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An Acoustic Analysis of Fricatives Produced by Typically Developing Child and Adult Speakers of Oromo

BY

DEJENE GESHE WOLDE

A DISSERTATION SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIALFULFILLMENT 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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This is to certify that the thesis prepared by Dejene Geshe entitled, *An Acoustic Analysis of Fricatives Produced by Typically Developing Child and Adult Speakers of Oromo* and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy (Experimental Phonetics) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Chair of Department or Graduate Program Coordinator

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ABSTRACT

The present study was aimed to investigate word initial and medial voiceless fricatives /f, s, ʃ, h/ produced by typically developing children between the age of 3 and 6 and adult speakers of Haraghe Oromo dialect. The study investigated whether fricatives were distinct as a function of noise duration, normalized amplitude, and spectral features. The work included fricatives both in singleton and geminate forms. The word initial fricatives were all in singleton form because word or syllable initial geminationation is not permissible in Oromo. The extent to which the sounds vary as a function of vowel context, speakers' age and gender in both phonetic contexts was investigated. Among the parameters analyzed, fricative duration, normalized amplitude and the first three spectral moments (spectral mean and spectral standard deviation and spectral skewness) were more effective to discriminate fricatives. But only the third spectral moment in the CV and VCV fricatives and the second spectral moment in the VCV fricatives distinguished all fricatives in terms place of articulation. The spectral kurtosis was the least or almost not robust cue to discriminate fricatives. Similarly, locus equation did not discriminate fricatives. The result supports the claim that locus equation is not a salient acoustic cue to distinguish fricatives.

In the study anatomical, physiological and developmental or behavioral factors played roles to bring variations as a function of place, vowel, age and gender. Surprisingly, gender difference was observed at early age which has been speculated to be conditioned by developmental or behavioral factors. The difference between geminate and singleton

fricatives was evident both in durational and spectral attributes indicating that the two phonemes vary temporally and physiologically. In the CV context the voiceless glottal fricative behaved predominantly like vocalic segments than consonants, especially in having highly elevated average measures of spectral skewness and kurtosis. Among all fricatives /s/ turned out to be the most resistant to coarticulation and the least to be classified by the linear discriminant analysis. This typical nature of the sound may indicate that it was the last to be acquired by children among the test fricatives.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The goal of any experimental investigation into speech sounds is to objectively analyze the nature of the segments. Such an investigation is based on acoustic analysis of sounds in terms of certain persistent features. Studies over the last many decades have been striving to search for such invariant acoustic parameters (Nissen 2003) which characterize speech sounds mainly in terms of articulatory features such as place, manner and voicing. The invariant acoustic cues are important in quantitatively and qualitatively characterizing speech sounds. But finding and conclusively describing the cues is difficult because they may be analyzed in different ways based on different conditioning factors such as phonetic contexts, age, gender and disorders.

It has been long that scholars have tried to discriminate speech sounds such as fricatives in terms of different acoustic cues (e.g., Jassem 1962; Strevens 1960; Huges and Halle 1956; Harris 1958). Most of these earlier studies were mainly based on spectral analysis of the sounds. The researchers categorized speech sounds into different places of articulations with the help of the spectral noise of the sounds. Nevertheless, recent works on the acoustic analysis of fricatives imply that the earlier studies were based on analysis of limited acoustic cues (Jongman et al. 1998). Jongman and colleagues claimed that they used considerable number of static cues, unlike the earlier works, which may facilitate

the search for the invariant acoustic cues. Besides, the earlier works employed less robust methodologies which were lacking to draw reliable conclusions.

Various acoustic investigations, including earlier works, have observed that there were inter and intra speaker variations in speech production and perception, especially in child speech. In normative speech, most of the variations were reported to occur due to phonetic contexts, age and gender differences. One of the typical examples is a classic study conducted on American English vowels by Peterson and Barny (1952). The authors observed that there were significant differences in vowel space and formant frequency values as a function of age and gender. Most of the recent works on fricatives have used multiple cues and have taken gender and age into account. The studies reported on fricatives have come up with similar conclusions that there were variations in the production of the consonants in terms of the acoustic attributes as a function of age and gender (Nittrouer et al. 1989; Nittrouer and Whalen 1990; Nissen and Fox 2005; Koenig et al. 2008; Romeo et al. 2013).

As indicated earlier, experimental works have identified that there were discrepancies between child and adult speech. The works have also speculated some of the sources of the variations. McGowan and Nittrouer (1988) have observed that fricatives produced by children were characterized with higher frequency, larger amplitude and more sensitivity to coarticulation. The authors attributed the variations to anatomical factors and articulatory dimensions which may affect the source of energy and filter transfer functions of the vocal tract of the children. Nittrouer et al. (1989) have drawn conclusion

from the study conducted on the two sibilant fricatives /s, ʃ/ that the discriminating ability of the children would be improved as they advance in age, while the tendency towards coariculation would be decreased. But Sussman et al. (1999) conducted a longitudinal study on a single child speaker of 7 to 40 months of age on CV stop consonants and observed that the pattern of coarticulatory development in the child varied based on different places of articulations of the stop consonants.

Nittrouer and colleagues in different works claimed that children first give primary emphasis to larger linguistic elements such as syllable and slowly acquire segment specific acoustic features (e.g., Nittrouer et al. 1989; Nittrouer 1992). Contrary to this finding, other studies have claimed that there was no coarticulatory difference between speech produced by children and adults (Katz et al. 1991; Goffman et al. 2008). These studies viewed variations from different angles: child speech is less intelligible (Katz et al., 1991) and physiologically more variable (Goffman et al. 2008). Perceptual studies, on the other hand, suggested that there were differences between adults and children in weighing the acoustic cues based on language experience, the nature of the segments and strategies children use (Mayo 2000; Mayo et al. 2003; Mayo and Turk 2004, 2005).

Different studies attempted to characterize variations of speech mainly in terms of age and gender. But such approach faced two major challenges. The first problem emanates from language specific features. Though different studies reported the age at which children acquire language and the manner in which they acquire, language specific features revealed some discrepancies. For instance, "English-speaking children generally

produced the alveolar fricative more accurately than the post-alveolar one, whereas the opposite was true for Japanese-speaking children" (Li et al. 2009). Another challenge to the studies into child language was that gender differences appear at early ages. The generally held view was that anatomical difference which governs the male-female discrepancies in different acoustic parameters was evident at puberty (Fitch and Giedd 1999). Contrary to this claim, some studies conducted on speech of prepubescent children revealed gender variations (Nissen 2003; Fox and Nissen 2005; Nissen and Fox 2005). The scholars speculated that such result was conditioned by developmental or behavioral and sociophonetic factors. The claims themselves could not answer the how and why questions because social and developmental factors are complex and go beyond the realm of experimental phonetic investigations.

Furthermore, though different studies have made attempt to objectively analyze the production of fricatives, the mist has not been clearly resolved in the area due to two major factors: 1) the predominant data of salient works (according the observation of the researcher) in the analysis of fricatives come from English and some other languages and 2) there are differences in the interpretations of the results among scholars (Koenig, 2008) which demand thorough investigation cross linguistically to come up with conclusive findings.

Thus, the goal of the present work was to conduct study on acoustic analysis of fricatives produced by typically developing young children in comparison with an adult group. The study employed multiple acoustic cues, especially the spectral moments outlined by

different scholars (Forrest et al. 1988; Jongman et al. 2000; Nissen and Fox 2005). The result of the present study was compared with the finding of previous works conducted on similar areas to examine universal and language specific trends. Thus, the spectral moment analysis was preferred in this regard because it is a focus of recent study conducted on obstruents and is more quantitative in approach to objectively characterize speech sounds.

1.2 Statement of the Problem

The current trend in studying speech sounds seem to prefer experimental approach to impressionistic studies. Experimental studies empirically analyze features which characterize the speech sounds in question. One advantage of experimental analysis over the impressionistic studies is that it could be replicated and checked following scientific procedures. On the other hand, impressionistic results are always debatable and less acceptable because auditory impressions may not provide reliable evidence, but may be good input for experimental analysis. The other importance of experimental studies is that they employ multiple cues at a time and may find some cues invariantly characterize the sounds than others. That is, experimental studies carry different useful information. Such varied information or cues characterize variations in speech in terms of phonetic contexts, age, sex, regional variations and so on.

Though the experimental investigation into speech sounds has greater importance, there are still little or no experimental works done on many Ethiopia languages. In fact, there were some experimental works done on Amharic, among which the recent ones were (Abebayehu 2007; Derib 2011; Feda 2013). The works could be forerunners and good

beginnings to encourage experimental works in the country. Nevertheless, almost no experimental study has been conducted on other languages including Oromo, one of the widely spoken languages in the country.

So far there were some impressionistic works done on the sound patterns of Oromo which descriptively investigated the sounds of the language. Some works directly conducted on the phonology or aspects of the Oromo phonology were Waqo (1981), Benyam (1988), Kebede (1994), Dejene (2010) and Dejene and Devardhi (2013). Besides, there were some other grammatical sketches on the language which discussed aspects of Oromo phonology (Gragg 1976; Bender and Mulugeta 1976; Andrzejewski 1957; Andrzejewski 1966; Habte 2003, among others). As already mentioned, the works were impressionistic, and there was no experimental study conducted on the acoustic features of the sounds of the language.

Besides, a lot of the works done in the country focused on adult speech and child language acquisition has been disregarded. Such a huge gap in the language need to be bridged by conducting series of experimental works. Shortage of experimental works in the language disables clinical supervisions done on child speech disorders because the normative data is crucial to compare with. Thus, the present study tries to investigate the acoustic features of fricatives produced by typically developing children in comparison with adult speech to address the aforementioned concerns.

1.3 Research Questions

The study tries to answer the following research questions:

i) How much do spectral, durational and amplitude parameters vary in terms of places of articulation?

ii) How much do spectral and temporal and amplitude characteristics of Oromo fricatives vary as a function of age and gender?

iii) Does coarticulatory effect of vowels affect the acoustic features of the frica tives?

vi) What features best discriminate Oromo fricatives produced by children and adults?

v) Is there any difference in acoustic measures between singleton and geminate Oromo fricatives?

1.4 Objectives of the Study

General Objective

The general objective of the study was to investigate the acoustic characteristics of Oromo fricatives produced by typically developing children and adults.

Specific Objectives

The study will be conducted with the following specific objectives in focus:

i) to assess the extent to which each acoustic attributes successfully classify fricatives in terms of place of articulation;

ii) to investigate the extent to which spectral, temporal and amplitude features of Oromo fricatives vary as a function of age and gender;

iii) to examine whether duration, amplitude and spectral measures vary as a func tion of vowel contexts;

vi) to analyze the extent to which different acoustic features distinguish frica tives in terms of place of articulation;

v) describe whether durational and spectral measures vary as a function of gemination.

1.4 Scope of the Study

The present study was delimited to describing the acoustic analysis of Hararghe Oromo voiceless fricatives /f, s, ʃ, h/. Though there were much demanding areas in the sound patterns of the language, it was impossible to go beyond this group of sounds because of time and budget limitations. In terms of the width of the study, the work focused only on the Hararghe variety and the other dialects were not considered because of the aforementioned reasons.

1.5 Significance of the Study

The study was the first work conducted on the acoustic analysis of fricatives produced by children and adults in Oromo. The work contributes for the development of the language in general. It resolves different mists held among scholars based on previous impressionistic works. The study objectively described the sounds and would be good beginning for further investigations in the area. The investigation also provides canonical data for future works done on child speech disorder and has paramount importance in clinical investigations.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Under this section review of relevant literature was discussed. The discussion included general picture of the language, mainly the dialectal variations and phoneme inventory of the language. The purpose was not to exhaustively summarize previous works conducted on Oromo; rather it was to brief readers with previous works conducted on speech sounds of the language and existing body of knowledge in related areas. Next, the source-filter theory of speech production was discussed because every test was conducted in line with this framework. Different features of speech production, in accordance with the objectives set, were also discussed. Finally, phonological development was briefly treated to have insight into processes by which children acquire speech sounds.

2.1 The Language

Oromo belongs to the Eastern Low Land Cushitic family. The language is currently spoken by a large number of people and may be one of the widely spoken languages by huge number of native speakers in the continent (Bender 1976, p.130). The language is spoken in "three countries of north eastern Africa: Ethiopia, Kenya and Somalia" (Kebede 2009, p. 1). The language is predominantly spoken in Ethiopia covering “a cruciform area extending from Wello in the north to Northern Kenya in the South, and from Wellega in the west to Harar in the east, with Addis Ababa in the intersection of the two axes” (Gragg 1976, p. 166).

The language is classified into different dialectal variations. But the classification of the varieties has not been settled yet. Scholars held different views on the dialectal variations of the language. Gragg (1976, P. 173) categorized the language into four major groups: "western (including Wellega), eastern (especially Hararghe) and southern (e.g., Borana), with the large transitional area in the centre (Shewa)". Others grouped the dialect into eight varieties: "Mecha (western), Tulema (central), Wello, Rayya (both northern), eastern, Arsi, Guji and Borena (the last three southern)" (Bender et al., 1976, p.130). Thus, the authors employed different classification mechanisms of the language into different varieties. While Bender (1976) attributed the dialectal variation of the language to ethnic affiliations, Kebede (2009) categorized the varieties based on the isoglosses. The present study was conducted based on the first approach because the purpose was to investigate the acoustic characteristics of fricatives of typical Hararghe dialect. Thus, the focus was not to reconstruct the variety, but to describe the acoustic attributes of fricatives of the dialect produced by young children and adults.

2.2 The Sounds of the Language

Oromo has 29 consonant phonemes, among which five of them are loan (v, p, z, s', ʒ). The loan segments are used only in loan words and are not as frequent as native segments of the language. Thus, they were not included in the present study. The following chart reveals the consonant phoneme inventory of the language.

Table 1. Chart of Oromo consonant phonemes

		Labial	Alveolar	Palatal	Velar	Glottal
Stop	Vd	b	ɗ	ʤ	g	
	V1	p	t	ʧ	k	ʔ
	Ejc	p’	t’	ʧ’	k’	
Implosive			ɗ			
Fricative	Vd	v	z	ʒ		
	Vl	f	s	ʃ	x*	h
	Ejc		s’			
Nasal		m	n	ɲ		
Lateral			l			
Tap/trill			r			
Glide		w		j		

Source: Dejene (2010) Kamisee Oromo Phonology (p.7)

* /x/ is a voiceless velar fricative found in Hararghe and Borana dialects. It has not been attested so far in other studies whether the segment exists across the varieties, but auditory impressions reveal that the segment exists in the two dialects as an allophone of a voiceless velar stop /k/. The distribution of the segment is restricted because it is blocked by gemination and is realized as [kk]. Thus, the sound has been excluded from the present study because the data indicated that it occurs only in casual speech and was less frequent to be regarded as a phoneme.

In table1, labial includes bilabials /b, m, p, p’/, labiodentals/v, f/ and the labiovelar approximant /w/, and palatal includes palatals /ʧ, ʧʼ ɲ, j/ and postalveolars /ʒ, ʃ/. The phonemes have been arranged this way based on economic representation of phonemes (Dejene 2010).

Impressionistic studies reveal that the language has five vowel phonemes /i, e, a, o, u/ with their longer counter parts /i:, e: a:, o:, u:/ (e.g., Dejene 2010). The major problem in the vowel inventory of Oromo is that no experimental study has identified so far whether the short-long dichotomy is based on duration alone or including qualitative variations. Thus, future investigation into the sounds may focus on whether Oromo has five or ten vowel phonemes. The following chart reveals the Oromo vowel phonemes currently used in the language.

Table 2. Chart of Oromo vowels

i	u
e	o
a	

Source: Dejene (2010) Kamisee Oromo Phonology (p.15)

2.3 Theory of Speech Production

Under this section, the theoretical framework and the acoustic characteristics of fricatives were discussed briefly. The process of speech production is complex and needs better understanding of anatomical dimensions, physiological processes and motor control which govern the process. This is the case because "the acoustic characteristics of any

speech sound are determined by the whole complex of the movement and configurations of the speech production process" (Harrington and Cassidy, 1999, p. 29). Different models or theories are used to describe such a complex process. The well known theory of the speech production is the source-filter theory outlined by Fant (1960).

*2.3.*1 Source-filter Theory

The source-filter theory, as the name implies, is the model which views the process of speech production in terms of source and filter functions of the vocal tract. The theory deals with the final stage of speech production which involves two independent components (Kent 1993; Hayward 2000; Lieberman and Blumstein 2002). In the model, the source generates the acoustic input and the filter shapes or modifies the energy and produces the final output (Fulop 2011). Take, for example, the vowel /i/. The voice source of the sound is the vibrating vocal folds and the supralaryngeal vocal tract modifies the aerodynamics and produces the vowel with the needed quality. This model implies that the source and the filter work independently. The role of the source is providing raw materials, while the filter molds and yields a needed product like an apparatus. Thus, most of the variations resulted in the productions of speech sounds which utilize the same source, for instance vowels, is due to variations of the filter functions of each sound.

The source-filter theory of speech production states that variation in the production of speech sounds partly emanates from the nature of the filter function or the supra laryngeal tube (Fulop 2011). According to the scholar, different parameters such as age, gender and height may bring variations based on the filter functions of the tube or the vocal tract. Thus, the source-filter theory involves anatomical and physiological variations of

individual speakers. Variations occur based on the size of the vocal cavity and the way constrictions are made. Based on this claim, the resonance frequencies of males, females and children considerably vary based on the size of the filter and configuration of the vocal tract during speech production. Sexual stereotype reveals that there are some discrepancies between men and women based on the way they configure their vocal tract. For instance, females may put their tongue more anterior when they produce some speech sounds which in turn result in variations compared to that of males' speech (Munson 2011).

There are three major acoustic sources in speech production: i) laryngeal voicing source, as in the case of vowels or voiced sonorants, ii) turbulent noise source, like in fricatives and iii) transient source, in the case of release burst of stop consonants (Kent 1993). The filter, on the other hand, involves the supraglottal cavity, from the top of the larynx to the lips. As discussed earlier, the nature of different speech sounds vary based on the filter functions or resonating cavities of the vocal tract. Sounds with the same manner of articulation may acoustically vary based on the way the aerodynamics is modified by the filter. Sibilants, for instance, differ from nonsibilants based on the size of the filter or the cavity in front of the source (Shadle 1985; Jongman et al. 2000).

2.3.2 The Source-filter Theory for Fricatives

Fricatives are formed by turbulent source of air in the vocal tract (Kent 1993; Shadle 1985; Ladefoged and Maddieson 1996; Stevens 1998). The turbulent source of energy is produced by narrow constriction somewhere in the vocal tract (Shadle 1985). With regard to the source of the acoustic energy, Shadle states that there are three major sources of

frication in the vocal tract. The first one is concerned with the obstacle source in which the jet of turbulent air perpendicularly strikes the incisors. Sibilant fricatives [s] and [ʃ] are formed with obstacle source. The second source of energy is what is called "a wall-source". In this case the turbulent acoustic energy generated by a source squeezes across the wall without directly striking an obstacle. Typical examples here are palatal and velar fricatives. Shadle states that there is also a third source of acoustic energy around the lips for labiodentals and bilabial fricatives.

The acoustic characteristics of fricatives vary based on the nature of the filter (Jongman et al. 2000). The filter function is generally affected by the presence or absence of the obstacle, the length of the cavity in front of the source, different articulatory maneuvers which alter the shape of the cavity and the rate of airflow in the vocal tract (Shadle 1985). Fricatives with obstacle source have high intensity compared to the non-obstacle ones (Hayward 2000; Cheon and Anderson 2008). Like the presence or absence of the obstacle, the length of the cavity also affects the transfer function of the fricatives. The cause of the difference between the two voiceless sibilant fricatives /s/ and /ʃ/ is one of the length of the cavity in front of the source. Accordingly, /s/ has maximum energy at high resonant frequency while /ʃ/ has maximum energy at lower noise frequency region (Harrington and Cassidy 1999).

As mentioned earlier, fricatives are produced with high aerodynamic energy source squeezed through narrow articulatory gaps. Such a random fluctuation of airflow through the narrow gap is a typical source of fricatives (Jongman et al. 2000, Frid and Lavner 2014). Apart from random fluctuation of flow velocity in the vocal tract, obstacles anterior to the source also play a crucial role as a potential source for some fricatives. The

incisors are used as extra boost for sibilant fricatives characterizing them with dominance of energy in higher frequency regions (Shadle 1985).

Research showed that fricatives need maximum articulatory and gestural precision (Ladefoged and Maddieson 1996). The acoustic feature of fricatives is affected by the articulatory dimensions which alter the shape and size of the tube. For instance, if the length of the tube is shorter, the spectral energy will have well defined peaks like in the case of alveolar sibilants. The postalveolar sibilant fricatives, on the other hand, may not reveal a well resolved peak like the alveolars because of the length of the tube. Labials do not have front cavity. Hence, they do not have clear peak or the peak is flat or diffuse (Strevens 1960; Jassem 1965; Jongman et.al. 2000). The other influence of the length of the tube anterior to the source of fricatives is energy dominance in different frequency regions. Accordingly, previous findings reported that alveolar sibilants have energy dominance from 3.5 to 5 kHz frequency regions, while their platoalveolar counter parts have the peaks at lower level, from 2.5 to 3.5 kHz. The dental and labiodental fricatives, on the other hand, have energy prominence at fairly low frequency region, from 1.4 to 2kHz (Behrens and Blumstein 1988).

2.4 Acoustic Cues to Places of Articulation of Fricatives

Previous studies tried to characterize fricatives in terms of persistent acoustic parameters. The attempts made were to discriminate fricatives in terms of places of articulation (Koenig et al. 2013). The earlier works focused on analyzing noise spectra of fricatives. Spectral attributes play leading role in discriminating fricatives than other cues such as amplitude (Behrens and Blumstein 1988) and duration (Jongman1989). Fricatives are characterized with turbulence of acoustic energy displayed on the spectrogram. The

distribution of the energy varies based on the place of articulation of the sounds (Hayward 2000). Hence, qualitative observations were made from the spectral display of the sounds. The recent investigations into the acoustic characteristics of fricatives, both in children and adults, on the other hand, were based on spectral, amplitude and durational features (Behrens and Blumstein 1988; Fox and Nissen 2005; Jongman et al. 2000; Haleyet al. 2010; Wagner 2013; Romeo et al. 2013). Thus, the recent approach became more quantitative and objective than the earlier works. Under this section, the three major cues, duration, amplitude and spectral features, were discussed in detail as follows.

2.4.1 Durational Cues

Duration is one of acoustic parameters which characterize fricatives. It has been long identified that duration distinguishes fricatives into voiced and voiceless categories (Denes 1955; Cole and Cooper 1975; Klatt 1976; Manrique and Massone 1981; Pirello et al. 1997; Stevens et al. 1992). These studies reported that voiceless fricatives were longer than their voiced counter parts. Klatt claims that "Voiceless fricatives are about 40 ms longer in duration than the corresponding voiced fricatives" (p. 1213). Similarly, Stevens et al. (1992) found that "the duration of the voiced fricative is about 30 ms shorter than that of the voiceless fricative." Denes conducted a perceptual study on vowel-fricative (VC) sequence of monosyllabic words to dichotomize fricatives in terms of voicing. The result demonstrated that syllable final fricatives could be perceived as voiced or voiceless based only on duration. The scholar concluded that durational cues can distinguish speech sounds like spectral parameters. Similar result was found in perceptual study conducted on the two palatal affricates /ʧ, ʤ/ and alveolar sibilants /s, z/ in Spanish by Cole and Cooper. The result revealed that shortening of duration of the fricatives and

affricates resulted in more percepts of the voiced fricatives and affricates than the voiceless ones.

Although duration readily distinguishes syllable initial and syllable final fricatives into voiced vs. voiceless category, studies showed that there were overlaps (Baum and Blumstein 1987; Crystal and House 1988). Baum and Blumstein examined the data gathered from three phoneticians using six syllable initial fricatives /f, ɵ, s, v, ð, z/ followed by five monophtongal vowels /i, e, a, o, u/. The preliminary observation made by the researchers revealed that the general duration may categorize fricatives into voiced vs. voiceless category. But the result turned out to exhibit great overlap between voiced and voiceless percepts. Crystal and House analyzed word-initial fricatives (FV) and word-final fricatives (VF) in connected speech and found similar result. The finding exhibited that voiceless fricatives were significantly longer than the voiceless ones, with considerable overlap between the two groups. The scholars also observed that "fricatives in connected speech are shorter than those in citation form" (p.1932). Thus, duration of fricatives may vary as a function of voicing, but could not be the sole cue to readily categorize the two groups.

Duration also discriminated fricatives in terms of class categories, such as sibilance (Baum and Blumstein 1987; Stevens et al. 1992; Pirello et al. 1997; Jongman et al. 1998; 2000; Nissen and Fox 2005; Fox and Nissen 2005). The studies reported that sibilant fricatives were longer than nonsibilant fricatives. The result obtained by Jongman et al. (1998) demonstrated that sibilant fricatives were significantly longer than nonsibilant fricatives (123 ms, 146 ms, 148 ms and, 150 ms) for /f, v/, /ɵ, ð/, /s, z/ and /ʃ, ʒ/, respectively. Fox and Nissen examined syllable initial (FV) voiceless English fricatives

/f, ɵ, s, ʃ/ produced by pre- and post-pubescent children of 6-14 years old and adults. They obtained that duration distinguished sibilant fricatives from nonsibilants. The mean duration for /s/ and / ʃ/ was 199ms and 207 ms, while it was 142 ms and 139 ms for /f/ and /ɵ/, respectively. But noise duration did not distinguish within sibilant /s, ʃ/ and nonsibilant /f, ɵ/ fricatives. Though the main effect was statistically significant, Nissen and Fox (2005) did not report that duration was effective to categorize all places of articulations. The same was true for the work conducted on adult speech by Jongman et al. (2000). They found that noise duration distinguished only sibilant fricatives from nonsibilants.

Though many studies depicted that duration is important cue to discriminate fricatives, the result obtained by Jongman (1989) was contrary to the results reported by the aforementioned studies. The experimenter examined the frication duration of seven syllable initial (CV) naturally produced fricatives /s, f, ɵ, ʃ, v, z, ð/. The frication duration was edited by computer, ranging from 20 to 70 ms and entire noise duration in 10 ms steps. The recoded data was presented to 12 listeners for identification of the fricatives. The result exhibited that the correct percept of the fricatives may not need entire duration and varied for different fricatives. Only 30 ms was required to identify /ʃ, z/, and /f, s, v/ needed fairly longer duration (50ms). On the other hand, /ɵ, ð/ needed full frication duration to be distinguished. The researcher concluded that full duration may not be needed to discriminate fricatives and noise duration was not robust cue to categorize fricatives as an only parameter.

Contrary to the finding of Jongman (1989), Whalen (1991) claimed that entire noise duration carried necessary information to discriminate the two voiceless sibilant fricatives /s, ʃ/. On the other hand, a recent study conducted on syllable initial fricatives (CV) examined the role of lengthening frication duration and formant transition duration in perception of fricatives and exhibited contrasting result. The result signified that the increment of the duration of formant transition by 50% increased the percept, while lengthening the frication duration with 50 % and 100% did not change the perception of the sounds. Based on the result, the author concluded that duration was not robust cue to place of articulation and voicing (Shobha 2012).

2.4.2 Amplitude

Like duration, noise amplitude has been utilized as an acoustic cue to characterize fricatives (Strevens 1960; Heinz and Stevens 1961; Shadle 1985; Gurlekian 1981). In most of the earlier works amplitude distinguished sibilant fricatives from nonsibilants. The studies displayed that sibilant fricatives had higher amplitude, while the nonsibilant ones had lower amplitude. For instance, Behrens and Blumstein (1988) found that the amplitude of the nonsibilant fricatives was from 15-21 dB less than the amplitude of adjacent vowels, whereas the amplitude of the sibilant fricatives was from 2-6 dB less than that of the adjacent vowels on average. Strevens categorized fricatives into three distinctive groups: front, mid and back, with each place being characterized with different intensity levels. The researcher observed that the front fricatives were characterized by low intensity and lengthy spectra, while the mid fricatives showed dominance of energy at higher frequency level and had higher amplitude. On the other hand, the back fricatives

had intermediate amplitude compared to the two groups and their spectrum also fell between the two groups in length.

Works conducted so far on noise amplitude of fricatives employed different methods and reached different conclusions. The studies examined fricative-vowel (FV) syllables by cross-splicing the amplitude of one fricative with formant transitions appropriate to other fricatives. The works obtained results in which amplitude cues discriminated sibilant fricatives from nonsibilants (McCasland 1979a, b; Gurlekian 1981). Lower amplitude of the fricatives resulted in more nonsibilant percepts, while the high amplitude turned out to be perceived more as sibilants. Based on the findings, the scholars concluded that amplitude was a robust cue to discriminate fricatives in terms of places of articulation.

Gurlekian (1981) examined the role of amplitude in discriminating the two Spanish voiceless fricatives /s, f/ and obtained similar results. He employed synthetic fricatives followed by /a/ at fixed noise amplitude. The synthetic fricatives had noise information appropriate to /s/ in natural speech, while the vowel had the vocalic formant transition associated with bilabial feature. That is, the spectral feature was related to /s/ and the vocalic attribute was associated to /f/. Finally, the stimuli were presented to six Argentine Spanish, and six speakers of American English to discriminate the fricatives. The result exhibited that both speakers of Spanish and American English identified the fricative with higher amplitude as /sa/ and the one with lower amplitude as /fa/. Thus, this result suggested that amplitude can be taken as invariant cue to categorize fricatives as a function of place of articulation.

Contrary to the aforementioned studies, Behrens and Blumstein (1988) found different result by following different methods. The scholars state that the aforementioned studies have methodological limitations. They argue that methods used by McCasland (1979a,b) was not sound to draw reliable conclusion because the result obtained may be attributed to either the manipulated amplitude or the conflicting formant transition. The mere fact that the lower amplitude resulted in more nonsibilant percept and the increment of the amplitude gave rise to more sibilant responses did not mean that amplitude was the sole attribute to discriminate fricatives. The formant transitions should be both compatible and incompatible to compare the contrast.

Behrens and Blumstein (1988) examined the role of amplitude by utilizing naturally produced voiceless fricative consonants. The four voiceless test fricatives / f, ɵ, s, ʃ/ preceding the three quantal vowels /i, a, u/ were produced by two phoneticians and processed for listening experiment. The amplitude of the sibilant fricatives /s, ʃ/ was decreased to be appropriate to that of the nonsibilant fricatives; conversely, the amplitude of the nonsibilant fricatives was also increased to be fitting to that of the sibilant ones. Finally, the data was presented to twenty listeners to identify the fricatives. The result indicated that: 1) unlike in the previous studies, when the amplitude and the formant transitions were appropriate to test fricatives, the manipulation of the amplitude played little role. 2) In agreement with the previous studies, decreasing the amplitude of the sibilant fricatives resulted in more percept of /f/ and /ɵ/. 3) Contrary to the previous studies, increasing the amplitude of the nonsibilant fricatives did not result in more responses of the sibilant fricatives. Based on the result, the scholars have drawn two key

conclusions. 1) Amplitude varies together with spectral properties and 2) the spectral parameters, rather than amplitude cues, are salient features to discriminate fricatives.

Hedrick and Ohde (1993) explored relative amplitude of synthetic prevocalic fricative consonant contrasts /s/-/ʃ/ and /s/-/ɵ/ in F3 and F5 frequency regions. They varied different parameters such as frication duration from 30 ms to 140 ms, cross-splicing frication noise with different incompatible formant transitions, and varying formant transition and amplitude of the given spectral region without altering relative amplitude. Furthermore, to test the effect of amplitude and spectral parameters, the experimenters presented the frication portion separately and inserted silent-gap between frication noise and vocalic portion. The stimuli were presented to listeners for identification. The result revealed that "relative amplitude was perceived across vowel context and frication duration, and overrode context-dependent formant transition cue" (p.2005). The experimenters suggested that the role played with duration was less crucial in distinguishing the fricatives because as short as 30 ms duration may suffice to distinguish some fricatives. They concluded that although formant transition and duration affect the perception of the test fricatives, they were not as salient as the relative amplitude.

Many other studies reached similar conclusion with Hedrick and Ohde (1993) that amplitude (both relative and RMS) distinguish fricatives in terms of places of articulation (Jongman et al. 1998; Nissen and Fox, 2005; Fox and Nissen 2005; Koenig et al. 2008), at least sibilant fricatives from nonsibilant ones. Jongman and colleagues explored the eight voiced and voiceless English fricatives employing spectral, duration and amplitude attributes to discriminate the sounds in terms of place of articulation. The result indicated

that the noise amplitude robustly discriminated all places of articulation of the fricatives. The result also signified that noise amplitude varied as a function of voicing. Voiceless fricatives revealed significantly higher amplitude than their voiced cognates (-11.1 and -15.9 dB, respectively), relative to the adjacent vowels. In their subsequent study conducted on American English fricatives, Jongman et al. (2000) found similar result utilizing both dynamic and static cues. They observed that both relative and normalized amplitude discriminated all fricatives in terms of places of articulation.

Studies conducted on both adults and children also found that amplitude discriminates fricatives in terms of sibilance (Fox and Nissen 2005; Nissen and Fox 2005; Koenig et al., 2008). Nissen and Fox found that normalized amplitude was robust to distinguish sibilant fricatives from nonsibilants. The normalized amplitude for sibilant fricatives (-3.6 dB for /s/ and -3.0 dB for /ʃ/) was significantly higher than that of the nonsibilant fricatives (-13.7 dB for /f/, -11.9 dB for /ɵ/). Fox and Nissen also obtained similar results that sibilant fricatives revealed significantly higher amplitude than their nonsibilant counter parts. Koenig et al. (2008) explored three fricatives /s, z, h/ produced by adults and children and found that amplitude robustly discriminated sibilant fricatives /s, z/ from the voiceless glottal fricative /h/. Furthermore, amplitude also varied as a function of age. Children exhibited higher amplitude than adults. Thus, though there were contrasting reports whether amplitude was salient cue or not, studies predominantly display that amplitude is a robust cue to discriminate fricatives as a function of sibilance and in terms of place of articulation and may also vary as a function of age and gender. The present study also examine whether amplitude discriminate fricatives as a function of age and gender.

2.4.3 Spectral Cues

The noise spectra of fricatives have been the most utilized and the most reliable attribute compared to other features. In this study spectral features include spectral peak location, spectral moments (spectral mean, spectral standard deviation, spectral skewness and spectral kurtosis) and transition cues (locus equation and F2 onset). The role of these features in characterizing fricatives in terms of places of articulation was discussed as follow.

2.4.3.1 Spectral Peak Location

Spectral peak location characterizes sounds by classifying them in terms of energy dominance in different frequency regions. Jongman et al. (2000) define spectral peak location as "the highest amplitude peak of the FFT spectrum" (p.1255). Earlier studies employed the peak of the fricative spectra to categorize the sounds in terms of place of articulation (Hughes and Halle 1956; Strevens 1960; Heinz and Stevens 1961). The most known role of spectral peak was that it distinguished sibilant and nonsibilant fricatives. Sibilant fricatives have energy dominance at higher frequency region (from 3.5- 5 kHz for /s/ and 2.5- 3.5 for /ʃ/, while it was 1.4- 2 and at 7- 8.5 kHz for /f/ and /ɵ/ (Behrens and Blumstein 1988). Different studies also indicated that spectral peak location classified within sibilant fricatives as a class. The alveolar /s, z/ and postalveolar sibilants /ʃ, ʒ/ can be discriminated on the basis of their spectral peak (Heinz and Stevens 1961; Hughes and Halle 1956; Strevens 1960; Shadle 1985; Jongman et al. 1998). The studies reported that the alveolar sibilants had higher peaks than the postalveolar sibilants.

Hughes and Halle (1956) explored prevocalic and postvocalic fricative consonants produced by males and females in isolated words. They used large window of 50 ms for spectral analysis. They extracted spectral peak of the fricatives produced by different individuals and made qualitative observation. They found that spectral values and the line spectra discriminated fricatives, regardless of individual variations. They found the spectral energy of the voiced fricatives /v, z, ʒ/ was stronger at lower frequency region, around 700 Hz, and observed that the spectral peak was inversely related to the length of the cavity downstream. Consequently, /s, z/ have spectral peak location at higher frequency region than /ʃ, ʒ/, and because /f, v/ have no or little front cavity, they do not have clear peak below 10 kHz. Similar study was conducted by Manrique and Massone (1981) on Argentine Spanish fricatives and found that the peak distinguished fricatives as a function of place of articulation. The scholars reported that "/s/ spectrally peaks around 5000 and 8000 Hz, /ʃ/ around 2500 and 5000 Hz, /f/ around 1500 and 8500 Hz, Ix] around 1000 and 4000 Hz and [ç] around 2000 and 4000 Hz" (p. 1145).

Strevens (1960) investigated nine voiceless fricatives /ɸ, f, ɵ, s, ʃ, ç, x, χ, h/ produced by trained phoneticians and found that spectral peak distinguishes the fricatives. Front fricatives exhibited less clear spectral peak and long spectrum, with low intensity; the mid fricatives had shorter spectrum, higher spectral peak and higher intensity. The back fricatives, on the other hand, showed "formant-like pattern of energy", and intermediate intensity compared to the other two groups (p. 32).

A study conducted on American English fricatives by Jongman et al. (1998) depicted interesting patter of variations among the sounds. Like in other studies discussed so far, the location of the peak categorized sibilant from nonsibilant fricatives and alveolar

sibilants from postalveolar sibilants. The vivid pattern in the study was as the palace of the articulation moves back in the vocal tract, the peak becomes lower. It is 7678 Hz for labiodentals /f, v/, 7503 Hz for inter dentals /ɵ, ð/, 6882 Hz for alveolars, and 3712 Hz for postalveolrs /ʃ, ʒ/. But the peak failed to distinguish labiodental fricatives /f, v/ from the interdental ones /ɵ, ð/. The location of the spectral peak also varied as a function of gender. As expected, the spectral peak was higher for female speakers compared to that of male speakers (6809 Hz and 6066 Hz, respectively).

Similar result was obtained from the study conducted by Jongman et al. (2000) on American English fricatives /ʃ, ʒ, s, z, ɵ, ð, f, v/ by utilizing different acoustic parameters, among which the spectral peak location was one. They obtained clear pattern of distribution of the location of the peak across the place of articulation of the fricatives: 7733 Hz for labiodentals, 7470 Hz for dentals, 6839 Hz for alveolars, and 3280 Hz for postalveolars. The scholars observed that as the place of articulation moves anterior in the vocal tract, the spectral peak location of the fricatives increases. Besides distinguishing sibilant and nonsibilant fricatives, spectral peak in this work categorized all places of articulation. The study also revealed that the location of the peak varied as a function of voicing. Voiced fricatives revealed significantly lower spectral peak (6310 Hz) than their voiced cognates (6612 Hz). Furthermore, the spectral peak location also depicted different values for males and females. The average spectral peak of males was significantly lower than that of females, 6122 Hz and 6800 Hz, respectively. Another discrepancy observed between males and females was that the spectral peak value for males decreased as the place of articulation moves posterior in the vocal tract, but the female speakers depicted higher average peak values for dentals than labiodentals.

The result obtained by Fox and Nissen (2005) examining the acoustic features of American English voiceless fricatives (s, ʃ, f, ɵ) produced by adults and children revealed that spectral peak categorized all places, except /f/ and /ɵ/. The result displayed that the peak increased as the place moves anterior in the oral cavity (4518, 7497, 8056, 8348 Hz for /ʃ, s, ɵ, f/, respectively. Spectral peaks varied as a function of gender, too. The spectral peak of males (6895 Hz) was significantly lower than that of females (7365 Hz). The peak also varied for age. Spectral peak of younger children of age of 6-7 and 8-9 was significantly higher than that of older children and adults. The average spectral peaks for the speakers were 7357 Hz for 6-7 years old, 7384 Hz for 8-9 years old, 6851 Hz for 10-12 years old, 7229 Hz for 13-14 years old and 6822 Hz for adults.

2.4.3.2 Spectral Moments

Spectral moments, outlined by Forrest et al. (1988), are acoustic attributes which quantitatively characterize speech sounds employing the distribution of spectral information based on noise spectra of fricatives. Spectral moments include four metrics used in acoustic study of sounds: the first spectral moment (mean), the second spectral moment (standard deviation or variance), the third spectral moment (skewness) and the forth spectral moment (kurtosis).

Each moment serves different purpose in speech analysis (Jongman et al. 2000; Li et al. 2011). The first moment (M1) or center of frequency reveals the mean distribution of noise energy (of fricatives) in speech spectra and is inversely related to the cavity anterior to the source of sounds. That is sounds with longer front cavity have lower spectral mean compared to those with shorter front cavity. The second spectral moment (M2), on the

other hand, indicates the distribution of noise energy or the deviation of the noise energy in relation to first spectral moment or mean. Briefly put, it is an "index of variance" (Li et al. 2011, p. 1001). The third spectral moment (M3) deals with the noise energy tilt, thereby indicating the distribution of energy in higher or lower frequency region. The distribution of energy could be either positively skewed or negatively skewed. Positively skewed distribution indicates negatively tilted energy distribution, while negatively skewed energy reveals positively tilted energy. Jongman and colleagues explain that positively tilted energy indicates the dominance of energy in the lower frequency region while negative tilt exhibits the dominance of the energy in the higher spectral frequency region. Thus, the magnitude of spectral skewness is inversely related to the height of peak of energy. The fourth spectral moment (M4) deals with the peakedness of the noise energy. As discussed by Jongman et al. the positive kurtic value reveals "a relatively high peakedness (the higher the value, the more peaked the distribution), while negative values indicate a relatively flat distribution." (p. 1253). Positive values also depict clear peaks, while negative values indicate less defined or diffuse peaks.

An earlier work which outlined spectral moments, Forrest et al. (1988), described word initial fricatives and stops produced by ten adult speakers of American English. The authors examined the voiceless fricatives /f, ɵ, s, ʃ/ and analyzed the moments extracted from 20 ms sized windows. The random distribution of FFT noise spectra yielded measures of the moments for analysis. The scholars utilized the first, the third and the fourth spectral moments. The spectral values were computed by using both linear and bark spectra. The result exhibited that nonsibilant fricatives were not discriminated well in the analysis employed (only 75% for /f/ and 58% for /ɵ/). The discrimination of the

sibilant fricatives was, however, fairly better than that of the nonsibilant ones (85% for /s/ and 95 % for /ʃ/).

Subsequent studies which employed spectral moments both in child and adult language also found that the spectral moments discriminated speech sounds in terms of different parameters. For instance, a developmental study conducted by Nittrouer (1995) on voiceless sibilant fricatives /s, ʃ/ and voiceless stops /t, k/ produced by typically developing children of 3-7 years of age and adults made different observations. The study was conducted to examine developmental patterns which underscore child-adult variation by utilizing the first, the third, and the fourth spectral moments. As expected, the average value of M1 of children was higher than that of adults. Nittrouer attributed the discrepancy between children and adults to anatomical variations. That is the cavity in front of the source of the fricatives is smaller in children and resulted in higher spectral mean. The average value of M1 for /s/ across all age groups was higher than that of /ʃ/. Interesting coarticulatory effect was also obtained in the study. The mean values of M1 of fricatives were significantly higher before the front vowel /i/ than the two back vowels /u, ɑ/. The author concluded that the anticipatory coarticulatory effect, triggered by the front vowel, reduces the front cavity and increased the frequency of M1. The difference between the mean value of /s/ and /ʃ/ was higher in adults than in children. This would give us the impression that the children were yet to achieve adult-like articulatory gesture. The average M3 score revealed that adult's noise spectra was more positively skewed than that of the children. The distribution of the values was also somewhat positively skewed for /ʃ/ than for /s/. M4 exhibited that the spectra of /ʃ/ was somewhat flatter than the spectra of /s/.

