ACOUSTIC DESCRIPTION OF NEPALI VOWELS IN THE DARJEELING VARIETY

Dissertation submitted to the Jawaharlal Nehru University
in partial fulfillment of the requirements
for the award of the Degree of

MASTER OF PHILOSOPHY

BY
NISHANT LOHAGUN

Under the supervision of
PROF. VAISHNA NARANG

Centre for Linguistics
School of Language, Literature and Culture Studies
Jawaharlal Nehru University
New Delhi – 110067
India
2012

Centre for Linguistics
School of Language, Literature & Culture Studies
Jawaharlal Nehru University
New Delhi-110067, India

Dated: 25th July 2012

CERTIFICATE

This dissertation titled "**Acoustic Description of Nepali Vowels in the Darjeeling Variety**" submitted by **Nishant Lohagun**, Centre for Linguistics, School of Language, Literature and Culture Studies, Jawaharlal Nehru University, New Delhi, for the award of the degree of **Master of Philosophy**, is an original work and has not been submitted so far in part or in full, for any other degree of diploma of any other University or Institution.

This may be placed before the examiners for evaluation for the award of the degree of Master of Philosophy.

(PROF. VAISHNA NARANG)
Supervisor

(PROF. VAISHNA NARANG)
Chairperson

Dated 25th July 2012

DECLARATION BY THE CANDIDATE

This dissertation titled "**Acoustic Description of Nepali Vowels in the Darjeeling Variety**" ubmitted by me for the award of the degree of **Master of Philosophy**, is an original work nd has not been submitted so far in part or in full, for any other degree of diploma of any ther University or Institution.

Nishant Lohagun
Centre for Linguistics
School of Language, Literature and Culture Studies
Jawaharlal Nehru University
New Delhi – 110067

Dedicated to family and friends

Acknowledgements

I would like to express my heartfelt gratitude to Prof. Vaishna Narang for not only guiding me and making every resource available to me in the course of writing this dissertation but also for shaping my overall understanding relating to the discipline. I have greatly benefitted from her expertise and experience in diverse fields ranging from applied speech sciences, biolinguistics, neurolinguistics and cognitive linguistics, to name a few. I owe my knowledge regarding the various ethical issues in research involving human subjects to her, something which will always help me as a researcher.

This dissertation would not have been a reality without the participation of my eleven informants. I would like to thank Samir Sharma, Jigme Yeshi Lama, Pravhat Lama, Pravakar Rasaily, Binayak Sundas, Deepika Gahatraj, Meghlai Lama, Laysang Angmu Lama, Prativa Pradhan, Priya Tshedon Pradhan and Tahira Batt for their participation and making the effort to come to the Language Lab Complex on hot sunny days for recording. I also thank Kunal Allay and Yangchen Sherpa who had participated in earlier recordings. My gratitude is also extended to Mr.V.K. Sugathan and his associates at the Language Lab Complex, JNU, for allowing me to use the studio at a very short notice.

I am also grateful to Ms. Deepshikha Misra for her inputs and advice on different issues related to this study. Help has never been far away because of my friends and colleagues at the Centre for Linguistics, JNU. I thank all of them for their moral and intellectual support. Similarly, the countless hours spent in the company of Keny Kom, Rigzin Chodon, Dewakar Thatal, Sujoy Sarkar, Jigmey Tobgey and Rojio Usham has significantly helped in times of stress and develop newer perspectives for which I am very grateful.

Mostly importantly, I would like to thank my family, back home and here in Delhi, for their love, faith and belief in me. I thank my parents Mr.Nabin Lohagun and Mrs.Geeta Lohagun, and my brother Prashant for encouraging me and having faith in my abilities to pursue a career in research. I am also thankful to my sisters Saknim Lepcha, Neha Garg and Waiser Doma Wangdi here in Delhi for their love and encouragement. Finally, I am very grateful to Zipporah Ongmu Sherpa not only for her love, care and support but also for giving me the time and space to pursue my interests.

I sincerely apologize if I have failed to acknowledge the help and contribution of anyone in making this dissertation a reality. Finally I would also like to state that I bear sole responsibility for any errors and mistakes which may have inadvertently been made in this dissertation.

Table of Contents

List of Tables and Figures

1. List of Tables.

2. List of Figures

CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

This dissertation attempts to provide a description of the acoustic properties of vowels of Nepali as is spoken in the Darjeeling district of West Bengal in India. A language can be analyzed and described, in terms of its structure, at various linguistic levels. This study, however, is centered at the phonetic level. Phonetics is the primarily concerned with the description of speech sounds. An ideal phonetic description would account for the articulatory mechanisms, the acoustic properties and the auditory effects of all the sounds that occur in a language. However, considering the duration of the study, this dissertation has its boundaries limited with vowels being the subject of investigation and acoustics being the domain in which they are investigated.

The Nepali speaking population in the Darjeeling district has been living in the area for more than two centuries now and has since come in contact with languages like Hindi, Bangla, Tibetan, Lepcha, Santhali, Munda, Oraon, Rajbanshi and several other dialects. Nepali has, however, established itself as the *lingua franca* of the three sub-divisions namely Darjeeling Sadar, Kurseong and Kalimpong along with certain portion of the Terai region.

Recent political developments in Darjeeling and the demand for a separate state in the Indian union has got a very strong linguistic fervor to it. The residents of the hilly region have cited linguistic reasons as one of the markers of their distinct identity. This study will attempt to present a novel account of the vowels of Nepali as spoken in the Darjeeling district of West Bengal in India as existing literature on the topic is mainly based on data collected from citizens of Nepal.

The following sections of this chapter will provide a description about the language in question along with its geographical and demographic profile. This is followed by an insight into the district of Darjeeling with reference to its history, demography and society. The next section elucidates the nature and qualities of the subject matter of this study that is vowels. This is followed by a comprehensive discussion about acoustic phonetics and its relevance in linguistic theory. Remaining on the same theme, the discussion then moves to the source-filter theory of speech production carrying on to the topic of vowel acoustics. The notion of acoustic space in the light of the Dispersion Theory is discussed next along with some studies highlighting its applications in language pedagogy, language pathology, correlations between different formants and accounting for dialectal variations in languages. A brief analysis of the observations made by Pokharel (1989) regarding the acoustic characteristics of vowels of Nepali in his pioneering work is discussed next. This chapter ends with an overview of the scope and objectives of the present study.

1.1 Nepali

Nepali belongs to the Indo-Aryan branch of the Indo-European language family and is spoken in majority of the areas in Nepal; the Darjeeling district of West Bengal; Sikkim; Assam; Arunachal Pradesh; Bihar; Haryana; Himachal Pradesh; Uttar Pradesh; Uttarakhand; Manipur; Mizoram; Nagaland; Meghalaya, Tripura.[1]Generally considered to have been developed from Sanskrit, the works of Grierson (1916) and Turner (1931, 1966) suggest Nepali may have developed from the Northwestern variety of Prakrit.[2] Like most Indo-Aryan languages spoken in areas along the Himalayan and Aravalli ranges, Nepali is considered to be a member of the Outer group of Indo-Aryan languages by Hoernle (1880).

Nepali has been associated with different nomenclatures such as Khas Kura or language of the Khas people who lived in areas around the Himalayan mountain ranges, Parbatiya, Gorkhali and Pahari. Throughout the course of history, the Khas people have been in constant interaction with other cultures as a result of warfare and economic activities. In due course of time, the Devanagiri script was adopted for Nepali orthography. With the disintegration of the Khas empire, may loans from Persian and Arabic have been noted to make an entry into the language of the Khas people.[3]

According to Acharya (1991), there are many social variants of Nepali. Within Nepal, there are three dialects – Western, Central and Eastern, depending upon geographical factors as well as social hierarchy. The eastern dialect is considered to be the source for the standardized dialect. However, even within these three broad categories, there are further variations. Acharya (1991, p6) notes the Darjeeling variety of Nepali to be another distinct variety.

---

[1] http://www.ethnologue.com/show_language.asp?code=nep

[2] Pokharel, Madhav Prasad. "Origin and Development of Nepali Language." T.B. Subba, A.C. Sinha, G.S. Nepal & D.R.Nepal (eds). Indian Nepalis - Issues and Perspectives. New Delhi: Concept Publishing Company, 2009. pp327.

[3] See Pokharel 2009

Research on Nepali language began as early as 1820 in the work of J.A.Ayton who was the first to present a preliminary account of the grammar of Nepali. Since then, there have been numerous works such as Turnbull (1888), Dixitacharya (1913), Pradhan (1920), Dahal (1974),Pokharel (1979), (Acharya (1991),etc. which have described different aspects related to the language. Turnbull (1888) is the only study which has been conducted on the Darjeeling variety of Nepali.

There is an estimated total of 13,875,700 Nepali speakers across the globe according to the Ethnologue ,an encyclopedic reference guide to the known languages of the world. As per 2001 Census of Nepal, there are 11,100,000 native speakers of Nepali in Nepal. According to the Census of India 2001 there are 2,871,749 speakers of Nepali in India[4].In Darjeeling and Jalpaiguri districts of West Bengal, there are about 1,400,000 Nepali speakers. It is one of the languages which enjoys constitutional status following its inclusion into the Eighth Schedule of the Indian Constitution in 1992.

1.2 Darjeeling : History, Demography and Society

The Darjeeling district is the northernmost district of West Bengal. Four sub-divisions namely Darjeeling Sadar, Kalimpong, Kurseong and Siliguri constitute the district out of which the first three are located in the hilly regions while Siliguri sub-division falls in the Terai region at the foothills. The district shares two international boundaries with Nepal in the west and Bhutan in the east. The state of Sikkim lies in the north of the Darjeeling district. The southern side is bound by the Jalpaiguri district of West Bengal. The Darjeeling district located in the laps of the Eastern Himalayas has global presence in the field of tourism and has earned the title of 'Queen of Hill Stations' worldwide. Besides tourism, the region is also famous throughout the world for its tea industry.

Historically, Darjeeling had been a part of Sikkim and some parts were under the control of Bhutan till the advent of the British who were granted a deed of grant of the 138 mile square tract in 1835, in return for protection against the Gorkhas of Nepal and assuring the sovereignty of the Raja of Sikkim. The British established a sanatorium for ailing officers of the East India Company because of climatic conditions and natural beauty of the place. O'Malley (1907, p35.) states that in 1835 the population of Darjeeling was just 100 persons who were mostly

[4] http://www.censusindia.gov.in/Census_Data_2001/Census_Data_Online/Language/Statement1.htm

indigenous tribes. Encouraged by the British administrators, neighbouring tribes started the influx of migrants and by 1850, the population had reached 10000. By the time the first regular census for the district was carried out in 1871, the population had reached 92,712 persons. From 1881 to 1891, there was an average increase of 43.4 per cent and at the beginning of the 20th century in 1901, the population statistic stood as 249,117 persons.

The population expansion in the Darjeeling district at the latter half of the 19th century and the beginning of the 20th century can be attributed to two major factors. The first is the employment opportunities provided by the British in the tea gardens and the laying of the railway track. In addition, there were wide expanses of land which could be exploited by the Nepali immigrants who are highly proficient in agricultural practices. In fact, they were the pioneers of terrace farming in the hilly district of Darjeeling. The original inhabitants of the region, the Lepchas, were mostly hunters and gatherers and practiced slash and burn cultivation (Pradhan 2010,p 225). The citizens of Nepal, in search of better employment opportunities and living conditions, migrated in huge numbers and settled in Darjeeling and other places like Assam, Meghalaya, Manipur and Mizoram. According to the provisional data available on the Census of India 2011 released by the Government of India, the population of Darjeeling is 1,609,172 persons.[5]

Generally referred to as Nepalis, mostly on account of their language, the community itself is a complex mosaic composed of different elements. The term Nepali is an umbrella term for as many as fifteen ethnic tribes. The society in Darjeeling is characterized by diversity as reflected by the multiple ethnicities, multiculturalism and multilingualism. The present day composition of the society has its origins in a long list of ethnic groups with their respective languages belonging to different language families. On the basis of ethnicity, the demographic composition of the society in Darjeeling can be discussed on the basis of numerous groups such as the Nepalis, the Lepchas, the Bhutias, the Tibetans, the Bengalis and other Indians who reside there. The ancestry of most present day residents of the Darjeeling hills can be traced to the huge influx of immigrants because of better economic conditions and the job opportunities in tea industry in the 18th, 19th and early 20th centuries. Nepali emerged as the *lingua franca* for the members of the different ethnic groups and over time it has developed into a distinct regional variety.

[5] http://www.censusindia.gov.in/PopulationFinder/District_Master.aspx?state_code=19

1.3 Vowels

There can be no speech without sound. There are two categories of sounds which lie at the centre of any speech activity – consonants and vowels. Consonants are sounds which are produced when the air coming from the lungs is obstructed either by complete closure or narrowing of the vocal tract. In contrast, vowels are sounds in which there in no strict closure and the vocal tract is relatively open causing air to escape through the mouth or the nose. Of the two, vowels deserve special attention as they play a crucial role in the generative as well as cognitive processing of language. In the generative aspect, vowels form the nucleus of a syllable. They help in word differentiation and have the potential to convey prosodic information[6]. In the cognitive sphere, the information contained in vowels helps us in remarkable prediction and transformation of complex and infinite sound waves of speech into a convenient and organized array of words, phrases and sentences in little time throughout our lives.[7] In essence, vowels can be termed as the building blocks of a language. There can be as few as three vowels like in the aboriginal languages of Australia to twenty-eight as observed in Weert, a Dutch dialect which holds the record for the maximum number of vowels[8].

Vowel sounds are voiced segments. Voicing or phonation occurs when pulmonic air rises up to the lungs and is encountered by the vocal folds. The elastic vocal folds are in a state of tension as they are stretched by the arytenoid cartilages. When air pressure rising up from the trachea runs into the constriction created by the vocal folds, it causes it to open. Consequently the pressure in the sub-glottal chamber drops as air passes through the glottis and as the vocal folds are elastic in nature this drop in pressure causes them to return to their original position. Pressure is increased voluntarily. The rate at which the vocal folds open and close per second is known as the fundamental frequency. This vibration creates resonances in the air column and the air column also starts vibrating. The rate at which the air column vibrates determines the quality

---

[6]Strange, W. (1999). *Perception of vowels: dynamic constancy*. In J. M. Pickett (Ed.), *The acoustics of speech communication: fundamentals, speech perception theory, and technology* (pp. 153-165). Surry, Maine: Allyn and Bacon

[7] Fry, D.B. (1979). *The Physics of Speech*. (pp.141-142). London: Cambridge University Press

[8] Ladefoged, Peter. (2001). *Vowels and Consonants: An Introduction to the sounds of Languages*. (pp.176) University of California, Los Angeles

of the tone of voice. The pure tone is a mixture of the fundamental frequency and overtones which are harmonics or whole number multiples of natural frequency.

Unlike consonants, vowels are not very easy to describe with precision. They are usually described with reference to part of tongue raised, extent to which the tongue is raised, velum position and shape of the lips. Catford defines vowels as "a class of pulmonic pressure sounds normally voiced, with a maintainable central oral approximant or dorso-domal, or pharyngeal, articulatory channel"(1988:123)[9]. On the basis of these physiological correlates vowels can be distinguished in articulatory terms as front or back, high or low and rounded or unrounded. Almost all vowels can be described on the front-back or high-low criteria but differences in vowel length and quality are present in a language which makes it distinct.

1.4 Acoustic Phonetics: Scope, History and Development

Acoustic phonetics is concerned with the study of the properties of sound waves which are associated with speech sounds. Acoustics is a science which deals with the physical properties of sound. Like most of the natural sciences, phonetics has greatly benefitted by adopting experimental methods. Ohala (1979) observes how experimental methods have accelerated achievements in science. In the context of the language sciences Ohala believes that phonology stands greatly to benefit applying the principles of physics. Studies by Durand (1956); Fant (1972); Stevens (1972); Liljencrants and Lindblom (1972); Lindblom (1975); Jonasson (1972); Ohala (1974,1976, 1977) show how the principles of acoustics have been very instrumental in accounting for sound patterns of various languages[10]. Kent (1997)[11] states that "for most intents and purposes, the acoustic signal is the *sine qua non* of speech."

Investigations on the relations between vowel pitches and the vocal tract cavities had begun as early as in the 1830s in the works of Wheatstone (1837) and Willis (1830). The fact that cavities in the vocal tract act as simple resonators had already been established by Helmholtz (1954) in his experiments over the years. Though initial enquiries had already been made on the nature of speech sounds and their acoustic properties, it was not until the 1940s when major

---

[9] Catford, J.C. (1988). *A practical introduction to phonetics*. (pp. 123) New York: Oxford University Press.

[10] Ohala, J.J. (1979). *The Contribution of Acoustic Phonetics to Phonology*. In Lindblom, B. and Ohman, S. (Eds) *Frontiers of Speech Communication Research.* 355-363 : Academic Press

[11] Kent, R. D. (1997). *The speech sciences*. pp.366. San Diego: Singular Pub. Group.

developments in acoustic phonetics began to take place. The invention of the sound spectrograph marked the beginning of a new era in acoustic phonetic research. Applying the electric circuit analogy to the production of speech sounds, Ralph Potter and his colleagues had developed the sound spectrograph at Bell Laboratories. This was a major development considering the fact that spectral properties such as frequency and intensity along with temporal aspects could now be easily observed, something which in the time of Helmholtz's experiments was a daunting task. The spectrograph played an influential role in the development of Pattern Playback by Cooper and his associates at Haskins Laboratories. Pattern Playback was used to synthesize speech unisng information from spectrographs and it served as major tool for speech perception research.

On the other side of the world in Japan, Chiba and Kajiyama (1942) has also begun their efforts to introduce principles of natural sciences in the study of the language sciences. The idea that the acoustic properties of vowels is determined by the shape of the vocal tract was already proved in Chiba and Kajiyama (1942) who used X-ray imaging and other technologies to measure the area of the three-dimensional shape of the vocal tract. Their seminal work "The Vowel: Its Nature and Structure" published in 1942 contained the seeds of the acoustic theory of speech production which as later elaborated by Fant (1960).

Joos (1948) and Delattre (1951) were first to observe the relations between F1 and F2 of vowels and how they affected vowel positioning in the cardinal vowel chart developed by Daniel Jones. Their observations were consolidated in Peterson and Barney (1952) who demonstrated how formant patterns varied between speakers on the basis of their age and gender while remaining remarkably stable for a speaker.

The acoustic theory of speech production (Fant, 1960) exposes the dynamics of the relation between the vocal tract and the resultant acoustic output. The Source-Filter theory of sound production is a framework which can be used to describe the production of vowels in acoustic terms. Like most sounds, vowels sounds have their source in the vibrations created by the vocal folds. The articulators like the tongue body and lips alter the shape of the vocal tract. This altered shape of the vocal tract results in variations in the dimensions of the resonating cavities consequently changing the amplification and reduction of the sound source across a range of frequencies. In the case of vowels, these changes in resonances create a series of peaks of acoustic energy which reflects as formants on a spectrogram. The location of formant peaks in the frequency range does not occur arbitrarily but is determined in an orderly way by the shape of the mouth when forming the vowel. These formant frequency patterns serve as acoustic cues in speech perception and help in distinguishing between different vowels.

1.5 Acoustic Phonetics in Linguistic Theory

In the development of linguistic theory, acoustic phonetics was, for the first time, introduced in the work of Jakobson, Fant and Halle (1952). It was the first instance when linguistic theory was supported by acoustic notions. Jakobson, Fant and Halle identified the least number of features required to differentiate between utterances present in languages of the world. With the help of sound spectrographs, they defined these features in acoustic terms. They identified twelve binary oppositions (pp 40) and presented their acoustic correlates. The focus was more on acoustic features because of their importance in speech perception.

The next major development in theoretical linguistics where acoustic notions made further inroads was the publication of The Sound Pattern of English (1968) by Chomsky and Halle. Chomsky and Halle (1968) proposed a larger feature set consisting of twenty four binary features for contrasting speech segments based on both articulatory and acoustic properties. The SPE was focused more on explaining the sound patterns in one language and addressing core phonological concerns such as the representation of lexical contrasts, constraints in syllable formation and phonological alterations.

Acoustic phonetics gained further momentum in the 1970s with the works of Fant (1972); Stevens (1972); Liljencrants and Lindblom (1972); Lindblom (1975); Jonasson (1972); Ohala (1974,1976, 1977). Labov (1963,1966) adopted experimental methods and analyzed acoustic parameters such as formant frequencies to explain sociolinguistic issues such as sound change.

The characterization of features using acoustic data received another boost when K.N.Stevens (1972) proposed the Quantal Theory of Speech. Quantal Theory tries to explain why certain sounds are favoured crosslinguistically. He believes that contrasts in a language are due to differences between 'quantal' regions and all quantal areas define contrastive sounds. Stevens observes that the relation between the articulatory mechanisms and the resultant acoustic output is not linear. Using nomograms, Stevens demonstrates the acoustic output when a single articulatory parameter such as the place of constriction is taken into consideration. According to Stevens, there are certain regions, which he calls quantal regions, where changes in articulation do not have serious effect on the speech/acoustic output. He states that these stable acoustic regions are areas where two formants meet each other. This leads him to conclude that [a], [i] and [u] are quantal vowels as they exploit quantal regions and they are present in many languages. However, critics of the Quantal Theory object stating that it does not account for the contrasts which are observed across languages. Moreover, Stevens' theory does not provide sufficient account of the distinctions based on multiple articulatory parameters. The Quantal Theory, thus, does provide some leeway for articulatory sloppiness in speech but it is not deemed to be necessary. K.N. Stevens (1989, 2002, and 2005) and his colleagues are against the arbitrariness of a universal set of features. They believe that the features are result of the interplay between the articulatory features of speech and their acoustic effects.

1.6 Vowel Acoustics

A vowel sound is the combination of different pitches and these overtone pitches give a vowel its distinct quality. The vocal tract acts as an amplifier for different frequencies which are produced every time the vocal cords open and close setting the air in the vocal tract as well as the resonating cavities into vibration. These vocal cord vibrations create harmonics which are high frequency vibrations over and above the fundamental frequency. Depending upon the shape of the mouth, some harmonics are amplified more than the others. Acoustic information about the quality of a vowel can analyzed through its formant structure.

Ladefoged (1975) defines formants as “resonances of the vocal tract.”[12] A vowel is characterized by three formants – F1, F2 and F3. These formants are the result of the different shapes of the vocal tract and are distinct from the fundamental frequency, F0 or pitch, which is determined by the rate of vocal cord vibrations per second. The values of the formants can be obtained when a speech sound is analyzed through a spectrogram. In a spectrogram the formants are reflected as dark bands of acoustic energy.

Formant values are affected by the positions of the articulators such as lips, tongue and jaws. According to Ladefoged (1962), there are three factors which affect all the formant frequencies – “the position of the point of maximum constriction in the vocal tract (which is controlled by the backward and forward movement of the tongue); the size or cross-sectional

[12] Ladefoged, Peter. 1975. 1993 (3rd edn.), 2006 (5th edn.) *A Course in Phonetics*. pp.34. New York: Harcourt Brace, Jovanovich, Inc.

area of the maximum constriction (which is controlled by the movements of the tongue towards and away from the roof of the tongue); and the position of the lips."[13]

It has been noted that there exists an inverse relation between the degree of oral constriction and F1. A high vowel such as /i/ and /u/ are characterized by low F1 values whereas a low vowel such as /a/ is characterized by higher F1 values. F2 values for front vowels such as /i/ are higher while F2 values for back vowels such as /u/ are low. The amount of lip rounding reduces all the formant frequencies as is reflected in the low F1, F2 and F3 values of rounded vowels such as /u/ and /o/ as compared to unrounded vowels like /i/ and /e/ which return higher F1, F2 and F3 values. The characteristic tendencies of the first two formants enable us to distinguish between vowels. The first formant or F1 gives an indication of the open/close dimension as it is observed that open vowels have a high F1 while closed vowels have low F1 values. The second formant or F2 gives an indication of the front/back dimension as front vowels have high F2 while back vowels have low F2.[14]

It must be noted that formant values of vowel sounds are not constant and the reasons for its variability are phonological and physiological in nature. Vowels sounds very rarely occur in isolation. They are in most cases preceded and followed by a consonant sound. The acoustic properties of the vowel sounds are affected by the phonological environment in which they occur. Physiological factors such as age, sex and shape and size of the vocal tract also influence formant values. This can be noticed in the high frequency formants of women and children compared to the low formant frequencies of adult male speakers. However, the acoustic properties of vowels are still crucial in their identification in spite of inconsistencies, as Strange (1999) notes that the acoustic cues in speech perception provided by vowels remains more or less constant.

1.7 Pitch

The perceptual or auditory correlate of the acoustic feature fundamental frequency or F0 is known as pitch. Speech and language, to a major extent, depends upon the fundamental frequency of the vocal cords. Fundamental frequency is the number of times the vocal cords

---

[13] Ladefoged, Peter. 1962. *Elements of Acoustic Phonetics.* pp.104. The University of Chicago Press.

[14] *ibid.*

open and close per second. Pitch of a voice is dynamic and this dynamicity is reflected in the inter-speaker and intra-speaker variations in pitch. Low range of fundamental frequencies can be noticed in men while children's speech is characterized by high range of fundamental frequencies. The range of fundamental frequencies for women is higher than that of men but lower than that of children placing them in the intermediate zone. The average fundamental frequency for men, women and children are 120 Hz, 225 Hz and 265 Hz respectively.[15] Among several factors which affect the pitch of a voice, the crucial determinant is the tension of the vocal cords. Stretched vocal cords produce high pitch. Humans regularly manipulate the tension in the vocal cords which can be observed in the pitch variations in their speech. Another determinant of pitch is the amount of eggressive pulmonic air. Speakers usually apply extra breath force in speech to give the effect of stress which increases the pitch of the voice.

1.8 Vowel Duration

Though in the language under investigation vowel length is not phonemic, an understanding of the temporal aspect of vowels provides some useful insights. Duration of a vowel is essentially the time taken by a speaker to articulate a vowel sound. Vowel sounds can be sustained for long or short periods and this variation in length can be allophonic or phonemic. Lisker (1974) notes that the dependence of the duration of the vowel on two factors: the degree of opening of the vowel[16], and, the nature of the following consonant. According to Lehiste (1970), "the greater length of low vowels is due to the greater extent to the articulatory movements involved in their production"[17]. This statement can be analysed in the light of F1 values, which is associated with the open/close dimension of vowels, to understand the relation between vowel duration and opening.

1.9 Acoustic Space

Acoustic space is a tool which is employed to show how the formant frequencies help to objectively define the vowel space in a language. It helps us to empirically test the hypotheses of

---

[15] Fry, D.B. 1979. *The Physics of Speech*. pp.68.Cambridge: Cambridge University Press.

[16] Peterson, G.- Lehiste, I. (1960) "Duration of Syllable Nuclei in English", *Journal of the Acoustical Society of America* 32: 693-703

[17] Lehiste, I. 1970 *Suprasegmentals*. Pp. 19. MIT Press, Cambridge, Mass.

the Quantal theory and the Dispersion theory. The acoustic space tool helps to arrive at phonological distinctness and also to consolidate notions about vowels.

Dispersion Theory or the Theory of Adaptive Dispersion[18] (Liljencrants and Lindblom 1972, Lindblom1986,1990) was another approach to account for the sound patterns present in a language. The hypothesis of this theory is that in a language, the sounds are selected in a manner which serves to provide the element of maximal, or rather, sufficient perceptual contrast. To test the dispersion hypothesis, empirical methods have to be used. The acoustic space model has to be created to verify the notion of contrast. Liljencrants and Lindblom created such a model by plotting F1 values against F2 values. The perceptual contrast between two vowels was measured as the linear distance between them in mel units. This enabled researchers to fairly predict optimal vowel inventories of various sizes (Disner, 1984).

According to Ladefoged (2001), "the acoustic vowel space can be considered to be an area bounded by the possible ranges for the frequencies of the first two formants."[19] An adherence to a limit or space in the oropharyngeal cavity is observed by Catford (1988) in the production of vowels which defines the acoustic space of vowels in a language. A slight deviance from the space results in the production of an approximant type of sound. This idea of vowel limit or vowels space has influenced the Cardinal Vowel Chart designed by Daniel Jones. Ohala (1999) says that vowels are classified in terms of an 'abstract' vowel space which is represented by a four sided figure known as the 'Vowel Quadrilateral'. Vowel Quadrilaterals can be used to objectively represent the extent of the vowel space.

1.10 Some studies

There are numerous studies which have adopted the concept of acoustic space and formant analysis in areas of phonetics, language pedagogy (Kewley-Port et.al. 1996), language pathology (Kent, R.D and Vorperian, H.K. 2007), sociolinguistic research (Labov 1966; Clopper, Pisoni and deJong, 2005 ; Narang,V. and Misra,D. 2010) and speech technology.

---

[18] Lindblom,B. 1989. *Phonetic Universals in Vowel System*, In J. Ohala &J.Jaeger (Eds)Experimental Phonology, 13-44, New York: Academic Press

[19] Ladefoged, Peter. 2001. *Vowels and Consonants: An Introduction to the sounds of the Languages*.pp.39 University of Californnia, Los Angeles.

Kewley-Port et. al. (1996) adopt acoustic analysis of vowels to demonstrate its applicability in language pedagogy, more specifically in L2 learning. Using acoustic data of American English vowels produced by Japanese speakers, the authors state show the variations in vowel intelligibility depending on the vowels present in the native language or L1.[20]

Vorperian and Kent (2007) investigate relation between developmental changes in the vocal tract anatomy and its impact on the acoustics of speech.[21] This study uses formant specification to establish a systematic relationship between formant specification and vowel articulation. It is well known that the oral and pharyngeal cavities which constitute the vocal tract of an individual go through several changes in terms of its shape and its size in the course of maturation. Using imaging methods such as magnetic resonance imaging (MRI) and computed tomography (CT) to demonstrate changes in the anatomy of the vocal tract, the authors provide an account of the development of vowel space in males and females in the course of development from infancy to adulthood. The primary data for the study were the formant frequencies and vocal fundamental frequency observed in the vowels of both male and female speakers and speakers of various age groups.

More recently, Narang,V and Misra,D. (2010) conducted an empirical study on the basis of data collected from eight Thai speakers, four male and four female, to determine the acoustic space of Bangkok Thai. The authors also attempt to examine the durational contrast and centralization of vowels in the language.[22] Thai is a tonal language with five contrasting tones – mid, low, falling, high and rising. The data collected was analyzed to study F1 correlation with the F0 and the correlation of F3 with F2 and F1. Though the study was conducted on a small database, the results reveals that durational contrast was reflected more in the case of peripheral vowels such as / i, u, a / and gradually decreasing to centralized vowels. The authors note that the use of mid/level tone with all the 18 vowels shows that F0 values are inversely proportional

[20] Kewley-Port, et.al. (1996). *Intelligibility and Acoustic Correlates of Japanese Accented Englsih Vowels.* 4th ICSLP. Philadelphia. USA.

[21] Kent, Ray. D. & Voroperian, Hauri K. 2007. *Vowel Acoustic Space development in Children: A synthesis of Acoustic and Anatomical data.* Journal of Speech, Language and Hearing Research Vol.50. pp. 1510-1545 December 2007.

[22] Narang, V. and Misra, D.(2010). Acoustic Space, Duration and Formant Patterns in vowels of Bangkok Thai. *International Journal on Asian Language Processing 20(3): 123-140*

to F1. The acoustic space reflects no remarkable differences between short and long vowels as there is no noteworthy difference in their F1 or F2 values but the two peripheral vowels, /i/ and /a/, which show maximal durational contrast are placed differently in the acoustic space. The authors observe that /a:/ is more open than /a/ and /i:/ is more front and high than /i/. On the correlation of F3 with F2 and F1, the authors observe that F3 is inversely proportional to F1 if the front and the back vowels are examined separately. Lower F3 values were observed for back vowels and higher values were observed for their front counterparts.

Application of acoustic methods in sociolinguistics has provided great insights to account for the dialectal variations observed in languages. From Hagiwara (1997) we can assume that languages are constantly changing and vary considerably by geographic location[23]. According to Carver (1998), a dialect is "a variety of language distinguished from other varieties by a set of grammatical, phonetic and lexical features [24](pp.5). Even though syntactic and lexical properties of a language are considered as the core parameters in the identification of a dialect, researchers have commonly focused on the phonetic differences, especially in the context of dialects of American English (Clopper and Pisoni, 2004a, 2004b, 2006, 2007; Labov,1991 ; Clopper, Pisoni and deJong, 2005).

Clopper and Pisoni (2004b) have examined several acoustic measures to identify factors thath might be used to distinguish regional dialects across speakers of American Englsih. They find that features such as fricative voicing and duration, rhotacization, backness, diphthongization are all found to be very significantly depending on the regional dialect of the speaker.

Jacewicz, Fox and Salmons (2007a) also note how the differences in the rate and magnitude of the vowel formant frequency change, vowel duration and a speakers acoustic vowels space account for the regional variations in the context of American English. According to Clopper and Pisoni (2004a), vowels are majorly involved in the perceptual differences among dialects. Jacewicz, Fox and Salmons (2007b) have used vowel quadrilaterals to show significant differences among the Northern, Southern and Midland varieties of American English. They also

[23] Hagiwara, R. (1997). Dialect variation and formant frequency: The American English vowels revisited. *The Journal of the Acoustical Society of America, 102,* 655-658.

[24] Carver, C. M. (1998). English dialectology and the linguistic atlas. In M. Linn (Ed.), *Handbook of dialects and language variation* (2nd ed., pp. 5-28). San Diego, CA: Academic Press.

report that while the exact values of formant frequencies differ among dialects, speakers of different dialects seem to use a similar amount of space when producing vowels.

Labov (1991, 1998) says that dialects are formed by the systematic changes in vowel production. The production of vowel patterns and their usage are greatly influenced by various factors such as acceptance in society, culture, geographical location, educational and economic benefits. Traditionally, the patterns of vowel production which cause differences in dialects can be described in terms of chain shifts, mergers and changes in the acoustic vowel space.
Chain shift occurs when formant frequencies of many values systematically change while each vowel maintains its perceptual distinctness. In phonetics, mergers take place when two vowels combine to form a single phonemic category. Two vowels become indistinguishable, both perceptually and acoustically. Mergers often initiate chain shifts because when two vowels combine, an opening is created in the vowel system which allows a new vowel to take that space.

1.11 Pokharel's generalizations

Though an impressionistic account of the location of vowels in a cardinal chart had already been provided by Bandhu (1968, 1973), the first attempt to locate the vowels in the vowel quadrilateral in the form of a formant chart can be found in Pokharel (1989) [25]. His doctoral thesis entitled *Experimental Analysis of Nepali Sound System* was a pioneering study on the sound system of Nepali using experimental methods. His study was conducted with data collected from nine informants from various parts of midland Nepal.

Pokharel's generalizations on vowels on the basis of formant analysis can be listed as follows:

a. Pokharel states that [i] and [e] are front vowels while [ʌ],[a], [o] and[u] are back vowels. According to him, the vowel [ʌ] is also a back vowel though traditionally it could be considered to be a central vowel phonetically but it is a short variant of the vowel [a] and since [a] us is the backmost vowel in the vowel quadrilateral, [ʌ] is also considered to be a back vowel.

[25] Pokharel, Madhav Prasad. 1989. *Experimental analysis of Nepali sound system*. Ph.D. dissertation, University of Pune

b. Back high vowel [u] is fronter than the round back non high vowel [o]. Similarly[a] which is low back non round low tense vowel in fronter than low back non round low tense vowel [ʌ]. The tense high and low back vowels are fronter than their non tense counter parts on the axis of rounding.
c. Acoustic space formed by vowels of the open syllable is greater than those formed by vowels of the closed syllable.
d. Open syllable vowels are more tensed than closed syllable vowels.
e. The formant chart suggests that rounding of vowels in Nepali is related to the distance of the vowel from the point of origin.
f. Back round vowels like [u] and [o] are lower than the corresponding front vowels such as [i] and [e] in the case of closed syllables.
g. Progression from [i] to [u] reveals than front vowels reflect increasing F1 and decreasing F2 while the back vowels show diminishing F1.
h. Similarly in progression from [i], [e], [a],[ʌ], [o] to [u] the round vowels reflect steadily falling F2.
i. For front vowels the difference between F2 - F1 is greater that the difference between F3-F2. For back vowels the value of F2-F1 is less than the value of F3-F2.
j. The value of F3- F1 signifies quantal vowels. They are reported to be least for the central vowel [ʌ] and it gradually increases as we move to the left or right and is at its highest at the ends. Pokharel notes (p.60) that from [ʌ], slowly decreasing value of F3-F1 denotes progression towards the front vowels while the increasing value marks progressions towards the back vowels.
k. The value of F3-F1 is lowest for a low vowel signifying a direct correlation between the difference of the third and the first formants and the height of the vowel.
l. The front vowels have higher F2 than the back vowels.

In this present study, only closed syllabic words have been selected for elicitation and analysis.

1.12 Scope and Objectives

In discussing the scope of this dissertation, it is important to note that a comprehensive study on the sound system of a language entails several aspects such as sound production, its articulation, its transmission and its perception. Consonants, vowels, liquid and glides form the sound system of languages across the world and an ideal phonetic description of the sound system of a language would have to account for the articulatory mechanisms, acoustic features and auditory effects related to them. This study, however, has its scope delimited to the peripheral oral vowel sounds of Nepali of the Darjeeling variety which occur in word-medial positions as the subject matter for investigation and acoustics being the domain in which they are investigated.

Articulatory features provide a very general classification of vowels. The space in which these articulations take place is not uniform for all languages. Languages use this space differently in order to maintain maximum perceptual contrast[26]. In order to consolidate our notions on vowels they need to be quantified. Hence, the primary objectives of this study are:

1. To provide an acoustic description of the peripheral vowels of Nepali of the Darjeeling variety.
2. To determine the acoustic space for the peripheral vowels

The study is centered on some core parameters on the basis of which observations are made. They can be listed as follows:

a. Acoustic space and formant analysis of Nepali vowels.
b. Durational contrast.
c. Correlation between F1 and pitch.
d. Correlation of F3 with F2and F1

1.13 Significance of this study

There has been a significant amount of research conducted on the sound system of Nepali over the past few decades, the experimental approach has hardly been used. Experimental methods were first adopted by Poon and Mateer (1985) to study the effect of voice onset time on voicing and aspiration. In Pokharel (1989), we find the first elaborate description of the acoustic properties of the Nepali sound system. Recently, Khatiwada (2009) also adopted experimental methods to phonetically describe the sounds in Nepali. These studies, however, have been

---

[26] Lindblom,B. (1989). *Phonetic Universals in Vowel System*, In J. Ohala &J.Jaeger (Eds)Experimental Phonology, 13-44, New York: Academic Press

conducted on the basis of voice data collected from Nepalese[27] speakers. Though Nepali is the official language of republic of Nepal, it is also one of the languages which enjoys constitutional status since it was included in the Eighth Schedule of the Indian Constitution following the 71st Amendment Act of 1992. There are an estimated 2,871,749 speakers of Nepali in India, as per the Census of India 2001, half of which reside in the Darjeeling district of West Bengal. However, there are no experimental studies on the variety of Nepali spoken in India. This study is the first to provide an understanding regarding the properties of vowel sounds of this particular regional variety using experimental approach. The implications of the findings are immense considering its application in speaker identification, language pedagogy, language pathology and accounting for variation observed in languages.

1.14 Organization of this dissertation

This chapter has provided the reader with an overview of the language, the area where it is spoken along with social and demographic information and an account of the existing body of literature on the various issues related to the topic. The next chapter on methodology describes the various data elicitation and analytical procedures adopted while conducting this study. Chapter 3 presents the analysis of data along with some observation. Chapter 4 presents the conclusion and discusses future projections.

[27] Nepalese is the term used to refer to citizens of Nepal.

CHAPTER 2

METHODOLOGY

2.1 Introduction

The present study on vowel quality is an empirical study based on primary sources of quantitative data and spectrographic analysis of speech sounds. The study will attempt to analyze the formant patterns and the correlations observed in Nepali vowels of the Darjeeling variety to provide a detailed acoustic description. The notion of acoustic space will be used as a major tool in observing their organization in the vowel space which would further aid in consolidating the articulatory notions about vowels of this particular regional dialect with respect to their position in the vowel chart. Results will be useful reexamining the notions present in existing literature as found in Pokharel (1989) and Khatiwada (2007). Conforming to the quantitative-experimental nature of the research, the data present in literature will be used to serve as control data.

This chapter on methodology discusses the data elicitation methods and analytical procedures used to draw observations for this study. The chapter ends with a brief note on the software tools used.

2.2 Aims and Objectives

The main objectives of this study are:

3. To provide an acoustic description of the vowels of Nepali of the Darjeeling variety.
4. To determine the acoustic space for peripheral vowels.

In order to meet the objectives outlined above, certain core parameters are analyzed to facilitate this study. They can be listed as follows:

e. Formant analysis
f. Acoustic space.
g. Durational contrast.
h. Correlation between F1 and pitch.
i. Correlation of F3 with F2and F1

2.3 Hypothesis

This study provides a descriptive account of the acoustic properties of vowels of Nepali as it is spoken by the residents of the Darjeeling district of West Bengal. The parameters on the basis of which they are described are their formant frequencies and the correlations which exist between them. An account of the duration of these vowels is also provided. In addition, this study also attempts analyze the results in the light of the Dispersion Theory and the Quantal Theory which explain why certain sounds are preferred across languages.

2.4 Steps and Procedures

2.4.1 Data Elicitation

The core methodology applied for this study can basically be divided into two parts – data elicitation and analytical procedures. Data for this study is elicited and analyzed in a systematic manner beginning with the identification of vowel phonemes on the basis of minimal pairs test; compiling a word list with the vowel phonemes in the initial, medial and final position; identification of speakers; recording of voice samples. The analysis is facilitated through spectrographic analysis; data tabulation; and formant plotting. To determine the acoustic space, six peripheral vowels are investigated.F1, F2 and F3 readings are used to describe the characteristics of the vowel phonemes. For the purpose of the present study, the average of the steady state formants for each vowel will be calculated.

2.4.1.1 Identification of Nepali Vowel Phonemes

The following table outlines the vowels of Nepali.

Table 2.1 Nepali Vowel Chart

	Front	Central	Back
high	i		u
Close mid	e		o
Open mid			ʌ
open		a	

There are 6 oral vowels and 5 nasalized vowels. Out of the 6 oral vowels, [i] and [e] are front vowels while [u], [o], [a] and [ʌ] are back vowels. Khatiwada (2009) states that all vowels except [o] have a corresponding nasal counterpart which is distinctive in nature. This view has also been shared by Pokharel (1989,p.34). Stress, pitch and length are not phonemic in Nepali unlike nasalization and intonational pitch difference.

The fact that the six oral vowels constitute the contrasting vowels can be conclusively established using the minimal pair test which is illustrated in tables 2.2 and 2.3.

Table 2.2 Minimal pairs in the context of cVcv.

Vowel	Word	Gloss
/i/	/tsili/	Having bitten by a mosquito or stung by a bee. –i is a perfective marker
/e/	/tseli/	Female disciple, devotee or follower
/a/	/tsali/	Having driven a vehicle, walked by foot, rowed a boat; a female with an attitude in colloquial
/ʌ/	/tsʌli/	Continuous playful activity; moving; blowing like the wind
/o/	/tsoli/	Blouse worn by Nepali women
/u/	/tsuli/	Filled to the brim usually of a vessel, mountain top.

Table 2.3 Minimal pairs in the context of cVcv

Vowel	Word	Gloss
/i/	/t̪iri/	paid –PERFECTIVE.
/e/	/t̪eri/	your –FEM

/a/	/t̪ari/	strain, sieve –PERF
/ʌ/	/t̪ʌri/	cross or swim across-PERF
/o/	/t̪ori/	mustard seed
/u/	/t̪uri/	finish or complete –PERF

2.4.1.2 Vowel Nasalization

Nepali vowels can be nasalized and they are distinctive. Barring back vowel [o], there exists a phonemic contrast between the five oral vowels and their nasalized versions as is illustrated in the table 2.4 below.

Table 2.4 Phonemic contrasts between oral and nasal vowels.

Vowel	Oral	Gloss	Nasalized	Gloss
[i]	/i/	these	/ĩ/	right here
[e]	/d̪ekʰe/	(they) saw	/d̪ekʰẽ/	(I) Saw
[a]	/kati/	having cut	/kãti/	nail
[ʌ]	/gʌu/	sing	/gʌ̃u/	village, wheat
[u]	/d̪ʰua/	Make somebody wash something	/d̪ʰũa/	smoke

Though no phonemic contrast exists between the oral and nasalized variants of the phoneme /o/, there are a few words like /hõco/ - low, /sõts/ - thought, /dʰõɽe/ - a variety of bamboo, etc which can be found in the language. Hence for the purpose of analysis, the token /kʰõts/ has been recorded.

2.4.1.3 Diphthongs

According to Ladefoged (2001), diphthongs are "sounds that have a change in vowel quality during the course of a syllable." Pokharel (1989: 37–38) identifies ten diphthongs in Nepali. They are [ui], [ei], [oi], [ʌi], [ai],[iu], [eu], [ou], [ʌu] and [au]. In the Darjeeling variety of Nepali examples of all the ten diphthongs, except one [ou], can be observed. The following table lists some examples.

Table 2.5 Diphthongs

/ui/	/d̪uita/ - ‘two’
	/kuiyeko/ - ‘rotten’
	/kuina/ - ‘elbow’
/ei/	/t̪ei/ - ‘that’
	/kei/ - ‘some’
/oi/	/coita/ - ‘fragment’
	/koila/ - ‘coal’
/ʌi/	/ʌina/ - ‘mirror’ or ‘glass’
	/bʌɪni/ - ‘younger sister’
	/pʌit̪ala/ - ‘sole of the feet’
/ai/	/mait̪a/ - ‘a girls parent’s house’
	/sait̪/ - ‘a special day or time chosen for religious or cultural practices’
	/saĩla/ - ‘third eldest brother or son’
/iu/	/iu/ - ‘stone embedded on a ring’
	/jiud̪o/ - ‘living or alive’
	/ciura/ - ‘flattened rice’
/eu/	/euta/ - ‘one’
	/deuta/ - ‘God’
	/beura/ - ‘behaviour’ or ‘manners’
/ʌu/	/ʌula/ - ‘may come’
	/ʌ̃ula/ - ‘fingers’ or ‘toes’
	/tʌuko/ - ‘head’
	/pʌuɽi/ - ‘swimming’
/au/	/au/ - ‘come’
	/ghau/ - ‘wound’
	/mau/ - ‘mother’ (usually of an animal newborn)
	/cauri/ - wrinkle

Though Pokharel (1989, p.65) gives an example of a word with the vowel sequence [ou] as /dhou/ meaning "Wash !", this word is generally not observed in the Darjeeling variety of Nepali. For the same token to have the same meaning, the word /d̪ʰu/ or /d̪ʰuwʌ/ is used indicating w-insertion.

2.4.2 Preparation of the word list

For a better understanding of the phonetic behavior of the vowels in Nepali of the Darjeeling variety, a word list is compiled where the vowel occurs in initial, medial and final word positions.

Table 2.6 Word List containing vowel phonemes in Initial, Medial and Final positions.

Vowel	Word Initial	Gloss	Word Medial	Gloss	Word Final	Gloss
/i/	/it̪ru/	small	/pip/	Pus	/ keti/	Girl
/e/	/euta/	one	/tek/	Step or stamp on something-IMP	/d̪ekʰe/	saw (past)
/a/	/ayo/	came	/kat/	Cut -IMP	/pʌkka/	surely, firm
/ʌ/	/ʌrko/	another	/pʌt/	Onomatopoeic root for a manner of breaking	/sukʰʌ/	Prosperity
/o/	/oɖal/	cave	/tok/	Bite! -IMP	/oralo/	downhill
/u/	/umkyo/	escaped	/kut/	Hit! Beat! -IMP	/goru/	ox

The table above lists the vowels in initial, medial and final word positions. Words in the medial position are monosyllabic and they begin as well as end in voiceless stop consonants and hence, they present a uniform context of their occurrence. The words in the medial position are chosen for elicitation and acoustic analysis.

2.4.3 Participants

Empirical-quantitative research methods are usually applied to cross-sectional studies. This study may be deemed only as a partial cross-sectional study and a total of 11 participants have been selected for the purpose of data elicitation.

The participants for this study are Nepali speaking residents of the Darjeeling district of West Bengal in India currently pursuing various degrees from Jawaharlal Nehru University, New Delhi. Ideally, data from a monolingual speaker would have best served the purposes of this study but in an era of globalization, some bilingualism and multilingualism can be observed almost everywhere due to their economic and educational incentives. However, careful attention has been given to identify informants on the basis of their residential tenure in the area, level of exposure to other languages, similar educational qualifications and socio-economic status and gender representation. The average age for all participants is 24.18 years. Table 2.7 presents the list of participants who participated in the study.

Table 2.7 List of participants.

Participant	Age	Gender	Education	Mother tongue
SS	26	M	Ph.D	Nepali
PL	26	M	M.Phil	Nepali
PR	22	M	M.A.	Nepali
JY	26	M	M.Phil	Nepali
BS	26	M	M.Phil	Nepali
DG	22	F	M.A.	Nepali
LL	27	F	Ph.D	Nepali
ML	21	F	M.A.	Nepali
PP	24	F	M.A.	Nepali
PTP	23	F	M.A.	Nepali
TB	23	F	M.A.	Nepali

2.4.4 Recording

This study on the acoustic properties of vowels of Nepali as spoken in the Darjeeling region of India is conducted on the basis of voice data collected from 10 people whose mother tongue is Nepali. They are all students pursuing different academic degrees from various departments of Jawaharlal Nehru University, New Delhi. All the informants have completed their Senior Secondary education from the district of Darjeeling. The informants were asked out to read out a list of words which was written in the Devanagiri script which is used in Nepali orthography. A total of eight words were read out by each informant with each token being repeated six times. At the end of recording, there were a total of 528 voice samples (8 vowels * 6 repetitions * 11 participants).

The recording of voice samples was done in a noise-free environment at the Language Lab Complex using a Sony ICD-UX513F/B Digital Voice Recorder. In order to reduce sound-to-noise ratio, a Sony DR-130 headphone with microphone was attached to record the voice samples. All the sounds were recorded in LPCM mode and quantized at a sampling frequency of 44.1 kHz. Goldwave[28] , a professional digital audio editor, was used to remove any ambient noise and to save the audio file in .wav format.

Each recorded sample is labeled according to a pattern. The first two characters signify the initials for the name of the informant. The next two characters represents the age of the informant. The next character signifies the gender. This is followed by the vowel sound and the number at the end signifies the first, second or third repetition and so on. Therefore, a voice sample labeled SS26Mi1 is recorded from informant SS who is male and 26 years of age. The recorded sample is for the vowel /i/ and is the first repetition.

2.5 Analytical Procedures

This section discusses the various steps involved in analyzing and compiling data for this study. The main analytical procedures involve –

1. formant analysis,
2. data tabulation and plotting, and
3. acoustic space design

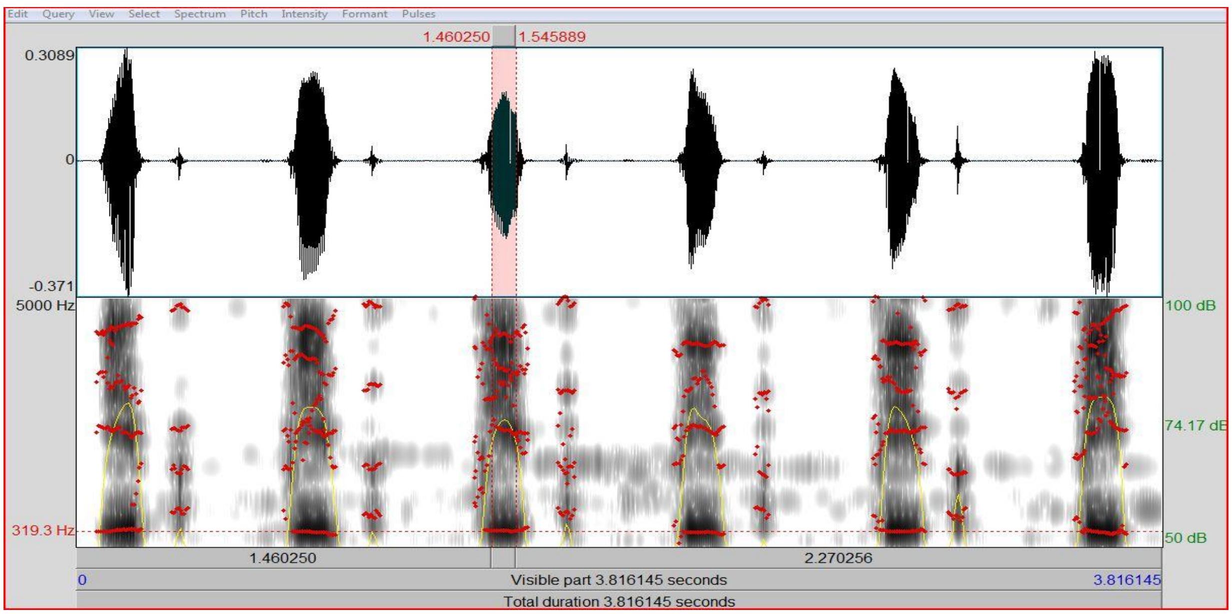
The primary data for this study is the voice samples recorded from eleven native speakers of the Darjeeling variety of Nepali. These voice samples were analyzed using PRAAT- a speech analysis software- keeping in mind the various parameters outlined earlier in this chapter. The readings obtained were then tabulated using Microsoft Excel 2007. The plotting of formants was also carried out using Microsoft Excel 2007. A brief discussion on the three main analytical procedures is given below.

