ROLE OF FORMANTS, F1 & F2 IN SPEAKER CHARACTERISATION:
A Study of Marwari speaking Monolinguals in Bikaner

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

MASTERS OF PHILOSOPHY

BY

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Dated: 26th July, 2017

CERTIFICATE

This thesis titled "**ROLE OF FORMANTS, F1 & F2 IN SPEAKECHARACTERISATION: A Study of Marwari speaking Monolinguals in Bikaner**" submitted by **Ms Nikita Suthar**, Centre for Linguistics, School of Language, Literature and Culture Studies, Jawaharlal Nehru University, New Delhi, for the award of the degree of M.Phil, is an original work and has not been submitted so far in part or in full, for any other degree or diploma of any University or Institution.

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

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DECLARATION

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This thesis titled ""**ROLE OF FORMANTS, F1 & F2 IN SPEAKER CHARACTERISATION:A Study of Marwari speaking Monolinguals in Bikaner**" submitted by me 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 or diploma of any University or Institute.

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Acknowledgment

First and foremost, I would like to acknowledge my guide Prof. Vaishna Narang, Centre for Linguistics, Jawaharlal Nehru University. Working under her guidance was an enriching learning experience for me. I thank her for her patience, immense support, encouragement and precious guidance at every step of this journey.

I would like to express my gratitude towards all the staff members at the Centre for Linguistics, Jawaharlal Nehru University.

I would like to express my gratitude towards the team of CFSL (The Central Forensic Science Laboratory), New Delhi, for me helping learn how to conduct a forensic enquiry.

I take this opportunity to sincerely thank the support from the University Grant Commission, for providing financial assistance in the form of Junior Research Fellowship, which helped me to conduct my research comfortably.

I would also like to thank my fellow research scholars, Chandni Dutta, Agniva and Stuti Bhagat for their constant help, support and information provided whenever I needed.

I am indebted to my family, Mrs. Manju Suthar, my mother and Mithlesh Suthar, my brother, not only for their endless support but also for helping me collect data by knocking door to door, that has helped me in completing my M.Phil dissertation.

Last but not the least, I would like to acknowledge the love and support I got from my friends, Ankita, Apurva, Richa, Ramchandra, Shyam, Simone and Suman.

To my many friends and colleagues whom I could not mention here, I extend my heartiest gratitude.

Nikita Suthar

DEDICATED To My NANAJI

And

My MOM

Thanks for making me who I am today…

Chapter 1. Introduction

"The limits of my language means the limits of my world"-(Ludwig Wittgenstein)

Language has always been an interesting phenomenon which has fascinated humans throughout its evolution. The Greeks and Sanskrit grammarians from 3rd and 4th century BC have the first known accounts of language studies. Language studies have gone through various stages since the time it started. In linguistics, we call them paradigm shifts or epistemological breaks or discontinuities. From the study of language changes with respect to its historical, to the current trend of studying language as an innate capability of human beings, there have been many paradigm shifts in linguistics. Over the centuries linguists have unraveled many universal truths about human language. The most primal language universal is that "spoken language is the primary form of human language." There are many languages in this world which do not have any written script but each and every known language in this world has a spoken form. With spoken forms come the sounds. Every language has vowels and consonants in its basic structure even though their numbers and combinations may vary from one language to another. Physicists and linguists have been constantly trying to explain how these vowels and consonants are produced and acquired by humans. Child language acquisition is the most challenging and interesting avenue of research in linguistics. The current technologies have enabled us to answer a lot of language related questions. Researchers are regularly exploring various language related fields. Other than language acquisition, there are many other areas of interest in which linguistics can help us understand this mysterious world a little better.

One of the major advancements in speech research is the development of visual speech spectrograph. It has helped us understand how speech signals are perceived through our ears, how our speech organs are unique enough to modify these signals.

In this research, we will go through each and every one of these speech organs along with their role in speech production and we will see if human voice can be characterized as unique as a fingerprint.