Other studies conducted on child and adult speech also employed spectral moments and the values varied as a function of different acoustic attributes (Nissen and Fox 2005; Fox and Nissen 2005). Nissen and Fox analyzed prevocalic American English voiceless fricatives /ɵ, f, s, ʃ/ produced by typically developing children of between 3 and 6 years of age and adults. Frequencies of the moments were extracted from 40 ms window positioned at the center of frication noise. The spectral mean discriminated three places of articulations of fricatives, without significant difference between /ɵ/ and /ʃ/. Surprisingly, the spectral mean of /ɵ, s, f/ was higher for males than for females. The scholars attributed such unexpected result to higher spectral mean value of male children. Like the result reported by Nittrour (1995), the difference between /s/ and /ʃ/ was nonsignificant in children of 3 and 4 years of age. But in other groups of children and adults, spectral mean of /s/ was higher than the average value of spectral mean of /ʃ/. The second spectral moment distinguished all fricatives in terms of place of articulation. The average scores of M2 for the fricatives /f, ɵ, s, ʃ/ were 6.26, 5.38, 2.39, and 3.30MHz, respectively. In addition, the work revealed, the mean value of the spectral variance of the nonsibilant fricatives was higher than the average value of spectral variance of the sibilants. Though main effects of place was obtained for the dependent measures of moments in this study, only the second spectral moment significantly distinguished all fricatives as a function of place of articulation. Another interesting feature was that the more children advance in age, the more they discriminate /s/and /ʃ/. Furthermore, the spectral value of kurtosis for females was significantly larger than that of males.

Similar study was conducted by Fox and Nissen (2005) on speech produced by children and adults. They examined voiceless fricatives produced by children of 6 -14 years of age utilizing different spectral moments and other attributes. The major goal was to discriminate fricatives, there by analyzing the discrepancy between children and adults. In this study only /ʃ/ varied significantly from other fricatives /f, ɵ, s/ in terms of spectral mean. The result revealed that the spectral mean of males (6910 Hz) was significantly lower than the average spectral mean of females (7140 Hz). Consistent with the result reported by Nissen (2003), the average measures of spectral mean of younger talkers were higher than that of the older ones. In addition, the mean value of M1 of adults was higher for nonsibilant fricatives than the mean value for the sibilant fricatives. The value of the spectral skewness was higher for younger children and the overall picture depicted that males have higher spectral skewness. Spectral kurtosis discriminated sibilant fricatives from nonsibilants and within sibilant themselves. The kurtic value of females was higher than the mean value of spectral kurtosis of male speakers.

A study conducted on syllable initial voiced /v, ð, z, ʒ/ and voiceless /f, ɵ, s, ʃ/ fricatives produced by 20 adult speakers also employed spectral moments and found that the moments varied as a function of different attributes (Jongman et al., 2000). The moments were computed using FFT spectra from 40 ms full hamming window positioned at four places across the noise spectra: at the beginning, middle, end, and at the transition of consonant and vocalic portion. The result indicated that the moments discriminated, at least three places of articulation. The average value of the spectral mean for the alveolar fricatives /s, z/ (6133 Hz) was significantly higher than the mean value of postalveolar fricatives /ʃ, ʒ/ (4229 Hz), While the average value of spectral mean for the labiodentals

/f, v/ was intermediate between the two classes (5108 Hz). The work depicted that the spectral variance of the sibilants was lower than that of the nonsibilants. Except the difference between /f, v/ and /ɵ, ð/, all the other places were significantly distinguished in terms of spectral variance. The experimenters observed that the highest mean spectral skewness emerged out for /ʃ, ʒ/, signifying that the sounds have dominance of energy in the lower frequency region. The difference between /f, v/ and /s, z/ was also not significant on the basis of spectral skewness. But both groups had high kurtic values which indicate that they were peaked.

Apart from differentiating fricatives in terms of places of articulation, the study by Jongman et al. (2000) revealed that the moments also vary as a function of other features such as voicing and gender. Voiced fricatives had lower values of the first (5036 Hz), the third (-0.009) and the fourth (1.38) moments than their voiceless counter parts which were 5267 Hz, 0.238 and 1.7, respectively. The three spectral moment values: the mean (5018 Hz), variance (4.5 Hz), and kurtosis (1.44) of males were significantly lower than the mean (5286 Hz), variance (4.9), and kurtosis (1.64) of females. But the mean spectral skewness of females (0.084) was significantly lower than the mean spectral skewness of males (0.145). Based on this result the scholars concluded that "compared to males, the spectra of females had clearer peaks and concentration of energy towards higher frequency" (p. 1257).

2.4.3.3 Locus Equation

Locus equation is an acoustic attribute which classifies consonants based on coarticulatory effect of an adjacent vowel. It is "the frequency of the second formant at vowel onset against the target frequency of the same formant for the vowel in a consonant–vowel sequence, across different vowel contexts" (Lofqvist 1999, p. 2022). The scholar states that locus equation indicates the degree of coarticulation between consonants and vocalic segments in which greater slope signifies more coariculatory tendency of a segment. F2 is computed at two places of frequency regions: at the vowel on set and at the midpoint of the vowel. And the slope of second formant frequency value at the onset of vowel (F2o) is fit to the F2 of the steady state or F2 frequency at the center of a vowel (F2v) to compute the slope. Though different studies employed locus equation to examine stop consonants (e.g., Lindblom 1963; Sussman et al.1991; Lofqvist 1999), it was recently that the parameter has been used to examine fricatives.

Different studies utilized locus equation and found different results whether locus equation distinguishes fricatives in terms of place of articulation or no. Fowler (1994) examined word initial obstruents in perceptual study and found that locus equation could vary based on different phenomena. The scholar found that locus equation was not robust cue when employed to test features other than place, such as manner of articulation. A discriminant analysis conducted to classify consonants spanning six places failed to yield promising result. Thus, the author concluded that locus equation was not salient cue to differentiate consonants in perception. Jongman (1998) also found that locus equation plays marginal role in classifying fricatives. The scholar concluded that rather than relying on a single cue to distinguish speech sounds, it is better to employ multiple cues.

Similarly, Jongman et al. (2000) analyzed locus equation and observed that the parameter was less robust to discriminate fricatives in terms of place of articulation. The work indicated that slope of locus equation distinguished only one place out of four. Only the average value of /f, v/ was statistically different from the rest. The average value of the y-intercept also distinguished only two places: /f, v/ and /ʃ, ʒ/, were significantly different, while /ɵ, ð/ and /s, z/ were not. Similarly, the mean value of F2o failed to distinguish /ɵ, ð/ and /s, z/. But the overall measure of F2 at onset of fricatives signified that as the place moves anterior in the oral cavity, the value decreases. Sussman and Shore (1996), on the other hand, conducted study on alveolar sounds /t, d, n, z, s/ utilizing locus equation and identified that the cue effectively classified obstruents in terms of place of articulation. A discriminant analysis conducted using slope and y-intercept classified the five obstruents 87.1%.

Some scholars attribute the less effectiveness of locus equation in distinguishing fricatives to the nature of the sounds (Tabain 2000; 2002). Tabain found that locus equation was not robust cue to classify fricatives in terms of place of articulation. The scholar suggested that the reason behind this fact emanates from the nature of fricatives themselves. The frication noise passes over to adjacent vocalic portion and disturbs the appropriate measurement of F2. This implies that the salience of acoustic cues may depend on the nature of speech sounds under investigation. Thus, rather than generally classifying cues as robust or not, the nature of test segments also need to bet taken into consideration.

2.4.3.4 Summary

Different works reported different results on the acoustic parameters discussed so far. But the works converge to some key points. Sibilant fricatives in many studies were characterized with longer durations than nonsibilant fricatives. Voiced fricatives were also marked for their shorter durations compared to their voiceless counter parts, though some perceptual works reported that there were overlaps between the two. In the same manner, spectral peak location of sibilant fricatives was reported to be higher than that of the nonsibilant fricatives. The peak also distinguished within the sibilant fricatives, the alveolar ones being characterized with higher peak. Another general observation reported in many studies was the peak increases as the place moves anterior in the vocal tract, consistent with the size of anterior cavity. The spectral peak location was also reported to be varied based on anatomical differences between different speakers. Thus, child and female speakers were characterized with higher spectral peak compared to adults and male speakers.

Noise amplitude was reported in some studies to be robust and not in others. But many works reported that it saliently distinguished sibilant and nonsibilant fricatives. For instance, sibilant fricatives showed higher normalized amplitude compared to nonsibilant fricatives. Furthermore, noise amplitude also was reported to vary as a function of age. Speech produced by child speakers was characterized by higher amplitude compared to that of adult speakers.

The spectral features were reported to be the most salient of all features, though there were differences among different works. Many studies indicated that the spectral mean of alveolar fricatives was higher than the other places. Furthermore, the average value of the

moment produced by child and female speakers were higher than that of adult and male speakers. The second spectral moment or standard deviation or variance in different works was effective to distinguish all palaces of articulation of fricatives. Spectral skewness of the alveolar fricatives was lower than other places, marking the sounds with dominance of energy in higher frequency region. Similarly, spectral skewness produced by child speakers was also lower than the value of the moment produced by adult speakers. The spectral kurtosis produced by female speakers was higher than that of male speakers, signifying that fricatives produced by females to be more peaked and well defined.

Finally, the majority of works conducted on locus equation reported that it was less robust or poorer compared to other acoustic attributes. But some scholars (e.g., Jongman et al., 2000) reported that the average value of F2o increases as the place of articulation moves posterior in the vocal tract. Nittruoer (1995) attributes this feature to the size of the back cavity of the source of fricatives. The scholar states that F2 of fricatives, unlike that of vowels is the result of the cavity behind the source which entails that as the places move back, the value of F2 elevates.

2.5 Geminate vs. Singleton Fricatives

Geminate consonants are produced when the constriction is maintained for relatively longer duration than singleton consonants. Many studies (e.g., Hassan 2002; Kraehenmann 2001; Muller 2001) attribute the discrepancy between singleton and geminate consonants to duration. Some studies indicated that the length of geminate consonants is relative and there was no clear cut durational difference between geminate

and singleton segments across consonants. The reason behind this fact was that some consonants were inherently longer than others. In such cases the duration of a singleton consonant may be equivalent or only slightly longer than other geminate consonants. For instance, a singleton fricative may be longer than other shorter geminates (Aoyama and Reid 2006). Contrary to this claim, other studies revealed that the duration of geminate consonants was double of their singleton counter parts (Al-Tamimi 2015; Arvaniti 2001). Such discrepancy among different studies may be because of language specific features which affect the difference between singleton and geminate sounds.

Based on the view of inherent nature of consonants, some works identified that different classes of consonants may have different singleton-geminate contrast in duration. For example, Aoyama and Reid (2006) found that the mean duration of shorter and longer singleton consonants were 67ms and 99ms, respectively, while that of the shorter and longer duration of geminates were 120 ms and 151ms. The researchers also found that the difference between singleton /s/ and geminate /ss/ was the narrowest compared to that of other consonants (99 ms and 120 ms, respectively). According to the work, gemination varies on the basis of manner of articulation of different segments and may differ from language to language. Aoyama and Reid also state that the occurrence of gemination may prefer some places of articulations to others because "alveolar was the cross-linguistically preferred place of articulation for geminate consonants" (p. 145).

Payne (2006) utilized non-durational parameters to examine acoustic correlates which characterize singleton and geminate consonants. The author analyzed data gathered using electro paleto graphic study (EPG) from a woman in her mid-thirties. The result revealed that the "geminate laterals, coronal stops and nasals" involved more palatalized

articulatory gesture and more contact between the articulators than their non-geminate counter parts (p.91). This non-durational approach to geminate and singleton consonants also indicated that there was difference in articulators involved in the production of singleton and geminate consonants. Geminate consonants tended to use blade of the tongue while their singleton counter parts employed the apical part of the tongue. The author interpreted this result that the more palatalized version of the geminate consonants stemmed from prolonged duration which enabled the articulators to successfully make contact, while such articulatory gesture was not maintained in singleton consonants and the articulatory target was less achieved.

Al-Tamimi and Khattab (2015) made detailed analysis of singleton and germinate fricatives and found that both durational and non-durational cues contributed to the differentiation of singleton and geminate fricatives in Lebanese Arabic. Compared to singleton fricatives, the geminate ones showed higher spectral mean and dynamic amplitude and lower value of the standard deviation. Other qualitative difference emerged from the study was that long vowels at the midpoint and end were centralized and final vowels exhibited breathy phonation. Finally, discriminant analysis was conducted and revealed that the temporal cue was 96% effective to classify singleton from geminate fricatives. Thus, this would give us the impression that though temporal cue is not the sole cue to discriminate singleton from geminate consonants, it is more salient attribute to distinguish the segments. Though some of the aforementioned studies used only some or no spectral moments, the present study differs in using large scale spectral cues to examine the difference between the two phonemes.

2.6 Phonological Development

Studies into child language production take the phonological development into account because children master language acquisition through process. Studies reveal that children first acquire phonemes before they master the sound pattern (e.g., Dodd et al. 2003). Dodd claims that phonetic feature acquisition precedes phonemic features. The scholars define the difference between phonetic and phonemic features as "the term 'phonetic' refers to speech sound production (articulatory/motor skills). The term 'phonemic' refers to speech sound use (functions/behavior/organization of the speech sound system)" (p.618). On the contrary, experimental investigations claim that children first manipulate features in the larger units such a syllable and slowly master segment specific elements (see Snowling and Hulme 1994; Nittrouer et al. 1989). The authors state that the development of phonological skills undergo a series of processes and refinement of units to achieve finer elements. Thus, such pattern of child language development signifies that the process is not haphazard, rather programmed and involves step by step mastery of elements of sound patterns.

Dodd et al. (2003) conducted extensive articulatory study on 684 children aged between 3 to 7 years of age and made different observations. The participants involved different age groups, gender and socioeconomic backgrounds. The study reported that as children advance in age, they become more accurate in production of sound patterns. Thus, they speculated phonetic acquisition precedes phonemic (sound patterns). The work revealed that /m, n, p, b, d, w/ were acquired earlier, while /ɹ, ɵ, ð/ acquired finally. Gender difference in this study was not evident until the age of 5; 1/2 (years and months). Female speakers tended to develop earlier phonologically than males. The experimenters

interpreted such gender discrepancy as "fine motor skills mature earlier in girls than boys" (p.637). They also identified that socioeconomic factors did not influence phonological development of the children.

Children produce speech differently from the norm set by adults. Such child-adult discrepancy disappears through process and slowly achieves the canonical norm. Typically, child speech is marked by "systematic substitutions, additions, deletions, and distortions of target sounds" (Munson 2004, p. 58). Though studies into phonological patterns signify that children by the age of 5 or 6 seem to acquire well intelligible phonemes to adults (Smith and McLean-Muse 1986), they are yet to master finer elements. Speech produced by children at this age may acoustically or articulatorily (the way they move their speech organs) somehow deviate from those of adults. Thus, though the surface phonetic realization of speech produced by children impressionistically appears to be well-formed, experimentally lots of correlates may signify adult-child discrepancies. Such phenomenon is called "covert contrast", which is less evident impressionistically, but could be distinguished acoustically (see Li et al., 2011). Thus, phonological studies which rely solely on traditional phonetic transcription may not fully account for speech variations between children and adults, but may highlight or indicate differences. The reason behind is that the difference between the two groups (child and adult) goes beyond surface utterances, which is shallow and lacks finer elements mastered at adolescence or so.

Acoustically itself there are considerable differences based on the age at which each segment is acquired or the way cues are utilized by children. For instance, a large scale study conducted on children of different ages (Lee et al. 1999) revealed that different phonemes were not acquired at similar age. The scholars observed that temporal variability between children narrows down starting between the age of 9 and 12 and became similar with those of adults by the age of 12. Contrary to this, the discrepancy in fundamental frequency and formant frequencies achieved adult-like production at 14 or 15 years of age. Many other studies also reported that child speech acoustically differed from that of adults (Nittrouer 1988; Nittrouer et al. 1989; Nittrouer 1992; smith 1978; Smith and Sugarman 1983; Smith 1992; Smith et al. 1983; Koenig 2000; Koenig et al.2008; Munson 2004; Mayo and Turk 2003, among others). The account of the studies showed that adult-child discrepancy in speech involved temporal, spectral and amplitude cues.

It has been reported that there was considerable temporal difference between child and adult speech. Child speech was predominantly characterized by longer and less persistent speech compared to that of adults (Smith 1978). Smith observed that adults were better at controlling duration of speech than children. On the contrary, though children also revealed attempt to control timing, they were not effective compared to adults. As a result, child speech was marked by longer duration. Smith (1992) conducted study on similar issue and found that duration and temporal differences decreased as children advance in age. Besides, it has been reported that the magnitude of duration was more similar to that of adult speech than trial-to-trial in speech produced by the children. Thus, the results suggest that children attempt to produce speech sounds similar with that of

adults, but because of different factors their speech differ from the norm and develops through process.

McGowan and Nittrouer (1988) explored fricatives produced by children and adults and observed that speech produced by children was characterized by three features: "(1) they were generally higher in frequency; (2) they were greater in amplitude relative to higher frequency regions; and (3)they showed greater effect of vowel context" (p.229). Similarly, Koenig et al. (2008) also found in study conducted on 5 and 10 years old children that child speech varied both in amplitude and duration from those of adults. Both acoustic correlates were more variable in child speech compared to speech produced by the adults. But it turned out to be that the amplitude cue in children was more similar with adult compared to duration. On the other hand, Smith et al. (1996) observed that though durational length decreases and temporal variability narrows down when children increase in age, such phenomenon may not be true for all children. That is, there was difference in the age at which cues were acquired, and there were individual variations between children.

Perceptual studies revealed that children tend more to weigh transitional cues than adults (e. g., Nittrouer and Studdert-Kennedy 1987; Nittrouer et al. 1989; Nittrouer and Miller 1997; Nittrouer et al. 1996). Nittrouer and Studert-Kennedy observed that child speech revealed larger overlap with a following vowel and their responses were more variable than those of adults. They postulated that children initiate their articulatory process at larger units first and master phoneme boundaries through time. Contrary to this finding, other studies have argued that there was no coarticulatory difference between speech

produced by children and adults (Katz et al. 1991; Goffman et al. 2008). These studies viewed variations from different angles: child speech was less intelligible (Katz et al. 1991) and physiologically more variable (Goffman et al. 2008). Still the third view also claims that adult speech was marked by its more tendencies towards anticipatory coarticulation than child speech (Sereno et al. 1987). Perceptual studies, on the other hand, suggested that there were differences between adults and children in weighing the acoustic cues based on language experience, the nature of the segments and strategies children use (Mayo 2000; Mayo et al. 2003; Mayo and Turk 2004; 2005).

Another interesting process in phonological development is concerned with the sequence of the acquisition of speech sounds. This may proof difficultly to readily characterize cross-linguistically because there are language specific features. Li et al. (2011), for instance, conducted study on the two sibilant fricatives /s, ʃ/ in English and Japanese and observed some language specific variations. Language specific studies have postulated some orders in acquisition of sounds, at least which sound is acquired first and which one last. The works displayed that fricatives were acquired latter than stops (Song et al. 2013). Lehr (2000) states the sequence of the acquisition of sounds that "children generally first acquire the nasals, followed by the stops, glides and liquids, fricatives and affricates". This may give us the impression that children are economical in their acquisition of sounds because fricatives involve complex articulatory and aerodynamic processes and need higher precision (Ladefoged and Maddieson 1996; Iskarous et al. 2011). Hence, children delay the sounds till they are anatomically and physiologically mature enough.

Phonological development also highlights child production of age appropriate segments. In this process failure to produce a segment at some age level may be attributed to developmental factors or speech disorder. Dodd (1995) states that children from 5 to 6 years of age may commit mispronunciation. The author warns that the reason must be known well before hastily concluding the result. The same is true in speech disorder. Forest et al. (1990) found that children with disordered speech failed to produce the voiceless velar stop /k/. The typically developing children in the study distinctly produced /t/ and /k/. On the contrary, the phonologically disordered children substituted /t/ for /k/. Such discrepancy in phonological development between typically developing children and phonologically disordered children also has effect in spectral displays. Forest et al. (1994) found that there were anomalies in the spectral characteristics of the word initial stops produced by normal and phonologically disordered children. Thus, phonological development is an index of both phonetic and phonemic acquisition processes. But phonological studies, if conducted purely impressionistically, may not account for all segmental variations and adult-child discrepancies; rather if the two approaches supplement each other, they may yield reliable results.

To sum up, different works indicate different aspects of language acquisition whether phonetic (speech sounds) or phonemic (sound patterns) are acquired first. But the two approaches converge to the view that children master phonological development through processes. The generally agreed upon fact is that children and adults produce speech differently. Most articulatory or impressionistic studies reported that children master a great deal of speech sounds between the age of 5 and 6 (Smith et al. 1990). On the contrary, experimental works indicated that there exist differences between speech

produced by children and adults in terms of acoustic parameters roughly until the age of 14 or 15 (Lee et al. 1999). While some works exhibited that children seldom distinguish between phonetic boundaries at their early age, the extent to which the claim was true was not agreed up on. But the general view was that child speech was more variable compared to adult speech and become developed in due course. The child-adult discrepancy may also be conditioned by some speech disorder. Thus, the case should be identified in view of normal language acquisition. Finally, language specific features also may bring variations cross linguistically among children of the same age and adults.

CHAPTER THREE

METHODOLOGY

This chapter deals with the general methods employed in the study. The methods in the present work were framed following previous approaches outlined by different scholars (Forest et al. 1988; Jongman et al. 2000; Nissen 2003). The design includes the participants (children and adults), data recording, segmentation of signals from wideband spectrogram and waveform, and the general procedures. Finally, different statistical analyses utilized in computing the measurements, including the discriminant analysis were outlined as follows.

3.1 Participants

The study was conducted on 48 children between the age of 3 and 6 (from 3; 0 to 3; 11, 4; 0 to 4; 11 and 5; 0 to 5; 11, year; month, 16 children in each group) in comparison with an adult group (N=16).The children were students of Dandi Boru KG and elementary School in Eastern Hararghe Zone of Oromia region. The adult speakers were preparatory students of Kersa Senior Secondary School, of the same region and area with child speakers, and their ages were from 19 to 23 years. The study included equal participation of both sexes (8 males and 8 females from each age group). All the participants were speakers of the Hararghe Oromo variety. The dialect was selected for the study because of its proximity to the university where the researcher taught so that he could have easily access to the data. The voiceless velar fricative was examined phonologically and turned out to be allophone of /k/ and was excluded from the study. All the speakers were checked to have visible front incisors (both upper and lower) at the time of the data

gathering. To avoid data from disordered speech, the parents and teachers of the children were asked if the children had language, speech, voice or hearing disorders and all were free from such problems. The children were given a pretest for age appropriate production of fricatives using some sample data before the final data gathering. Following Koenig et al. (2008), the children's proper hearing ability also was checked letting them listen to sounds at 25 dB from the frequency range of 250 to 800 Hz. The data was gathered from the participants with their full consent to give the acoustic information. The children were approached friendly and given some chocolate after the completion of the elicitation.

3.2 The Stimuli

The stimuli comprises test words which have the four Oromo fricatives [f, s, ʃ, h] at word initial and word medial positions followed and preceded by the two quantal vowels (i, u). The vowels were selected purposely to check front-back coarticulatory effect discrepancies. The test words include both actual and nonsense words because it is difficult to get all age appropriate actual words. Special focus was given to vowels preceding and following the fricatives, but the word final vowels in the VCV context were not controlled. Though coarticulatory effect of this final vowel context may affect the results of the acoustic measures, the effect was minimized because the measurements were taken from the centre of fricatives (Nissen and Fox 2005). The stimuli include both singleton and geminate forms as given in table 3.

Table 3.List of test words for the analysis of fricatives.

No.	**Words**	**Gloss**
1	Siree	bed
2	Gisaa	a type of scarlet made of palm tree
3	Busaa	malaria
4	Sunii	nonsense
5	Tissaa	nonsense
6	Lussaa	nonsense
7	ʃifii	small things
8	biʃaan	water
9	ʃumee	Personal name
10	buʃii	nonsense
11	giʃʃoo	nonsense
12	luʃʃee	nonsense
13	Filaa	comb
14	Sifuu	nonsense
15	Furuu	to untie
16	ɗufuu	to come
17	Miffaa	nonsense
18	Nuffuu	to become fed up
19	Hiree	chance
20	Mihaan	with utensils
21	Hubuu	to affect somebody (something)
22	Muhee	nonsense

Each stimulus was repeated 5 times. Thus, 110 tokens (22 words x 5 repetitions) were recorded for each participant. The stimuli were not embedded in carrier phrases or words because the data would be bulky and tempting the children's attention and patience. The data was gathered by using 'say after me' method. Different approaches such as picture naming were not used because the stimuli included nonsense words; thus, similar approach has to be used for all stimuli. An adult speaker of the dialect read the words with comfortably loud voice, and children repeated the words after him while the recording took place. The adult speakers were given lists of the words with test fricatives and recorded by reading loudly. From the five repetition of each token, the middle three were used for further analysis. From a total of 7,040 tokens recorded (22 words x 5 repetitions x 64 speakers) 4224 middle tokens were utilized for the final analysis.

3.3 Recording

The recoding of the data took place in quiet classrooms and offices. The head-mounted high fidelity microphone (Model PMD 661 and Rode NTG-2 condenser microphone) and Marantz solid state recorder was used to record the data. The microphone was placed at 45 degree and an average distance of 15 centimeter from the mouth of the speakers to minimize frication noise source directly impinging onto the microphone (Jongman et al. 2000). All the recordings were sampled at 44.1 kHz, low-pass filtered at 22.05 kHz and quantized at 16-bit. The data was recorded and filtered at this higher sampling rate and filtering because the speech produced by children might have energy at higher frequency region, sometimes beyond 10 kHz.

3.4 Data Analysis

All the data analyses processes in the present study were done using praat software package, version 5.3.57 (Boersma and Weenink, 2013,). The details of the analysis have been given as follows.

3.4.1 Segmentation of Speech

In this study, waveform and broadband spectrogram were utilized for the segmentation of the signals. The segmentation process mainly focused on the onset of fricatives, the offset of the fricatives, the onset and the offset of vowels and the beginning and the end of the words. All the above measurements were labeled based on the procedures outlined by different scholars (Nissen 2003; Jongman et al. 2000). Frication onset was marked at a point where maximum frequency energy starts to be displayed or a point at which zero-crossing considerably increases. Frication offset, on the other hand, is marked by the point at which minimum intensity appears preceding the onset of vocalic elements. The onset of the vowel begins from the offset of the fricatives and the offset of the vowels is marked by the completion of the periodicity.

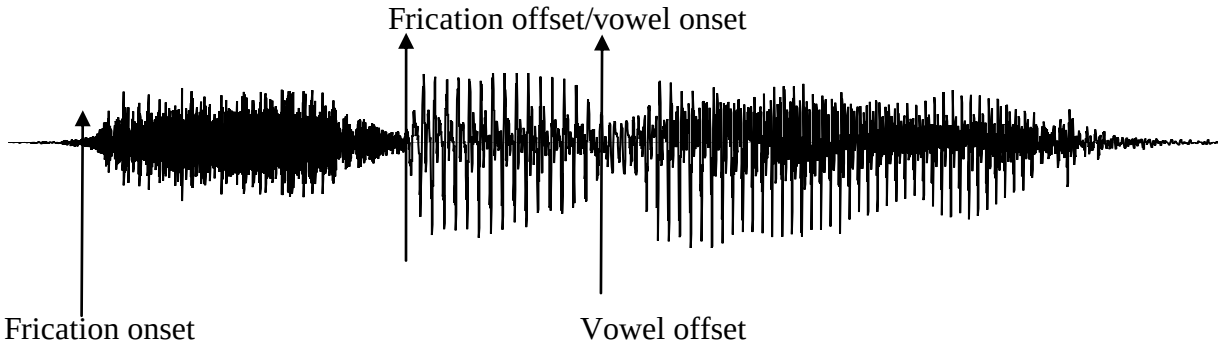

Figure 3.1 Segmentation of a fricative consonant and a vowel in the word *siree* 'bed' produced by an adult male speaker.

3.4.2 Spectral Peak Location

Spectral peak location was computed by placing a 40ms full Hamming Window at the center of frication noise following Jongman et al. (2000). Like in Nissen (2003), the peaks were computed from frequency range of 1 to 15kHz. Jongman and colleagues state that such a larger adjustment of the windows result in better resolution of frequency, but `is poor at temporal resolution. The authors justify that preferring for the frequency resolution in fricatives is more useful because the "frication noise showed that these properties are relatively stable throughout the noise portion" (Jongman et al., 2000, p. 1256). The spectral peak location, which is defined by Jongman and colleagues as "the highest spectral amplitude peak", was obtained from FFT (fast Fourier transform), from the aforementioned window size without pre-emphasis. The pre-emphasis in voiceless sounds may not be needed because they "would not be affected by the 6-dB per octave roll-off present in the glottal waveform" (Munson 2001 p. 1203).

3.4.3 Spectral Moments

To compute the spectral moments (mean, standard deviation, skewness and kurtosis), the methods outlined by Jongman et al. (2000) was implemented. According to this approach, the FFT spectra were calculated from four different places. A 40ms full Hamming window was placed at the beginning, middle, end and frication offset to compute the measurements. The fourth window employs the fricative offset (20ms) and the onset of the following vowel (20ms). Based on the length of the frication duration, there was from 25% to 50% overlap in the windows of analysis. In this study, only linear spectra were used to compute the moments following Jongman and colleagues. The

researchers claim that there was no considerable discrepancy between the two approaches and they reported the result using linear spectra. Thus, the same approach was used in the present study.

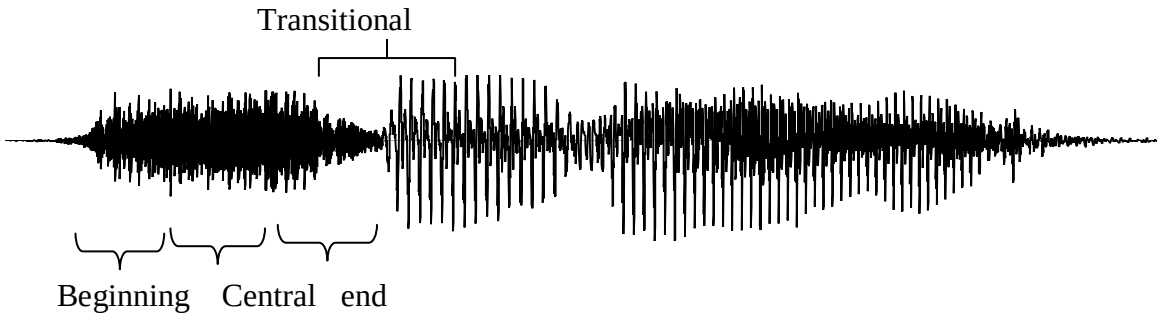

Figure 3.2 Segmentation of a fricative sound for measurements of spectral moments.

3.4.5 Duration

Durations of different parameters were measured from the signal displayed on the spectrogram. In this study, the overall duration was measured from the first segment to the last segment in each token. Durations of vowels preceding and following the fricatives were measured from vowel onset to vowel offset based on the segmentation previously discussed. The duration of the fricatives was measured from frication onset to offset. The ratios of each test fricatives to the words in which they exist was also employed to characterize the segments temporally as normalized duration. "Normalized duration" is "defined as the ratio of fricative duration to word duration" (Jongman et al., 2000).

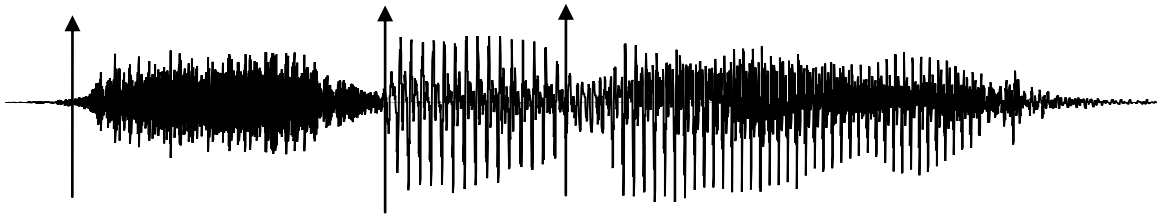

Figure 3.3 Segmentation of a fricative sound for measurements of durations.

3.4.6 Locus Equations

Locus equation was used to analyze the coarticulatory effect of vowels. Different scholars calculated locus equation at the beginning and at the center of a vowel from the FFT spectra (Sussman and Shore, 1996; Jongman et al., 2000). The same method was implemented in the present study. In this approach, 23.3ms full Hamming window was placed at the beginning and middle of vowel spectra to calculate F2. After obtaining the measurements from the stated windows, the following the procurers were outlined. The average results of the F2 at onset of fricatives (F2o) were fit to the F2 at the center of fricatives (F2v) to compute slope of locus equation. Besides, the y-intercept and F2o were statistically analyzed to examine the coarticulary affinity of each fricative with the adjacent vowels. The analysis of locus equation was done only for the fricatives in CV context.

3.4.7 Normalized Amplitude

To calculate this measurement, the methods used by different scholars such as Behrens and Blumstein (1988), Jongman et al. (2000), Fox and Nissen (2005) was implemented. Different measurements were taken for the consonants and the vowels. For fricatives the

entire frication noise amplitude was extracted. Then, three consecutive prominent peaks were measured for the vowels from FFT spectra. The peaks of the vowels were selected from the first 40ms window of the vowel spectra (Nissen and Fox 2005). Then normalized amplitude was obtained by deducting the root mean square (RMS) amplitude of the vowels from total frication noise amplitude. Such approach was used because it normalizes the discrepancy among individual tokens (Jongman et al., 2000). Like locus equation, the analysis of normalized amplitude was used only for fricatives in CV form.

3. 4.8 Reliability of the Data

As much as possible it has been attempted to make the data reliable. Firstly, the data gathering and extraction and analysis methods were adopted from previous salient works in the field such as Nissen (2003), Nissen and Fox (2005), Jongman et al. (2000), among others. Secondly, the researcher agreed on the procedure and measurements and crosschecked the procedure he used with his advisors and perused the measurement after getting go-ahead from his advisors. Thirdly, more or less the finding of the measurements corroborated with previous studies conducted on other languages, save some language specific features. Thus, the work was tried to be conducted with great care and precision to maintain it feasibility and reliability.

3.4.9 Statistical Analysis

Before any statistical analysis was implemented, the data had been organized as a repetition of each stimulus so as to make it ready for the analysis. Next to the organization of the data, a four-way repeated measures (place x vowel x age x gender) analysis of variance (ANOVA) was applied to compute the acoustic attributes of the

fricatives in CV context. On the other hand, for fricatives in the VCV phonetic context, a five-way ANOVA (place x gemination x vowel x age x gender) was used. The results of significant acoustic values were reported at alpha less than 0.05. The effect size was also computed from partial eta squared (η^2). Besides each acoustic measure, the descriptive mean of each parameter was reported. In all the statistical analyses, SPSS-20 software package was used.

Finally, to check how well each cue discriminates the fricatives as a function of places of articulation, linear discriminant analysis was computed following previous works (Jongman et al.2000). The jack-knife (stepwise) approach was used to compute the results of different predictors in both phonetic contexts (CV and VCV). The objective was to investigate to what extent the descriptors distinguish fricatives in terms of place of articulation. Moreover, the analysis was also computed the rate of classification of different age groups and gender to compare variations.

CHAPTER FOUR

ACOUSTIC ANALYSIS OF CV FRICATIVE CONSONANTS

Under this section, results obtained from CV fricatives were discussed. The attributes discussed included fricative duration, vowel duration, normalized duration (ratio of fricative duration to word duration), relative amplitude, spectral peak location, spectral moments (the first, the second, the third, and the fourth moments), locus equation, and discriminant analysis. For spectral measures, a general picture was presented first utilizing results obtained across windows of analyses (onset, middle, end and offset) using a one-way ANOVA. Next, detailed analyses were made employing results obtained from the middle 40 ms window. For fricative duration, vowel duration, normalized duration, normalized amplitude, spectral peak location, spectral moments of the middle (central) window, and locus equation, a four-way repeated measures ANOVA was employed. The ANOVA was mixed-designed in which place of articulation and vowel context were treated as within subject factors and age and gender were employed as between subject factors. In each variable, main effects and interaction effects of a parameter were described before proceeding to another attribute. For both main and interaction effects, results significant at alpha less than 0.05 were discussed.

4.1 Analysis of Duration and Amplitude Measures

4.1.1 Fricative Duration

For the dependent measure of fricative duration, a four-way (place x vowel x age x gender) ANOVA revealed main effect of place [F(2.291,128.273)=9.369, p<0.0001, η^2=0.586). The test depicted that there was significant difference between sibilant and nonsibilant fricatives (p<0.0001). The average duration of sibilant fricatives /s, ʃ/ was 130 ms, while that of nonsibilant fricatives /f, h/ was 100 ms. Thus, the main effect was mainly found due to the shorter duration of nonsibilant fricatives, as indicated in figure 4.1. Collapsed across speakers and vowel context, the mean measures of fricative duration for /f, s, ʃ, h/ were 110 ms, 131ms, 129 ms, 89 ms, respectively. The value displayed that the mean duration of /s/ was the longest and the average duration of /h/ was the shortest. The difference between the sibilant fricatives /s, ʃ/ was narrower, compared to that of nonsibilant fricatives as a class. Pairwise comparison indicated that the dependent measure of fricative duration distinguished three places of articulations. Except the difference between /s/ and /ʃ/, the rest places were significantly different (p<0.0001) in terms of fricative duration.

The AVOVA also yielded a significant interaction effect of place by age group [F(6.827, 128.273)=3.589, p<0.002, η^2=0.161]. As demonstrated in figure 4.2 the result was mainly driven from the longer duration of fricatives of /ʃ/ produced by three years old children and slightly shorter duration of /h/ produced by adult speakers because the other places depicted similar pattern in which the speech produced by adult speakers was longer than that of children. The five years old children had relatively the longest duration across all places compared to other child groups, while the four years old child

group had the shortest duration across places of articulations because it may be at this age that the children start to produce adult-like speech.

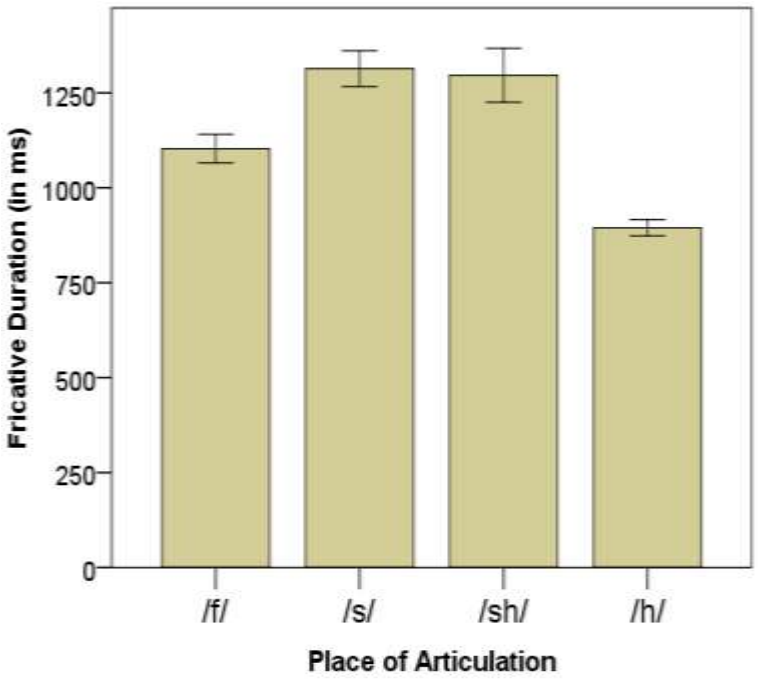

Figure 4.1 Fricative duration as a function of place of articulation in CV fricatives.

The result signified that the difference between child groups and adult speakers was big, though five years old children at all places had the longest duration compared to other child speakers.

Figure 4.3 demonstrated that a significant main effect of age was found for the dependent measure of fricative duration [$F(3, 56)=4.492$, $p<0.007$, $\eta^2=0.194$). The overall mean measure of fricative duration of the adults was the longest of all age groups and of the four years old children was the shortest. Collapsed across speakers and vowel context, the average measures of fricative duration were 126 ms for adult group, 112 ms for three years old, 107 ms for four years old, and 114 ms for five years old.

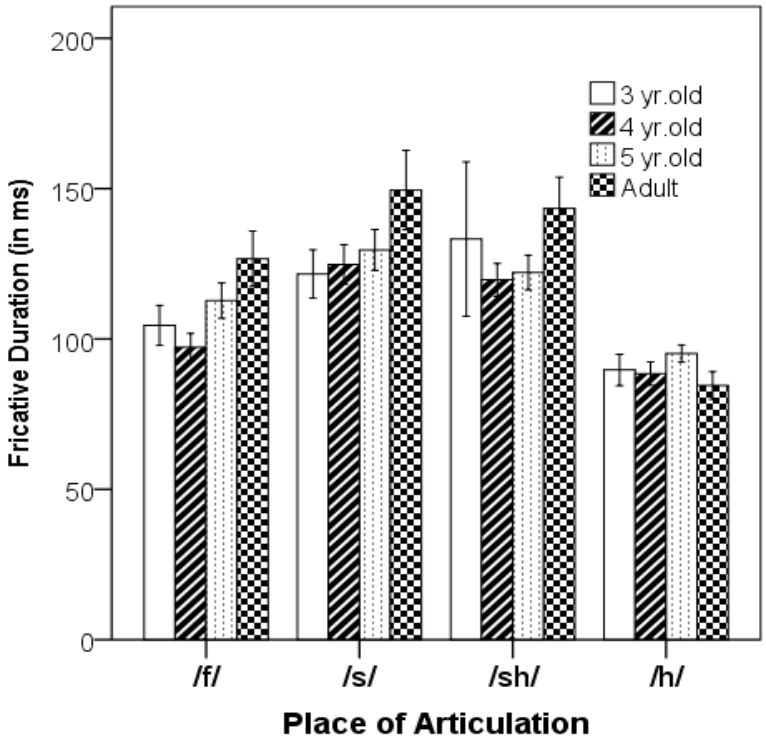

Figure 4.2 Fricative duration as a function of place of articulation and age groups in CV fricatives.

Thus, contrary to many other studies conducted on child and adult speakers (see, Smith 1978; Smith et al. 1996), the mean duration of fricatives produced by child speakers were shorter than that of adult speakers. Subsequent post hoc test exhibited that only the difference between the adult group and four years old children was significant ($p<0.005$) in terms of fricative duration.