[28] GoldWave v5.67 released on 21st March 2012 free evaluation version downloaded from http://www.goldwave.com

2.5.1 Formant Analysis

Once the voice samples were recorded and saved in the .wav format, they are individually analyzed using PRAAT. Since each word containing the vowel sample was repeated six times by each informant, six recordings of the same utterance had to be analyzed for F0, F1, F2 and F3 values of the vowels. For formant analysis, readings of steady state formants are taken and their average is calculated. In the case of duration, the entire length of the vowel was analyzed and its duration is duly noted. For pitch readings, the pitch contour is analyzed for pitch at the start and the end of selection. The readings obtained are then systematically tabulated using Microsoft Excel 2007. Given below is the spectrogram for the word /pip/.

Figure 2.1 Spectrogram for SSM26 /pip/



The average formant values and durational properties of six utterances of the vowel /i/ recorded from SS26M are presented in table 2.8.

Table 2.8 Formants and Duration for SS26Mi

Vowel		F1	F2	F3	-(F2-F1)	-F1	F0	Duration
Avg /i/1		309.27	2308.09	3379.59	-1998.82	-309.27	158.84	0.15
Avg /i/2		287.40	2278.62	2944.95	-1991.23	-287.40	139.06	0.14
Avg /i/3		295.88	2264.54	3246.67	-1968.67	-295.88	146.78	0.13
Avg /i/4		283.14	2263.01	3253.51	-1979.88	-283.14	137.77	0.13
Avg /i/5		297.09	2259.21	3228.58	-1962.12	-297.09	147.52	0.11
Avg /i/6		294.34	2321.31	3267.09	-2026.97	-294.34	129.32	0.11
Total Avg /i/		**294.52**	**2282.46**	**3220.06**	**-1987.95**	**-294.52**	**143.21**	**0.13**

Similarly, average formant values for all six repetitions of long and short oral vowels were tabulated in the manner as shown in table 2.9.

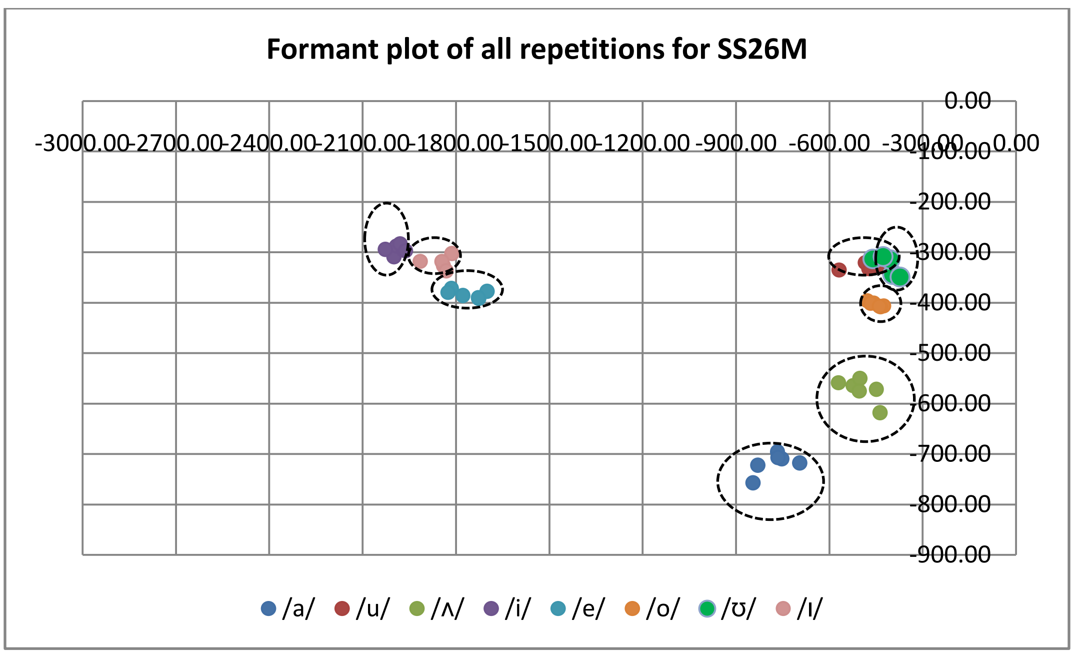
Table 2.9 Formants and Duration of all vowels for SS26M

Vowel		F1	F2	F3	-(F2-F1)	-F1	F0	Duration	F0 (Start)	F0 (End)
Avg /a/1		722.20	1552.61	1878.28	-830.41	-722.20	127.95	0.20	127.14	128.09
Avg /a/2		709.54	1462.68	2248.99	-753.14	-709.54	127.96	0.15	129.16	127.94
Avg /a/3		717.76	1413.20	2148.76	-695.44	-717.76	127.13	0.15	125.31	128.78
Avg /a/4		695.84	1463.18	2177.93	-767.33	-695.84	130.58	0.17	136.92	130.29
Avg /a/5		757.09	1603.21	2032.24	-846.12	-757.09	133.40	0.14	140.90	133.17
Avg /a/6		707.40	1473.00	2219.35	-765.60	-707.40	123.85	0.12	132.57	114.65
Total Avg /a/		**718.31**	**1494.65**	**2117.59**	**-776.34**	**-718.31**	**128.48**	**0.15**		
Avg /u/1		336.41	746.43	2477.43	-410.01	-336.41	175.75	0.15	161.86	183.06
Avg /u/2		332.41	805.60	2516.84	-473.19	-332.41	167.84	0.18	154.15	177.35
Avg /u/3		327.22	759.72	2371.26	-432.50	-327.22	163.22	0.14	152.87	169.51
Avg /u/4		320.55	805.12	2422.06	-484.56	-320.55	161.09	0.15	147.90	173.67
Avg /u/5		332.88	801.47	2393.24	-468.58	-332.88	162.02	0.13	155.79	163.31
Avg /u/6		335.29	904.06	2307.68	-568.77	-335.29	140.37	0.13	154.14	124.55
Total Avg /u/		**330.79**	**803.73**	**2414.75**	**-472.94**	**-330.79**	**161.72**	**0.15**		
Avg /ʌ/1		618.57	1056.12	2494.86	-437.55	-618.57	139.16	0.11	139.83	139.08
Avg /ʌ/2		558.77	1129.80	2590.66	-571.03	-558.77	126.34	0.10	128.36	127.52
Avg /ʌ/3		564.47	1088.71	2498.36	-524.25	-564.47	130.44	0.10	130.20	130.95
Avg /ʌ/4		550.13	1052.05	2358.78	-501.93	-550.13	125.92	0.10	127.07	125.67
Avg /ʌ/5		575.45	1079.83	2211.85	-504.38	-575.45	130.45	0.10	124.93	131.28
Avg /ʌ/6		572.09	1021.56	2506.39	-449.47	-572.09	121.54	0.09	125.76	114.75
Total Avg /ʌ/		**573.25**	**1071.35**	**2443.48**	**-498.10**	**-573.25**	**128.98**	**0.10**		
Avg /i/1		309.27	2308.09	3379.59	-1998.82	-309.27	158.84	0.15	151.43	166.20
Avg /i/2		287.40	2278.62	2944.95	-1991.23	-287.40	139.06	0.14	139.79	133.22
Avg /i/3		295.88	2264.54	3246.67	-1968.67	-295.88	146.78	0.13	145.08	147.31
Avg /i/4		283.14	2263.01	3253.51	-1979.88	-283.14	137.77	0.13	139.14	134.73
Avg /i/5		297.09	2259.21	3228.58	-1962.12	-297.09	147.52	0.11	147.17	135.10
Avg /i/6		294.34	2321.31	3267.09	-2026.97	-294.34	129.32	0.11	142.17	113.46
Total Avg /i/		**294.52**	**2282.46**	**3220.06**	**-1987.95**	**-294.52**	**143.21**	**0.13**		
Avg /e/1		391.41	2118.20	2693.87	-1726.79	-391.41	135.56	0.12	132.11	134.51
Avg /e/2		377.16	2076.90	2982.11	-1699.73	-377.16	132.96	0.18	133.37	138.40
Avg /e/3		371.41	2185.70	3172.30	-1814.29	-371.41	132.80	0.19	130.24	134.42
Avg /e/4		379.57	2204.79	3078.63	-1825.23	-379.57	131.34	0.15	126.00	135.18
Avg /e/5		385.52	2162.80	2999.61	-1777.28	-385.52	131.99	0.16	132.33	130.57
Avg /e/6		390.13	2118.14	3069.75	-1728.01	-390.13	128.14	0.14	136.39	124.91
Total Avg /e/		**382.53**	**2144.42**	**2999.38**	**-1761.89**	**-382.53**	**132.13**	**0.16**		
Avg /o/1		406.44	832.07	2418.01	-425.63	-406.44	157.36	0.18	143.75	163.00
Avg /o/2		396.30	874.30	2436.13	-478.00	-396.30	141.52	0.15	137.67	148.37
Avg /o/3		400.79	859.02	2458.86	-458.23	-400.79	152.51	0.15	143.22	162.87
Avg /o/4		401.37	868.96	2429.52	-467.59	-401.37	137.84	0.14	134.11	152.50
Avg /o/5		408.18	843.74	2500.32	-435.56	-408.18	142.87	0.13	136.92	155.69
Avg /o/6		407.15	846.43	2468.63	-439.28	-407.15	124.36	0.12	141.08	97.58
Total Avg /o/		**403.37**	**854.09**	**2451.91**	**-450.72**	**-403.37**	**142.74**	**0.15**		
Avg /ʊ/1		344.04	741.10	2536.08	-397.06	-344.04	153.78	0.07	153.89	152.92
Avg ʊ/2		313.55	773.99	2485.66	-460.45	-313.55	148.47	0.08	154.97	138.40
Avg /ʊ/3		314.74	719.15	2433.17	-404.41	-314.74	147.54	0.07	150.95	142.74
Avg /ʊ/4		308.60	736.16	2446.09	-427.56	-308.60	147.77	0.07	152.39	139.11
Avg /ʊ/5		349.38	722.55	2684.92	-373.17	-349.38	152.22	0.08	161.96	134.47
Total Avg /ʊ/		**326.06**	**738.59**	**2517.18**	**-412.53**	**-326.06**	**149.96**	**0.07**		
Avg /ɪ/1		317.79	2233.09	2743.36	-1915.30	-317.79	164.54	0.07	172.36	168.05
Avg /ɪ/2		326.53	2167.02	2471.30	-1840.49	-326.53	161.07	0.07	165.58	167.09
Avg /ɪ/3		302.18	2115.43	2613.78	-1813.25	-302.18	156.49	0.05	163.56	158.49
Avg /ɪ/5		318.33	2163.83	2551.69	-1845.50	-318.33	155.70	0.06	154.79	164.44
Avg /ɪ/6		336.77	2168.22	2531.13	-1831.45	-336.77	149.73	0.07	164.77	144.47
Total Avg /ɪ/		**320.32**	**2169.52**	**2582.26**	**-1849.20**	**-320.32**	**157.51**	**0.06**		

2.5.2 Acoustic Space Design

To determine the acoustic space, eight peripheral oral vowels, long and short, are investigated.F1, F2 and F3 readings are used to describe the characteristics of the vowel phonemes. For the purpose of the present study, the averages of the steady state formants for each vowel are calculated. The quality of a vowel, in terms of its height, can be judged from F1. The relative positions of F1 and F2 values reflect the frontness or the backness of a vowel. F2 alone cannot adequately characterize frontness or backness so the difference in values between F2 and F1 is taken into consideration. Front vowels have higher values of F2-F1 while back vowels have lower values of F2-F1. The acoustic space can be determined by plotting F1 values against F2-F1 values. Negative values are plotted so that the resultant graph closely resembles the cardinal vowel chart. This method of plotting was initially suggested by Ladefoged (1993) but later in Ladefoged (2001) he suggests a simple plotting of F1 against F2. Katrina Hayward (2000)[29] also recommends plotting F1 against F2 as she considers the plotting of F1 against F2-F1 values unsatisfactory because of its effect on the placing of central vowels.[30] Figure 2.2 represents the formant plot for all oral vowels for SS26M.

Figure 2.2 Formant plot for all vowels for SS26M



[29] Hayward, Katrina (2000) *Experimental Phonetics*, Harlow, UK: Pearson.

[30] This study will adopt the negative F1values against negative values of F2-F1 plots as only the peripheral vowels will be analyzed.

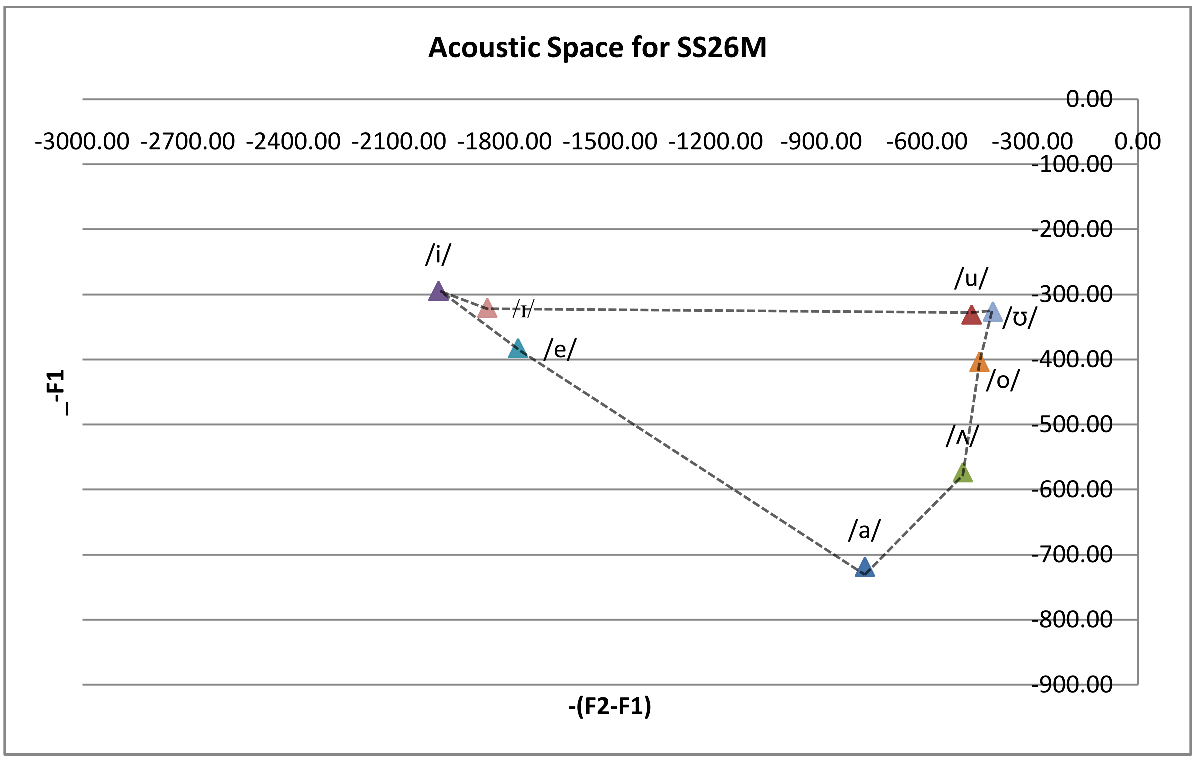
In a manner similar to the one adopted for the investigation of /i/ for SS26M, formant values for all the other peripheral vowels occurring in the word-medial position are tabulated and then their averages are calculated for the three repetitions for all the informants. The table below lists the average formant values for the eight long and short vowels of Nepali recorded from SS26M. The average values of the six repetitions for the oral vowels are then compiled and the overall average for every vowel is calculated. Table 2.10 lists the overall average of all six peripheral vowels of SS26M.

Table 2.10 Overall average formant values and duration for SS26M

Vowel	F1	F2	F3	-(F2-F1)	-F1	F0	Duration
Total Avg /a/	718.31	1494.65	2117.59	-776.34	-718.31	128.48	0.15
Total Avg /u/	330.79	803.73	2414.75	-472.94	-330.79	161.72	0.15
Total Avg /ʌ/	573.25	1071.35	2443.48	-498.10	-573.25	128.98	0.10
Total Avg /i/	294.52	2282.46	3220.06	-1987.95	-294.52	143.21	0.13
Total Avg /e/	382.53	2144.42	2999.38	-1761.89	-382.53	132.13	0.16
Total Avg /o/	403.37	854.09	2451.91	-450.72	-403.37	142.74	0.15
Total Avg /ʊ/	326.06	738.59	2517.18	-412.53	-326.06	149.96	0.07
Total Avg /ɪ/	320.32	2169.52	2582.26	-1849.20	-320.32	157.51	0.06

The average values are then plotted on a scatter chart with negative F2-F1 values on the X-axis and negative F1 values on the Y-axis. The resultant graph as show in Figure 2.2 is the acoustic space for the peripheral oral vowels of SS26M.

Figure 2.2 Acoustic Space for SS26M



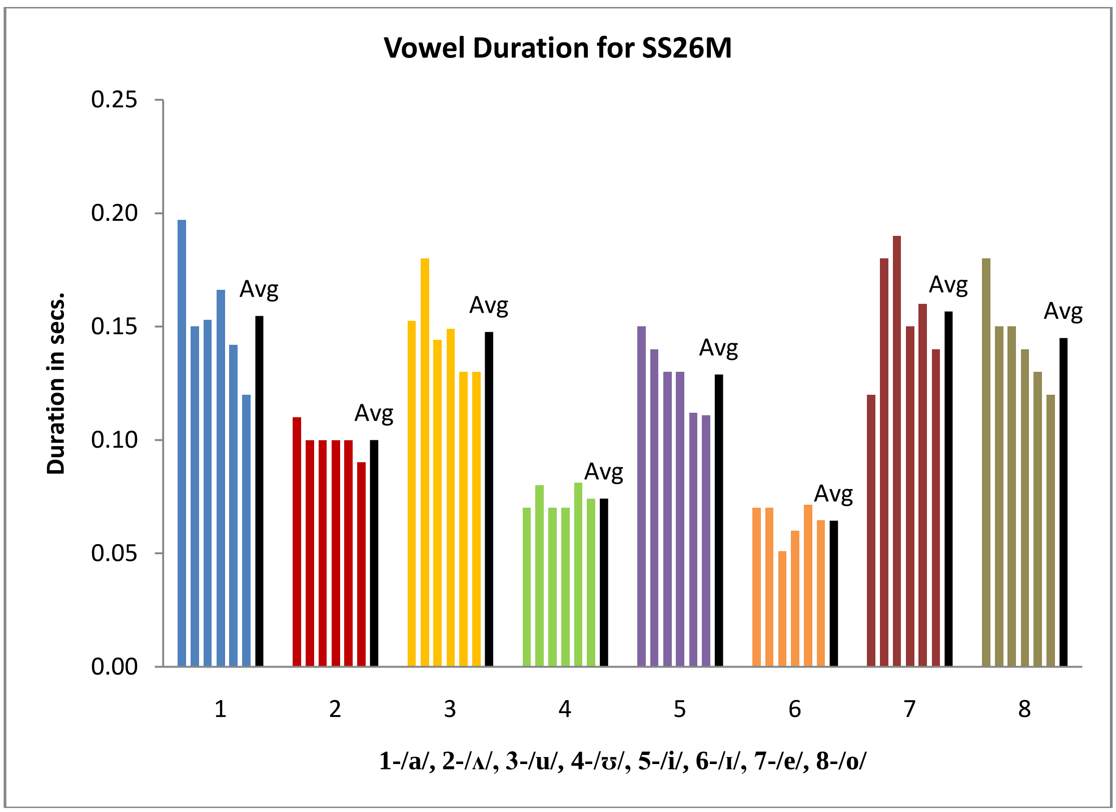
2.5.3 Duration

The duration of a vowel is initially calculated for each of the six repetitions and then the average duration is determined for the particular vowel. This process in repeated for all the vowels. The average values are then plotted for graphical representation. The following table lists the duration of all vowels recorded from SS26M.

Table 2.11 Vowel Duration for SS26M

Vowel Duration for SS26M							
	1	2	3	4	5	6	Average
/a/	0.20	0.15	0.15	0.17	0.14	0.12	0.15
/ʌ/	0.11	0.10	0.10	0.10	0.10	0.09	0.10
/u/	0.15	0.18	0.14	0.15	0.13	0.13	0.15
/ʊ/	0.07	0.08	0.07	0.07	0.08	0.07	0.07
/i/	0.15	0.14	0.13	0.13	0.11	0.11	0.13
/ɪ/	0.07	0.07	0.05	0.06	0.07	0.06	0.06
/e/	0.12	0.18	0.19	0.15	0.16	0.14	0.16
/o/	0.18	0.15	0.15	0.14	0.13	0.12	0.11

Figure 2.3 Vowel Duration for SS26M



In a similar manner, the average vowel duration has been calculated for all eight vowels for all eleven participants.

2.5.4 Fundamental Tone or Pitch

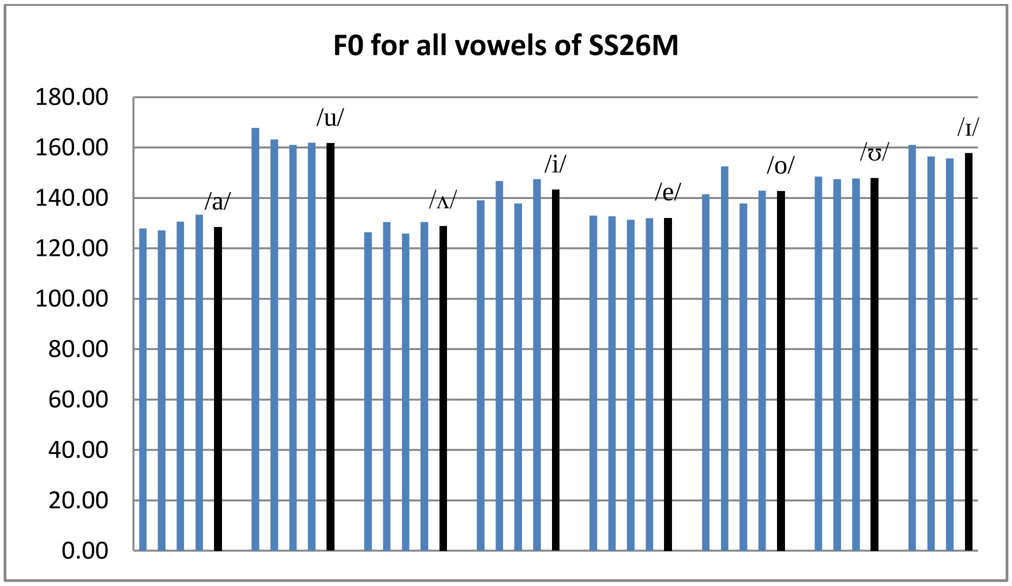
This study investigates the correlation between F0 and F1. In acoustic terms, the fundamental tone and it auditory correlate – pitch, is signified by F0. Unlike formant analysis, where averages of all six repetitions are tabulated for better accuracy, the same cannot be done for pitch values because normally the pitch tends to fall at the end of a sentence. In order to obtain an accurate idea of the pitch of a vowel, it is important to analyze those values only which are steady or show little variation. So instead of taking the F0 values for all six repetitions, only values for the middle ones are selected. F0 values have also been analyzed to observe the pitch contour and readings at the start and end of selection have been noted. Table 2.12 lists the F0 values of vowels analyzed from voice samples recorded from SS26M.

Table 2.12 F0 for SS26M

Vowel	F0		F0 (Start)		F0 (End)
Avg /a/2	127.96		129.16		127.94
Avg /a/3	127.13		125.31		128.78
Avg /a/4	130.58		136.92		130.29
Avg /a/5	133.40		140.90		133.17
Total Avg /a/	**129.77**				
Avg /u/2	167.84		154.15		177.35
Avg /u/3	163.22		152.87		169.51
Avg /u/4	161.09		147.90		173.67
Avg /u/5	162.02		155.79		163.31
Total Avg /u/	**163.54**				
Avg /ʌ/2	126.34		128.36		127.52
Avg /ʌ/3	130.44		130.20		130.95
Avg /ʌ/4	125.92		127.07		125.67
Avg /ʌ/5	130.45		124.93		131.28
Total Avg /ʌ/	**128.29**				
Avg /i/2	139.06		139.79		133.22
Avg /i/3	146.78		145.08		147.31
Avg /i/4	137.77		139.14		134.73
Avg /i/5	147.52		147.17		135.10
Total Avg /i/	**142.78**				
Avg /e/2	132.96		133.37		138.40
Avg /e/3	132.80		130.24		134.42
Avg /e/4	131.34		126.00		135.18
Avg /e/5	131.99		132.33		130.57
Total Avg /e/	**132.27**				
Avg /o/2	141.52		137.67		148.37
Avg /o/3	152.51		143.22		162.87
Avg /o/4	137.84		134.11		152.50
Avg /o/5	142.87		136.92		155.69
Total Avg /o/	**143.68**				
Avg ʊ/2	148.47		154.97		138.40
Avg /ʊ/3	147.54		150.95		142.74
Avg /ʊ/4	147.77		152.39		139.11
Total Avg /ʊ/	147.93				
Avg /ɪ/2	161.07		165.58		167.09
Avg /ɪ/3	156.49		163.56		158.49
Avg /ɪ/5	155.70		154.79		164.44
Total Avg /ɪ/	157.75				

The tabulated data is represented in a column graph representing F0 values for all vowels of SS26M in figure 2.4.

Figure 2.4 F0 of all vowels of SS26M



The average F0 values for all eight oral vowels for all participants have been tabulated in this manner.

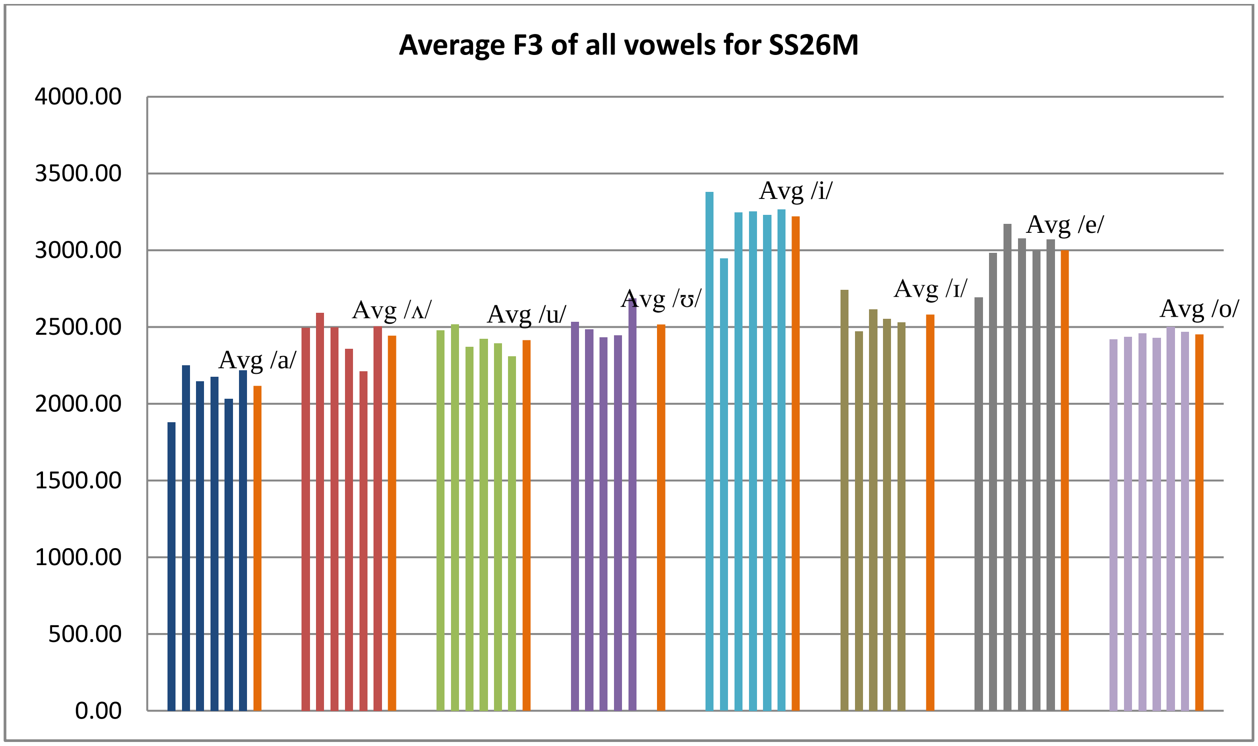
2.5.5 F3

The third formant complements the information provided by F1 and F2. F1 and F2 data is already tabulated for plotting values to determine the acoustic space. However, F3 values are also significant in certain respects.F3 values indicate whether a vowel is rounded or not. A low F3 value indicates that it is a round vowel whereas a high F3 value means the vowel is unrounded. One of the core parameters on which this study seeks to investigate is the correlation of F3 with F2 and F1. Towards this end, a list is compiled for all vowels containing their average F3 values. Table 2.13 and figure 2.5 below illustrates the F3 values of all oral vowels of SS26M.

Table 2.13 F3 of all vowels for SS26M

/a/	**/ʌ/**	**/u/**	**/ʊ/**	**/i/**	**/ɪ/**	**/e/**	**/o/**
1878.28	2494.86	2477.43	2536.08	3379.59	2743.36	2693.87	2418.01
2248.99	2590.66	2516.84	2485.66	2944.95	2471.30	2982.11	2436.13
2148.76	2498.36	2371.26	2433.17	3246.67	2613.78	3172.30	2458.86
2177.93	2358.78	2422.06	2446.09	3253.51	2551.69	3078.63	2429.52
2032.24	2211.85	2393.24	2684.92	3228.58	2531.13	2999.61	2500.32
2219.35	2506.39	2307.68	*	3267.09	*	3069.75	2468.63
2117.59	**2443.48**	**2414.75**	**2517.18**	**3220.06**	**2582.26**	**2999.38**	**2451.91**

Figure 2.5 Average F3 for SS26M



2.6 Correlation between F0, F1, F2 and F3

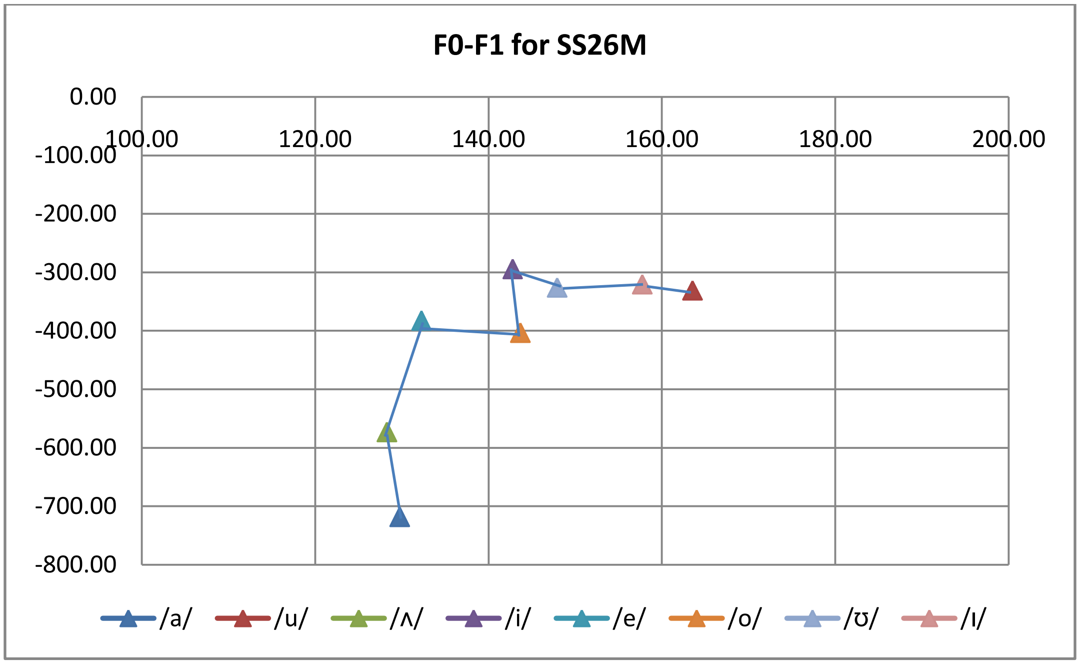
2.6.1 F0-F1 Correlation

To investigate the correlation between F0 and F1, average F0 values are plotted against negative average F1 values. The average F0 values are plotted along the x-axis whereas negative values of F1 are plotted on the y-axis. The resultant graph helps to analyze the relationship between the pitch and the height of a vowel. Using average F0 and F1 data as listed in table 2.14 for SS26M, an example is presented figure 2.6.

Table 2.14 F0-F1 data for SS26M

SS26M	F1	-F1	F0
Total Avg /a/	718.31	-718.31	129.77
Total Avg /u/	330.79	-330.79	163.54
Total Avg /ʌ/	573.25	-573.25	128.29
Total Avg /i/	294.52	-294.52	142.78
Total Avg /e/	382.53	-382.53	132.27
Total Avg /o/	403.37	-403.37	143.68
Total Avg /ʊ/	326.06	-326.06	147.93
Total Avg /ɪ/	320.32	-320.32	157.75

Figure 2.6 F0-F1 Correlation for SS26M



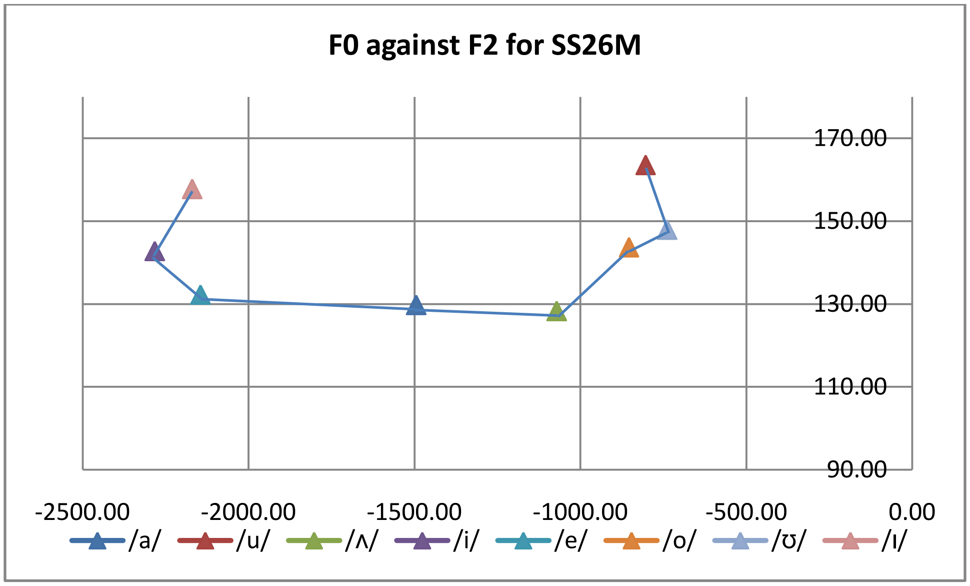
2.6.2 F0-F2 Correlation

To observe the correlation between the F0 and F2, negative values of F2 are plotted on the x-axis while F0 values are plotted on the y-axis. This correlation is significant in a sense that it provides regarding pitch and the open-close dimension in which vowels are classified. Table 2.15 lists the average values of F0 and F2 and figure 2.7 present the graph for SS26M.

Table 2.15 F0-F2 data for SS26M

SS26M	F0	F2	-F2
Total Avg /a/	129.77	1494.65	-1494.65
Total Avg /u/	163.54	803.73	-803.73
Total Avg /ʌ/	128.29	1071.35	-1071.35
Total Avg /i/	142.78	2282.46	-2282.46
Total Avg /e/	132.27	2144.42	-2144.42
Total Avg /o/	143.68	854.09	-854.09
Total Avg /ʊ/	147.93	738.59	-738.59
Total Avg /ɪ/	157.75	2169.52	-2169.52

Figure 2.7 F0-F2 Correlation for SS26M



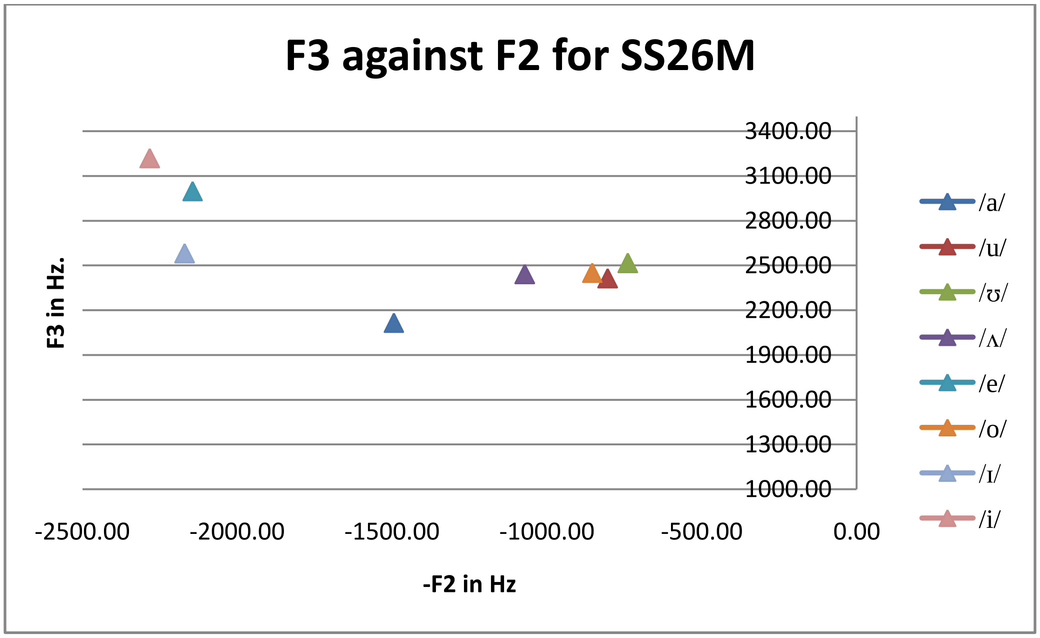
2.6.3 F3-F2 Correlation

The third formant has implications relating to lip-rounding whereas the second formant frequency has implications for the front-back criteria of vowels. To observe the correlation between the two sets of frequencies, they are first listed, as shown in table 2.16, and then plotted on a graph, as shown in figure 2.8, with average negative values of F2 on the x-axis and F3 values on the y-axis.

Table 2.16 F3-F2 data for SS26M

SS26M	F2	-F2	F3
Total Avg /a/	1494.65	-1494.65	2117.59
Total Avg /u/	803.73	-803.73	2414.75
Total Avg /ʌ/	1071.35	-1071.35	2443.48
Total Avg /i/	2282.46	-2282.46	3220.06
Total Avg /e/	2144.42	-2144.42	2999.38
Total Avg /o/	854.09	-854.09	2451.91
Total Avg /ʊ/	738.59	-738.59	2517.18
Total Avg /ɪ/	2169.52	-2169.52	2582.26

Figure 2.8 F3-F2 Correlation for SS26M



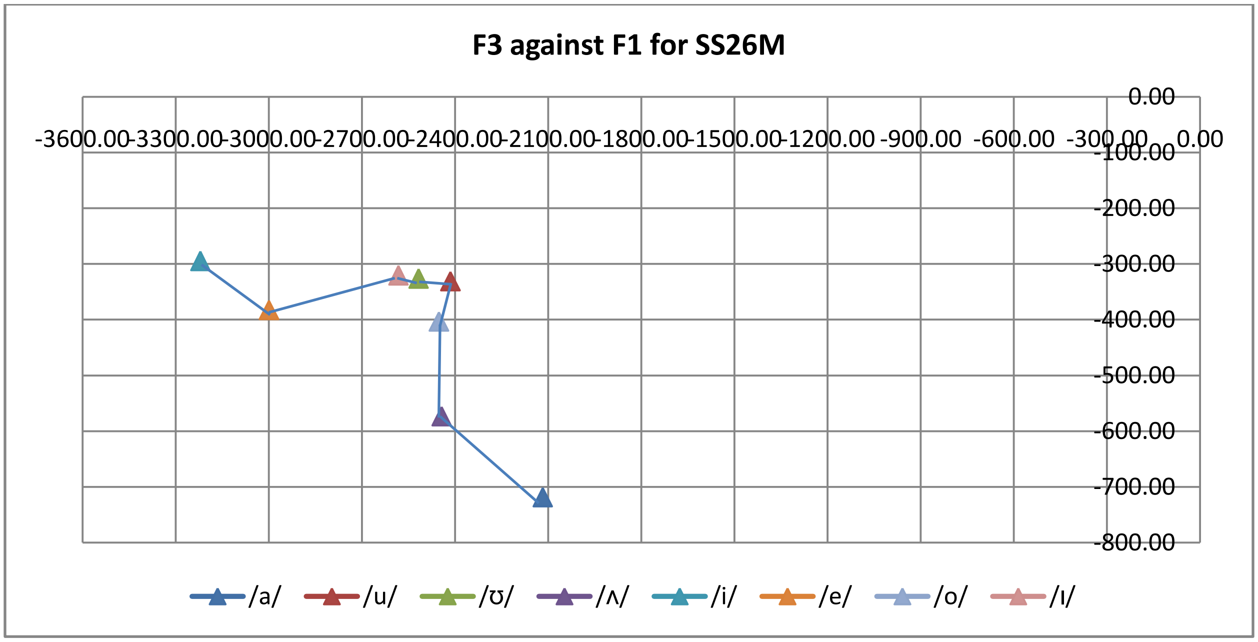
2.6.4 F3-F1 Correlation

The examination of the correlation between F3 and F1 is carried out by plotting the average negative values of F3 on the x-axis and average negative values of F1 on the y-axis for all vowels. Table 2.17 list the average F1 and F3 values while figure 2.9 represents the plot.

Table 2.19 F3- F1 data for SS26M

SS26M	-F1	-F3
Total Avg /a/	-718.31	-2117.59
Total Avg /u/	-330.79	-2414.75
Total Avg /ʌ/	-573.25	-2443.48
Total Avg /i/	-294.52	-3220.06
Total Avg /e/	-382.53	-2999.38
Total Avg /o/	-403.37	-2451.91
Total Avg /ʊ/	-326.06	-2517.18
Total Avg /ɪ/	-320.32	-2582.26

Figure 2.9 F3-F1 Correlation for SS26M



To conclude the discussion on methodology adopted for the purpose of this study, a brief description about software tools used is provided in the next section.

2.7 Software Tools

2.7.1 Praat

Praat[31] is free software which is used widely by linguists and researchers for the analysis of speech. Designed by Paul Boersma and David Weenink of the University of Amsterdam, this software offers a great deal of operational flexibility as it can run on a wide range of operating systems such as Microsoft Windows (95, 98, NT, ME, 2000, XP, Vista, Windows 7), different Unix versions, Linux and Mac. It has an in-built sound recorder but also provides the functionality of using sounds recorded by other means. Praat enables users to save the recorded files in different formats such as .wav, .flac, .aifc, .aiff, etc. It can record and analyze mono and stereo signals. It facilitates spectrographic analysis of sound waves and indicates aspects such as intonation, intensity, formants, pitch contour, amplitude and other details. Praat can support speech synthesis as well as articulatory synthesis. The Praat interface is quite user-friendly.

[31] Boersma, Paul & Weenink, David (2012). Praat: doing phonetics by computer [Computer program]. Version 5.2.35, retrieved 12 August 2011 from http://www.praat.org/

Praat has been used extensively throughout this study for the spectrographic analysis of voice data.

2.7.2 Goldwave

Unlike Praat, Goldwave has limited operational flexibility as it can only be used on the Microsoft Windows environment. Goldwave can be used for recording, playing, analyzing, converting and editing sound files. A limited time period evaluation version can be downloaded from the website. Goldwave has been used in this study primarily for the purpose of noise reduction, whenever required.

This concludes the discussion on the methodology adopted for this study. The next chapter deals with the analysis of data, obtained after spectrographic study of the voice samples, on the basis of the various parameters identified earlier in this chapter.

CHAPTER 3

DATA ANALYSIS

3.1. Introduction

This chapter presents a detailed observation of the data obtained after spectrographic analysis of the voice samples. Eleven native speakers of Nepali, all pursuing various degrees at different schools and centres of Jawaharlal Nehru University, participated in the study. All participants lie in the age group of 22-26, have no articulatory defects and have a similar socio-economic and educational background. A total of six female and five male speakers were asked to read out a list of words which were recorded and then analyzed.

The major objective of this study is to describe the vowels acoustically and examine the importance of their relative positions. This study of vowels sounds of Nepali as spoken in the Darjeeling district of West Bengal being restricted to the acoustic domain, the various parameters identified are formant analysis in terms of F0, F1, F2 and F3 and the relations between them. Acoustic space is used as a tool to organize the vowels in terms of their formant frequencies to determine the vowel space in this variety of Nepali. Another objective is to examine the correlation between pitch, known as F0 in acoustic terms, and F1 which gives an indication regarding the height of the vowel. This study also seeks to examine how F3 correlates with F1 and F2. Though length is not phonemic in the language under consideration, this study also notes the duration of vowels and its effects on the acoustic vowel space.

In the sections that follow, a comprehensive analysis regarding the parameters outlined above is presented. In the beginning, every vowel is described in terms of its F1, F2 and F3 values. They are graphically represented on a scatter plot. A representative sample of all vowels for a participant is presented and its averages are plotted. Then the averages of all other participants are listed and an overall average is presented for each speaker. This process is separately followed for male and female participants. Since there are almost equal numbers of male and female participants, a contrastive analysis on the basis of gender is also presented. The data is plotted separately for male and female participants to present the male and female acoustic vowel space. The overall averages for all participants are then plotted on the X-axis and Y-axis to design the consolidated acoustic space.

3.2 Male Participants

A total of five male informants participated in the study. Given below is the analysis of SS26M. Every vowel is analyzed individually for SS26M representing the other male participants. The data in terms of F1, F2 and F3 is presented. A formant plot for all the six repetitions and its average are plotted horizontally and vertically. The vertical axis reflects height of the vowel and F1 values are represented in this axis. The horizontal axis represents the difference between the second and first formants as F2 reading alone cannot adequately describe the vowel as front or back.

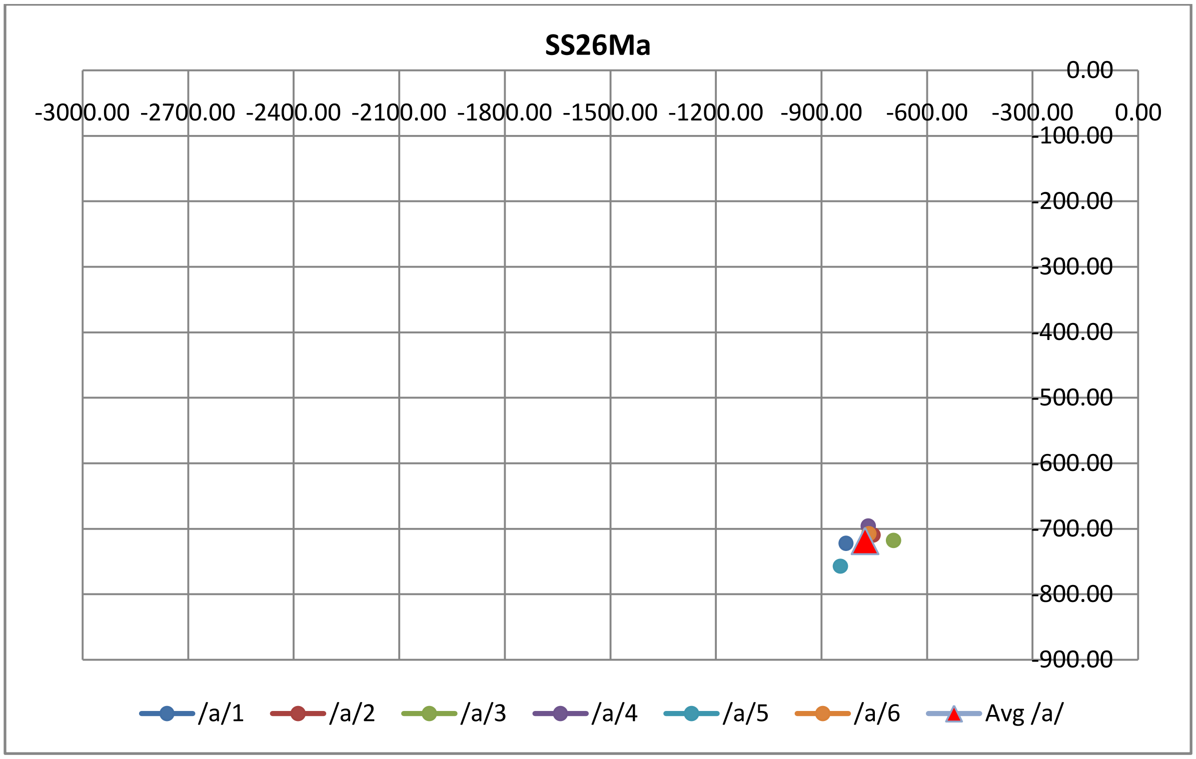
3.2.1 SS26M - Vowel /a/

The table below lists the average values of the vowel /a/ for the six repetitions of the word /kat/. F1 values ranged from 695.84 Hz to 757.09 Hz. The overall average for F1 is 718.31 Hz. F2 values ranged from 1413.18 Hz to 1603.21 Hz. F3 values ranged from 1878.28 Hz to 2248.99 Hz and the overall F3 average was 2117.59. The overall value of negative F2-F1 was recorded at -776.34. The scatter plot represents the average negative F2-F1 values on X-axis and negative F1 values on the Y-axis.

Table 3.0 SS26Ma formants

Vowel	F1	F2	F3	-(F2-F1)	-F1
Avg /a/1	722.20	1552.61	1878.28	-830.41	-722.20
Avg /a/2	709.54	1462.68	2248.99	-753.14	-709.54
Avg /a/3	717.76	1413.20	2148.76	-695.44	-717.76
Avg /a/4	695.84	1463.18	2177.93	-767.33	-695.84
Avg /a/5	757.09	1603.21	2032.24	-846.12	-757.09
Avg /a/6	707.40	1473.00	2219.35	-765.60	-707.40
Total Avg /a/	**718.31**	**1494.65**	**2117.59**	**-776.34**	**-718.31**

Figure 3.0 SS26Ma formant plot



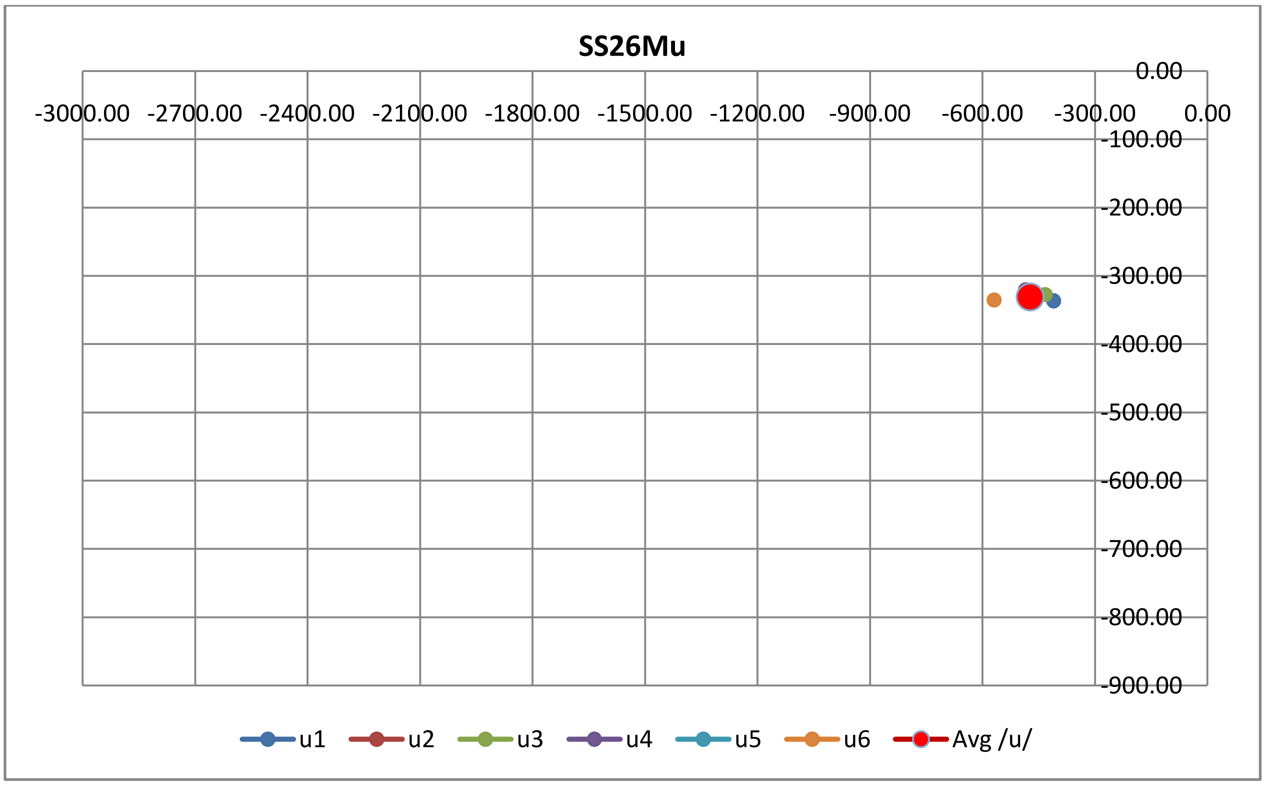
3.2.2 SS26M - Vowel /u/

The table below highlights the average values of the vowel /u/ for the six repetitions of the word /kut/. F1 values ranged from 320.55Hz to 336.41 Hz and 330.79 is overall average F1. F2 values ranged from 746.43 Hz to 904.06 Hz and the overall average is 803.73Hz. The overall average for F3 is 2414.75 Hz with values ranging from 2307.68Hz to 2516.84 Hz. The overall average for negative values of F2-F1 is -472.94Hz. The scatter plot below presents a diagrammatic representation of negative values of F2-F1 against F1.

