46	-.0182	.8749
			SD	543.31067	456.381	.58791	2.31815

Appendix V: Mean and SD values of voice measurements: individual results. Group results based on gender given as total for each stop.

Sound	Gender	Subject		F0 at Onset in Hz	F0 at Mid in Hz	F0 Perturbation in Hz	Jitter at Onset in %	Jitter at Mid in %	Jitter Perturbation in %
b	Female	W1	Mean	224.9983	224.7967	.2017	2.0293	.3788	1.6505
			SD	5.29580	6.83026	9.55397	1.70582	.19056	1.67218
		W2	Mean	222.9967	211.8900	11.1067	4.6105	.2788	4.3317
			SD	3.34851	3.20606	2.30492	.52281	.11812	.42073
		W3	Mean	229.8940	210.2320	19.6620	6.0256	.7734	5.2522
			SD	7.11053	1.58924	7.18457	1.22584	.59891	1.71804
		W4	Mean	237.6950	224.5600	13.1350	3.1333	.6405	2.4928
			SD	10.05729	9.60142	12.00370	1.86107	.34901	1.68776
		Total	Mean	228.0105	217.5962	10.4143	3.9286	.4940	3.4345
			SD	8.06270	8.78322	10.50611	2.01578	.37981	1.99012
	Male	M1	Mean	100.7750	98.1933	2.5817	1.8595	.8963	.9632
			SD	4.27681	2.66983	2.45320	1.84274	1.12458	2.17135
		M2	Mean	121.4775	116.0525	5.4250	4.0115	.3920	3.6195
			SD	6.71528	3.62583	5.31457	2.84440	.20194	2.70525
		M3	Mean	111.8800	113.9600	-2.0800	2.8180	1.3720	1.4460
			SD	3.64926	4.41061	2.94444	2.65224	.99277	3.35701
		M4	Mean	126.0100	119.7280	6.2820	6.4498	.6592	5.7906
			SD	2.01304	1.39114	3.02711	5.41326	.20301	5.29782
		Total	Mean	113.8995	111.2271	2.6724	3.6362	.8797	2.7565
			SD	10.79478	9.21585	4.61434	3.58286	.84229	3.82592
d	Female	W1	Mean	224.3900	220.5507	3.8393	1.1669	22.8346	.7384
			SD	8.29769	8.98381	4.40146	.90516	83.80351	.92085
		W2	Mean	225.4643	223.0757	2.3886	2.5032	.5014	2.0019
			SD	6.69467	12.47867	7.14966	1.37151	.19849	1.33557
		W3	Mean	227.3777	221.6964	6.8546	3.4748	.6156	2.8592
			SD	6.62601	14.74147	11.77692	1.74288	.21547	1.75082
		W4	Mean	229.7946	224.5577	5.2369	2.6777	.6225	2.0552
			SD	8.45208	10.78745	7.43887	1.51687	.20040	1.54238
		Total	Mean	226.6889	222.4322	4.5256	2.4516	6.2439	1.9111
			SD	7.63354	11.71946	8.00046	1.61399	42.26690	1.58015
	Male	M1	Mean	102.6400	100.2343	2.4057	4.1717	1.2814	2.8904
			SD	8.57001	9.24667	5.14806	3.62505	.89855	3.92888
		M2	Mean	126.0300	124.0600	1.9700	2.5364	1.0008	1.5356
			SD	6.91442	9.67295	6.02143	2.06729	.70014	2.13713
		M3	Mean	120.0879	120.7000	-.6121	2.7033	1.0181	1.6851
			SD	7.93132	8.09841	2.65234	2.06424	.53880	2.06950
		M4	Mean	124.4693	126.7936	-2.3243	2.0952	1.0854	1.0098