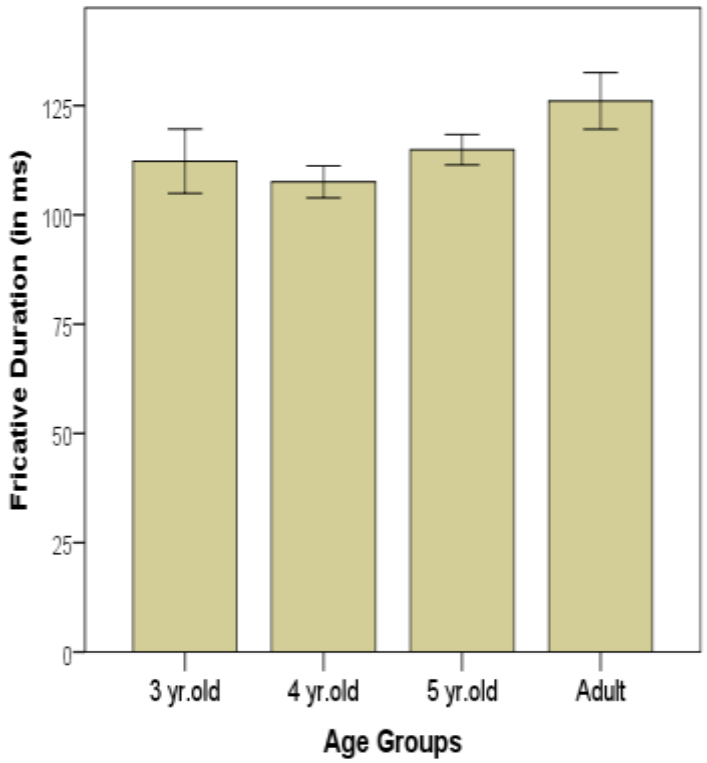

Figure 4.3 Fricative duration as a function of age groups in CV fricatives.

4.1.2 Vowel Duration

A four- way ANOVA was computed, employing place of articulation and vowel context as within subject factors and age groups and gender as between subject factors, for the dependent measure of vowel duration. The test yielded main effect of place of articulation [$F(2.514, 140.771)=11.275$, $p<0.0001$, $\eta^2=0.168$], as showed in figure 4.4. The average duration of vowels was longer following /h/ and shorter following /f/. The mean measures of duration of vowels following the fricatives /f, s, ʃ, h/ were 89 ms, 95 ms, 90 ms, and 101 ms, respectively.

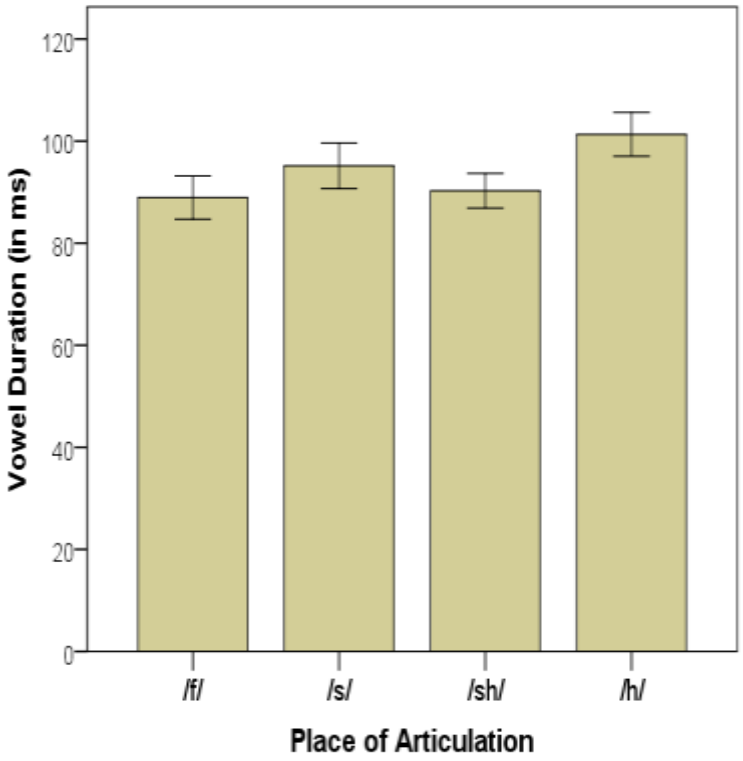

Figure 4.4 Vowel duration as a function of place of articulation in CV fricatives.

Subsequent pairwise comparison revealed that the differences between /f/ and /s/ ($p<0.028$), /f/ and /h/ ($p<0.0001$) and /ʃ/and /h/ ($p<0.001$) were statistically significant. The test yielded a main effect of vowel context [$F(1.000, 56.000)=85.929$, $p<0.0001$, $\eta^2=0.605$]. As indicated in figure 4.5, the mean duration of /i/ following fricatives was shorter (87 ms) than /u/ (100 ms).

The ANOVA also exhibited that a place by vowel context interaction was significant [$F(2.886, 161.629)=18.841$, $p<0.0001$, $\eta^2=0.252$). As signified in figure 4.6, /u/ was longer than /i/, except when following /ʃ/. No other main or interaction effect was found for the rest factors.

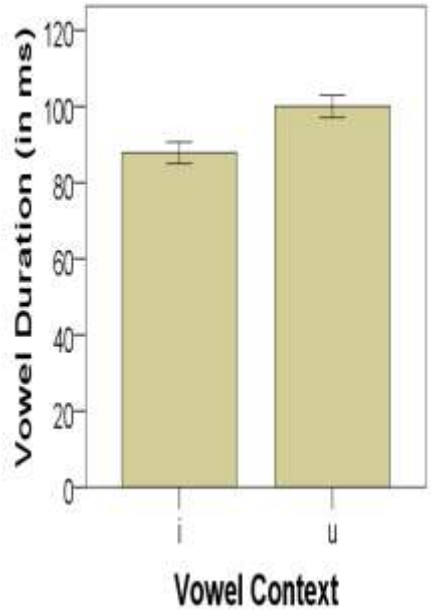

Figure 4.5 Vowel duration as a function of vowel context in CV fricatives.

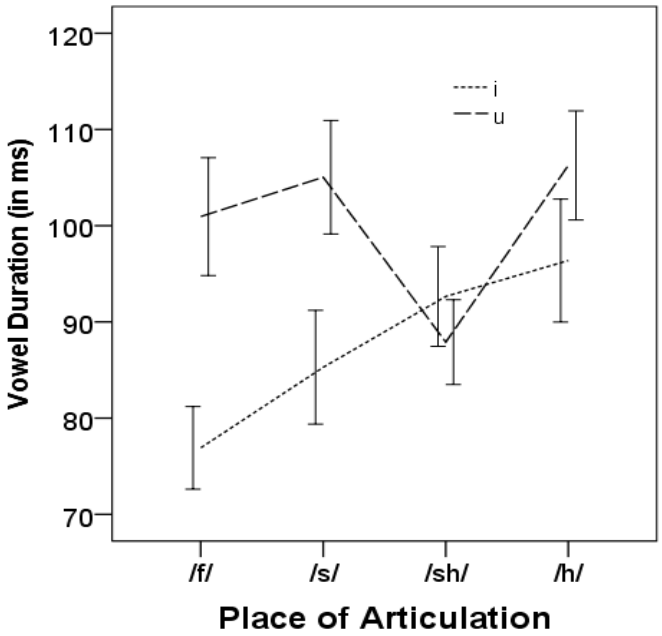

Figure 4.6 Vowel duration as a function of place of articulation and vowel context in CV fricatives**.**

4.1.3 Normalized Duration

The four- way repeated measures ANOVA (place x vowel x gender x age) exhibited main effect of place [F(2.407, 134.772)=52.486, p<0.0001, η^2=0.484] as indicated in figure 4.7. The statistical effect was obtained mainly because of significantly decreased (p<0.0001) mean normalized duration of voiceless glottal fricative /h/. Pairwise comparison indicated that the differences between /f, ʃ/ and /s, ʃ/ were not significant. The other places were significantly distinct at p<0.0001. The mean normalized duration of fricatives /f, s, ʃ, h/ were 0.240, 0.271, 0.253, and 0.190, respectively.

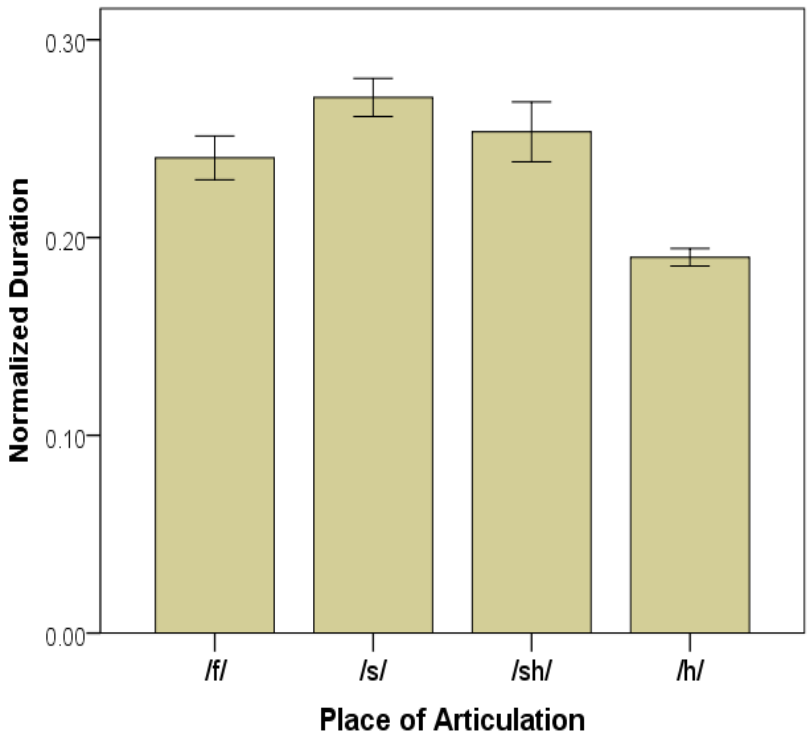

Figure 4.7 Normalized duration as a function of place of articulation in CV fricatives.

A significant place by age group interaction [F(7.220, 134.772)=3.794, p<0.001, η^2 =0.169] was obtained as illustrated in figure 4.8. The significant interaction was found mainly because of longer mean normalized duration of adult groups in all fricatives except for the voiceless glottal fricative /h/. A worthy of note feature of duration as demonstrated in figure 4.8 is that the difference between adult and child speakers in nonsibilant fricatives was narrower compared to that of sibilant fricatives. This may indicate that children could not sustain the durations in sibilant fricatives like adults because sibilant fricatives involve complex aerodynamic processes (Iskarous et al. 2011) which children of this age have not mastered.

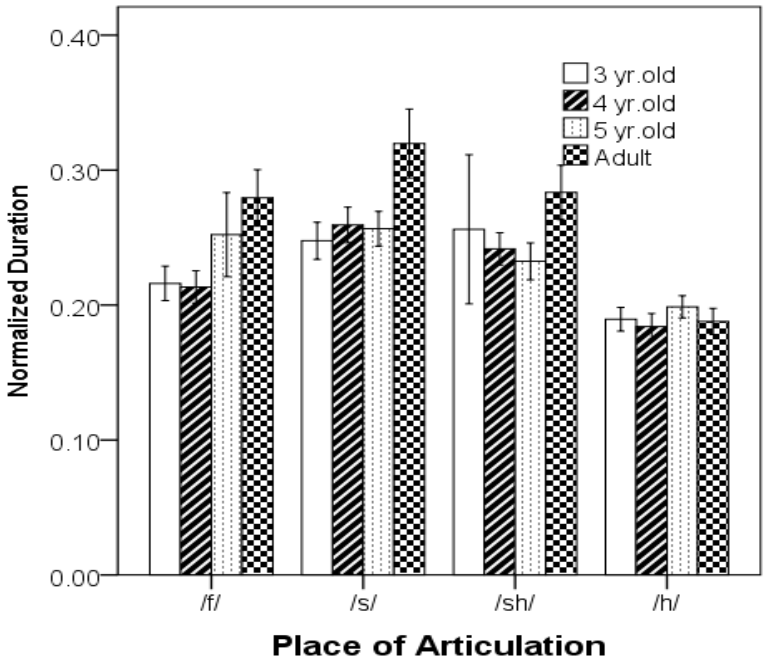

Figure 4.8 Mean normalized duration as a function of place of articulation and age groups in CV fricatives.

Figure 4.9 exhibited that the interaction of place by vowel context was significant [F(1.901, 106.453) = 4.010, p< 0.023, η^2=0.067] in terms normalized duration. The statistically significant value was mainly derived from the increased normalized duration of /s/ in the context of /i/.

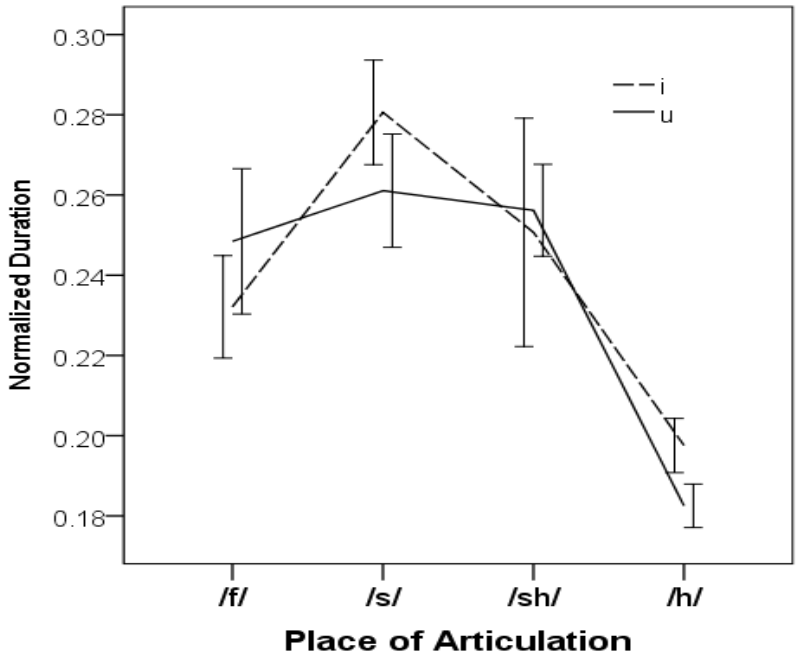

Figure 4.9 Normalized duration as a function of place of articulation and vowel context in CV fricatives.

The ANOVA also yielded a significant main effect for age groups ([F (3, 56) =6.333, p<0.001, η^2 =0.253]), as clearly displayed in figure 4.10. The result was found primarily because of longer mean fricative durations produced by the adult group. The overall durations of fricatives produced by adults, three years, four years and five years old children were 0.268, 0.227, 0.225, and 0.235, respectively. Subsequent post hoc test revealed that the adult group was significantly different from all child groups (p<0.004 for adult and three years old children, p<0.002 for adult and four years of age children

and p<0.03 for adult and five years old children). But there was no difference among all child groups. Finally, the test also depicted a significant main effect of gender [F (1, 56)=4.161, p<.04) with small effect size (η^2 =0.069), as signified in figure 4.11. Like the result reported by Jongman et al. (2000), the average normalized duration of male speakers (0.247) was longer than that of female speakers (0.231).

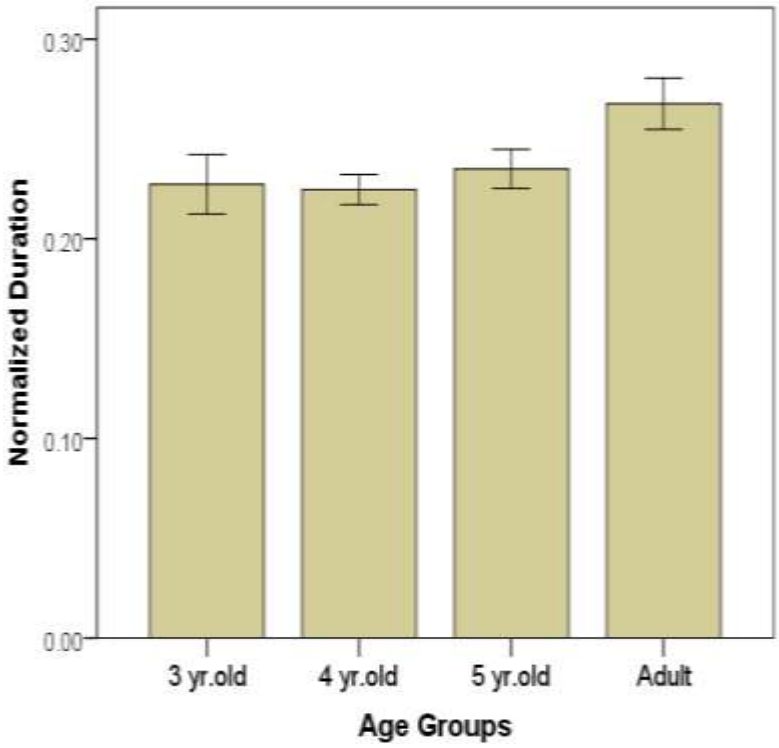

Figure 4.10 Normalized duration as a function of age groups in CV fricatives.

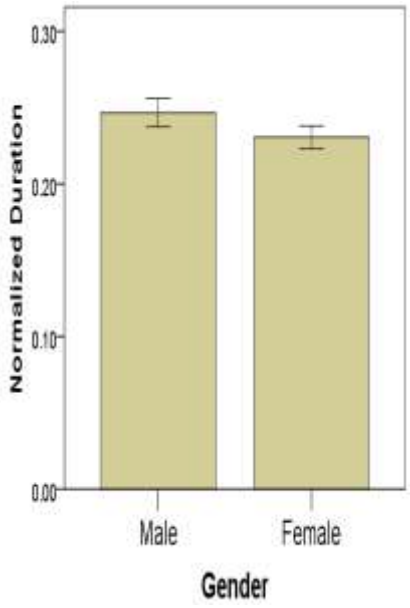

Figure 4.11 Normalized duration as a function of gender in CV fricatives.

4.1.4 Normalized Amplitude

A four-way ANOVA (place x vowel x age x gender), utilizing place and vowel context as within subject factors and gender and age groups as between subject factors, was computed for normalized amplitude. The analysis exhibited a main effect of place [$F(3,168)=144.810$, $p<0.0001$, $\eta^2=.721$]. As clearly shown in figure 4.12, the result was mainly stemmed from significantly decreased ($p<0.0001$) average measures of normalized amplitude of nonsibilant fricatives. The average normalized amplitude was -14 dB for /f/, -9.3 dB for /s/, -9.4 dB for /ʃ/ and -15.5 dB for /h/. Thus, taken as a group, the normalized amplitude of sibilant fricatives /s, ʃ/ (-9.3 dB) was greater than that of the nonsibilant ones (-14.8 dB). Pairwise comparison revealed that there was no statistical difference between /s/ and /ʃ/ in terms of normalized amplitude. The rest places were significantly distinct. Thus, while normalized amplitude distinguished sibilant fricatives

from nonsibilant ones and within the nonsibilants /f, h/ as a class, it failed to differentiate within the sibilant fricatives /s, ʃ/.

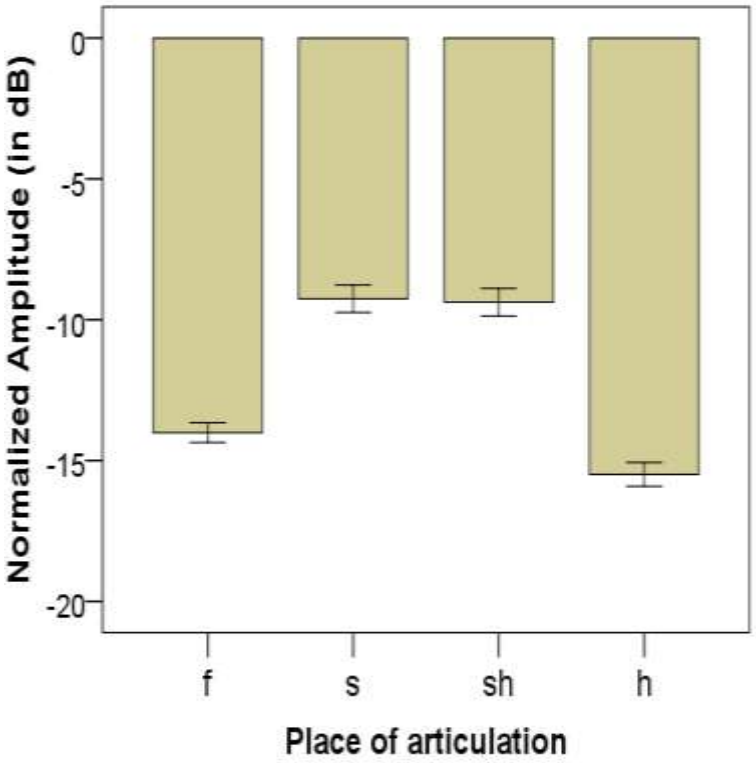

Figure 4.12 Normalized amplitude as a function of place of articulation in CV fricatives.

A main effect was obtained for vowel context [F (1, 56) =5.099, p<0.028, η^2=0.083]. Though the difference between the two vowel contexts were not big, the mean normalized amplitude was slightly greater in the context of the front high unrounded vowel /i/ (-11.7 dB for /i/ and -12.4 dB for /u/). This main effect has been illustrated in figure 4.13. The statistical test showed that a place by vowel context interaction was also significant[F(3, 168)=14.313, p<0.0001, η^2=0.204]. The average measures of normalized amplitude (RMS) were higher in the context of high front unrounded vowel /i/ for sibilant fricatives /s, ʃ/, while the trend was reversed for nonsibilant fricatives (figure 4.14).

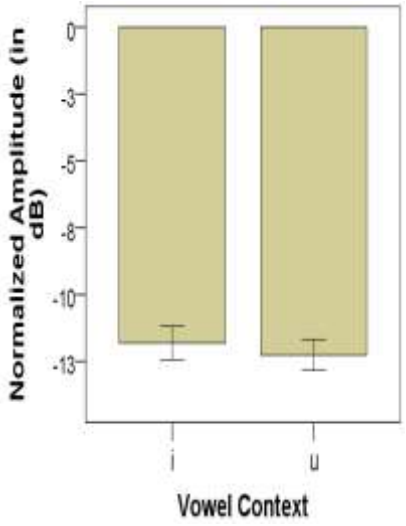

Figure 4.13 Normalized amplitude as a function of vowel context in CV fricatives.

In addition, the four-way repeated measures ANOVA displayed a significant vowel by gender interaction [F (1, 56) =6.622, p<.01, η^2=.106]. The mean measure of normalized amplitude of male speakers was increased in both vowel contexts, with greater difference noted in the context of /u/, while the value for female speakers was similar in both phonetic conditions (figure 4.15).

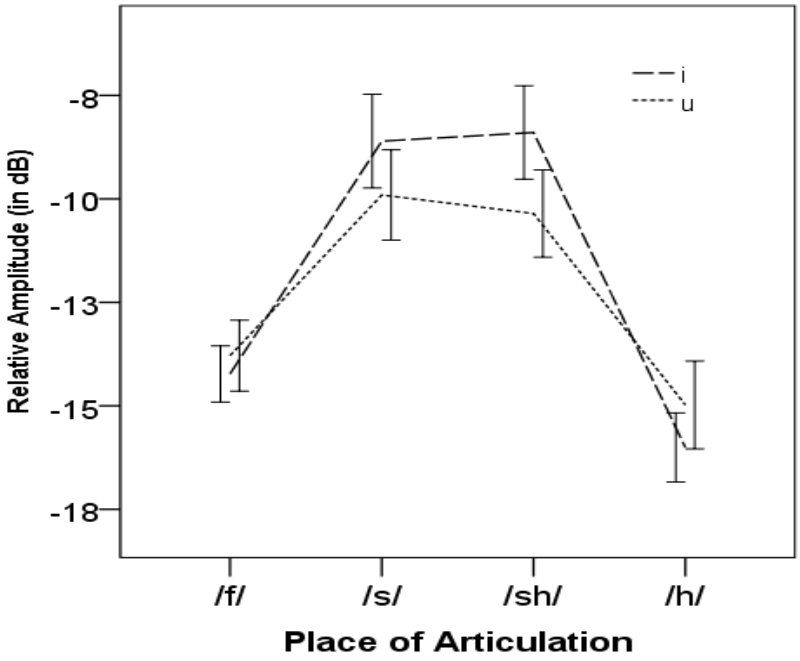

Figure 4.14 Normalized amplitude as a function of place of articulation and vowel context in CV fricatives.

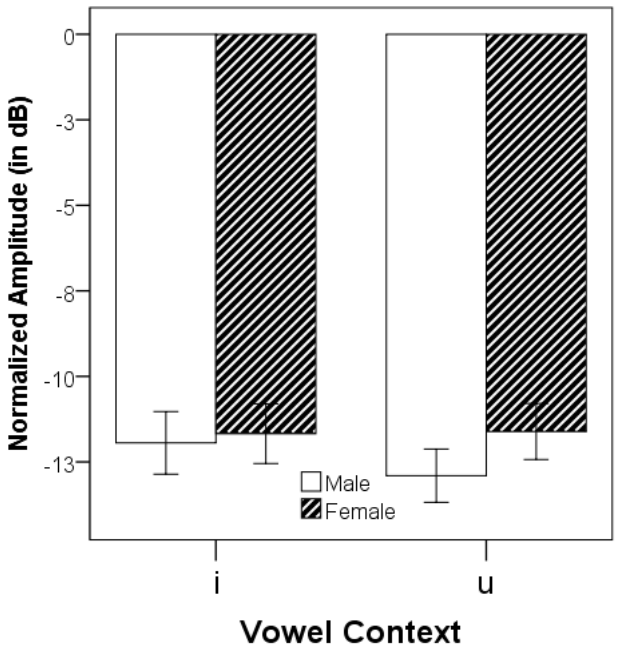

Figure 4.15 Normalized amplitude as a function of vowel context and gender in VCV fricatives.

The ANOVA also yielded main effect of age for the dependent measure of normalized amplitude [F (3, 56) =19.665, p<.001, η^2=0.513]. Interestingly, as the age of speakers increases, the average normalized amplitude decreases (figure 4.16). The overall measures of the attribute were -10 dB, -10.5 dB, -11.8 dB and -15.6 dB for third, fourth, and fifth years of age children and adult speakers, respectively. Bonferroni post hoc test displayed that the adult group was significantly different from all child groups (p<0.0001). On the contrary, the measures of normalized amplitude of all child groups were not different from one another.

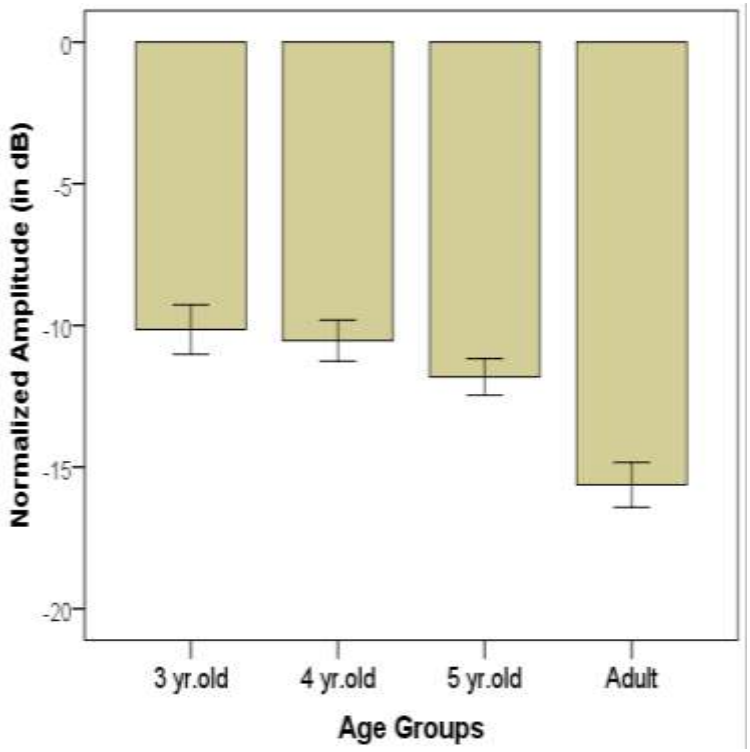

Figure 4.16 Normalized amplitude as a function of age groups in VCV fricatives.

4.2 Spectral Measures

4.2.1 Spectral peak Location

A four-way repeated measures analysis of variance (ANOVA) revealed a main effect of place [F (3, 168) =259.373, p<0.0001, η^2=0.822] for the dependent measure of spectral peak. The result mainly stemmed from significantly lowered mean measure of spectral peak of voiceless postalveolar fricative /ʃ/ and voiceless glottal fricative /h/. Interestingly, the mean spectral peak decreases as the places move posterior in the vocal tract (figure 4.17). The overall spectral measures were 7767 Hz, 7356 Hz, 5051 Hz, and 3548 Hz for fricatives /f, s, ʃ, h/, respectively. Pairwise comparison signified that the difference between /f/ and /s/ was nonsignificant. But the difference between other fricatives was highly significant (p<0.0001). The test showed that the mean value of spectral peak of sibilant fricatives (6204 Hz) was significantly (p<0.005) higher than the mean measure of spectral peak of nonsibilant fricatives (5657 Hz) due to highly decreased mean value of spectral peak of the voiceless glottal fricative /h/. This result was evidence that /h/ is mainly similar with neighboring vowels because the peak of this sound was by far lower than that of other fricatives.

Figure 4.18 illustrated that a place by vowel interaction [F (3, 168) =5.950, p<0.001, η^2 =0.096] was significant. Except for the voiceless alveolar fricative /s/, the average measures of spectral peaks of all fricatives were slightly higher in the context of /u/. In addition, the four-way analysis of variance also revealed a main effect of age [F (3, 56)=3.848, p<0.01, η^2=0.171]. The result was obtained mainly as a result of lowered average spectral peak produced by adult group, as indicated in figure 4.19. The mean measures of spectral peak of three, four, and five years old children and adult group were

5932 Hz, 6299 Hz, and 5969 Hz, 5520 Hz, respectively. Bonferonni adjusted post hoc test indicated that only the difference between adult and four years old children was significant ($p<0.008$) in terms of spectral peak location.

The ANOVA revealed that an age group by gender interaction was also significant [$F(3, 56) = 3.520$, $p<0.02$, $\eta^2=0.159$]. As indicated in figure 4.20, spectral peaks produced by adult females and four years old female children were higher, while in other child groups the result has been reversed.

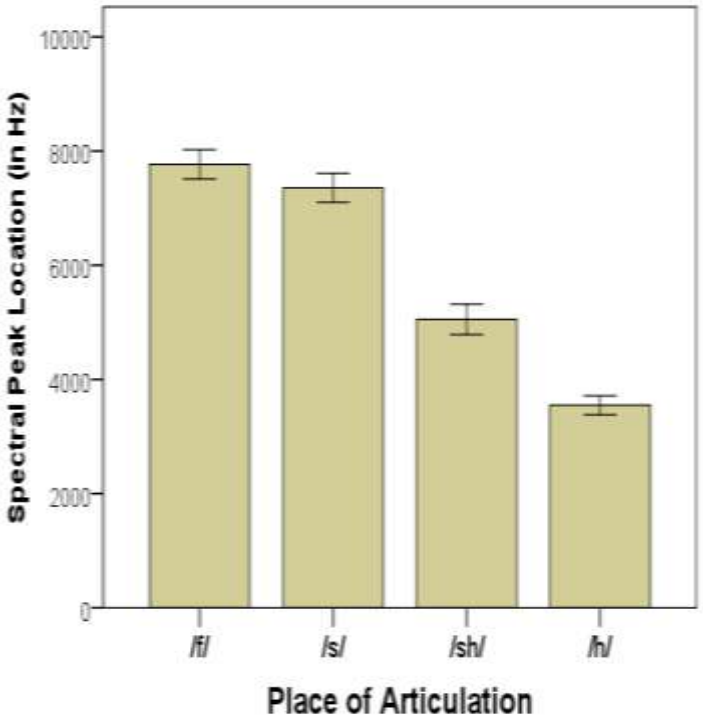

Figure 4.17 Spectral peak location as a function of place of articulation in CV fricatives.

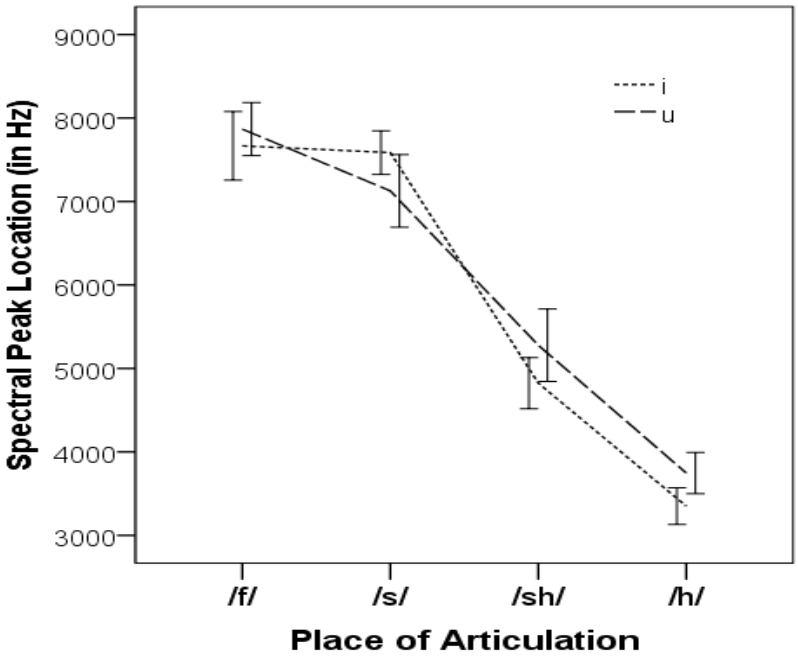

Figure 4.18 Spectral peak location as a function of place of articulation and vowel context in CV fricatives.

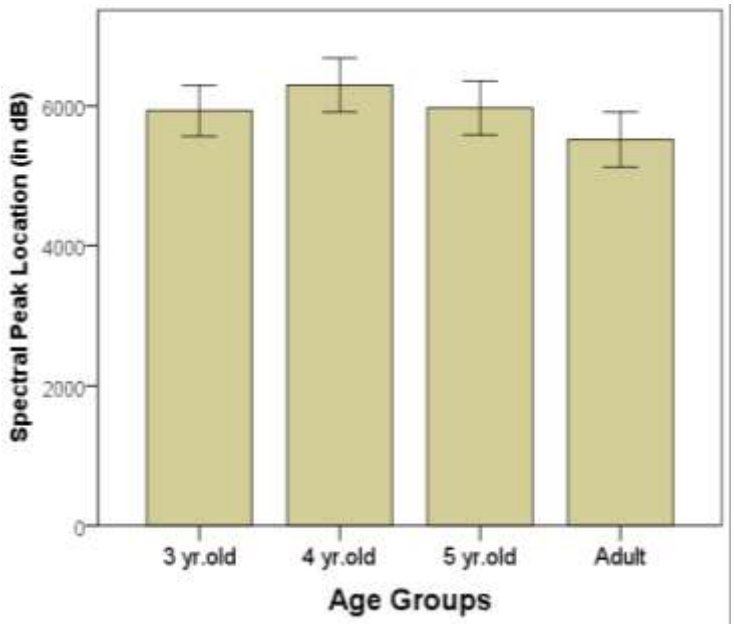

Figure 4.19 Spectral peak location as a function of age groups in CV fricatives.

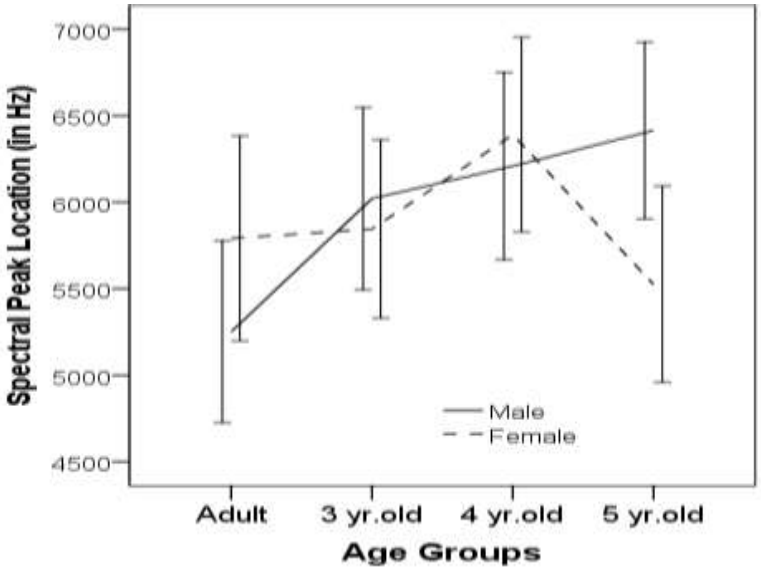

Figure 4.20 Spectral peak location as a function of age groups and gender in CV fricatives.

4.2.2 Spectral Mean

A one-way ANOVA was conducted to test whether the windows significantly differ or no. The result revealed that the first moment (spectral mean) varied across all the four window locations [$F(3, 2044) = 70.399$, $p < .001$]. The result stemmed from the significantly increased average measure of spectral mean of the second (central) window and decreased average measure of spectral mean of the transitional (fourth) window of analysis ($p < 0.001$), as demonstrated in figure 4.22. The overall dependent measures of the spectral mean were 4390 Hz, 5338 Hz, 4947 Hz, and 3290 Hz for the onset, central, end and transitional windows, respectively. It is expected that the result of the central window of analysis should be higher as it is aloof from coarticulatory effects of preceding and following vowels (Nissen 2003).

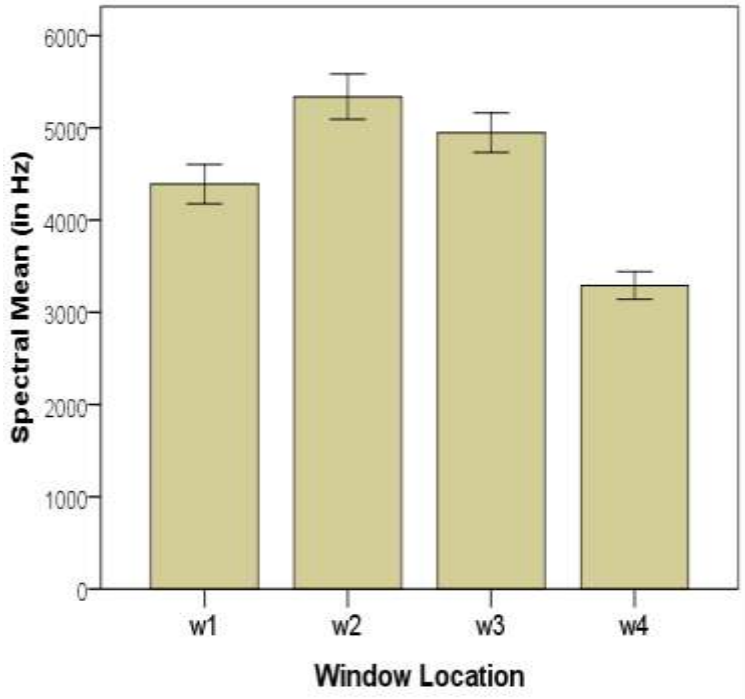

Figure 4.21 Spectral mean as a function of window location for CV fricatives

Next, for individual windows of analysis a four-way ANOVA (place x vowel x age x gender) was conducted to test their significance. As indicated in figure 4.22, except the central one, all windows distinguished all fricatives, with great difference noted between the voiceless alveolar fricative /s/ and the voiceless glottal fricative /h/ and narrower difference was displayed between /f/ and /ʃ/. On the other hand, the central window failed to distinguish /f/ and /ʃ/.

The overall windows of analysis revealed that the average spectral mean varied as a function of vowel context. The average spectral mean was higher in the context of the front unrounded vowel /i/, as expected (figure 4.23). Due to the coarticulatory effect of

this vowel the front cavity becomes smaller; consequently, the average spectral mean is increased in this phonetic environment.

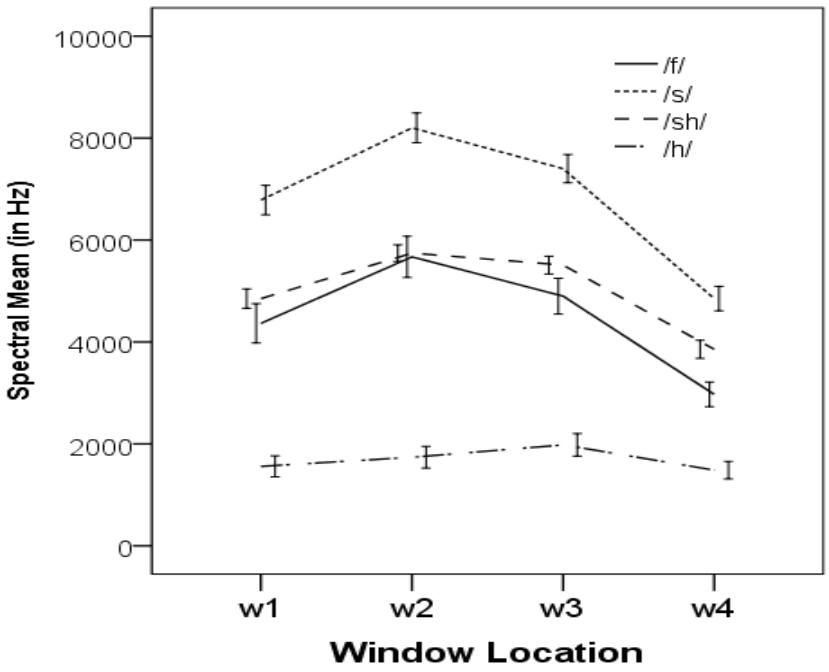

Figure 4.22 Spectral mean as a function of window location and place of articulation in CV fricatives.

The four-way Analysis of variance for the 40 ms central window showed a main effect of place of articulation [$F(2.278, 127.547)=358.983$, $p<0.0001$, $\eta^2=0.865$]. As indicated in figure 4.24, the result was obtained mainly due to the decreased average spectral measure of the first moment for the voiceless glottal fricative /h/, as well as the elevated average measure of the moment of voiceless alveolar fricative /s/. The average spectral mean for the fricatives /f, s, ʃ, h/ were 5670 Hz, 8200 Hz, 5743 Hz, and 1737 Hz, respectively. Pairwise comparison revealed that all fricatives, except /f/ and /ʃ/, were significantly different ($p<0.0001$) in terms of the average spectral mean. This result is consistent with

the claim that the voiceless glottal fricative /h/ behaves like voiceless counter part of a neighboring vowels. That is why many scholars excluded /h/ from the analysis of fricatives (e.g., Jongman et.al. 2000).

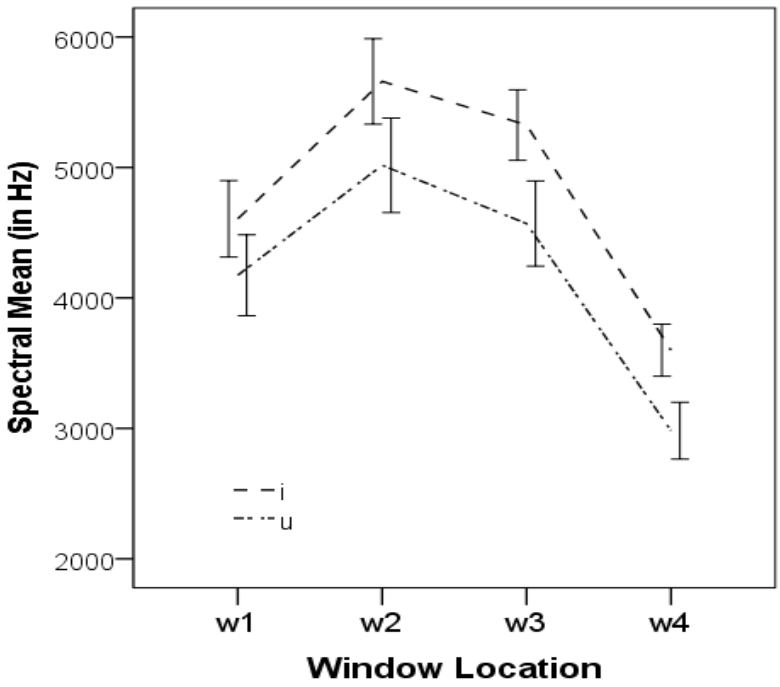

Figure 4.23 Spectral mean as a function of window location and vowel context in CV fricatives.