Table 3.1 SS26Mu formants

Vowel	F1	F2	F3	-(F2-F1)	-F1
Avg /u/1	336.41	746.43	2477.43	-410.01	-336.41
Avg /u/2	332.41	805.60	2516.84	-473.19	-332.41
Avg /u/3	327.22	759.72	2371.26	-432.50	-327.22
Avg /u/4	320.55	805.12	2422.06	-484.56	-320.55
Avg /u/5	332.88	801.47	2393.24	-468.58	-332.88
Avg /u/6	335.29	904.06	2307.68	-568.77	-335.29
Total Avg /u/	**330.79**	**803.73**	**2414.75**	**-472.94**	**-330.79**

Figure 3.1 SS26Mu formant plot



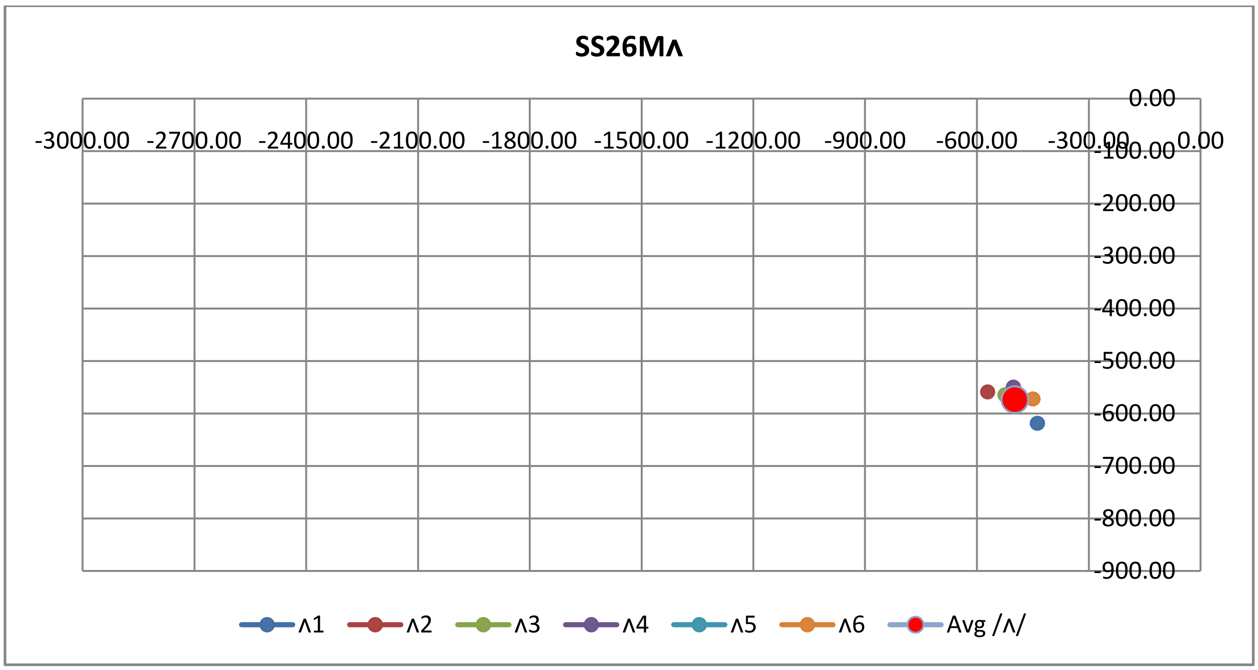
3.2.3 SS26M - Vowel /ʌ/

The table below highlights the average values of the vowel /ʌ/ for the six repetitions of the word /pʌt/. F1 values ranged from 550.13Hz to 618.57 Hz and 573.25 is the overall average F1. F2 values ranged from 1021.56 Hz to 1129.80 Hz and the overall average is 1071.35Hz. The overall average for F3 is 2443.48Hz with values ranging from 2211.85Hz to 2590.66 Hz. The overall average for negative values of F2-F1 is -498.10Hz.. The scatter plot below presents a graphical representation of negative values of F2-F1 against F1.

Table 3.2 SS26Mʌ formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /ʌ/1		618.57	1056.12	2494.86	-437.55	-618.57
Avg /ʌ/2		558.77	1129.80	2590.66	-571.03	-558.77
Avg /ʌ/3		564.47	1088.71	2498.36	-524.25	-564.47
Avg /ʌ/4		550.13	1052.05	2358.78	-501.93	-550.13
Avg /ʌ/5		575.45	1079.83	2211.85	-504.38	-575.45
Avg /ʌ/6		572.09	1021.56	2506.39	-449.47	-572.09
Total Avg /ʌ/		**573.25**	**1071.35**	**2443.48**	**-498.10**	**-573.25**

Figure 3.2 SS26Mʌ formant plot



3.2.4 SS26M - Vowel /i/

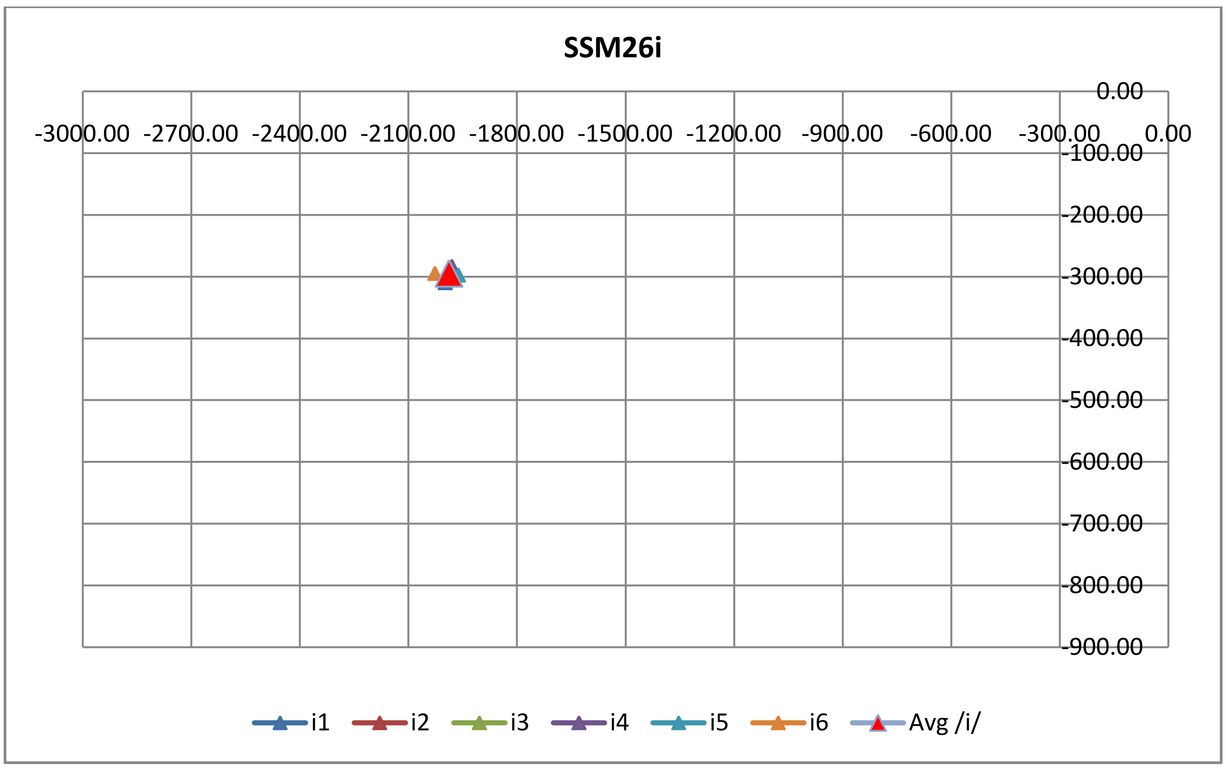
The table below highlights the average values of the vowel /i/ for the six repetitions of the word /pip/. F1 values ranged from 283.14Hz to 309.27Hz and 294.52Hz is the overall average

F1. F2 values ranged from 2263.01Hz to 2321.31Hz and the overall average is 2282.46Hz. The overall average for F3 is 3220.06Hz with values ranging from 2944.95Hz to 3379.59Hz. The overall average for negative values of F2-F1 is –1987.95Hz. The scatter plot below presents a diagrammatic representation of negative values of F2-F1 against F1.

Table 3.3 SS26Mi formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /i/1		309.27	2308.09	3379.59	-1998.82	-309.27
Avg /i/2		287.40	2278.62	2944.95	-1991.23	-287.40
Avg /i/3		295.88	2264.54	3246.67	-1968.67	-295.88
Avg /i/4		283.14	2263.01	3253.51	-1979.88	-283.14
Avg /i/5		297.09	2259.21	3228.58	-1962.12	-297.09
Avg /i/6		294.34	2321.31	3267.09	-2026.97	-294.34
Total Avg /i/		**294.52**	**2282.46**	**3220.06**	**-1987.95**	**-294.52**

Figure 3.3 SS26Mi formant plot



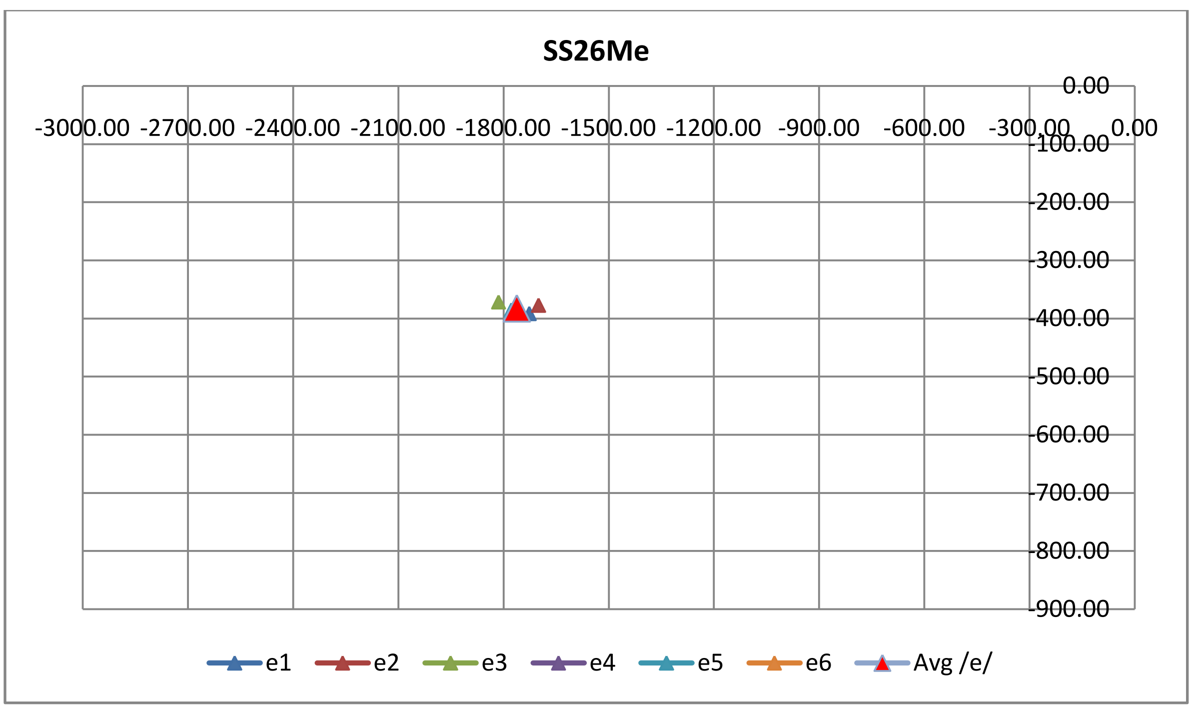
3.2.5 SS26M - Vowel /e/

The table below highlights the average values of the vowel /e/ for the six repetitions of the word /tek/. F1 values ranged from 371.41Hz to 391.41 Hz and 382.53Hz is the overall average F1. F2 values ranged from 2076.90Hz to 2185.70Hz and the overall average is 2144.42Hz. The overall average for F3 is 2999.38Hz with values ranging from 2693.87Hz to 3172.30Hz. The overall average for negative values of F2-F1 is -1761.89Hz. The scatter plot below presents a graphical representation of negative values of F2-F1 against F1.

Table 3.4 SS26Me formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /e/1		391.41	2118.20	2693.87	-1726.79	-391.41
Avg /e/2		377.16	2076.90	2982.11	-1699.73	-377.16
Avg /e/3		371.41	2185.70	3172.30	-1814.29	-371.41
Avg /e/4		379.57	2204.79	3078.63	-1825.23	-379.57
Avg /e/5		385.52	2162.80	2999.61	-1777.28	-385.52
Avg /e/6		390.13	2118.14	3069.75	-1728.01	-390.13
Total Avg /e/		**382.53**	**2144.42**	**2999.38**	**-1761.89**	**-382.53**

Figure 3.4 SS26Me formant plot



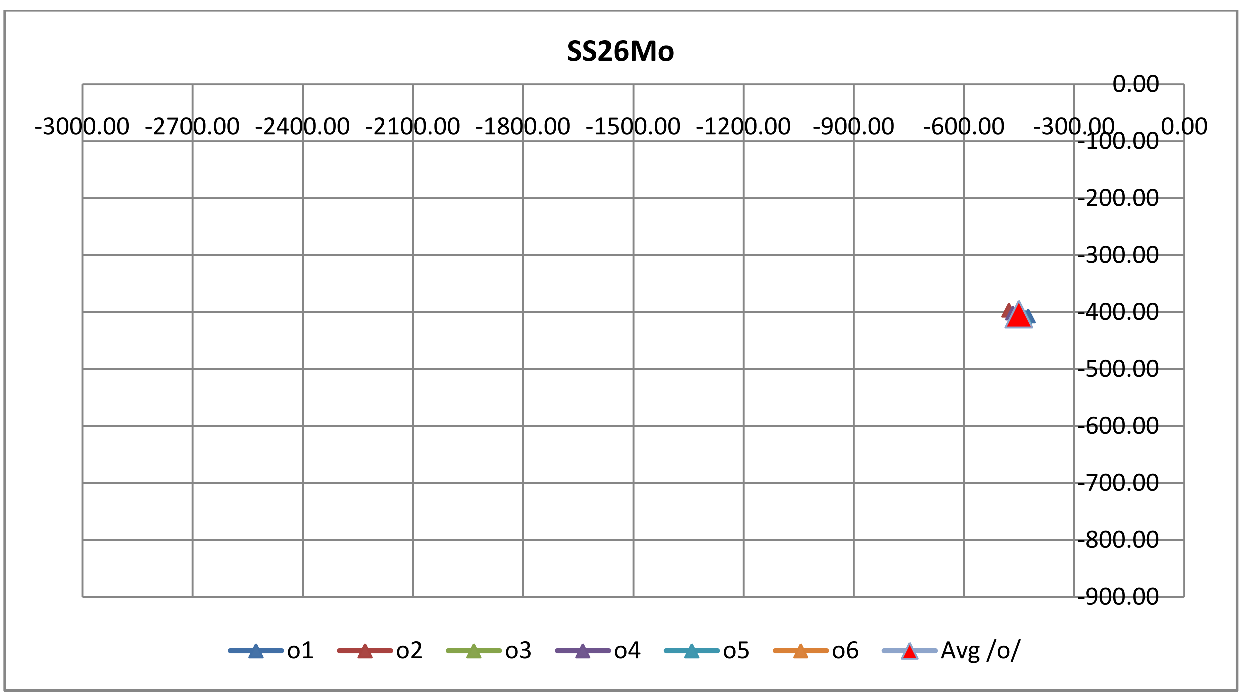
3.2.6 SS26M - Vowel /o/

The table below lists the average values of the vowel /o/ for the six repetitions of the word /tok/. F1 values ranged from 396.30Hz to 408.18Hz. The overall average for F1 is 403.37Hz. F2 values ranged from 832.07 Hz to 874.30Hz. F3 values ranged from 2418.01Hz to 2500.32Hz and the overall F3 average was 2451.91Hz. The overall value of negative F2-F1 was recorded at –450.72Hz. The scatter plot represents the average negative F2-F1 values on X-axis and negative F1 values on the Y-axis.

Table 3.5 SS26Mo formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /o/1		406.44	832.07	2418.01	-425.63	-406.44
Avg /o/2		396.30	874.30	2436.13	-478.00	-396.30
Avg /o/3		400.79	859.02	2458.86	-458.23	-400.79
Avg /o/4		401.37	868.96	2429.52	-467.59	-401.37
Avg /o/5		408.18	843.74	2500.32	-435.56	-408.18
Avg /o/6		407.15	846.43	2468.63	-439.28	-407.15
Total Avg /o/		**403.37**	**854.09**	**2451.91**	**-450.72**	**-403.37**

Figure 3.5 SS26Mo formant plot



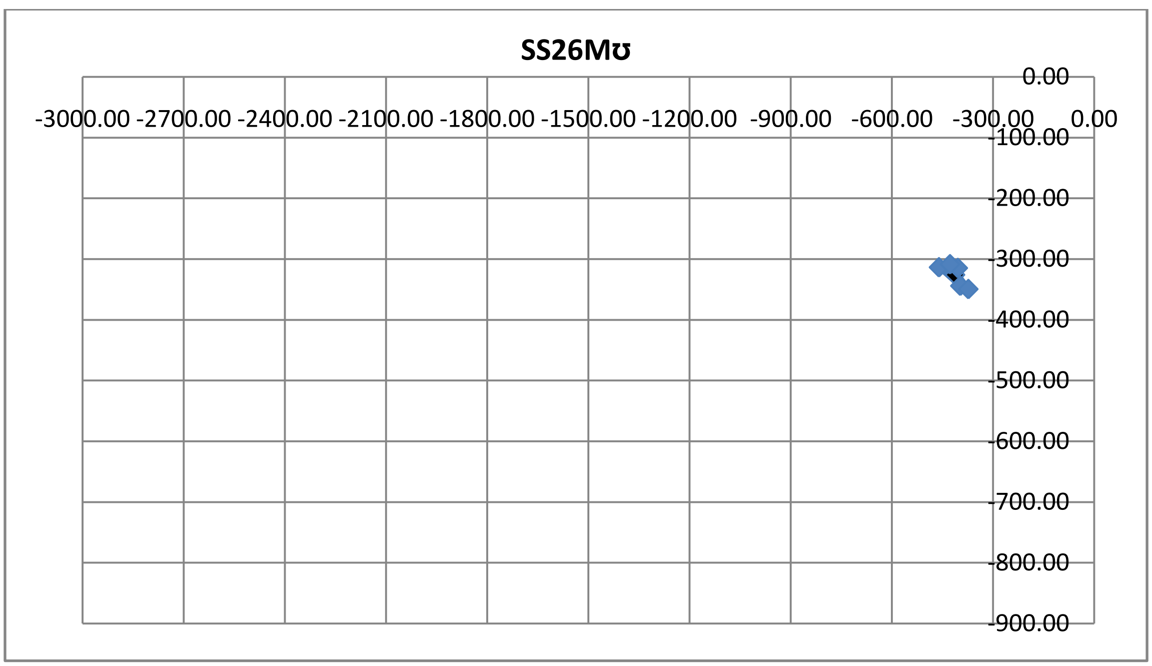
3.2.7 SS26M - Vowel /ʊ/

The table below lists the average values of the short vowel /ʊ/ for the five repetitions of the word /kʊkkur/. F1 values ranged from 308.60Hz to 349.38Hz. The overall average for F1 is 326.06Hz. F2 values ranged from 719.15Hz to 773.99Hz. F3 values ranged from Hz to 2433.17Hz to 2684.92Hz and the overall F3 average was 2517.18Hz. The overall value of negative F2-F1 was recorded at –412.53Hz. The scatter plot represents the average negative F2-F1 values on X-axis and negative F1 values on the Y-axis.

Table 3.6 SS26Mʊ formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /ʊ/1		344.04	741.10	2536.08	-397.06	-344.04
Avg ʊ/2		313.55	773.99	2485.66	-460.45	-313.55
Avg /ʊ/3		314.74	719.15	2433.17	-404.41	-314.74
Avg /ʊ/4		308.60	736.16	2446.09	-427.56	-308.60
Avg /ʊ/5		349.38	722.55	2684.92	-373.17	-349.38
Total Avg /ʊ/		**326.06**	**738.59**	**2517.18**	**-412.53**	**-326.06**

Figure 3.6 SS26Mʊ formant plot



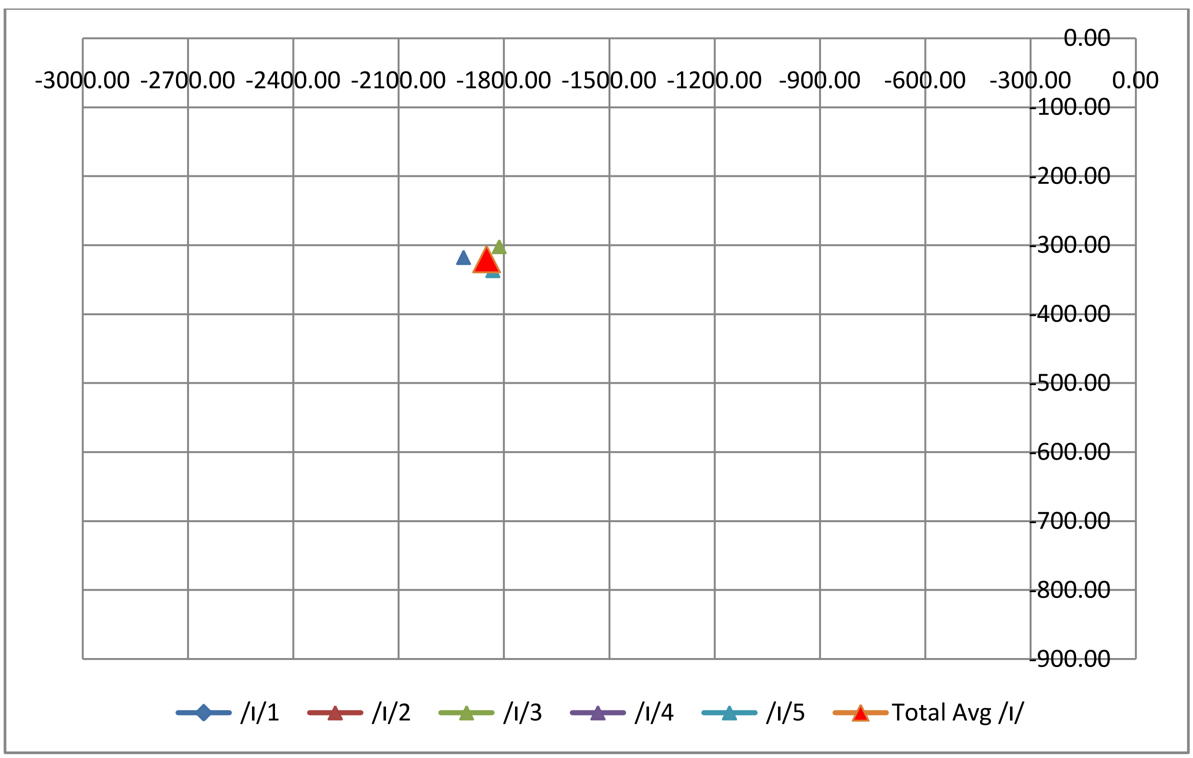
3.2.8 SS26M - Vowel /ɪ/

The table below lists the average values of the short vowel /ɪ/ for the five repetitions of the word /tʰɪkkʌ/. F1 values ranged from 302.18Hz to 336.77Hz. The overall average for F1 is 320.32Hz. F2 values ranged from 2115.43Hz to 2233.09Hz. F3 values ranged from 2571.30Hz to 2743.36 and the overall F3 average is 2582.26Hz. The overall value of negative F2-F1 was recorded at –-1849.20Hz. The scatter plot represents the average negative F2-F1 values on X-axis and negative F1 values on the Y-axis.

Table 3.7 SS26Mɪ formants

		F1	F2	F3	-(F2-F1)	-F1
Avg /ɪ/1		317.79	2233.09	2743.36	-1915.30	-317.79
Avg /ɪ/2		326.53	2167.02	2471.30	-1840.49	-326.53
Avg /ɪ/3		302.18	2115.43	2613.78	-1813.25	-302.18
Avg /ɪ/4		318.33	2163.83	2551.69	-1845.50	-318.33
Avg /ɪ/5		336.77	2168.22	2531.13	-1831.45	-336.77
Total Avg /ɪ/		**320.32**	**2169.52**	**2582.26**	**-1849.20**	**-320.32**

Figure 3.7 SS26Mɪ formant plot



3.2.9 SS26M – All oral vowels

The table below represents the average F1,F2 and F3 values for all six repetitions of all eight oral peripheral vowels for SS26M.

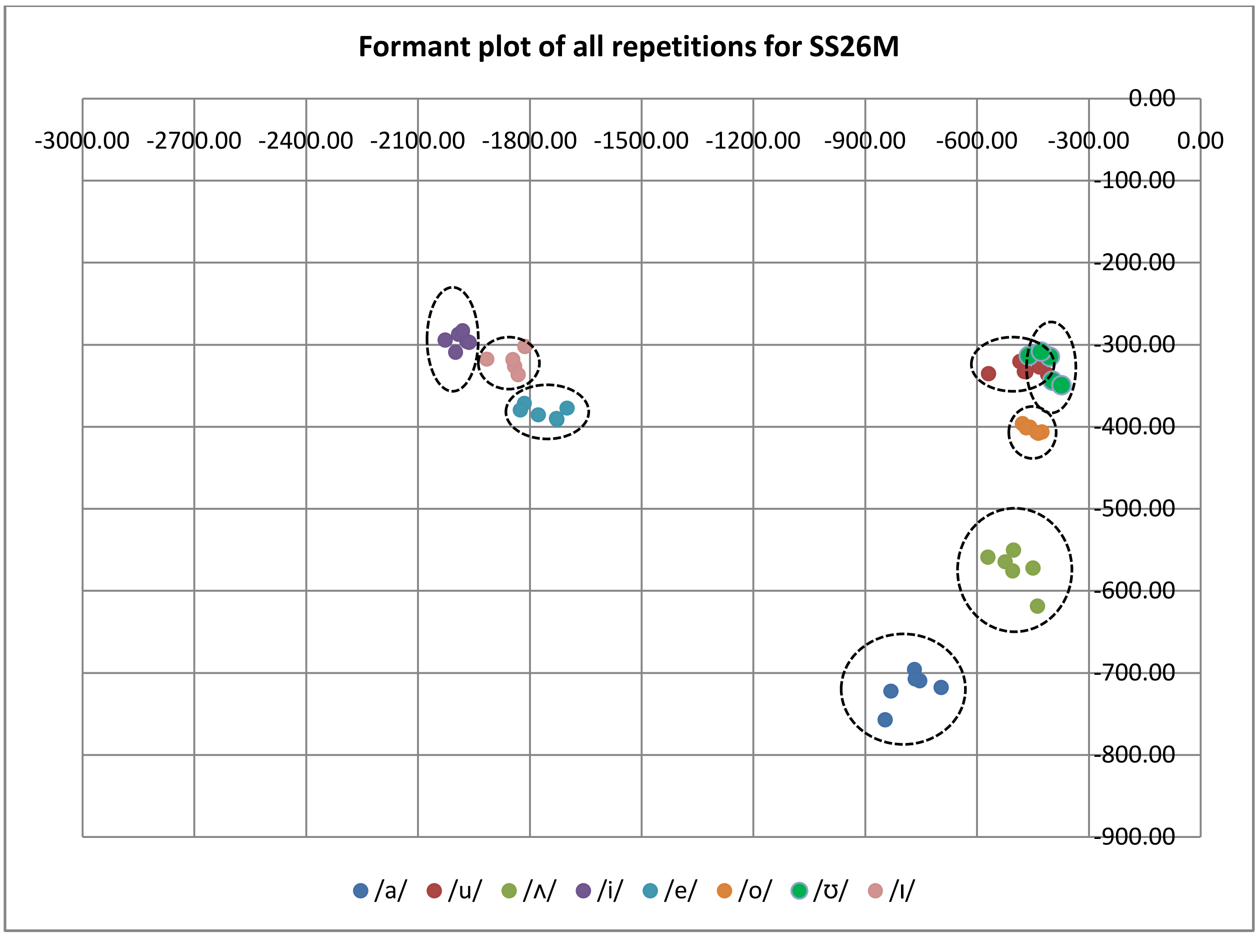
Table 3.8 Formants of all vowels for SS26M

Vowel		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
Avg /a/1		722.20	1552.61	1878.28	-830.41	-722.20
Avg /a/2		709.54	1462.68	2248.99	-753.14	-709.54
Avg /a/3		717.76	1413.20	2148.76	-695.44	-717.76
Avg /a/4		695.84	1463.18	2177.93	-767.33	-695.84
Avg /a/5		757.09	1603.21	2032.24	-846.12	-757.09
Avg /a/6		707.40	1473.00	2219.35	-765.60	-707.40
Total Avg /a/		**718.31**	**1494.65**	**2117.59**	**-776.34**	**-718.31**
Avg /u/1		336.41	746.43	2477.43	-410.01	-336.41
Avg /u/2		332.41	805.60	2516.84	-473.19	-332.41
Avg /u/3		327.22	759.72	2371.26	-432.50	-327.22
Avg /u/4		320.55	805.12	2422.06	-484.56	-320.55
Avg /u/5		332.88	801.47	2393.24	-468.58	-332.88
Avg /u/6		335.29	904.06	2307.68	-568.77	-335.29
Total Avg /u/		**330.79**	**803.73**	**2414.75**	**-472.94**	**-330.79**
Avg /ʌ/1		618.57	1056.12	2494.86	-437.55	-618.57
Avg /ʌ/2		558.77	1129.80	2590.66	-571.03	-558.77
Avg /ʌ/3		564.47	1088.71	2498.36	-524.25	-564.47
Avg /ʌ/4		550.13	1052.05	2358.78	-501.93	-550.13
Avg /ʌ/5		575.45	1079.83	2211.85	-504.38	-575.45
Avg /ʌ/6		572.09	1021.56	2506.39	-449.47	-572.09
Total Avg /ʌ/		**573.25**	**1071.35**	**2443.48**	**-498.10**	**-573.25**
Avg /i/1		309.27	2308.09	3379.59	-1998.82	-309.27
Avg /i/2		287.40	2278.62	2944.95	-1991.23	-287.40
Avg /i/3		295.88	2264.54	3246.67	-1968.67	-295.88
Avg /i/4		283.14	2263.01	3253.51	-1979.88	-283.14
Avg /i/5		297.09	2259.21	3228.58	-1962.12	-297.09
Avg /i/6		294.34	2321.31	3267.09	-2026.97	-294.34
Total Avg /i/		**294.52**	**2282.46**	**3220.06**	**-1987.95**	**-294.52**
Avg /e/1		391.41	2118.20	2693.87	-1726.79	-391.41
Avg /e/2		377.16	2076.90	2982.11	-1699.73	-377.16
Avg /e/3		371.41	2185.70	3172.30	-1814.29	-371.41
Avg /e/4		379.57	2204.79	3078.63	-1825.23	-379.57
Avg /e/5		385.52	2162.80	2999.61	-1777.28	-385.52
Avg /e/6		390.13	2118.14	3069.75	-1728.01	-390.13
Total Avg /e/		**382.53**	**2144.42**	**2999.38**	**-1761.89**	**-382.53**
Avg /o/1		406.44	832.07	2418.01	-425.63	-406.44
Avg /o/2		396.30	874.30	2436.13	-478.00	-396.30
Avg /o/3		400.79	859.02	2458.86	-458.23	-400.79
Avg /o/4		401.37	868.96	2429.52	-467.59	-401.37
Avg /o/5		408.18	843.74	2500.32	-435.56	-408.18
Avg /o/6		407.15	846.43	2468.63	-439.28	-407.15
Total Avg /o/		**403.37**	**854.09**	**2451.91**	**-450.72**	**-403.37**

3.2.10 Formant plot of all vowels for SS26M

On the basis of data listed in table 3.8, a plot representing average F1 and F2-F1 values is illustrated in figure 3.8. From the plot it is apparent how the vowels organize themselves within the limit on the basis of their formant frequencies. In the graph, it can be noticed that some repetitions of the rounded high back vowel /u/ and its shorter variant /ʊ/ show little spectral difference. However, when the average of the six repetitions are calculated, the picture gets clearer.

Figure 3.8 Formant plot of all repetitions for all vowels of SS26M



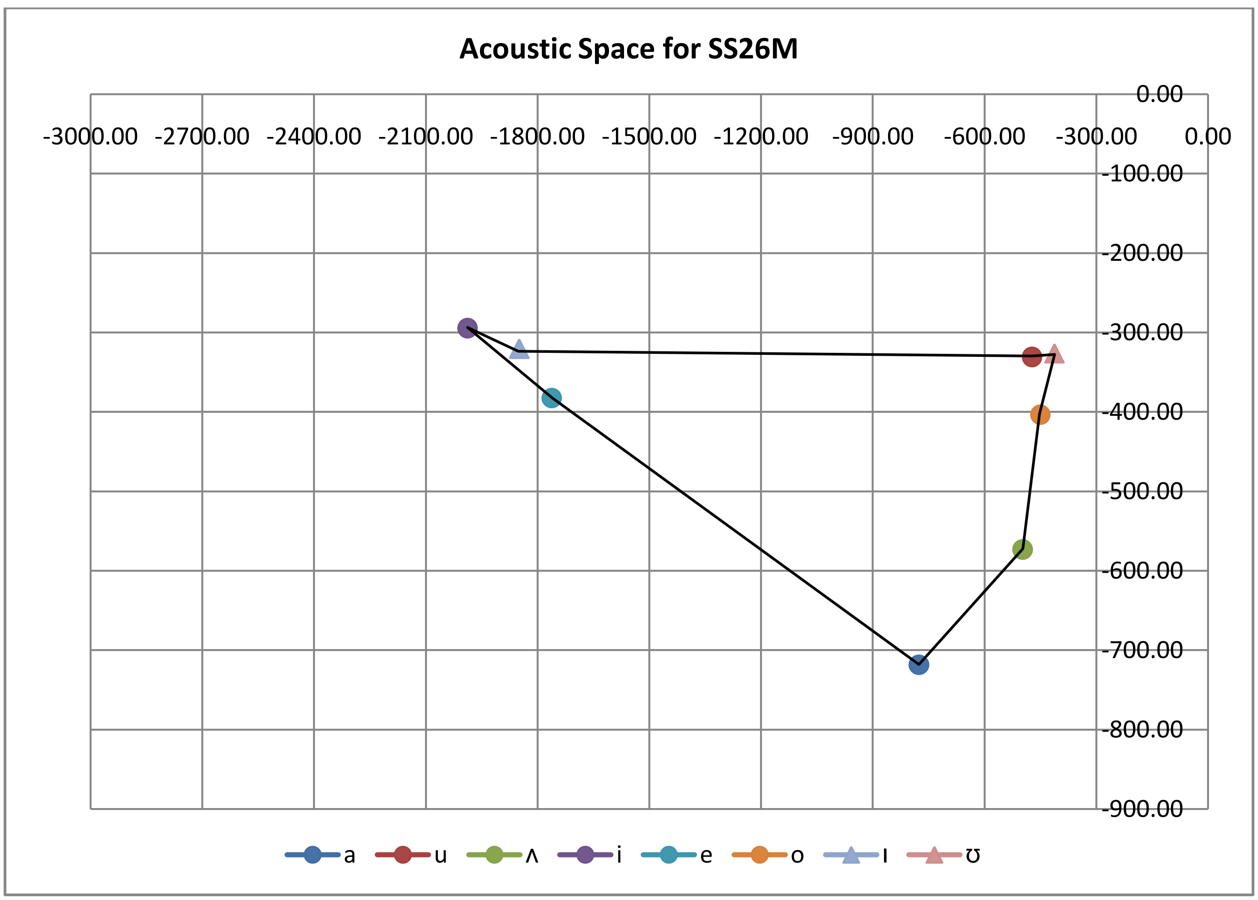
3.2.11 Acoustic Space for SS26M

The total average of all six repetitions of every vowel is calculated and presented in the table below. In the figure below, the acoustic space of SS26M is presented.

Table 3.9 Average formant values for all vowels for SS26M

Vowel		F1	F2	F3	-(F2-F1)	-F1
Total Avg /a/		718.31	1494.65	2117.59	-776.34	-718.31
Total Avg /u/		330.79	803.73	2414.75	-472.94	-330.79
Total Avg /ʌ/		573.25	1071.35	2443.48	-498.10	-573.25
Total Avg /i/		294.52	2282.46	3220.06	-1987.95	-294.52
Total Avg /e/		382.53	2144.42	2999.38	-1761.89	-382.53
Total Avg /o/		403.37	854.09	2451.91	-450.72	-403.37
Total Avg /ʊ/		326.06	738.59	2517.18	-412.53	-326.06
Total Avg /ɪ/		320.32	2169.52	2582.26	-1849.20	-320.32

Figure 3.9 Acoustic Space for SS26M



3.3.1 Vowel /a/ for all male speakers

The following table lists the average of the six repetitions of the vowel /a/ for all male speakers. F1 values are observed in the range between 684.90Hz to 795.72Hz. F2 values range from 1287.81Hz to 1544.36Hz. F3 values can be found ranging from 2117.59Hz to 2948.43Hz. The average values of F1,F2 and F3 values for all male speakers are 729.90Hz, 1428.01Hz and 2536.45Hz respectively. The average value of negative F2-F1 is -698.11Hz.

Table 3.10 Averages of /a/ for all male participants

Averages of /a/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /a/	718.31	1494.65	2117.59	-776.34	-718.31
PL26M	Total Avg /a/	693.52	1287.81	2545.97	-594.29	-693.52
PR22M	Total Avg /a/	757.03	1372.60	2656.35	-615.57	-757.03
JY26M	Total Avg /a/	795.72	1544.36	2948.43	-748.64	-795.72
BS26M	Total Avg /a/	684.90	1440.60	2413.92	-755.71	-684.90
All males	**Consolidated Average**	**729.90**	**1428.01**	**2536.45**	**-698.11**	**-729.90**

3.3.2 Vowel /u/ for all male speakers

The following table lists the average of the six repetitions of the vowel /u/ for all male speakers. F1 values are observed in the range between 330.79Hz to403.79Hz. F2 values range from 695.72Hz to 1162.08 Hz. F3 values can be found ranging from 2364.15Hz to 2532.59Hz. The average values of F1,F2 and F3 values for all male speakers are 381.59Hz, 962.03Hz and 2419.53Hz respectively. The average value of negative F2-F1 is -580.44

Table 3.11 Averages of /u/ for all male participants

Averages of /u/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /u/	330.79	803.73	2414.75	-472.94	-330.79
PL26M	Total Avg /u/	389.22	1082.84	2364.15	-693.63	-389.22
PR22M	Total Avg /u/	403.79	1065.77	2453.97	-661.97	-403.79
JY26M	Total Avg /u/	381.24	695.72	2532.59	-314.48	-381.24
BS26M	Total avg /u/	402.92	1162.08	2332.18	-759.17	-402.92
All males	**Consolidated Average**	**381.59**	**962.03**	**2419.53**	**-580.44**	**-381.59**

3.3.3 Vowel /ʌ/ for all male speakers

The following table lists the average of the six repetitions of the vowel /ʌ/ for all male speakers. F1 values are observed in the range between 573.25Hz to 675.80Hz. F2 values range from 1071.35Hz to 1376.41Hz. F3 values can be found ranging from 2260.38Hz to 2537.56Hz. The average values of F1,F2 and F3 values for all male speakers are 621.22Hz, 1272.77Hz and 2383.25Hz respectively. The average value of negative F2-F1 is -651.56Hz.

Table 3.12 Averages of /ʌ/ for all male participants

Averages of /ʌ/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /ʌ/	573.25	1071.35	2443.48	-498.10	-573.25
PL26M	Total Avg /ʌ/	611.96	1277.07	2316.35	-665.11	-611.96
PR22M	Total Avg /ʌ/	644.45	1310.55	2537.56	-666.11	-644.45
JY26M	Total Avg /ʌ/	675.80	1328.47	2358.47	-652.67	-675.80
BS26M	Total Avg /ʌ/	600.63	1376.41	2260.38	-775.79	-600.63
All males	**Consolidated Average**	**621.22**	**1272.77**	**2383.25**	**-651.56**	**-621.22**

3.3.4 Vowel /i/ for all male speakers

The following table lists the average of the six repetitions of the vowel /i/ for all male speakers. F1 values are observed in the range between 294.52Hz to 393.52Hz. F2 values range from 1836.52 to 2282.46Hz. F3 values can be found ranging from 2584.04Hz to 3220.06Hz. The average values of F1,F2 and F3 values for all male speakers are 355.49Hz, 2102.60Hz and 2868.69Hz respectively. The average value of negative F2-F1 is -1747.32Hz.

Table 3.13 Averages of /i/ for all male participants

Averages of /i/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /i/	294.52	2282.46	3220.06	-1987.95	-294.52
PL26M	Total Avg /i/	332.34	2164.63	2914.46	-1832.30	-332.34
PR22M	Total Avg /i/	363.58	2024.13	2615.73	-1660.54	-363.58
JY26M	Total Avg /i/	393.52	2205.27	3009.16	-1811.76	-393.52
BS26M	Total Avg /i/	392.49	1836.52	2584.04	-1444.03	-392.49
All males	**Consolidated Average**	**355.29**	**2102.60**	**2868.69**	**-1747.32**	**-355.29**

3.3.5 Vowel /e/ for all male speakers

The following table lists the average of the six repetitions of the vowel /e/ for all male speakers. F1 values are observed in the range between 382.05Hz to 463.07Hz. F2 values range from 2022.97Hz to 2173.36Hz. F3 values can be found ranging from 2610.81Hz to 2999.38Hz. The average values of F1, F2 and F3 values for all male speakers are 422.59Hz, 2120.42Hz and 2762.87Hz respectively. The average value of negative F2-F1 is -1697.84Hz.

Table 3.14 Averages of /e/ for all male participants

Averages of /e/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /e/	382.53	2144.42	2999.38	-1761.89	-382.53
PL26M	Total Avg /e/	382.05	2147.61	2693.94	-1765.56	-382.05
PR22M	Total Avg /e/	463.07	2022.97	2610.81	-1559.90	-463.07
JY26M	Total Avg /e/	446.09	2173.36	2899.19	-1727.27	-446.09
BS26M	Total Avg /e/	439.18	2113.75	2611.04	-1674.57	-439.18
All males	**Consolidated Average**	**422.59**	**2120.42**	**2762.87**	**-1697.84**	**-422.59**

3.3.6 Vowel /o/ for all male speakers

The following table lists the average of the six repetitions of the vowel /o/ for all male speakers. F1 values are observed in the range between 403.37Hz to 530.09Hz. F2 values range from 854.09Hz to 1292.36Hz. F3 values can be found ranging from 2431.96Hz to 2679.99Hz. The average values of F1, F2 and F3 values for all male speakers are 478.85Hz, 1061.76Hz and 2492.70Hz respectively. The average value of negative F2-F1 is -582.90Hz.

Table 3.15 Averages of /o/ for all male participants

Averages of /o/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /o/	403.37	854.09	2451.91	-450.72	-403.37
PL26M	Total Avg /o/	465.87	1090.23	2381.80	-624.36	-465.87
PR22M	Total Avg /o/	482.12	1074.57	2679.99	-592.45	-482.12
JY26M	Total Avg /o/	530.09	997.53	2431.96	-467.44	-530.09
BS26M	Total avg /o/	512.82	1292.36	2517.84	-779.54	-512.82
All males	**Consolidated Average**	**478.85**	**1061.76**	**2492.70**	**-582.90**	**-478.85**

3.3.7 Vowel /ʊ/ for all male speakers

The following table lists the average of the six repetitions of the short vowel /ʊ/ for all male speakers. F1 values are observed in the range between 326.06Hz to 514.25Hz. F2 values range from 801.84Hz to 1290.36Hz. F3 values can be found ranging from 2345.04Hz to 2674.76Hz. The average values of F1, F2 and F3 values for all male speakers are 397.59Hz, 938.00Hz and 2508.15Hz respectively. The average value of negative F2-F1 is -540.41Hz.

Table 3.16 Averages of /ʊ/ for all male participants

Averages of /ʊ/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /ʊ/	326.06	738.59	2517.18	-412.53	-326.06
PL26M	Total Avg /ʊ/	514.25	1290.36	2674.76	-776.11	-514.25
PR22M	Total Avg /ʊ/	333.03	801.84	2641.03	-468.81	-333.03
JY26M	Total Avg /ʊ/	409.99	939.19	2362.76	-529.20	-409.99
BS26M	Total Avg /ʊ/	404.63	920.01	2345.04	-515.38	-404.63
All males	**Consolidated Average**	**397.59**	**938.00**	**2508.15**	**-540.41**	**-397.59**

3.3.8 Vowel /ɪ/ for all male speakers

The following table lists the average of the six repetitions of the short vowel /ɪ/ for all male speakers. F1 values are observed in the range between 320.32Hz to 396.19Hz. F2 values range from 1981.30Hz to 2169.52Hz. F3 values can be found ranging from 2465.28Hz to 2582.26Hz. The average values of F1, F2 and F3 values for all male speakers are 374.52Hz, 2053.62Hz and 2518.72Hz respectively. The average value of negative F2-F1 is -1679.11Hz.

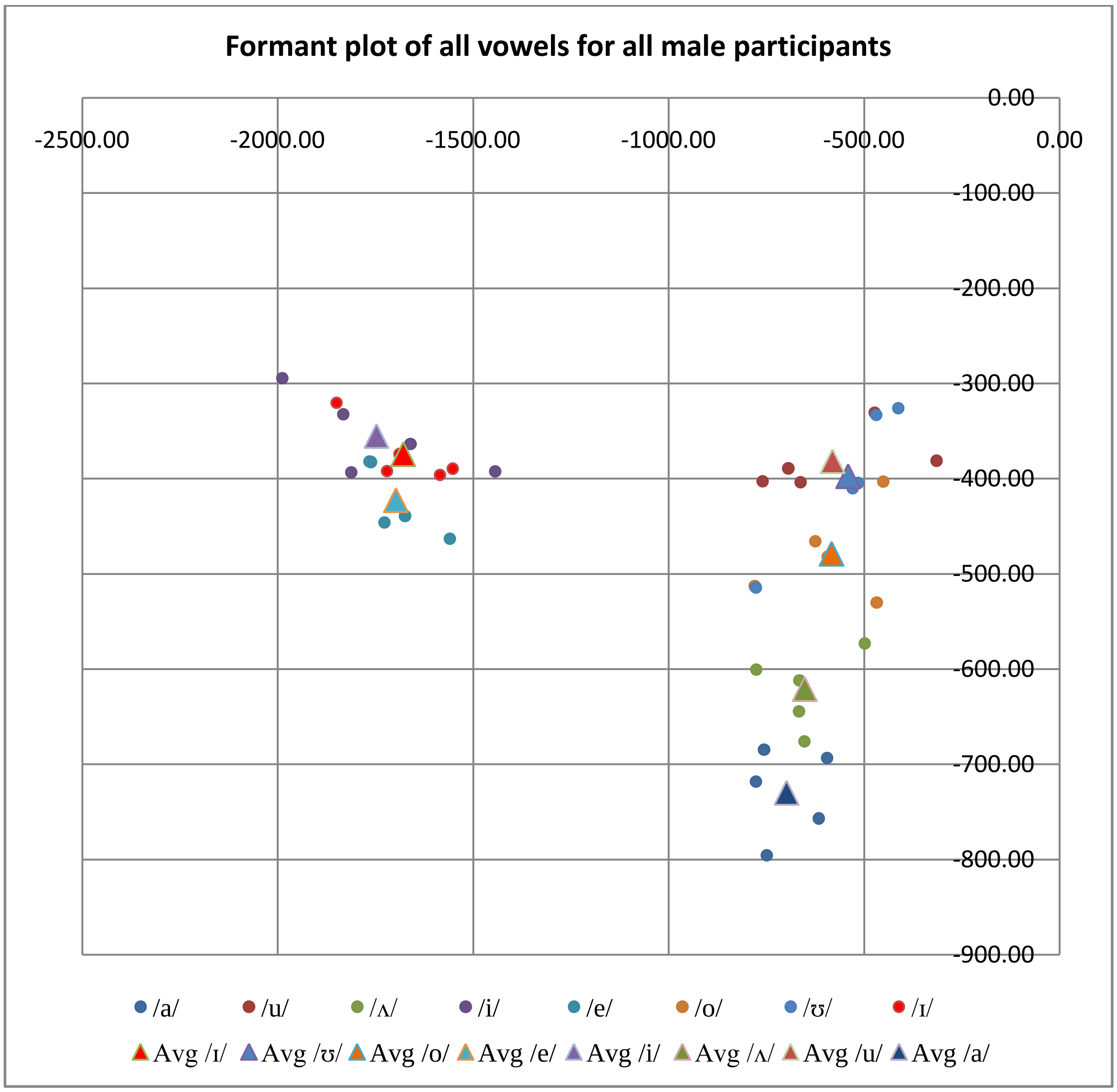
Table 3.17 Averages of /ɪ/ for all male participants

Averages of /ɪ/ for all male participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
SS26M	Total Avg /ɪ/	320.32	2169.52	2582.26	-1849.20	-320.32
PL26M	Total Avg /ɪ/	389.70	1942.29	2570.80	-1552.59	-389.70
PR22M	Total Avg /ɪ/	396.19	1981.30	2465.28	-1585.11	-396.19
JY26M	Total Avg /ɪ/	374.20	2062.44	2481.57	-1688.24	-374.20
BS26M	Total Avg /ɪ/	392.16	2112.56	2493.71	-1720.40	-392.16
All males	**Consolidated Average**	**374.52**	**2053.62**	**2518.72**	**-1679.11**	**-374.52**

3.3.9 Formant plot of all vowels for all male participants

The data listed in tables 3.10 to 3.17 have been plotted on the horizontal and vertical axis in figure 3.10. From the graph where negative values of F2-F1 and F1 have been plotted on the x-axis and y-axis respectively, it can be observed that there is some interspeaker variation.

Figure 3.10 Formant plot of all vowels for all male participants



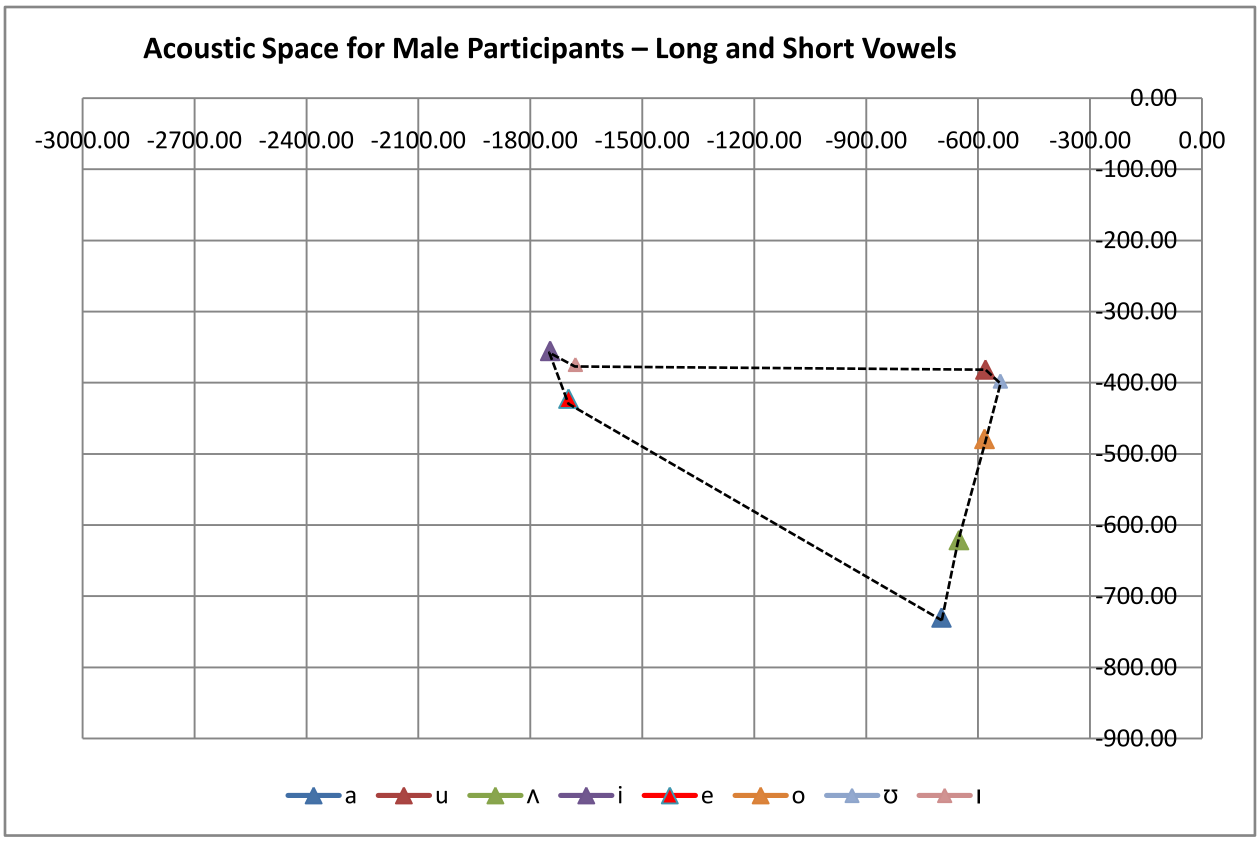
3.3.10 Acoustic Space for Male Participants – Long and Short Vowels

. The following table lists the consolidated averages of all eight oral vowels which is then plotted in the graph to present the overall acoustic space of oral vowels for male participants.