1.1 Forensic Speaker Identification :

There are some voices which are familiar to our ears, for example the voices of our family members. Even if they are calling from a mobile phone, with bad connectivity we can easily identify their voices. This shows us that there are some unique properties of human voice. After the development of latest technologies like microphone, recorders or mobile phones, there have been many instances where officials have acquired a recording of human voice with relation to a particular case. For example, in a case about the kidnapping and murder of an 11-year-old German girl, voice samples of the kidnapper were collected or recorded or taped and analyzed. It was then matched with the voice samples of one of the suspects. These kinds of cases show us the importance of voice recognition. Different people have defined forensic speaker identification differently. According to Philip Rose, "Expert Opinion sought in a legal process as to whether two or more recordings of speech are from same speaker or not is usually termed as Forensic Speaker Identification." (Rose, 2002)

We can summarize all these definitions to arrive at their essence:

"*Analyzing two or more than two recordings and deducting whether these particular recordings belong to a single person (which usually is one of the suspects in a criminal case or for a legal query) or not, is known as Forensic Speaker Identification*."

In forensic speaker identification, one has to acquire a speech sample from an unknown speaker and compare it to the set of speech samples from known suspects. This unknown speech sample is usually termed as Question Sample. When the question sample shows unquestionable similarities to one of the speech samples of a suspect further enquiry can be made. Nowadays the applicability of Speaker Identification technology has been amplified from forensics to many other purposes. There are many kinds of locks, which only open once it hears a particular person's voice. The advancement in technology is helping in designing applications for speaker identification. For example, there are many applications in mobile phones which use an individual's voice to search for information, grant access to services as well as speech-to-text conversion.

1.2 Forensic Phonetics :

Forensic Speaker Identification is a part of Forensic phonetics, which is a practical application of phonetics for legal purposes. Phonetics can be helpful for many purposes, for example identifying a particular dialect on the basis of sounds produced by the

suspect. Every dialect is slightly different from another on the basis of its linguistic features and structure. Phonetic and phonological dissimilarities constitute is one of the differences which makes a dialect uniquely distant from other. For example, amongst the many varieties of Marwari, Brahmin Variety always uses the sound /o/ slightly nasalized where as other varieties lack this particular feature. This makes any Brahmin speaker easily distinguishable.

Different experts have different opinions regarding the accuracy of this field. Over the time forensic speaker identification has gone through many stages. Before 1965, recordings were not admissible in court. But gradually various countries have recognized their significance. In India voice recordings are admissible as evidence if they are supported by other evidences as well. So in a murder case if all the evidences are pointing towards one suspect and the prosecutor has a recorded evidence to support his or her findings, that recording will be admissible. But if it is only the recording which is available against a particular person, it is not admissible.

1.3 Voice vs Fingerprint

As mentioned above voice recognition has been a field with a lot of doubts Experts have been striving to achieve the level of accuracy of fingerprint technology. Comparing voice samples to fingerprint is not a valid comparison. Because as mentioned by Cain, “Fingerprints have static images that don’t change unless some damage is done to the fingerprint ridge detail. In voiceprints, these are dynamic qualities. For example, when you say good morning to your wife or husband early in the morning there will be some changes in the pitch of your voice and how you stress certain vowels, that’s why we get several repetitions of a speaker’s voice, saying the same thing, so we can find the range of variation” (Cain, 1995). This is just an example of an intraspeaker variation. The articulatory maneuvers used by a single speaker can drastically change the speech uttered by him/ her and if we are analyzing samples from various speakers (interspeaker comparison) the comparison would become very complicated. There are so many parameters to be taken care of before a voice sample is matched to its question sample. In fingerprint analysis the number of parameters is limited and very accurate. Along the course of time even the voice recognition accuracy has increased.

These recordings are gaining accuracy worldwide. The parameters to analyze a voice sample are being set by respective governments for their countries.

1.4 A quantitative introduction to the physiology of speech -(Lieberman and Blumstein, 1988)

1.4.1 What is Voice? How is it Produced :

The sound which is produced in a person's larynx and which is uttered through the mouth, in the form of speech or song is defined by the Oxford English Dictionary as voice. However, the forensic phoneticians do not lay importance to the sound created by the larynx as that sound maybe a scream or a laugh which is not used in forensic analysis but it is instead the speech that is analyzed and not voice itself. They analyze the speech units, i.e. vowels and consonants. Despite this the fact is that the experts analyze voice as well as several features of voice is encoded in these speech units.

It is very important for us to know how voice is produced because this helps in determining the quality of voice.

The expiration is responsible for the articulation of human speech. The process of expiration requires the air to flow up the trachea and exhale through mouth or the nose. While doing so the air passes through the larynx. The larynx contains the vocal cords which are parallel flaps of tissue extending from each side of the interior of the larynx wall. The vocal cords have a slit between them called the glottis. The vocal cords are very flexible. If the back ends of the folds are held apart, the glottis opens and as the back ends of the folds are brought together, the glottis narrows down to a slit and completely closes as the folds are pressed together. In this position, passage of air through larynx is prevented.