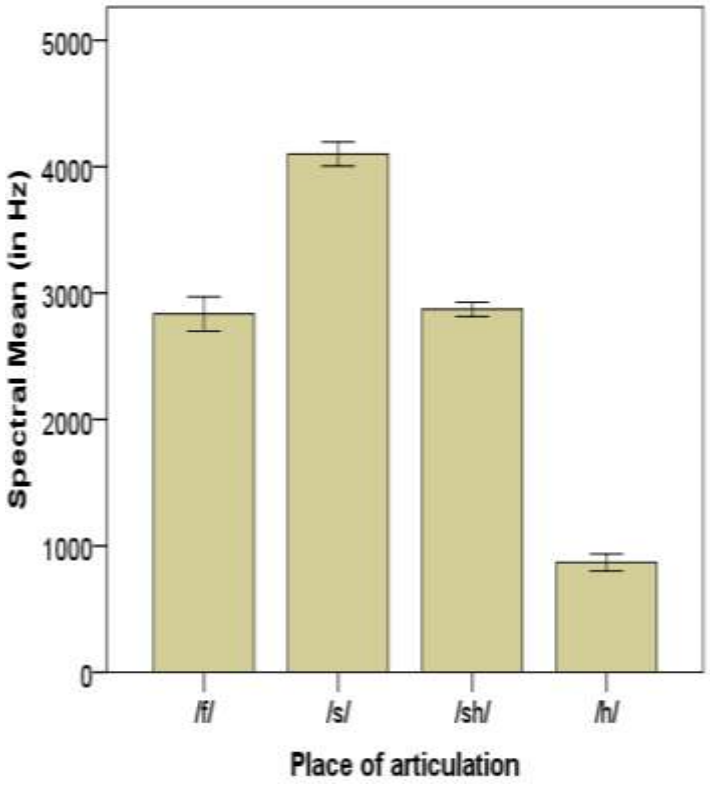

Figure 4.24 Spectral mean as a function of place of articulation in CV fricatives.

The analysis of variance showed a marginally significant place by gender interaction [F (2.278, 127.547)=2.938, p<0.05] with small effect size (η^2=0.050). As indicated in 5.25, the place by gender interaction for the average measure of spectral mean exhibited three different patterns. The average value of spectral mean produced by male speakers was elevated for /f/ and decreased for /h/, while the difference was negligible for sibilant fricatives /s, ʃ/.

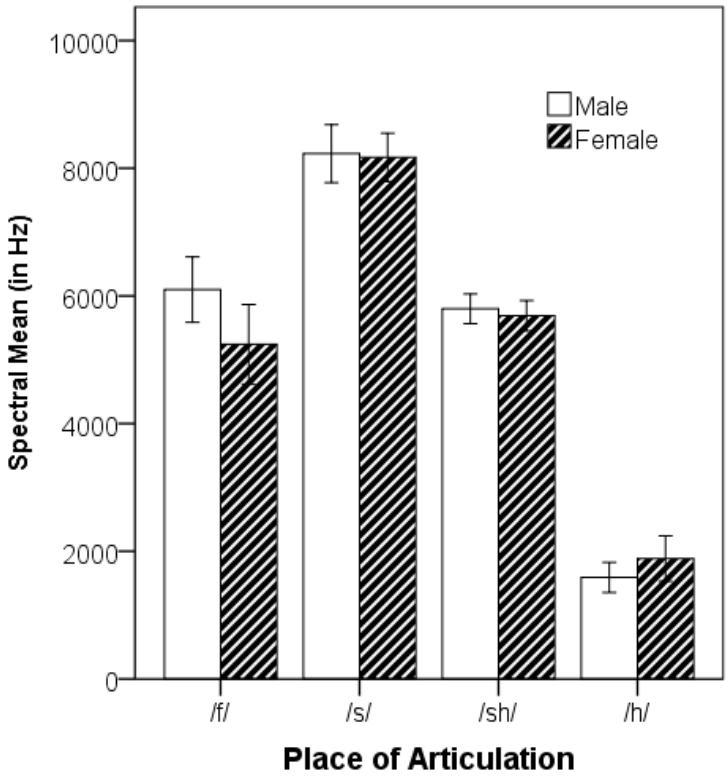

Figure 4.25 Spectral mean as a function of place of articulation and gender in CV fricatives.

The ANOVA exhibited that a place by age interaction effect was highly significant [F (6.833, 127.547) =5.493, p<0.0001, η^2=0.227]. As demonstrated in figure 4.26, the average spectral mean produced by adult group was higher for nonsibilant fricatives, while the average spectral mean values produced by child groups were increased for sibilant fricatives.

As displayed in figure 4.27 the analysis of variance also indicated a main effect of vowel context [F(1.000, 56.000)=44.494, p<0.0001,η^2=0.443]. As expected, the average spectral mean was higher in the context of the front high unrounded vowel /i/ (5659 Hz) compared to the average spectral mean of fricatives in the context of high back rounded

vowel /u/ (5016 Hz). A place by vowel context interaction was also significant for the dependent measure of spectral mean [F (1.996, 111.774) =9.423, p<0.0001, η^2 =0.144]. As clearly shown in figure 4.28, the average measure of spectral mean produced by all speakers were increased for /f, s, h/ in the context of /i/, whereas there was no mean difference for /ʃ/ in both vowel contexts.

Finally, the analysis of variance depicted a significant age by gender interaction [F(3, 56)=2.943, p<0.04, η^2 =0.136] (figure 4.29).The average measures of spectral mean produced by three years and five years old male speakers were elevated. But there was no difference between the two sexes for four years child speakers. On the other hand, the average measure of spectral mean produced by adult female speakers was high as expected. Such discrepancy between male and female is unexpected at this age because there was no anatomical difference until the age of pubescent (Fitch and Giedd 1999). Different scholars attribute such discrepancy that occurs at this age to developmental or behavioral and sociophonetic factors (Nissen and Fox 2005; Fox and Nissen 2005).

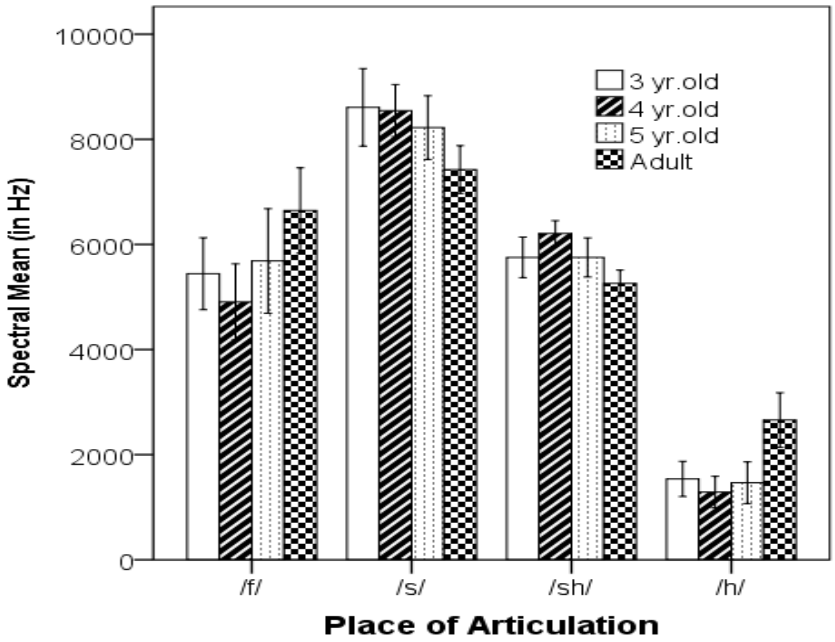

Figure 4.26 Spectral mean as a function of place of articulation and age groups in CV fricatives.

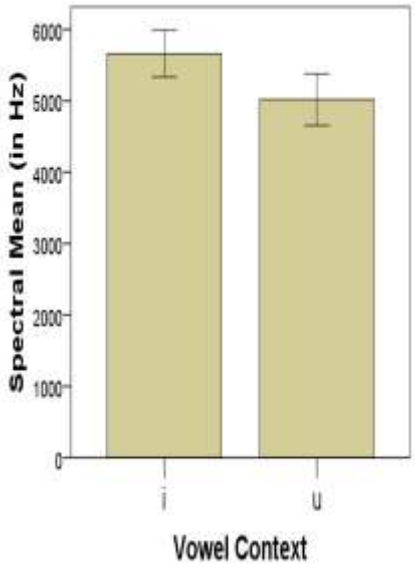

Figure 4.27 Spectral mean as a function of vowel context in CV fricatives.

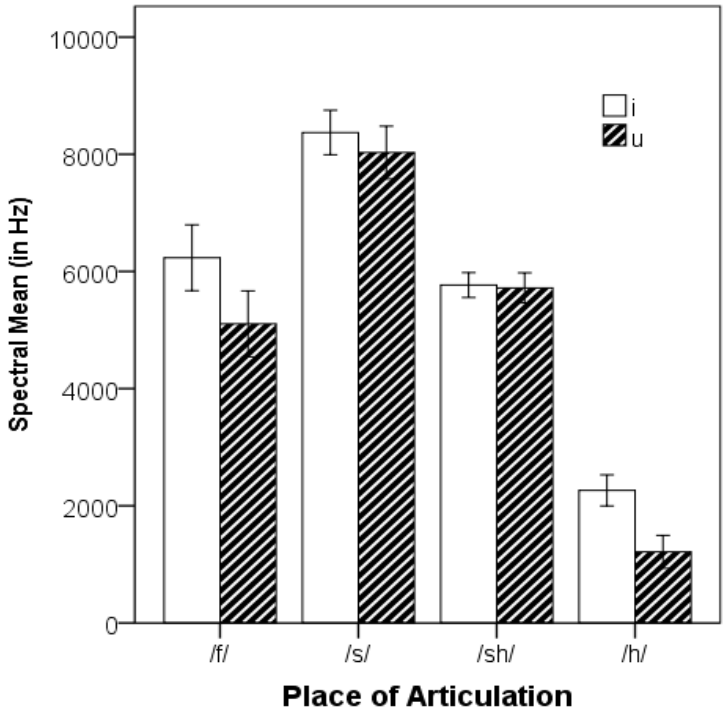

Figure 4.28 Spectral mean as a function of place of articulation and vowel context in CV fricatives.

4.2.3 The Spectral Standard Deviation

A one-way ANOVA exhibited that the second spectral moment (spectral standard deviation) was significantly different ($F\ [3,\ 2047)=70.399$, $p<0.004$]) in terms of windows of analysis. The result was mainly derived from higher average measures of spectral standard deviation of the onset and transitional windows. The overall measure

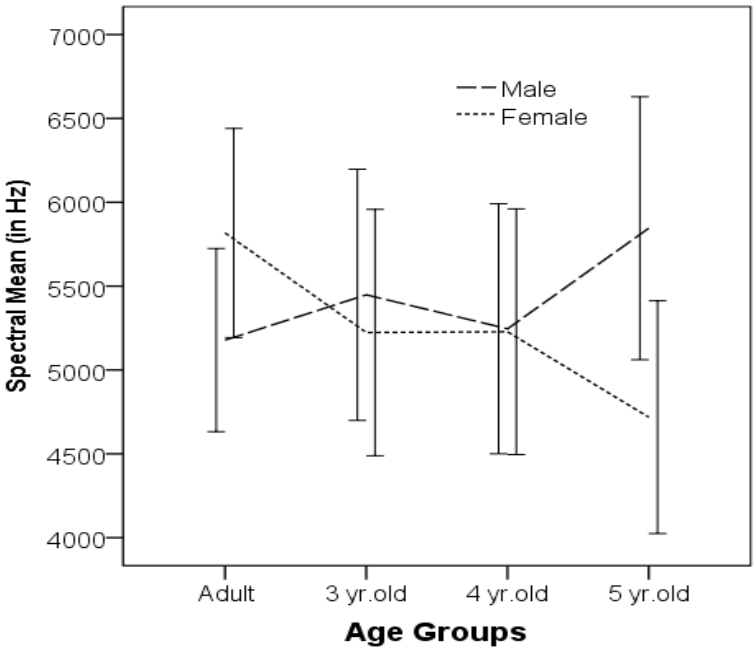

Figure 4.29 Spectral mean as a function of age groups and gender in CV fricatives.

of the spectral standard deviations of the first, second, third and fourth windows were 3356 Hz, 3159 Hz, 3184 Hz and 3338 Hz. Like in the first spectral moment the result of individual window locations has been computed employing four-way ANOVA (with place and vowel context as within subject factors and gender and age groups as between subject factors). As indicated in figure 4.31, at least the first and the second windows distinguished all places of articulations.

As figure 4.32 demonstrated, the second spectral moment (spectral standard deviation) varied for vowel context across windows. The overall standard deviation was higher in the context of the front high unrounded vowel /i/ (3347 Hz) compared to the mean value in the context of /u/ (3173 Hz). Similarly, the average dependent measure of the standard

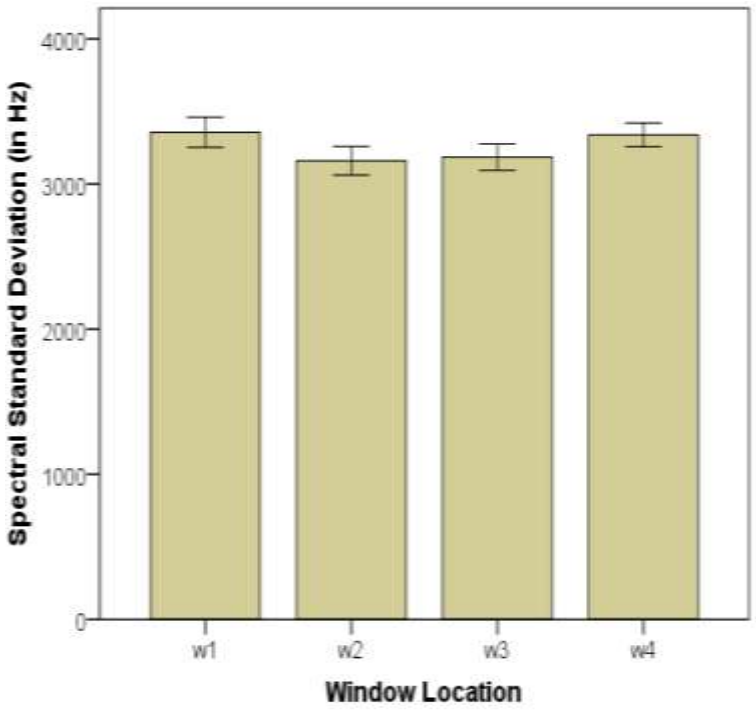

Figure 4.30 Spectral standard deviation as a function of window location in CV fricatives.

deviation also varied for gender at all window locations. As illustrated in figure 4.33, the average standard deviation of female speakers (3312 Hz) was higher than that of the male speakers (3207 Hz).

For detailed analysis, the spectral standard deviation was computed for the central 40 ms window utilizing a four-way (place x vowel x age x gender) repeated measures ANOVA. A main effect was obtained for place of articulation [F (3, 168) =62.905, $p<0.0001$, $\eta^2=0.529$]. As indicated in figure 4.34, the result was mainly derived from the increased mean value of standard deviation of the voiceless labiodental fricative /f/. Collapsed across speakers and vowel context, the average measures of standard deviation were 4080 Hz, 3063 Hz, 2504 Hz, and 2989 Hz for /f, s, ʃ, h/, respectively. Pairwis comparison

revealed that the voiceless alveolar fricative /s/ and the voiceless glottal fricative /h/ were not statistically different. The comparison showed that the other fricatives varied in terms of spectral standard deviation ($p<0.002$ for /ʃ/ and /h/, $p<0.0001$ for the rest).

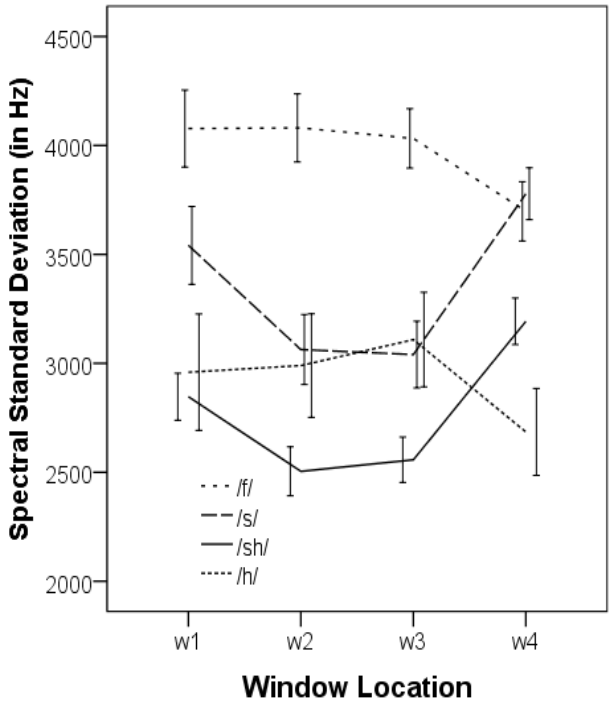

Figure 4.31 Spectral standard deviation as a function of place of articulation and window location in CV fricatives.

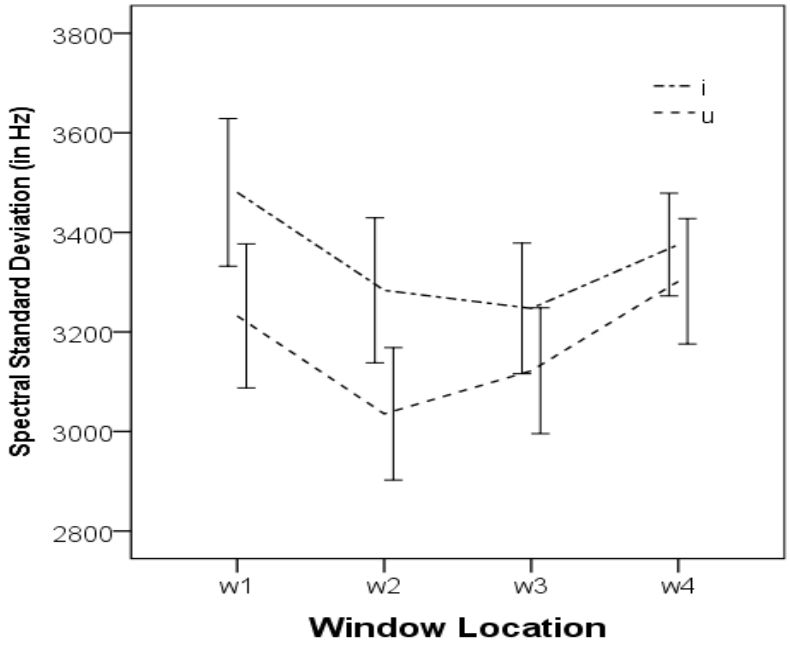

Figure 4.32 Spectral standard deviation as a function of vowel context and window location for CV fricatives.

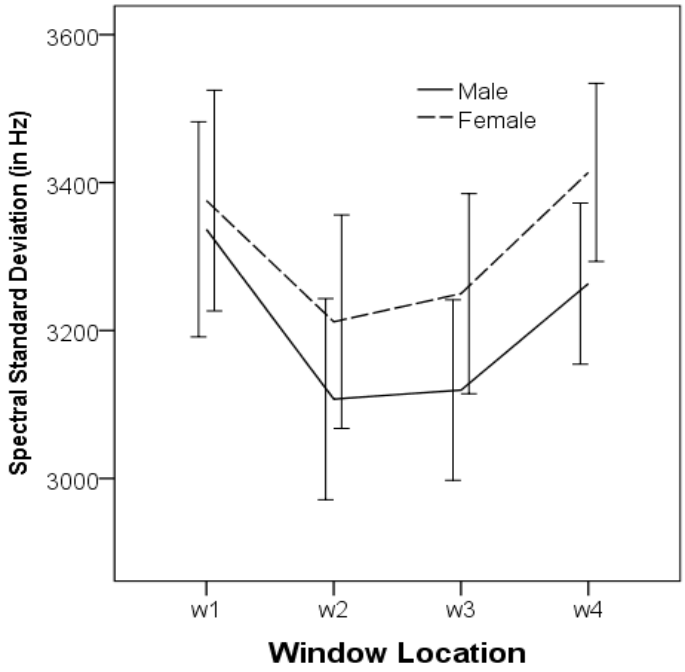

Figure 4.33 Spectral standard deviation as a function of gender and window location in CV fricatives.

A place by age group interaction was also significant [F (9, 168) =12.528, p<0.0001, η^2 =0.402]. The average spectral standard deviation of adult speakers was highly elevated in nonsibilant fricatives /f, h/, while the value was increased for the child groups in sibilant fricatives /s, ʃ/ (figure 4.35).

The analysis of variance indicated that the spectral standard deviation of fricatives varied as a function of vowel context [F(1, 56)=23.819, p<0.0001, η^2=0.298]. The average dependent measure of standard deviation was higher in the context of /i/ (3292 Hz) than in the context of /u/ (3026 Hz), as indicated in figure 4.36. Similarly, the ANOVA revealed that the place by vowel context interaction effect was significant [F(3, 168)=20.029, p<0.0001, η^2 =0.263]. As illustrated in figure 4.37, the mean standard deviation of the nonsibilant fricatives was higher in the context of /i/, while the average measure of the standard deviation of the postalveolar fricative /ʃ/ was higher in the context of the high back rounded vowel /u/. On the other hand, the mean spectral standard deviation was similar for /s/ in both vowel contexts.

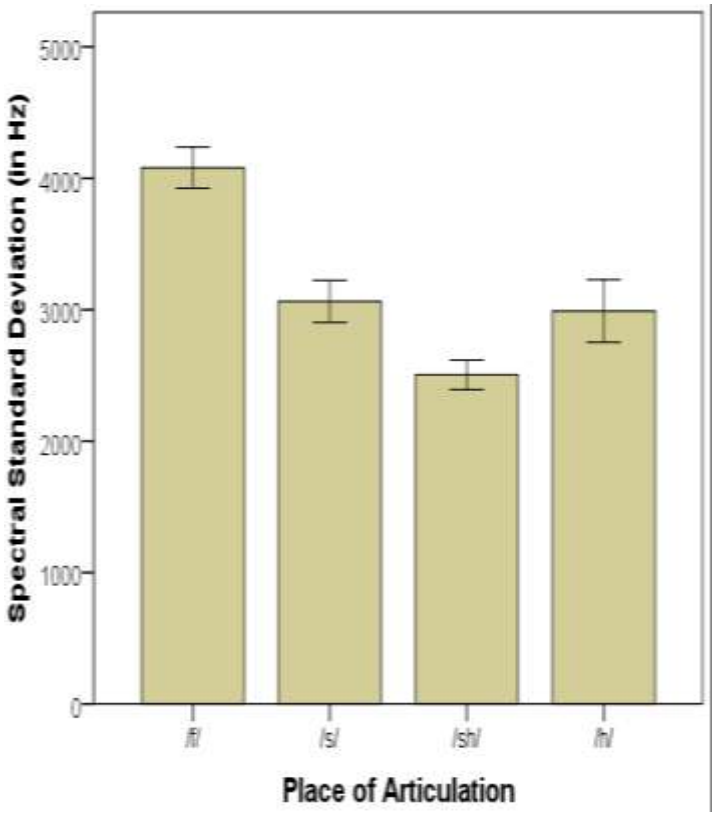

Figure 4.34 Spectral standard deviation as a function of place of articulation in CV fricatives.

Finally, the analysis of variance for the dependent measure of standard deviation (the second moment) revealed a significant vowel by age interaction [F (3, 56)=4.088, $p<0.01$, $\eta^2=0.180$]. The significant interaction was obtained mainly as a result of elevated average spectral standard deviation of adult speakers in both vowel contexts and increased mean value of the three years old children in the context of /u/ (figure 4.38). The four years old child speakers also revealed increased mean measure of spectral standard deviation in the context of /i/.

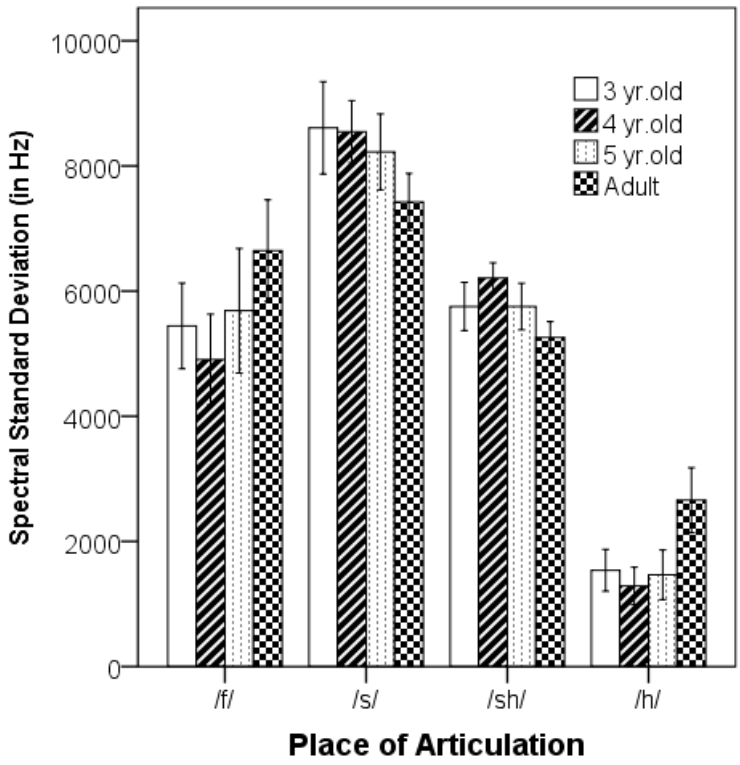

Figure 4.35 Spectral standard deviation as a function of place of articulation and age groups in CV fricatives.

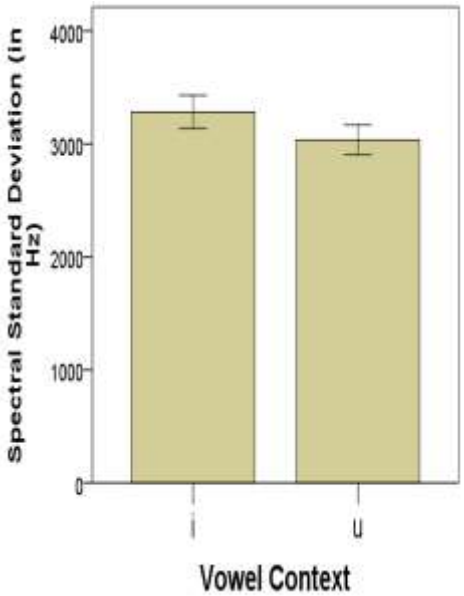

Figure 4.36 Spectral standard deviation as a function of vowel context in CV fricatives.

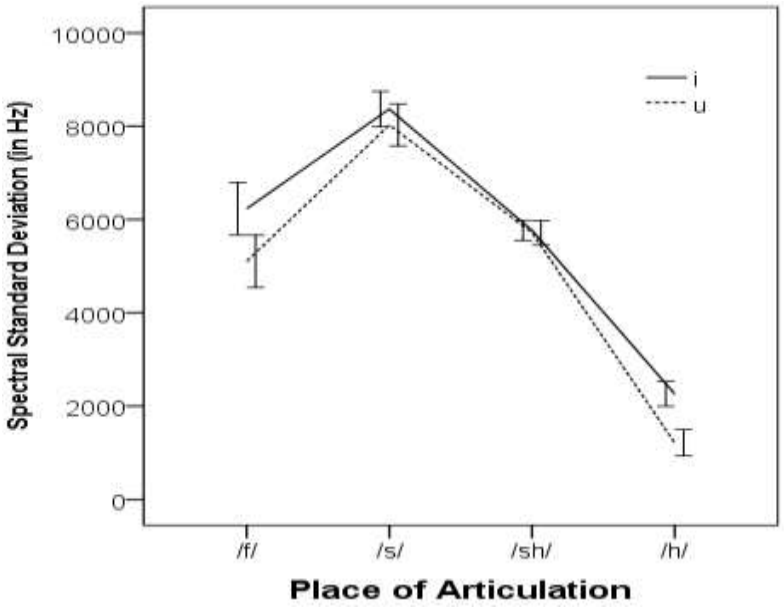

Figure 4.37 Spectral standard deviation as a function of place of articulation and vowel context in CV fricatives.

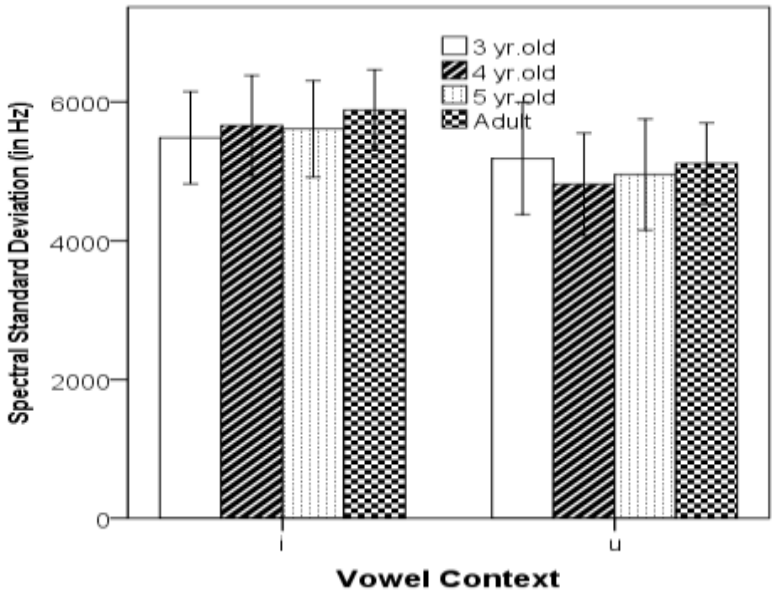

Figure 4.38 Spectral standard deviation as a function of vowel context and age groups in CV fricatives.

4.2.4 The Spectral Skewness

A one-way ANOA displayed that a mean spectral skewness significantly differed as a function of window location [F(3, 2044)=6.517, p<0.0001]. As indicated in figure 4.39, the result was mainly obtained as a result of high average measure of spectral skewness of the onset and the transitional windows of analysis. The overall dependent measures of spectral skewness of the first, second, third and fourth windows were 2.28, 1.79, 1.68, and 2.49, respectively.

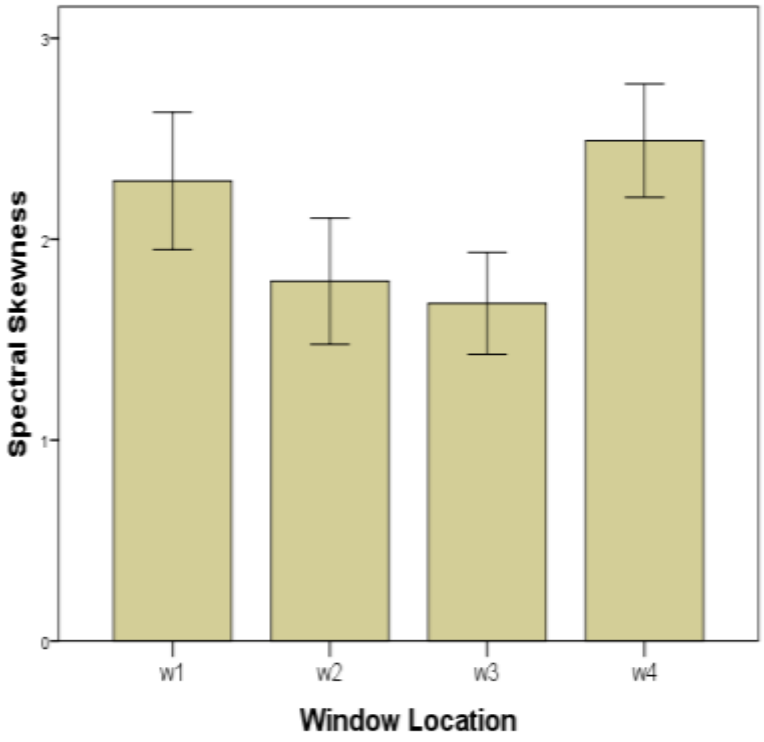

Figure 4.39 Spectral skewness as a function of window location in CV fricatives.

Especially the increased measure of the transitional window was consistent with the anticipatory coarticulation. That is the high positively skewed measure of this window signified the dominance of spectral energy in the lower frequency region due to coarticulatory effect of the following vowels (Jongman et al. 2000).

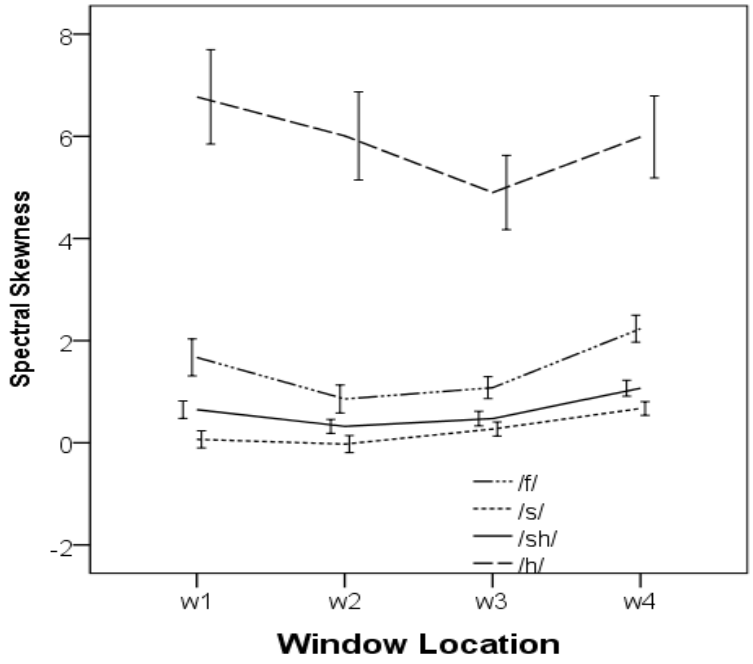

Figure 4.40 Spectral skewness as a function of place of articulation and window location in CV fricatives.

The four-way ANOVA was conducted for individual windows of analysis and the onset and transitional windows distinguished three places of articulations as indicated in figure 4.40, with great difference noted among the voiceless glottal fricatives /h/ and other fricatives. The central and offset windows distinguished only two places each. In addition, figure 4.41 illustrated that the mean measure of spectral skewness varied across windows as a function of vowel context. The average measure of spectral skewness was

highly elevated in the context of the high back rounded vowel /u/ (1.46 for /i/ and 2.66 for /u/), indicating the dominance of energy in lower frequency region in this phonetic environment.

The four-way analysis of variance (place x vowel x age x gender) for the 40 ms central window was computed. The test showed a main effects of place, [F(1.519, 85.085)=196.057, p<0.0001, η^2=0.778]. As illustrated in figure 4.42, the result was obtained because of highly elevated average measure of spectral skewness of voiceless glottal fricative /h/. The overall measures of spectral skewness were 0.858, -0.0245, 0.322, and 6 for /f, s, ʃ, h/, respectively. Taken as a class, the spectral skewness of

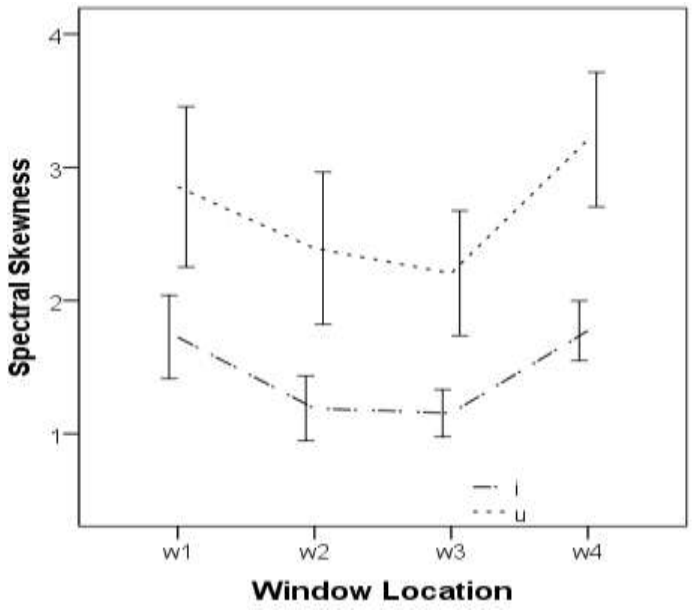

Figure 4.41 Spectral skewness as a function of vowel context and window location in CV fricatives.

nonsibilant fricatives was significantly ($p<0.0001$) higher than that of the sibilant fricative (3.43, and .148, respectively). Pairwise comparison showed that all places were significantly different in terms of spectral skewness, $p<0.002$ for /f, s/ and /s, ʃ/, and $p<0.0001$ for the rest.

The test indicated that the place by age group interaction was significant [$F(4.558, 85.085)=9.314$, $p<0.0001$, $\eta^2=0.333$]. As indicated in figure 4.43, the overall measures of spectral skewness of all age groups were higher for the voiceless glottal fricative /h/, with highly greater value noted for four years old children. The test also yielded a significant place by gender interaction [$F(1.519, 85.085)=3.754$, $p<0.03$, $\eta^2=0.063$]. The average spectral skewness produced by male speakers was increased for /h/, while the average value produced by female speakers was increased for /f/ (figure 4.44). The difference between the two sexes was not wide for the sibilant fricatives /s, ʃ/.

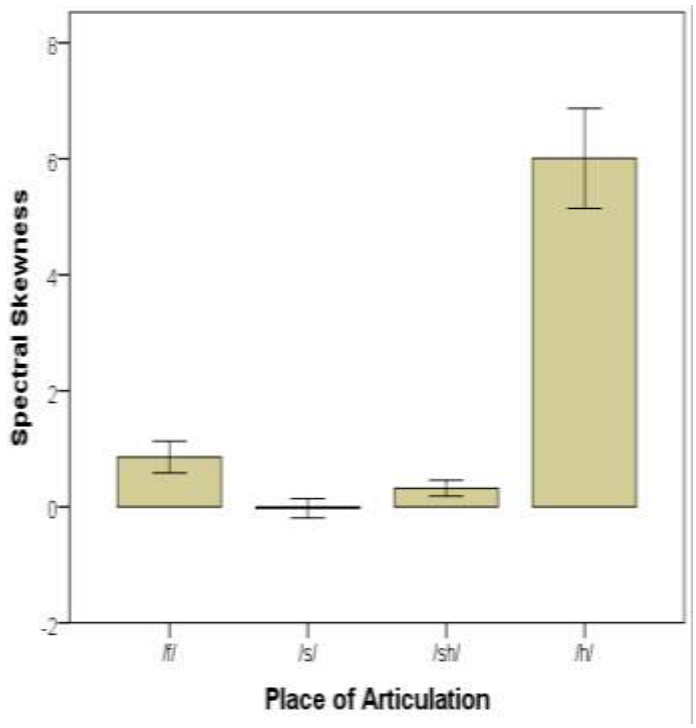

Figure 4.42 Spectral skewness as a function of place of articulation in CV fricatives.

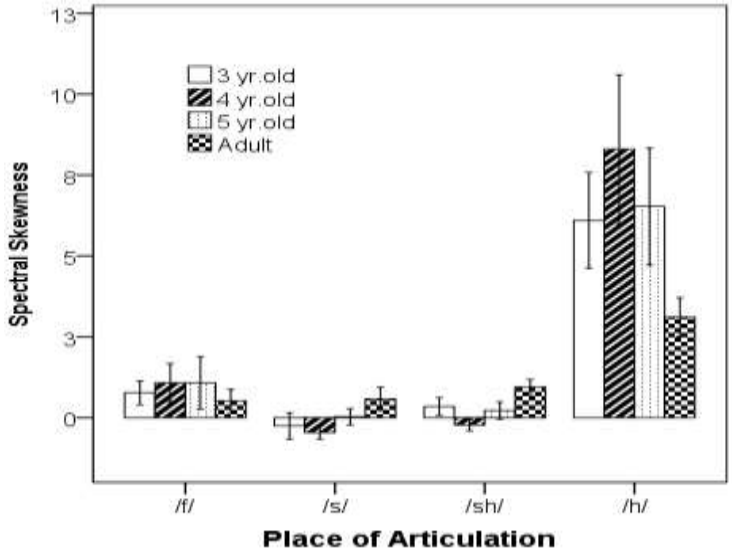

Figure 4.43 Spectral skewness as a function of place of articulation and age groups in CV fricatives.

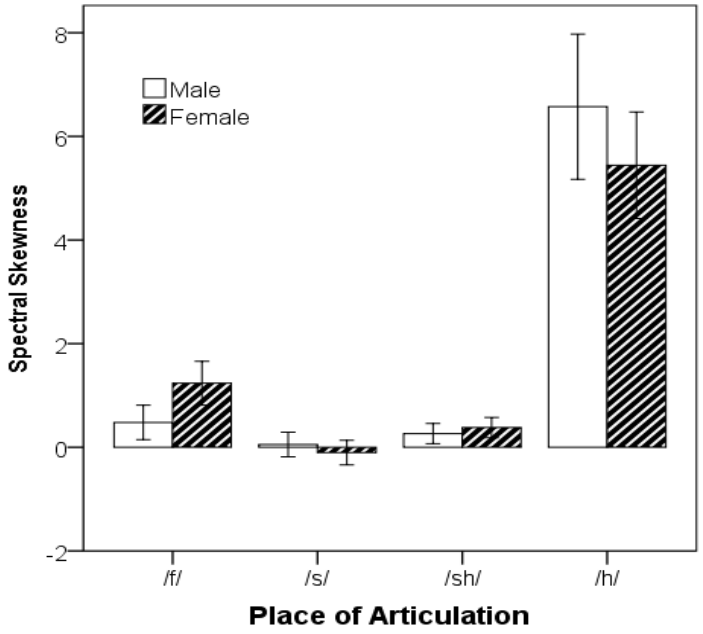

Figure 4.44 Spectral skewness as a function of place of articulation and gender in CV fricatives.

The test showed that spectral skewness differed in terms of vowel context [F (1.000,56.000) 81.328, p<0.0001, η^2=0.592]. As demonstrated in figure 4.45, the overall measure of spectral skewness of fricatives was higher in the context of /u/. The value was.590 for fricatives preceding /i/ and 2.99 before/u/.

The analysis of variance also exhibited a significant place by vowel context interaction effect [F(1.340, 75.041)=84.429, p<0.0001, η^2=0.601]. This result mainly stemmed from high mean spectral skewness of /h/ in the context of /u/, as illustrated in figure 4.46.

The analysis of variance displayed that a vowel context by age group ([F(3.000, 56.000)=6.433, p<0.001, η^2 =0.256] interaction was significant. Figure 4.47 showed that the result was greatly obtained because of the highly increased average measure of

spectral skewness produced by the child groups in the context of the high back rounded vowel /u/, whereas the value was almost similar for all age groups in the context of /i/.