Table 3.18 Consolidated Formant Averages for Male Participants

Consolidated Averages for Male Participants - Long and Short Vowels						
		F1	**F2**	**F3**	**-(F2-F1)**	**-F1**
All males	**Consolidated Average /a/**	729.90	1428.01	2536.45	-698.11	-729.90
All males	**Consolidated Average /u/**	381.59	962.03	2419.53	-580.44	-381.59
All males	**Consolidated Average /ʌ/**	621.22	1272.77	2383.25	-651.56	-621.22
All males	**Consolidated Average /i/**	355.29	2102.60	2868.69	-1747.32	-355.29
All males	**Consolidated Average /e/**	422.59	2120.42	2762.87	-1697.84	-422.59
All males	**Consolidated Average /o/**	478.85	1061.76	2492.70	-582.90	-478.85
All males	**Consolidated Average /ʊ/**	397.59	938.00	2508.15	-540.41	-397.59
All males	**Consolidated Average /ɪ/**	374.52	2053.62	2518.72	-1679.11	-374.52

Figure 3.11 Acoustic Space for Male Participants



3.4 Female Participants

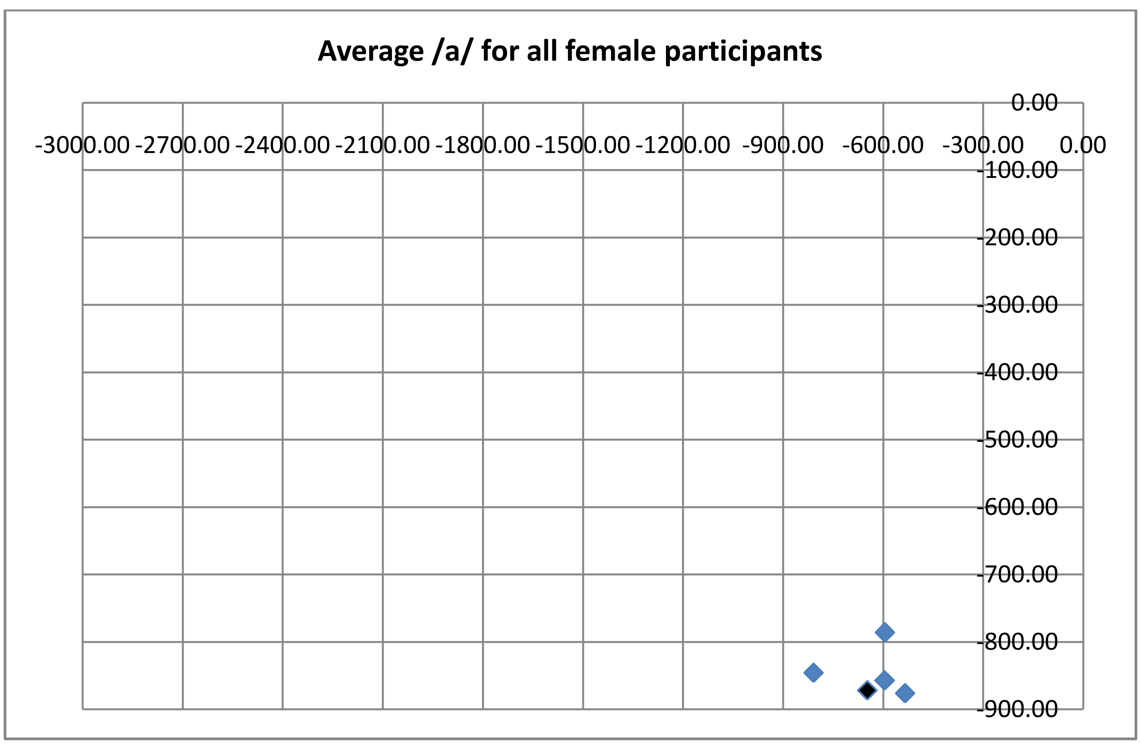
A total of six female native speakers of Nepali participated in this study. The sections that follow present an account of the averages of all six vowels on the basis of data elicited from them. The table lists the average values of six repetitions of every female speaker and the scatter plot represents that vowels location in the vowel space.

3.4.1 Vowel /a/ - All female speakers

Table 3.19 Averages of /a/ for all female participants

Averages of /a/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /a/	901.97	1573.32	2607.79	-671.35	-901.97
LL27F	Total Avg /a/	846.06	1654.88	2925.55	-808.82	-846.06
ML21F	Total Avg /a/	964.16	1640.43	2842.15	-676.27	-964.16
PP24F	Total Avg /a/	876.41	1410.86	2549.95	-534.45	-876.41
PTP23F	Total Avg /a/	786.25	1381.08	2634.05	-594.83	-786.25
TB23F	Total Avg /a/	857.33	1452.42	2360.90	-595.09	-857.33
All females	**Consolidated Average /a/**	872.03	1518.83	2653.40	-646.80	-872.03

Figure 3.12 Vowel /a/ plot for female participants

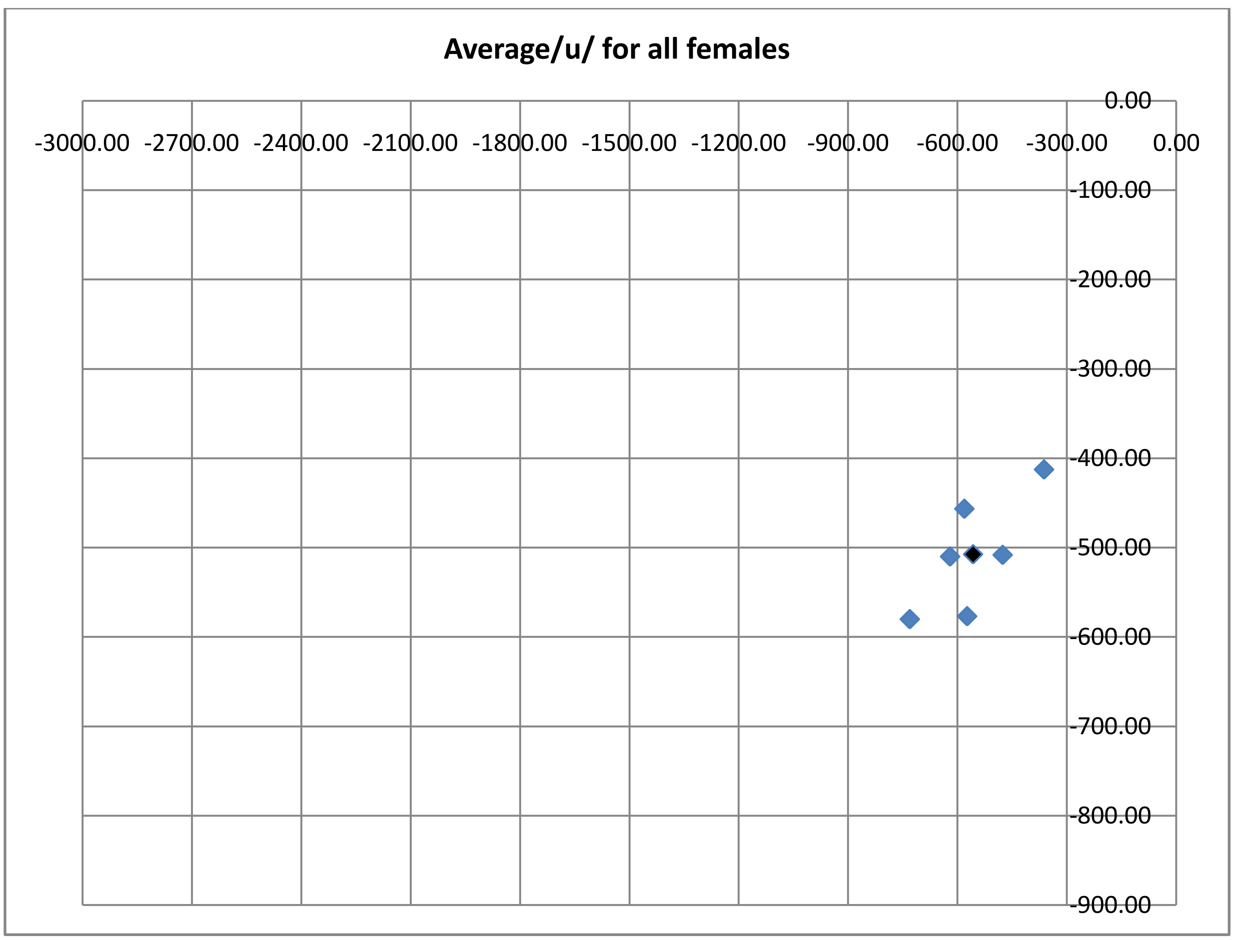


3.4.2 Vowel /u/ -All female speakers

Table 3.20 Averages of /u/ for all female participants

Averages of /u/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /u/	508.27	984.66	2593.45	-476.39	-508.27
LL27F	Total Avg /u/	580.20	1310.86	2850.46	-730.67	-580.20
ML21F	Total Avg /u/	510.09	1130.52	3063.58	-620.44	-510.09
PP24F	Total Avg /u/	456.69	1037.96	2708.56	-581.27	-456.69
PTP23F	Total Avg /u/	412.72	775.80	1941.18	-363.08	-412.72
TB23F	Total Avg /u/	576.91	1150.58	2976.55	-573.67	-576.91
All females	**Consolidated Average /u/**	507.48	1065.07	2688.96	-557.59	-507.48

Figure 3.13 Vowel /u/ plot for female participants

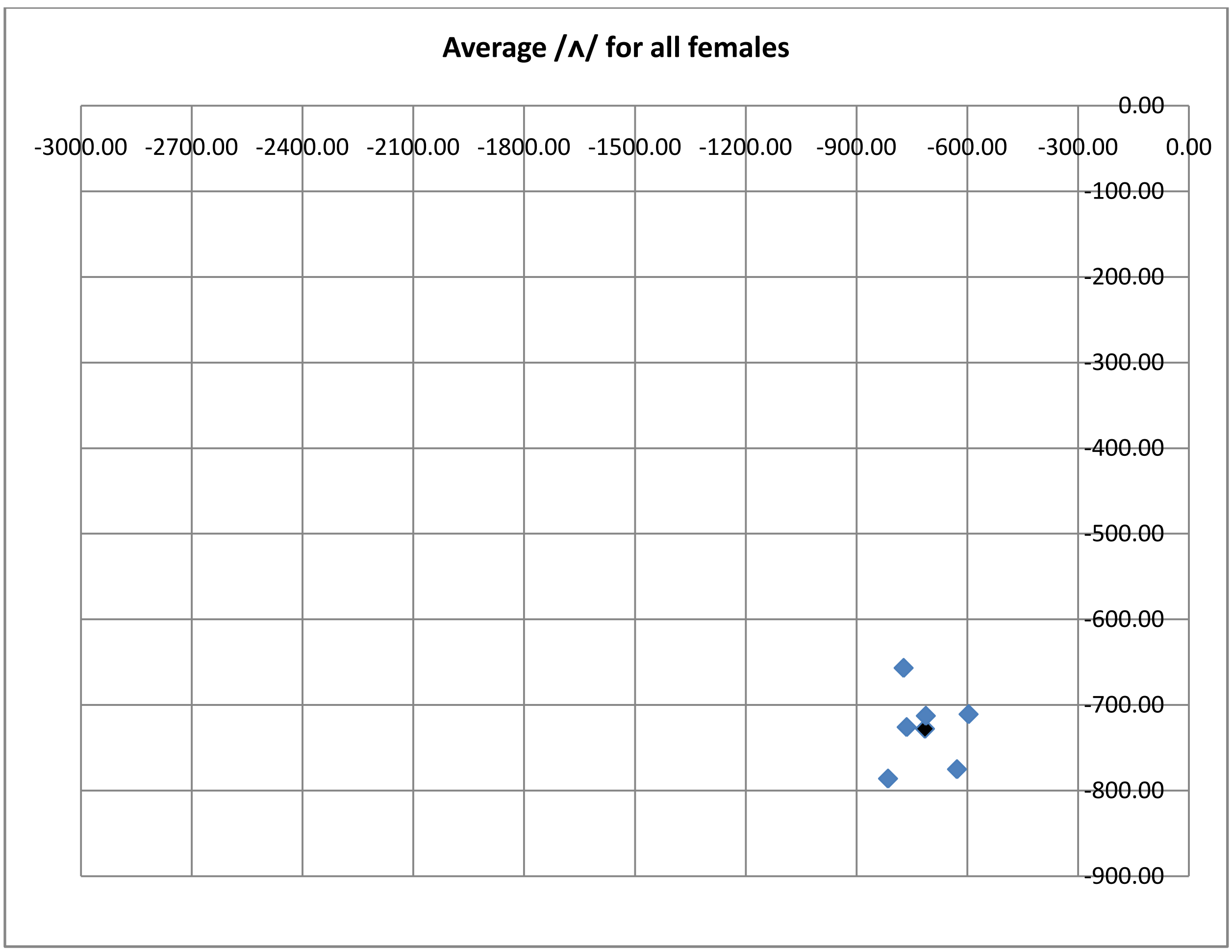


3.4.3 Vowel /ʌ/ - All female speakers

Table 3.21 Averages of /ʌ/ for all female participants

Averages of /ʌ/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /ʌ/	726.00	1489.94	2550.21	-763.94	-726.00
LL27F	Total Avg /ʌ/	656.78	1428.92	2632.58	-772.14	-656.78
ML21F	Total Avg /ʌ/	786.19	1600.65	2831.64	-814.47	-786.19
PP24F	Total Avg /ʌ/	710.92	1306.97	2565.59	-596.05	-710.92
PTP23F	Total Avg /ʌ/	712.79	1424.74	2653.80	-711.95	-712.79
TB23F	Total Avg /ʌ/	775.23	1402.69	2866.87	-627.46	-775.23
All females	**Consolidated Average /ʌ/**	727.98	1442.32	2683.45	-714.34	-727.98

Figure 3.14 Vowel /ʌ/ plot for female participants

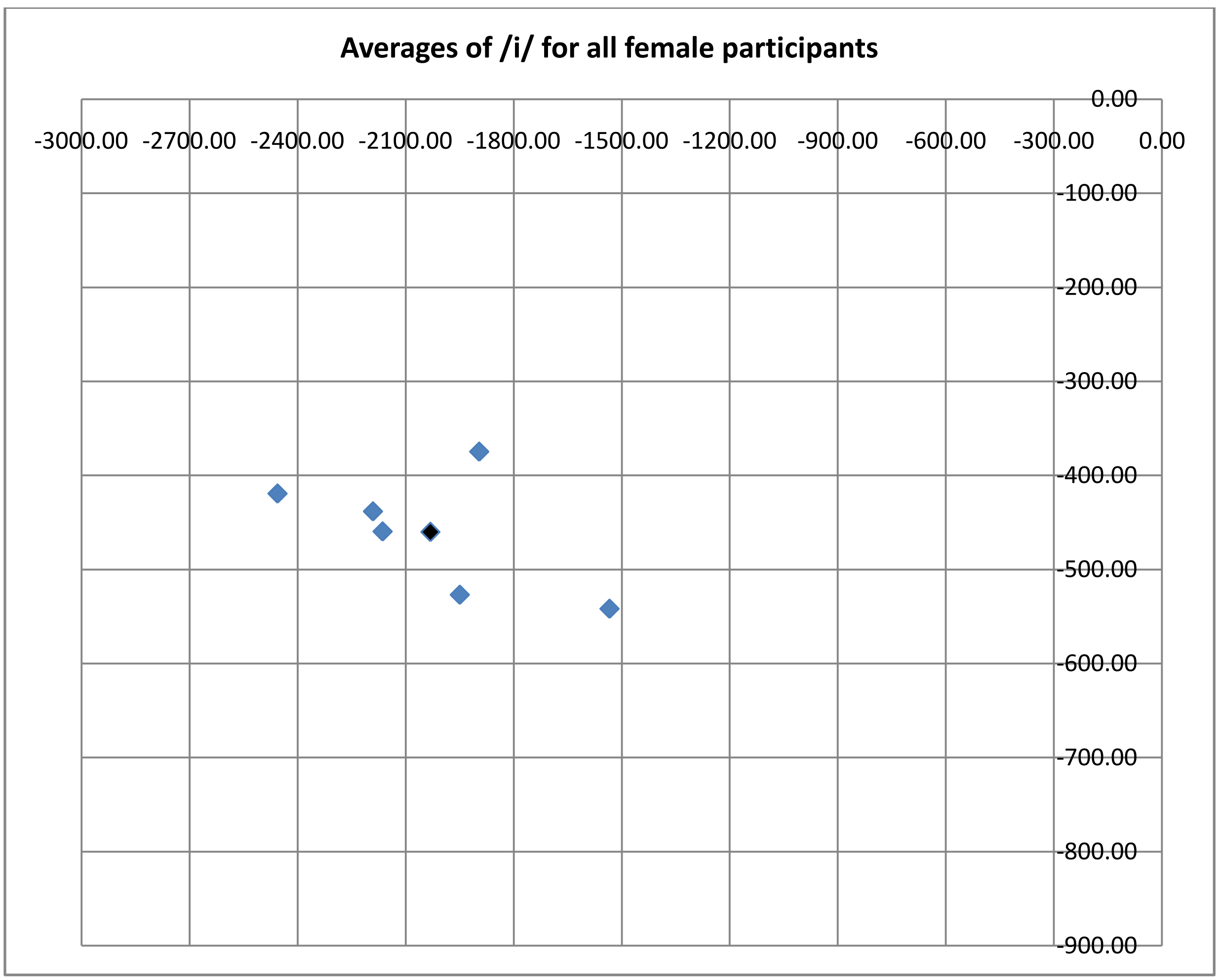


3.4.4 Vowel /i/ - All female speakers

Table 3.22 Averages of /i/ for all female participants

Averages of /i/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /i/	541.85	2075.79	2697.63	-1533.94	-541.85
LL27F	Total Avg /i/	374.93	2270.49	2904.05	-1895.56	-374.93
ML21F	Total Avg /i/	419.47	2874.74	3590.96	-2455.27	-419.47
PP24F	Total Avg /i/	438.39	2628.77	3113.58	-2190.39	-438.39
PTP23F	Total Avg /i/	527.02	2476.38	3312.62	-1949.36	-527.02
TB23F	Total Avg /i/	459.73	2623.39	3454.46	-2163.66	-459.73
All females	**Consolidated Average /i/**	460.23	2491.59	3178.88	-2031.36	-460.23

Figure 3.15 Vowel /i/ plot for female participants

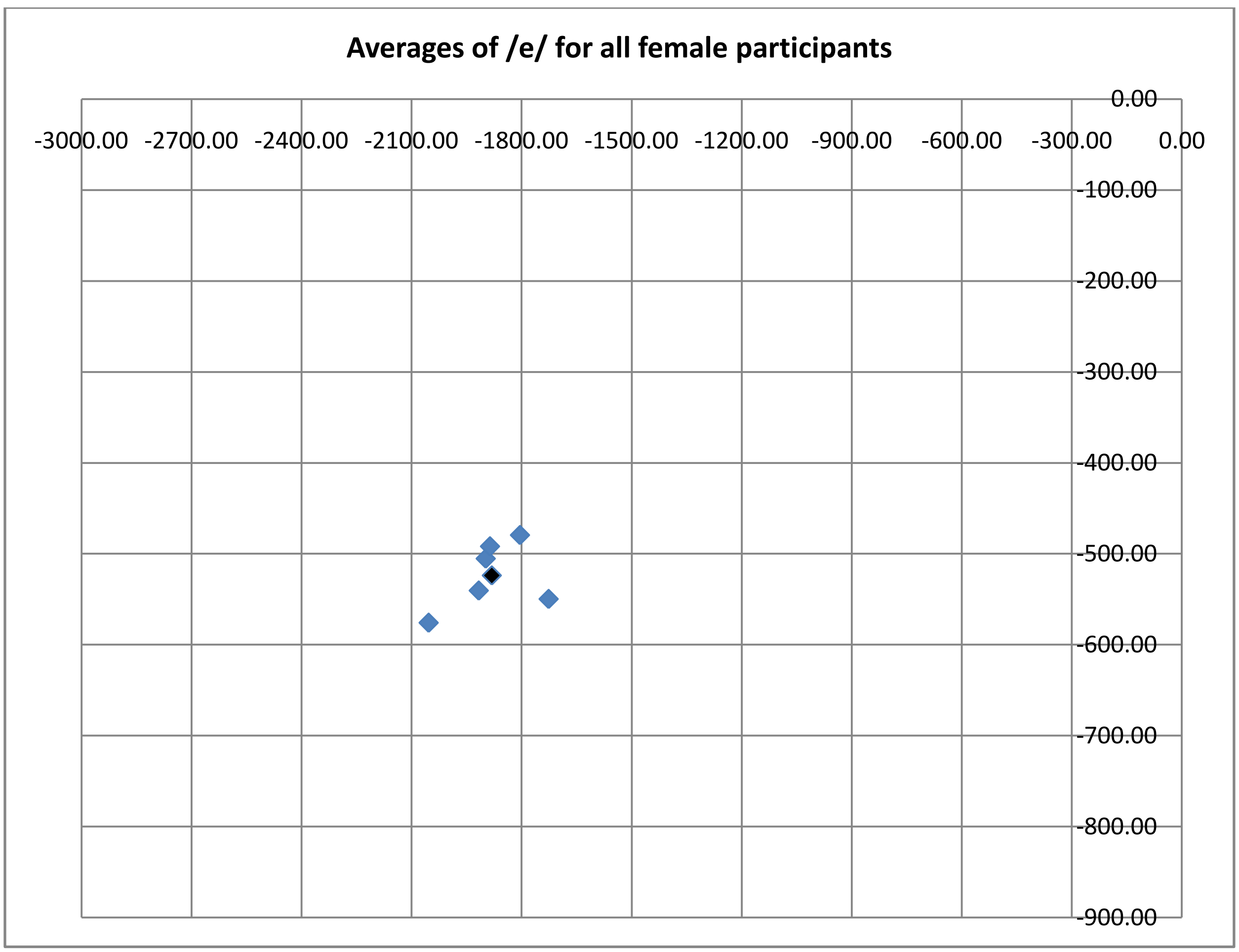


3.4.5 Vowel /e/ - All female speakers

Table 3.23 Averages of /e/ for all female participants

Averages of /e/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /e/	549.61	2276.15	2897.09	-1726.55	-549.61
LL27F	Total Avg /e/	505.31	2403.44	2985.30	-1898.13	-505.31
ML21F	Total Avg /e/	575.66	2629.48	3213.43	-2053.81	-575.66
PP24F	Total Avg /e/	491.87	2378.35	2975.43	-1886.48	-491.87
PTP23F	Total Avg /e/	479.52	2284.21	2965.65	-1804.69	-479.52
TB23F	Total Avg /e/	540.38	2457.56	3204.69	-1917.18	-540.38
All females	**Consolidated Average /e/**	523.72	2404.87	3040.26	-1881.14	-523.72

Figure 3.16 Vowel /e/ plot for female participants

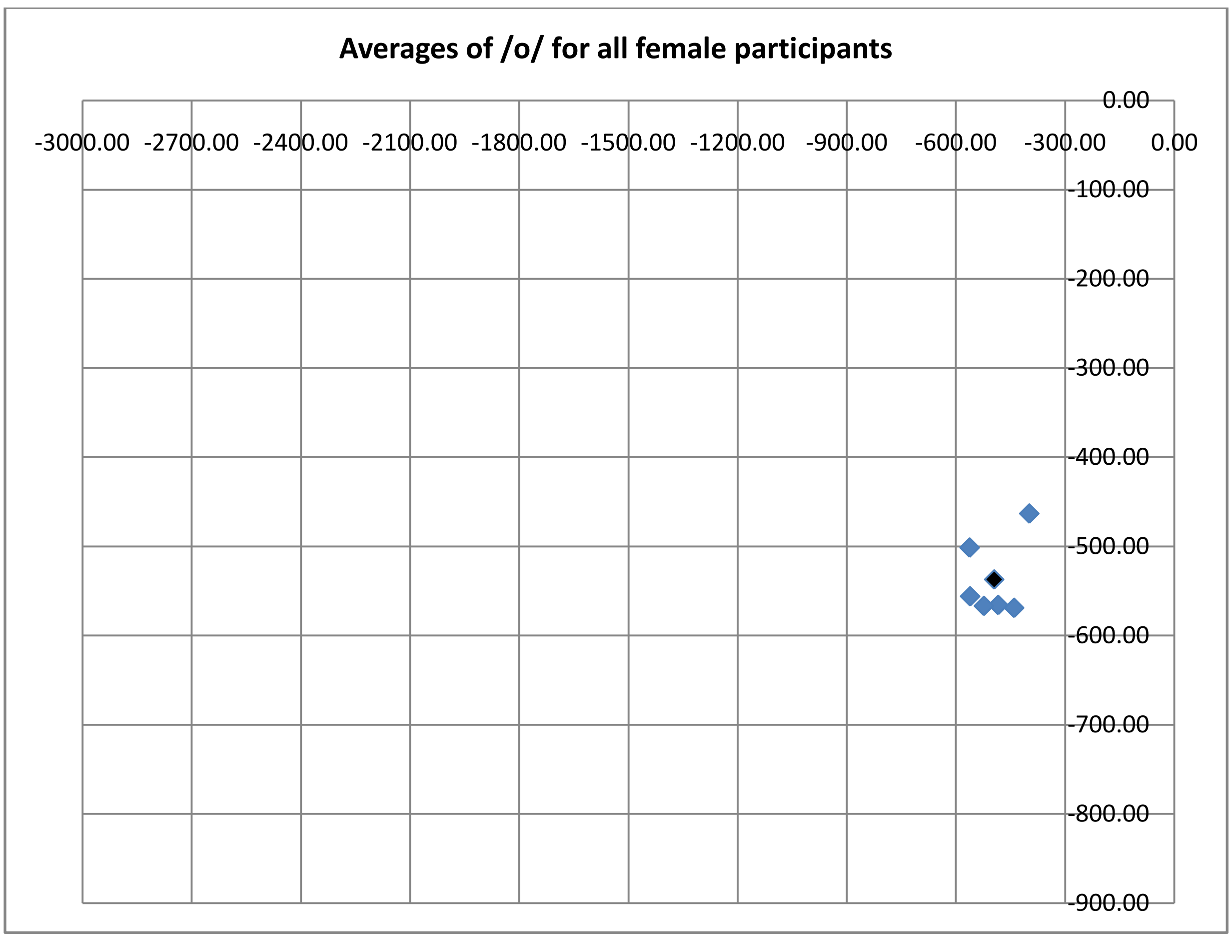


3.4.6 Vowel /o/ - All female speakers

Table 3.24 Averages of /o/ for all female participants

Averages of /o/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /o/	565.76	1049.71	2767.50	-483.95	-565.76
LL27F	Total Avg /o/	556.04	1116.91	2789.46	-560.87	-556.04
ML21F	Total Avg /o/	566.78	1089.87	2822.71	-523.09	-566.78
PP24F	Total Avg /o/	501.45	1063.64	2838.06	-562.19	-501.45
PTP23F	Total Avg /o/	463.32	861.97	2424.79	-398.65	-463.32
TB23F	Total Avg /o/	569.00	1009.25	3297.99	-440.24	-569.00
All females	**Consolidated Average /o/**	537.06	1031.89	2823.42	-494.83	-537.06

Figure 3.17 Vowel /o/ plot for female participants

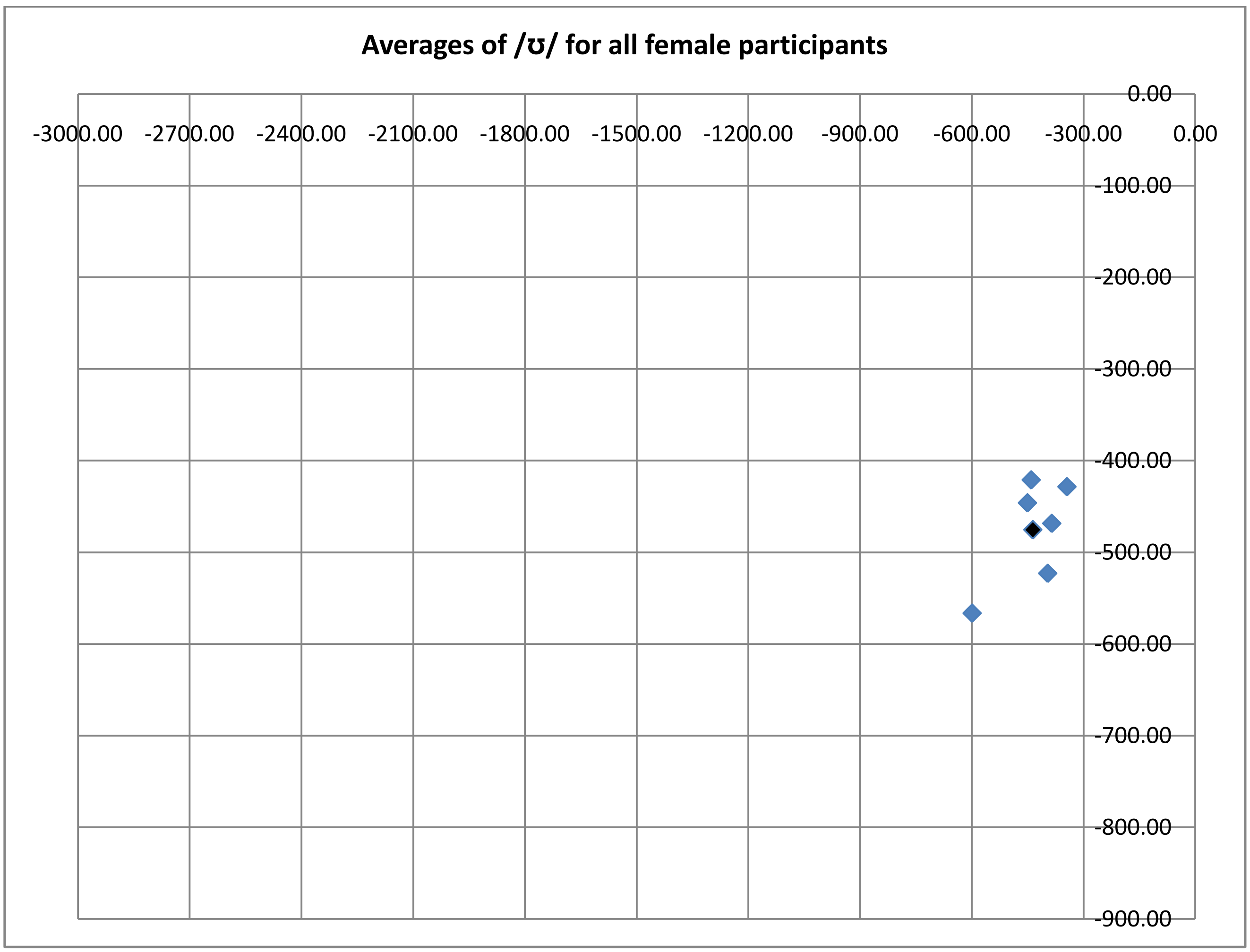


3.4.7 Vowel /ʊ/ - All female speakers

Table 3.25 Averages of /ʊ/ for all female participants

Averages of /ʊ/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /ʊ/	522.95	919.44	2577.29	-396.49	-522.95
LL27F	Total Avg /ʊ/	566.39	1165.94	3059.01	-599.55	-566.39
ML21F	Total Avg /ʊ/	446.05	896.94	2904.30	-450.89	-446.05
PP24F	Total Avg /ʊ/	420.99	861.84	2670.45	-440.85	-420.99
PTP23F	Total Avg /ʊ/	428.43	773.19	2394.62	-344.76	-428.43
TB23F	Total Avg /ʊ/	468.43	854.03	3012.91	-385.60	-468.43
All females	**Consolidated Average /ʊ/**	475.54	911.90	2769.76	-436.36	-475.54

Figure 3.18 Vowel /ʊ/ plot for female participants

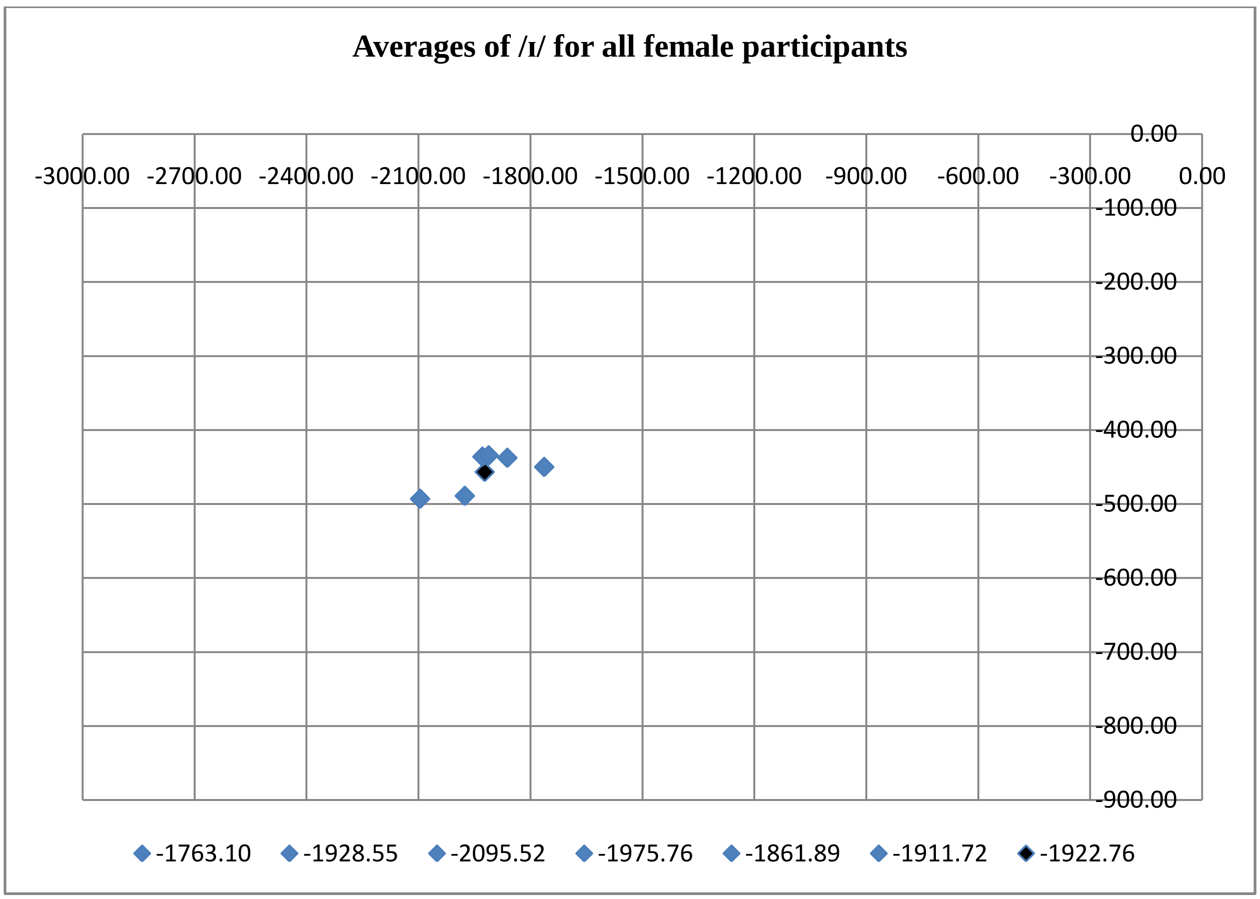


3.4.8 Vowel /ɪ/ - All female speakers

Table 3.26 Averages of /ɪ/ for all female participants

Averages of /ɪ/ for all female participants						
Speaker		**F1**	**F2**	**F3**	**-(F2-F1)**	**-F1**
DG22F	Total Avg /ɪ/	450.26	2213.35	2717.50	-1763.10	-450.26
LL27F	Total Avg /ɪ/	436.35	2364.90	2766.40	-1928.55	-436.35
ML21F	Total Avg /ɪ/	493.31	2588.84	3070.94	-2095.52	-493.31
PP24F	Total Avg /ɪ/	489.33	2465.10	2979.28	-1975.76	-489.33
PTP23F	Total Avg /ɪ/	437.90	2299.79	2756.15	-1861.89	-437.90
TB23F	Total Avg /ɪ/	434.59	2346.32	2995.51	-1911.72	-434.59
All females	**Consolidated Average /ɪ/**	456.96	2379.72	2880.96	-1922.76	-456.96

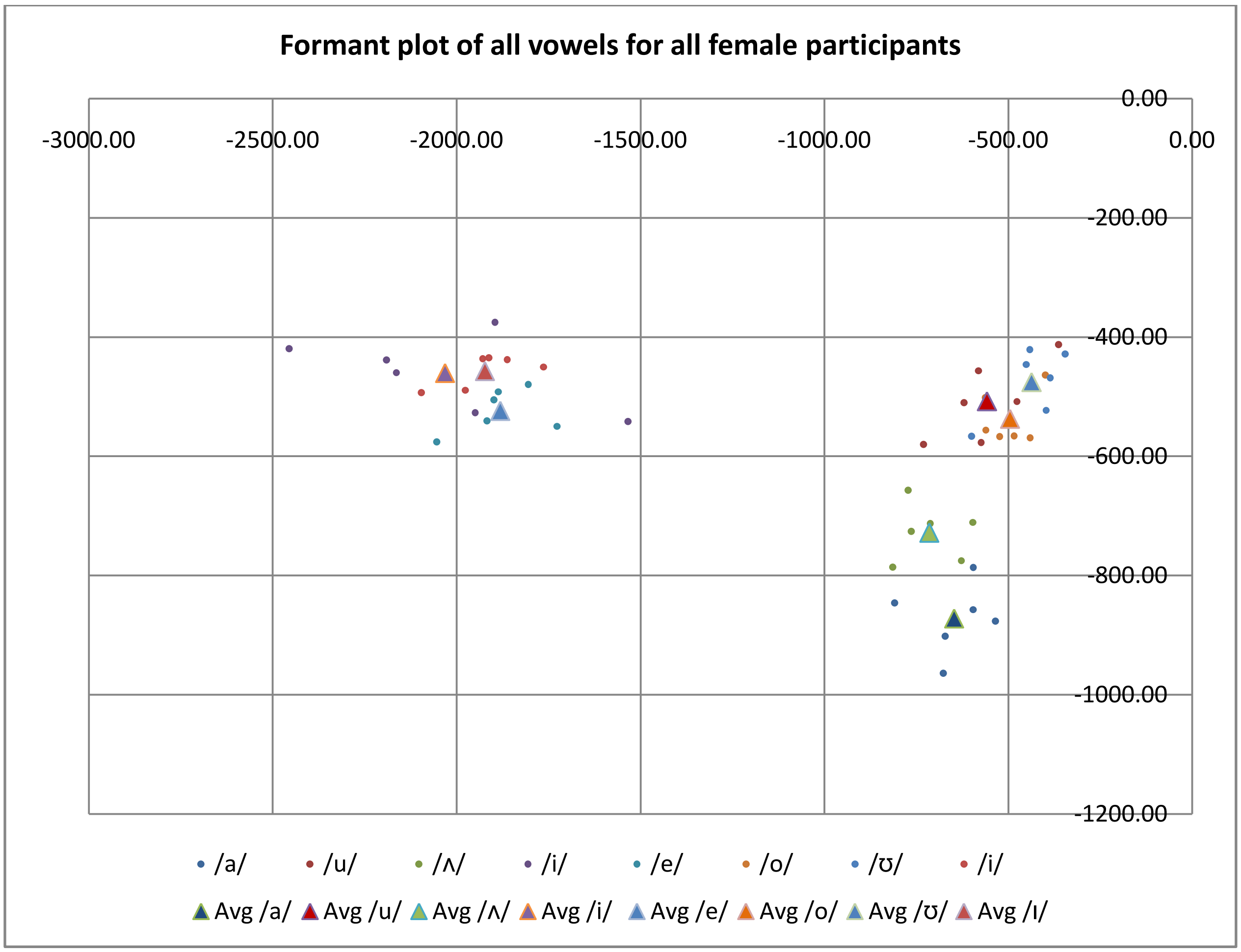
Figure 3.19 Vowel /ɪ/ plot for female participants



3.4.9 Formant plot of all vowels for all female participants

The data presented in tables 3.19 to 3.26 can be plotted in the manner similar to the one done for male participants to observe the location of vowels in the vowel space according to their acoustic properties. Figure 3.20 presents the plot of negative values of F1 against negative values of F2-F1 of all eight oral vowels for female speakers.

Figure 3.20 Formant plot of all vowels for all female participants

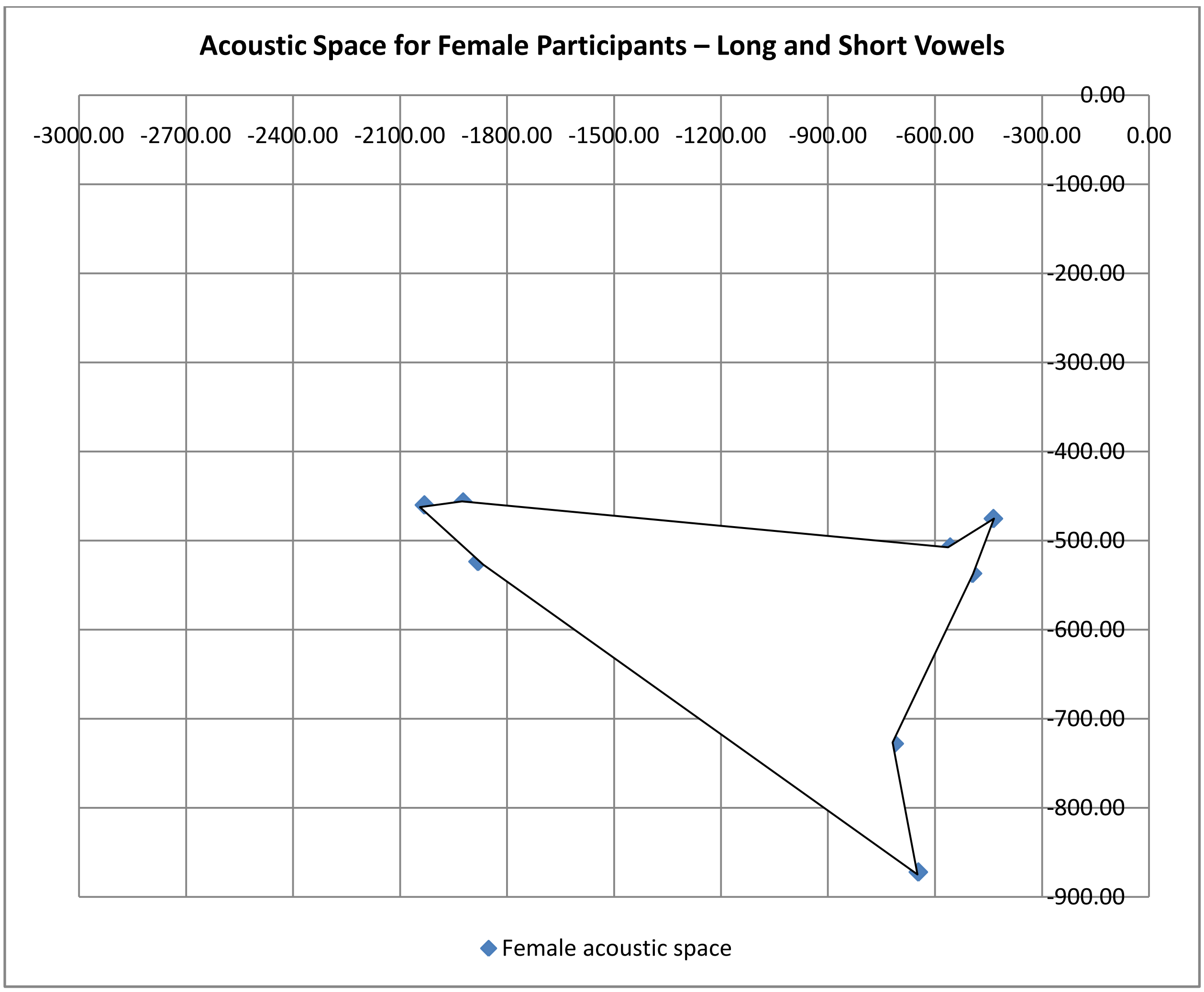


3.4.10 Acoustic Space for Female Participants – Long and Short Vowels

Table 3.27 Consolidated Formant Averages for Female Participants

Consolidated Averages for Female Participants - Long and Short Vowels						
All females	**Consolidated Average /a/**	872.03	1518.83	2653.40	-646.80	-872.03
All females	**Consolidated Average /u/**	507.48	1065.07	2688.96	-557.59	-507.48
All females	**Consolidated Average /ʌ/**	727.98	1442.32	2683.45	-714.34	-727.98
All females	**Consolidated Average /i/**	460.23	2491.59	3178.88	-2031.36	-460.23
All females	**Consolidated Average /e/**	523.72	2404.87	3040.26	-1881.14	-523.72
All females	**Consolidated Average /o/**	537.06	1031.89	2823.42	-494.83	-537.06
All females	**Consolidated Average /ʊ/**	475.54	911.90	2769.76	-436.36	-475.54
All females	**Consolidated Average /ɪ/**	456.96	2379.72	2880.96	-1922.76	-456.96

Figure 3.21 Acoustic Space for Female Participants – Long and Short Vowels

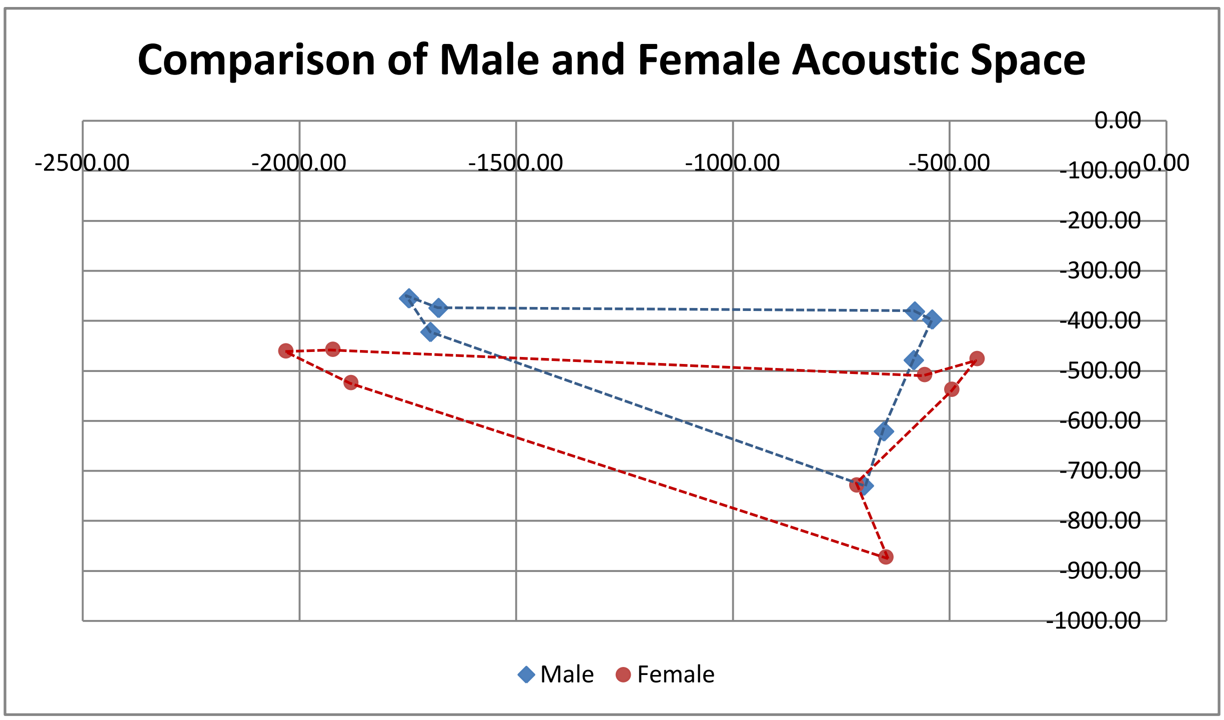


3.5 Comparision of Male and Female Acoustic Space –Peripheral Vowels

Table 3.28 Comparison of Formants for Male and Female Participants

Consolidated Averages for Male and Female Participants - Long and Short Vowels						
		F1	**F2**	**F3**	**-(F2-F1)**	**-F1**
All males	**Consolidated Average /a/**	729.90	1428.01	2536.45	-698.11	-729.90
All males	**Consolidated Average /u/**	381.59	962.03	2419.53	-580.44	-381.59
All males	**Consolidated Average /ʌ/**	621.22	1272.77	2383.25	-651.56	-621.22
All males	**Consolidated Average /i/**	355.29	2102.60	2868.69	-1747.32	-355.29
All males	**Consolidated Average /e/**	422.59	2120.42	2762.87	-1697.84	-422.59
All males	**Consolidated Average /o/**	478.85	1061.76	2492.70	-582.90	-478.85
All males	**Consolidated Average /ʊ/**	397.59	938.00	2508.15	-540.41	-397.59
All males	**Consolidated Average /ɪ/**	374.52	2053.62	2518.72	-1679.11	-374.52
All females	**Consolidated Average /a/**	872.03	1518.83	2653.40	-646.80	-872.03
All females	**Consolidated Average /u/**	507.48	1065.07	2688.96	-557.59	-507.48
All females	**Consolidated Average /ʌ/**	727.98	1442.32	2683.45	-714.34	-727.98
All females	**Consolidated Average /i/**	460.23	2491.59	3178.88	-2031.36	-460.23
All females	**Consolidated Average /e/**	523.72	2404.87	3040.26	-1881.14	-523.72
All females	**Consolidated Average /o/**	537.06	1031.89	2823.42	-494.83	-537.06
All females	**Consolidated Average /ʊ/**	475.54	911.90	2769.76	-436.36	-475.54
All females	**Consolidated Average /ɪ/**	456.96	2379.72	2880.96	-1922.76	-456.96

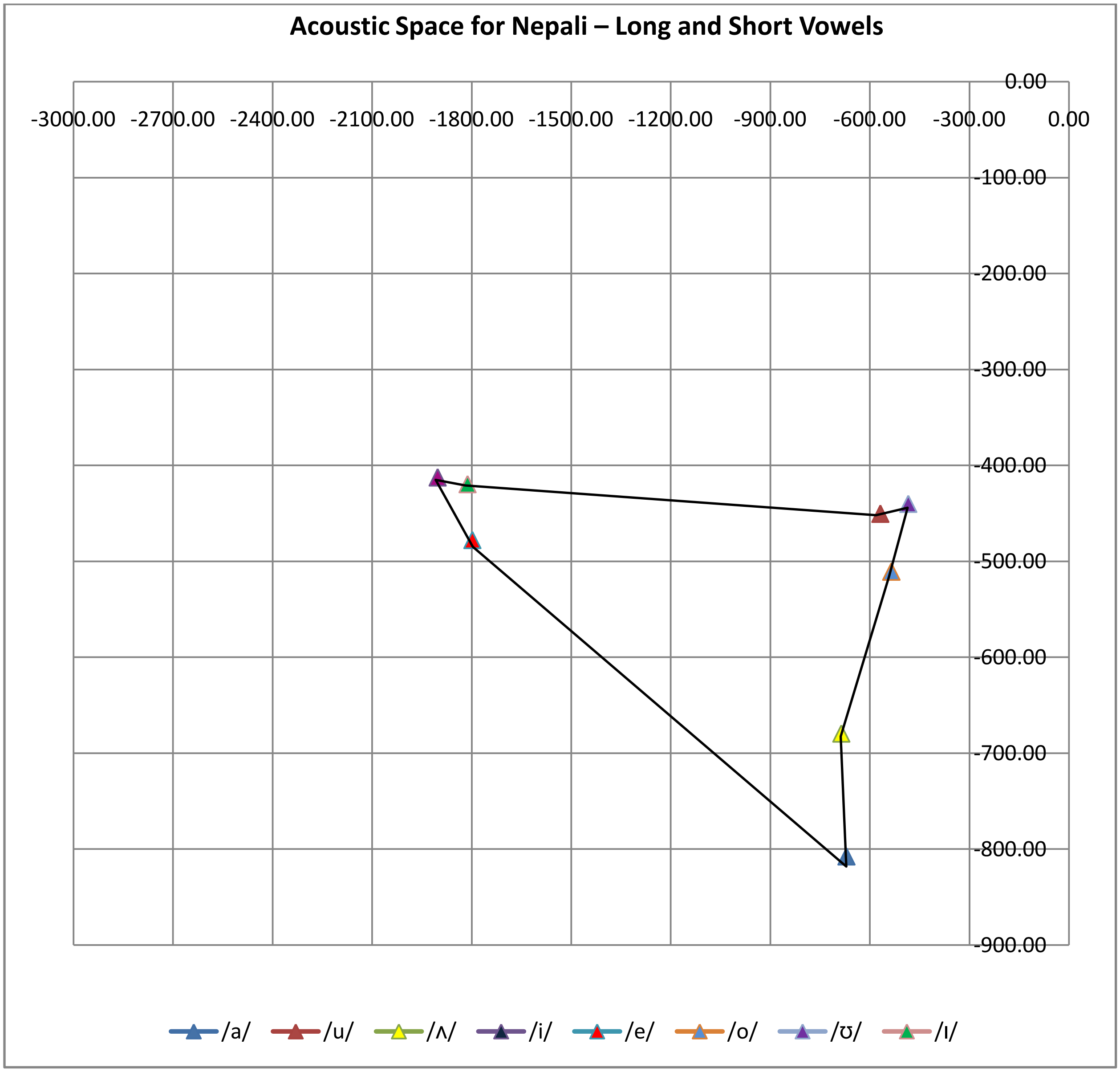
Figure 3.22 Comparison of Male and Female Acoustic Space



3.6 Acoustic Space for Nepali – Long and Short Vowels

After calculating the average F1 and F2 frequencies for all vowels of all participants, their negative values are plotted on a graph as suggested by Hayward (2000) to determine the acoustic space of Nepal vowels in the Darjeeling variety.