			SD	5.36861	8.75867	5.96456	2.41827	.65673	2.44788
		Total	Mean	118.3068	117.9470	.3598	2.8766	1.0964	1.7802

			SD	11.76759	13.68147	5.35776	2.66929	.69992	2.76388
g	Female	W1	Mean	223.3771	217.7443	5.6329	2.0681	.5071	1.5610
			SD	9.17166	7.59106	4.83190	1.57521	.31993	1.55609
		W2	Mean	228.5346	218.0415	10.4931	5.9027	.5118	5.3908
			SD	3.85154	5.85597	5.48807	1.69819	.57594	2.07702
		W3	Mean	220.9750	209.8038	11.4767	3.3642	.6148	2.7494
			SD	3.96715	3.56236	6.63122	1.83168	.50121	1.70799
		W4	Mean	229.8143	218.6114	11.2029	2.9287	.4389	2.4898
			SD	10.01491	6.28669	7.57595	1.55351	.20165	1.56105
		Total	Mean	225.7987	216.1291	9.6194	3.5264	.5165	3.0099
			SD	8.12514	6.89155	6.50990	2.15888	.41359	2.20501
	Male	M1	Mean	103.5709	98.7791	4.7918	5.6536	.9475	4.7062
			SD	6.86041	9.24794	3.66380	3.38843	.53837	3.31729
		M2	Mean	123.8950	118.4596	5.4354	3.1082	.5680	2.5402
			SD	4.33379	5.04967	7.67583	2.45932	.42479	2.66347
		M3	Mean	118.7692	121.5750	-2.8058	2.2872	1.0310	1.2562
			SD	3.74542	7.41568	4.96570	1.64854	.38037	1.59923
		M4	Mean	127.2820	122.1130	5.1690	4.2306	.4065	3.8241
			SD	3.40244	3.24351	3.50026	3.82085	.19838	3.91151
		Total	Mean	118.0530	115.1441	2.9089	3.7913	.7567	3.0345
			SD	10.24046	11.77380	6.15633	3.09542	.47192	3.15130
			SD	54.62149	51.28146	7.15580	2.60434	.45416	2.65125
k	Female	W1	Mean	229.4650	218.5500	10.9150	2.0218	.4116	1.6102
			SD	6.88412	7.99331	5.18272	1.41164	.21321	1.38939
		W2	Mean	230.6457	224.5893	6.0564	2.6103	.5703	2.0400
			SD	6.50728	10.24780	7.01379	1.09659	.18603	1.12047
		W3	Mean	232.3829	228.3070	4.0759	3.0923	.8769	2.2154
			SD	3.91964	15.00358	17.61153	1.34062	.63199	1.52905
		W4	Mean	245.4762	223.8250	13.9977	2.9051	.7068	2.1983
			SD	3.46939	29.75114	8.11265	1.10707	.52785	1.12819
		Total	Mean	234.4749	224.0129	8.5812	2.6809	.6499	2.0310
			SD	8.27072	17.97407	11.24645	1.26794	.46178	1.28481
	Male	M1	Mean	110.1900	101.6654	8.5246	5.3670	1.8569	3.5101
			SD	16.29150	13.75054	8.81198	5.23483	2.36739	5.62438
		M2	Mean	134.0954	122.6554	11.4400	5.8876	.9686	4.9190
			SD	8.12271	12.17958	10.52924	4.50408	.60357	4.66783
		M3	Mean	126.5121	125.3493	1.1629	3.6717	.8184	2.8533
			SD	9.23393	7.54716	3.23175	2.75897	.61278	3.10120
		M4	Mean	130.8136	128.6179	2.1957	5.0333	1.2052	3.8281
			SD	7.49825	9.57324	4.32859	3.52557	.59124	3.59432
		Total	Mean	125.5235	119.8465	5.6770	4.9663	1.2049	3.7614