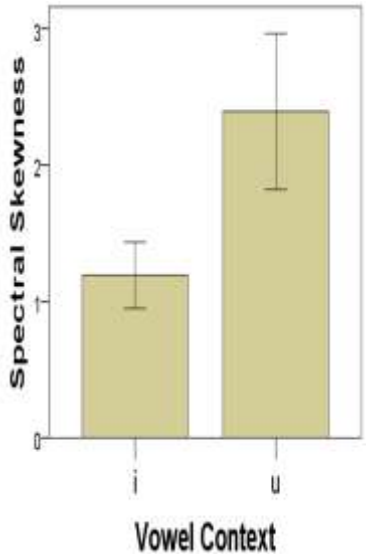

Figure 4.45 Spectral skewness as a function of vowel context in CV fricatives.

Finally, the four-way analysis of variance exhibited a main effect of age groups [F(3,56) =3.109, p<0.034, η^2 =0.143]. Figure 4.48 illustrated that the result was obtained mainly because of the decreased mean spectral skewness of the adult group. Collapsed across speakers and vowel context, the average measure of spectral skewness of three years, four years and five years old children and adults were 1.74, 2.17, 1.96, and 1.29, respectively. Thus, spectral skewness is higher in the child groups, characterizing child speech with the dominance of spectral energy at lower frequency spectra. Bonferroni post hoc test revealed that only the difference between four years old children and adults significantly distinct (p<0.03) in terms of spectral skewness.

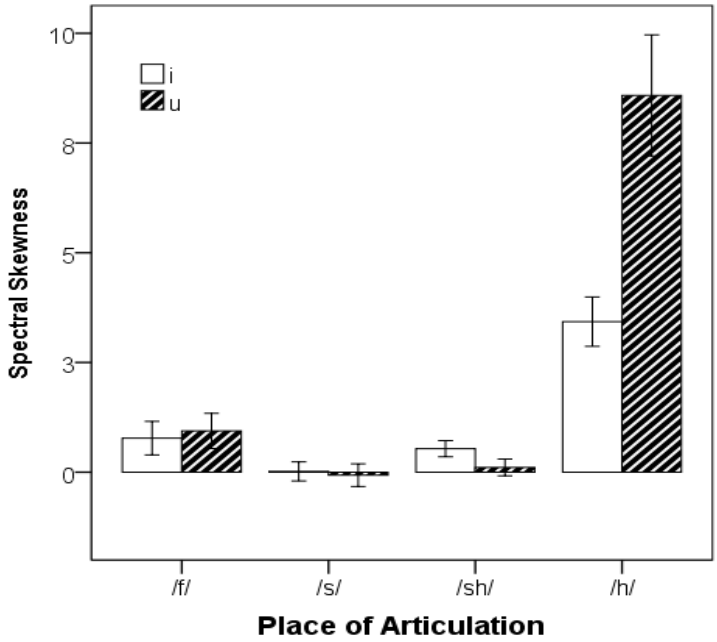

Figure 4.46 Spectral skewness as a function of place of articulation and vowel context in CV fricatives.

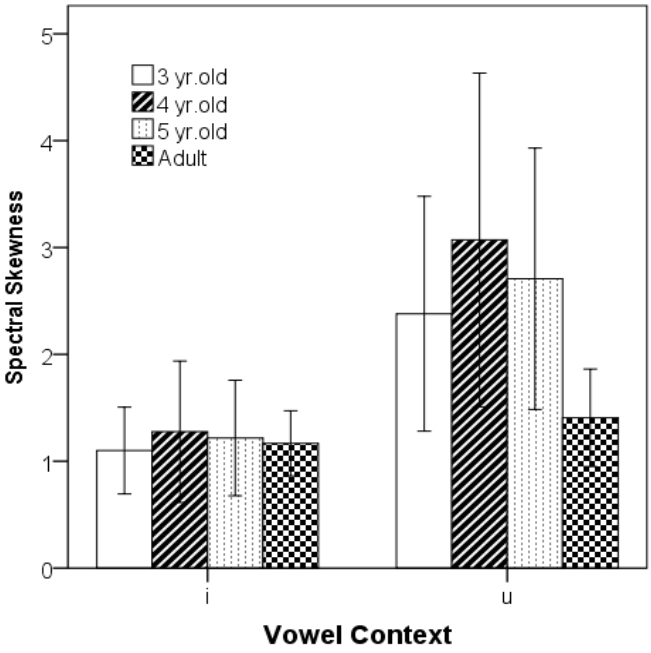

Figure 4.47 Spectral skewness as a function of vowel context and age groups in CV fricatives.

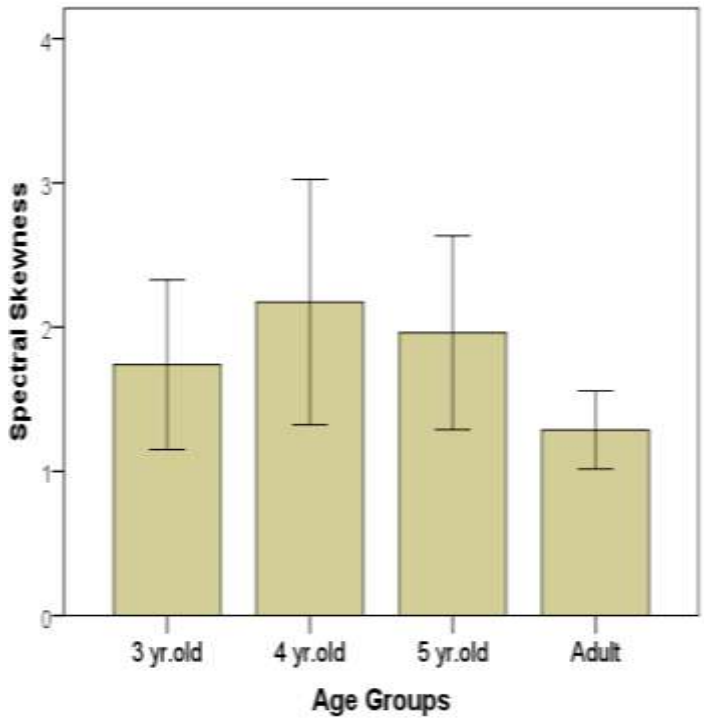

Figure 4.48 Spectral skewness as a function of age groups in CV fricatives.

4.2.5 The Spectral Kurtosis

A one-way ANOVA depicted that the fourth spectral moment (spectral kurtosis) was not significant as a function of windows of analysis. Spectral kurtosis of the central window was computed employing four-way repeated measures of analysis of variance and main effect was found for place [$F(1.020, 57.146)=31.865$, $p<0.0001$, $\eta^2=0.363$]. Figure 4.49 signified that the main effect was obtained as a result of highly elevated ($p<0.001$) mean spectral kurtosis of the voiceless glottal fricative /h/. The overall spectral kurtosis, collapsed across speakers and vowel context, was 4.31 for /f/, 3.52 for /s/, 2.86 for /ʃ/, and 75.83 for /h/. Taking the first three fricatives into consideration, the pattern showed

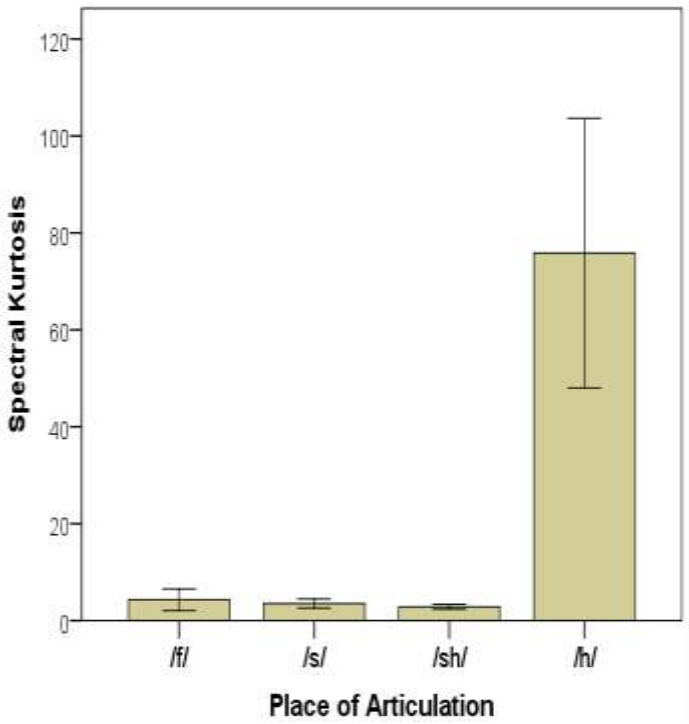

Figure 4.49 Spectral kurtosis as a function of place of articulation in CV fricatives.

that as the place moves posterior in the vocal tract, the average spectral kurtosis decreases. The average measure of the kurtic value of the voiceless glottal fricative /h/ was highly increased, characterizing the sound with highly peakedness. Thus, this sound has aloof feature from the rest fricatives which indicates that it has rather similar feature with vowel sounds than fricatives. Bonferroni post hoc test indicated that only the difference between /h/ and other fricatives was significant ($p<0.0001$).

The test yielded a significant place by age group interaction [$F(3.061, 57.146) = 5.060$, $p<0.003$, $\eta^2=0.213$]. The significant interaction was led by greater mean spectral kurtosis of child groups, with the highest measure noted for four years old children in /h/, as demonstrated in figure 4.50.

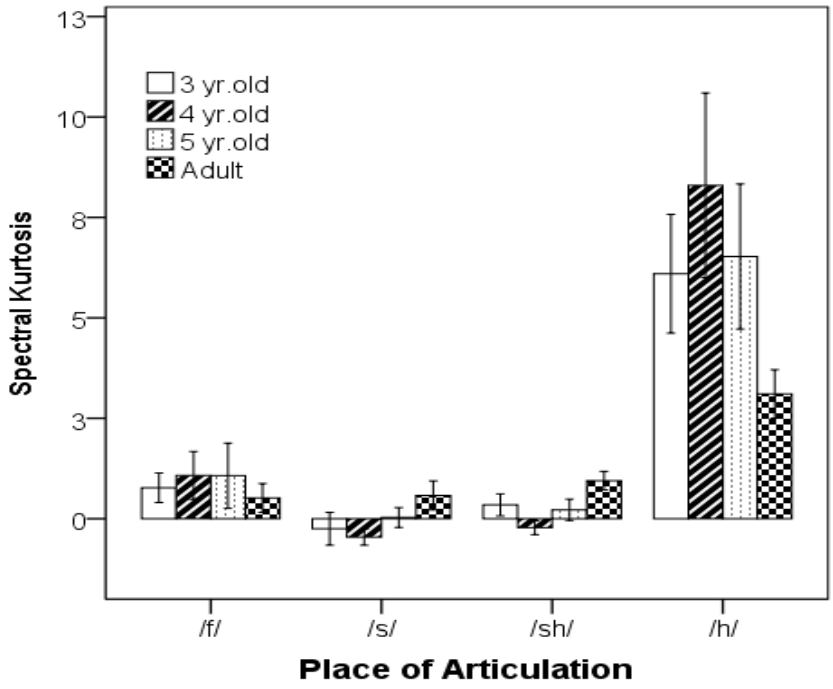

Figure 4.50 Spectral kurtosis as a function of place of articulation and age groups in CV fricatives.

As illustrated in figure 4.51, a main effect of vowel context was obtained for the dependent measure of spectral kurtosis of the central window [F(1.000, 56.000)=25.168, p<0.0001, η^2=0.310]. The overall dependent measure of spectral kurtosis of the central window of fricatives was higher in the context of /u/ (35) compared to the average value of in the context of /i/ (8.21).

A place by vowel context interaction was also significant [F(1.012, 56.672)=23.145, p<0.0001, η^2=0.292]. Figure 4.52 showed that the mean measure of spectral kurtosis of the voiceless glottal fricative was highly increased in the context of /u/. Moreover, this sound also exhibited relatively higher average value of kurtosis in the context of /i/ compared to other fricatives, which did not vary in both phonetic contexts. The test also

yielded significant interaction of vowel by age groups [F(3.000, 56.000)=4.068, p<0.01, η^2=0.179]. The average measure of spectral kurtosis of child groups was greater in the context of /u/, with the highest value being observed for four years old child speakers(figure 4.53).

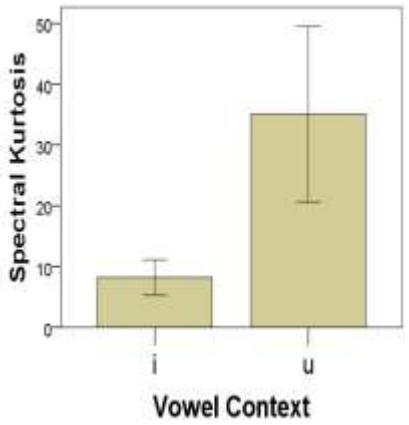

Figure 4.51 Spectral kurtosis as a function of vowel context in CV fricatives.

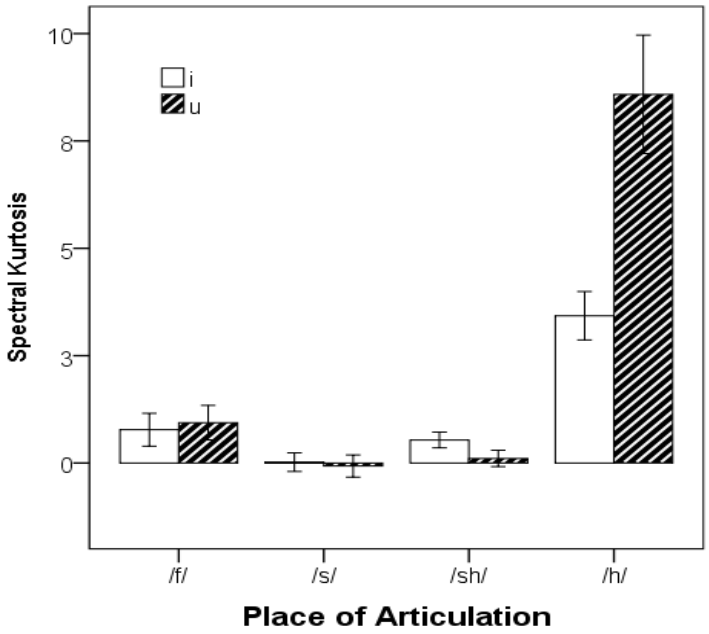

Figure 4.52 Spectral kurtosis as a function of place of articulation and vowel context in CV fricatives.

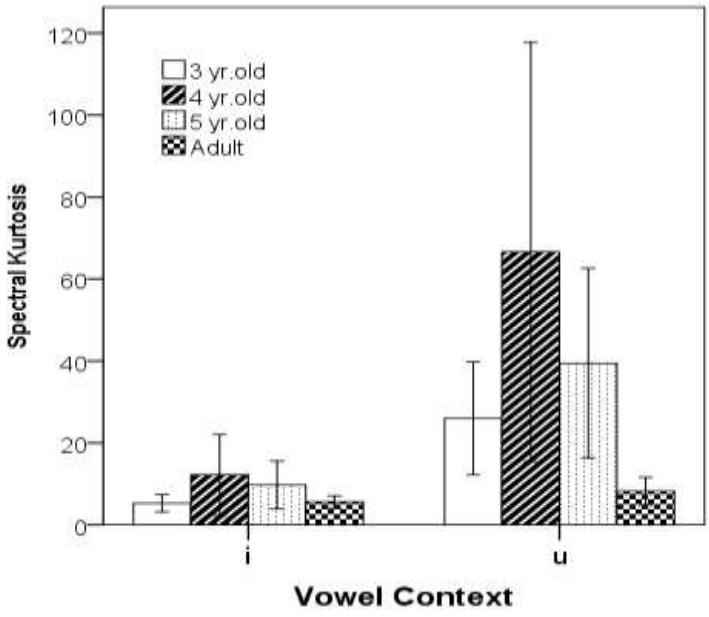

Figure 4.53 Spectral kurtosis as a function of vowel context and age groups in CV fricatives.

Finally, a main effect was obtained for age groups [F(3, 56)=4.724, p<0.005, η^2=0.202]. Figure 4.54 depicted that the average values of spectral kurtosis produced by three years old child and adult speakers were decreased. The average spectral kurtosis of three, four and five years old children and adult speakers were, 15.62, 39.39, and 24.59, 6.92, respectively. The mean values indicated that fricatives produced by child speakers were more picked or defined than that of the adult speakers. Subsequent post hoc test showed only the mean dependent measure of spectral kurtosis produced by four years old children significantly (p<0.004) differed from that of the adult speakers.

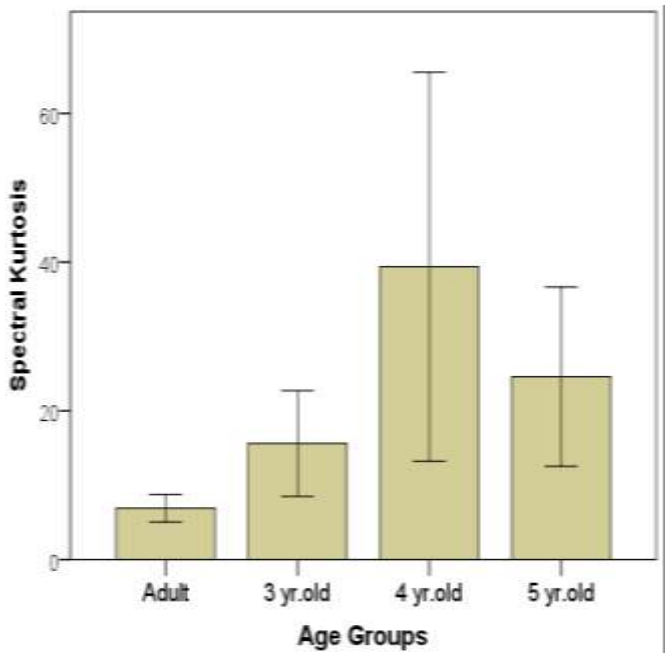

Figure 4.54 Spectral kurtosis as a function of age groups in CV fricatives.

4.2.6 Locus Equation

4.2.6.1 Slope

The four-way analysis of variance was conducted to test the average value of slope of locus equation. The test depicted a main effect of vowel [F(1.000, 56.000)=180.721, p<0.0001, η^2=0.763]. The average value of locus equation of slope of fricatives was higher in the context of /u/ (.988) than in the context of /i/ (.853) (figure 4.55).

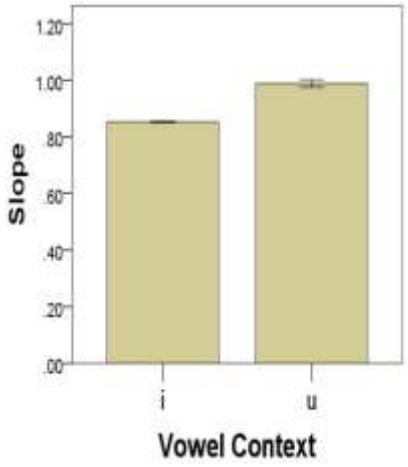

Figure 4.55 Slope as a function of vowel context in CV fricatives.

The test also showed that the speech produced by male and female speakers varied as a function of the following vowels [F(1.000, 56.000)=20.182, p<0.0001, η^2=0.265]. As clearly illustrated in figure 4.56, the average value of slope of male speakers was increased in both vowel contexts, with great difference noted between the two sexes in the context of /u/.

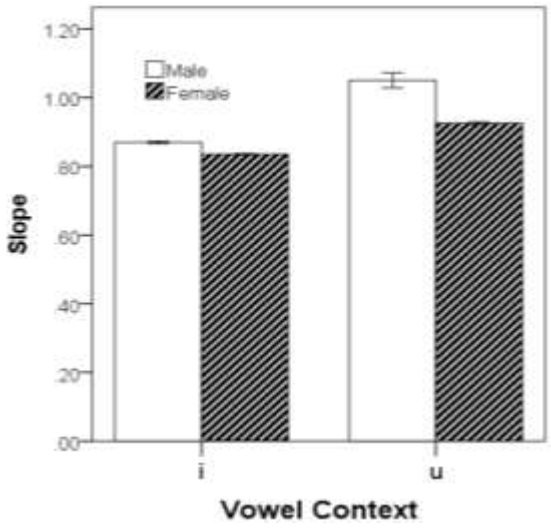

Figure 4.56 Slope as a function of vowel context and gender in CV fricatives.

The four-way analysis of variance (place x vowel x age x gender) also revealed main effects of gender [F(1, 56)=64.060, p<0.0001, η^2=0.534]. The average slope of male speakers was greater than the average slope of female speakers (figure 4.57). The overall slope, collapsed across speakers and vowel context, of the male speakers was .960 and of the female speakers was .881. The magnitude of slope shows coarticulatory strength of a test attribute (Lofqvist 1999). That is the bigger a slope is, a stronger a coarticulatory tendency is. Thus, this study depicted that male speakers were more tended towards anticipatory coarticulation than female speakers.

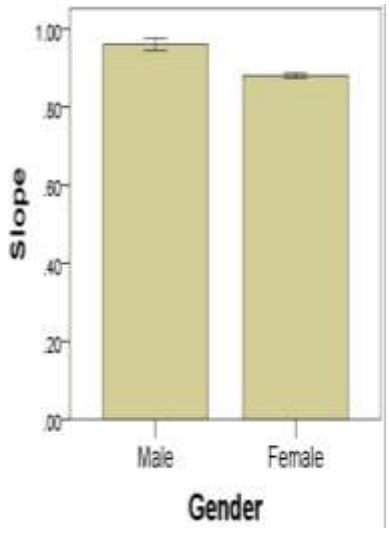

Figure 4.57 Slope as a function of gender in CV fricatives.

No other main effect or interaction effect, including place of articulation, was found to be significant. This may give us the impression that locus equation plays a marginal role in discriminating fricatives in terms of place of articulation. Moreover, this finding was also contrary to the claim that child speakers were more sensitive to coarticulation than adult

speakers (e.g., Nittrouer et al.1989) because there was no main effect or significant interaction of age.

4.2.6.2 Y-intercept

The analysis of variance showed significant main effect of vowel context [F (1.000, 56.000)=497.381, p<0.0001, η^2 =0.899]. As indicated in figure 4.58, the mean value of y-intercept was highly elevated in the context of /i/ (298 Hz) than in the context of /u/ (144 Hz). The vowel by gender interaction was also significant for the dependent measure of y-intercept [F(1.000, 56.000)=33.734, p<0.0001, η^2 =0.376]. In both vowel contexts the average value of y-intercept produced by female speakers was highly increased, with greater difference noted in the context of /u/ (figure 4.59).

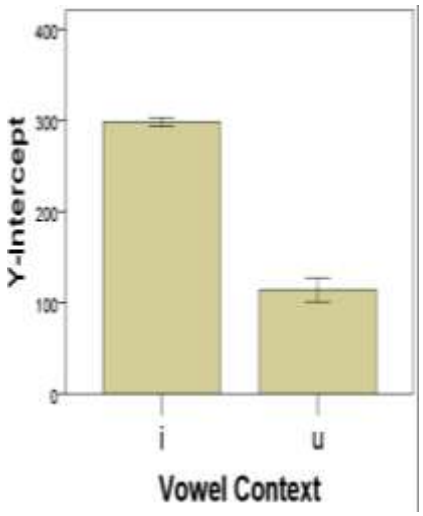

Figure 4.58Y-intercept as a function of vowel context in CV fricatives.

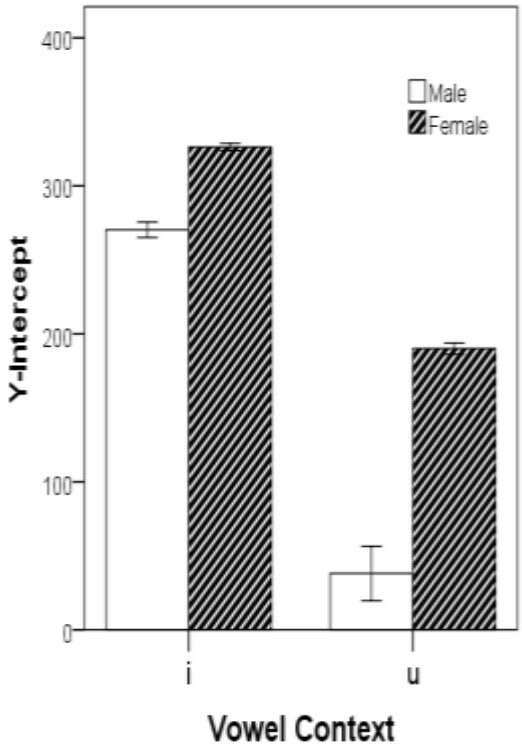

Figure 4.59 Y-intercept as a function of vowel context and gender in CV fricatives.

The four-way (place x vowel x gender x age) ANOVA revealed main effect of gender [$F(1, 56)=108.604$, $p<0.0001$, $\eta^2 =.660$]. The mean value of y-intercept of the female speakers (258 Hz) was highly elevated than that of the male speakers (154Hz) (figure 4.60). No other main effect or interaction was significant.

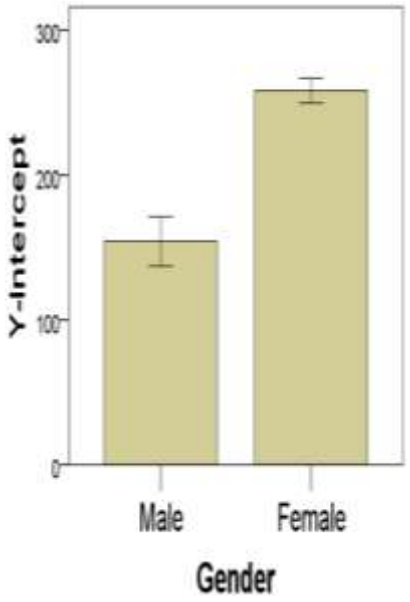

Figure 4.60 Y-intercept as a function of gender in CV fricatives.

4.2.6.3 F2 Onset

The four-way ANOVA was computed for the dependent measure of F2 onset and exhibited main effect of place [F(2.595, 145.343)=68.895, p<0.0001, η^2=0.552]. The result was obtained due to the decreased average dependent measure of F2 at onset of vowels for the nosibilant fricatives, as shown in figure 4.61. Collapsed into sibilance groups, the average measure of F2o was 1871 Hz for sibilants and 1556 Hz for nonsibilant fricatives. This discrepancy between sibilant and nonsibilant fricatives was highly significant at p<0.0001. The average measures of F2o of fricatives /f, s, ʃ, h/ were 1589 Hz, 1768 Hz, 1973 Hz, and 1514 Hz, respectively. Subsequent pairwise comparison revealed that the difference between nonsibilant fricatives /f, h/ was not significant. The rest fricatives were different from each other in terms of F2o (p<0.0001).

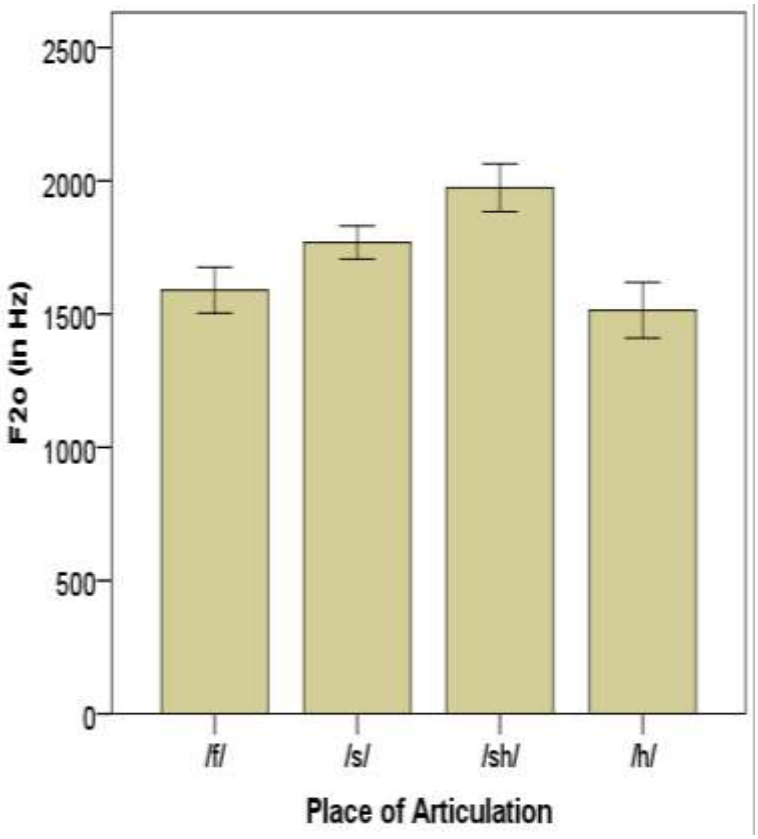

Figure 4.61 F2o as a function of place of articulation in CV fricatives.

Figure 4.62 depicted that the mean value of F2 at the beginning of vowels produced by speakers of different ages varied across different places of articulations [F(7.786, 145.343)=2.652, p<0.01, η^2=0.124]. The place by age interaction exhibited three different patterns. The mean value of F2 at onset of vowel (F2o) was decreased for three years old child speakers in /f/ and similar for the rest age groups. The attribute was slightly increased for child speakers than adult speakers for /s/ and /ʃ/, with no difference observed between five years old children and adult speakers for /ʃ/. On the contrary, the value for the glottal fricative depicted that as the age increased the mean value of F2o also increased.

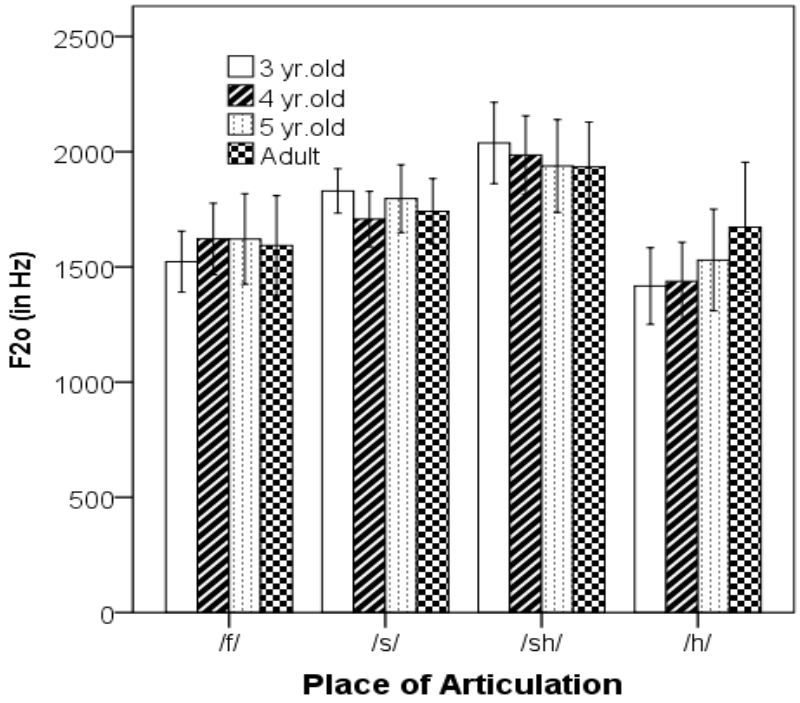

Figure 4.62 F2o as a function of place of articulation and age groups for CV fricatives.

Figure 4.64 showed that a place by vowel interaction was significant [F(2.679, 150.041)=22.538, p< 0.0001, η^2=0.287]. The dependent measure of F2 at the beginning of vowels was higher in the context of /i/ compared to the value in the context of /u/ for all fricatives.The main effect of vowel context [F(1.000, 56.000)=285.585, p<0.0001, η^2=0.836] revealed that the mean value of F2 at onset of vowels for fricatives was higher in the context of /i/ (2020 Hz) than the mean F2o of fricatives in the context of /u/ (1403 Hz), as clearly shown in figure 4.63.

Finally, the analysis of variance showed that an age by gender interaction was significant [F(3, 56)=3.599, p<0.02, η^2=0.162] for the dependent measure of F2o. The significant interaction was obtained as a result of higher mean spectral value of F2o produced by five years old and adult female speakers (Figure 4.65).

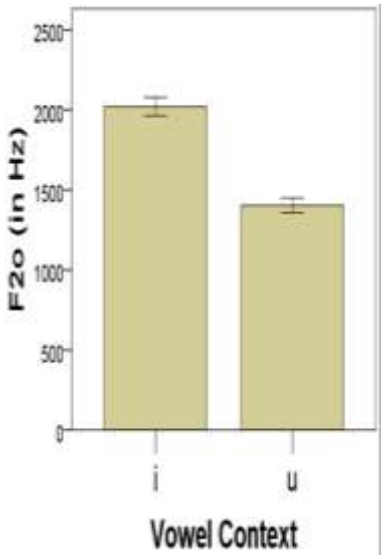

Figure 4.63 F2o as a function of vowel context for CV fricatives.

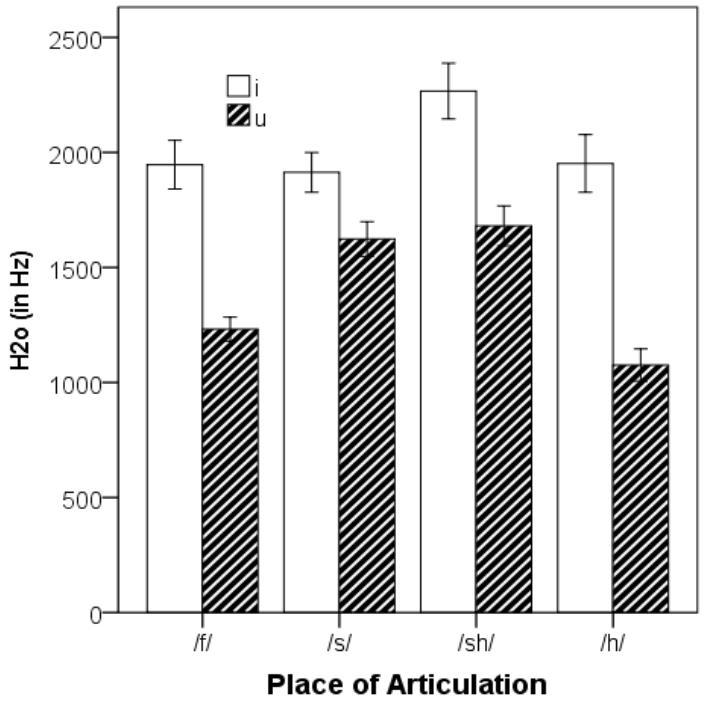

Figure 4.64 F2o as a function of place of articulation and vowel context in CV fricatives.

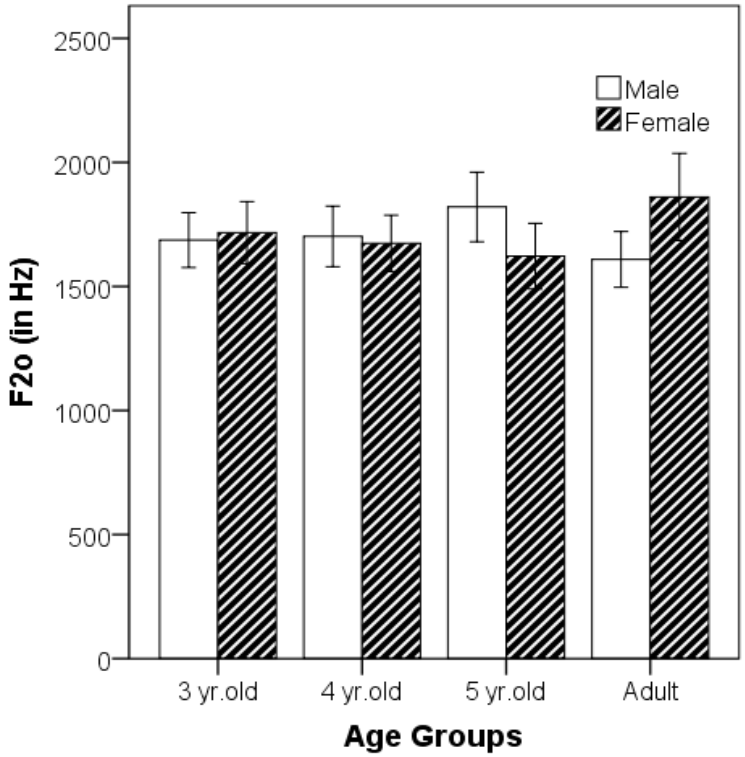

Figure 4.65 F2o as a function of age and gender in CV fricatives.

4.3 Discriminant Analysis

Discriminant analysis was conducted on the acoustic measures used in the analysis of CV fricatives. The objective was to examine the extent to which the attributes discriminate fricatives as a function of place of articulation. Moreover, the test also analyzed the rates of classifications for age groups. In the analysis the Jack-knife (standard stepwise) approach was used. Generally, 22 acoustic measures (predictors) were entered into the analysis. The predictors were fricative duration, vowel duration, normalized duration, normalized amplitude (RMS), spectral peak location, 16 spectral moments (4 moments x four windows), and F2 transition at vowel onset (F2o).

The Jack-knife (stepwise) classification method signified overall correct classification rate of 84.2 %. The classification rate for adult group was lower (83.6 %) compared to that of the child groups. The classification rate was 85.9 % for three years old, 86.7 % for four years old, and 85.2 % for five years of age child speakers. The classification rate of female speakers (81.2 %) was lower than that of male speakers (84 %).

The standardized canonical discriminant function coefficients selected nine predictors: fricative duration, normalized amplitude, spectral peak location, moment one of window one, moment one of window two, moment one of window three, moment two of window two, moment three of window one and moment four of window one. When only this nine predictors were entered into the analysis, the overall classification rate was 83.8 %. Finally, only five predictors: moment one of window one, moment one of window two, moment one of window three, moment two of window two, moment three of window one, was employed and the classification rate was decreased to 76.2%.

The jack-knife classification approach correctly classified fricatives 84.2 % utilizing 22 descriptors. The classification rate was 82 % for /f/, 76.6 % for /s/, 82.8 % for /ʃ/ and 95.3 % for /h/. Classification error crossed the sibilant and nonsibilant category. The result indicated that the classification of /f, s, ʃ/ confused one another other. When the analysis considered the classification of fricatives on the basis of sibilance, the jack-knife classification method correctly classified the sounds 91.6%. The rate of classification of sibilants (92.6 %) was better than that of nonsibilant fricatives (90.6 %).

The classification rate of fricatives was also computed utilizing data from individual group of speakers to examine variations as a function of age. The rate of classification of fricatives when adult group was considered was 78.1 % for /f/, 75 % for /s/, 81.3 % for /ʃ/ and 100 % for /h/. For three years old child speakers the rates of classification of /f, s, ʃ, h/ were 87.5 %, 81.3 %, 81.3 %, and 93.8 %, respectively. The rate was 84.4 % for /f/ 78.1 % for /s/, 87.5 % for /ʃ/ and 96.9 % for /h/ in fricatives produced by four years old children. Finally, 81.3 %, 78.1 %, 87.5 % and 93.8 were rates of classifications of fricatives /f, s, ʃ, h/, respectively for five years old children.

CHAPTER FIVE

ACOUSTIC ANALYSIS OF VCV FRICATIVE CONSONANTS

Under this section, results obtained from VCV fricatives were discussed. This part mainly focused on singleton/geminate contrast. The test fricatives included here were only /f, s, ʃ/ because /h/ does not have geminate counterpart and always exists in singleton form. The acoustic features included were fricative duration, vowel duration, normalized duration (the ratio of fricative duration to word duration), spectral peak location, spectral moments (mean, standard deviation, skewness, and kurtosis) extracted from 40 ms window placed at center of fricatives. Five-way ANOVA (place x vowel x gemination x age x gender) was conducted to compute the features. The analysis of variance was of a mixed-design type in which place, vowel and gemination were used as within subject factors and age and gender were used as between subject factors. The results discussed were significant at alpha less than 0.05.

5.1 Analysis of Duration Measures

5.1.1 Fricative Duration

For the dependent measure of noise duration of fricatives, five-way repeated measures ANOVA (place x vowel x gemination x age x gender) was computed. The ANOVA is a mixed designed in which place, vowel context and gemination were entered as within subject and gender and age groups were treated as between subject factors. The test yielded only main effect of gemination [$F(1.000, 56.000)=399.607$, $p<0.0001$, $\eta^2=0.877$]. As expected, the main effect was obtained as a result of longer average measure of noise duration of geminate fricatives (109 ms for singleton and 171 ms for

geminate fricatives). The difference between the two durations was illustrated in figure 5.1. No other main effect, including place of articulation, was found.

Similarly, only a place by vowel interaction effect was significant [F(1.256, 70.351)=7.679, p<0.004, η^2=0.121]. Though both place and vowel context were not significant, their interaction displayed some patterns of difference between the two vowel contexts. The mean noise duration of fricatives (averaged for speakers, vowel context and gemination) was higher in the context of /u/ for /f/ and /ʃ/, while the measure was increased for /s/ in the context of /i/ (figure 5.2).

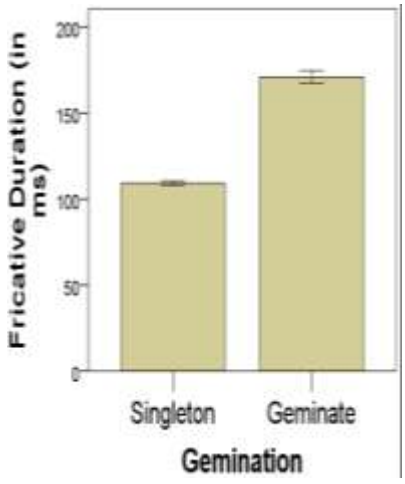

Figure 5.1 Fricative duration as function of gemination in VCV fricatives.

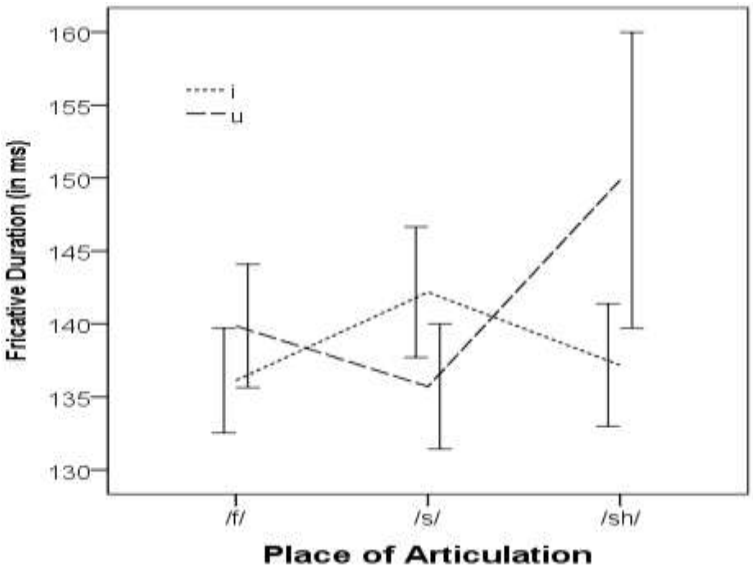

Figure 5.2 Fricative duration as function of place of articulation and vowel context in VCV fricatives.

5.1.2 Vowel Duration

A five-way ANOVA exhibited main effect of place [F(2, 112)=49.775, p<0.0001, η^2 =0.471] for the dependent measure of vowel duration. As shown in figure 5.3, the main effect stemmed from shorter average measure of duration of vowels preceding the voiceless alveolar fricative /s/. Collapsed across speakers, vowel context and gemination, the average measure of duration of vowels preceding fricatives /f, s, ʃ/ were 83 ms, 70 ms, and 75 ms, respectively. Subsequent Bonferroni adjusted post hoc test displayed that all fricatives were significantly different in terms of vowel duration (p<0.0001).