Figure 3.23 Acoustic Space for Nepali vowels in the Darjeeling variety



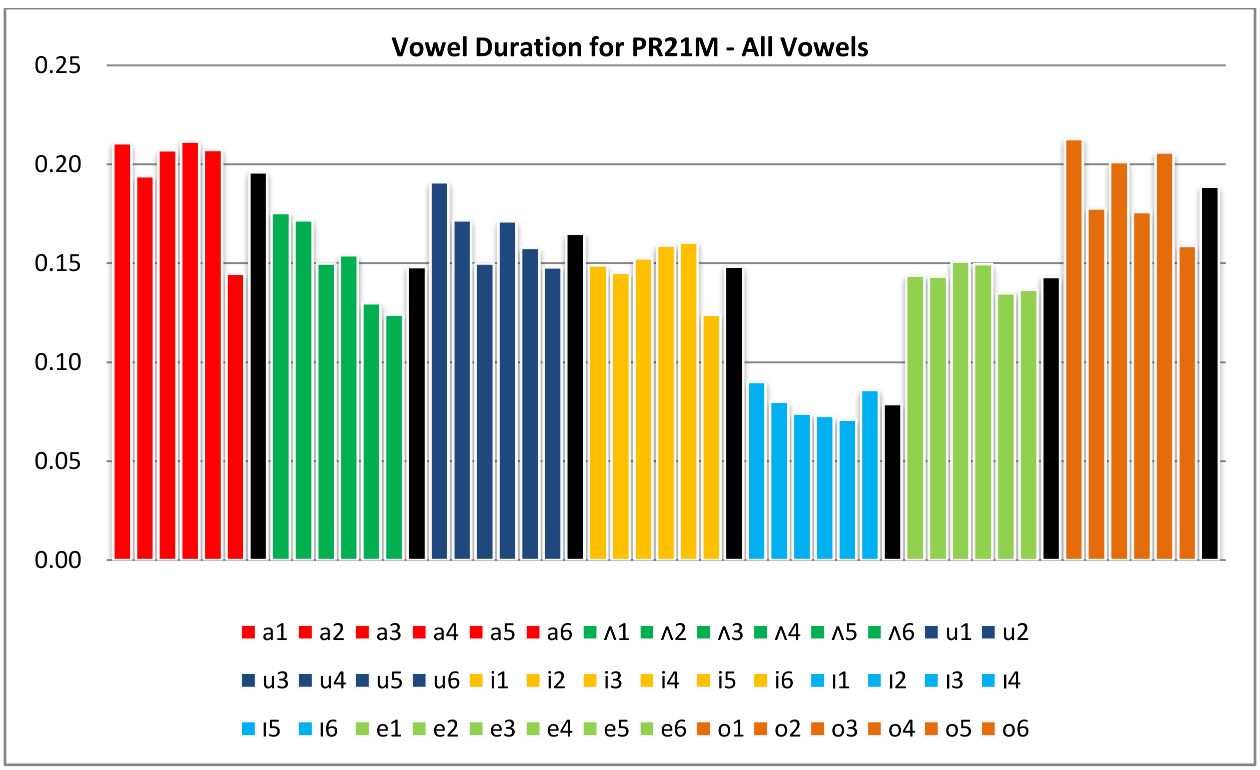
3.7 Vowel Duration

The present section of this chapter looks into the durational properties of the vowels of Nepali as spoken in the Darjeeling district of West Bengal. The table below outlines the duration of a vowel in all six repetitions of a randomly selected subject and lists the overall average. The figure below gives a graphical representation of vowel duration for the selected subject.

Table 3.29 Vowel Duration of all vowels for PR21M

	Vowel Duration - All Vowels -PR21M							
Repetition	**a**	**ʌ**	**u**	**ʊ**	**i**	**ɪ**	**e**	**o**
1	0.21	0.18	0.19	0.09	0.15	0.09	0.14	0.21
2	0.19	0.15	0.17	0.09	0.15	0.08	0.14	0.18
3	0.21	0.15	0.15	0.08	0.15	0.07	0.15	0.20
4	0.21	0.15	0.17	0.08	0.16	0.07	0.15	0.18
5	0.21	0.13	0.16	0.09	0.16	0.07	0.13	0.21
6	0.14	0.12	0.15	0.09	0.12	0.09	0.14	0.16
Average	**0.20**	**0.15**	**0.16**	**0.09**	**0.15**	**0.08**	**0.14**	**0.19**

Figure 3.24 Vowel Duration of all for all vowels for PR21M



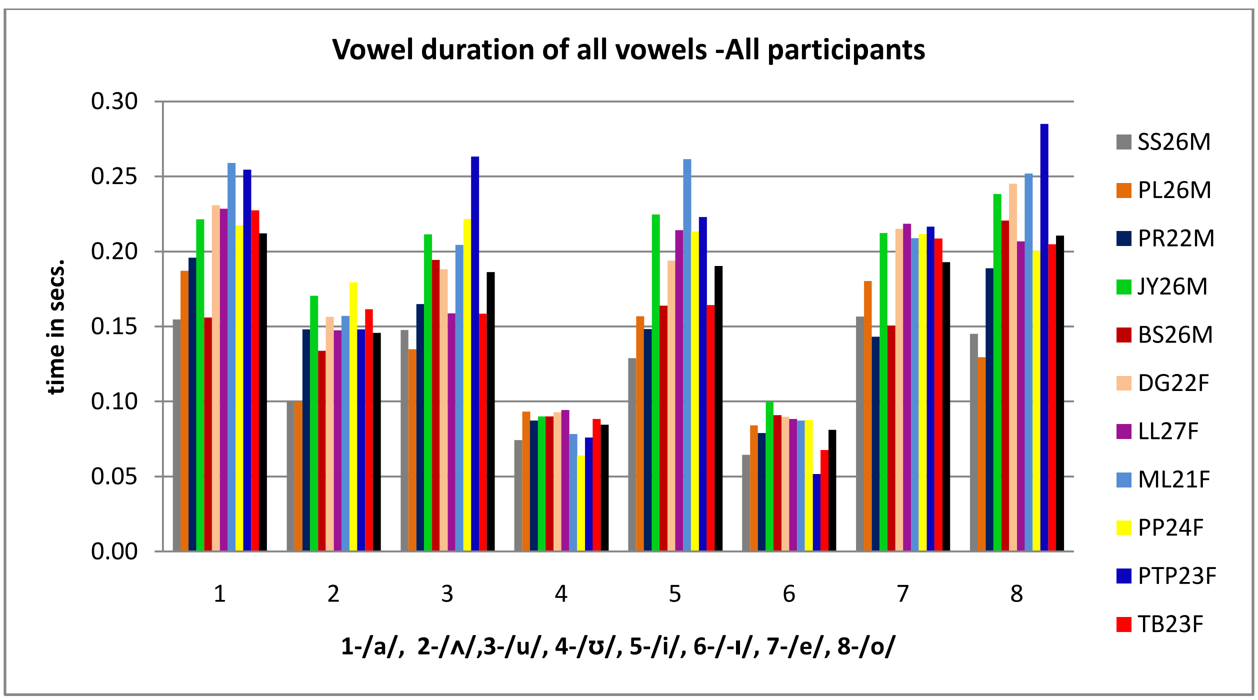
3.7.1 Vowel Duration of all vowels for all participants

Similarly averages of all vowels for all speakers were calculated and the overall consolidated average vowel duration is listed in the table below.

Table 3.30 Vowel Duration of all participants

Speaker	a	ʌ	u	ʊ	i	ɪ	e	o
SS26M	0.15	0.10	0.15	0.07	0.13	0.06	0.16	0.15
PL26M	0.19	0.10	0.13	0.09	0.16	0.08	0.18	0.13
PR22M	0.20	0.15	0.16	0.09	0.15	0.08	0.14	0.19
JY26M	0.22	0.17	0.21	0.09	0.22	0.10	0.21	0.24
BS26M	0.16	0.13	0.19	0.09	0.16	0.09	0.15	0.22
DG22F	0.23	0.16	0.19	0.09	0.19	0.09	0.22	0.25
LL27F	0.23	0.15	0.16	0.09	0.21	0.09	0.22	0.21
ML21F	0.26	0.16	0.20	0.08	0.26	0.09	0.21	0.25
PP24F	0.22	0.18	0.22	0.06	0.21	0.09	0.21	0.20
PTP23F	0.25	0.15	0.26	0.08	0.22	0.05	0.22	0.29
TB23F	0.23	0.16	0.16	0.09	0.16	0.07	0.21	0.20
Average	0.21	0.15	0.19	0.08	0.19	0.08	0.19	0.21

Figure 3.25 Vowel Duration of all participants



On the basis of the data presented in the above table and column chart, some tentative conclusions regarding vowel duration in this particular regional variety of Nepali can be arrived at. The duration of the long vowel /a/ ranges from 0.15 seconds to 0.26 seconds. The average duration for vowel /a/ is 0.23 seconds. In contrast, the length of vowel /ʌ/ lies in the range of 0.10 seconds to 0.18 seconds and the overall average length for /ʌ/ is 0.15 seconds. The length of the high-back vowel /u/ ranges between 0.13 seconds to 0.26 seconds while the length of its shorter counterpart /ʊ/ ranges between 0.06 seconds to 0.09 seconds. The overall average duration for /u/ and /ʊ/ are 0.19 seconds and 0.08 seconds respctively. The high-front vowel /i/ has its duration ranging from 0.13 seconds to 0.26 seconds. Its average duration is 0.19 seconds. Meanwhile, its shorter counterpart /ɪ/ has its duration ranging from 0.05 seconds to 0.10 seconds and its overall for all speakers is 0.08 seconds. Th duration of vowel /e/ ranges between 0.14 seconds to 0.22 seconds and its average for all speakers is 0.19 seconds. Finally, the duration of vowel /o/ ranges between 0.13 seconds to 0.29 seconds. The average duration of vowel /o/ for all speakers in 0.21 seconds.

Analysis of duration of Nepali vowels tentatively suggests that the duration of longs vowels /a/, /u/ and /i/ are nearly double the length of its shorter counterparts /ʌ/, /ʊ/ and /ɪ/, respectively. Moreover, the contrast in duration of the vowels /i/ and /u/ with /ɪ/ and /ʊ/ reveals that distinction in length is more prominent in the case of peripheral vowels. The length of a vowel, however, is also dependent on the nature of the following consonant. In the present study, the vowel phonemes selected for analysis appeared in the CVC context and the consonants were voiceless stops. For a better understanding of vowel duration, the present results need to be verified from a larger database.

3.8 Fundamental Frequency (F0) or Pitch

Pitch is the auditory correlate of the acoustic feature denoted by F0 values. The auditory sensation bears a direct correlation to the acoustic correlate – the higher the frquency, higher is the pitch. The pitch of vowels of Nepali of the Darjeeling variety in this study is done of the basis of F0 values obtained after spectrographic analysis of the voice samples. A point to be noted here is that, though every word had six repetitions which was recorded and analyzed, only the average F0 values of the middle four repetitions have been taken into account for stable readings as the pitch of our voice decreases at the end of an utterance. The tables and figures in the subsequent sub-sections illustrate the F0 values obtained after spectrographic analysis. Data is tabulated and graphically represented separately for male and female participants and then a consolidated average is average is presented.

The table given below lists the average F0 values for long and short vowels of all male participants. Of the six repetitions spectrographically analzyed, values of the middle four are taken and their averages computed for all male speakers

Table 3.31 Average F0 values for male participants

Average F0 values for Male Participants									
Speaker	**Repetition**	**/a/**	**/ʌ/**	**/u/**	**/ʊ/**	**/i/**	**/ɪ/**	**/e/**	**/o/**
SS26M	2	127.96	126.34	167.84	148.47	139.06	161.07	132.96	141.52
SS26M	3	127.13	130.44	163.22	147.54	146.78	156.49	132.80	152.51
SS26M	4	130.58	125.92	161.09	147.77	137.77	155.70	131.34	137.84
SS26M	5	133.40	130.45	162.02	*	147.52	*	131.99	142.87
Average		**129.77**	**128.29**	**163.54**	**147.93**	**142.78**	**157.75**	**132.27**	**143.68**
PL26M	2	126.18	123.87	160.48	156.68	146.06	153.16	134.39	142.80
PL26M	3	128.72	121.92	158.92	152.89	139.77	152.43	131.75	139.23
PL26M	4	125.51	124.85	148.31	154.79	136.23	153.96	134.23	142.05
PL26M	5	122.47	114.61	147.25	153.03	137.77	151.64	130.03	143.86
Average		**125.72**	**121.31**	**153.74**	**154.35**	**139.96**	**152.80**	**132.60**	**141.98**
PR22M	2	137.12	142.33	152.07	165.85	148.92	152.98	142.44	143.39
PR22M	3	141.35	141.29	155.13	154.61	151.28	146.68	147.23	149.91
PR22M	4	130.20	136.41	140.11	149.82	139.65	136.77	132.24	135.47
PR22M	5	138.24	137.26	151.33	154.13	144.29	138.55	140.72	142.72
Average		**136.73**	**139.32**	**149.66**	**156.10**	**146.04**	**143.74**	**140.65**	**142.87**
JY25M	2	172.97	173.24	219.54	232.90	206.49	242.07	179.67	197.74
JY25M	3	178.15	169.10	224.21	235.90	197.36	233.01	183.03	195.64
JY25M	4	176.40	169.50	222.21	238.38	203.48	236.33	180.66	198.20
JY25M	5	175.85	169.42	216.29	235.79	199.63	216.26	182.11	200.88
Average		**175.84**	**170.32**	**220.56**	**235.74**	**201.74**	**231.92**	**181.37**	**198.11**
BS26M	2	150.25	141.51	195.73	178.98	181.93	156.89	152.89	158.59
BS26M	3	140.50	139.59	197.27	177.97	179.74	158.30	142.97	150.88
BS26M	4	142.42	133.03	182.46	181.63	189.06	155.28	151.41	157.91
BS26M	5	143.07	142.17	182.39	183.37	178.54	172.36	156.17	166.07
Average		**144.06**	**139.07**	**189.46**	**180.49**	**182.32**	**160.71**	**150.86**	**158.36**

The table below outlines the average F0 values for long and short vowels of all female participants as observed in the four repetitions of words containing vowel tokens.

Table 3.32 Average F0 values for female participants

Average F0 values for Female Participants									
Speaker	**Repetition**	**/a/**	**/ʌ/**	**/u/**	**/ʊ/**	**/i/**	**/ɪ/**	**/e/**	**/o/**
DG22F	2	265.10	250.37	302.59	291.58	284.71	274.81	274.02	291.10
DG22F	3	267.48	253.17	300.63	301.84	276.81	257.49	270.44	280.24
DG22F	4	266.84	253.76	305.03	296.47	278.24	263.95	276.15	287.79
DG22F	5	267.26	245.88	298.16	300.06	274.03	258.84	271.86	283.50
Average		**266.67**	**250.79**	**301.60**	**297.49**	**278.45**	**263.77**	**273.12**	**285.66**
LL26F	2	253.85	268.49	298.35	328.06	288.35	307.08	281.14	290.09
LL26F	3	249.81	246.53	327.36	320.90	286.54	298.08	265.96	281.54
LL26F	4	236.99	244.88	315.97	309.38	279.90	300.05	250.53	272.06
LL26F	5	232.91	243.51	322.80	323.11	277.69	283.82	243.91	262.97
Average		**243.39**	**250.85**	**316.12**	**320.36**	**283.12**	**297.26**	**260.38**	**276.66**
ML22F	2	275.28	275.33	321.54	326.97	291.20	324.89	289.70	288.23
ML22F	3	264.19	279.42	321.33	304.16	297.57	314.03	286.93	284.57
ML22F	4	257.56	276.70	317.87	302.36	288.16	290.82	282.70	286.65
ML22F	5	265.34	281.37	313.85	302.39	289.52	298.48	282.36	282.11
Average		**265.59**	**278.21**	**318.65**	**308.97**	**291.61**	**307.05**	**285.42**	**285.39**
PP23F	2	231.85	193.33	243.50	253.99	249.21	257.65	242.15	245.22
PP23F	3	233.53	216.52	244.46	250.31	247.35	252.13	243.54	246.78
PP23F	4	232.04	234.15	240.23	243.28	244.79	252.68	241.99	242.89
PP23F	5	231.29	234.08	239.20	240.57	242.08	249.94	241.96	237.53
Average		**232.18**	**219.52**	**241.85**	**247.03**	**245.86**	**253.10**	**242.41**	**243.10**
PTP22F	2	199.02	208.32	231.81	221.99	223.62	217.67	214.82	212.70
PTP22F	3	192.19	210.02	222.23	220.77	213.78	212.60	209.94	198.90
PTP22F	4	199.11	208.34	211.33	214.26	203.53	216.44	205.78	197.28
PTP22F	5	182.76	195.87	204.97	209.72	202.99	208.71	193.23	189.67
Average		**193.27**	**205.64**	**217.59**	**216.68**	**210.98**	**213.85**	**205.94**	**199.64**
TB23F	2	267.24	271.56	313.40	257.77	288.92	237.93	266.93	291.59
TB23F	3	263.77	274.52	317.95	250.74	276.34	233.62	275.81	291.39
TB23F	4	272.52	272.82	304.13	249.05	285.93	227.57	276.75	296.59
TB23F	5	262.60	267.05	307.76	239.94	275.35	223.65	280.85	297.15
Average		**266.53**	**271.49**	**310.81**	**249.37**	**281.64**	**230.69**	**275.09**	**294.18**

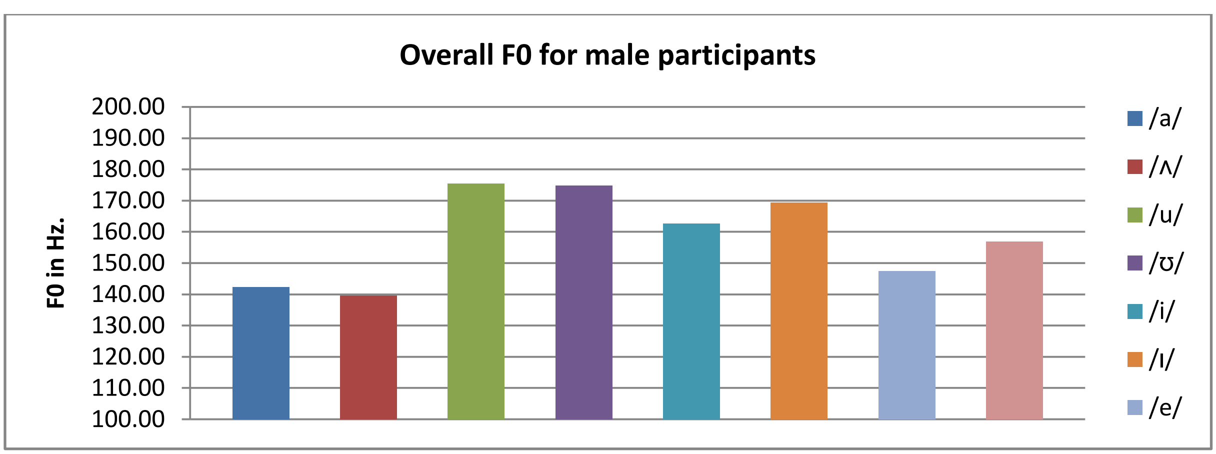
3.8.1 Overall F0 for male participants

The table given below lists the average F0 values of all male participants in this study. For the low central vowel /a/, the average F0 value is 142.42 with values ranging from 125.72Hz to 175.84Hz. The vowel /ʌ/ recorded an overall average F0 value of 136.66 Hz as values ranged from 121.31Hz to 170.32Hz. F0 values for the high back vowel /u/ ranged from 149.66Hz to 220.56Hz and the overall average is 175.39Hz. Its shorter counterpart /ʊ/ recorded an overall average of 174.92 with values ranging between 147.93Hz to 235.74Hz. The front vowel /i/ had F0 values in the range of 139.96Hz to 201.74Hz and its overall average is 162.57Hz. The overall F0 average for the short vowel /ɪ/ is 169.38Hz with values ranging from 143.74Hz to 231.92Hz. The F0 values mid-high vowel /e/ range between 132.27Hz to 181.37Hz and its overall average is 147.55Hz. The average value of long vowels and their shorter versions does not reflect any significant differences. Finally, values for the vowel /o/ range between 141.98Hz to 198.11Hz with 157.00 Hz being the overall F0 average.

Table 3.33 Overall F0 of all vowels for male participants

Overall F0 Average for males								
	/a/	**/ʌ/**	**/u/**	**/ʊ/**	**/i/**	**/ɪ/**	**/e/**	**/o/**
SS26M Average F0	129.77	128.29	163.54	147.93	142.78	157.75	132.27	143.68
PL26M Average F0	125.72	121.31	153.74	154.35	139.96	152.80	132.60	141.98
PR22M Average F0	136.73	139.32	149.66	156.10	146.04	143.74	140.65	142.87
JY25M Average F0	175.84	170.32	220.56	235.74	201.74	231.92	181.37	198.11
BS26M Average F0	144.06	139.07	189.46	180.49	182.32	160.71	150.86	158.36
Overall F0 Average for males	**142.42**	**139.66**	**175.39**	**174.92**	**162.57**	**169.38**	**147.55**	**157.00**

Figure 3.26 Overall F0 for male participants



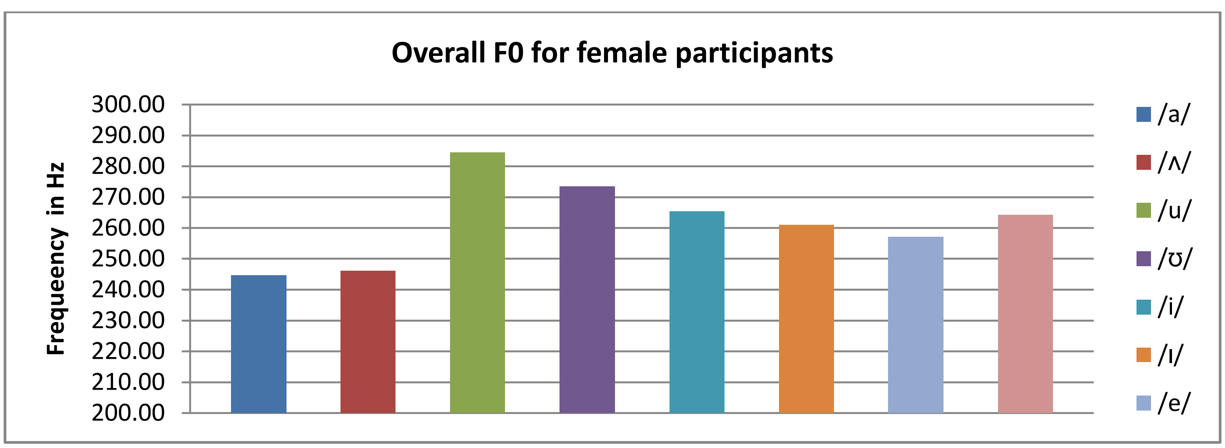
3.8.2 Overall F0 for female participants

The table given below lists the average F0 values of all female participants in this study. For the low central vowel /a/, the average F0 value is 244.60Hz with values ranging from 193.27Hz to 266.67Hz. The vowel /ʌ/ recorded an overall average F0 value of 246.08Hz as values ranged from 205.64Hz to 278.21Hz. F0 values for the high back vowel /u/ ranged from 217.59Hz to 318.65Hz and the overall average is 284.43Hz. Its shorter counterpart /ʊ/ recorded an overall average of 273.32Hz with values ranging between 216.68Hz to 320.36Hz. The front vowel /i/ had F0 values in the range of 210.98Hz to 291.61Hz and its overall average is 265.28Hz. The overall F0 average for the short vowel /ɪ/ is 260.95Hz with values ranging from 213.85Hz to 307.05Hz. The F0 values mid-high vowel /e/ range between 205.94Hz to 285.42Hz and its overall average is 275.09Hz. Comparison of the average F0 vowels of long and short vowels reveals that there is minimal difference between them. Finally, values for the vowel /o/ range between 199.64Hz to 294.18Hz with 264.11 Hz being the overall F0 average.

Table 3.34 Overall F0 for female participants

Overall F0 Average for females								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
DG22F Average F0	266.67	250.79	301.60	297.49	278.45	263.77	273.12	285.66
LL26F Average F0	243.39	250.85	316.12	320.36	283.12	297.26	260.38	276.66
ML22F Average F0	265.59	278.21	318.65	308.97	291.61	307.05	285.42	285.39
PP23F Average F0	232.18	219.52	241.85	247.03	245.86	253.10	242.41	243.10
PTP22F Average F0	193.27	205.64	217.59	216.68	210.98	213.85	205.94	199.64
TB23F Average F0	266.53	271.49	310.81	249.37	281.64	230.69	275.09	294.18
Overall F0 Average for Females	**244.60**	**246.08**	**284.43**	**273.32**	**265.28**	**260.95**	**257.06**	**264.11**

Figure 3.27 Overall F0 for female participants



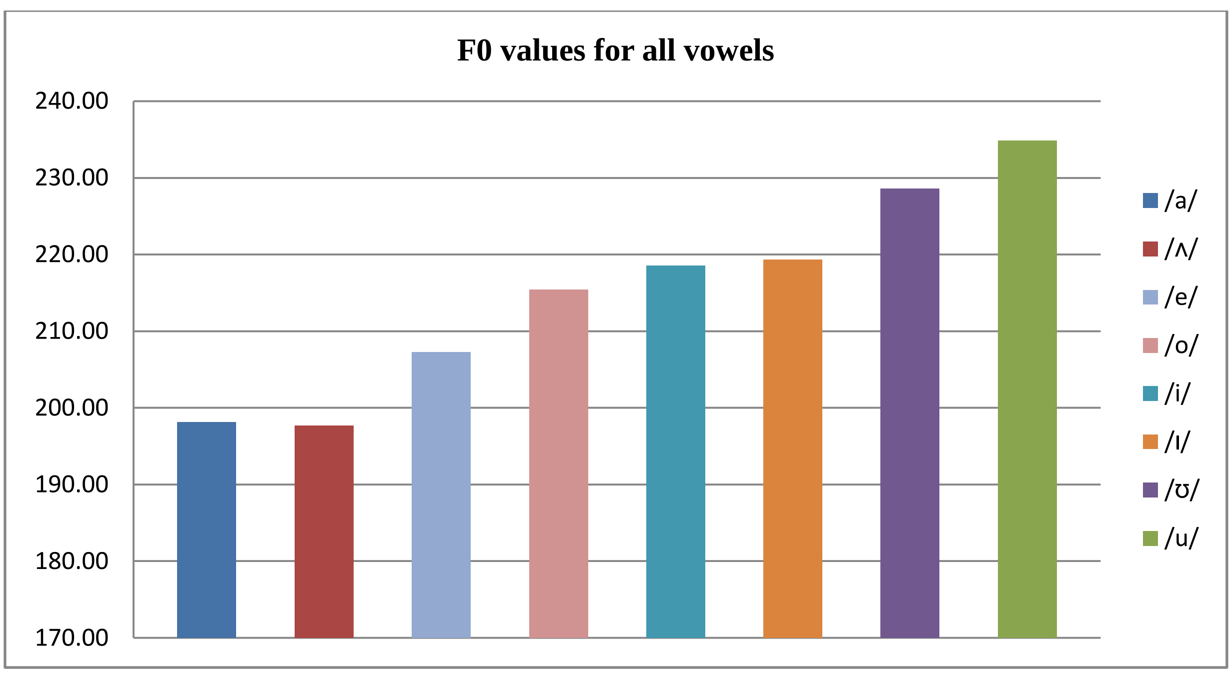
3.8.3 Overall F0 for all participants

The table below lists the overall F0 averages for all vowels.

Table 3.35 Overall F0 for all participants

Overall F0 Averages for all participants								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
SS26M Average F0	129.77	128.29	163.54	147.93	142.78	157.75	132.27	143.68
PL26M Average F0	125.72	121.31	153.74	154.35	139.96	152.80	132.60	141.98
PR22M Average F0	136.73	139.32	149.66	156.10	146.04	143.74	140.65	142.87
JY25M Average F0	175.84	170.32	220.56	235.74	201.74	231.92	181.37	198.11
BS26M Average F0	144.06	139.07	189.46	180.49	182.32	160.71	150.86	158.36
DG22F Average F0	266.67	250.79	301.60	297.49	278.45	263.77	273.12	285.66
LL26F Average F0	243.39	250.85	316.12	320.36	283.12	297.26	260.38	276.66
ML22F Average F0	265.59	278.21	318.65	308.97	291.61	307.05	285.42	285.39
PP23F Average F0	232.18	219.52	241.85	247.03	245.86	253.10	242.41	243.10
PTP22F Average F0	193.27	205.64	217.59	216.68	210.98	213.85	205.94	199.64
TB23F Average F0	266.53	271.49	310.81	249.37	281.64	230.69	275.09	294.18
Overall F0 Averages for all participants	**198.16**	**197.71**	**234.87**	**228.59**	**218.59**	**219.33**	**207.28**	**215.42**

Figure 3.28 Overall F0 for all participants



From the table and the column graph above on overall F0 values for all participants, some preliminary observations can be drawn. Due to anatomical differences the vocal tract, it is well attested that the pitch of a female voice is generally higher than that of a male voice. The overall fundamental frequencies of all vowels of male participants are significantly lower than those of the female participants. The average F0 values for the low vowel /a/ range from 125.72Hz to 175.84Hz for male participants while for the same vowel the range of F0 frequencies for female participants lie in the region of 193.27Hz to 266.67Hz. In the case of the high vowels /i/ and /u/ their overall F0 frequencies are162.57Hz and 175.39Hz respectively for the male participants while for the female participants they are 265.28Hz and 284.43Hz respectively.

It is evident that the F0 values for high vowels are higher than those of low vowels. The overall F0 values of /i/ and /u/ for all speakers are 218.59 Hz and 234.87Hz respectively while overall F0 of the low vowel /a/ is 198.16Hz. The F0 of mid-high vowels /e/ and /o/ is slightly less at 207.28Hz and 215.42Hz respectively, than that of the /i/ and /u/. A direct relation can be seen between the height of a vowel, which is indicated by F1, and its fundamental frequency. The next section of this chapter investigates the F1 of Nepali vowels of the Darjeeling variety and the correlation between F0 and F1.

3.9 F1

F1 values indicate vowel height. The relationship is not direct but an inverse one as low F1 denotes high vowel and vice versa. The table given below illustrates the F1 values of all six repetitions of all vowels for SS26M. The table indicates that for the randomly selected subject, the F1 values for high and mid-high vowels such as /i/, /u/ and /e/ the average values are 294.52Hz, 330.79 Hz and 382.53Hz respectively. For the low central vowel /a/, it is the highest at 718.31Hz.

Table 3.36 F1 for SS26M

Speaker	**Repetition**	**/a/**	**/ʌ/**	**/u/**	**/ʊ/**	**/i/**	**/ɪ/**	**/e/**	**/o/**
SS26M	1	722.20	618.57	336.41	344.04	309.27	317.79	391.41	406.44
SS26M	2	709.54	558.77	332.41	313.55	287.40	326.53	377.16	396.30
SS26M	3	717.76	564.47	327.22	314.74	295.88	302.18	371.41	400.79
SS26M	4	695.84	550.13	320.55	308.60	283.14	318.33	379.57	401.37
SS26M	5	757.09	575.45	332.88	349.38	297.09	336.77	385.52	408.18
SS26M	6	707.40	572.09	335.29		294.34		390.13	407.15
SS26M	Average F1	**718.31**	**573.25**	**330.79**	**326.06**	**294.52**	**320.32**	**382.53**	**403.37**

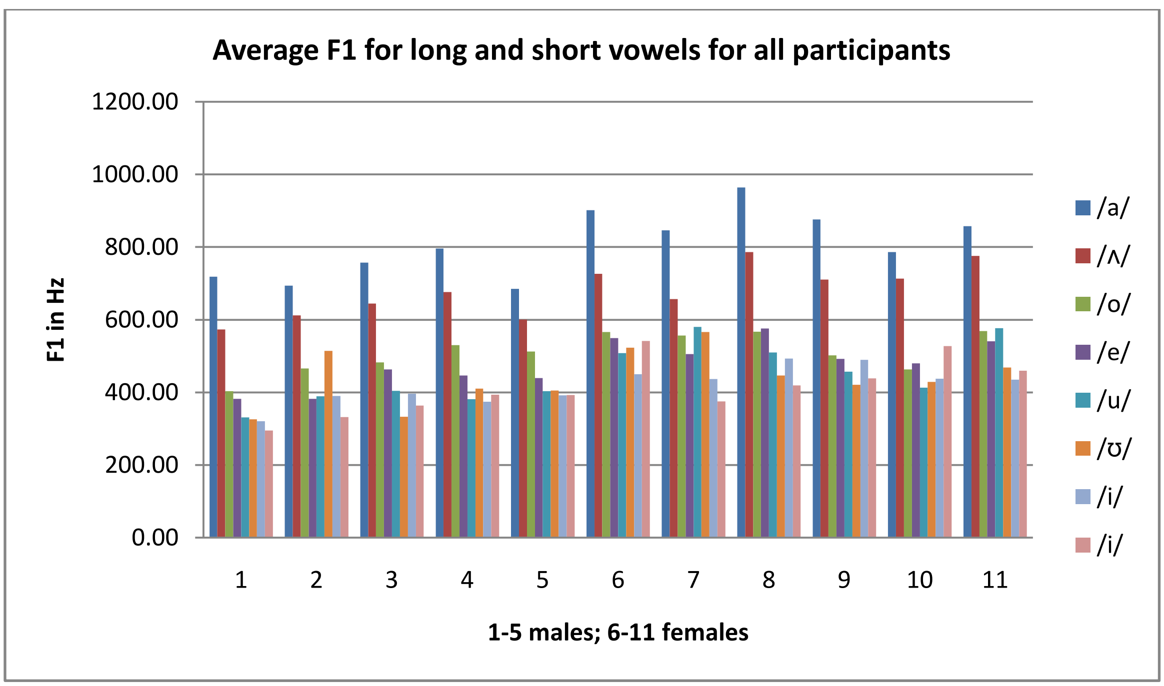
Similarly, overall F1 averages for all speakers have been tabulated and are illustrated in the following table.

Table 3.37 Overall F1 for all speakers

Overall F1 Average for All Speakers								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
SS26M Average F1	718.31	573.25	330.79	326.06	294.52	320.32	382.53	403.37
PL26MAverage F1	693.52	611.96	389.22	514.25	332.34	389.70	382.05	465.87
PR22MAverage F1	757.03	644.45	403.79	333.03	363.58	396.19	463.07	482.12
JY25MAverage F1	795.72	675.80	381.24	409.99	393.52	374.20	446.09	530.09
BS26MAverage F1	684.90	600.63	402.92	404.63	392.49	392.16	439.18	512.82
DG22F Average F1	901.97	726.00	508.27	522.95	541.85	450.26	549.61	565.76
LL26F Average F1	846.06	656.78	580.20	566.39	374.93	436.35	505.31	556.04
ML22F Average F1	964.16	786.19	510.09	446.05	419.47	493.31	575.66	566.78
PP23F Average F1	876.41	710.92	456.69	420.99	438.39	489.33	491.87	501.45
PTP22F Average F1	786.25	712.79	412.72	428.43	527.02	437.90	479.52	463.32
TB23F Average F1	857.33	775.23	576.91	468.43	459.73	434.59	540.38	569.00
Overall F1 Average for all Speakers	**807.42**	**679.45**	**450.26**	**440.11**	**412.53**	**419.48**	**477.75**	**510.60**

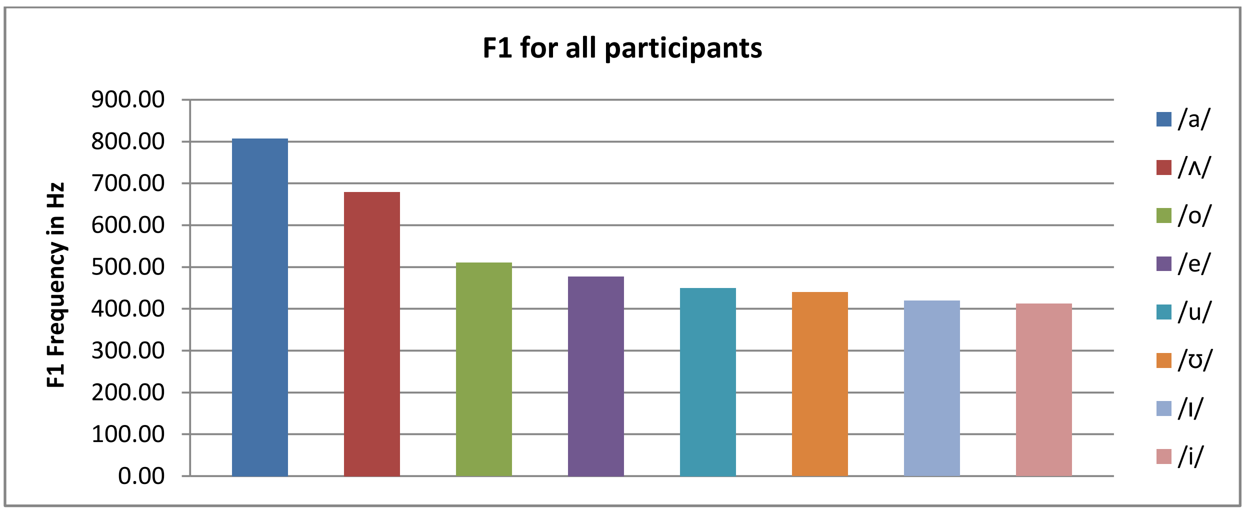
The bar graph below presents a graphical representation of F1 values for all participants.

Figure 3.29 F1 for all participants



The column graph provides evidence to the inverse nature of relationship between F1 and vowel height. As we go higher from /a/ to /i/, the graph above reflects decreasing F1 values. The low open vowel /a/ has the highest F1 value measured at 806.42Hz, in relation to other vowels. Moving from /a/ to mid–high or mid–close front vowel /e/, the F1 values decreases as the average F1 value for /e/ is 477.75Hz. Going higher up to the close high front vowel /i/, the average F1 values further decrease to 412.53Hz.Similarly, F1 value for the open mid-high vowel /ʌ/ is measured at 679.45Hz and going higher up along this continuum, the F1 values are decreasing for the close mid-high vowel /o/ at 510.60Hz to 450.26Hz for the closed high vowel /u/. This is better reflected in the column graph below which represents the overall average values for all participants.

Figure 3.30 F1 for all participants



3.10 F0-F1 Correlation

Earlier in the discussion on fundamental frequency or F0, the relationship between F0 and the height of a vowel was noted. It was observed that high vowels like /i/ and /u/ had higher F0 values in relation to mid-high, mid- and low vowels such as /e/,/o/, /ʌ/ and /a/. This evidence for this observation can be graphically presented by plotting the F1 values against F0 values. In the figure below, F0 values are plotted on the x-axis while negative values of F1 are plotted on the y-axis to show the height of a vowel in relation to pitch.

Table 3.38 Overall F0 and F1 for all participants

Overall F0 and F1 Average for all participants								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
Overall F0 Average for all participants	198.16	197.71	234.87	228.59	218.59	219.33	207.28	215.42
Overall F1 Average for all participants	807.42	679.45	450.26	440.11	412.53	419.48	477.75	510.60

Figure 3.31 F0-F1 correlation

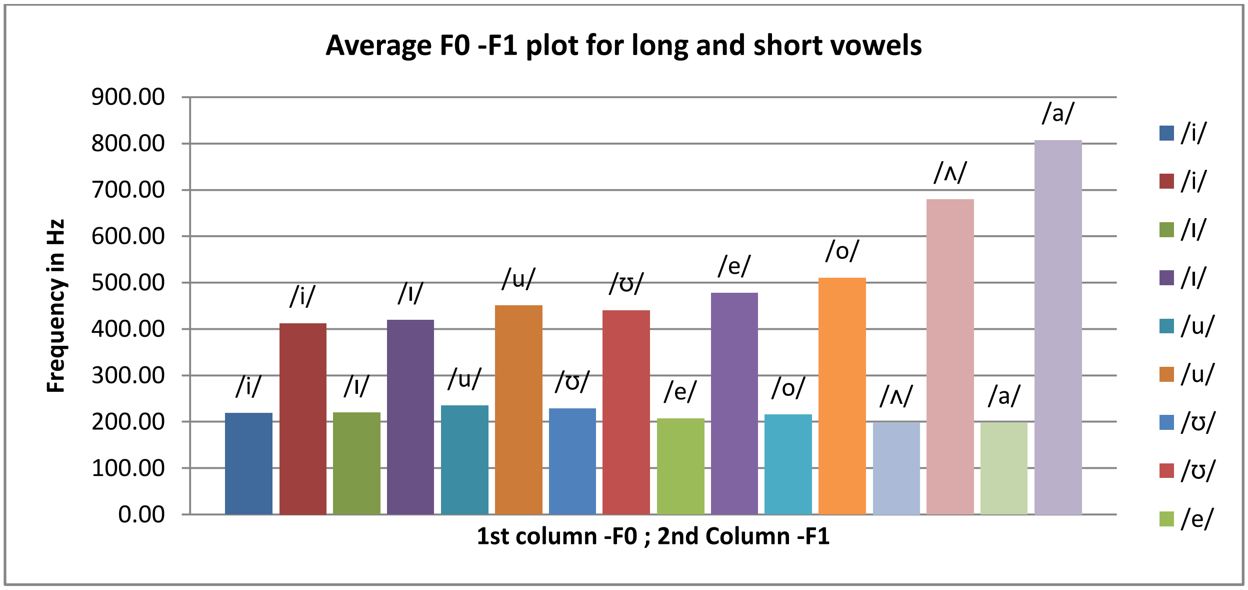
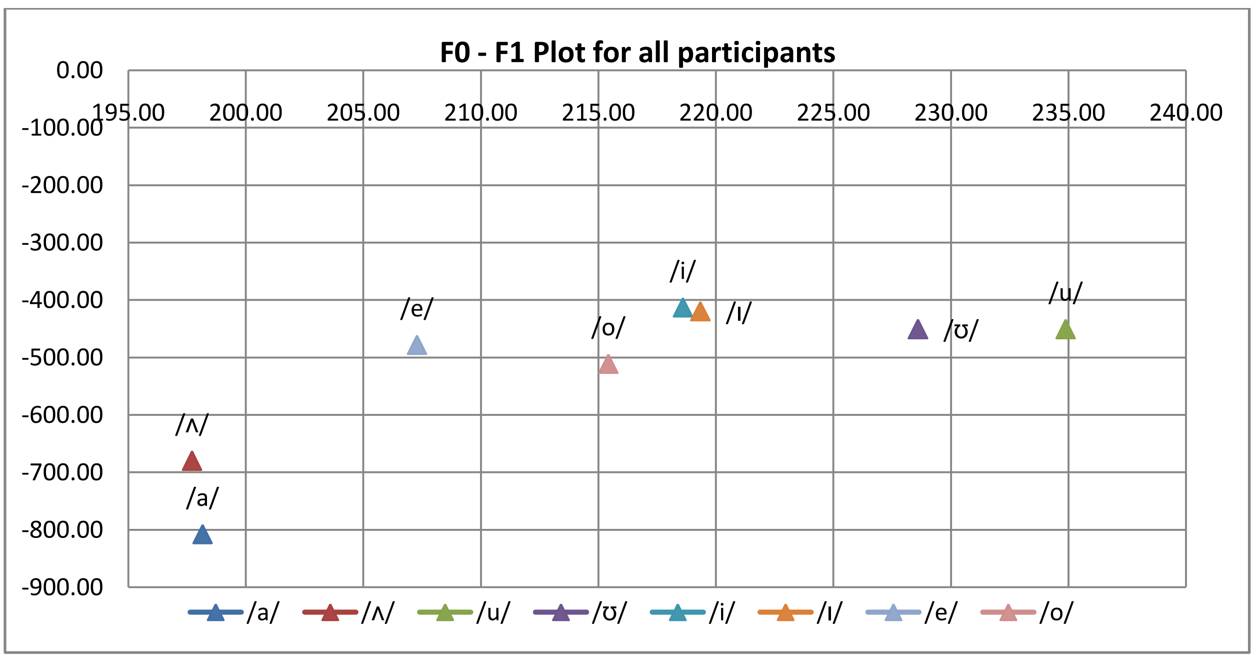


Figure 3.32 F0-F1 plot



The graph reveals that low pitch values for low and mid-low vowels /a/ and /ʌ/ at 198.16 Hz and 197.71 Hz, respectively. Meanwhile, their F1 values are high in relation to other vowels at 807.42Hz for /a/ and 679.45 Hz for /ʌ/.The F0 for high vowels /i/ and /u/ are also very high at 218.59Hz and 234.87Hz. The short vowels /ɪ/ and/ʊ/ also record high pitch values at 219.33Hz and 228.59Hz, respectively. However, all high vowels are characterized by low F1 values as they range from 412.53Hz to 450.26 Hz. The mid vowels /e/ and /o/ fall in the intermediate range, both in terms of pitch values and F1 frequencies, in relation to the high and low vowels.

3.11 F2

The second formant frequency is dependent on the position of the tongue body on the front-back dimension. A high F2 frequency indicates a front vowel whereas a low F2 frequency indicates that it is a back vowel. The following table and figure presents the average F2 frequencies for all participants for both long and short vowels.

Table 3.39 F2 for all participants

	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
SS26M Average F2	1494.65	1071.35	803.73	738.59	2282.46	2169.52	2144.42	854.09
PL26MAverage F2	1287.81	1277.07	1082.84	1290.36	2164.63	1942.29	2147.61	1090.23
PR22MAverage F2	1372.60	1310.55	1065.77	801.84	2024.13	1981.30	2022.97	1074.57
JY25MAverage F2	1544.36	1328.47	695.72	939.19	2205.27	2062.44	2173.36	997.53
BS26MAverage F2	1440.60	1376.41	1162.08	920.01	1836.52	2112.56	2113.75	1292.36
DG22F Average F2	1573.32	1489.94	984.66	919.44	2075.79	2213.35	2276.15	1049.71
LL26F Average F2	1654.88	1428.92	1310.86	1165.94	2270.49	2364.90	2403.44	1116.91
ML22F Average F2	1640.43	1600.65	1130.52	896.94	2874.74	2588.84	2629.48	1089.87
PP23F Average F2	1410.86	1306.97	1037.96	861.84	2628.77	2465.10	2378.35	1063.64
PTP22F Average F2	1381.08	1424.74	775.80	773.19	2476.38	2299.79	2284.21	861.97
TB23F Average F2	1452.42	1402.69	1150.58	854.03	2623.39	2346.32	2457.56	1009.25
Overall F2 Average for participants	**1477.55**	**1365.25**	**1018.23**	**923.76**	**2314.78**	**2231.49**	**2275.57**	**1045.47**

Figure 3.33 F2 for all participants

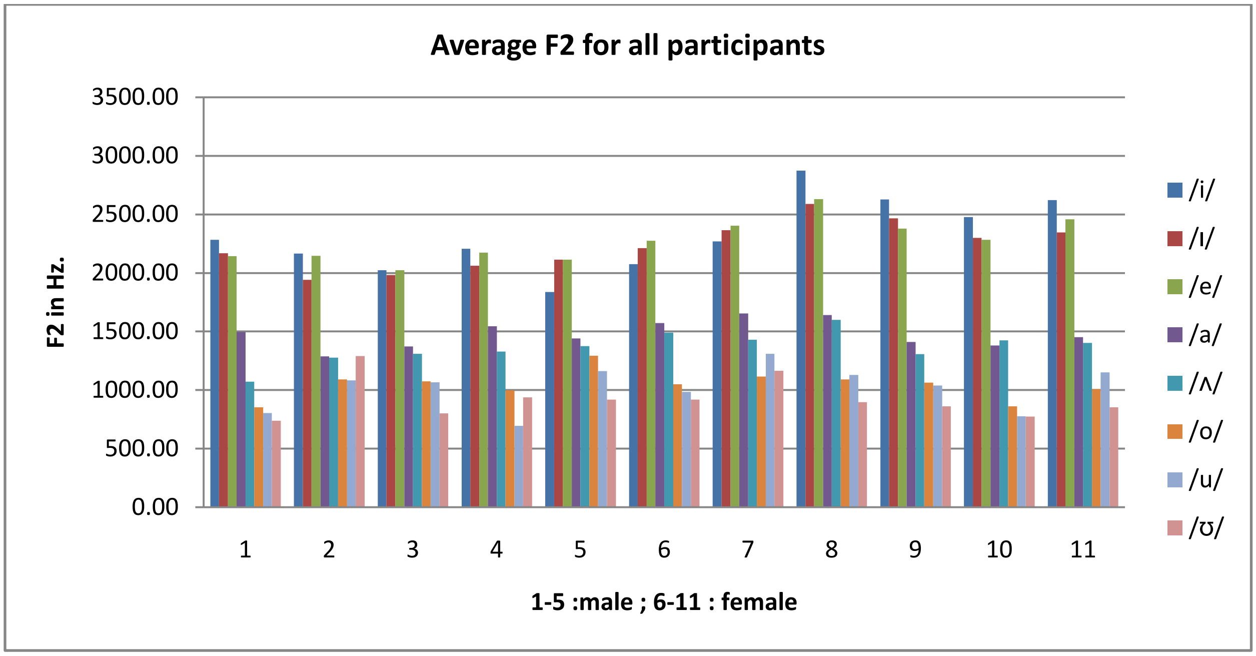
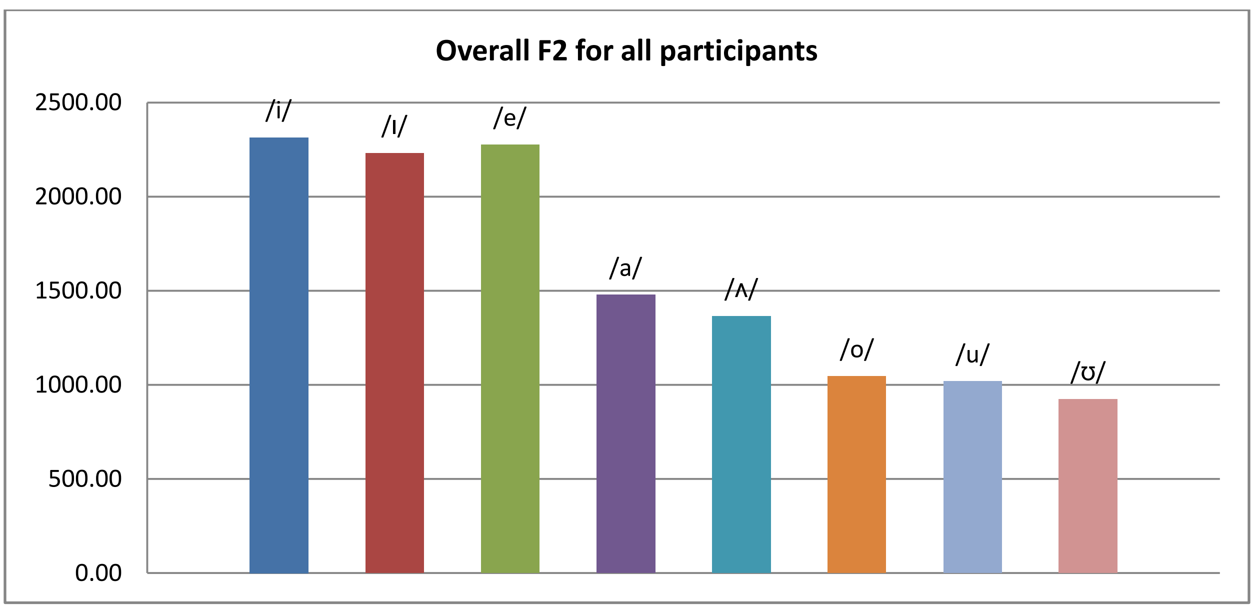


Figure 3.34 Overall F2 Averages



Average F2 values for long and short vowels are observed to be decreasing as we move from /i/ to /u/ along the front-back plane. For the front vowels /i/ and /ɪ/, F2 values stand at 2314.78Hz and 2231.49Hz respectively. The near-front vowel /e/ shows slightly less F2 value in relation to /i/ at 2275.57Hz. The central vowel /a/ has its average F2 frequency at 1477.55Hz and moving further back, the average F2 value for the vowel /ʌ/ is 1365.25Hz. In tune with the same principle, the average F2 for the vowel /o/ is 1045.47Hz. The high back vowel /u/ and its shorter variant /ʊ/ record the lowest F2 averages at 1018.23Hz and 923.76Hz, respectively.