The process of phonation requires the vocal cord to vibrate in such a way that it produces voice. It is solely because of a reaction taking place between their elastic properties and the sub-glottal pressure involved that the vocal cords are set in vibration aerodynamically, the myoelastic-aerodynamic theory of phonation is based on the Bernoulli Effect. It provides an explanation of how the vocal folds actually vibrate. Soft tissues are in layers which later on form vocal cords. All the layers are different properties which makes it easier for them to move independently with a layer of elasticity, with the outmost layer providing the most degree of elasticity. The main task

of the vocal cords is to vibrate that leads to the production of voice. When the vocal folds are adducted during phonation, the air-stream is momentarily stopped by the vocal folds. Because of the tension with which arytenoids cartilages pull them together, the adduction of vocal folds takes place. At this point, sub-glottic pressure begins and builds up below the vocal folds. At this point, sub-glottic pressure begins and builds up below the vocal folds. The air-stream through the vocal folds then accelerates causing drop in pressure. This drop in pressure then sucks the vocal folds back together. Sub-glottic pressure then builds up again and the process continues. This cycle of vocal folds motion create the air compression and rarefaction that produces voice. (Ladefoged, 1993)

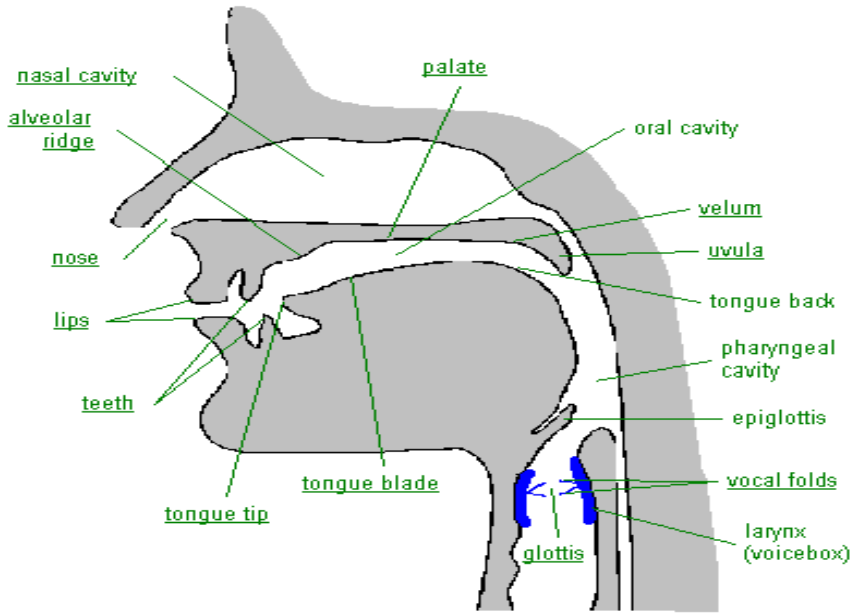


Figure 1.1: outline of some important vocal tract structures (Bickford & David, n.d.)

The human anatomy influences many parts of speech output however the basic modules that have directly had an influence on the speech output are vocal chords and supralaryngeal vocal tract.

1.4.2 Function of Vocal Cords : its Forensic Relevance When there is an increase in tension in the vocal chords, it results in them vibrating. With increase in speed, the vibration occurs at a higher rate. That is why the frequency of vibration of the vocal chords decides its pitch of the speaker. This analysis is of great importance for forensic speech analysis. Hence if there is an increase in the frequency of vibration of the vocal

cords, the pitch of the speaker also increases. However, the pitch of a speaker can vary over a range. Therefore, we have both within-speaker variations as well as between-speaker variations in determining pitch of a speaker.

Vocal chords help in regulating the different types of phonation. By vibrating one's vocal cords in different ways one can produce different modes of phonation, examples are creaky voice, whisper etc. Different types of phonation are used to differentiate between words in many other languages. This further helps with the evaluation of forensic speech samples. In most of the criminal cases, culprits deliberately control their vocal cords to produce different phonation types, such as, creaky or breathy voice which may not be the way they normally speak.

1.4.3 Function of Supralaryngeal Tract: its Forensic Relevance : the supralaryngeal vocal tract extends from the vocal cords up to the lips. It consists of three cavities, the oral cavity, the pharyngeal cavity and the nasal cavity. The main speech function of these cavities is that they act like resonators. During the production of speech, especially in the production of vowels, the air in these cavities vibrates in a complex way that is determined by the shape of the cavities. This vibratory response largely determines the quality of the speech sound.