For the dependent measure of noise duration of vowels preceding fricatives a five-way analysis of variance depicted main effect of vowel [F(1, 56)=68.944, p<0.0001, η^2 =0.552]. The mean duration of vowel preceding fricatives was higher in the context of /u/ (figure 5.4). Averaged for speakers, vowel context and gemination (singleton and

geminates), the mean duration of vowels preceding fricatives was 72 ms in the context of /i/ and 80 ms in the context of /u/.

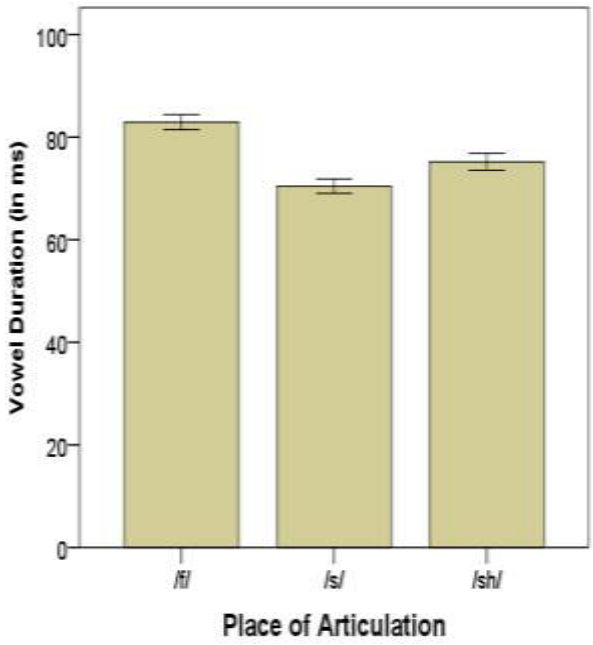

Figure 5.3 Fricative duration as function of place of articulation in VCV fricatives.

As illustrated in figure 5.5, a significant place by vowel interaction ([F(2, 112)=26.965, p<0.0001, η^2=0.325] exhibited that the mean duration of /u/ was longer preceding /s/ and /ʃ/, with highly increased measure noted preceding postalveolar fricative /ʃ/. On the contrary, the difference was negligible preceding /f/.

The test depicted a significant place by gemination [F(2, 112)=6.128, p<0.003, η^2 =0.099]. As illustrated in figure 5.6, the mean duration of vowels preceding singleton /f/, geminate /ss/ and /ʃʃ/ was longer. No other main effect or interaction was obtained for vowel duration.

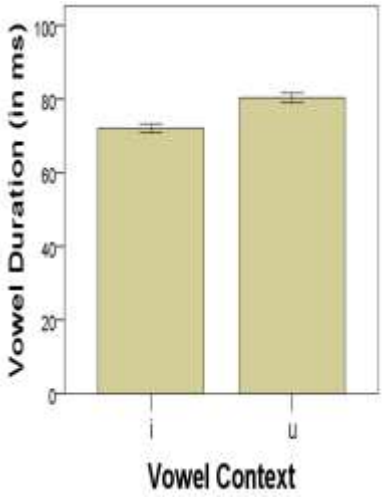

Figure 5.4 Fricative duration as function of vowel context in VCV fricatives.

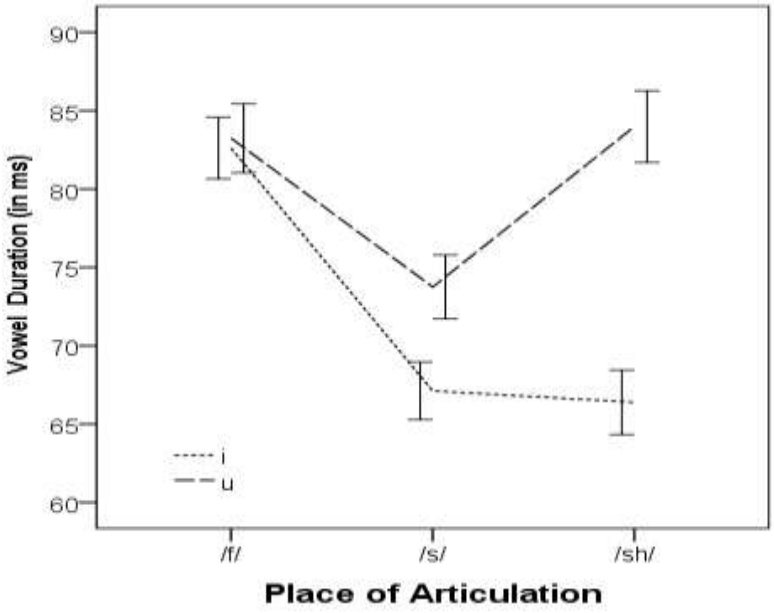

Figure 5.5 Fricative duration as function of place of articulation and vowel context in VCV fricatives.

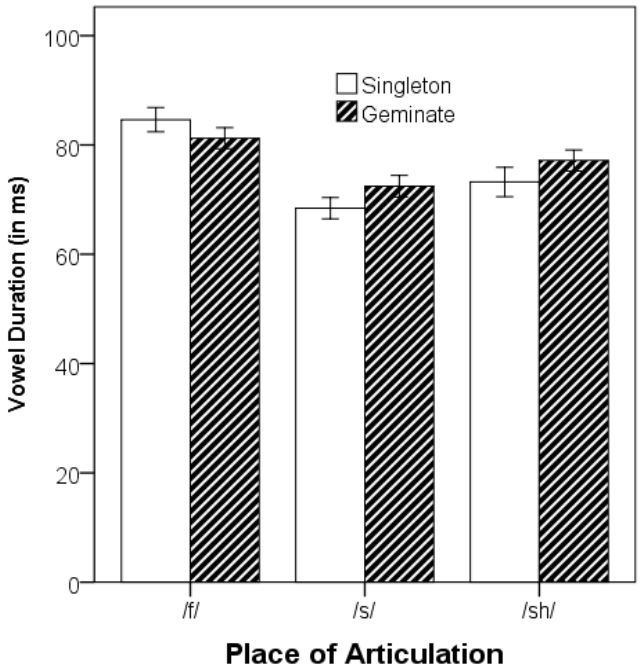

Figure 5.6 Fricative duration as a function of place of articulation and gemination in VCV fricatives.

5.1.3 Normalized Duration

The Five-way analysis of variance (place x vowel x gemination x gender x age) was computed to test the dependent measure of normalized duration and a main effect of place was found [$F(2, 112)=12.305$, $p<0.0001$, $\eta^2=0.180$]. As indicated in figure 5.7, the main effect was obtained due to slightly decreased measure of average normalized duration of /f/. The mean measure of normalized duration was 0.285 for /f/, 0.303, for /s/, and 0.302 for /ʃ/. Normalized duration distinguished only one place of articulation. Only the difference between /f/ and the other two fricatives was statistically significant ($p<0.02$).

The analysis of variance showed that a significant place by vowel interaction [F(2, 112)=13.765, p<0.0001, η^2 =0.197] was obtained as a result of elevated value of normalized duration of /s/ in the context of /i/. On the contrary, the value for /f/ and /ʃ/ increased in the context of /u/. The interaction was shown in figure 5.8.

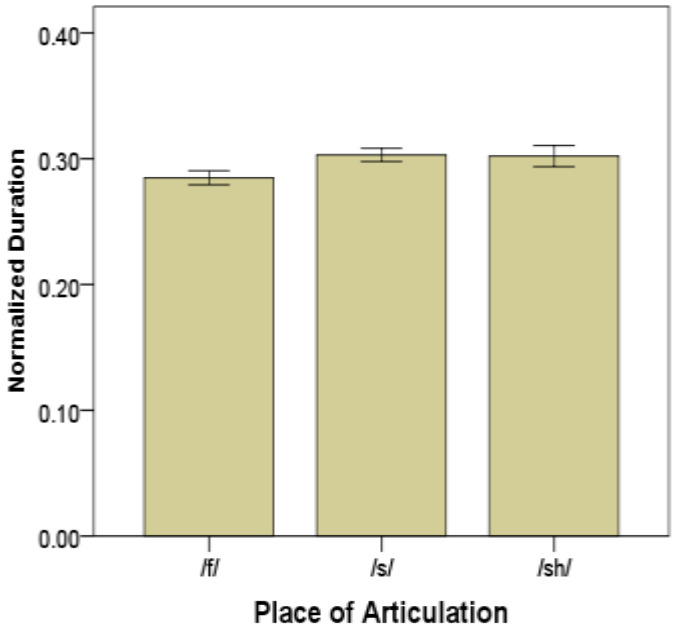

Figure 5.7 Normalized duration as a function of place of articulation in VCV fricatives.

A significant place by gender interaction [F(2, 112)=3.495, p<0.03, η^2=0.059] indicated different patterns for males and female speakers(figure 5.9. The male speakers revealed longer mean normalized duration in /f/ and /s/, while female speakers hadlonger average value of normalized duration in /ʃ/.

The average value of normalized duration varied as a function of gemination [F(1, 56)=505.146, p<0.0001, η^2=0.900], as demonstrated in figure 5.10. As expected, the dependent measure of normalized duration of geminate fricatives (0.347) was longer than

the mean normalized duration of singleton fricatives (0.246). Figure 5.11 illustrated that a significant gemination by vowel interaction was obtained [F(1, 56)=15.536, p<0.0001, η^2=0.217]. The interaction exhibited that normalized duration of singleton fricatives was longer in the context of /u/, while that of geminate fricatives was slightly increased in the context of /i/.

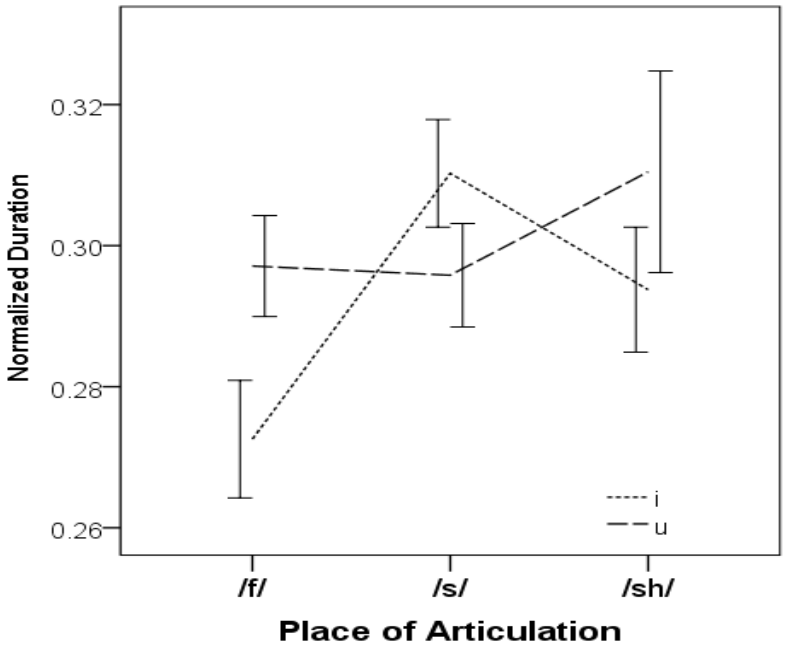

Figure 5.8 Normalized duration as function of place of articulation and vowel context in VCV fricatives.

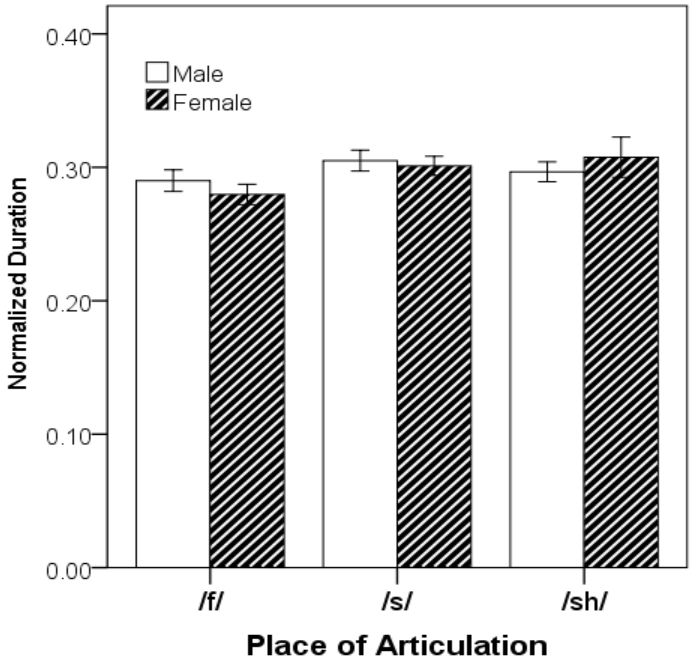

Figure 5.9 Normalized duration as function of place of articulation and gender in VCV fricatives.

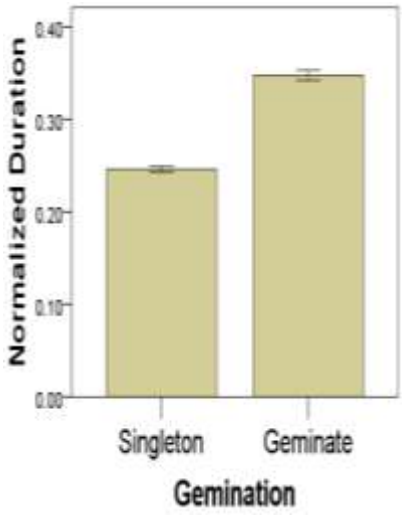

Figure 5.10 Normalized duration as function of gemination in VCV fricatives.

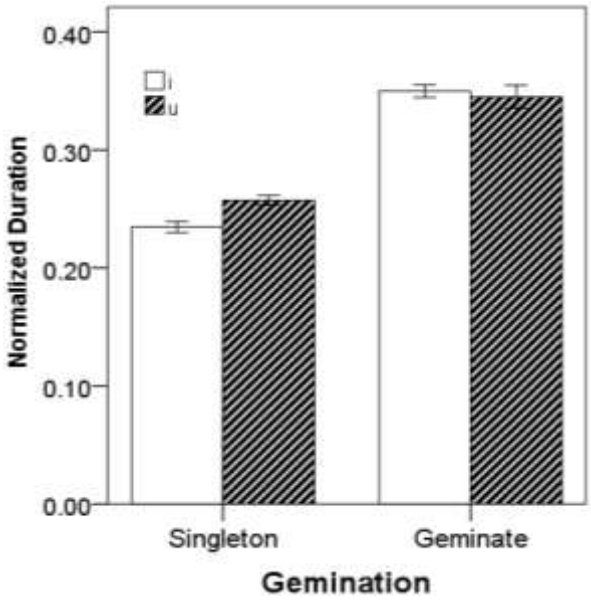

Figure 5.11 Normalized duration as function of gemination and vowel context in VCV fricatives.

5.2 Spectral Features

5.2.1 Spectral Peak Location

A five-way analysis of variance (place x vowel x gemination x age x gender) was conducted to test the dependent measure of spectral peak location. Main effect was obtained for place [$F(2, 112)=147.695$, $p<0.0001$, $\eta^2=0.725$], as demonstrated in figure 5.12. Collapsed across speakers, vowel context and gemination, the average measures of spectral peaks were 8095 Hz, 7542 Hz, and 5424 Hz for fricatives /f, s, ʃ/, respectively. The spectral peak depicted interesting pattern: as the places of articulation moves back further in the vocal tract, the mean spectral peak decreases. This result is consistent with the size of the vocal tract anterior to the source of the fricatives. That is the size of the vocal tact anterior to the source of fricatives is inversely related to the size of the peak.

Pairwise comparison revealed that all fricatives were significantly different in terms of spectral peak ($p<0.001$ for /f, s/ and $p<0.0001$ for the rest).

Figure 5.13 displayed that a place by age group interaction was significant [$F(6, 112) =2.214$, $p<0.04$, $\eta^2=0.106$]. The significant interaction was obtained mainly because the average spectral peak of adult group was decreased for all places of articulation. While the difference among all age groups was not that big for /f/, the difference between child and adult speakers became wider as the place moves posterior in the vocal tract, with only slight difference between child groups. However, the five years old children revealed decreased spectral peak for /s/ compared to other child groups.

The spectral peak significantly varied based on the context of vowels following the fricatives [$F(1, 56)=8.323$, $P<0.006$, $\eta^2 =0.129$]. The average measure of spectral peak of fricatives in the context of /i/ (7134 Hz) was higher than in the context of /u/ (6906 Hz), as expected. A significant place by vowel interaction [$F(2, 112)=15.516$, $p<0.0001$, $\eta^2 =0.217$] exhibited two different patterns for the dependent measure of spectral peak. The mean values of fricatives were higher for /f/ and /s/ in the context of /i/ and slightly increased for /ʃ/ in the context of /u/. The effects were illustrated in figure 5.14.

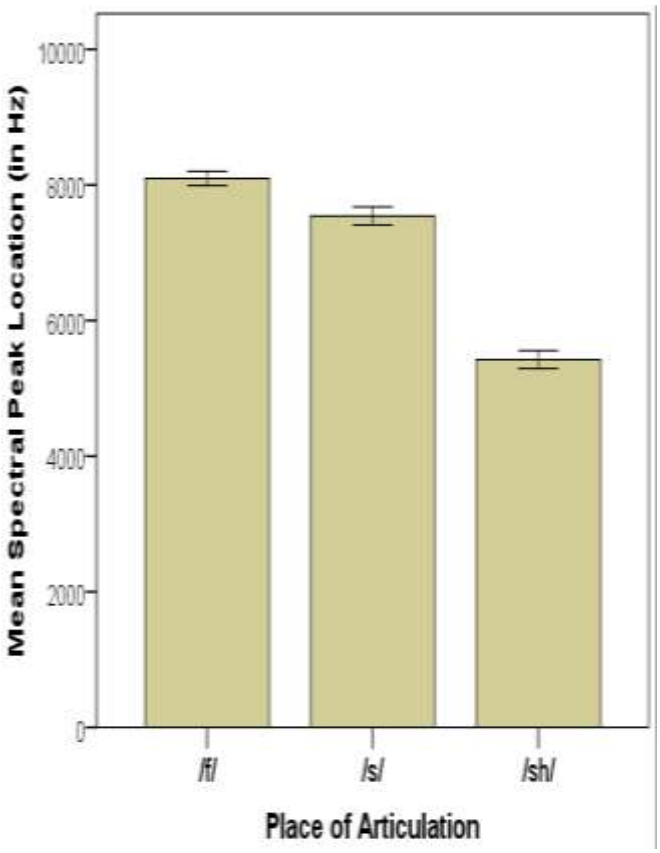

Figure 5.12 Spectral peak locations as function of place of articulation in VCV fricatives.

A significant vowel by age [3, 56)=3.225, p<0.03, η^2=0.147] showed different trends. As illustrated in figure 5.15, the significant interaction was obtained mainly as a result of decreased average spectral peak produced by adult speakers in both vowel contexts. The mean value of the peak for child speakers was almost similar, with slightly increased value for four years old child speakers in the context of /u/.

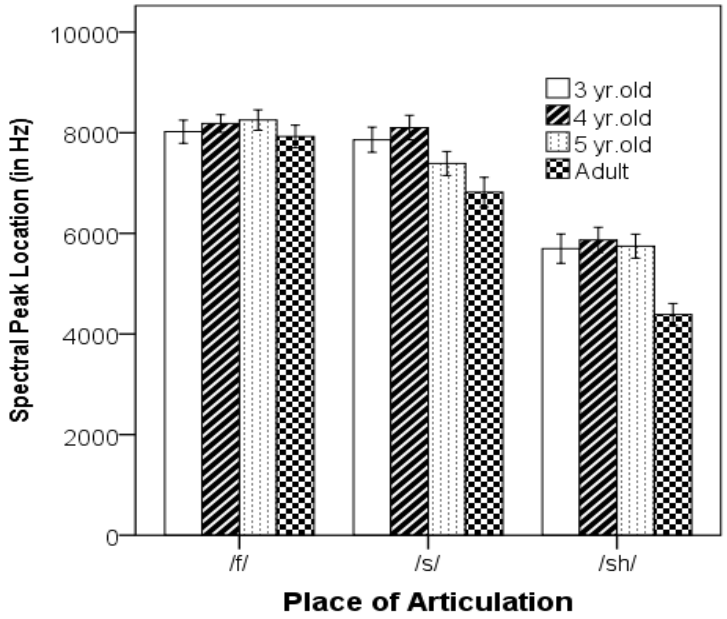

Figure 5.13 Spectral peak locations as a function of place of articulation and age groups in VCV fricatives.

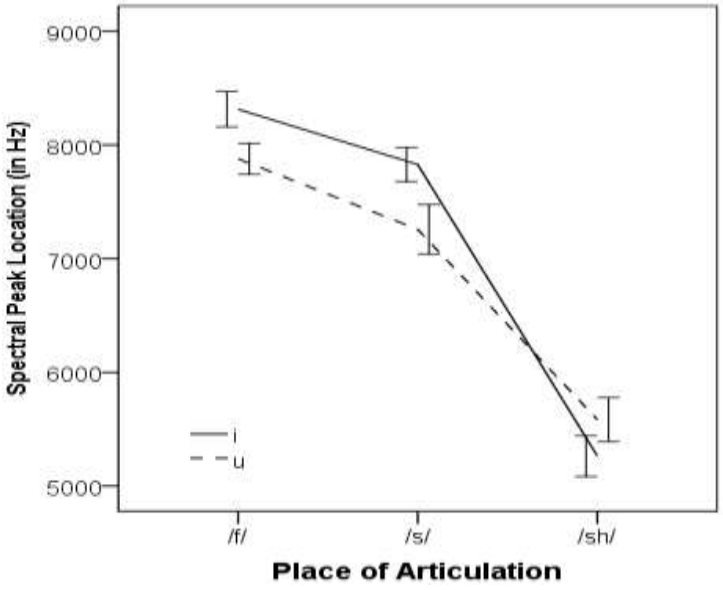

Figure 5.14 Spectral peak locations as a function of place of articulation and vowel context in VCV fricatives.

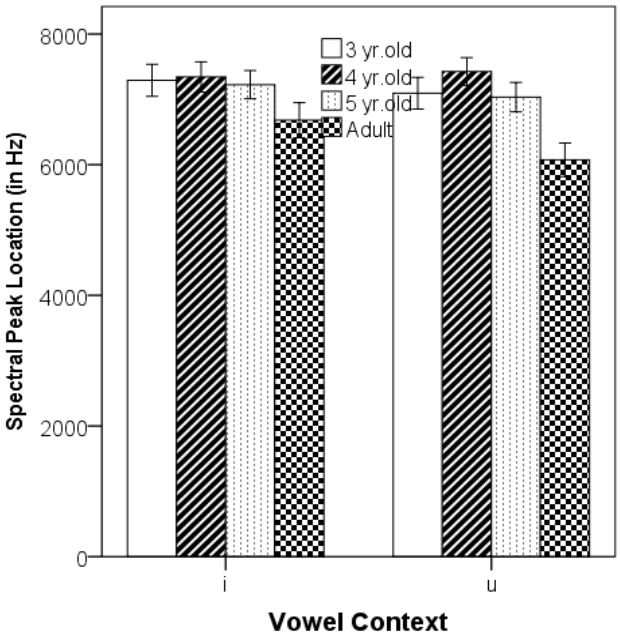

Figure 5.15 Spectral peak locations as a function of vowel context and age groups in VCV fricatives.

A significant main effect for gemination [F(1, 56)=7.778, p<0.007, η^2=0.122] depicted that the average measure of spectral peak of geminate fricatives (7137 Hz) was slightly increased than the mean value of the peak of singleton fricatives (6904 Hz) (figure 5.16).

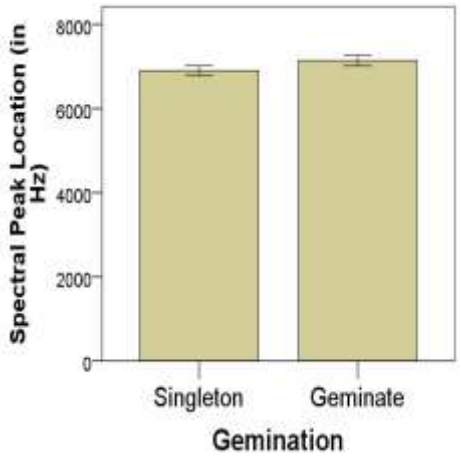

Figure 5.16 Spectral peak locations as a function of gemination in VCV fricatives.

The analysis of variance also depicted a main effect of age [F(3, 56)=6.580, p<0.001, η^2 =0.261], as shown in figure 5.17. The main effect was triggered by lowered measure of average spectral peak produced by the adult group. Averaged for speakers, vowel context and gemination, the mean measures of spectral peak were 7192 Hz, 7384 Hz, 7128 Hz, and 6377 Hz for three, four, five years old children and adult speakers, respectively. Subsequent post hoc test exhibited that the mean spectral peak of adult speakers was significantly different from all child groups (p<0.009 for adult and three years old, p<0.001 for adult and four years and p<0.01 for adult and five years old children), with no difference between child groups.

A significant age by gender interaction [F(3, 56)=3.257, p<0.028, η^2=0.149] showed that the average spectral peak produced by female speakers was predominantly higher than average spectral peak produced by male speakers, as expected. As indicated in figure 5.18, across all age groups, the mean spectral peak produced by female speakers was elevated, except for five years old children. Because there is no anatomical difference at this early age, gender variation occurred was developmental in nature (Nissen 2003).

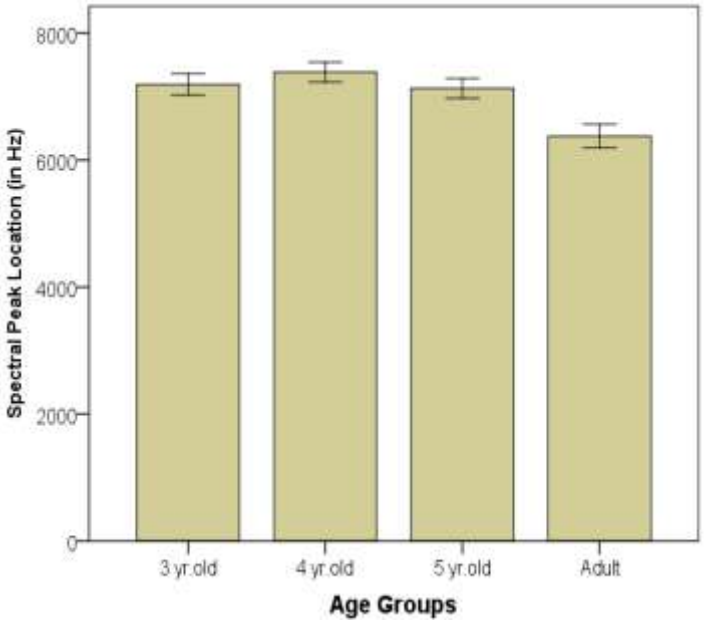

Figure 5.17 Spectral peak locations as a function of age groups in VCV fricatives.

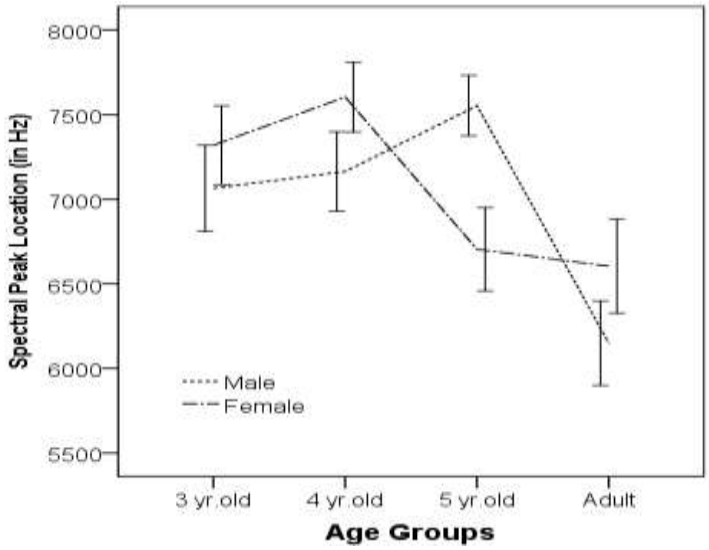

Figure 5.18 Spectral peak locations as a function of age groups and gender in VCV fricatives.

5.2.2 The Spectral Mean

For the dependent measure of spectral mean, a five-way ANOVA (place x vowel x gemination x age x gender) displayed a main effect of place [F(1.702, 95.302)=112.146, p<0.0001, η^2 =0.667]. As indicated in figure 5.19, the main effect was found due to highly increased average measure of spectral mean of /s/. Averaged for speakers, vowel context and gemination, the spectral mean was 5514 Hz for /f/, 8541 for /s/, and 5813 Hz for /ʃ/. Subsequent pairwise comparison exhibited that the difference between /f/ and /ʃ/ was statistically not significant. But the others /f, s/ and /s, ʃ/ were statistically different at p<0.0001.

A main effect of vowel [F(1.000, 56.000)=20.704, p<0.0001, η^2=0.270] indicated that the average measure of spectral mean of fricatives in the context of /i/ (6883 Hz) was higher than the average value of spectral mean of fricatives in the context of /u/ (6361Hz) (figure 5.20). A significant place by vowel interaction [F(1.507, 84.407)=6.538, p<0.005, η^2=0.105] was also found for the dependent measure of spectral mean. As indicated in figure 5.21, the interaction stemmed from elevated measure of spectral mean of fricatives in the context of /i/ for /f/ and /s/.

In addition, a main effect of gemination [F(1.000, 56.000)=25.614, p<0.0001, η^2=0.314] signified that the average measure of spectral mean for geminate fricatives (6949 Hz) was higher than that of singleton fricatives (6622 Hz) (figure 5.22).The analysis of variance also exhibited a significant place by gemination interaction [F(1.686, 94.417)=25.757, p<0.0001, η^2=0.315]. As illustrated in figure 5.23, the significant interaction revealed two vivid patterns. The average spectral mean of singleton /f/ was decreased compared to

the average value of the geminate/ff/. On the contrary, there was almost no difference between the mean values of singleton and geminate fricatives for /s/ and /ʃ/.

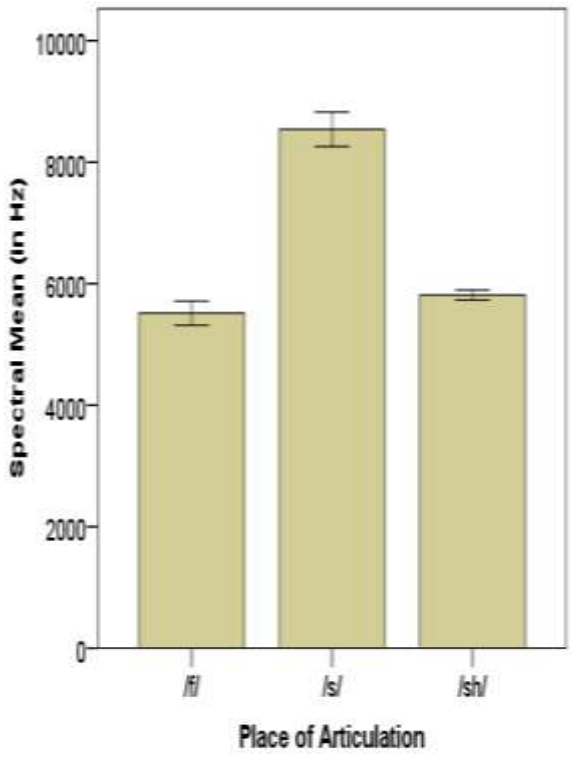

Figure 5.19 Spectral mean as a function of place of articulation in VCV fricatives.

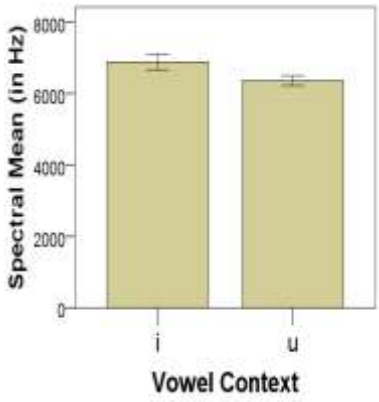

Figure 5.20 Spectral mean as a function of vowel context in VCV fricatives.

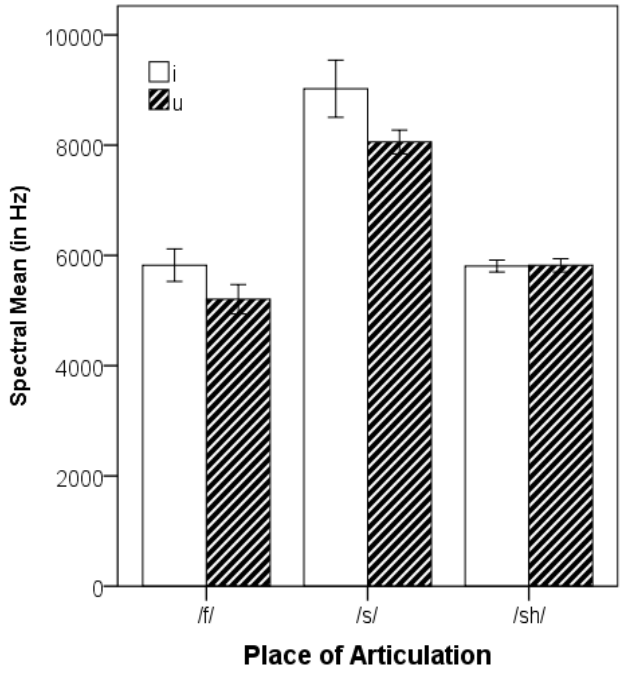

Figure 5.21 Spectral mean as a function of place of articulation and vowel context in VCV fricatives.

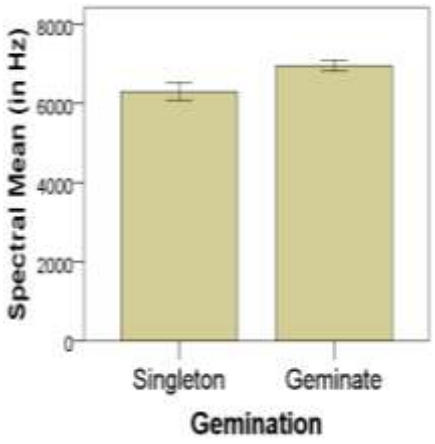

Figure 5.22 Spectral mean as a function of gemination in VCV fricatives.

Finally, the test showed that spectral mean varied as a function of age [F(3, 56)=5.602, p<0.002, η^2=0.231]. The main effect was stemmed from lowered average spectral mean produced by adult speakers(figure 5.24). The average spectral mean values for three, four, and five years old children and adult speakers were 6957 Hz, 6808 Hz, 7012 Hz, and 5713 Hz, respectively. Subsequent Bonferroni adjusted post hoc test showed that only the adult group statistically varied from all child groups in terms of spectral mean. Moreover, an age by gender interaction was also significant [F(3, 56)=4.946, p<0.004, η^2 =0.209]. As illustrated in figure 5.25, the adult and child groups revealed different trends. The pattern was as expected in adult group, with female speakers revealing higher average spectral mean. On the contrary, in the youngest and oldest child groups (three years and five years old) the average measures of spectral mean produced by male children were higher compared to average values of spectral mean produced by female children, with highly pronounced difference in five years old children.

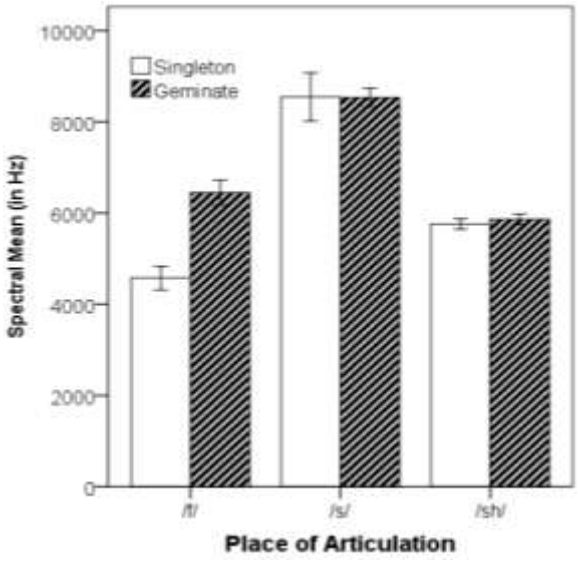

Figure 5.23 Spectral mean as a function of place of articulation and gemination for VCV fricatives.

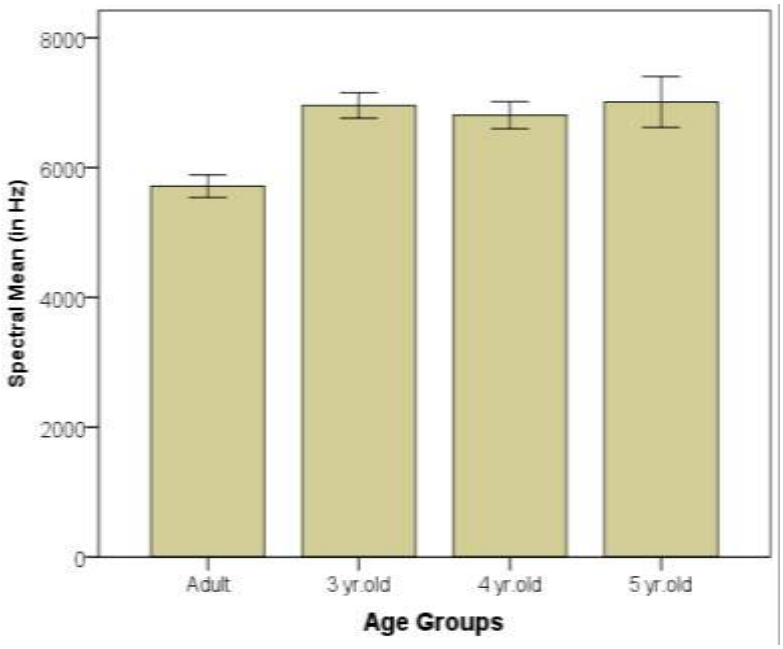

Figure 5.24 Spectral mean as a function of age groups for VCV fricatives.

In four years old children, the pattern was similar with that of adult speakers in which average spectral mean produced by female speakers slightly increased.

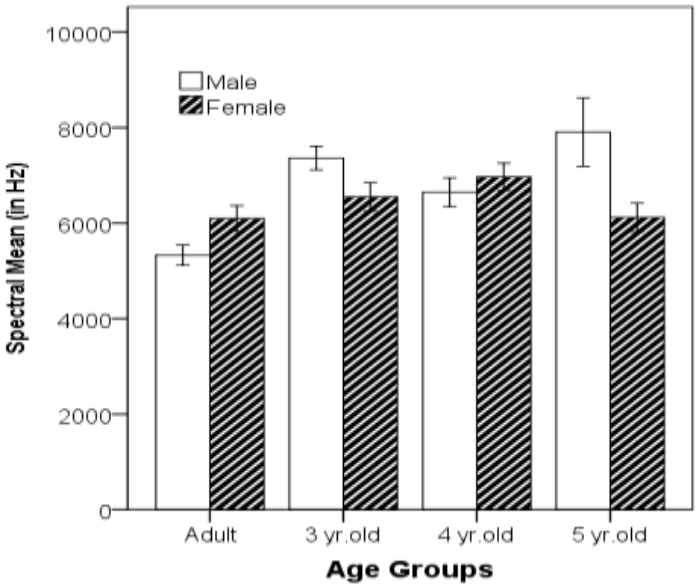

Figure 5.25 Spectral mean as a function of age groups and gender for VCV fricatives.

5.2.3 The Spectral Standard Deviation

A five-way repeated measures ANOVA (place x vowel x gemination x age x gender) was computed to test the dependent measure of spectral standard deviation (the second moment). As demonstrated in figure 5.26, a main effect was obtained for place [$F(2, 112)=120.699$, $p<0.0001$, $\eta^2=0.683$]. The main effect was greatly stemmed from highly decreased mean spectral deviation of the voiceless postalveolar fricative /ʃ/. The mean values of spectral standard deviation for the three fricatives /f, s, ʃ/ were 3940 Hz, 3271 Hz, and 2369 Hz, respectively. The mean value indicated that as places move anterior in the vocal tract, the average value of spectral standard deviation increases. Bonferroni adjusted post hoc test exhibited that all fricatives were significantly different from each another in terms of spectral standard deviation ($p<0.0001$).

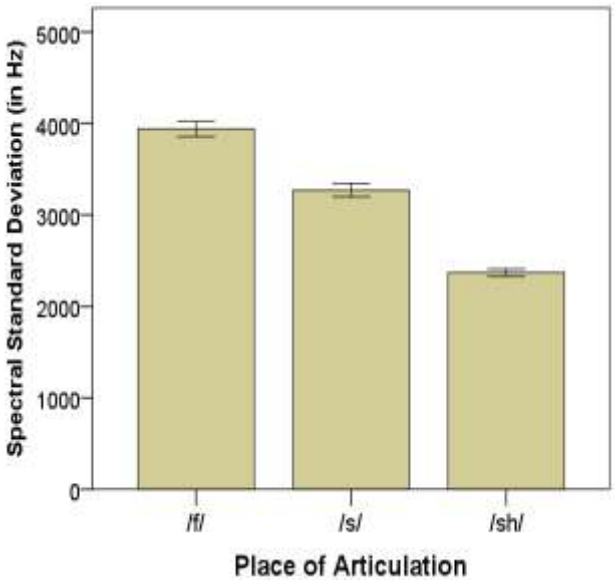

Figure 5.26 Spectral standard deviation as a function of place of articulation in VCV fricatives.

Figure 5.27 revealed that a place by age group interaction was significant [$F(6, 112)=3.105$, $p<0.008$, $\eta^2=0.143$]. The average spectral standard deviation for different age groups exhibited different patterns. For /f/ and /ʃ/ the difference among age groups was narrow, with slightly increased mean value of standard deviation of three years old children for /f/ and four years old children for /ʃ/. On the other hand, the child-adult discrepancy for spectral standard deviation was pronounced for the alveolar fricative /s/. The average measures of standard deviation of all child groups were increased compared to the adult speakers, with highly increased value for four years of age children. On the other hand, the mean value of spectral standard deviation of three years was decreased for /s/ compared to the mean value of the moment in the other two fricatives. Though a main effect of age was not significant, the mean value of spectral standard deviation was higher for child groups. The overall measures of spectral standard deviation, collapsed across speakers, vowel context and gemination, were 3264 Hz, 3281 Hz, 3192 Hz and

3036 Hz for three, four, and five years old children and adults, respectively. This finding was in accord with a commonly held view that speech produced by children is more variable compared to that of adults (Koenig et al. 2008; Nittrouer and Studdert-Kennedy 1986, among others).

For the dependent measure of average spectral standard deviation, significant main effect of gemination was obtained [F(1,56)=11.312, p<.001, η^2=0.168]. The mean value of the moment was slightly higher for geminate fricatives (3266 Hz) compared to the mean value of the moment for the singleton fricatives (3120 Hz) (figure 5.28). A place by gemination interaction was also significant [F(2, 112)=25.015, p<.0001, η^2=0.309]. As indicated in figure 5.29, the significant place by gemination interaction stemmed from the higher average measure of spectral standard deviation of geminate /ff/ compared to other singleton and geminate fricatives.