3.12 F0-F2 Correlation

The analysis of pitch in relation to the second formant leads to some observations regarding the vowels along the open-close dimension.

Table 3.40 Overall F0 and F2 for all participants

Overall F0 and F2 Average for all participants								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
Overall F0 Average for all participants	198.16	197.71	234.87	228.59	218.59	219.33	207.28	215.42
Overall F2 Average for all participants	1477.55	1365.25	1018.23	923.76	2314.78	2231.49	2275.57	1045.47

Figure 3.35 F0-F2 Correlation

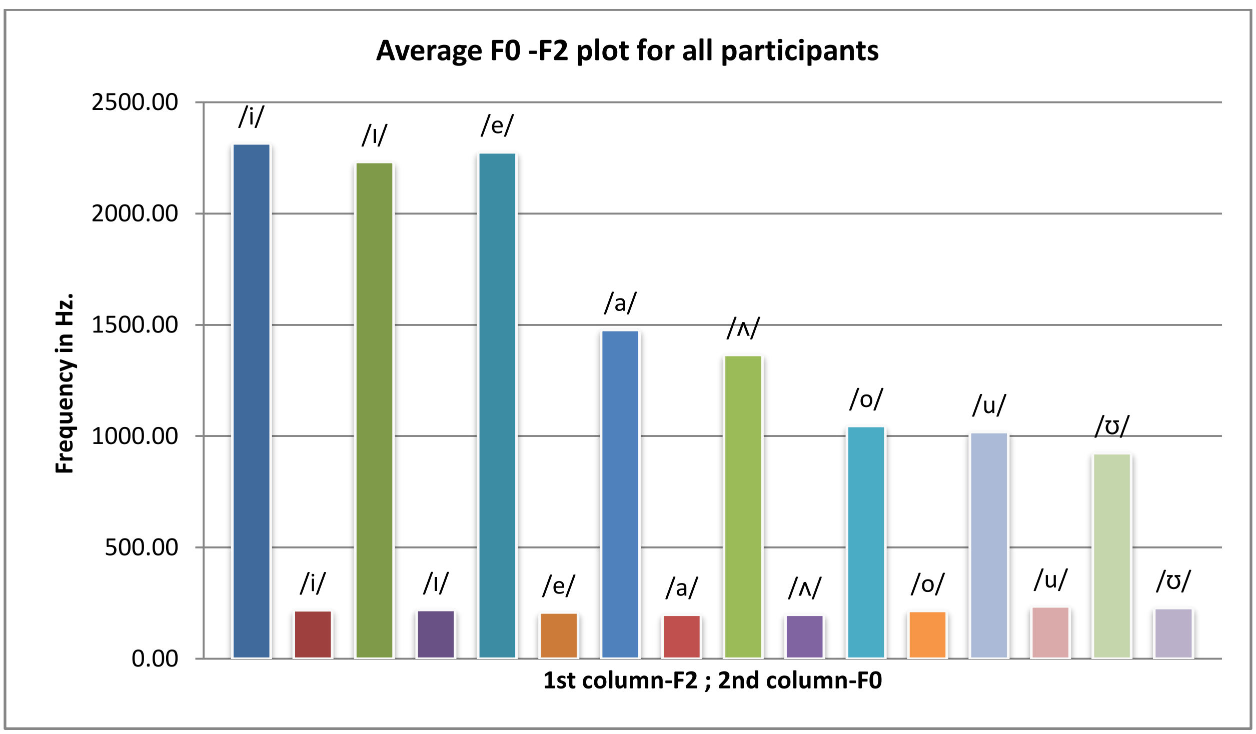
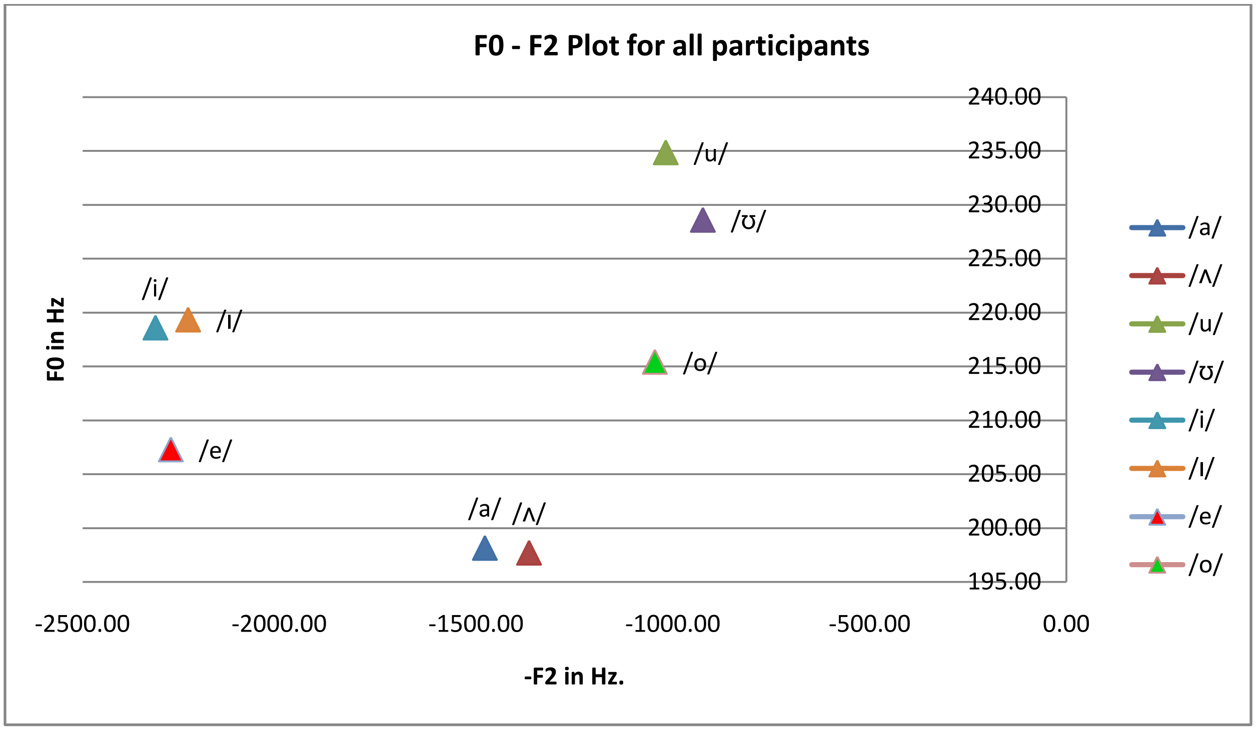


Figure 3.36 F0-F2 plot



From the figure above where F0 has been plotted on the vertical axis and negative values of F2 on the horizontal axis, we can observe that front vowels /i/ and /ɪ/, near-front vowel /e/ and back vowels /u/, /ʊ/ and /o/ ,with the exception of /ʌ/, are marked by significantly higher pitches than the central vowel /a/. Another observation which can be drawn is that open vowels /a/ and /ʌ/ are marked by lower pitch values than the close and mid-close vowels such as /i/, /ɪ/, /u/, /ʊ/, /e/ and /o/.

3.13 F3

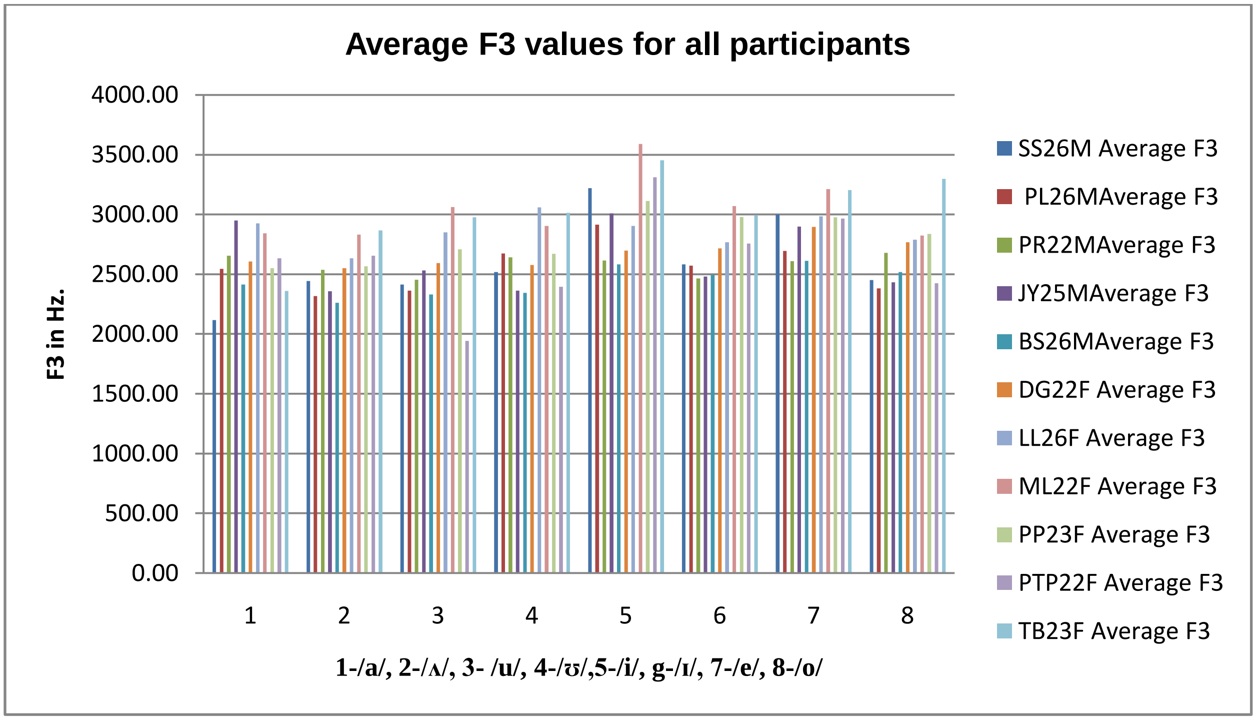
The third formant complements the acoustic description of vowels in terms of formants frequencies. In the previous sections and sub-sections, Nepali vowels have been analyzed in terms of their F0, F1 and F2 frequencies. This section analyzes the F3 frequencies of the long and short oral vowels of the Darjeeling variety of Nepali. In addition, an analysis of F3 in relation to F1 and F2 is also provided.

The following table lists the average F3 values for both long and short vowels for participants in this study. The figure below provides a graphical representation.

Table 3.41 F3 for all participants

Overall F3 Average for Participants								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
SS26M Average F3	2117.59	2443.48	2414.75	2517.18	3220.06	2582.26	2999.38	2451.91
PL26MAverage F3	2545.97	2316.35	2364.15	2674.76	2914.46	2570.80	2693.94	2381.80
PR22MAverage F3	2656.35	2537.56	2453.97	2641.03	2615.73	2465.28	2610.81	2679.99
JY25MAverage F3	2948.43	2358.47	2532.59	2362.76	3009.16	2481.57	2899.19	2431.96
BS26MAverage F3	2413.92	2260.38	2332.18	2345.04	2584.04	2493.71	2611.04	2517.84
DG22F Average F3	2607.79	2550.21	2593.45	2577.29	2697.63	2717.50	2897.09	2767.50
LL26F Average F3	2925.55	2632.58	2850.46	3059.01	2904.05	2766.40	2985.30	2789.46
ML22F Average F3	2842.15	2831.64	3063.58	2904.30	3590.96	3070.94	3213.43	2822.71
PP23F Average F3	2549.95	2565.59	2708.56	2670.45	3113.58	2979.28	2975.43	2838.06
PTP22F Average F3	2634.05	2653.80	1941.18	2394.62	3312.62	2756.15	2965.65	2424.79
TB23F Average F3	2360.90	2866.87	2976.55	3012.91	3454.46	2995.51	3204.69	3297.99
Overall F3 Average for Participants	**2600.24**	**2546.99**	**2566.49**	**2650.85**	**3037.89**	**2716.31**	**2914.18**	**2673.09**

Figure 3.37 Average F3 values for all participants

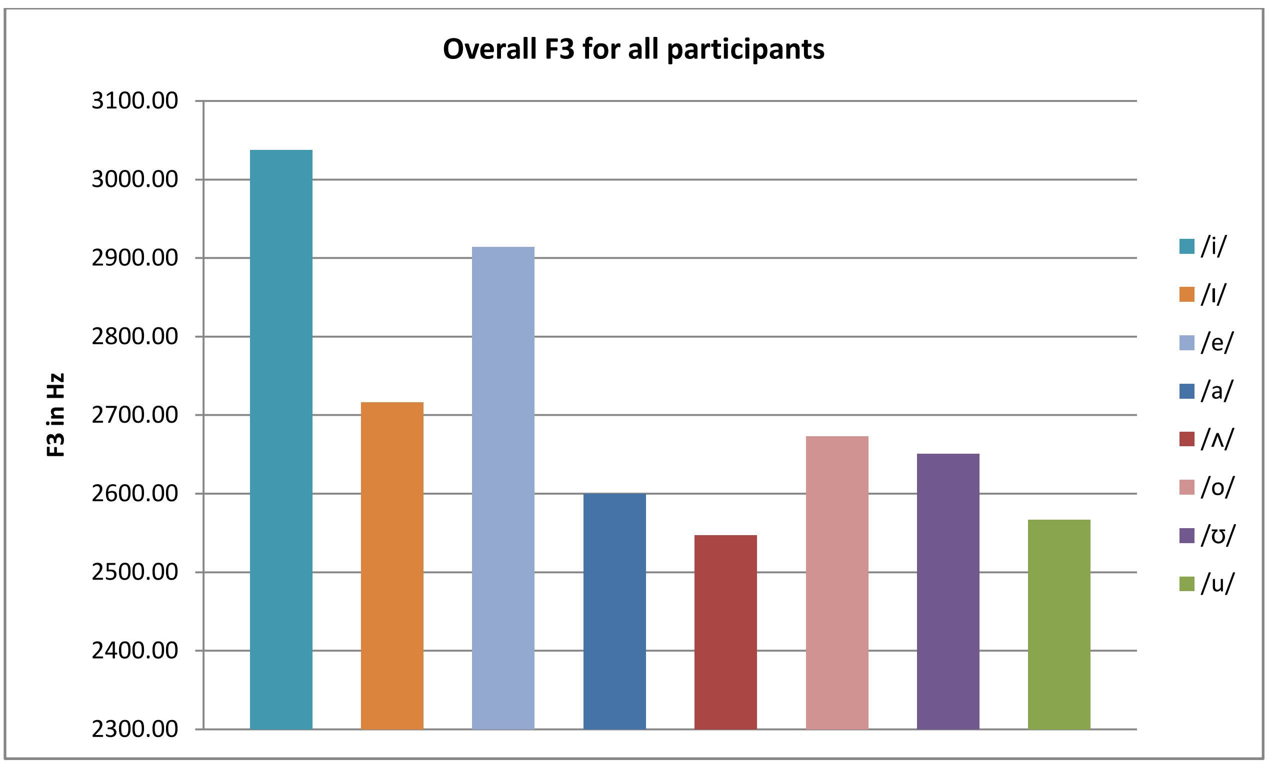


An analysis of the F3 values of both long and short oral vowels reveal that relatively low F3 values are associated with rounded back vowels such as /u/and /o/. The average F3 value of all participants for the high back rounded vowel /u/ and mid-high rounded vowel /o/ are 2566.49Hz and 2673.09Hz respectively. It is observed that lip rounding enhances the backness of vowels and distinguishes them from front vowels. The average F3 values for the unrounded vowels /i/ and/e/ are 3037.89 Hz and 2914.18 Hz. The same can be said about the shorter variants of /i/ and /u/. The average F3 values for the short high front unrounded vowel /ɪ/ is higher at 2716.31 Hz as compared to the short high back unrounded vowel /ʊ/ which is measured at 2650.85 Hz.

Table 3.42 Overall F3 for all vowels

Overall F3 Average for Participants								
	/a/	/ʌ/	/u/	/ʊ/	/i/	/ɪ/	/e/	/o/
Overall F3 Average for Participants	**2600.24**	**2546.99**	**2566.49**	**2650.85**	**3037.89**	**2716.31**	**2914.18**	**2673.09**

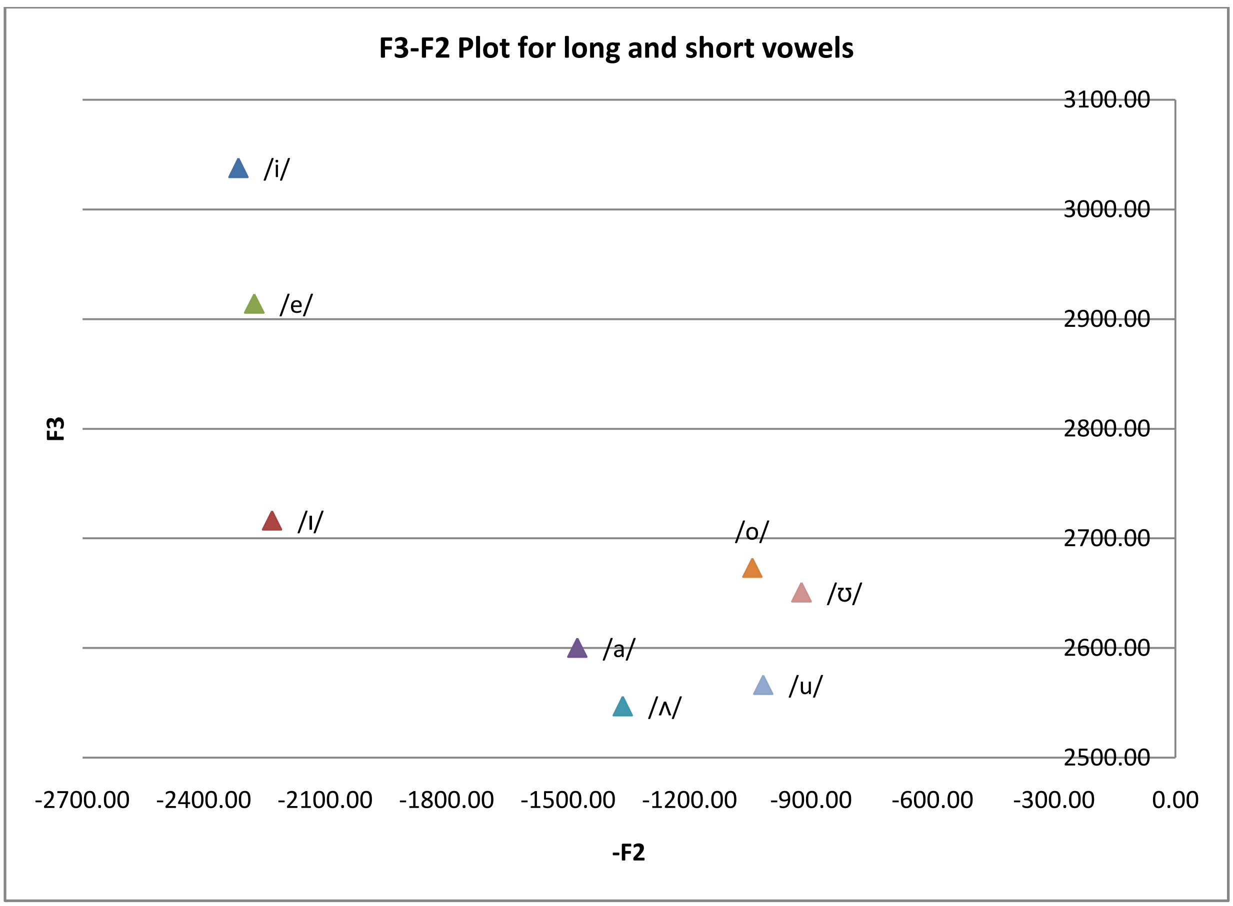
Figure 3.38 F3 for all participants



3.14 F3-F2 Correlation

In the earlier discussion on F3, it was observed that the average F3 frequencies of front vowels are higher in comparison to back vowels. Similarly in the discussion on F2, it was found that F2 had a bearing on the front-back criteria of vowel description. In this section, an analysis of F3 in relation to F2 is provided to understand the correlation existing between the second and the third formant. From the graph below where negative values of F2 frequencies are plotted on the x-axis and F3 values on the y-axis for all speakers, we can tentatively say that in relation to the back vowels, the front vowels have higher F3 values. Along the rounded-unrounded axis, it can be observed that the unrounded vowels such as /i/, /ɪ/ and /e/ are marked by higher F3 values in comparison to the rounded vowels such as /o/ and /u/.

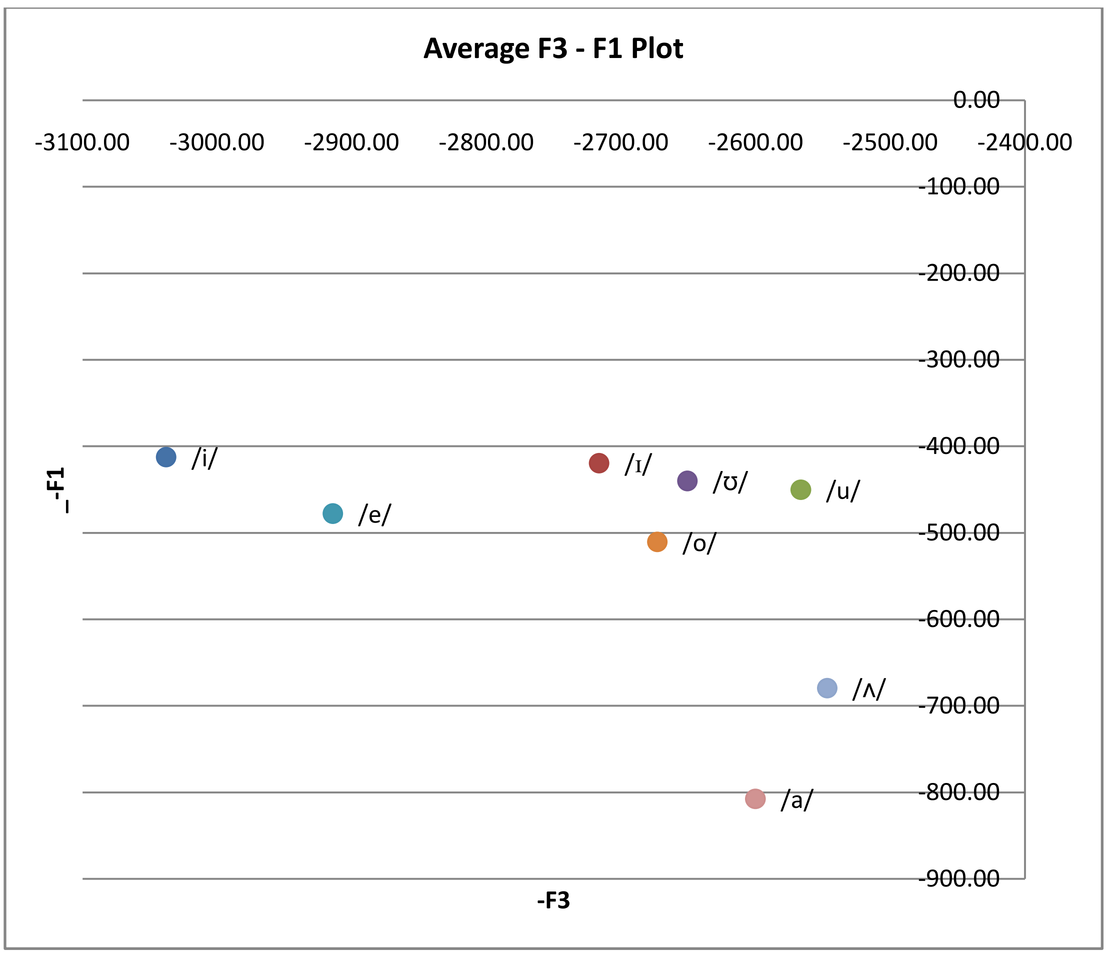
Figure 3.39 F3-F2 Correlation



3.15 F3-F1 Correlation

On examining the correlation between F1 and F3 values, it can be observed that an inversely proportional relationship exists between the two acoustic parameters. In the open-close dimension, it can be observed that the open vowels /ʌ/ and /a/ have comparatively lower average values than the close vowels /i/ and /e/. The close vowels /u/ and /o/ reflect lower average F3 because of lip rounding. The high vowels such as /u/ and /i/ and their shorter variants /ʊ/ and /ɪ/ are marked by higher F3 values while the low vowel such as /a/ is characterized by low F3 frequency. The mid-high front and back vowels /e/ and /o/ are associated with similar F3 frequencies.

Figure 3.40 F3-F1 Correlation



3.16 Discussion

In this chapter on data analysis, with the help of various analytical tools and on the basis of different analytical procedures, a description of the Nepali vowels in the Darjeeling variety was provided. Keeping in line with the various acoustic parameters outlined for the study, in the different sections and sub-sections an analysis of the vowels in terms of their F0, F1, F2 and F3 frequencies was presented. Observations were also made regarding the correlation between them. On the basis of the formant frequencies, notably the negative values of F1 and the difference between F2 and F1, the acoustic space was determined to observe the organization of the vowel. This was done separately for both males and females and then the overall acoustic space was designed for the oral vowels of Nepali as spoken in the Darjeeling district of West Bengal.

Most of the findings are in agreement with Pokharel's generalizations. The vowels /i/, /ɪ/ and /e/ are front vowels while /a/, /ʌ/, /o/, /u/ and /ʊ/ are back vowels judging by their positioning in the acoustic space. Findings also attest Pokharel's observation that /ʌ. is a back vowel. The fact that /i/ and /e/ are positioned higher than /u/ and /o/ also reconfirms Pokharel's observation. The increase in F1 values as we move from /i/ to /u/ and decreasing F2 values along the same direction are also in agreement with Pokharel's findings.

However, some findings of this study tend to differ from Pokharel's observations. Pokharel states that /a/ is the backmost vowel in the vowel quadrilateral. Finding of this study reveal that /ʊ/ is backmost vowel followed by /o/. In Pokharel (1989) we do not find any reference to the short vowel /ʊ/ in the vowel quadrilateral. The vowel /ʊ/ displays a tendency to move towards the periphery as has been observed in the acoustic space for both male and female participants. This observation needs to be tested with a larger set of data.

CHAPTER 4

CONCLUSION

This study on the acoustic description of Nepali vowels in the Darjeeling variety was conducted with an aim to present an account of the vowels in this particular regional variety on the basis of certain acoustic parameters. Another major aim was to determine the acoustic space for the vowels of this variety of Nepali. The set of vowels chosen for analysis were the oral peripheral long and short vowels. A total of eight vowels which are /i/, /ɪ/, /u/,/ʊ/,/e/, /o/, /ʌ/ and /a/ were chosen as the subject matter for the study. The vowel phonemes formed the nucleus of monosyllabic words where both the releasing and the arresting consonants were voiceless stop consonants.

A total of eleven native speakers of Nepali from the Darjeeling district of West Bengal participated in the study. All eleven participants are students who are pursuing various degrees at Jawaharlal Nehru University, New Delhi and have a similar socio-economic and educational background. The participants read out a list of words from a word-list prepared in advance. Six repetitions of every word was recorded from all eleven participants in a noise-free environment at the Language Lab Complex,JNU. The voice samples were recorded using a Sony ICD-UX513F/B Digital Voice Recorder. The sounds were recorded in LPCM mode and quantized at a sampling frequency of 44.1 kHz. In total there were 528 voice samples (8 vowels * 6 repetitions * 11 participants) which underwent spectrographic analysis using Praat.

Several acoustic parameters were identified on the the basis of which the analysis was carried out. These parameters are :

1. F0 or pitch
2. F1, F2 and F3 frequencies
3. Correlations between F0, F1, F2 and F3
4. Acoustic space
5. Durational properties

4.0 Results and Discussion

4.1 Formant Frequency

4.1.1 F0

The analysis of pitch values of both male and female participants reveals that pitch is directly proportional to the height of the vowel as is shown in figures 4.1 and 4.2. The low and mid-low vowels have the lowest pitch while the high vowels are characterized by higher pitch values. The mid high vowels lie in the intermediate range with. Due to anatomical differences in the vocal tract, the pitch values for female participants is relatively higher for all vowels

Figure 4.1 Comparision of F0 for males and females

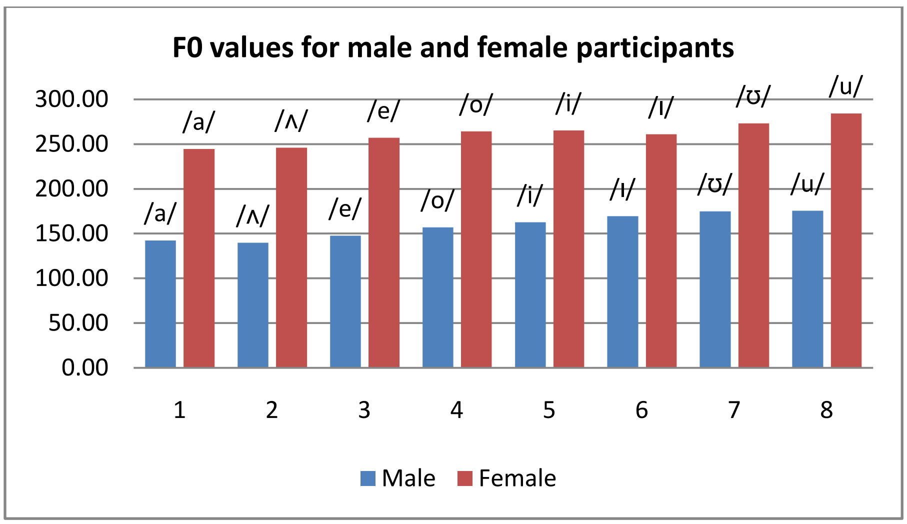
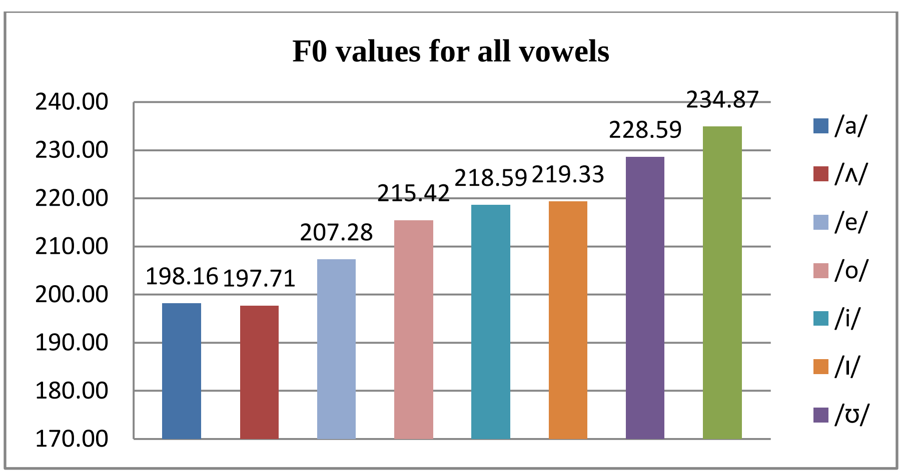


Figure 4.2 Comparision of F0 for males and females



4.1.2 F1

The analysis of eight oral long and short vowels of Nepali which are /i/, /ɪ/, /u/, /ʊ/, /e/, /o/, /ʌ/ and /a/ reveals an inversely proportional relationship between F1 and the height of a vowel. Average F1 frequency for both male and female speakers are observed to be increasing from /i/ to /a/. The overall F1 values for all particpants also present the same picture. The vowel /a/ has the highest F1 value at 807.42Hz followed by /ʌ/ at 679.42Hz. The F1 for vowels /o/ and /e/ are 510.60Hz and 477.75Hz. The F1 values for vowel /u/, /ʊ/, /ɪ/ and /i/ are 450.26Hz, 440.11Hz, 419.48 Hz and 412.53 Hz, respectively. Tentatively, it can be said that open vowels have high F1 while the close vowels are marked by relatively low F2 values.

Figure 4.3 Comparison of F1 values for male and female participants

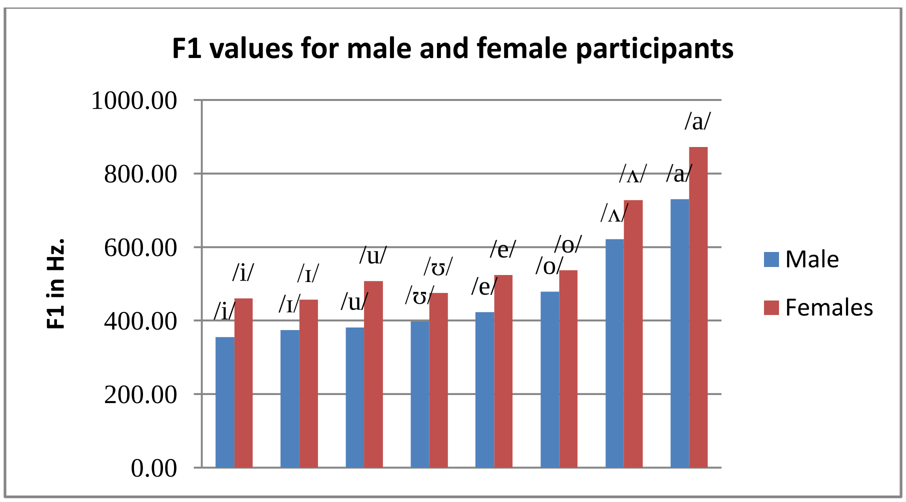
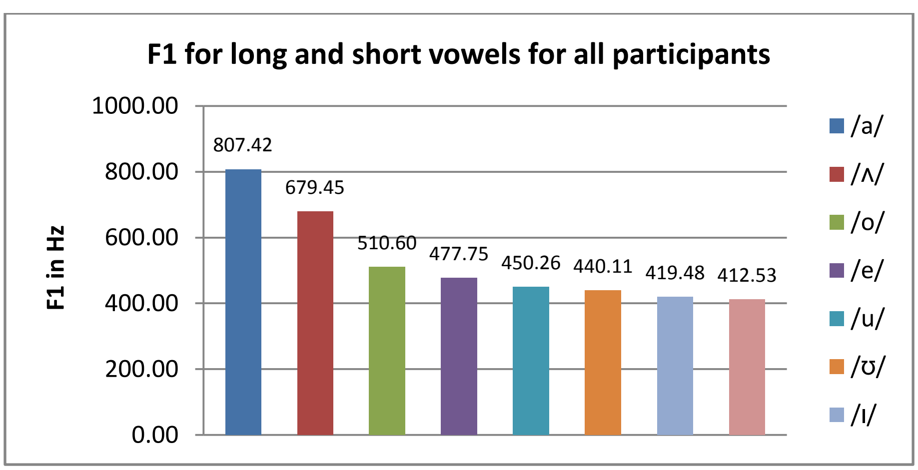


Figure 4.4 Comparison of F1 values for male and female participants



4.1.3 F2

Average F2 values for long and short vowels are observed to be decreasing as we move from /i/ to /u/ along the front-back plane. For the front vowels /i/ and /ɪ/, F2 values stand at 2314.78Hz and 2231.49Hz respectively. The near-front vowel /e/ shows slightly less F2 value in relation to /i/ at 2275.57Hz. The central vowel /a/ has its average F2 frequency at 1477.55Hz and moving further back, the average F2 value for the vowel /ʌ/ is 1365.25Hz. In tune with the same principle, the average F2 for the vowel /o/ is 1045.47Hz. The high back vowel /u/ and its shorter variant /ʊ/ record the lowest F2 averages at 1018.23Hz and 923.76Hz, respectively.

Figure 4.4 Comparison of F2 values for male and female participants

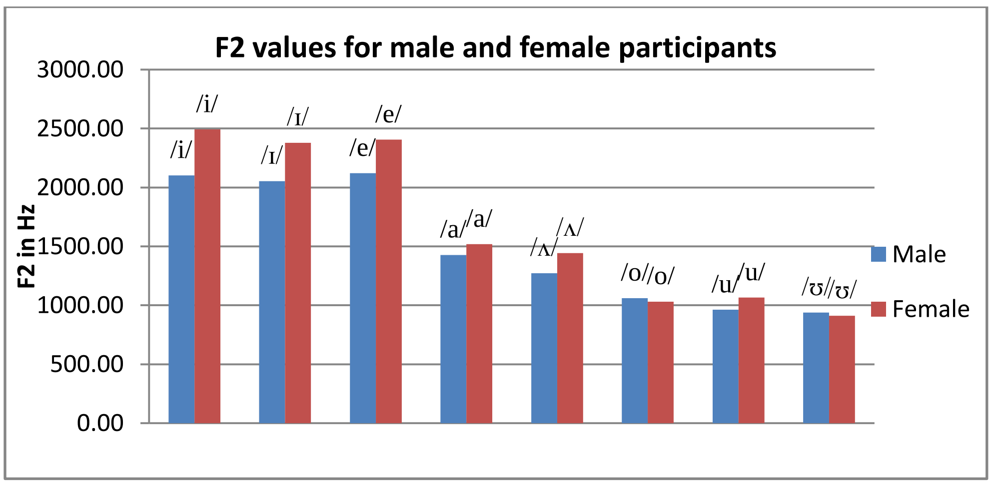
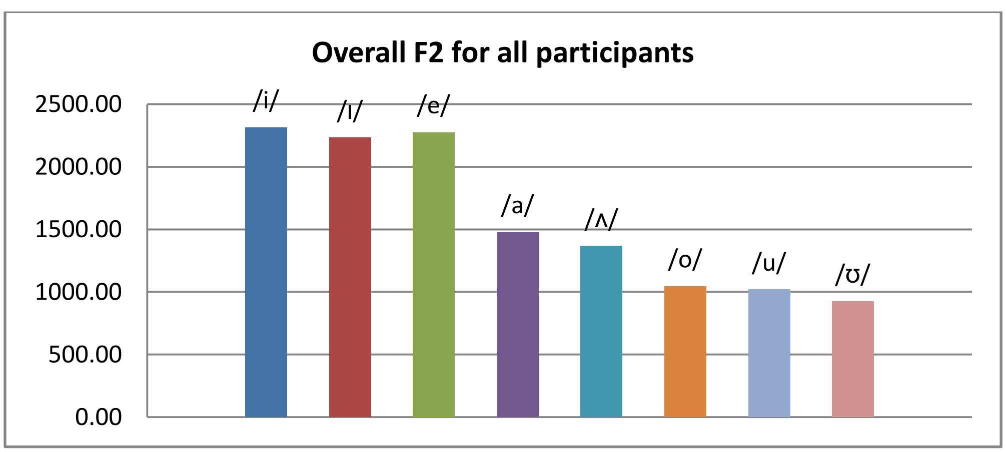


Figure 4.5 Comparison of F2 values for male and female participants



4.1.4 F3

An analysis of the F3 values of both long and short oral vowels for both male and female participants reveal that relatively low F3 values are associated with rounded back vowels such as /u/and /o/. The average F3 value of all participants for the high back rounded vowel /u/ and mid-high rounded vowel /o/ are 2566.49Hz and 2673.09Hz respectively. The average F3 values for the unrounded vowels /i/ and/e/ are 3037.89 Hz and 2914.18 Hz. The average F3 values for the short high front unrounded vowel /ɪ/ is higher at 2716.31 Hz as compared to the short high back unrounded vowel /ʊ/ which is measured at 2650.85 Hz

Figure 4.6 Comparison of F3 values for male and female participants

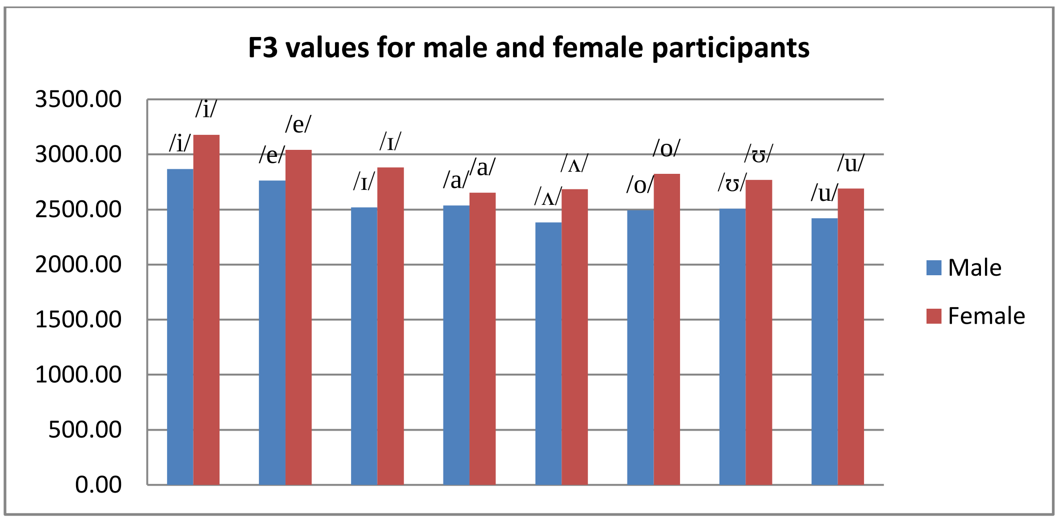
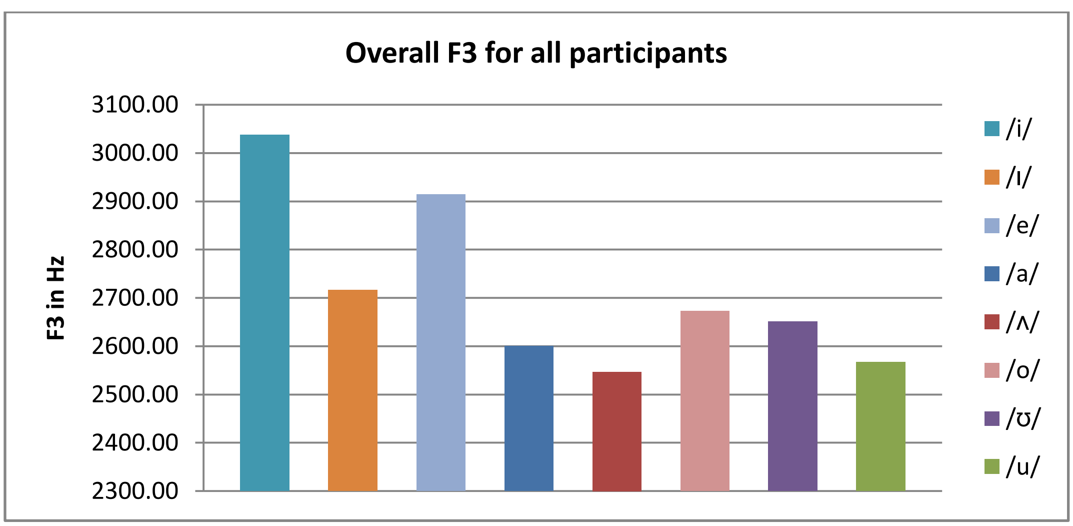


Figure 4.7 Comparison of F3 values for male and female participants



4.2 Correlations between F0, F1, F2 and F3

4.2.1 Correlation between F0 and F1

The analysis of F0 in relation to F1 has added weight to the observation that the pitch of a vowel is directly proportional to its height. To observe this correlation, pitch values were plotted on the x-axis while negative values of F1 was plotted on the y-axis. The resultant graph demosntrates increasing pitch values as we move from low and mid-low vowels /a/ to /ʌ/ and then to mid-high vowels /e/ and /o/ till we reach the high vowels /i/,/ɪ/, /ʊ/ and /u/.

Figure 4.8 F0-F1 Correlation

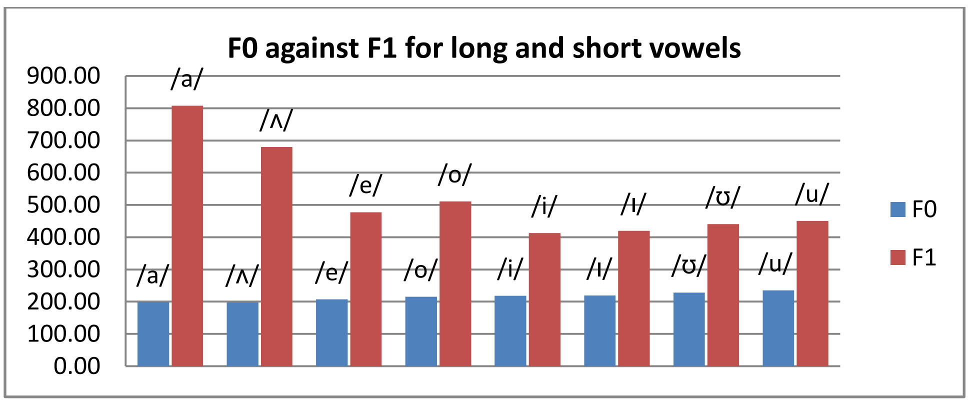
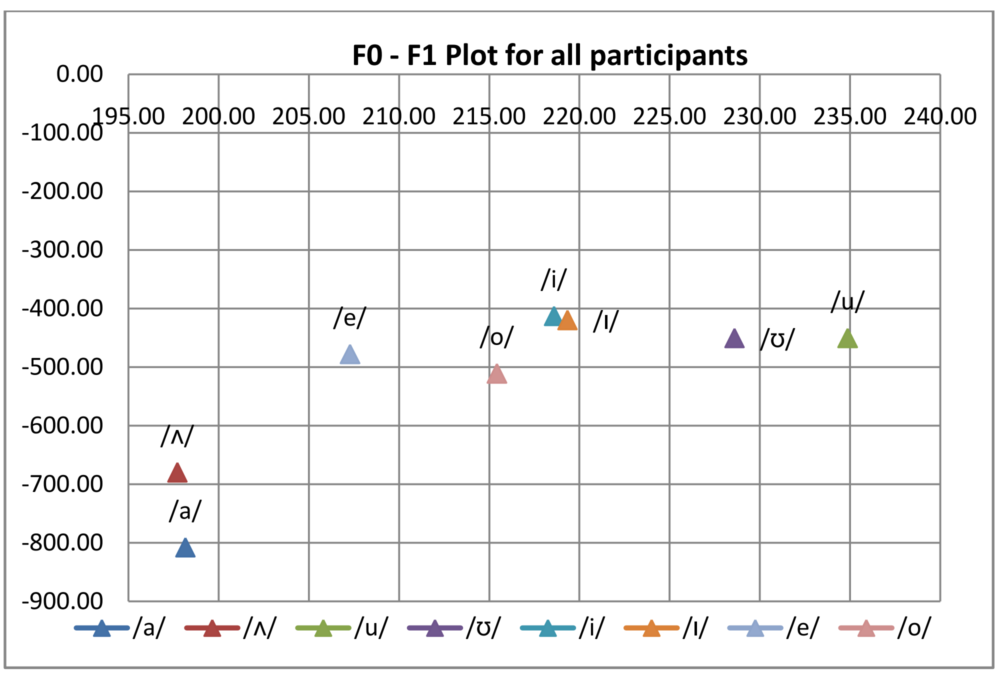


Figure 4.9 F0-F1 plot



4.2.2 Correlation between F0 and F2

The front vowels /i/ and /ɪ/, near-front vowel /e/ and back vowels /u/, /ʊ/ and /o/ ,with the exception of /ʌ/, are marked by significantly higher pitches than the central vowel /a/. Another observation which can be drawn is that open vowels /a/ and /ʌ/ are marked by lower pitch values than the close and mid-close vowels such as /i/, /ɪ/, /u/, /ʊ/, /e/ and /o/.

Figure 4.10 F0-F2 Correlation

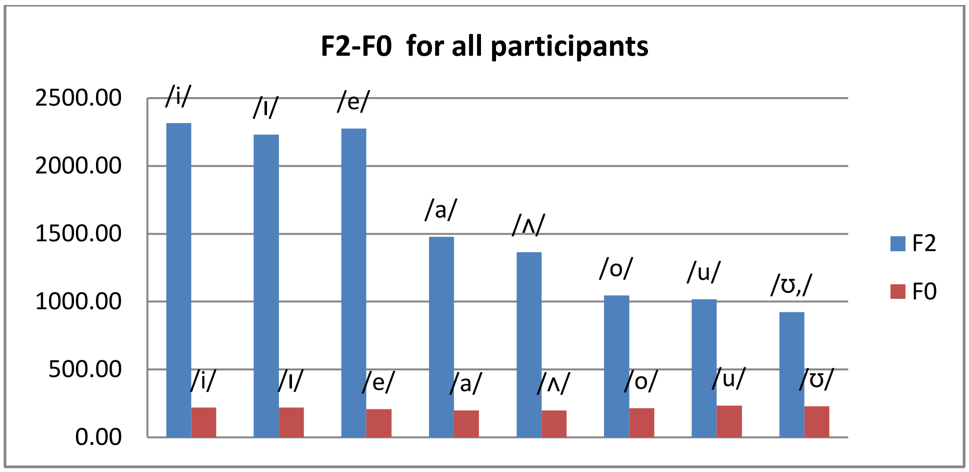
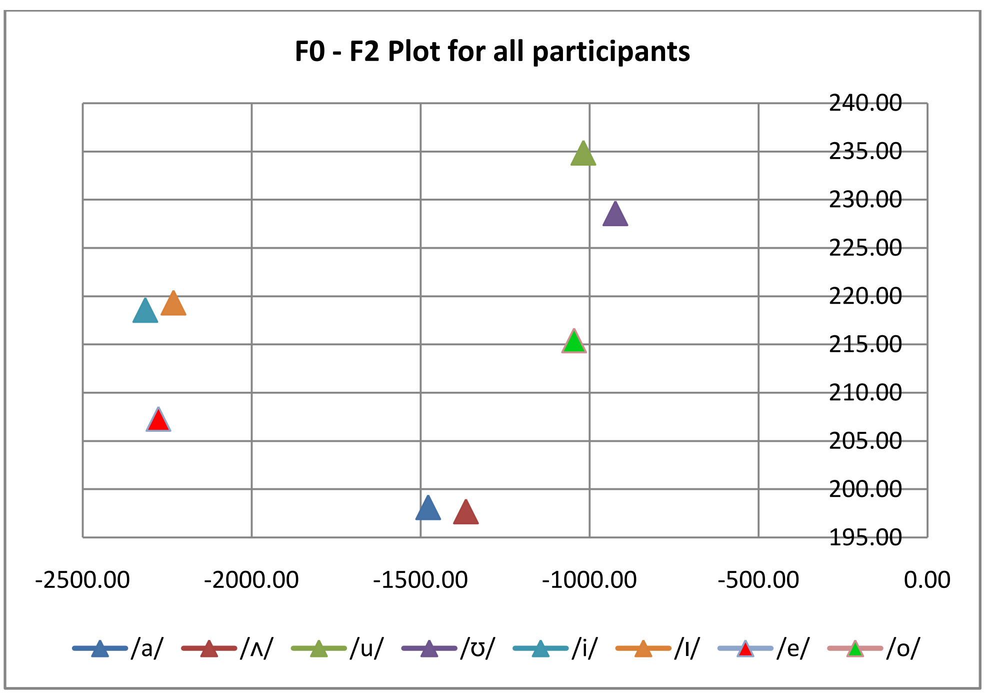


Figure 4.11 F0-F2 plot



4.2.3 Correlation between F3 and F2

Regarding the correlation between F3 and F2, we can tentatively say that in relation to the back vowels, the front vowels have higher F3 values. Along the rounded-unrounded axis, it can be observed that the unrounded vowels such as /i/, /ɪ/ and /e/ are marked by higher F3 values in comparison to the rounded vowels such as /o/ and /u/.