Sounds that are referred to as nasals is produced when the soft palate is lowered, the oral cavity is completely shut and the air is allowed to pass only through the nasal cavity. Whereas sounds called nasalized are produced when the soft palate is lowered and the air is allowed to flow through both the oral cavity as well as the nasal cavity,

Nasal consonants like [m] or [ŋ] are forensically relevant because their acoustic characteristics are assumed to be among the strongest automatic speaker identification parameters. This is because the relative rigidity of the nasal cavity ensures a low within-speaker variation in the acoustic features associated with the cavity's acoustic resonances, and its internal structure and dimensions are complicated enough to contribute to relatively high between-speaker variation. (Rose, 2002, p. 147)

Nasalized sounds are also forensically relevant. Nasalized sounds are of linguistic, extra-linguistic and paralinguistic importance. Linguistically, nasalized sounds are contrastive in some languages. Extra-linguistically, there are some people who speak

with a nasal twang. Paralinguistic relevance of nasalization can be seen in languages where it marks the status of a person in the society. In Bolivian language Cayuvava, nasalised sounds are used by an individual of lower status towards one of higher status. The task of this information is to help with speaker profiling.

1.4.4 Vocal Tract Length and its Forensic Relevance According to studies it can be seen that with the increases of length of the supralaryngeal vocal tract, the resonant frequencies (F1, F2, F3….) decreases and vice-versa. It means that the resonant frequencies vary with the length of the supralaryngeal vocal tract and they are inversely proportional to each other. Therefore, when a speaker has short supralaryngeal vocal tract, he/she will have high resonances in comparison to the speaker with a long supralaryngeal vocal tract, who will have low resonant frequencies. Thus, one can draw the conclusion that since average height of females is less than those of average males, than the females also have a supralaryngeal vocal tract that is shorter than the males. As a result we find that the formant frequencies of females are higher than those of the males. Which means that males have a longer supralaryngeal vocal tract which produces a lower formant frequencies.

This kind of variation can be found in the same sex groups too depending on the height of the speaker or, to be more specific, the length of his/her supralaryngeal vocal tract.

The acoustic output of a vocal tract is a unique function of the vocal tract that produces. In other words, one can predict the acoustic output if the dimensions of the vocal tract are already known. (Or, more accurately, since the vocal tract is usually in motion from one speech sound target to another, if we know the trajectories of the vocal tract over a short stretch of time we can predict the trajectories of the acoustics.) It is in this sense that the acoustic wave-form carries the imprint of the tract that produced it.

There is a possibility to establish a relationship between acoustics and human anatomy, however one needs to keep in mind the relationship between the length of the supralaryngeal vocal tract and the formant frequencies. Despite this, the relationship must be treated with caution due to several reasons.

The length of the human supralaryngeal vocal tract is not invariant to a speaker. It is highly deformable. Every speaker can alter the length of his/her supralaryngeal vocal

tract by lengthening or shortening it during the production of speech. This process requires the speaker to protrude the lips or to alter the vertical length of the larynx which in turn alters the length of the supralaryngeal vocal tract by a minimum of one centimeter.

The supralaryngeal vocal tract is highly plastic in nature. The variation that takes place in terms of the tract length is also very narrow among the individuals. Therefore, this results in low ratios of within-speaker and between-speaker variations.

Therefore, one cannot simply jump to the conclusion that if a speaker produces low formant frequencies, he/she has a longer supralaryngeal vocal tract. Instead it is also a possibility that the person may be habitual of producing sound by lowering his/her larynx.

Physiology is a science that deals with the functioning of biological systems. A physiologist would have to consider bones and muscles of human body with regard to their function.

The three physiological components of speech production:

1. The larynx: It is a reference point of a three-ways split. The primary role of larynx in the production of speech is to convert a relatively steady flow of air from the lungs into a series of almost periodic .i.e. quasi periodic puffs of air. The larynx does this by rapidly closing and opening the airway by moving the vocal cords together and pulling them apart. The puffs of air contain acoustic energy at audible frequencies. The larynx thus is a valve that can rapidly open and close, generating a source of acoustic energy. This acoustic energy characterizes phonation.
2. The sub glottal component: It consists of the lungs and associated respiratory musculature. The sub glottal component generates the airflow that powers speech production.
3. The third component is the superalyrangeal vocal tract. It consists of the airways above the larynx, which includes airways of nose, mouth and pharynx. During the production of speech, this acts as a variable acoustic filter that acts on the source of acoustic energy. It is a variable acoustic filter because the speaker changes the shape of his vocal tract as he speaks. The superalyangeal vocal tract

lets proportionately more energy at certain frequencies that are called formant frequencies.