			SD	13.89533	14.97275	8.28009	4.05032	1.29873	4.26458
k'	Female	W1	Mean	181.0900	201.1283	-20.0383	4.1132	.6360	3.4772
			SD	56.32028	47.01111	44.89058	2.59835	.38783	2.78416

		W2	Mean	147.1167	216.7400	-69.6233	2.3935	.3768	2.0167
			SD	61.76521	2.91454	60.49489	2.22021	.16292	2.32358
		W3	Mean	190.6700	212.4443	-21.7743	4.6464	.5764	4.0700
			SD	46.69376	4.36669	44.40132	4.89771	.44728	5.18683
		W4	Mean	218.2171	217.9071	.3100	2.3241	.6157	1.7084
			SD	53.34904	8.25178	46.21718	1.92971	.39116	2.03860
		Total	Mean	185.8250	212.2950	-26.4700	3.3782	.5547	2.8235
			SD	57.17578	22.54152	52.76931	3.17973	.36122	3.33561
	Male	M1	Mean	101.1792	112.1525	-10.9733	5.1206	1.0860	4.0346
			SD	8.50282	32.74819	29.51708	4.40652	.87614	4.76384
		M2	Mean	120.2030	115.0300	5.1730	4.2244	.5547	3.6697
			SD	11.33620	3.00647	13.26242	2.75206	.31112	2.68218
		M3	Mean	122.3291	127.4173	-5.0882	2.2376	.9170	1.2106
			SD	5.38429	6.86500	4.20927	1.59321	.40180	1.58767
		M4	Mean	130.6382	121.5818	9.0564	9.5858	.9513	8.6345
			SD	13.13951	6.25193	15.81241	5.13562	.92282	5.52787
		Total	Mean	118.0051	119.2690	-1.2639	5.3921	.9138	4.3717
			SD	14.97922	18.86529	20.04399	4.64088	.71465	4.81542
p	Female	W1	Mean	215.3717	225.6550	-10.2833	3.5892	.5930	2.9962
			SD	48.81326	8.01794	51.41428	4.09710	.47693	3.91154
		W2	Mean	228.2550	221.3750	6.8800	1.6017	.3395	1.2622
			SD	7.07345	8.62005	2.89905	.58371	.08801	.64053
		W3	Mean	237.2133	210.3033	26.9100	4.2832	.5710	3.7122
			SD	8.40395	24.03571	20.55095	1.24588	.41159	1.34554
		W4	Mean	255.4180	213.3167	-.4683	3.0773	.4853	2.5920
			SD	7.92626	46.83559	58.30331	1.34700	.36853	1.38542
		Total	Mean	233.1361	217.6625	5.7596	3.1378	.4972	2.6406
			SD	28.11246	25.92099	40.01945	2.33817	.35753	2.24832
	Male	M1	Mean	115.5900	112.0760	3.5140	4.8434	.8632	3.9802
			SD	3.72355	3.01045	5.69085	6.41675	.42572	6.70944
		M2	Mean	129.2680	124.6920	5.7200	4.6548	.5216	4.1332
			SD	7.28459	4.92909	6.76174	4.30846	.32449	4.29479
		M3	Mean	126.8433	126.0617	.7817	2.8105	1.2877	1.5228
			SD	3.47026	4.57100	3.07835	2.17716	.63920	2.14430
		M4	Mean	126.0633	120.9583	5.1050	2.3088	.6972	1.6117
			SD	2.55960	1.89998	1.79639	1.88165	.47272	1.99854
		Total	Mean	124.6241	121.1800	3.6081	3.5549	.8560	2.6988
			SD	6.61374	6.45615	4.52484	3.82563	.54050	3.96829
p'	Female	W1	Mean	164.0500			1.2550		
			SD	.			.		