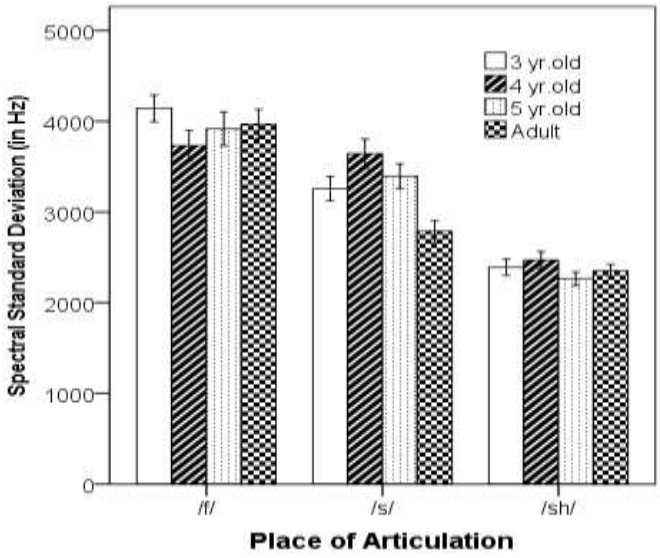

Figure 5.27 Spectral standard deviation as a function of place of articulation and age groups in VCV fricatives.

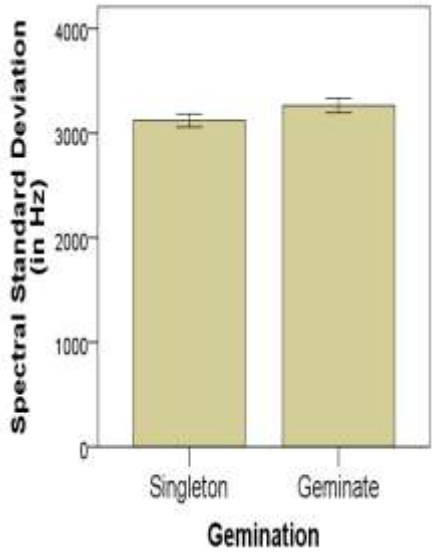

Figure 5.28 Spectral standard deviation as a function of vowel context in VCV fricatives.

In addition, figure 5.30 demonstrated that the five-way repeated measures analysis of variance yielded a significant main effect of vowel [$F(1, 56)=17.100$, $p<0.0001$, $\eta^2=0.234$]. The effect of vowel context was obtained as a result of slightly increased average measure of spectral standard deviation of fricatives in the context of /i/ (3284 Hz and 3102 Hz, in the /i/ and /u/ contexts, respectively).

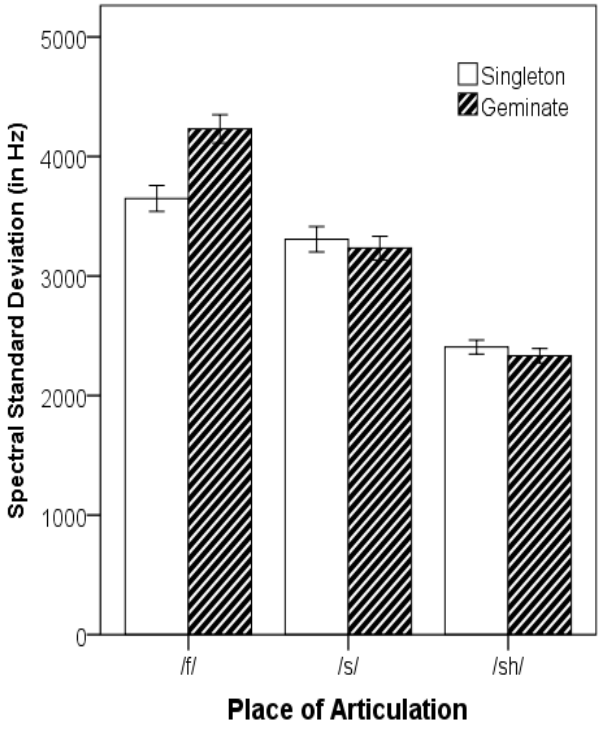

Figure 5.29 Spectral standard deviation as a function of place of articulation and gemination in VCV fricatives.

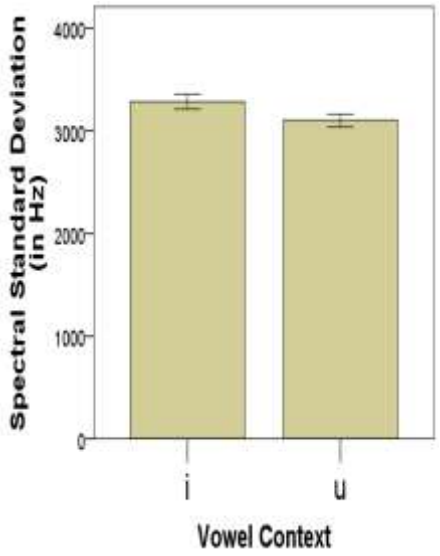

Figure 5.30 Spectral standard deviation as a function of vowel context in VCV fricatives.

5.2.4 The Spectral Skewness

A five-way ANOVA (place x vowel x gemination x age x gender) revealed a main effect of place for the dependent measure of spectral skewness [F(1.488, 83.330)=28.968, p<0.0001, η^2 =0.341], (figure 5.31). The effect of place was found mainly as a result of increased average measure of spectral skewness of /f/ and lowered mean value of spectral skewness of /s/. Collapsed across speakers, vowel context and gemination, the mean measures of spectral skewness for fricatives /f, s, ʃ/ were 0.787, -0.186 and 0.128, respectively.Subsequent pairwise comparison indicated that all fricatives were significantly different in terms of spectral skewness (p<0.001 for /s, ʃ/ and p<0.0001 for the rest). The worthy of note feature here is that only /s/ had negatively skewed value. Thus, the sound was characterized with the dominance of energy in the higher frequency region.

The analysis of variance yielded a main effect of gemination [F(1.000, 56.000)=12.032, p<0.001, η^2=0.177]. The main effect was obtained because of the highly elevated average measure of spectral measure of singleton fricatives, as indicated in figure 5.32. The average measure of spectral skewness of singleton fricatives was 0.368 and of the geminate fricatives was 0.118.In addition, a place by gemination interaction was found [F(1.435, 80.360)=18.117, p<0.0001, η^2=0.244], as indicated in figure 5.33. The significant interaction was obtained because of the highly increased spectral skewness of singleton /f/.

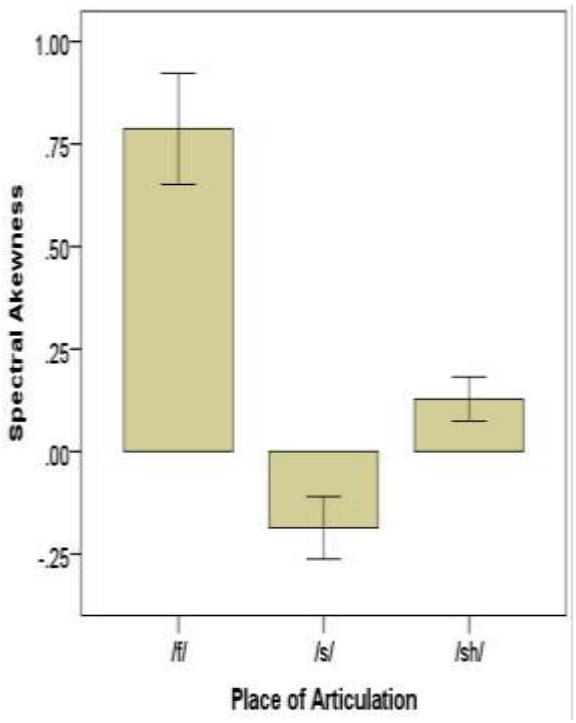

Figure 5.31 Spectral skewness as a function of place of articulation in VCV fricatives.

A significant gemination by vowel interaction [F (1.000, 56.000)=4.741, p<0.03, η^2 =0.078] indicated two different patterns. As indicated in figure 5.34, the mean value of spectral skewness of singleton fricatives was highly increased in the context of /u/, whereas the value was increased for geminate fricatives in the context of /i/.

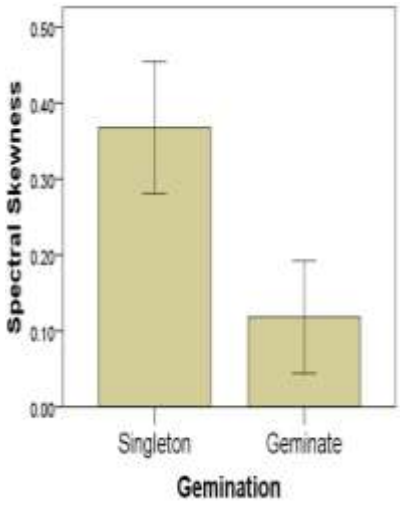

Figure 5.32 Spectral skewness as a function of gemination in VCV fricatives.

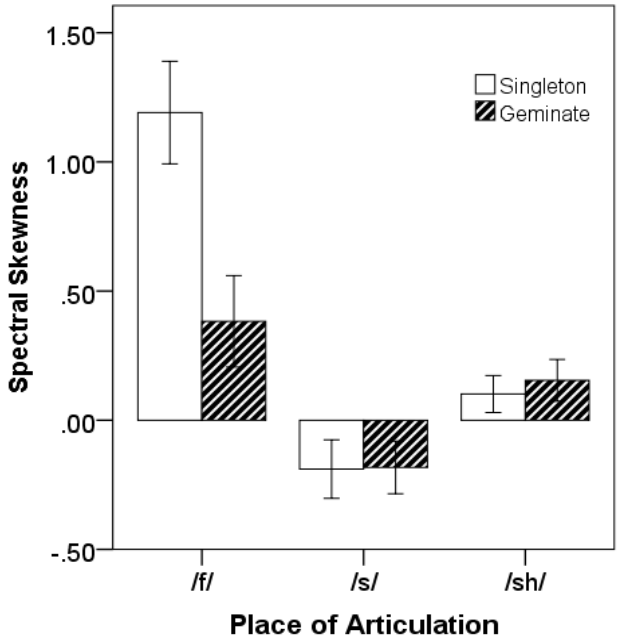

Figure 5.33 Spectral skewness as a function of place of articulation and gemination in VCV fricatives.

Moreover, the ANOVA depicted that a main effect of age group was marginally significant [F(3, 56)=2.768, p<0.05, η^2 =0.129]. Figure 5.34 illustrated that the effect of age was obtained importantly as a result of highly elevated average measure of spectral skewness produced by adult speakers. The average measures of spectral skewness was 0.170 for three years old, 0.057 for four years old, 0.196 for five years old, and 0.549 for adult speakers. Bonferroni post hoc test indicated that only the difference between adult and child groups was significant (p<0.05).

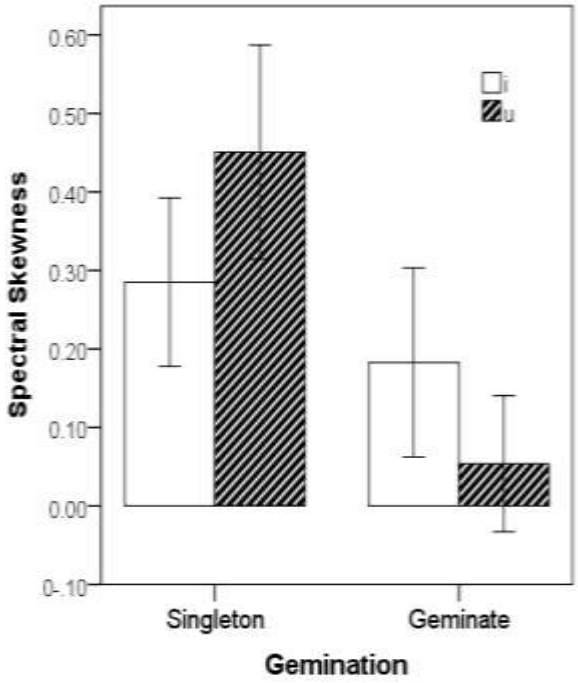

Figure 5.34 Spectral skewness as a function of gemination and vowel context in VCV fricatives.

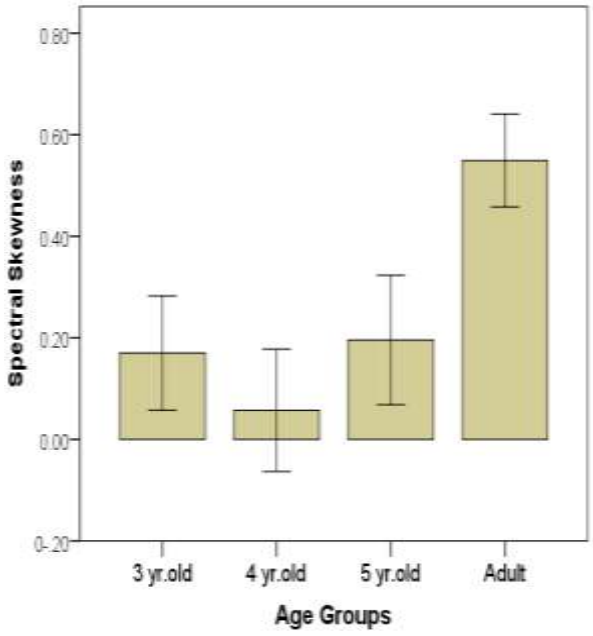

Figure 5.35 Spectral skewness as a function of age groups in VCV fricatives.

5.3 Discriminant Analysis

Eight descriptors, fricative duration, vowel duration, normalized duration, spectral peak location, spectral moments (the first, the second, the third, and the fourth) moments, were entered into the initial stepwise linear discriminant analysis. The spectral measures of the moments were derived from 40 ms window placed at the center of frication noise. The objective was to examine the extent to which the predictors classify fricatives in terms of place of articulation. The Jack-knife or standard stepwise procedure was utilized to examine the classification rates.

The cross-validation method depicted 74.8 % correct classification of fricatives. The correct classification rate was 79.2 % for adult speakers, 78.6 % for three years old child speakers, 79.2 % for four years of age children, and 75.2 % for five years old child speakers. Thus, while the rate of classification of the two younger groups (three years and

four years old) and adult speakers displayed relatively higher classification rates, the five years old child speakers exhibited lower classification. The rate of classification of female speakers (76.6 %) was better than that of male speakers (73.4 %).

The standardized canonical discriminant function coefficients identified six important descriptors: fricative duration, vowel duration, spectral peak location, moment one, moment two and moment three, according to their order of contribution. When only these predictors were utilized, the fricatives were correctly classified 74.8 %. When only spectral peak location and the first three moments were analyzed, the classification rate was 73.8 %. Finally, the first three spectral moments (mean, standard deviation, and skewness) were entered into the analysis and correctly classified 72.9%. The classification rate of the voiceless postalveolar fricative /ʃ/ was the highest (85.5 %) and that of the voiceless alveolarfricative /s/ was the lowest (64.5 %). The voiceless labiodental fricative had intermediate classification rate (74.5 %). Error of classification confused between /f/ and /s/.

Furthermore, to examine whether the variation of age of speakers result in different classification rates in terms of places articulation, the data of each age group were utilized. When only the adult data was considered, the classification rate was 79.7 % for /f/, 70.8 % for /s/ and 87 % for /ʃ/. For three years old child speakers the rates of classification were 76.6 %, 72.4 %, 87 % for /f, s, ʃ/, respectively. The classification rates of fricatives for four years were 65.6 % for /f/, 79.7 % for /s/ and 92.2 % for /ʃ/. Finally, the rates were 77.6 %, 57.8 %, and 90.1 % for fricatives /f, s, ʃ/, respectively when only the data from five years old children was considered.

CHAPTER SIX

DISCUSSION

The present study analyzed voiceless fricatives /f, s, ʃ, h/ produced by typically developing children between 3 and 6 years of age and adult speakers of Haraghe Oromo dialect. The sounds were produced in two phonetic contexts (FV and VFV). In the CV phonetic environment, the fricatives existed only in singleton forms because word initial gemination is not permissible in Oromo. The purpose in the FV section was to examine to what extent acoustic attributes such as amplitude, duration and spectral features vary as a function of places of articulation, vowel context, age of speakers and gender. The VFV section dealt with singleton and geminate fricatives. Under this section durational and spectral features have been utilized to examine the difference between the two phonemes in terms of place, vowel context, age and gender. Unlike in the first section, normalized amplitude and locus equation were not included. The work gives insight into the degree of variation of singleton and geminate fricatives in terms of durational and non-durational acoustic attributes. Finally, under both sections, all the acoustic attributes have been tested for their role in discriminating fricatives in terms of places of articulation employing linear discriminant analysis. So as to examine whether the study has answered the questions posed first, the discussion has been done in line with the objectives set as follows.

6.1 Fricative Vowel

Analyze the extent to which different acoustic features distinguish fricatives in terms of place of articulation

The average measure of duration of 64 speakers in the present study distinguished three places out four. The parameter did not differentiate the two sibilant fricatives /s, ʃ/. The average measures of noise duration of fricatives/f, s, ʃ, h/ were 110ms, 131ms, 129ms, 89 ms, respectively. As expected, the mean duration of sibilant fricatives (130 ms) was significantly longer than that of the nonsibilant fricatives (100 ms). The result was in agreement with previous works (e.g., Baum and Blumstein 1987; Jongman et al. 1998; 2000; Nissen 2003, Fox and Nissen 2005; Nissen and Fox 2005) which reported that sibilant fricatives were significantly longer than the nonsibilant ones. The fact that sibilant fricatives were longer than the nonsibilant fricatives may be due to their inherent nature. Sibilant fricatives require articulatory and aerodynamic precisions (Ladefoged & Maddieson 1996) which may take appreciably longer duration to accurately produce the sounds compared to the nonsibilant fricatives.

The average duration of vowels following fricatives was less effective because it distinguished only two places, /f, h/ and /ʃ, h/. The duration of vowels following the voiceless glottal fricative /h / was slightly longer than that of the others (89 ms, 95 ms, 90 ms, and 101 ms following /f, s, ʃ, h/, respectively). Similarly, the average normalized duration failed to distinguish /f, ʃ/ and /s, ʃ/. The mean normalized duration also revealed that the difference between the fricatives was narrow (0.240, 0.271, 0.253, and 0.190, for /f, s, ʃ, h/, respectively). Consistent with the finding of Jongman et al. (2000), normalized

duration of nonsibilant fricatives (0.215) was significantly shorter than the mean normalized duration of sibilant fricatives (0.262).

Like fricative duration, normalized amplitude also distinguished only three places of articulations, without difference between /s/ and /ʃ/. Collapsed across speakers and vowel context, the average value of normalized amplitude was -14 dB for /f/, -9.3 dB for /s/, -9.4 dB for /ʃ/ and -15.5 dB for /h/. Like in many other studies (Strevens 1960; Heinz and Stevens 1961; Fox and Nissen 2005; Nissen and Fox 2005), the dependent measure of average normalized amplitude of sibilant fricatives was significantly higher than the mean value of RMS of nonsibilant fricatives (-9.3 dB, and -14.8 dB, respectively). While normalized amplitude distinguished within the nonsibilant fricatives /f/ and /h/, it failed to do so within the sibilant fricatives /s, ʃ/, contrary to results reported by Jongman et al. (1998; 2000).

Al-Khairy (2005) attributes the increased amplitude of the sibilant fricatives to the inherent nature of the sounds. The scholar claimed that sibilant fricatives are characterized with greater articulatory force to let air out through narrow constriction than the nonsibilant fricatives. This process increases average measure of noise amplitude of sibilant fricatives. In addition, the obstacle source which perpendicularly strikes sibilant fricatives (Shadle 1985) further boosts the intensity of sibilant fricatives (Hayward 2000; Cheon and Anderson 2008).

Consistent with previous works (Jongman et al. 2000; 1998; Fox and Nissen 2005), the average measure of spectral peak decreases as the places of articulation move posterior in the vocal tract (7767 Hz, 7356 Hz, 5051 Hz, and 3548 Hz for /f, s, ʃ, h/, respectively). The result is in accord with the size of the front cavity of the source of fricatives which increases as the place moves back in the oral cavity. The peak failed to distinguish /f/ and /s/. Though the mean values of /f/ and /s/ were not statistically different, the spectral peak of nonsibilant fricatives (5657 Hz) was significantly lower than that of the sibilant fricatives (6204 Hz) because of the highly decreased mean value of the spectral peak of /h/. The result was in agreement with many other works which depicted that spectral peak location varied as a function of sibilance (e.g., Jongman et al. 1998; 2000). Moreover the peak also distinguished within sibilant fricatives, the alveolar fricative /s/ being characterized with elevated peak compared to that of the postalveolar fricative /ʃ/, consistent with many previous works (Heinz and Streven 1961; Hughes and Halle 1956; Strevens 1960; Shadle 1985).

The spectral mean did not distinguish the voiceless labiodental fricative /f/ and the voiceless postalveolar fricative /ʃ/. The overall measure of spectral mean was higher for the alveolar fricative /s/ (8200 Hz) and lower for the glottal fricative /h/ (1737 Hz). The value was almost similar for /f/ (5670 Hz) and /ʃ/ (5743 Hz). Thus, in agreement with previous studies (e.g., Nissen 2003; Jongman et al. 2000), the average value of the spectral mean of voiceless alveolar fricative /s/ was the highest of all other places. The average spectral mean of sibilant fricatives was significantly greater (6972 Hz) than the average measure of spectral mean of nonsibilant fricatives (3704 Hz) because of the lower value of spectral mean of the voiceless glottal fricative /h/.

The second spectral moment distinguished three places of articulation. It failed to distinguish /s/ and /h/. Averaged for speakers and vowel context, the mean measures of the moment were 4080 Hz, 3063 Hz, 2504 Hz, and 2989 Hz for /f, s, ʃ, h/, respectively. The nonsibilant fricatives were characterized with increased value of the spectral standard deviation (3535 Hz) than the sibilant fricatives (2783 Hz). The value suggested that the production of nonsibilant fricatives was more variable and the sounds were more diffuse than sibilant fricatives.

The spectral skewness distinguished all places of articulation. Only the average skewness of voiceless alveolar fricative /s/ was negative, signifying that it was characterized with the dominance of energy in the higher frequency region. The mean values of fricatives, collapsed across speakers and vowel context, were .858, -.0245, .322, and 6 for /f, s, ʃ, h/, respectively. In agreement with Nittrouer (1995), the mean value of spectral skewness of /ʃ/ was positively skewed than /s/, indicating that it had higher concentration of energy in lower spectral region.

The overall spectral kurtosis was 4.31 for /f/, 3.52 for /s/, 2.86 for /ʃ/, and 75.83 for /h/. The result was in accord with Nissen (2003) in that all fricatives depicted positive values. When only the first three places of articulation (oral fricatives) were considered, the average spectral kurtosis decreases as the place moves posterior in the vocal tract. That is as the places move further back in the vocal tract, the flatter becomes the fricatives. The result of the two sibilant fricatives /s, ʃ/ was in agreement with the finding reported by Nittrouer (1995). The experimenter observed that the mean value of spectral kurtosis of

/s/ was increased than that of /ʃ/. The average value of skewness and kurtosis of sibilant fricatives /s, ʃ/ signified that /s/ was characterized with concentration of energy in higher spectral region and more peaked compared to /ʃ/. Only the mean value of spectral kurtosis of voiceless glottal fricative /h/significantly varied from all places in terms of spectral kurtosis. The study provided concrete evidence that /h/ behaves like adjacent vowels because of its highly elevated mean spectral kurtosis. Such feature characterizes the sound with highly defined peak of energy which relates it to vowels than fricatives.

The slope of locus equation and y-intercept did not reveal a main effect of place. Only the average spectral measure of F2 at onset of vowels distinguished three places. The difference between /f/ and /h/ was not significant in terms of F2o. Thus, F2 transition at onset of vowels distinguished within sibilant fricatives /s, ʃ/. Considering only the first three places (the oral fricatives) /f, s, ʃ/, the mean value of F2o increases as places move posterior in the oral cavity (1589 Hz, 1768 Hz, 1973 Hz, respectively). The finding was consistent with the result reported by Jongman et al. (2000). The mean value of /h/ was relatively the smallest of all (1514 Hz). Nittrouer et al. (1989) attributed the result to the size of the cavity at the back of the sources of the fricatives. Since F2 is the result of the resonance of the back cavity, as the places move posterior in the oral cavity, the average value of F2o increases because the size of the cavity decreases.

Generally, the present result was in accord with the findings of previous studies (Jongman 1998; 2000; Tabain 2000; 2002). The studies reported that locus equation was less robust to discriminate fricatives in terms of place of articulation. Tabain attributes the reason to inherent feature of fricatives. According to the researcher, the noise of fricatives

lingers into the neighboring vowels and disturbs the acoustic measure of F2o. In addition, because the nature of data generated from child speakers lack better mastery of articulatory gestures, they may not control leaking of noise into neighboring vowels. Koenig et al.(2008) suggested "that young children do not achieve equivalent phasing control of all articulators at the same time" (p, 3168). Thus, this also makes the acoustic attribute less invariant compared to the other features in the present study.

Examine whether vowel context brings variations in terms of acoustic measures

The result obtained for noise duration was in accord with the finding of Jongman et al. (1998) and Nissen and Fox (2005) which indicated slightly increased mean value of noise duration of fricatives in the context of /u/ compared to the value in the context of /i/. Similarly, Nissen (2003) observed that as the vowel context moves further back in the vocal tract, the average value of vowel durations preceding fricatives increases. Moreover, a place by vowel interaction depicted that /u/ was longer than /i/, except after /ʃ/.

Like in Jongman et al. (1998; 2000), the mean measure of noise amplitude was slightly higher in the context of /i/ (-11.7 dB) compared to the mean value of RMS in the context of /u/ (-12.4 dB). A place by vowel interaction also depicted that the average value of normalized amplitude of sibilant fricatives /s, ʃ/ was higher in the context of /i/, while that of the nonsibilant fricatives was elevated in the context of /u/.

The vowel by place interaction for the dependent measure of average spectral peak exhibited two different trends. The peak was increased in the context /i/ for the voiceless alveolar fricative /s/. Surprisingly, for the other fricatives the peak was slightly increased in the context of /u/. Though it is difficult to interpret why the peaks of the three places /f, ʃ, h/ were high in the context of /u/, the result depicted that /u/ had higher coarticulatory affinity than /i/ in this parameter and many others which will be discussed later why so.

As expected the average spectral moment one (mean) was elevated in the context of /i/ (5659 Hz) compared to /u/ (5016 Hz). Nittrouer (1995) attributes this fact to anticipatory coarticulation. That is when the tongue moves forward in anticipation of the following front vowels; the cavity before the source of fricatives will be smaller, concomitantly increasing the spectral mean of the fricatives.

The vowel by gender interaction revealed that the average measure of spectral mean was increased for male speakers in both contexts. This may appear surprising because the average value of spectral mean was expected to be higher for female speakers based on the anatomical variation. But close inspection into the result depicted that the result stemmed from the increased measure of spectral mean of three years and five years old male speakers. Such result in which male children led the elevated spectral measures was also evident in Nissen (2003). The scholar attributed the discrepancy at this early age to developmental than anatomical features. Like in Nittrouer (1995) there was no vowel by age interaction which "indicates that the magnitude of this vowel-related fronting was similar for children and adults" (p. 524).

The mean value of spectral standard deviation of fricatives was elevated in the context of /i/ (3283 Hz) compared to the average value of the moment in the context of /u/ (3035 Hz). The place by vowel interaction revealed three different trends in terms of spectral standard deviation. The mean value of the moment of nonsibilant fricatives was elevated in the context of /i/; the value was similar in both contexts for /s/, and increased for /ʃ/ in the context of /u/. Thus, the overall results revealed that the production of fricatives was more variable and diffuse when they are followed by /i/.

The average measure of spectral skewness of fricatives was highly elevated in the context of high back rounded vowel /u/ (2.99) compared to in the context of /i/ (0.590). The result was consistent with physiological process triggered by coarticulatory effect. That is the decreased average spectral skewness in the context of /i/ exhibits the dominance of energy in the higher frequency region as a resulted of smaller front cavity.

A place by vowel interaction revealed different patterns in terms of spectral skewness. The value was highly elevated for /h/ and slightly increased for /f/ in the context of /u/. On the contrary, the mean value of the moment was somewhat higher for /ʃ/ in the context of /u/ and almost similar for /s/ in both phonetic contexts. The fact that /s/ in this and other spectral moments were similar in both phonetic contexts suggests that it is highly resistant to coarticulation which emanates from its complex physiological and aerodynamic natures (Iskarous, et al. 2011).

The vowel by age group interaction for the dependent measure of spectral skewness exhibited that there was almost negligible difference between all age groups in the context of /i/, with slightly decreased value for three years old child speakers. On the other hand, the value was elevated for all child groups in the context of /u/, with the most increased value noted for four years of age child speakers. Similarly, the vowel by gender interaction also depicted that the mean measure of the third spectral moment was higher for male speakers in the context of /u/, while the difference was negligible in the context of /i/. The result suggested that the fricatives produced in the context of high back rounded vowel /u/ were characterized by abundance of energy in the lower frequency region, consistent with anticipatory coarticulation. The cumulative effect of vowel by age and vowel by gender interaction in Haraghe Oromo depicted that /u/ highly triggers coarticulation than /i/.

The mean value of spectral kurtosis of fricatives was higher in the context of /u/ (35) compared to the value in the context of /i/ (8.21). The value was highly elevated for the voiceless glottal fricative /h/ in the context of /u/, with no clear difference noted between the other fricatives in both vowel contexts. The vowel by age group interaction for the dependent measure of kurtosis depicted two different patterns. The value was almost similar in the context of /i/, with only slightly increased spectral skewness produced by four and five years old child speakers. On the contrary, all child groups exhibited highly elevated spectral kurtosis in the context of /u/ compared to the value produced by adult speakers. From the child speakers,the four years of age speakers depicted the highest of all average kurtic value in this phonetic context. The coarticulatory process depicted that fricatives were characterized with more defined peaks in the context of /u/ than in /i/.

Once again the claim that the back high rounded vowel triggers coarticulation than the front high unrounded vowel /i/ was evident in kurtosis.

The average value of locus equation slope of fricatives was elevated in the context of /u/ (0.988) than in the context of /i/ (0.853). That is the back high rounded vowel /u/ triggers coarticulation of adjacent fricatives than the front high unrounded vowel /i/. There was significant difference between male and female speakers as a function of the following vowels in terms of slope of locus equation. The average value of slope of male speakers was increased in both vowel contexts, with great difference noted between two sexes in the context of /u/. The main effect of age or place by age group interaction was not significant in terms of F2o signifying that there was no difference in coarticulation between child and adult speakers, consistent with the result reported by Sereno et al. (1987).

In agreement with Nittrouer et al. (1989), the average measure of F2o in the context of /i/ (2020 Hz) was higher compared to the value in the context of /u/ (1403 Hz). Similarly, the place by vowel interaction demonstrated that the average value of F2 at the beginning of vowels was higher in the context of /i/. The discrepancy observed was consistent with coarticulatory process. The front high unrounded vowel /i/ has higher value of F2 than /u/. Thus, the increased result in the context of /i/ was triggered by anticipatory coarticulation with the vowel.

Investigate the extent to which spectral, temporal and amplitude features of Oromo fricatives vary as a function of age

The dependent measure of noise duration of adult speakers was longer (126 ms) compared to that of the child speakers (112 ms, 107 ms, 115 ms for three, four and five years of age children, respectively). But only the difference between the noise duration produced by adult and all child groups was significant. Generally, studies depicted two different adult-child discrepancies in terms of noise duration. 1) Many works reported that the mean noise duration produced by child speakers was longer than that of adults (Smith and Kenny 1998; Smith 1978; 1992; Smith et al. 1996; Fox and Nissen 2005). 2) Some other works (e.g., Munson 2004) observed that there was no difference between noise duration produced by adults and children. In addition, the present work indicated longer mean noise duration of fricatives produced by adult speakers.

Normalized duration discriminated the adult groups and all child groups, without any difference among child speakers. The place by age group interaction showed that the average measure of noise normalized duration produced by adult speakers was longer in the first three places of articulations / f, s, ʃ/ and the mean values produced by child speakers were slightly longer for the voiceless glottal fricatives /h/. The child-adult discrepancy was more pronounced in sibilant fricatives. This may be interpreted in light of the nature of sibilant fricatives. Because of the complex production processes sibilant fricatives involve (Iskarous et al. 2011), children could not sustain the duration unlike in nonsibilant fricatives.

Different interpretations can be suggested with regards to the differences in mean measures duration for adult and child groups of fricatives between the present study and previous works. The first interpretation could be language specific futures which may affect the measure of any acoustic attribute. Different studies conducted both on child and adult speakers (e.g., Li et al. 2011; Li 2012; Reidy 2016) investigated different acoustic attributes and observed language specific child-adult discrepancies. Such language specific features may also be true for duration. The second reason could by methodological differences which could affect acoustic measures (Fox and Nissen 2005; Nittrouer et al. 1989). But this reason may not be stronger enough because the results of other attributes were more or less as expected and similar with many other works.

The average measure of normalized amplitude depicted interesting pattern: as the age of speakers increases, the mean measures of normalized amplitude decrease (-10 dB, -10.5 dB, -11.8 dB and -15.6 dB for third, fourth, and fifth year old children and adult speakers, respectively). Like in many other noise attributes, only the mean measure of normalized amplitude produced by adult speakers was different from that of the child groups. The result was consistent with findings of previous works (e.g., McGowan and Nitrrouer 1988) which depicted that child speech was characterized with higher amplitude than that of adult. The fact that child speech is marked with higher amplitude is may be due to aerodynamic conditions. As mentioned by Koenig et al. (2008) there was "greater overall noise in developing speakers" which could result in increased normalized amplitude of children than adults.

Consistent with Nissen (2003), the spectral peak produced by child groups (5932 Hz, 6299 Hz, and 5969 Hz for three, four, and five years of age speakers, respectively) was higher than that of adults (5520 Hz). Such discrepancy is caused by anatomical factors. That is spectral peak is inversely related to the length of a cavity anterior to the source of fricatives (Nissen 2003). Since children have shorter anterior cavity, their speech is characterized with higher spectral peak. The fact that there was no significant difference among child groups depicts that there was no anatomical difference at these ages. The peak significantly varied only between four years old children and adult speakers. The age by gender interaction indicated that the spectral peaks produced by four years old and adult female speakers were higher than that of male speakers. On the other hand, the average peaks produced by three and five yearsold male children were higher than the peaks produced by female speakers.

Similarly, the age by gender interaction revealed three different trends in terms of spectral mean. The overall values of measures of spectral mean produced by three and five years old male children were higher, with highly elevated value for five years male speakers. There was no difference between spectral mean produced by four years old male and female children. As expected, the mean value of female adult speakers was greater than that of male speakers. The difference between male and female child speakers of this age is not attributed to anatomical difference because the vocal tract dimorphism may not occur until puberty (Fitch and Giedd 1999).The possible interpretation given to the gender difference at early ages in this study, both in spectral peak and spectral mean, was suggested to be behavioral or developmental than anatomical (Nissen 2003; Fox and Nissen 2005).

In terms of spectral standard deviation, the place by age group interaction exhibited that the value was increased for three years old children and adults for /f/. The mean value of the moment produced by adult speakers slightly decreased for sibilant fricatives / s, ʃ/ and highly decreased for the voiceless glottal fricative /h/. The average value of the spectral moment produced by four years old child speakers for /s/ and those produced by three years old children for /ʃ, h/ was elevated. Thus, sibilant fricatives produced by child speakers were more variable than that of adult speakers; whereas, nonsibilant fricatives produced by adult speakers were more variable than that of child speakers. The result was consistent with the finding reported by Stathopoulos (1995) who reported that "in some instances, adults displayed more variable speech behaviors than children" (p.67). The fact that children showed more variable production of sibilant fricatives was that they acquire these sounds latter than other fricatives (Nittrouer 1995; Nissen 2003).

Collapsed across speakers and vowel context, the average measures of spectral skewness of three, four and five year old children and adults were1.74, 2.17, 1.96, and 1.29, respectively. Only the mean spectral skewness produced by adults and four years old child speakers was significantly different. Contrary to previous studies (Nittrouer 1995; Nissen 2003; Fox and Nissen 2005), the present work indicated that child speakers were characterized with elevated mean spectral skewness compared to the adult speakers.

When we closely scrutinize the above result, it was not in contrast with the previous works in many cases. The mean value of the spectral skewness produced by adult group was higher for sibilant fricatives /s, ʃ/. On the other hand, the value was slightly increased

for child groups for /f/ and highly elevated for /h/. The glottal fricative in many instances led the discrepancy between sibilant and nonsibilant fricatives. Thus, this sound behaves like vowels. For instance it showed highly elevated spectral skewness, which characterizes it with the dominance of energy in the lower frequency region. Therefore, when only sibilant fricatives /s, ʃ/ are considered, the finding was similar with those of Nissen (2003) and Nittrouer (1995) that child speech is marked by its lower spectral skewness.

The dependent measure of mean spectral kurtosis produced by four years old children was significantly differed from the average spectral kurtosis of the adult speakers, without any statistical variation among child groups. The overall measures of spectral kurtosis produced by adult speakers (6.92) were lower than the average value of the moment produced by child speakers (15.62, 39.39, and 24.59 for three, four and five years old children, respectively). Thus, fricatives produced by children were more peaked or had defined peak than those produced by adults. Similarly, the place by age group interaction revealed that the mean measure of spectral kurtosis produced by children was increased for voiceless glottal fricative /h/, with highly elevated value noted for four years of age children. Thus, the adult-child discrepancy mainly stemmed from the highly elevated average spectral kurtosis of /h/. Thus, the result suggests that the spectral kurtosis was not or less robust to discriminate fricatives as a function of place of articulation because most of the discrepancies discussed so far were driven from kurtic value of /h/ which is claimed to be not typical fricative.

Compared to other variables involved in the present study, the main effects of gender was the least to be significant which indicate that both sexes produced speech similarly in many parameters. Such result is not surprising because there were no anatomical variations between male and female child speakers. The mean measure of normalized duration of male speakers (0.248) was longer than that of the female speakers (0.231). Similarly, the slope of locus equation was higher for male (0.960) speakers than for females (0.881). On the contrary, consistent with Jongman et al. (2000), the mean value of y-intercept was highly increased for female speakers (258 Hz) compared to male speakers (151Hz). The place by gender interaction also revealed that the average measure of y-intercept of female speakers was higher than that of male speakers across places of articulation. When the slope of locus equation is elevated, it entails lower y-intercept and the inverse is also true (Everett 2008). Because the higher slope and lower y-intercept indicates strong coarticulatory tendency, male speakers were more sensitive to anticipatory coarticulation than female speakers.

Analyze how each acoustic attribute successfully classifies fricatives in terms of place of articulation

Linear discriminant analysis was employed to examine the effectiveness of each predictor in classifying fricatives in terms of place of articulation. The jack-knife approach correctly classified fricatives 84.2%. Consistent with Nissen (2003) adult speakers had relatively lower classification rate (83.6 %) compared to the child groups (85.9 % for three years, 86.7 % for four years, and 85.2 % for five years of age child speakers). Thus, all child groups had almost similar classification rates indicating that the speech they produced was less distinct. The speech produced by male speakers (84 %) was classified

better than that of female speakers (81.2 %). The classification rate of the voiceless glottal fricative was highly accurate (95.3 %) and the voiceless alveolar fricative was the least (76.6 %) accurate compared to other fricatives. On the other hand, the voiceless labiodental fricative /f/ and the voiceless postalveolar fricatives /ʃ/ had intermediate classification rates and similar results (82 % and 82.8 %, respectively). The reason that /s/ had the least classification rate may be attributed to the difficult nature of the sound to be acquired by child speakers (Iskarous et al. 2011). The classification rate of sibilants (92.6 %) was somewhat better than that of the nonsibilant fricatives (90.6 %).

6.2 Vowel Fricative

Investigate the extent to which different acoustic features distinguish fricatives in terms of place of articulation

Fricatives in VCV context were not different in terms of noise duration. The present study showed contrary finding with some previous works who claimed that gemination of fricatives differ on the basis of inherent feature of the places of articulations (Aoyama and Reid 2006). The scholars stated that different classes of segments may be characterized with different geminate-singleton lengths based on place of articulation which was not confirmed in the present study. Similarly, the other main effects, such as vowel, age and gender were not different in terms of fricative duration which signify that the sounds in both phonetic contexts /i, u/ did not involve different coarticulatory gestures. Furthermore, speakers of different ages and males and females also produced fricatives with similar duration. On the other hand, a place by vowel context revealed

that the average noise duration of /s/ was increased in the context of /i/, while the value was increased for /f/ and /ʃ/ in the context of /u/.

Averaged across speakers, vowel context and gemination, the mean measure of duration of vowels preceding fricatives /f, s, ʃ/ were 83 ms, 70 ms, and 75 ms, respectively. All places were significantly different in terms of mean duration of vowels preceding fricatives. The mean duration of vowels was longer preceding /s/ and /ʃ/, while there was no difference preceding /f/. This finding is consistent with the inherent nature of fricatives. Sibilant fricatives need complex aerodynamic and production process (Ladefoged and Maddieson 1996; Iskarous et al. 2011) which need appreciably longer duration to be produced. Thus, vowels produced preceding sibilant fricatives may also share such phonetic feature and need longer duration.

Like in the case of CV fricatives, the spectral peak location depicted interesting pattern, increasing as places move anterior in the vocal tract (8095 Hz, 7542 Hz, and 5424 Hz for fricatives /f, s, ʃ/, respectively). The average peak was not distinct for /f/ and /s/. The place by age group interaction indicated that the mean spectral peak produced by adult group was decreased across fricatives, with the difference being pronounced in /s/ and /ʃ/. A place by vowel interaction for the dependent measure of the peak was higher for /f/ and /s/ in the context of /i/, while the result was reversed for /ʃ/. The cumulative result revealed that the result was consistent with anatomy and physiology of speech production. As the place moves anterior in the vocal tract, the front cavity becomes smaller and the average spectral peak will be higher. Child speakers were characterized with higher spectral peak because of their smaller cavity. Finally, the vowel by place

interaction was also predominantly as expected, higher in the context of /i/, because of the anticipatory coarticulation.

The first spectral moment (spectral mean) was highly elevated for the voiceless alveolar fricative /s/ (8541 Hz), lowest for /f/ (5514 Hz) and intermediate for /ʃ/ (5813 Hz).The spectral mean was not distinct for /f/ and /ʃ/. The average value of spectral mean of geminate /ff/ was highly increased, while almost there was no singleton-geminate discrepancy in sibilant fricatives /s, ʃ/. Thus, this non-durational feature, spectral mean, varied only in the most anterior place of articulation /f/. The result would give us the impression that there was no physiological (fronting) difference between singleton and geminate phonemes in the two posterior places /s/ and /ʃ/.

The average value of the second spectral moment significantly distinguished all places of articulation like in CV context. The mean measure of spectral standard deviation indicated that as the place moves further back in the vocal tract, the spectral standard deviation of fricatives decreases(3940 Hz, 3271 Hz, and 2369 Hz for /f, s, ʃ/, respectively). That is as the place moves anterior in the vocal tract or oral cavity, the production of fricatives becomes more variable and marked with diffused energy.

The mean value of the second spectral moment of /f/ was slightly increased for three years old child speakers and slightly decreased for four years of age speakers. The average spectral standard deviation produced by child speakers was highly increased than the average value of the moment produced by adult speakers for /s/. On the contrary, the difference was negligible for /ʃ/. This would give us the impression that the voiceless alveolar fricative produced by child speakers was more diffused than the sound produced

by adult speakers. The result is consistent with the previous findings that /s/ is difficult to produce and the last segment to be acquired by children (Iskarous, et al. 2011; Sander 1972). Obviously because geminate segments need more control of aerodynamics to sustain source of air to produce the sound, this process also put more challenge on children. Generally, the elevated mean value of standard deviation revealed more token-to-token variation in child speech.