Figure 4.12 F3-F2 correlation

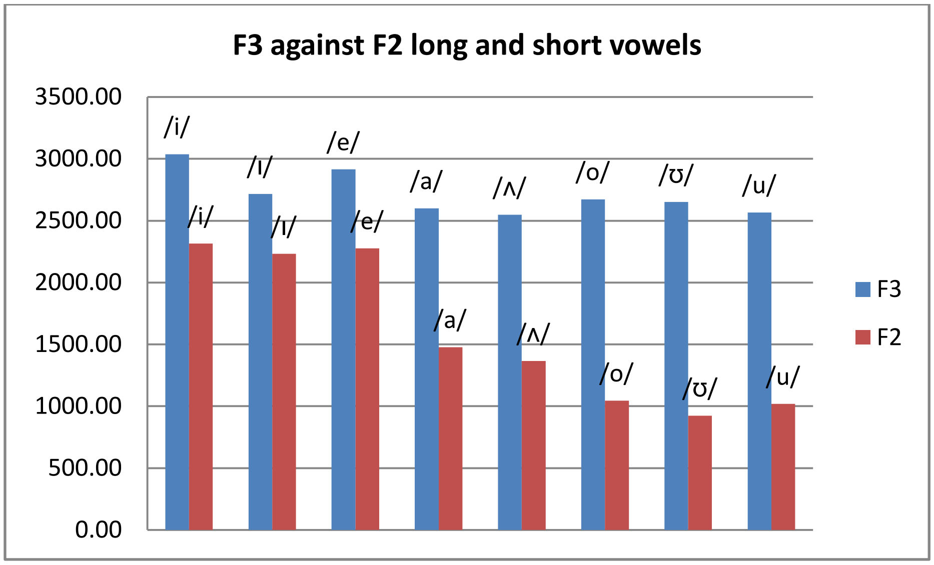
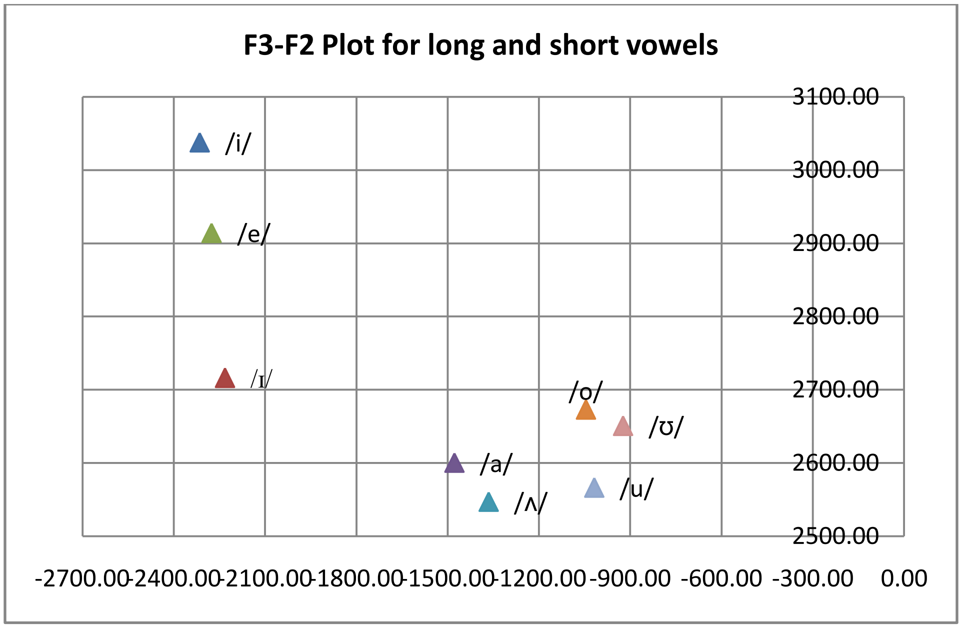


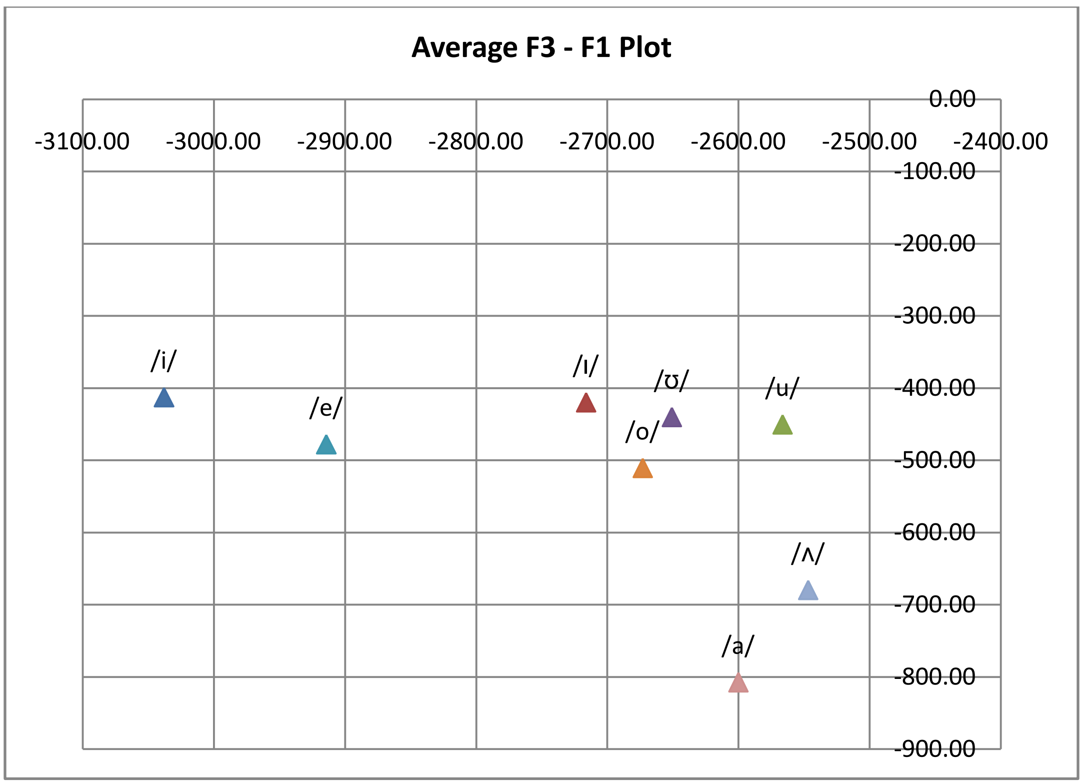
Figure 4.13 F3-F2 plot



4.2.4 Correlation between F3 and F1

Investigating the correlation between F3 and F1, preliminary findings lead to the observation that open vowels have lower F3 values than close vowels. The close vowels /u/ and /o/ reflect lower average F3 because of lip rounding. The high vowels such as /u/ and /i/ and their shorter variants /ʊ/ and /ɪ/ are marked by higher F3 values while the low vowel such as /a/ is characterized by low F3 frequency. The mid-high front and back vowels /e/ and /o/ are associated with similar F3 frequencies.

Figure 4.14 F3-F1 plot



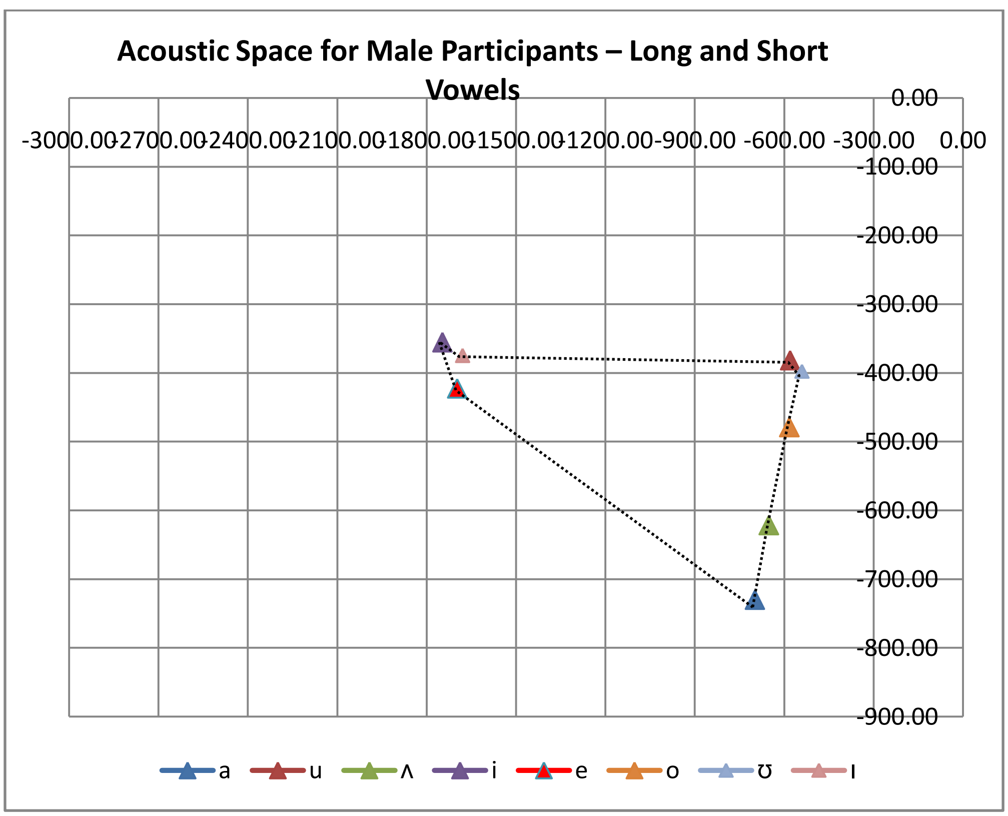
4.3 Acoustic Space

On the basis of formant values obtained after spectrographic analysis of the long and short vowels of the Darjeeling variety of Nepali, the negative values of F1 and negative values of F2-F1 were plotted on the vertical and horizontal axis respectively to determine the acoustic space or the limit within which the articulation of the vowels take place.

4.3.1 Acoustic Space for male participants

The figure below represents the acoustic space of long and short vowels for all male participants. It can be seen that the vowel /a/ occupies the lowest position in the space. The vowels /i/ and /u/ are placed high in the space, the former at front while the latter is placed high at the back. The short vowels /ɪ/ and /ʊ/ are marginally lower and display a tendency to move back marginally. The vowels / /e/ and /o/ occupy the mid postitions but are located at the front and back, respectively. The vowel /ʌ/ is placed in a mid-low postition lying above /a/ but below /o/.

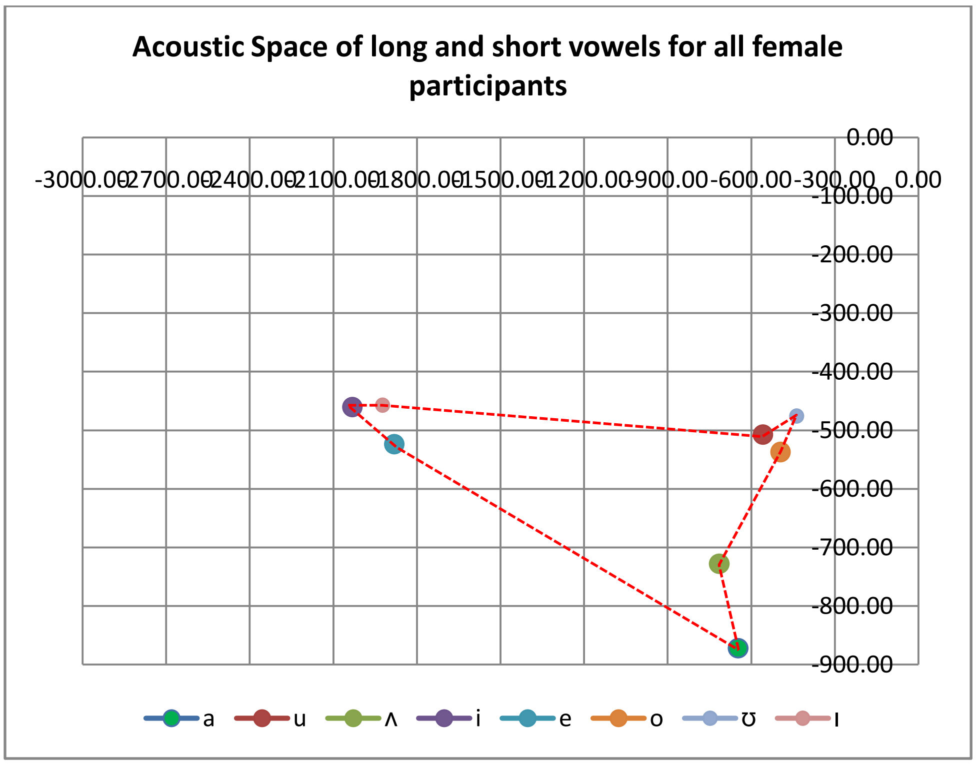
Figure 4.15 Acoustic space for male participants



4.3.2 Acoustic Space for female participants

The figure below represents the acoustic space for female participants. Judging by the organization of the vowels in this space, it can be said that /i/, /ɪ/, /u/ and /ʊ/ are high vowels with /i/ and /ɪ/ in the front portion and /u/ and /ʊ/ occupying the back position in the space. The vowels /o/ and /e/ occupy the mid positions. The vowel /a/ is the lowest vowel while /ʌ/ occupies the mid-low position.

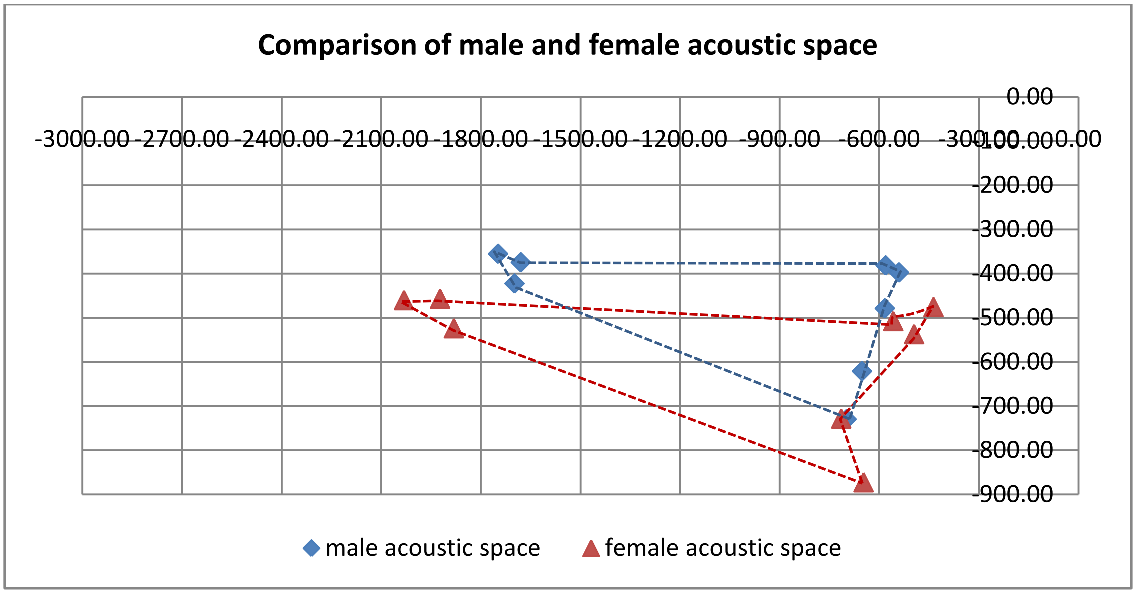
Figure 4.16 Acoustic space for female participants



4.3.3 Comparison of male and female acoustic space

Figure 4.17 presents a comparision of the male and female acoustic space. It can be seen that the female acoustic space is characterized by higher formant frequencies of all vowels. The female acoustic space is lower than that of male participants. In the case of females, the front vowels appear to be more front than in comparison to male participants and the back vowels appear to be more back than the back vowels of male participants. The vowel /a/ is also lower for female particpants than for male participants. In general, it can be observed that space enclosed by vowels of female speakers is bigger in comparison to male speakers.

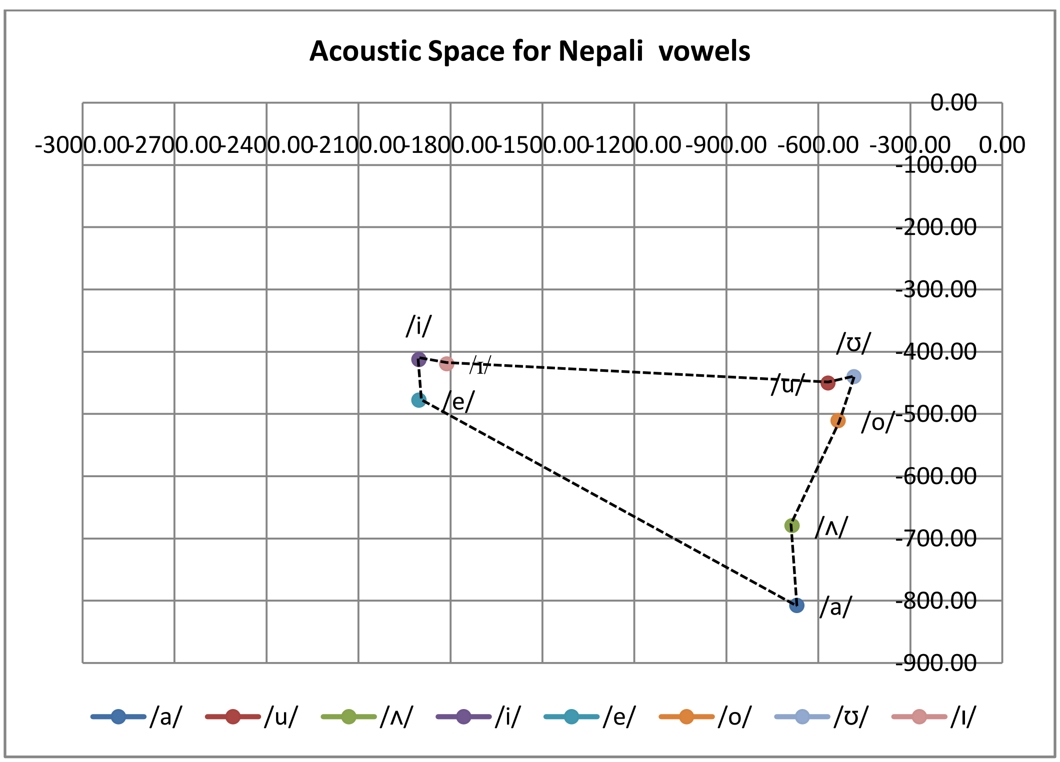
Figure 4.17 Comparison of male and female acoustic space



4.3.4 Overall acoustic space for Nepali vowels

Figure 4.18 presents the overall acoustic space for Nepali vowels in the Darjeeling variety.

Figure 4.18 Acoustic Space for Nepali vowels



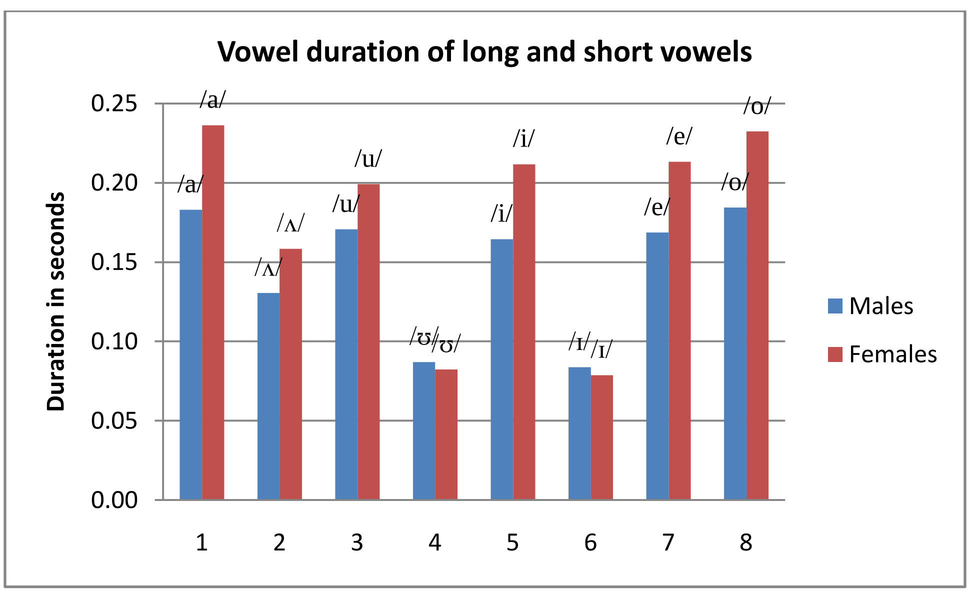
On the basis of the organization of vowels in the acoustic vowel space, certain tentative observations can be drawn regarding the descpription of Nepali vowels in the Darjeeling variety:

1. The vowels /i/, /ɪ/ and /e/ are front vowels.
2. Vowels /u/, /ʊ/ and /o/ are back vowels.
3. The vowel /a/ is the lowest vowel in the vowel quadrilateral.
4. The vowels /i/,/ɪ/, /e/, /u/ and /o/ are high vowels with low average F1 values.
5. The vowels /i/,/ɪ/, /e/, /u/ and /o/ are close vowels with low average F1 values.
6. The low and mid-low vowels /a/ and /ʌ/ are open and characterized by high F1 values.
7. The rounded vowels /u/, /ʊ/ and /o/ have low F2 frequencies as a consequence of lip rounding which places them at the back position.
8. The short vowel /ɪ/ displays a centralizing tendency whereas the short vowel /ʊ/ displays a tendency to move towards the periphery.

4.4 Vowel Duration

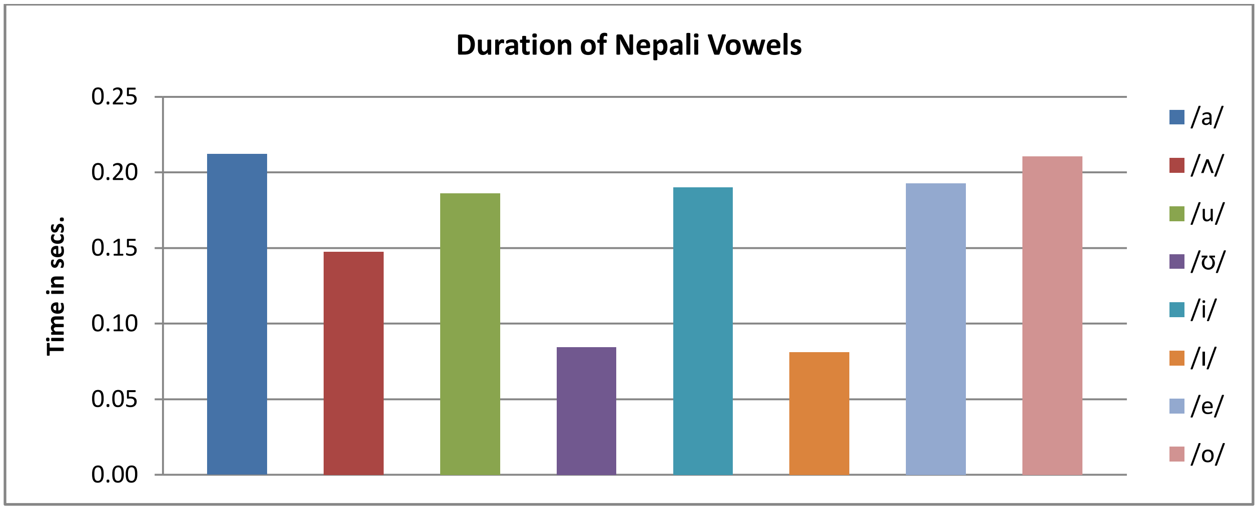
The duration of vowels of male and female speakers in presented in figure 4.19. The contrast between long and short vowels is apparant.

Figure 4.19



The average duration of all vowels for all participants is represented in figure 4.20. From the figure it is clear that /a/, /o/, /i/ and /e/ are long vowels whereas /ʌ/, /ɪ/ and /ʊ/ are short vowels. The average duration for vowels /a/ and /o/ is 0.21 seconds while for the vowels /u/, /i/ and /e/, it is 0.19 seconds. The average duration for short vowel /ʌ/ is / 0.15 seconds while for /ɪ/ and /ʊ/ the average duration across all participants is 0.08 seconds. It can be observed that open vowel

Figure 4.20



4.5 Discussion

After the analysis of formant frequencies and their correlations with each other, the durational properties of Nepali vowels in the Darjeeling variety and their organization in the vowel space we can tentatively conclude that :

1. The vowel /i/ is high-front vowel with average F1 frequency of 412.53Hz. Its average F2 frequency is 2314.78 Hz and its F3 value is 3037.89Hz. The high F3 value indicates it is an unrounded vowel. The pitch of the vowel /i/ is 218.59 Hz which also supports the observation that it is a high vowel as pitch was found to be directly proportional to height. Its duration was clocked at 0.19 seconds.
2. The vowel /ɪ/ also a high-front unrounded vowel with an average F1 frequency of 419.48Hz for all participants. Its respective F2 and F3 values are 2231.49Hz and

2716.31Hz. It is shorter variant of /i/ and its duration is 0.08 seconds. In the vowel space, the vowel /ɪ/ displays a centralizing tendency moving towards the right. The average pitch value recorded for this vowel is 219.33 Hz.

3. The vowel /u/ is a rounded high-back vowel. The height categorization is supported by low average F1 and F2 values recorded at 450.26Hz and .1018.23 Hz, respectively for all speakers. Due to the effect of lip rounding, its average F3 value is 2566.49Hz. The average duration for the vowel /u/ is 0.19 seconds. It average pitch value is 234.87 Hz.
4. The vowel /ʊ/ is the shorter counterpart of the vowel /u/ and like /u/ it is also a rounded high-back vowel characterized by low F1, F2 and F3 frequencies. Its pitch is measured at 228.59 Hz. Its average F1, F2 and F3 values are 440.11Hz, 923.76Hz and 2650.85Hz, respectively. On the basis of data analyzed, it appears that the vowel /ʊ/ is further back than /u/ and does not display a centralizing tendency. This observation needs to be tested with a larger set of data.
5. The vowel /e/ is a unrounded mid-high front vowel with an average pitch of 207.28 Hz. Its average F1, F2 and F3 values are 477.75 Hz, 2275.57Hz and 2914.18Hz. It lies slightly below /i/ in the front portion of the acoustic space. Its average duration is 0.19 seconds.
6. The vowel /o/ is a rounded mid-high back vowel. Its average F1 value is 510. 60 Hz signifying that it is slightly lower than /i/ and /u/. Its average F2 value is recorded at 1045.47Hz placing it at the back of the acoustic space. It average F3 value is 2673.09Hz which is low in comparison to /i/ but almost similar to that of /u/ suggesting that it is a rounded vowel. It average pitch is 215.42 Hz and its duration is measured at 0.21 seconds.
7. The vowel /ʌ/ is an unrounded mid-low back vowel with an average pitch of 197.71 Hz for all participants. Its average F1 value is 679.45 Hz which suggests it falls low in the height dimension. It F2 value is 1365.25 Hz and its average F3 value is 2546.99Hz. Its average duration is 0.15 seconds suggesting that it is a short vowel.
8. The vowel /a/ is low back open and occupies the lowest postion in the acoustic vowel space. Its average F1, F2 and F3 frequencies are 807.42Hz, 1477.55Hz and 2600.24 Hz, respectively. The average pitch for the vowel /a/ is 198.16Hz signifying the inverse relationship between F0 and F2 values. Its average duration is 0.21 seconds.

4.6 Concluding remarks and future projections

Since the present study was constrained by time, the scope for this disseratation had to be restricted to the peripheral oral vowels only. In the language under consideration, all oral vowels can be nasalized which offer phonemic contrast except /o/. Diphthongs are also present in the language with /i/ and /u/ as the targets for the movement of the other vowel. Due to the absence of a uniform context for nasalized vowels and diphthongs along with paucity of time, they could not be included within the scope of this dissertation. A better picture can definitely be presented if diphthongs and nasalized vowels are also taken within the scope of study. In addition, Nepali speakers from India and Nepal can be included to observe differences and similarities, if any, in the acoustic properties of vowels for Nepali language. Our knowledge regarding the acoustic properties of vowels of Nepali can further be enriched with the addition of more acoustic parameters such as the correlation between F1 and duration. The observations in this study need to be strengthened with more analysis from a larger set of data.

Bibliography

Acharya, Jayaraj. A Descriptive Grammar of Nepali and an Analyzed Corpus. Washington D.C.: Georgetown University Press, 1991.

Ashby, M. and Maidment, J. Introducing Phonetic Science. Cambridge: Cambridge University Press, 2005.

Bandhu, C. Nepali bhasako utpatti. Kathmandu: Sajha Prakashan, 1968.

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

Carver, C. M. "English dialectology and the linguistic atlas." (Ed.), In M. Linn. Handbook of dialects and language variation (2nd ed.). San : Academic Press, 1998. 5-28.

Catford, J.C. A practical introduction to phonetics. New York: Oxford University Press, 1988.

—. Fundamental Problems in Phonetics. Edinburgh: Edinburgh University Press, 1977.

Chomsky, Noam and Halle, Morris. The Sound Pattern of English. New York: Harper & Row, 1968.

CIIL Mysore. Language Information Service (LIS) - India. 12 September 2011 <http://www.lisindia.net/Nepali/Nepali.html>.

Clopper CG, Pisoni DB, de Jong K. "Acoustic characteristics of the vowel systems of six regional varieties of American English." Journal of the Acoustical Society of America; 118 (2005): 1661–1676.

Cooper, F.S., Liberman,A.M. and Borst,J.M. "The interconversion of audible and visble patterns as a basis for research in perception of speech." Proceedings of the National Academy of Science, 37. 1951. 318-325.

Dahal, Ballabh Mani. A Description of Nepali: Literary and Colloquial. Ph.D thesis. University of Poona, 1974.

Delattre, P. "The physiological interpretation of sound spectrograms." Publications of the Modern Language Association, 66 (1951): 864-875.

Disner, S. "Vowel quality: The relation between universal and language-specific factors." UCLA Working Papers in Phonetics, 1983. 58.

Dixitacharya, Bishwamani. Gorkha Byakarana Bodha. Kathmandu, 1913.

Fant, Gunar. Acoustic Theory of Speech Production. The Hauge: Mouton, 1960.

Fry, D.B. The Physics of Speech. London: Cambridge University Press, 1979.

Grierson, G.A. 1916. Calcutta: Government of India, Linguistic Survey of India 9.4.

Hagiwara, R. "Dialect variation and formant frequency: The American English vowels revisited." The Journal of the Acoustical Society of America, 102 (1997): 655-658.

Hayward, Katrina. Experimental Phonetics. Harlow, UK: Pearson, 2000.

Hoernle, A.F.R. Comparative Grammar of the Gaudian Languages with Special Reference to the Eastern Hindi. London: Rubner, 1880.

Jacewicz, E., Fox, R. A., & Salmons, J. "Vowel duration in three American English dialects." American Speech, 82 (2007a): 367-385.

Jacewicz, E., Fox, R.A., & Salmons, J. "Vowel space areas across dialects and gender." Proceedings of the XVIth International. Congress of Phonetic Sciences. 2007 b. 1465-1468.

Jakobson, R., Fant, G. and Halle, M. Preliminaries to Speech Analysis. The distinctive features and their correlates. Technical Report No. 13 (58 pages). Cambridge, MA: Acoustics Laboratory, Massachusetts Inst. of Technology (Re-published by MIT press, seventh edition, 1967)., 1952.

Johnson, K. Acoustic and auditory phonetics. London: Blackwell, 1997.

Joos, M. Acoustic Phonetics. Language Monograph No.23. Language, 24.2, Suppl. Baltimore: Linguistic Society of America, 1948.

Kent, R. D. The Speech Sciences. San Diego: Singular Publishing Group, 1997.

Kent, Ray. D. & Voroperian, Hauri K. "Vowel Acoustic Space development in Children: A synthesis of Acoustic and Anatomical data." Journal of Speech, Language and Hearing Research Vol.50. (2007): 1510-1545.

Kewley-Port, et.al. "Intelligibility and Acoustic Correlates of Japanese Accented English Vowels." 4th ICSLP. Philadelphia. USA., 1996. 450-453.

Khatiwada, Rajesh. ""Nepali"." Journal of International Phonetic Association 39 (3) (2009): 337–380.

Khawas, Vimal. "Nepali v/s Nepalese." The Hindu 19 June 2005.

—. Socio-Economic Conditions of Tea Garden Labourers in Darjeeling Hills. New Delhi: Council for Social Development, Sangha Rachana, 2006.

Labov, W. "The Social Motivation of Sound Change." Word, 19 (1963): 273-309.

Ladefoged, P. and Broadbent, D.E. "Information Conveyed by Vowels." he Journal of the Acoustical Society of America. Volume 29. Number 1 (January 1957): 98-104.

Ladefoged, Peter. A Course in Phonetics. New York: Harcourt Brace, Jovanovich, Inc., 2006 (5th edn.).

—. Elements of Acoustic Phonetics. Chicago : The University of Chicago Press, 1962.

—. Vowels and Consonants: An Introduction to the sounds of Languages. . Los Angeles: Blackwell Publishing, 2001.

Lehiste, I. Suprasegmentals. Massachussets: MIT Press, Cambridge, 1970.

Lewis, M. Paul (ed.). Ethnologue: Languages of the World, Sixteenth edition. Dallas, 2009.

Liljencrants, J. L., & Lindblom, B. "Numerical simulation of vowel quality systems: The role of perceptual contrast." Language, 48 (1972): 839-862.

Lindblom, B. "Phonetic Universals in Vowel System." (Eds), In J. Ohala &J.Jaeger. Experimental Phonology. New York: Academic Press, 1986. 13-44.

Lisker, Leigh. "On "explaining" vowel duration variation." Glossa 8 (1974): 233-48.

Mattingly, Ignatius. "A Short History of Acoustic Phonetics in the US." In Proceedings of the XIVth International Congress of Phonetic Sciences, ed. John.J.Ohala et al. San Francisco: Haskins, 1999. 1-6.

Misra, Deepshikha. Formant Structures of Hindi and Punjabi Vowels: A study in Comparing Acoustic Space. Unpublished M.Phil Dissertation. Centre for Linguistics, JNU. New Delhi, 2009.

Narang, V. and Lee, Hyunkyung. "A Study in Comparing Acoustic Space: Korean and Hindi Vowels." International Journal on Asian Language Processing 20 (3) (2010).

Narang, V.,Misra,D,,Punyayodhin,S. and Yadav,R. 2010. "A Contrastive Study of F3 correlation with F2 and F1 in Thai and Hindi." International Journal on Asian Language Processing 20 (3) (2010).

Narang, Vaishna. "A Spectrographic Study of Punjabi Vowels." OPEL,vol.3, CLE/JNU (1989).

Narang, Vaishna. and Misra, Deepshikha. "Acoustic Space, Duration and Formant Patterns in vowels of Bangkok Thai." International Journal on Asian Language Processing 20 (3) (2010): 123-140.

Office of The Registrar General & Census Commissioner, India, New Delhi. Abstract of Speakers' Strength of Languages and Mother Tongues - 2001 . 2010-11. 12 August 2012 <http://www.censusindia.gov.in/Census_Data_2001/Census_Data_Online/Language/Statement1.htm>.

Ohala, J.J. "The Contribution of Acoustic Phonetics to Phonology." In Lindblom, B. and Ohman, S. (Eds). Frontiers of Speech Communication Research. New York: Academic Press, 1979. 355-363.

Ohala, J.J. "Phonetics in phonology." 4th Seoul International Conference on Linguistics [SICOL] 11-15 Aug 1997. Seoul , 1997. 45-50.

O'Malley, L.S.S. Darjeeling District Gazetteer . New Delhi: Reprint published by Gyan Publishing House, 1907.

Peterson, G. and Lehiste, I. "Duration of Syllable Nuclei in English." Journal of the Acoustical Society of America 32 (1960): 693-703.

Pickett, J. M. The Sounds of Speech Communication - A Primer of Acoustic Phonetics. Boston: Allyn and Bacon, 1996.

Pokharel, Madhav Prasad. "Origin and Development of Nepali Language." T.B. Subba, A.C. Sinha, G.S. Nepal & D.R.Nepal (eds). Indian Nepalis - Issues and Perspectives. New Delhi: Concept Publishing Company, 2009. 325-338.

Pokharel, Madhav Prasad. Experimental Analysis of Nepali Sound System. Ph.D. dissertation, University of Pune, 1989.

Ram, Gopal. Acoustic Description of Bagri Vowels. Unpublished M.Phil. Dissertation. Centre for Linguistics, JNU. New Delhi, 2009.

Roy, B. "Darjeeling District Census Handbook 1961." Calcutta, 1968.

Stevens, K. N. "On the quantal nature of speech." Journal of Phonetics 17 (1989): 3–46.

Stevens, K. N. Acoustic Phonetics. Cambridge, MA: MIT Press, 1998.

—. Acoustic Phonetics. Cambridge, MA: The MIT Press, 1998.

Stevens, K. N., & House, A. "Perturbation of vowel articulations by consonantal context: An acoustical study." Journal of Speech and Hearing Research, 6 (1963): 112-128.

Stevens, K.N. "The quantal nature of speech: evidence from articulatory-acoustic data." (Eds.), In E. Davis & D.P. Denes. Human Communication: a Unified View. New York: McGraw Hill, 1972. 51-66.

Strange, W. "Perception of vowels: dynamic constancy." (Ed.), In J. M. Pickett. The acoustics of speech communication: fundamentals, speech perception theory, and technology. Surry, Maine: Allyn and Bacon, 1999. 153-165.

Turnbull, Archibald. The Nepali Grammar and Vocabulary. Calcutta: Baptist Mission Press. [3rd edn], 1888.

Appendix 1

Map of Darjeeling district

Retrieved from http://www.calcuttaweb.com/maps/img/darjeeling.jpg on July 21, 2012

Appendix 2

Proforma of Informed consent form for Principal investigator Consent form for patient or the subject. Retrieved from http://www.jnu.ac.in/IERB/Proposals.html

CONSENT FORM (for the subject/ patient)

The advantages and disadvantages of the research in which I am expected to participate, for which I have to donate blood/sputum/hair/voice sample has been explained to me.

I willingly, under no pressure from the researcher-

(i) agree to take part in this research, and agree to participate in all investigations which will help acquire knowledge for the benefit of the mankind,

(ii) agree to voice sample

My consent is explicitly not for disclosing any personal information. For disclosing any such personal information obtained from the investigations conducted on my samples, further consent should be obtained.

I have been informed that JNU and the researchers (PI .... and her/his colleagues) will take my prior consent before they draw benefits from research based on my samples.

Signatures

--------------------------	------------------	-------------------
Subject/patient	Witness	Principle Investigator.

Appendix 3

Census Report (2001) for Nepali published by the Government of India.

India/State/Union Territory#	Persons	Male	Female
India*	2,871,749	1,534,746	1,337,003
West Bengal	1,022,725	514,596	508,129
Assam	564,790	293,122	271,668
Sikkim	338,606	174,068	164,538
Uttar Pradesh	263,982	145,106	118,876
Arunachal Pradesh	94,919	52,276	42,643
Uttaranchal	91,047	54,655	36,392
Himachal Pradesh	70,272	42,346	27,926
Maharashtra	63,480	41,028	22,452
Meghalaya	52,155	28,385	23,770
Manipur *	45,998	24,539	21,459
Delhi#	44,367	27,997	16,370
Nagaland	34,222	19,347	14,875
Haryana	20,362	13,899	6,463
Punjab	19,778	13,328	6,450
Bihar	18,763	9,861	8,902
Jharkhand	17,326	9,558	7,768
Gujarat	17,123	11,336	5,787
Madhya Pradesh	10,923	6,778	4,145
Rajasthan	10,569	7,225	3,344
Karnataka	10,038	6,661	3,377
Orissa	9,927	5,850	4,077
Mizoram	8,948	5,429	3,519
Andhra Pradesh	8,233	5,025	3,208
Jammu & Kashmir	8,199	5,787	2,412

Chandigarh#	5,390	3,516	1,874
Tamil Nadu	4,323	2,719	1,604
Chhattisgarh	3,424	1,995	1,429
Tripura	3,377	2,086	1,291
Kerala	2,715	1,912	803
Goa	2,135	1,478	657
Daman & Diu#	1,407	1,223	184
Dadra & Nagar Haveli#	1,030	840	190
Andaman & Nicobar Islands#	782	479	303
Pondicherry#	411	295	116
Lakshadweep#	3	1	2

Appendix 4

FORMANT DATA TABULATION FOR ORAL VOWELS - ALL SPEAKERS								
MALE								
		F1	F2	F3	-(F2-F1)	-F1	F0	DURATION
SS26M								
Total Avg /a/		718.31	1494.65	2117.59	-776.34	-718.31	129.77	0.15
Total Avg /u/		330.79	803.73	2414.75	-472.94	-330.79	163.54	0.15
Total Avg /ʌ/		573.25	1071.35	2443.48	-498.10	-573.25	128.29	0.10
Total Avg /i/		294.52	2282.46	3220.06	-1987.95	-294.52	142.78	0.13
Total Avg /e/		382.53	2144.42	2999.38	-1761.89	-382.53	132.27	0.16
Total Avg /o/		403.37	854.09	2451.91	-450.72	-403.37	143.68	0.15
Total Avg /ʊ/		326.06	738.59	2517.18	-412.53	-326.06	147.93	0.07
Total Avg /ɪ/		320.32	2169.52	2582.26	-1849.20	-320.32	157.75	0.06
PL26M								
Total Avg /a/		693.52	1287.81	2545.97	-594.29	-693.52	125.72	0.19
Total Avg /u/		389.22	1082.84	2364.15	-693.63	-389.22	153.74	0.13
Total Avg /ʌ/		611.96	1277.07	2316.35	-665.11	-611.96	121.31	0.12
Total Avg /i/		332.34	2164.63	2914.46	-1832.30	-332.34	139.96	0.16
Total Avg /e/		382.05	2147.61	2693.94	-1765.56	-382.05	132.60	0.18
Total Avg /o/		465.87	1090.23	2381.80	-624.36	-465.87	141.98	0.13
Total Avg /ʊ/		514.25	1290.36	2674.76	-776.11	-514.25	154.35	0.09
Total Avg /ɪ/		389.70	1942.29	2570.80	-1552.59	-389.70	152.80	0.08
PR22M								
Total Avg /a/		757.03	1372.60	2656.35	-615.57	-757.03	136.73	0.20
Total Avg /u/		403.79	1065.77	2453.97	-661.97	-403.79	149.66	0.16
Total Avg /ʌ/		644.45	1310.55	2537.56	-666.11	-644.45	139.32	0.15
Total Avg /i/		363.58	2024.13	2615.73	-1660.54	-363.58	146.04	0.15
Total Avg /e/		463.07	2022.97	2610.81	-1559.90	-463.07	140.65	0.14
Total Avg /o/		482.12	1074.57	2679.99	-592.45	-482.12	142.87	0.19
Total Avg /ʊ/		333.03	801.84	2641.03	-468.81	-333.03	156.10	0.09
Total Avg /ɪ/		396.19	1981.30	2465.28	-1585.11	-396.19	143.74	0.08
JY25M								
Total Avg /a/		795.72	1544.36	2948.43	-748.64	-795.72	175.84	0.22
Total Avg /u/		381.24	695.72	2532.59	-314.48	-381.24	220.56	0.21
Total Avg /ʌ/		675.80	1328.47	2358.47	-652.67	-675.80	170.32	0.17
Total Avg /i/		393.52	2205.27	3009.16	-1811.76	-393.52	201.74	0.22
Total Avg /e/		446.09	2173.36	2899.19	-1727.27	-446.09	181.37	0.21
Total Avg /o/		530.09	997.53	2431.96	-467.44	-530.09	198.11	0.24
Total Avg /ʊ/		409.99	939.19	2362.76	-529.20	-409.99	183.91	0.09
Total Avg /ɪ/		374.20	2062.44	2481.57	-1688.24	-374.20	167.44	0.10
BS26M								
Total Avg /a/		684.90	1440.60	2413.92	-755.71	-684.90	144.06	0.16
Total avg /u/		402.92	1162.08	2332.18	-759.17	-402.92	189.46	0.19
Total Avg /ʌ/		600.63	1376.41	2260.38	-775.79	-600.63	139.07	0.13
Total Avg /i/		392.49	1836.52	2584.04	-1444.03	-392.49	182.32	0.16
Total Avg /e/		439.18	2113.75	2611.04	-1674.57	-439.18	150.86	0.15
Total avg /o/		512.82	1292.36	2517.84	-779.54	-512.82	158.36	0.22
Total Avg /ʊ/		404.63	920.01	2345.04	-515.38	-404.63	180.49	0.09
Total Avg /ɪ/		392.16	2112.56	2493.71	-1720.40	-392.16	160.71	0.09

Appendix 5

FORMANT DATA TABULATION FOR ORAL VOWELS - ALL SPEAKERS								
FEMALE								
		F1	F2	F3	-(F2-F1)	-F1	F0	DURATION
DG22F								
Total Avg /a/		901.97	1573.32	2607.79	-671.35	-901.97	266.67	0.23
Total Avg /u/		508.27	984.66	2593.45	-476.39	-508.27	301.60	0.19
Total Avg /ʌ/		726.00	1489.94	2550.21	-763.94	-726.00	250.79	0.16
Total Avg /i/		541.85	2075.79	2697.63	-1533.94	-541.85	278.45	0.19
Total Avg /e/		549.61	2276.15	2897.09	-1726.55	-549.61	273.12	0.22
Total Avg /o/		565.76	1049.71	2767.50	-483.95	-565.76	285.66	0.25
Total Avg /ʊ/		522.95	919.44	2577.29	-396.49	-522.95	297.49	0.09
Total Avg /ɪ/		450.26	2213.35	2717.50	-1763.10	-450.26	263.77	0.09
LL26F								
Total Avg /a/		846.06	1654.88	2925.55	-808.82	-846.06	243.39	0.23
Total Avg /u/		580.20	1310.86	2850.46	-730.67	-580.20	316.12	0.16
Total Avg /ʌ/		656.78	1428.92	2632.58	-772.14	-656.78	250.85	0.15
Total Avg /i/		374.93	2270.49	2904.05	-1895.56	-374.93	283.12	0.21
Total Avg /e/		505.31	2403.44	2985.30	-1898.13	-505.31	260.38	0.22
Total Avg /o/		556.04	1116.91	2789.46	-560.87	-556.04	276.66	0.21
Total Avg /ʊ/		566.39	1165.94	3059.01	-599.55	-566.39	320.36	0.09
Total Avg /ɪ/		436.35	2364.90	2766.40	-1928.55	-436.35	297.26	0.09
ML22F								
Total Avg /a/		964.16	1640.43	2842.15	-676.27	-964.16	265.59	0.26
Total Avg /u/		510.09	1130.52	3063.58	-620.44	-510.09	318.65	0.20
Total Avg /ʌ/		786.19	1600.65	2831.64	-814.47	-786.19	278.21	0.16
Total Avg /i/		419.47	2874.74	3590.96	-2455.27	-419.47	291.61	0.26
Total Avg /e/		575.66	2629.48	3213.43	-2053.81	-575.66	285.42	0.21
Total Avg /o/		566.78	1089.87	2822.71	-523.09	-566.78	285.39	0.25
Total Avg /ʊ/		446.05	896.94	2904.30	-450.89	-446.05	308.97	0.08
Total Avg /ɪ/		493.31	2588.84	3070.94	-2095.52	-493.31	307.05	0.09
PP23F								
Total Avg /a/		876.41	1410.86	2549.95	-534.45	-876.41	232.18	0.22
Total Avg /u/		456.69	1037.96	2708.56	-581.27	-456.69	241.85	0.22
Total Avg /ʌ/		710.92	1306.97	2565.59	-596.05	-710.92	219.52	0.18
Total Avg /i/		438.39	2628.77	3113.58	-2190.39	-438.39	245.86	0.21
Total Avg /e/		491.87	2378.35	2975.43	-1886.48	-491.87	242.41	0.21
Total Avg /o/		501.45	1063.64	2838.06	-562.19	-501.45	243.10	0.20
Total Avg /ʊ/		420.99	861.84	2670.45	-440.85	-420.99	247.03	0.06
Total Avg /ɪ/		489.33	2465.10	2979.28	-1975.76	-489.33	253.10	0.09
PTP22F								
Total Avg /a/		786.25	1381.08	2634.05	-594.83	-786.25	193.27	0.25
Total Avg /u/		412.72	775.80	1941.18	-363.08	-412.72	217.59	0.26
Total Avg /ʌ/		712.79	1424.74	2653.80	-711.95	-712.79	205.64	0.15
Total Avg /i/		527.02	2476.38	3312.62	-1949.36	-527.02	210.98	0.22
Total Avg /e/		479.52	2284.21	2965.65	-1804.69	-479.52	205.94	0.22
Total Avg /o/		463.32	861.97	2424.79	-398.65	-463.32	199.64	0.29
Total Avg /ʊ/		428.43	773.19	2394.62	-344.76	-428.43	216.68	0.08
Total Avg /ɪ/		437.90	2299.79	2756.15	-1861.89	-437.90	213.85	0.05
TB23F								
Total Avg /a/		857.33	1452.42	2360.90	-595.09	-857.33	266.53	0.23
Total Avg /u/		576.91	1150.58	2976.55	-573.67	-576.91	310.81	0.16
Total Avg /ʌ/		775.23	1402.69	2866.87	-627.46	-775.23	271.49	0.16
Total Avg /i/		459.73	2623.39	3454.46	-2163.66	-459.73	281.64	0.16
Total Avg /e/		540.38	2457.56	3204.69	-1917.18	-540.38	275.09	0.21
Total Avg /o/		569.00	1009.25	3297.99	-440.24	-569.00	294.18	0.20
Total Avg /ʊ/		468.43	854.03	3012.91	-385.60	-468.43	249.37	0.09
Total Avg /ɪ/		434.59	2346.32	2995.51	-1911.72	-434.59	230.69	0.07

Appendix 6

Average Formant Frequencies for all 6 repetitions of all vowels for SS26M							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	722.20	1552.61	1878.28	127.95	0.20	127.14	128.09
Avg /a/2	709.54	1462.68	2248.99	127.96	0.15	129.16	127.94
Avg /a/3	717.76	1413.20	2148.76	127.13	0.15	125.31	128.78
Avg /a/4	695.84	1463.18	2177.93	130.58	0.17	136.92	130.29
Avg /a/5	757.09	1603.21	2032.24	133.40	0.14	140.90	133.17
Avg /a/6	707.40	1473.00	2219.35	123.85	0.12	132.57	114.65
Total Avg /a/	**718.31**	**1494.65**	**2117.59**	**128.48**	**0.15**		
Avg /u/1	336.41	746.43	2477.43	175.75	0.15	161.86	183.06
Avg /u/2	332.41	805.60	2516.84	167.84	0.18	154.15	177.35
Avg /u/3	327.22	759.72	2371.26	163.22	0.14	152.87	169.51
Avg /u/4	320.55	805.12	2422.06	161.09	0.15	147.90	173.67
Avg /u/5	332.88	801.47	2393.24	162.02	0.13	155.79	163.31
Avg /u/6	335.29	904.06	2307.68	140.37	0.13	154.14	124.55
Total Avg /u/	**330.79**	**803.73**	**2414.75**	**161.72**	**0.15**		
Avg /ʌ/1	618.57	1056.12	2494.86	139.16	0.11	139.83	139.08
Avg /ʌ/2	558.77	1129.80	2590.66	126.34	0.10	128.36	127.52
Avg /ʌ/3	564.47	1088.71	2498.36	130.44	0.10	130.20	130.95
Avg /ʌ/4	550.13	1052.05	2358.78	125.92	0.10	127.07	125.67
Avg /ʌ/5	575.45	1079.83	2211.85	130.45	0.10	124.93	131.28
Avg /ʌ/6	572.09	1021.56	2506.39	121.54	0.09	125.76	114.75
Total Avg /ʌ/	**573.25**	**1071.35**	**2443.48**	**128.98**	**0.10**		
Avg /i/1	309.27	2308.09	3379.59	158.84	0.15	151.43	166.20
Avg /i/2	287.40	2278.62	2944.95	139.06	0.14	139.79	133.22
Avg /i/3	295.88	2264.54	3246.67	146.78	0.13	145.08	147.31
Avg /i/4	283.14	2263.01	3253.51	137.77	0.13	139.14	134.73
Avg /i/5	297.09	2259.21	3228.58	147.52	0.11	147.17	135.10
Avg /i/6	294.34	2321.31	3267.09	129.32	0.11	142.17	113.46
Total Avg /i/	**294.52**	**2282.46**	**3220.06**	**143.21**	**0.13**		
Avg /e/1	391.41	2118.20	2693.87	135.56	0.12	132.11	134.51
Avg /e/2	377.16	2076.90	2982.11	132.96	0.18	133.37	138.40
Avg /e/3	371.41	2185.70	3172.30	132.80	0.19	130.24	134.42
Avg /e/4	379.57	2204.79	3078.63	131.34	0.15	126.00	135.18
Avg /e/5	385.52	2162.80	2999.61	131.99	0.16	132.33	130.57
Avg /e/6	390.13	2118.14	3069.75	128.14	0.14	136.39	124.91
Total Avg /e/	**382.53**	**2144.42**	**2999.38**	**132.13**	**0.16**		
Avg /o/1	406.44	832.07	2418.01	157.36	0.18	143.75	163.00
Avg /o/2	396.30	874.30	2436.13	141.52	0.15	137.67	148.37
Avg /o/3	400.79	859.02	2458.86	152.51	0.15	143.22	162.87
Avg /o/4	401.37	868.96	2429.52	137.84	0.14	134.11	152.50
Avg /o/5	408.18	843.74	2500.32	142.87	0.13	136.92	155.69
Avg /o/6	407.15	846.43	2468.63	124.36	0.12	141.08	97.58
Total Avg /o/	**403.37**	**854.09**	**2451.91**	**142.74**	**0.15**		
Avg /ʊ/1	344.04	741.10	2536.08	153.78	0.07	153.89	152.92
Avg ʊ/2	313.55	773.99	2485.66	148.47	0.08	154.97	138.40
Avg /ʊ/3	314.74	719.15	2433.17	147.54	0.07	150.95	142.74
Avg /ʊ/4	308.60	736.16	2446.09	147.77	0.07	152.39	139.11
Avg /ʊ/5	349.38	722.55	2684.92	152.22	0.08	161.96	134.47
Total Avg /ʊ/	**326.06**	**738.59**	**2517.18**	**149.96**	**0.07**		
Avg /ɪ/1	317.79	2233.09	2743.36	164.54	0.07	172.36	168.05
Avg /ɪ/2	326.53	2167.02	2471.30	161.07	0.07	165.58	167.09
Avg /ɪ/3	302.18	2115.43	2613.78	156.49	0.05	163.56	158.49
Avg /ɪ/5	318.33	2163.83	2551.69	155.70	0.06	154.79	164.44
Avg /ɪ/6	336.77	2168.22	2531.13	149.73	0.07	164.77	144.47
Total Avg /ɪ/	**320.32**	**2169.52**	**2582.26**	**157.51**	**0.06**		