		W2	Mean	154.2000	182.4000	-28.2000	1.9722	.4685	1.5038
			SD	89.59265	38.10248	112.31629	1.25227	.38052	1.31999
		W3	Mean	253.7575	205.5175	48.2400	4.7882	.5555	4.2328
			SD	19.63276	5.38266	23.54011	2.35457	.38482	2.05674

		W4	Mean	195.6650	216.6000	-20.9350	3.5990	.4722	3.1268
			SD	59.73548	17.91220	42.23753	1.47961	.21224	1.40083
		Total	Mean	198.3492	201.5058	-.2983	3.2841	.4988	2.9544
			SD	69.05555	26.69814	73.29930	2.00732	.30647	1.87998
	Male	M1	Mean	109.7120	108.9540	.7580	8.8922	1.5396	7.3526
			SD	7.26519	4.87070	6.56252	5.76034	.44168	6.07679
		M2	Mean	138.4780	124.2083	15.0360	5.9615	1.9938	3.9677
			SD	23.29638	4.92474	20.06249	3.38364	3.13491	3.64409
		M3	Mean	121.6300	123.0333	-1.4033	6.3850	1.1727	5.2123
			SD	4.28424	2.10690	2.88209	5.97243	.80956	5.73224
		M4	Mean	137.2660	117.8960	19.3700	8.0634	.8570	7.2064
			SD	20.12285	2.79590	21.81086	3.56922	.58492	4.05827
		Total	Mean	127.3428	118.3474	9.5339	7.3527	1.4455	5.9073
			SD	20.00425	7.34273	17.28789	4.35294	1.77014	4.64642
t	Female	W1	Mean	226.3067	218.8992	7.4075	2.1023	.4177	1.6847
			SD	7.09615	7.82358	3.27962	1.57356	.28432	1.39339
		W2	Mean	228.3671	218.4943	9.8729	2.3546	.4397	1.9149
			SD	5.82125	4.15766	3.97181	.96014	.15088	.93088
		W3	Mean	223.8338	209.7231	14.1108	2.3730	.7225	1.6505
			SD	7.27597	4.18815	7.59987	1.00418	.89494	1.33000
		W4	Mean	240.5464	222.9991	17.5473	2.3749	.5025	1.8724
			SD	4.71915	5.07221	5.14596	.89250	.26143	.95927
		Total	Mean	229.3734	217.3020	12.0714	2.3033	.5218	1.7815
			SD	8.75001	7.17142	6.37901	1.10590	.49963	1.14041
	Male	M1	Mean	112.6081	101.1841	11.4239	7.4783	1.3315	6.1468
			SD	9.66726	7.29605	7.85045	4.79742	.94534	5.02053
		M2	Mean	128.7908	120.2375	8.5533	4.6309	.6830	3.9479
			SD	9.72927	5.52468	7.45909	4.47292	.34914	4.57372
		M3	Mean	128.9736	127.3529	1.6207	3.8437	.8124	3.0314
			SD	6.95429	6.45506	4.78177	2.03533	.52335	2.10641
		M4	Mean	124.6423	118.1008	6.5415	5.9516	.5101	5.4415
			SD	3.40562	2.37126	3.43698	4.24903	.35091	4.20029
		Total	Mean	123.3443	116.2752	7.0691	5.5357	.8550	4.6807
			SD	10.34138	11.53827	7.06299	4.16986	.67605	4.20394
t'	Female	W1	Mean	176.3500	223.5800	-47.2300	3.4220	.7935	2.6285
			SD	57.29472	6.43274	58.45023	3.62138	.51385	3.74051
		W2	Mean	164.9988	204.5975	-39.5987	4.5450	.4060	4.1390
			SD	75.93193	31.12823	73.26736	3.67932	.27077	3.64650
		W3	Mean	166.5900	196.5700	-27.0733	4.4173	.5061	3.9111
			SD	53.48181	39.87025	45.90797	3.74538	.45944	3.85994
		W4	Mean	185.3944	201.1911	-15.7967	4.7861	.7557	4.0304
			SD	61.86811	33.87497	50.76540	3.75915	.32453	3.72452
		Total	Mean	173.8326	204.2075	-30.0119	4.4301	.5988	3.8314
			SD	61.17376	31.98231	56.42296	3.53100	.39181	3.56095

	Male	M1	Mean	94.5911	97.1356	-2.5444	4.3880	.4659	3.9221
			SD	6.28302	3.24943	6.77984	3.10600	.36582	3.03433
		M2	Mean	122.7789	115.9489	6.8300	5.5552	.4249	5.1303
			SD	22.77320	4.14814	19.68873	3.73942	.28970	3.82911
		M3	Mean	121.4592	133.3831	-5.2638	5.3042	.7018	4.6023
			SD	8.41977	22.72883	6.20756	4.38867	.31387	4.42515
		M4	Mean	127.1009	117.2736	9.8273	7.6179	3.1555	7.0492
			SD	9.29284	3.71216	11.13445	4.65392	5.43676	5.79386
		Total	Mean	117.3646	117.6607	1.8629	5.7676	1.2792	5.2533
			SD	17.52399	18.20760	12.99714	4.11644	3.03616	4.51319