Finally, the place by gemination interaction indicated that the overall measure of second spectral moment of geminate /ff/ was increased, while the difference was narrow in the other two places. That is geminate /ff/ was more diffused than singleton fricatives and other geminate fricatives. Moreover, the diffuseness of the geminates was less evident in the posterior fricatives. This finding was consistent with the nature of the fricatives. Labiodental fricatives are characterized with diffused energy while the alveolar and postalveolar fricatives have well defined peak (Hayward 2000) which was more evident in geminate /ff/ in the present study.

All fricatives were significantly different in terms of spectral skewness. The mean measure of spectral skewness of /s/ was highly decreased (-0.186), while that of /f/ was highly increased (0.787). On the other hand, /ʃ/ had lower positive spectral skewness (0.128) compared to that of /f/. The result suggests that /s/ was characterized with dominance of energy in higher frequency region compared to the other two places and /f/ was characterized with the concentration of energy in lower spectra.

Examine whether vowel context brings variations in the production of the sounds

The average noise duration of vowels preceding fricatives was longer in the context of /u/ (80 ms) than in the context of /i/ (72 ms). Fricatives both in the CV and VCV contexts were longer in the context of the high back rounded vowel /u/ compared to the front high unrounded vowel /i/. Based on this result it is possible to speculate that coarticulation is almost redundant in the context of /i/, especially the sibilant fricatives /s, ʃ/ are produced around similar region with /i/. That is why different acoustic measures predominantly tended towards anticipatory coarticulation in the context of /u/.

As expected, the average spectral mean of fricatives in the context of /i/ (6883 Hz) was elevated than the mean value of spectral mean of fricatives in the context of /u/ (6361Hz). This is in accord with physiology of speech production conditioned by coarticulation. During the production of fricatives preceding the front high unrounded vowel /i/, the tongue moves forward in anticipation of the vowel. This process in turn reduces the cavity anterior to the constriction which yields higher spectral mean (Nittrouer 1995). Similarly, the mean value of spectral standard deviation was also elevated in the context of /i/ (3284 Hz and 3102 Hz in the contexts of /i/ and /u/, respectively). That is the production of fricatives was more variable in the context of the front high unrounded vowel /i/ than in the context of high back rounded vowel /u/.

Describe whether durational and spectral measures vary as a function of gemination

As expected, the average duration of geminate fricatives (171 ms) was longer than that of singleton fricative (109 ms). Contrary to some previous works (Al-Tamimi 2015; Arvaniti 2001) which reported that the length of geminate fricatives was double of the

singleton fricatives, geminate fricatives were only around 40 ms longer than the singleton fricatives. In the same manner the mean normalized noise duration of geminate fricatives (0.347) was longer than that of the singleton fricative (0.246).

The average measure of spectral mean of geminate fricatives (6949 Hz) was higher than that of singleton fricatives (6622 Hz). The result was in agreement with the process of production of singleton and geminate fricatives. The production of geminate fricatives involves more constriction and more achievement of the articulatory target compared to the singleton ones (Payne 2006). This may result in more fronting of the constriction of geminate fricatives which reduces the cavity anterior to the source and yields high average spectral mean.

The overall measure of spectral skewness varied as a function of gemination. The mean value of the spectral skewness of singleton fricatives (0.368) was higher than that of geminate fricatives (0.118). The result suggests that geminate fricatives were characterized with concentration of energy in the higher spectral region than the singleton ones. Thus, such discrepancy in skewness and other moments indicate that the singleton and geminate fricatives differ not only in duration but also in physiological processes.

The mean value of spectral skewness of singleton /f/ was highly elevated, whereas the value was slightly increased for geminate /ʃʃ/. On the contrary, there was no discrepancy between geminate and singleton /s/ in terms of spectral skewness. The finding depicted that the dominance of energy in singleton-geminate dichotomy indicated discrepancy based on places of articulation. The singleton /f/ and geminate /ʃʃ/ were characterized

with dominance of energy in lower frequency spectra compared to their respective geminate and singleton phonemes. On the contrary, there was no such difference between singleton and geminate /s/. Moreover, this result once again suggests that the singleton-gemination discrepancy may also account for non-durational attributes as claimed by Payne (2006) and Al-Tamimi and Khattab (2015). The fact that both singleton /s/ and geminate /ss/ had similar spectral skewness suggested that both phonemes resist coarticulation in similar manner.

Investigate the extent to which spectraland durational features of Oromo fricatives vary as a function of age

As expected the mean spectral peak of child speakers (7192 Hz, 7384 Hz, 7128 Hz for 3, 4, and 5 years of age, respectively) was higher than that produced by adult speakers (6377 Hz). Only the spectral peak produced by adult speakers was significantly different from the mean value of the peak produced by child groups. The result was consistent with anatomical variations between children and adults. The cavity anterior to the source or constriction of fricatives is smaller in children which elevated the mean spectral peak (Nissen 2003). The age by gender interaction revealed that the mean spectral peak produced by three years and adult female speakers were increased, while the peak produced by five years male speakers was elevated than that of female children.

Only the spectral mean produced by child and adult speakers was statistically distinct. The average spectral mean for three, four, and five years old and adult speakers were 6957 Hz, 6808 Hz, 7012 Hz, and 5713 Hz, respectively. This difference is consistent with the size of the cavity downstream (Nittrouer 1995). The size of the cavity is inversely

related to the magnitude of the average spectral mean. The age by gender interaction depicted that the average value of spectral mean produced by three years and five years old male children was elevated than the mean value of the moment produced by females of the same age. As indicated in CV fricatives, such discrepancy between males and females at this earlier age stems from developmental or behavioral patterns than anatomical features because such morphological difference is less evident before pubescent (Nissen 2003; Fox and Nissen 2005; Fitch and Giedd 1999).

The average measures of spectral skewness was 0.170 for three years old, 0.057 for four years old, 0.196 for five years old, and 0.549 for adult speakers. The result depicted that the average spectral skewness produced by adult speakers was higher than that of child speakers. This characterized fricatives produced by children with the abundance of spectral energy in the higher spectral region. Like in other many attributes, only the mean spectral skewness produced by adult speakers was different from the mean values of the moment produced by child groups, signifying no anatomical difference between child groups at this age.

Investigate the extent to which each acoustic attribute successfully classifies fricatives in terms of place of articulation

The jack-knife approach correctly classify fricatives with accuracy rate of 74.8 %. The five years old child speakers had relatively the least accurate rate of classification (75.2 %) compared to other groups of speakers. The adult and three years old child speakers had similar classification rates (79.2 %) and the four years old child speakers depicted 78.6 % correct classification of fricatives. Unlike in CV context, fricatives produced by

male speakers (73.4 %) in VCV section was less accurate than those produced by female speakers (76.6 %). The voiceless postalveolar fricative /ʃ/was the highest (85.5 %), the voiceless alveolar fricative was the lowest (64.5 %) and the voiceless labiodental fricative /f/ was intermediate (74.5 %) to be correctly classified. Like in CV fricatives, the voiceless alveolar fricative /s/ was also characterized by low classification rate in VCV fricatives. This may depict that the complex physiological and aerodynamic nature it involves (Ladefoged and Maddieson 1996; Iskarous et al. 2011) to be acquired by children.

The study analyzes speech produced by typically developing children between 3 and 6 (3; 0 and 5; 11) years of age and adults. It is reasonable to expect that children start to produce adult like fricatives within this age range. Different developmental investigations into speech produced by typically developing children reported that between the age of 5 and 6 children produce the majority of speech sounds (Smith etal.1990). But experimental studies indicated that adult like accuracy of speech sound production cannot be achieved until the age of 14 or 15 (Lee et al. 1999). Nissen and Fox (2005) observed that children start to produce some acoustic attributes form four years onwards.

Though the child speakers did not show linear progress starting from 3 to 5 years, their attempt indicated that they start to tune at four years. The difference was less evident in amplitude and durational cues, but some patterns were observed in spectral features. The four years old child speakers depicted the highest spectral peak of all age groups. Especially, the spectral mean of some segments, spectral skewness and kurtosis produced by four years old children was highly elevated compared to the other groups of speakers.

Similarly, the four years old children depicted the least spectral skewness of the sibilant fricatives /s, ʃ/ and actually the highest skewness of all age groups for /h/. The same child group also depicted stronger anticipatory coarticulation of both vowels in terms of spectral skewness. Similar feature was depicted in both CV and VCV contexts, but the difference was not as vivid as in CV fricatives because geminate fricatives may be more complex than the singleton fricatives to acquire for this age group.

Thus, the results indicated that children in Oromo begin to tune speech from four years onwards. But one may argue that the pattern did not continue in five years old children. It is possible to speculate that children start to produce adult-like speech at four years of age, but fluctuate when they want to acquire finer elements. That is why some of the acoustic parameters elevated for four years child speakers and reduced for five years of age speakers.

6.3 The relevance of the study

This part has been aspired to briefly comment on the relevance and theoretical implications of the work. The work corroborated with previous works such as Nissen (2003), Nissen and Fox (2005), Jongman et al. (2000), Nittrouer (1995), among others. The finding of the result revealed that some acoustic cues are more salient than others in characterizing fricatives. It also threw light on the fact that speech sounds, at least fricatives can be characterized by some persistent acoustic cues. Though the work revealed some phonetic universal pictures, it also depicted language specific features which were not the case in many other languages. A case in point was the fact that fricative produced by younger children were shorter than that of the adult speakers.

As a pioneering study on Oromo, the work has strong significance in encouraging experimental study on the language. The study paves the ways for both segmental and superasegmental features in the language. Furthermore, the data or the finding of the study would be of great importance as a normative reference to encourage clinical studies conducted on the language. Finally, for those who are interested in theorizing some core findings such as language specific discrepancies in duration, early gender variations in some measurements and the singleton-gemination differences both temporally and spectrally may get a stepping stone to peruse.

CHAPTER SEVEN

CONCLUSION

The present study depicted that the Haraghe Oromo fricatives varied in terms of different acoustic attributes. Noise duration, relative amplitude, spectral peak location, spectral mean and spectral standard deviation were important acoustic cues in distinguishing at least three places. The spectral moments, especially the first three, were more robust in distinguishing fricatives compared to the other parameters. The second spectral moment (spectral standard deviation) was the sole acoustic cue to distinguish all fricatives in both phonetic contexts (CV and VCV). The VCV context depicted that the singleton-geminate discrepancy was indicated by both durational and spectral parameters. Thus, geminate and singleton fricatives vary both temporally and physiologically. In many instances /s/ was less sensitive to anticipatory coarticulation and had the least rate of discrimination compared to other fricatives, which signifies that it involves complex production processes and the last to be acquired by children of between 3 to 6 years of age. Finally, because the four years old children revealed increased measures of acoustic parameters and significantly different from adults in terms of many parameters, children in the present study begin to produce adult-like fricatives from four years onwards. This study exclusively focused on production of voiceless fricatives /f, s, ʃ, h/. In the future, perceptual analysis is required to examine the extent to which the acoustic features characterize Oromo fricatives.

REFERENCES

Abebayehu Mesele. (2007). An acoustic analysis of a pathological speech: the case of an Amharic speaking person with flaccid dysarthria.MA thesis. Addis Ababa Uni versity:Addis Ababa.

Al-Khairy, A. M. Acoustic characteristics of Arabic fricatives.Unpublished doctoral dissertation, The University of Florida.

Andrzejewski, B. W. (1966). "The role of tone in the Borana Dialect of Galla," *In: Pro ceedingsof the Third International Conference of Ethiopian Studies II*, Addis Ab aba: Institute ofEthiopian Studies, 88-98.

Al-Tamimi, J., and Khattab, G. (2015)."Acoustic cue weighting in the singleton vs gem inate contrast in Lebanese Arabic: The case of fricative consonants," *J. Acoust. Soc. Am.*344-360.

Andrzejewski, B.W. (1957). "Some preliminary observations on the Borana dialect of Galla," *Bulletin of the School of Oriental and African Studies, 19: 354-374.*

Arvanti, M. (2001)."Cypriot greek and the phonetics and phonology of geminates".*In Proceedings of the First International Conference of Modern Greek Dialects and Linguistic Theory* ,University of Patras, pp. 19-29.

Aoyama, K., & Reid, L. A. (2006). "Cross-linguistic tendencies and durational contrasts in geminate consonants: An examination of Guinaang Bontok geminates" *J. Acoust. Soc. Am.*36,145–157.

Baum, S. R. and S. E. Blumstein (1987). "Preliminary observations on the use of duration as a cue to syllable-initial fricative consonant voicing in English," *J. Acoust. Soc. Am.* 82 (3), 1073–1077.

Behrens, S. J., & Blumstein, S. E. (1988).‘‘On the role of the amplitude of the fricative noise in the perception of place of articulation in voiceless fricative conso nants,’’*J. Acoust. Soc. Am.* 84, 861–867.

Bender, M. L, Mulugeta Etefa & Stinson, D.L.(1976).Two Cushitic languages. In: *Language in Ethiopia.* Bender, M.L. J.D. Bowen, R.L. Cooper, C. A. Fergusen (eds).London: Oxford University Press, 130-148

Bender, M.L. (1976).*The Non-Semitic languages of Ethiopia*. Monograph No.5, Occa sional Papers Series, Committee on Ethiopian Studies, East Lansing Carbondale, African Studies Centre, Michigan State University.

Binyam Abebe. (1988). The phonology of Rayya Oromo. Unpublished senior paper. Addis Ababa: Addis Ababa University.

Boersma, P. and Weenink, D. (2013). Praat: doing phonetics by computer[Computer pro gram]. Version 5.3.57 Retrieved January 13, 2013. http://www.praat.org

Cheon, S.Y. & Anderson, V. B. (2008). "Acoustic and perceptual similarities between Englishand Korean sibilants: implications for second language acquisition," *In ternational Circle of Korean Linguistics*, 14, 41-64.

Crystal, T. and A. House (1988). "Segmental durations in connected-speech signals: Current results," *J. Acoust. Soc. Am.* 83, 1553–1573.

Dejene Geshe & Devardhi, J. (2013)."Assimilation in Oromo phonology," *Language in India*, 13, 331-358.

Dejene Geshe (2010). Kamisee Oromo phonology: Unpublished M.A Thesis. Addis Ab aba:Addis Ababa University.

Denes, P. (1955)."Effect of Duration on the Perception of Voicing," *J. Acoust.Soc. Am*. 27 (4) 761–764.

Cole, R. A. and W. E. Cooper (1975)."Perception of voicing in English affricates and fricaitves,"*J. Acoust. Soc Am*. 58 (6), 1280–1287.

Derib Ado. (2011). An acoustic analysis of Amharic vowels plosives and ejectives. Unpub-lished doctoral dissertation, Addis Ababa: Addis Ababa University.

Dodd, B. (1995). "Children's acquisition of phonology". In: Differential diagnosis and treatment of children with speech disorder. Crystal, D., Lesser, R. and Snowling, M. (eds). California: Singular Publishing Group, Inc.

Dodd, B., Holm, A., Hua, Z. & Crosbie, Sh. (2003). "Phonological development: a nor mative study of British English-speaking children," *Clinical Linguistics & Pho netics*, 17(8), 617–643.

Everett, C. (2008). "Locus Equation Analysis as a Tool for Linguistic Fieldwork," *Lan guage Documentation & Conservation*, 2 (2), 185–211.

Fant, G. 1960. *Acoustic Theory of Speech Production*. The Hague: Mouton and Co.

Feda Negesse. (2013). Vowel and voice characteristics of prelingually deaf children*:* acousticand perceptual experiments. Unpublished doctoral dissertation, Addis Ababa University, Addis Ababa, Ethiopia.

Fitch, W. T., and Giedd, J. (1999).“Morphology and development of the human vocal tract: Astudy using magnetic resonance imaging,” *J. Acoust.Soc. Am*. 106, 1511–1522.

Forrest, K., Weismer, G., Milenkovic, P., & Dougall, R. (1988)."Statistical analysis of word initial voiceless obstruents: preliminary data," *J. Acoust.Soc. Am.* 84, 115–124.

Forrest, K., Weismer, G., Hodge, M., Dinnsen, D.A. (1990). Statistical analysis of word-initial /k/ and /t/ produced by normal and phonologically disordered children. *Clinical Linguistics and Phonetics, 4*, 327-340.

Forrest, K., Weismer, G., Elbert, M., and Dinnsen, D.A. (1994)."Spectral analysis of tar get /t/ and /k/ produced by phonologically disordered and normally articulating children,"*Clinical Linguistics and Phonetics, 8*, 267-281.

Frid, A. & Lavner, Y. (2014)." Spectral and textural features for automatic classification offricatives using SVM," *IEEE*, 99-102.

Fox, R. A. & Nissen, S. L. (2005**)**. "Sex-related acoustic changes in voiceless English fricatives," *J. Speech Lang. Hear. Res*. 48, 753–765.

Fowler, C. _1994_."Invariants, specifiers, cues: An investigation of locus equations as information for place of articulation," *Percept.Psychophys*. 55, 597–610.

Fulop, S. A. (2011). *Speech Spectrum Analysis*. Berlin: Springer.

Gragg, G (1976). Oromo of Wellega. In Bender, M.L. (ed.), *The Non-Semitic Languages of Ethiopia* (pp. 166- 195).

Goffman, L., Smith, A., Heisler, L.& Ho, M. (2008)."The breadth of coarticulatory units inchildren and adults," *J Speech Lang Hear Res*. 51(6), 1424–1437.

Gurlekian, J. A. (1981). "Recognition of the Spanish fricatives /s/ and /f/," *J. Acoust.Soc. Am.* 70 (6), 1624–1627.

Habte Bulti. (2003). Analysis of tone in Oromo.Unpublished M.A Thesis. Addis Ababa: Addis Ababa University.

Haley, K. L., Seelinger, E., Mandulak, K. C. & Zajac, D. J. (2010). "Evaluating the spec tral dis tinction between sibilant fricatives through a speaker-centered ap proach," *J Phon*. 38(4), 548–554.

Harrington, J. & Cassidy, S. (1999). *Techniques in Speech Acoustics*. AA Dordrecht: KluwerAcademic Publishers.

Harris, K. S. (1958). "Cues for the discrimination of American English fricatives in spo ken syl lables," *Lang. Speech*,1, 1–7.

Hassan. M. Z. (2002). "Gemination in Swedish & Arabic with aparticular reference to the preceding vowel duration.An instrumental & comparative approach," *TMH-QPSR 44, 81–84.*

Hayward, K. (2000). *Experimental Phonetics.*New York: Longman.

Hedrick, M. S. and R. N. Ohde (1993). "Effect of relative amplitude of frication on perception of place of articulation," *J. Acoust. Soc. Am.* 94 (4), 2005–2027.

Heinz, J. M., and Stevens, K. N. (1961)."On the properties of fricative consonants," *J. Acoust.Soc. Am.* 33, 589–593.

Heinz, J. M., and Stevens, K. N. (1961)."On the properties of fricative consonants," *J. Acoust. Soc. Am.* 33, 589–593.

Hughes, G. W., & Halle, M. (1956)."Spectral properties of fricative consonants," *J. Acoust. Soc.Am.* 28, 303–310.

Iskarous, K., Shadle, C. H., & Proctor, M. I. (2011)."Articulatory-acoustic kinematics: The production of American English /s/,"*J. Acoust. Soc. Am.*, 129, 944–954.

Jassem, W. (1962). "The acoustics of consonants", In A. Sovijäravi and P. Alto (eds.), *Proceedings of the 4th international conference of phonetic science*, Mouton, The Hogue,50-72.

Jongman, A. (1989). "Duration of frication noise required for identification of English fricatives," *J. Acoust. Soc. Am.* 85, 1718–1725.

Jongman, A. (1998). "Are locus equations sufficient or necessaryfor obstruent perception?" *Behavioral and brain sciences* (1998) 21, 241–299.

Jongman, A., Wayland, R. and Wong, S. (1998). "Acoustic characteristics of English fricatives: I. Static cues," *Working papers of Cornell phonetics laboratory*, 12, 195-205.

Jongman, A., Wayland, R., and Wong, S. (2000). "Acoustic characteristics of English fric atives," *J. Acoust. Soc. Am.* 108, 1252–1263.

Katz, W. F., Kripke, C. and Tallal, P. (1991). "Anticipatory co-articulation in the speech of adultsand young children: Acoustic, perceptual, and video data," *Journal of Speech and Hearing Research*, 34:1222–1232.

Kebede Hordofa. (1994). Baatee (Wello) Oromo phonology: Palatalization of Alveo-dental Consonants and Related Issue.Unpublished M.A thesis, Addis Ababa: Addis Ababa University.

Kebede Hordofa. (2009). Towards the genetic classification of the Afaan Oromoo Dia lects. Unpublished Doctoral Dissertation, The University of Oslo, Oslo, Nor way.

Kent, R. D. (1993). "Vocal tract acoustics," *Journal of voice*, 7(2), 97-117.

Klatt. H, D. (1976). "Linguistic uses of segmental duration in English: Acoustic and perceptual evidence," *J. Acoust. Soc. Am.*59 (5) 1208–1221.

Koenig, L. L. (2000). "Laryngeal factors in voiceless consonant production in men, women, and5-year-olds," *J. Speech Lang. Hear. Res.,*43, 1211– 1228.

Koenig, L. L. Shadle, Ch. H., Preston, J. L. and Mooshammer, Ch. R. (2013). "Toward ImprovedSpectral Measures of /s/: Results From Adolescents," *Journal of Speech, Language, and Hearing Research,* 56, 1175–1189.

Koenig, L. L., Lucero, J. C., & Perlman, E. (2008)."Speech production variability in fricativesof children and adults: Results of Functional Data Analysis," *J. Acoust. Soc. Am.* 124, 3158– 3170.

Koenig, L., & Lucero, J. C. (2002)."Oral-laryngeal control patterns for fricatives in 5-year-olds and adults," *Proceedings of the 7th International Conference on Spoken Language Processing* (ICSLP), Denver, CO.

Kraehenmann, A. (2001). "Swiss German stops: geminates all over the word,". Cam bridge University press. *Phonology* 18 (2001),109-145.

Ladefoged, P., & Maddieson, I. (1996.)*The Sounds of the World's Languages.*Blackwel Publishers Inc.

Lee, S., Potamianos, A., and Narayanan, S. (1999). "Acoustics of children's speech: Developmen tal changes of temporal and spectral parameters." *J. Acoust. Soc. Am.* 105, 1455–1468.

Lehr, F. R. (2000). The Sequence of Speech-Sound acquisition in the letter people pro grams. *Abrams and Company Publishers,* Inc.1–4.

Li, F., Edwards, J., and Beckman, M. E. (2009). “Contrast and covert contrast: The pho netic development of voiceless sibilant fricatives in English and Japanese todd lers,” *J. Phonetics* 37, 111–124.

Li, F., Munson, B., Edwards, J., Yoneyama, K. and Hall, K. (2011)."Language specificity in the perception of voiceless sibilant fricatives in Japanese and English: Impli cations for cross-language differences in speech-sound development," *J. Acoust.Soc. Am.* 129 (2), 999–1011.

Li, F. (2012).“Language-specific developmental differences in speech production: A cross-language acoustic study,” *Child Dev.* 83(4), 1303–1315.

Lieberman, Ph. & Blumistein, Sh. E. (1988).*Speech physiology, speech perception, and acousticphonetics*. Cambridge: Cambridge University Press.

Löfqvist, A. (1999). “Interarticulator phasing, locus equations and degree of coarticulation,” *J. Acoust. Soc. Am.* 106, 2022–2030.

Lindblom, B. (1963). “Spectrographic study of vowel reduction,” *J. Acoust.Soc. Am.* 35, 1773– 1781.

Maddieson, I. (1984). *Patterns of sounds.*Cambridge: Cambridge University Press.

Mayo, C**.** (2000). *The relationship between phonemic awareness and cue weighting in speech perception: Longitudinal and cross-sectional child studies*. Unpublished doctoral disser tation, Queen Margaret University College, Edinburgh, United Kingdom.

Manrique, A. M. and M. I. Massone (1981). "Acoustic analysis and perception of Spanish fricative consonants," *J. Acoust. Soc. Am.* 69 (4), 1145–1153.

Mayo, C., Scobbie, J. M., Hewlett, N., and Waters, D. (2003). “The influence of phone micawareness development on acoustic cue weighting in children’s speech per ception,” *J. Speech Lang. Hear. Res*. 46, 1184–1196.

Mayo, C. and Turk, A. (2004). "Adult–child differences in acoustic cue weighting are in fluenced by segmental context: Children are not always perceptually biased toward transitions,"*J. Acoust. Soc. Am.*115(6), 3184-3194.

_____. (2005)."The influence of spectral distinctiveness on acoustic cue weighting in children’s and adults’ speech perception," *J. Acoust. Soc. Am*. 118 (3), 1730–1741.

McCasland, G. P. (1979a). "Noise intensity and spectrtuirt cues for spoken fricatives," *J. Acoust. Soc. Am.* Suppl 165, 78–79.

McCasland,G . (1979b). "Noise intensity cues of spoken fricatives," *J .Acoust. Soc. Am.* Suppl. 1 66, S88.

McGowan, R. S., & Nittrouer, S. (1988). "Differences in fricative production between childrenand adults: Evidence from an acoustic analysis of /ʃ/ and /s/," *J. Acoust. Soc. Am.* 83, 229–236.

Muller, J. (2001). The phonology and phonetics of word-initial geminates.Doctoral dis sertation, Ohio State University.

Munson, B. (2001). A method for studying variability in fricatives using dynamic measures of spectral mean.*J. Acoust. Soc. Am.* 110, 1203–1206.

Munson, B. (2004). "Variability in /s/ production in children and adults: Evidence from dynamic measures of spectral mean," *J. Speech Lang. Hear. Res*, 47, 58–69.

Munson, B. (2011). "The influence of actual and imputed talker gender on fricative

perception, revisited (L)," *J. Acoust. Soc. Am.* 130 (5), 2631–2634.

Nissen, S. L. (2003). An acoustic analysis of voiceless obstruents produced by adults and typical ly developing children.Unpublished doctoral dissertation, Department of Speech and Hearing Science, The Ohio State University.

Nissen, S. L., and Fox, R. A. (2005). "Acoustic and spectral characteristics of young chil dren's fricative productions: A developmental perspective," *J. Acoust. Soc. Am.* 118, 2570–2578.

Nissen, S. L., & Fox, R. A. (2009). "Acoustic and spectral patterns in young children's stop consonant productions," *J. Acoust. Soc. Am.*126 (3), 1369-1378.

Nittrouer, S. (1992).''Age-related differences in perceptual effects of formant transitions within syllables and across syllable boundaries,'' *J. Phon*. 20, 1–32.

Nittrouer, S. (1995). "Children learn separate aspects of speech production at different rates: Evidence from spectral moments" *J. Acoust. Soc. Am*. 97, 520-530.

Nittrouer, S. (2002). "Learning to perceive speech: How fricative perception changes, and how it stays the same," *J Acoust Soc. Am*, 112:711–719.

Nittrouer, S.& Whalen, D. H. (1989). "The perceptual effects of child-adult differences in frica tive-vowel coarticulation," *J. Acoust.Soc. Am*. 86 (4), 1266–1276.

Nittrouer, S., & Lowenstein, J. H. (2009). "Does harmonicity explain children's cue weighting of fricative-vowel syllables?" *J. Acoust. Soc. Am*. 125, 1679– 1692.

Nittrouer, S., & Lowenstein, J. H. (2010). "Learning to perceptually organize speech sig nals in native fashion," *J. Acoust. Soc. Am.* 127, 1624–1635.

Nittrouer, S., and Miller, M. E.(1997). ''Predicting developmental shifts in perceptual weighting schemes,*''J. Acoust. Soc. Am.* 101, 2253–2266.

Nittrouer, S., E. Miller, M., S. Crowther, C., and J. Manhart, M. (2000). "The effect of segmentalorder on fricative labeling by children and adults," *Perception & Psychophysics,* 62 (2),266-284.

Nittrouer, S., and Studdert-Kennedy, M. (1987)."The role of coarticulatory effects in the percep tion of fricatives by children and adults," *Journal of Speech and Hearing Research*, 30, 319-329.

Nittrouer, S., Studdert-Kennedy, and T. Neely, S. (1996)."How children learn to organize theirspeech gestures: further evidence from fricative-vowel syllables," *American SpeechLanguageHearing Association*, 39, 379-389.

Nittrouer, S., Studdert-Kennedy, M., & McGowan, R. S. (1989)."The emergence of pho neticsegments: Evidence from the spectral structure of fricative-vowel syllables spoken bychildren and adults," *J. Speech Lang. Hear. Res.* 32, 120–132.

Peterson, G. E. & Barney, H. L. (1952). "Control methods used in a study of the vowels," *J. Acoust. Soc. Am., 24,* 175-184.

Pirello, K., S. E. Blumstein, and K. Kurowski (1997).The characteristics of voicing in syllable-initial fricatives in American English. J Acoust Soc Am 101 (6), 3754–3765.

Payne, E. M. (2006). "Non-durational indices in Italian geminate consonants," *J. Int. Phon. Assoc.* 36(1), 83–95.

Reidy, F.P. (2016). "Spectral dynamics of sibilant fricatives are contrastive and language specif ic," *J. Acoust Soc. Am.* 140 (4), 2518–2529.

Romeo, R., Hazan, V. & Pettinato, M. (2013)."Developmental and gender-related trends of in-tra talker variability in consonant production," *J. Acoust Soc. Am*. 134 (5), 3781-3792.

Sereno, J. A., Baum, S. R., Marean, G. c., & Lieberman, P. (1987)."Acoustic analyses and perceptual data on anticipatory labial coarticulation in adults and children"' *J. Acoust. Soc.Am*. 81, 512-519.

Shadle, C. (1985). "The acoustics of fricative consonants," *RLE Technical Report*, 506, MIT.

Shadle, C. H., & Mair, S. J. (1996). ‘‘Quantifying spectral characteristics of fricatives,’’ Proc. Int. Conf. Spoken Lang. Proc. (ICSLP) ,1521–1524 (unpublished).

Shobha, N. H. (2012). "The Perception of Consonant Voicing and Place of Articulation in Fricatives-Vowels with Consonant Duration Modifications," *International Jour nal of Engineer*ing Science Invention. 1 (1) 5–12.

Smith, B. L. (1978). "Temporalaspectso f Englishspeechproduction: A developmental perspective,"*J . Phon*. 6, 37-68.

Smith, B. L. (1992). “Relationships between duration and temporal variability in chil dren’s speech,” *J. Acoust.Soc. Am*. 91, 2165–2174.

Smith L.B. and McLean-Muse.A. (1986)."Articulatory movement characteristics of la bial consonant productions by children and adults," *J. Acoust. Soc.Am.*80 (5)1321–1328.

Smith, B.L., Kenney, K. M. (1998). "An assessment of several acoustic parameters in children 'sspeech production development: longitudinal data," *Journal of Phonet ics*, 26, 95–108.

Smith, B.L., Kenney, K. M. and Hussain, S. (1996). "A longitudinal investigation of du ration and temporal variability in children's speech production," *J. Acoust.Soc. Am*. 99 (4), 2344–2349.

Snowling, M.J., and Hulme, C. (1994)."The development of phonological skills," *Philo sophical Transactions of the Royal Society of London*, 346, 21–27.

Song, J.Y., Demuth, K., Evans, K. & Shattuck-Hufnagel, S. (2013). "Durational cues to fricative codas in 2-year-olds' American English: Voicing and morphemic fac tors," *J. Acoust. Soc.Am.* 133 (5), 2931–2946.

Souza, P. E. (2002). Effects of Compression on Speech Acoustics, Intelligibility, and Sound Quality. Westminster Publications, Inc.,6(04), 131-165.

Stevens, K.N. (1998). *Acoustic Phonetics.*Massachusetts, California: MIT Press.

Stevens, K. N., Blumstein, E.S., Glicksman, L., Burton, M., and Kurowski, K. (1992). Acoustic and perceptual characteristics of voicing in fricatives and fricative clusters," *J. Acoust.Soc. Am.*91 (5) 2979–3000.

Strevens, P. (1960). "Spectra of fricative noise in human speech," *Language and Speech*, 3, 32– 49.

Stathopoulos, E. T. _1995_. "Variability revisited: An acoustic, aerodynamic, and respir atory kinematic comparison of children and adults during speech," *J. Phonetics* 23, 67–80. Stathopoulos Elaine. **T. Stathopoulos**

Sussman, H. M., McCaffrey, H. A., and Mathews, S. A. (1991). "An investigation of lo cus equations as a source of relational invariance for stop place categorization," *J. Acoust. Soc. Am. 90, 1309–1325.*

Sussman, H. M., and Shore, J. (1996).‘‘Locus equations as phonetic descriptors of con sonantal place of articulation,’’ *Percept. Psychophys,* 58, 936–946.

Sussman, H. M, Duder, C., Dalston, E. (1999). “An Acoustic Analysis of the “Development of CV Coarticulation: A Case Study,” *JSLHR* 42, 1080-1096

Wagner, A. (2013). "Cross-language similarities and differences in the uptake of place information," *J. Acoust. Soc. Am*. 133 (6), 4256-4267.

Tabain, M. (2000).“Coarticulation in CV syllables: A comparison of locus equation and EPG data,” *J. Phonetics* 28, 137–159.

Tabain, M. (2000). "Voiceless Consonants and Locus Equations: A Comparison with Electropalatographic Data on Coarticulation," *Phonetica* 2002 (59)20–37..

Wako Tola . (1981). The phonology of Mecha Oromo. Unpublished MA thesis, Addis Ababa: Addis Ababa University.

Whalen, D. H. (1981). ‘‘Effects of vocalic formant transitions and vowel quality on the English /s–ʃ/ boundary,’’ *J. Acoust. Soc. Am*. 69, 275–282.

Whalen, D. H. (1983)."Vowel information in postvocalic fricative noises," *Language and Speech*, 26, 91-100.

Whalen, D. H. (1991). "Perception of the English /s/-/ʃ/ distinction relies on fricative noises and transitions, not on brief spectral slices," *J. Acoust. Soc. Am*. 90, 1776–1785.

Appendix I: Mean measurements of Fricative Duration (Fr_durn), Vowel Duration (Vl_durn), Normalized Duration (Nrm_durn) and Normalized Amplitude (Nrm_amp) as a function of age, place and gender in CV fricatives.

Age groups	Variables	Male				Female			
		f	s	sh	h	f	s	sh	h
Adult	Fr_durn	135.708	149.083	141.521	84.583	117.667	149.958	145.313	84.479
	Vl_durn	80.65	76.94	81.15	88.31	98.81	110.00	99.04	107.02
	Nrm_durn	.31	.34	.30	.20	.24	.30	.27	.18
	Nrm_amp	-17.44	-12.88	-13.94	-20.27	-17.38	-10.77	-12.40	-19.96
3 yr olds	Fr_durn	110.000	117.208	144.479	90.917	99.042	126.021	121.979	88.500
	Vl_durn	92.85	91.50	86.98	104.73	89.54	95.50	97.02	101.29
	Nrm_durn	.23	.25	.29	.19	.20	.25	.22	.19
	Nrm_amp	-11.67	-8.06	-7.23	-15.08	-13.00	-6.02	-7.52	-12.58
4 yr olds	Fr_durn	101.896	127.479	119.000	93.146	92.583	122.042	120.375	83.792
	Vl_durn	89.06	94.46	83.79	109.29	91.77	102.23	84.81	102.19
	Nrm_durn	.22	.26	.24	.19	.21	.26	.24	.18
	Nrm_amp	-13.27	-9.19	-9.25	-14.69	-12.23	-6.79	-6.58	-12.29
5 yr olds	Fr_durn	112.063	125.063	122.917	93.688	113.396	134.083	121.333	96.646
	Vl_durn	84.73	96.21	96.29	100.69	84.04	94.48	93.10	97.06
	Nrm_durn	.25	.25	.24	.20	.26	.26	.23	.20
	Nrm_amp	-13.81	-9.69	-7.50	-14.79	-13.27	-10.65	-10.58	-14.27

Appendix II: Mean measurements of Spectral Peak Location (Spl_loc), Spectral Mean (M1), Spectral Standard Deviation (M2), Spectral Skewness (M3) and Spectral Kurtosis (M4) as a function of age, place and gender in CV fricatives.

Age groups	Variables	Male				Female			
		F	s	sh	h	f	s	sh	h
Adult	Spl_loc	7609.38	5866.54	4260.92	3266.44	7014.67	7970.00	4635.85	3542.98
	M1	6616.13	6778.17	5174.08	2144.52	6676.23	8072.46	5345.96	3173.94
	M2	4001.31	2464.60	2321.38	3911.48	4330.69	2222.58	2324.50	4720.27
	M3	.28	.98	.87	3.43	.75	.18	1.03	2.79
	M4	.98	6.40	3.97	15.29	2.83	8.20	5.41	12.25
3 yr olds	Spl_loc	7549.33	7586.58	4799.06	4147.13	7355.21	7374.29	5083.06	3567.00
	M1	5678.54	8568.10	5815.54	1730.58	5208.21	8647.92	5691.96	1345.29
	M2	4334.00	3418.44	2824.81	3079.29	4230.40	3146.06	2558.88	2617.96
	M3	.75	-.27	.52	6.12	.79	-.23	.17	6.08
	M4	2.06	2.22	2.50	49.13	1.81	2.66	1.56	63.01
4 yr olds	Spl-loc	8217.60	7635.08	5559.08	3423.29	8289.73	7785.50	6171.04	3315.67
	M1	5100.10	8604.04	6012.02	1266.65	4711.77	8488.08	6404.52	1308.10
	M2	3662.27	3437.29	2450.96	2181.40	4236.54	3562.13	2740.83	2560.98
	M3	1.02	-.45	-.29	10.06	1.13	-.46	-.16	6.54
	M4	5.51	1.73	1.67	228.97	3.25	2.32	1.94	69.74
5 yr olds	Spl-loc	8350.71	7872.27	5692.10	3744.54	7749.50	6760.88	4207.56	3381.25
	M1	6999.08	8968.98	6191.46	1222.46	4372.02	7478.63	5312.98	1710.81
	M2	4134.17	3158.98	2205.96	2129.90	3714.60	3096.06	2609.81	2717.58
	M3	-.14	-.05	-.04	6.68	2.28	.11	.48	6.37
	M4	1.35	2.20	3.32	82.44	16.72	2.41	2.48	85.85

Appendix III: Mean measures of F2 at onset of vowels (F2O), F2 at the middle of vowel (F2V) and Slope of Locus equation (Slope) as a function of age, place and gender in CV fricatives.

Age groups	Variables	Male				Female			
		F	s	sh	h	f	s	sh	h
Adult	F2 O	1478.27	1597.73	1766.25	1594.83	1707.46	1884.50	2101.48	1750.50
	F2 V	1390.42	1521.69	1595.67	1515.04	1717.08	1842.69	1989.75	1726.69
	Slope	.691	.691	.691	.690	.713	.714	.714	.711
3 yr olds	F2 Onset	1518.48	1865.13	2008.29	1356.06	1527.06	1794.35	2068.02	1477.71
	F2 Vowel	1396.04	1766.83	1813.60	-11.67	-8.06	-7.23	-15.08	-13.00
	Slope	.615	.737	.740	.523	.660	.665	.662	.661
4 yr olds	F2 Onset	1679.15	1708.71	1955.25	1464.04	1563.88	1706.25	2015.29	1410.50
	F2 Vowel	1774.65	1731.17	1843.58	1570.50	1569.85	1617.88	1958.31	1565.56
	Slope	.699	.700	.699	.699	.684	.682	.683	.685
5 yr olds	F2 Onset	1742.58	1915.50	1973.10	1650.79	1499.75	1677.31	1903.02	1408.83
	F2 Vowel	1780.25	1685.71	1945.29	1476.40	1582.17	1583.23	1772.25	1452.63
	Slope	.660	.659	.660	.659	.679	.680	.679	.679

Appendix IV: Mean measurements of Fricative Duration (Fr_durn), Vowel Duration (Vl_durn) and Normalized Duration as a function of age, place and gender in VCV fricatives.

Age Groups	Variables	Male				Female			
		/f/	/s/	/sh/	/h/	/f/	/s/	/sh/	/h/
Adult	Fr_durn	128.66	127.21	128.57	99.25	140.71	139.85	166.70	87.67
	Vl_durn	77.60	68.78	70.24	82.85	93.59	74.27	84.73	88.50
	Nrn_durn	.29	.29	.28	.21	.28	.31	.34	.18
3 yr olds	Fr_durn	147.00	145.95	152.42	100.38	140.79	142.88	145.89	98.38
	Vl_durn	79.55	73.46	74.03	91.50	89.59	72.23	77.74	77.29
	Nrn_durn	.31	.31	.32	.22	.27	.29	.29	.22
4 yr olds	Fr_durn	129.44	133.78	129.69	93.75	132.13	130.22	134.96	88.42
	Vl_durn	80.74	68.60	74.21	85.65	77.19	70.42	75.57	76.56
	Nrn_durn	.28	.30	.28	.21	.29	.30	.31	.20
5 yr olds	Fr_durn	143.73	146.21	145.54	97.40	141.50	145.46	144.38	99.60
	Vl_durn	85.48	68.57	70.13	67.48	79.68	67.15	74.85	67.56
	Nrn_durn	.29	.31	.31	.22	.28	.31	.29	.22

Appendix V: Mean measurements of Spectral Peak Location (Spl_loc), Spectral Mean (M1), Spectral Standard Deviation (M2), Spectral Skewness (M3) and Spectral Kurtosis (M4) as a function of age, place and gender in VCV fricatives.

Age Groups	Variables	Male				Female			
		/f/	/s/	/sh/	/h/	/f/	/s/	/sh/	/h/
Adult	Spl_loc	8053.72	6024.93	4369.79	3929.65	7797.84	7611.29	4404.58	3632.67
	M1	4409.35	6645.24	4935.86	386.25	5352.65	7848.19	5089.02	975.76
	M2	4103.81	2844.61	2439.32	788.17	3834.41	2730.01	2263.06	1652.94
	M3	.98	.25	.36	30.14	.99	-.05	.77	11.16
	M4	2.15	2.33	1.82	661.27	4.84	97.82	3.94	307.00
3 yr olds	Spl_loc	7808.44	7771.42	5615.77	3929.00	8233.78	7949.21	5775.51	3435.52
	M1	6997.45	8881.48	6217.61	1043.96	5055.49	8537.88	6052.97	730.25
	M2	4174.60	3412.97	2417.18	1394.48	4110.19	3102.28	2366.01	1003.19
	M3	.16	-.27	.27	10.86	.99	-.08	-.04	12.72
	M4	1.72	1.87	2.48	254.22	4.21	3.29	2.54	332.84
4 yr olds	Spl_loc	7991.55	7918.39	5582.20	2967.71	8374.30	8286.78	6151.35	3385.38
	M1	5444.20	8678.34	5817.46	1141.85	5133.66	9185.79	6586.79	1197.73
	M2	3657.40	3665.13	2472.41	1538.81	3802.75	3618.28	2467.51	1838.44
	M3	.86	-.33	-.19	8.71	.66	-.39	-.26	8.08
	M4	7.99	1.53	1.26	167.73	4.82	1.39	2.17	130.92
5 yr olds	Spl_loc	8430.06	7797.49	6432.42	2909.13	8074.48	6979.59	5059.59	2743.85
	M1	6573.30	10805.50	6332.65	1242.31	5145.26	7741.81	5471.71	1451.04
	M2	4085.76	3557.66	2152.13	1534.60	3748.07	3233.76	2375.61	1746.06
	M3	.09	-.53	-.16	7.16	1.57	-.07	.27	6.91
	M4	3.75	2.43	2.54	130.97	10.83	1.68	2.31	129.50