Appendix 7

Average Formant Frequencies for BS26M							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	709.93	1527.92	2536.24	145.74	0.13	141.36	147.48
Avg /a/2	676.37	1463.57	2432.42	150.25	0.17	142.75	157.63
Avg /a/3	649.78	1436.59	2288.56	140.50	0.18	135.37	142.94
Avg /a/4	690.51	1385.84	2554.62	142.42	0.14	132.12	146.00
Avg /a/5	681.01	1423.55	2334.10	143.07	0.17	136.57	147.88
Avg /a/6	701.77	1406.14	2337.57	139.94	0.14	142.10	139.75
Total Avg /a	**684.90**	**1440.60**	**2413.92**	**143.66**	**0.16**		
Avg /u/1	367.19	1000.61	2585.93	199.48	0.19	181.24	192.74
Avg /u/2	422.42	1260.32	2392.93	195.73	0.23	182.15	104.23
Avg /u/3	418.25	1251.51	2193.37	197.27	0.18	190.13	197.85
Avg /u/4	435.53	1087.58	2149.70	182.46	0.18	171.41	183.83
Avg /u/5	407.08	1322.85	2245.60	182.39	0.22	167.71	183.68
Avg /u/6	367.02	1049.63	2425.54	183.38	0.17	182.69	185.44
Total avg /u/	**402.92**	**1162.08**	**2332.18**	**190.12**	**0.19**		
Avg /ʌ/1	615.10	1318.55	2132.28	154.72	0.15	144.56	155.81
Avg /ʌ/2	612.18	1438.81	2168.69	141.51	0.13	138.40	141.87
Avg /ʌ/3	599.64	1467.96	2183.75	139.59	0.14	134.77	142.05
Avg /ʌ/4	601.37	1420.37	2280.81	133.03	0.13	131.82	132.57
Avg /ʌ/5	604.93	1295.38	2455.02	142.17	0.15	141.49	143.07
Avg /ʌ/6	570.55	1317.40	2341.71	131.30	0.12	134.93	134.10
Total Avg /ʌ	**600.63**	**1376.41**	**2260.38**	**140.39**	**0.13**		
Avg /i/1	391.10	1649.79	2487.50	185.31	0.19	171.63	187.29
Avg /i/2	377.30	1492.03	2365.15	181.93	0.21	175.73	183.09
Avg /i/3	395.20	2083.06	2833.45	179.74	0.15	175.55	167.17
Avg /i/4	409.01	2225.18	2933.49	189.06	0.14	171.43	165.57
Avg /i/5	383.48	1859.05	2536.39	178.54	0.15	176.22	176.61
Avg /i/6	398.83	1710.00	2348.24	188.56	0.15	180.99	188.64
Total Avg /i/	**392.49**	**1836.52**	**2584.04**	**183.86**	**0.16**		
Avg /e/1	416.50	1861.95	2610.65	156.89	0.19	165.26	157.40
Avg /e/2	450.91	2258.16	2720.35	152.89	0.15	160.86	144.70
Avg /e/3	442.59	2186.32	2536.92	142.97	0.13	147.92	131.11
Avg /e/4	439.84	2129.12	2678.42	151.41	0.16	156.50	152.67
Avg /e/5	442.88	2120.48	2590.13	156.17	0.16	157.91	159.26
Avg /e/6	435.34	2096.92	2485.11	157.26	0.14	159.75	159.51
Avg /e/7	446.21	2143.31	2655.68	149.97	0.13	152.08	149.68
Total Avg /e	**439.18**	**2113.75**	**2611.04**	**152.51**	**0.15**		
Avg /o/1	546.78	1390.04	2750.33	173.39	0.22	170.37	174.57
Avg /o/2	486.16	1266.05	2387.03	158.59	0.25	160.68	159.44
Avg /o/3	515.30	1282.95	2540.26	150.88	0.24	163.00	165.91
Avg /o/4	504.76	1232.97	2289.66	157.91	0.19	162.19	159.11
Avg /o/ 5	518.12	1376.72	2694.47	166.07	0.22	166.30	166.51
Avg /o/6	505.80	1205.41	2445.27	163.23	0.21	156.93	165.54
Total avg /o/	**512.82**	**1292.36**	**2517.84**	**161.68**	**0.22**		
Avg /ʊ/1	395.27	851.04	2550.49	182.35	0.09	186.50	186.30
Avg/ʊ/2	407.41	993.38	2385.44	178.98	0.10	186.16	181.56
Avg /ʊ/3	365.32	835.97	2457.93	177.97	0.10	182.99	179.77
Avg /ʊ/4	399.50	935.82	2322.83	181.63	0.09	188.63	183.21
Avg /ʊ/5	415.16	883.90	2277.39	183.37	0.09	192.23	181.99
Avg /ʊ/6	409.99	939.19	2362.76	183.91	0.09	188.57	173.58
Avg /ʊ/7	439.76	1000.77	2058.45	175.27	0.07	181.30	169.02
Total Avg /ʊ	**404.63**	**920.01**	**2345.04**	**180.50**	**0.09**		
Avg /ɪ/1	393.12	2137.05	2551.38	164.62	0.10	166.89	165.37
Avg /ɪ/2	374.20	2062.44	2481.57	167.44	0.10	173.59	163.15
Avg /ɪ/3	388.03	2078.56	2502.84	156.89	0.08	162.00	150.98
Avg /ɪ/4	417.41	2118.92	2427.08	158.30	0.10	158.31	158.97
Avg /ɪ/5	424.51	2098.72	2534.68	155.28	0.08	154.41	150.09
Avg /ɪ/6	355.71	2179.70	2464.71	172.36	0.09	175.73	172.88
Total Avg /ɪ/	**392.16**	**2112.56**	**2493.71**	**162.48**	**0.09**		

Appendix 8

Average Formant Frequencies for all 6 repetitions of all vowels for PL26M							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	693.42	1348.00	2411.98	131.90	0.20	127.35	147.51
Avg /a/2	684.74	1285.83	2587.22	126.18	0.19	127.43	127.34
Avg /a/3	696.80	1300.88	2528.58	128.72	0.19	125.44	132.22
Avg /a/4	691.14	1267.67	2579.11	125.51	0.18	121.84	127.26
Avg /a/5	689.48	1269.30	2673.29	122.47	0.19	123.42	126.38
Avg /a/6	705.55	1255.22	2495.62	115.79	0.17	120.04	105.57
Total Avg /a/	**693.52**	**1287.81**	**2545.97**	**125.09**	**0.19**		
Avg /u/1	387.18	1086.29	2446.01	183.89	0.16	163.70	191.45
Avg /u/2	403.36	936.36	2339.88	160.48	0.14	153.64	158.33
Avg /u/3	359.08	1066.66	2523.92	158.92	0.11	155.30	157.95
Avg /u/4	388.91	1110.46	2284.53	148.31	0.13	146.14	147.20
Avg /u/5	389.10	1122.98	2345.59	147.25	0.14	145.23	148.17
Avg /u/6	407.69	1174.31	2244.95	124.56	0.13	139.80	97.11
Total Avg /u/	**389.22**	**1082.84**	**2364.15**	**153.90**	**0.13**		
Avg /ʌ/1	604.30	1203.73	2216.31	131.68	0.08	126.13	135.78
Avg /ʌ/2	619.01	1358.78	2393.00	123.87	0.10	123.26	125.52
Avg /ʌ/3	597.33	1333.38	2296.57	121.92	0.12	122.92	121.54
Avg /ʌ/4	610.61	1229.20	2370.99	124.85	0.15	124.27	125.80
Avg /ʌ/5	628.54	1260.25	2304.88	114.61	0.14	118.10	112.03
Total Avg /ʌ/	**611.96**	**1277.07**	**2316.35**	**123.39**	**0.12**		
Avg /i/1	311.76	2300.54	3091.85	152.07	0.16	141.91	146.69
Avg /i/2	315.79	2194.53	2934.33	146.06	0.18	137.61	150.17
Avg /i/3	338.33	2157.27	2902.95	139.77	0.18	133.80	141.31
Avg /i/4	335.11	2144.28	3034.84	136.23	0.16	133.01	132.77
Avg /i/5	329.38	2127.92	2893.05	137.77	0.14	133.38	140.94
Avg /i/6	363.66	2063.27	2629.71	125.33	0.13	130.28	117.25
Total Avg /i/	**332.34**	**2164.63**	**2914.46**	**139.54**	**0.16**		
Avg /e/1	371.41	2308.29	2989.15	141.52	0.20	131.36	146.76
Avg /e/2	387.01	2162.76	2665.05	134.39	0.20	128.07	138.32
Avg /e/3	383.82	2136.63	2608.28	131.75	0.18	128.87	135.91
Avg /e/4	390.32	2116.63	2671.79	134.23	0.18	131.55	138.64
Avg /e/5	386.34	2117.73	2651.73	130.03	0.18	129.85	129.11
Avg /e/6	373.41	2043.63	2577.62	121.42	0.14	126.97	105.35
Total Avg /e/	**382.05**	**2147.61**	**2693.94**	**132.22**	**0.18**		
Avg /o/1	461.67	973.55	2369.94	146.82	0.15	140.62	150.34
Avg /o/2	457.30	1116.32	2414.49	142.80	0.15	140.46	147.42
Avg /o/3	455.91	1121.05	2280.60	139.23	0.12	138.59	142.30
Avg /o/4	466.87	1187.23	2415.79	142.05	0.11	139.19	151.21
Avg /o/5	462.53	1053.28	2374.95	143.86	0.12	141.66	148.46
Avg /o/6	490.94	1089.95	2435.00	130.17	0.12	139.37	119.55
Total Avg /o/	**465.87**	**1090.23**	**2381.80**	**140.82**	**0.13**		
Avg /ʊ/1	527.17	1492.35	2964.09	164.02	0.11	171.88	167.00
Avg /ʊ/2	516.51	1462.55	2676.88	156.68	0.09	162.04	156.23
Avg /ʊ/3	611.46	1423.53	2961.25	152.89	0.07	155.46	153.09
Avg /ʊ/4	475.25	1136.27	2541.21	154.79	0.10	159.74	152.35
Avg /ʊ/5	478.63	1101.86	2511.87	153.03	0.10	166.27	151.04
Avg /ʊ/6	476.48	1125.60	2393.24	152.90	0.09	161.95	152.64
Total Avg /ʊ/	**514.25**	**1290.36**	**2674.76**	**155.72**	**0.09**		
Avg /ɪ/1	358.64	1968.47	2766.56	165.68	0.09	171.97	167.92
Avg /ɪ/2	393.93	1923.21	2433.72	153.16	0.08	158.11	154.81
Avg /ɪ/3	404.49	1897.62	2641.44	152.43	0.09	158.78	153.14
Avg /ɪ/4	369.41	1971.70	2563.21	153.96	0.08	157.32	155.03
Avg /ɪ/5	401.34	1983.85	2592.83	151.64	0.09	164.67	152.89
Avg /ɪ/6	410.42	1908.91	2427.04	138.55	0.07	153.19	118.66
Total Avg /ɪ/	**389.70**	**1942.29**	**2570.80**	**152.57**	**0.08**		

Appendix 9

Average Formant Frequencies for all 6 repetitions of all vowels for PR22M							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	788.66	1422.45	2715.19	152.01	0.21	141.59	164.75
Avg /a/2	761.45	1354.85	2671.27	137.12	0.19	135.70	140.11
Avg /a/3	782.74	1401.26	2698.88	141.35	0.21	138.19	144.12
Avg /a/4	731.26	1339.13	2622.37	130.20	0.21	131.04	130.85
Avg /a/5	765.85	1363.50	2679.84	138.24	0.21	137.55	121.23
Avg /a/6	712.24	1354.42	2550.55	109.89	0.14	121.52	96.90
Total Avg /a/	**757.03**	**1372.60**	**2656.35**	**134.80**	**0.20**		
Avg /u/1	396.77	1082.06	2482.16	169.69	0.19	168.23	171.13
Avg /u/2	411.29	1104.74	2485.80	152.07	0.17	152.38	152.33
Avg /u/3	418.74	1052.44	2461.73	155.13	0.15	154.10	153.96
Avg /u/4	414.78	1065.20	2412.30	140.11	0.17	141.94	135.22
Avg /u/5	404.67	1016.39	2495.17	151.33	0.16	152.42	157.49
Avg /u/6	376.50	1073.77	2386.66	118.88	0.15	133.24	114.71
Total Avg /u/	**403.79**	**1065.77**	**2453.97**	**147.87**	**0.16**		
Avg /ʌ/1	670.27	1337.20	2596.70	150.91	0.18	145.22	152.23
Avg /ʌ/2	625.85	1336.16	2541.48	142.33	0.15	144.46	141.25
Avg /ʌ/3	663.95	1328.31	2631.90	141.29	0.15	140.70	141.36
Avg /ʌ/4	627.36	1312.75	2499.06	136.41	0.15	138.73	134.60
Avg /ʌ/5	653.03	1301.10	2548.76	137.26	0.13	137.24	135.17
Avg /ʌ/ 6	626.22	1247.80	2407.48	107.73	0.12	116.93	98.88
Total Avg /ʌ/	**644.45**	**1310.55**	**2537.56**	**135.99**	**0.15**		
Avg /i/1	347.85	2082.78	2666.68	163.32	0.15	158.58	157.61
Avg /i/2	364.82	2021.45	2589.39	148.92	0.15	149.91	137.12
Avg /i/3	355.13	1999.36	2575.20	151.28	0.15	147.81	149.90
Avg /i/4	381.40	2039.96	2658.75	139.65	0.16	141.34	127.27
Avg /i/5	375.80	1990.11	2564.02	144.29	0.16	146.79	136.02
Avg /i/6	356.51	2011.11	2640.36	118.10	0.12	128.77	113.67
Total Avg /i/	**363.58**	**2024.13**	**2615.73**	**144.26**	**0.15**		
Avg /e/1	471.14	2076.45	2654.63	154.92	0.14	152.03	157.59
Avg /e/2	469.88	2020.05	2622.93	142.44	0.14	153.05	141.79
Avg /e/3	466.73	1989.53	2614.25	147.23	0.15	153.51	147.02
Avg /e/4	465.40	2007.73	2608.53	132.24	0.15	142.14	128.78
Avg /e/5	455.29	2054.99	2606.00	140.72	0.13	139.12	139.77
Avg /e/6	450.00	1989.09	2558.51	115.41	0.14	137.39	100.21
Total Avg /e/	**463.07**	**2022.97**	**2610.81**	**138.82**	**0.14**		
Avg /o/1	515.02	1090.11	2712.14	157.43	0.21	153.93	162.64
Avg /o/2	509.16	1107.61	2660.39	143.39	0.18	144.37	139.16
Avg /o/3	505.02	1221.11	2573.39	149.91	0.20	146.51	153.37
Avg /o/4	454.64	1042.51	2575.46	135.47	0.18	140.16	128.68
Avg /o/5	465.69	975.84	2794.14	142.72	0.21	140.88	143.62
Avg /o/6	443.18	1010.24	2764.43	109.50	0.16	124.42	99.24
Total Avg /o/	**482.12**	**1074.57**	**2679.99**	**139.74**	**0.19**		
Avg /ʊ/1	346.38	870.54	2427.22	171.10	0.09	175.49	179.31
Avg /ʊ/2	334.71	833.34	2410.65	165.85	0.09	173.80	152.25
Avg /ʊ/3	339.98	786.26	2915.16	154.61	0.08	164.94	147.98
Avg /ʊ/4	316.05	761.16	2756.11	149.82	0.08	159.05	135.66
Avg /ʊ/5	316.21	778.80	2711.00	154.13	0.09	158.85	157.76
Avg /ʊ/6	344.87	780.97	2626.05	145.03	0.09	153.46	129.53
Total Avg /ʊ/	**333.03**	**801.84**	**2641.03**	**156.76**	**0.09**		
Avg /ɪ/1	389.46	1943.33	2392.63	159.09	0.09	168.58	161.37
Avg /ɪ/2	403.30	2038.26	2676.71	152.98	0.08	171.24	154.87
Avg /ɪ/3	412.56	2022.86	2377.22	146.68	0.07	156.27	136.08
Avg /ɪ/4	382.80	1898.72	2294.23	136.77	0.07	156.36	123.99
Avg /ɪ/5	412.26	2053.07	2643.91	138.55	0.07	155.24	123.18
Avg /ɪ/6	376.77	1931.58	2406.98	121.39	0.09	138.50	106.18
Total Avg /ɪ/	**396.19**	**1981.30**	**2465.28**	**142.58**	**0.08**		

Appendix 10

Average Formant Frequencies for all 6 repetitions of all vowels for JY26M							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	798.17	1531.74	3008.62	181.98	0.24	164.18	195.63
Avg /a/2	787.37	1512.29	2848.45	172.97	0.26	163.40	183.07
Avg /a/3	790.55	1519.23	3076.33	178.15	0.24	174.03	184.49
Avg /a/4	788.45	1555.63	2908.58	176.40	0.20	167.62	185.37
Avg /a/5	793.34	1531.88	2863.56	175.85	0.22	172.54	183.46
Avg /a/6	816.47	1615.41	2985.04	163.64	0.17	167.97	160.52
Total Avg /a/	**795.72**	**1544.36**	**2948.43**	**174.83**	**0.22**		
Avg /u/1	398.87	681.68	2596.63	216.88	0.23	196.15	217.07
Avg /u/2	394.27	699.04	2587.16	219.54	0.22	194.67	224.82
Avg /u/3	383.41	690.14	2598.49	224.21	0.21	202.76	224.20
Avg/u/4	364.79	690.28	2327.67	222.21	0.20	205.92	217.84
Avg /u/5	390.72	703.16	2670.63	216.29	0.21	193.12	223.89
Avg /u/6	355.41	710.02	2414.98	201.04	0.20	196.94	190.11
Total Avg /u/	**381.24**	**695.72**	**2532.59**	**216.70**	**0.21**		
Avg /ʌ/1	690.12	1424.76	2416.86	174.71	0.16	171.64	174.05
Avg /ʌ/2	700.33	1362.36	2408.36	173.24	0.21	170.05	173.18
Avg /ʌ/3	644.35	1215.68	2384.86	169.10	0.16	168.62	166.31
Avg /ʌ/ 4	670.84	1363.69	2282.74	169.50	0.16	170.37	166.79
Avg /ʌ/5	677.54	1342.12	2330.63	169.42	0.17	171.00	167.44
Avg /ʌ/6	671.60	1262.21	2327.39	166.27	0.17	168.63	164.46
Total Avg /ʌ/	**675.80**	**1328.47**	**2358.47**	**170.37**	**0.17**		
Avg /i/1	381.79	2078.51	2692.70	207.28	0.28	198.47	210.21
Avg /i/2	404.84	2210.13	2983.36	206.49	0.22	197.70	199.40
Avg /i/3	391.64	2269.09	3414.49	197.36	0.20	190.22	192.16
Avg /i/4	401.81	2219.31	3289.83	203.48	0.16	192.57	192.04
Avg /i/5	399.84	2277.50	2706.15	199.63	0.26	192.51	205.00
Avg /i/6	381.18	2177.11	2968.41	189.11	0.23	195.68	192.90
Total Avg /i/	**393.52**	**2205.27**	**3009.16**	**200.56**	**0.22**		
Avg /e/1	429.31	2208.50	3171.34	183.54	0.20	178.14	184.19
Avg /e/2	457.36	2120.34	2744.01	179.67	0.20	177.50	181.40
Avg /e/3	457.08	2166.16	2995.14	183.03	0.27	179.33	184.93
Avg /e/4	445.40	2196.41	2939.61	180.66	0.20	184.77	181.65
Avg /e/5	433.69	2184.75	2861.71	182.11	0.22	180.46	183.90
Avg /e/6	453.72	2163.99	2683.31	172.49	0.19	179.51	168.73
Total Avg /e/	**446.09**	**2173.36**	**2899.19**	**180.25**	**0.21**		
Avg /o/1	511.56	1126.57	2577.16	202.79	0.24	192.88	210.76
Avg /o/2	490.43	880.66	2364.91	197.74	0.25	185.83	212.24
Avg /o/3	561.59	948.39	2368.11	195.64	0.22	184.58	209.17
Avg /o/4	560.69	1025.63	2399.32	198.20	0.23	191.24	211.40
Avg /o/5	512.82	1023.53	2315.31	200.88	0.25	197.99	212.33
Avg /o/6	543.42	980.41	2566.94	176.48	0.24	187.65	170.65
Total Avg /o/	**530.09**	**997.53**	**2431.96**	**195.29**	**0.24**		

Appendix 11

Average Formant Frequencies for all 6 repetitions of all vowels for DG22F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	970.32	1577.76	2707.35	272.80	0.27	265.94	288.87
Avg /a/2	905.30	1575.51	2459.74	265.10	0.24	259.50	278.17
Avg /a/3	925.06	1561.41	2702.26	267.48	0.25	256.25	283.03
Avg /a/3	923.85	1537.19	2663.29	266.84	0.23	256.36	280.56
Avg /a/ 4	920.42	1551.47	2659.37	267.26	0.24	256.95	283.21
Avg /a/5	871.53	1615.42	2619.73	263.61	0.19	257.50	281.45
Avg /a/6	797.31	1594.49	2442.77	212.25	0.20	229.86	191.83
Total Avg /a/	**901.97**	**1573.32**	**2607.79**	**259.33**	**0.23**		
Avg /u/1	529.68	1039.23	2741.20	307.56	0.17	277.18	297.33
Avg /u/2	539.19	986.49	2607.76	302.59	0.18	272.02	323.70
Avg /u/3	520.05	966.27	2623.64	300.63	0.18	272.74	297.04
Avg /u/4	504.69	958.97	2592.27	305.03	0.21	274.20	314.44
Avg /u/5	532.56	973.64	2563.57	298.16	0.20	267.09	315.17
Avg /u/6	423.43	983.36	2432.27	216.71	0.19	219.09	213.09
Total Avg /u/	**508.27**	**984.66**	**2593.45**	**288.45**	**0.19**		
Avg /ʌ/1	749.47	1451.79	2571.09	256.93	0.14	241.17	277.71
Avg /ʌ/2	738.44	1509.82	2601.60	250.37	0.20	243.38	249.02
Avg /ʌ/3	735.65	1507.36	2554.86	253.17	0.14	247.74	252.81
Avg /ʌ/4	746.39	1513.44	2579.93	253.76	0.16	247.04	262.51
Avg /ʌ/5	735.34	1511.07	2589.97	245.88	0.16	239.89	251.60
Avg /ʌ/6	650.71	1446.17	2403.83	205.27	0.13	224.64	198.18
Total Avg /ʌ/	**726.00**	**1489.94**	**2550.21**	**244.23**	**0.16**		
Avg /i/1	518.94	1933.62	2954.55	292.95	0.21	280.46	294.62
Avg /i/2	571.14	2192.02	2558.89	284.71	0.19	269.24	284.73
Avg /i/3	570.52	2246.10	2638.32	276.81	0.19	263.71	278.38
Avg /i/4	549.83	1900.30	2587.40	278.24	0.19	268.07	277.22
Avg /i/5	554.91	2395.46	2684.54	274.03	0.18	273.26	274.92
Avg /i/6	485.79	1787.24	2762.06	221.95	0.20	230.60	200.49
Total Avg /i/	**541.85**	**2075.79**	**2697.63**	**271.45**	**0.19**		
Avg /e/1	589.06	2389.72	2946.04	282.89	0.21	269.62	290.24
Avg /e/2	560.93	2265.37	2913.52	274.02	0.23	267.11	284.34
Avg /e/3	551.30	2284.41	2838.12	270.44	0.24	263.26	282.03
Avg /e/4	566.89	2271.14	2873.69	276.15	0.22	267.63	282.64
Avg /e/ 5	558.16	2243.79	2828.29	271.86	0.22	257.61	278.27
Avg /e/6	471.32	2202.50	2982.88	207.14	0.17	229.93	190.41
Total Avg /e/	**549.61**	**2276.15**	**2897.09**	**263.75**	**0.22**		
Avg /o/1	614.85	1103.56	2740.26	294.26	0.24	276.66	311.97
Avg /o/2	592.63	1024.45	2781.85	291.10	0.28	272.60	295.54
Avg /o/3	563.74	1097.60	2836.44	280.24	0.26	266.84	294.78
Avg /o/4	576.30	1030.64	2808.69	287.79	0.23	273.68	297.24
Avg /o/5	574.66	1058.47	2748.28	283.50	0.25	269.31	298.65
Avg /o/6	472.40	983.54	2689.49	225.64	0.22	246.45	219.38
Total Avg /o/	**565.76**	**1049.71**	**2767.50**	**277.09**	**0.25**		
Avg /ʊ/1	506.63	1123.44	2607.36	295.65	0.08	305.68	268.35
Avg /ʊ/2	528.12	1032.87	2554.85	291.58	0.11	298.57	303.32
Avg /ʊ/3	489.62	810.32	2476.76	301.84	0.09	302.58	271.63
Avg /ʊ/4	553.24	855.63	2571.91	296.47	0.09	297.30	274.47
Avg /ʊ/5	579.38	862.75	2626.30	300.06	0.09	298.09	286.20
Avg /ʊ/6	480.70	831.64	2626.56	273.98	0.10	285.59	251.60
Total Avg /ʊ/	**522.95**	**919.44**	**2577.29**	**293.26**	**0.09**		
Avg /ɪ/1	462.74	2203.18	2785.89	255.45	0.09	262.39	249.98
Avg /ɪ/2	414.06	2116.60	2637.04	274.81	0.09	293.54	281.28
Avg /ɪ/3	517.51	2224.60	2784.29	257.49	0.11	260.56	239.32
Avg /ɪ/4	432.27	2191.29	2793.52	263.95	0.08	270.79	238.50
Avg /ɪ/5	448.34	2257.15	2601.79	258.84	0.09	265.56	242.78
Avg /ɪ/6	426.61	2287.30	2702.48	255.65	0.08	276.35	220.22
Total Avg /ɪ/	**450.26**	**2213.35**	**2717.50**	**261.03**	**0.09**		

Appendix 12

Average Formant Frequencies for all 6 repetitions of all vowels for LL26F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	912.52	1710.62	2979.31	297.47	0.24	283.08	305.28
Avg /a/2	883.15	1691.88	2938.24	253.85	0.24	260.72	255.57
Avg /a/3	816.16	1650.77	2963.41	249.81	0.26	246.16	251.08
Avg /a/4	832.79	1627.89	2951.79	236.99	0.24	241.05	236.92
Avg /a/5	843.59	1621.42	2884.85	232.91	0.20	236.02	236.05
Avg /a/6	788.16	1626.69	2835.68	211.29	0.19	229.33	204.93
Total Avg /a/	**846.06**	**1654.88**	**2925.55**	**247.05**	**0.23**		
Avg /u/1	613.35	1417.27	2898.76	340.55	0.16	322.36	348.89
Avg /u/2	575.57	1351.72	2760.97	298.35	0.15	292.00	301.02
Avg /u/3	600.33	1293.99	2945.16	327.36	0.16	312.81	333.21
Avg /u/4	592.62	1259.08	2930.42	315.97	0.16	298.69	314.92
Avg /u/5	606.85	1395.20	2818.49	322.80	0.14	308.13	327.53
Avg /u/6	492.46	1147.93	2748.94	259.56	0.18	284.59	261.04
Total Avg /u/	**580.20**	**1310.86**	**2850.46**	**310.77**	**0.16**		
Avg /ʌ/1	621.09	1359.20	2855.40	294.24	0.14	265.93	313.71
Avg /ʌ/2	646.04	1406.17	2985.78	268.49	0.18	259.00	275.19
Avg /ʌ/3	685.72	1402.65	2358.01	246.53	0.17	244.76	249.77
Avg /ʌ/4	659.95	1381.73	3021.52	244.88	0.13	243.21	251.65
Avg /ʌ/5	678.42	1475.68	2430.13	243.51	0.13	247.21	241.61
Avg /ʌ.6	649.45	1548.08	2144.61	224.59	0.13	236.48	222.11
Total Avg /ʌ/	**656.78**	**1428.92**	**2632.58**	**253.71**	**0.15**		
Avg /i/1	381.81	2466.55	2978.94	321.78	0.23	306.05	335.76
Avg /i/2	364.44	2435.65	3065.82	288.35	0.24	284.36	309.41
Avg /i/3	368.18	2186.42	2852.73	286.54	0.21	281.27	295.77
Avg /i/4	375.30	2202.53	2773.21	279.90	0.21	272.77	287.06
Avg /i/5	366.57	2051.78	2780.68	277.69	0.22	276.11	279.96
Avg /i/6	393.29	2279.99	2972.94	241.53	0.18	265.83	219.07
Total Avg /i/	**374.93**	**2270.49**	**2904.05**	**282.63**	**0.21**		
Avg /e/1	577.25	2494.02	2968.59	304.66	0.22	278.61	323.47
Avg /e/2	544.70	2401.96	3091.19	281.14	0.25	269.22	302.94
Avg /e/3	517.40	2352.33	2945.28	265.96	0.23	257.71	281.71
Avg /e/4	485.80	2360.77	2933.76	250.53	0.23	247.98	268.30
Avg /e/5	479.94	2391.57	3009.54	243.91	0.19	240.41	250.79
Avg /e/6	426.75	2419.98	2963.43	207.91	0.19	226.51	194.84
Total Avg /e/	**505.31**	**2403.44**	**2985.30**	**259.02**	**0.22**		
Avg /o/1	658.21	1213.11	2854.48	337.71	0.24	305.32	348.59
Avg /o/2	574.71	1133.88	2801.39	290.09	0.19	282.39	314.85
Avg /o/3	546.51	1088.91	2908.02	281.54	0.21	274.29	283.85
Avg /o/4	540.21	1072.00	2841.13	272.06	0.24	270.66	280.30
Avg /o/5	530.67	1125.02	2814.55	262.97	0.21	261.57	264.34
Avg /o/6	485.96	1068.57	2517.21	229.06	0.15	252.44	202.35
Total Avg /o/	**556.04**	**1116.91**	**2789.46**	**278.90**	**0.21**		
Avg /ʊ/1	559.57	1285.62	2858.98	328.06	0.09	336.21	328.13
Avg /ʊ/2	611.00	1115.70	3213.91	320.90	0.09	333.50	310.47
Avg /ʊ/3	540.95	1024.49	3185.01	309.38	0.11	320.38	312.25
Avg /ʊ/4	587.45	1234.37	3176.99	323.11	0.09	335.08	315.46
Avg /ʊ/5	532.98	1169.50	2860.13	290.77	0.09	302.89	284.68
Total Avg /ʊ/	566.39	1165.94	3059.01	314.44	0.09		
Avg /ɪ/1	471.68	2374.09	2784.16	319.09	0.11	328.86	317.81
Avg /ɪ/2	441.57	2374.55	2808.06	307.08	0.10	345.43	306.57
Avg /ɪ/3	446.30	2401.81	2768.92	298.08	0.08	318.83	280.96
Avg /ɪ/4	446.84	2347.05	2787.66	300.05	0.08	315.95	284.95
Avg /ɪ/5	405.92	2483.46	2808.73	283.82	0.08	332.88	275.38
Avg /ɪ/6	405.79	2208.45	2640.88	275.84	0.08	313.58	276.66
Total Avg /ɪ/	**436.35**	**2364.90**	**2766.40**	**297.33**	**0.09**		

Appendix 13

Average Formant Frequencies for all 6 repetitions of all vowels for ML21F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	956.38	1605.19	2724.86	268.57	0.25	282.49	279.58
Avg /a/2	948.69	1570.58	2776.36	275.28	0.29	276.77	287.59
Avg /a/3	988.84	1621.47	2790.73	264.19	0.28	267.84	282.68
Avg /a/4	952.65	1619.26	2757.59	257.56	0.27	269.72	273.59
Avg /a/5	969.53	1699.20	2932.21	265.34	0.25	275.64	276.90
Avg /a/6	968.86	1726.90	3071.15	258.63	0.22	268.06	272.87
Total Avg /a/	**964.16**	**1640.43**	**2842.15**	**264.93**	**0.26**		
Avg /u/1	563.37	1070.22	2942.26	315.82	0.21	304.93	320.99
Avg /u/2	503.14	1090.01	3164.53	321.54	0.28	308.97	335.08
Avg /u/3	492.70	1123.99	3165.51	321.33	0.22	308.54	334.74
Avg /u/4	527.03	1194.55	3038.37	317.87	0.16	308.24	330.44
Avg /u/5	518.33	1109.76	3123.90	313.85	0.22	304.64	318.98
Avg /u/6	455.95	1194.63	2946.92	250.11	0.14	263.51	234.16
Total Avg /u/	**510.09**	**1130.52**	**3063.58**	**306.75**	**0.20**		
Avg /ʌ/1	775.31	1579.92	2900.27	271.06	0.18	260.71	283.35
Avg /ʌ/2	767.57	1585.99	2816.36	275.33	0.18	264.81	287.56
Avg /ʌ/3	799.12	1661.86	2826.26	279.42	0.15	268.92	283.56
Avg /ʌ/4	807.52	1647.76	2844.45	276.70	0.16	267.02	282.71
Avg /ʌ/5	771.30	1572.71	2817.84	281.37	0.14	269.68	285.90
Avg /ʌ/6	796.31	1555.67	2784.69	268.91	0.14	262.59	270.83
Total Avg /ʌ/	**786.19**	**1600.65**	**2831.64**	**275.47**	**0.16**		
Avg /i/1	385.20	2584.85	3685.28	289.48	0.28	286.99	304.23
Avg /i/2	443.21	3074.21	3643.79	291.20	0.25	288.07	303.56
Avg /i/3	451.15	2956.72	3493.86	297.57	0.25	294.74	316.62
Avg /i/4	471.81	2946.28	3535.06	288.16	0.26	278.93	305.88
Avg /i/5	395.72	2903.55	3570.71	289.52	0.25	286.88	305.34
Avg /i/6	369.70	2782.82	3617.08	283.07	0.28	273.44	282.57
Total Avg /i/	**419.47**	**2874.74**	**3590.96**	**289.83**	**0.26**		
Avg /e/1	590.44	2666.93	3236.98	296.65	0.28	281.63	306.47
Avg /e/2	583.46	2602.26	3236.73	289.70	0.23	283.58	303.79
Avg /e/3	577.41	2613.28	3203.12	286.93	0.19	282.87	293.27
Avg /e/4	569.36	2609.99	3153.23	282.70	0.19	272.15	290.86
Avg /e/5	564.79	2608.52	3207.12	282.36	0.19	272.87	293.03
Avg /e/6	568.52	2675.89	3243.37	282.96	0.18	270.66	291.67
Total Avg /e/	**575.66**	**2629.48**	**3213.43**	**286.88**	**0.21**		
Avg /o/1	580.18	1107.16	2774.46	291.91	0.24	284.14	295.00
Avg /o/2	568.86	1104.33	2861.43	288.23	0.27	279.88	303.53
Avg /o/3	562.23	1025.25	2825.96	284.57	0.25	277.65	292.08
Avg /o/4	566.91	1127.04	2748.39	286.65	0.22	286.76	295.64
Avg /o/5	557.32	1096.78	2995.07	282.11	0.28	275.34	292.72
Avg /o/6	565.16	1078.67	2730.96	284.22	0.26	273.25	291.95
Total Avg /o/	**566.78**	**1089.87**	**2822.71**	**286.28**	**0.25**		
Avg /ʊ/1	423.63	926.60	2632.56	317.82	0.08	338.35	328.34
Avg /ʊ/2	435.08	980.04	2850.01	326.97	0.09	338.47	297.48
Avg /ʊ/3	442.08	903.71	3018.52	304.16	0.08	307.55	288.03
Avg /ʊ/4	457.14	886.24	3044.78	302.36	0.07	309.09	287.69
Avg /ʊ/5	454.50	881.42	2969.78	302.39	0.08	312.15	283.27
Avg /ʊ/6	463.85	803.60	2910.17	274.10	0.08	289.10	246.58
Total Avg /ʊ/	**446.05**	**896.94**	**2904.30**	**304.64**	**0.08**		
Avg /ɪ/1	452.91	2663.86	3122.90	327.69	0.08	318.97	328.61
Avg /ɪ/2	471.67	2545.88	3077.48	324.89	0.08	331.89	335.25
Avg /ɪ/3	522.85	2611.40	3149.46	314.03	0.10	314.26	297.06
Avg /ɪ/4	509.50	2574.58	3060.30	290.82	0.09	299.71	296.36
Avg /ɪ/5	499.07	2548.17	3070.35	298.48	0.09	308.97	284.85
Avg /ɪ/6	503.89	2589.13	2945.13	255.14	0.09	275.16	249.11
Total Avg /ɪ/	**493.31**	**2588.84**	**3070.94**	**301.84**	**0.09**		

Appendix 14

Average Formant Frequencies for all 6 repetitions of all vowels for PP24F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	947.97	1395.73	2485.35	237.54	0.21	241.51	234.02
Avg /a/2	869.78	1376.00	2654.91	231.85	0.23	240.97	231.69
Avg /a/3	864.50	1457.86	2492.57	233.53	0.23	241.33	229.66
Avg /a/4	865.44	1408.41	2711.11	232.04	0.23	234.16	229.31
Avg /a/5	871.63	1413.73	2598.71	231.29	0.22	239.76	228.05
Avg /a/6	839.14	1413.44	2357.04	210.32	0.19	236.66	189.46
Total Average /a/	**876.41**	**1410.86**	**2549.95**	**229.43**	**0.22**		
Avg /u/1	425.76	965.44	2866.69	257.89	0.21	260.28	259.40
Avg /u/2	461.19	996.79	2671.12	243.50	0.23	241.54	250.12
Avg /u/3	495.38	1110.55	2746.34	244.46	0.26	232.54	253.56
Avg /u/4	467.95	1020.54	2547.04	240.23	0.22	232.75	246.06
Avg /u/5	459.70	1054.48	2789.21	239.20	0.24	237.21	238.78
Avg /u/6	430.14	1079.97	2630.96	215.56	0.18	215.35	200.17
Total Avg /u/	**456.69**	**1037.96**	**2708.56**	**240.14**	**0.22**		
Avg /ʌ/1	714.00	1394.30	2788.18	240.63	0.19	242.65	240.76
Avg /ʌ/2	738.85	1288.91	2634.82	193.33	0.17	118.39	225.48
Avg /ʌ/3	748.53	1343.84	2644.88	216.52	0.18	118.52	228.04
Avg /ʌ/4	688.07	1321.20	2585.04	234.15	0.21	241.34	228.64
Avg /ʌ/5	688.60	1197.90	2063.14	234.08	0.17	237.12	222.80
Avg /ʌ/6	687.44	1295.66	2677.50	216.50	0.15	119.41	216.66
Total Avg /ʌ/	**710.92**	**1306.97**	**2565.59**	**222.54**	**0.18**		
Avg /i/1	415.57	2559.19	2993.89	262.51	0.20	262.53	261.42
Avg /i/2	405.17	2622.66	3257.39	249.21	0.23	250.03	251.27
Avg /i/3	445.73	2635.75	2971.76	247.35	0.23	246.10	252.35
Avg /i/4	435.44	2655.67	3216.46	244.79	0.23	244.73	253.98
Avg /i/5	451.58	2663.91	3156.99	242.08	0.22	242.46	259.57
Avg /i/6	476.83	2635.45	3085.02	217.83	0.18	234.35	210.54
Total Avg /i/	**438.39**	**2628.77**	**3113.58**	**243.96**	**0.21**		
Avg /e/1	509.61	2437.00	2975.36	249.62	0.21	252.01	252.28
Avg /e/2	494.75	2381.74	2979.92	242.15	0.22	241.98	240.76
Avg /e/3	495.54	2415.15	3028.66	243.54	0.22	246.97	242.30
Avg /e/4	493.55	2374.71	2971.71	241.99	0.26	243.51	239.96
Avg /e/5	491.48	2316.93	2958.99	241.96	0.20	244.76	236.69
Avg /e/6	466.30	2344.58	2937.92	230.85	0.15	244.62	195.74
Total Avg /e/	**491.87**	**2378.35**	**2975.43**	**241.68**	**0.21**		
Avg /o/1	506.91	1028.37	2937.57	248.58	0.20	255.56	253.81
Avg /o/2	491.18	1004.44	2988.22	245.22	0.22	250.28	254.13
Avg /o/3	502.10	1092.28	2954.88	246.78	0.20	248.61	254.20
Avg /o/4	500.38	1102.79	2370.36	242.89	0.21	246.17	249.11
Avg /o/5	493.32	1079.87	2963.87	237.53	0.20	240.09	237.69
Avg /o/6	514.84	1074.10	2813.43	218.69	0.18	241.93	195.14
Total Avg /o/	**501.45**	**1063.64**	**2838.06**	**239.95**	**0.20**		
Avg /ʊ/1	379.09	792.57	2539.62	266.15	0.06	269.85	249.85
Avg /ʊ/2	438.64	853.20	2779.23	253.99	0.07	258.63	238.22
Avg /ʊ/3	438.89	931.74	2699.10	250.31	0.06	254.94	242.73
Avg /ʊ/4	413.15	833.91	2534.90	243.28	0.06	250.59	230.88
Avg /ʊ/5	421.06	896.69	2806.56	240.57	0.06	246.88	228.75
Avg /ʊ/6	435.09	862.94	2663.26	238.13	0.07	245.55	220.62
Total Avg /ʊ/	420.99	861.84	2670.45	248.74	0.06		
Avg /ɪ/1	474.94	2513.80	2938.35	268.53	0.05	268.16	258.14
Avg /ɪ/2	497.38	2473.13	2971.15	257.65	0.11	256.58	259.69
Avg /ɪ/3	499.93	2444.28	2948.47	252.13	0.10	253.06	258.32
Avg /ɪ/4	503.46	2476.85	3084.38	252.68	0.09	253.64	254.33
Avg /ɪ/5	494.27	2400.46	2923.88	249.94	0.10	246.93	254.26
Avg /ɪ/6	466.01	2482.06	3009.47	228.59	0.07	235.85	207.66
Total Avg /ɪ/	489.33	2465.10	2979.28	251.59	0.09		

Appendix 15

Average Formant Frequencies for all 6 repetitions of all vowels for PTP22F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	803.19	1409.69	2644.86	219.04	0.30	212.83	237.52
Avg/a/2	787.44	1420.67	2654.00	199.02	0.26	206.83	189.67
Avg /a/3	784.53	1372.14	2629.78	192.19	0.28	203.03	191.14
Avg /a/4	799.18	1375.82	2661.15	199.11	0.24	204.97	196.11
Avg /a/5	767.80	1334.24	2659.35	182.76	0.25	191.49	179.67
Avg /a/6	775.35	1373.89	2555.14	167.77	0.19	192.98	150.78
Total Avg /a/	**786.25**	**1381.08**	**2634.05**	**193.31**	**0.25**		
Avg /u/1	431.88	737.20	2616.27	249.75	0.30	239.79	253.20
Avg /u/2	423.02	681.07	2117.29	231.81	0.32	233.05	231.75
Avg /u/3	418.54	749.27	1973.61	222.23	0.27	226.44	219.33
Avg /u/4	415.17	876.10	2055.65	211.33	0.29	217.09	209.28
Avg /u/5	390.77	816.16	1316.43	204.97	0.23	217.73	193.77
Avg /u/6	396.95	795.01	1567.81	184.77	0.17	202.17	185.30
Total Avg /u/	**412.72**	**775.80**	**1941.18**	**217.48**	**0.26**		
Avg /ʌ/1	703.36	1361.64	2678.66	231.56	0.17	227.04	242.10
Avg /ʌ/2	700.03	1461.95	2576.80	208.32	0.16	208.79	211.79
Avg /ʌ/3	717.84	1469.78	2652.42	210.02	0.15	210.65	207.86
Avg /ʌ/4	740.36	1439.86	2650.35	208.34	0.15	211.37	200.52
Avg /ʌ/5	725.06	1386.88	2714.42	195.87	0.15	201.90	181.94
Avg /ʌ/6	690.09	1428.34	2650.15	176.75	0.12	192.49	165.82
Total Avg /ʌ/	**712.79**	**1424.74**	**2653.80**	**205.14**	**0.15**		
Avg /i/1	602.33	2530.44	3411.75	244.54	0.23	241.69	246.02
Avg /i/2	566.33	2431.77	3257.38	223.62	0.26	231.17	217.07
Avg /i/3	548.19	2446.98	3262.59	213.78	0.24	218.09	213.04
Avg /i/4	507.71	2448.25	3349.50	203.53	0.20	210.24	209.19
Avg /i/5	505.07	2447.77	3307.83	202.99	0.23	209.05	201.76
Avg /i/6	432.48	2553.06	3286.68	179.77	0.18	199.56	167.33
Total Avg /i/	**527.02**	**2476.38**	**3312.62**	**211.37**	**0.22**		
Avg /e/1	487.51	2325.97	3146.80	235.12	0.23	231.06	238.60
Avg /e/2	461.61	1998.16	2739.00	214.82	0.23	223.23	215.62
Avg /e/3	452.48	2276.91	2925.19	209.94	0.25	220.36	208.71
Avg /e/4	457.68	2348.01	3037.14	205.78	0.22	218.09	197.66
Avg /e/5	517.01	2353.55	3017.71	193.23	0.22	208.15	189.80
Avg /e/6	500.83	2402.65	2928.08	171.91	0.15	191.59	157.32
Total Avg /e/	**479.52**	**2284.21**	**2965.65**	**205.13**	**0.22**		
Avg /o/1	479.56	895.35	2584.66	238.64	0.30	228.99	241.63
Avg /o/2	464.90	922.22	2533.13	212.70	0.32	224.83	201.88
Avg /o/3	467.24	836.78	2463.25	198.90	0.31	208.72	189.47
Avg /o/4	447.88	822.09	2361.88	197.28	0.33	214.78	188.80
Avg /o/5	462.66	812.27	2407.26	189.67	0.27	196.44	185.86
Avg /o/6	457.67	883.11	2198.56	177.25	0.19	198.91	158.02
Total Avg /o/	**463.32**	**861.97**	**2424.79**	**202.41**	**0.29**		
Avg /ʊ/1	435.21	682.26	2348.63	230.29	0.07	231.82	224.85
Avg /ʊ/2	448.31	819.14	2268.75	221.99	0.08	228.58	203.07
Avg /ʊ/3	434.82	733.54	2437.69	220.77	0.08	221.91	208.32
Avg /ʊ/4	430.59	753.48	2523.39	214.26	0.08	214.39	204.63
Avg /ʊ/5	416.55	817.04	2405.26	209.72	0.07	213.71	203.91
Avg /ʊ/6	405.09	833.70	2383.99	201.62	0.07	209.12	192.32
Total Avg /ʊ/	**428.43**	**773.19**	**2394.62**	**216.44**	**0.08**		
Avg /ɪ/1	457.61	2341.02	2716.59	225.78	0.05	232.37	217.05
Avg /ɪ/2	444.21	2333.37	2718.24	217.67	0.06	234.66	198.74
Avg /ɪ/3	441.66	2353.96	2807.18	212.60	0.05	225.56	191.89
Avg /ɪ/4	434.30	2273.61	2838.91	216.44	0.05	222.15	209.67
Avg /ɪ/5	415.59	2174.63	2539.85	208.71	0.06	225.62	219.03
Avg /ɪ/6	434.01	2322.12	2916.11	178.43	0.04	188.14	168.73
Total Avg /ɪ/	**437.90**	**2299.79**	**2756.15**	**209.94**	**0.05**		

Appendix 16

Average Formant Frequencies for all 6 repetitions of all vowels for TB23F							
Vowel	**F1**	**F2**	**F3**	**F0**	**Duration**	**F0 (Start)**	**F0 (End)**
Avg /a/1	896.76	1408.91	2276.20	293.99	0.24	290.36	346.41
Avg /a/2	825.27	1393.19	2219.93	267.24	0.23	250.05	314.29
Avg /a/3	845.97	1377.44	2125.48	263.77	0.23	253.56	291.84
Avg /a/4	884.20	1478.27	2565.59	272.52	0.24	260.26	307.04
Avg /a/5	891.09	1468.07	2315.78	262.60	0.21	252.35	290.10
Avg /a/6	800.70	1588.68	2662.42	220.07	0.22	236.75	208.81
Total Avg /a/	**857.33**	**1452.42**	**2360.90**	**263.36**	**0.23**		
Avg /u/1	568.18	1175.78	2836.54	311.30	0.12	279.33	312.81
Avg /u/2	561.56	1041.85	2996.67	313.40	0.17	293.33	320.40
Avg /u/3	614.35	1144.32	3231.09	317.95	0.14	289.37	334.49
Avg /u/4	605.00	1199.40	2898.09	304.13	0.16	279.38	314.72
Avg /u/5	602.90	1193.09	3012.65	307.76	0.21	278.36	318.97
Avg /u/6	509.50	1149.07	2884.28	247.98	0.16	248.75	234.41
Total Avg /u/	**576.91**	**1150.58**	**2976.55**	**300.42**	**0.16**		
Avg /ʌ/1	801.78	1336.88	3018.26	273.65	0.17	256.69	315.98
Avg /ʌ/2	776.53	1369.15	2868.81	271.56	0.16	253.85	293.01
Avg /ʌ/3	805.14	1399.96	2914.95	274.52	0.17	256.58	309.32
Avg /ʌ/4	767.26	1381.67	2776.06	272.82	0.16	250.43	306.01
Avg /ʌ/5	785.48	1438.16	2862.07	267.05	0.16	246.24	280.94
Avg /ʌ/6	715.22	1490.35	2761.08	215.20	0.15	222.58	211.42
Total Avg /ʌ/	**775.23**	**1402.69**	**2866.87**	**262.47**	**0.16**		
Avg /i/1	403.52	2342.25	3284.24	293.92	0.18	275.50	309.72
Avg /i/2	497.05	2554.50	3390.05	288.92	0.20	271.22	308.06
Avg /i/3	363.72	2543.57	3412.47	276.34	0.18	270.89	323.53
Avg /i/4	488.37	2698.05	3544.06	285.93	0.17	270.90	317.63
Avg /i/5	476.45	2773.37	3564.52	275.35	0.14	259.04	305.50
Avg /i/6	529.27	2828.59	3531.42	229.87	0.11	248.52	200.21
Total Avg /i/	**459.73**	**2623.39**	**3454.46**	**275.06**	**0.16**		
avg /e/1	517.20	2336.88	3212.48	287.75	0.22	271.10	323.93
Avg /e/2	497.98	2457.86	3324.30	266.93	0.22	271.07	304.87
Avg /e/3	554.42	2531.90	3260.96	275.81	0.21	257.53	293.20
Avg /e/4	559.86	2460.41	3021.94	276.75	0.22	267.38	290.06
Avg /e/5	584.22	2456.07	3098.29	280.85	0.21	262.20	306.36
Avg /e/6	528.59	2502.22	3310.20	216.06	0.17	242.07	218.68
Total Avg /e/	**540.38**	**2457.56**	**3204.69**	**267.36**	**0.21**		
Avg /o/1	588.95	1018.19	3335.68	296.84	0.23	280.70	332.40
Avg /o/2	575.49	1003.93	3308.93	291.59	0.20	279.64	319.57
Avg/o/3	577.60	1035.23	3240.32	291.39	0.21	274.89	319.51
Avg /o/4	583.14	1021.05	3303.81	296.59	0.22	277.32	343.70
Avg /o/5	585.25	986.50	3332.44	297.15	0.19	272.81	322.54
Avg /o/6	503.59	990.58	3266.74	217.74	0.19	242.99	219.26
Total Avg /o/	**569.00**	**1009.25**	**3297.99**	**281.88**	**0.20**		
Avg /ʊ/1	425.26	816.30	3032.72	261.53	0.11	285.46	257.40
Avg /ʊ/2	473.66	819.37	2943.94	257.77	0.09	266.95	256.14
Avg /ʊ/3	500.28	888.34	2869.92	250.74	0.12	259.04	252.36
Avg /ʊ/4	494.95	947.54	3062.67	249.05	0.08	261.97	250.38
Avg /ʊ/5	429.98	763.52	2898.94	239.94	0.07	261.91	238.59
Avg /ʊ/6	486.46	889.13	3269.26	239.06	0.06	253.28	230.78
Total Avg /ʊ/	**468.43**	**854.03**	**3012.91**	**249.68**	**0.09**	**264.77**	**247.61**
Avg /ɪ/1	374.43	2183.09	2927.67	237.93	0.05	255.50	223.77
Avg /ɪ/2	466.34	2214.68	3040.60	233.62	0.07	250.41	236.79
Avg /ɪ/3	443.31	2681.27	3055.98	227.57	0.08	244.80	226.02
Avg /i/5	454.30	2306.24	2957.78	223.65	0.07	241.63	214.65
Total Avg /ɪ/	**434.59**	**2346.32**	**2995.51**	**230.69**	**0.07**		