All these components have the primary function of maintaining life. Speech production is not their primary purpose. Even though during the course of evolution some changes have occurred in human larynx, these show the adaptations that enhance the communications.

Human speech is thus, in part, structured by the constraints of physiological mechanisms whose primary function is non-linguistic. (Lieberman and Blumstein, 1988).

Phonation: The process of phonation involves an alteration of forces. The air flow out of the lungs first pushes the vocal cords apart, letting lots of air through. The vocal cords are then pulled together by the elastic properties of their stretched tissue and the suction generated by the flow of air through the glottal constriction. The force generated by the airflow through the glottal constriction, the Bernoulli force, is similar to the suction that occurs when a bus passes close to a car at a high speed. Phonation consists of the vocal cords rapidly opening and closing under the control of the laryngeal muscles, powered by the air flow from the lungs. The respiratory muscles can also exert control on phonation.

1.5 Formants

In speech, there are certain resonant frequencies of the vocal tract which are louder than the others. These loudest resonant frequencies are known as formant frequencies. Formants are easily recognizable as the peaks of the spectrum.

With vowels, the frequencies of the formants determine which vowel we hear and, in general, are responsible for the differences in quality among different periodic sounds. At any one point in time (as with spectra) there may be any number of formants, but for speech the most informative are the first three, appropriately referred to as F1, F2, and F3.

The first formant (F1) in vowels is inversely related to vowel height: The higher the vowel, the lower the first formant (and vice versa). The second formant (F2) in vowels is somewhat related to degree of backness. The more front the vowel, the higher the second formant (but affected by lip-rounding). The distance between F1 and F2 is a

better predictor of degree of backness in vowels. The closer F1 and F2 are to each other, the more back a vowel is.

1.5.1 Role of Formants in Speaker Identification

We have discussed earlier that every sound generates a pattern of waves, which are transmitted to our ear with the help of air molecules. Tunning fork is good instrument to demonstrate the activities involved in any sound production. When a tuning fork vibrates, the air molecules around it also vibrates, which results in the rapid vibration movement of these air molecules, all the way to our ears. This shows the process involved in sound production very clearly.

A sound wave is a combination of many properties, for eg. Amplitude (peak deviation of a pressure fluctuation from normal to atmospheric pressure), Frequency (the vibration rate of the air molecules, number of cycles per unit of time), pitch etc. Sound waves often consist only one frequency, this type of sound wave is called pure tone. Sounds waves containing more than one frequency is called complex tone. This kind of sound waves shows a complex wave form. Complex tones can also be further divided into periodic and aperiodic, former being a complex wave pattern, however complex it is repeating itself, and the later being a wave form in which the vibration is random and has no deductible pattern.

In a speech sample, we look for a periodic wave form which is usually the result of conversation, and try to avoid the aperiodic waveform, which is the result of the background voices or any other disturbance to the recording device. Every periodic wave form contains numerous frequencies. For the purpose of any acoustic enquiry the first three frequencies play a very important role. The lowest frequency, is called the fundamental frequency(F0). F0 is also represents the pitch of the person. F0 constantly varies during the speech production because while speaking, human voice tend to go high and low according to the situation. The later frequencies are called the harmonics of F0. F1 represents the vowel height and F2 is the indicator of the frontness and backness of the vowel. F1 is inversely proportional to the vowel height i.e. the high the is the low the F1 will be. On the other hand, high F2 represents the front vowel and low F2 is the indicator of back vowel. Lip rounding sometimes affect the values of F2.

1.5.2 Formants in vowel perception

Reasons for the prominence of F1 (height) in vowel system

This can be explained in two ways, acoustically speaking, a lower frequency usually shows higher amplitude. This results in lower peaks of energy to be first picked up by the vowel system. Human ears pick the F1 first, its only after that the later frequencies come into the picture. The second explanation is auditory, according to which, human ears prefer lower frequencies because it is picked up by them easily. So, if we take auditory phonetics into account, the frequency regions of different vowels will show a better distinction.

The importance of vowel formants has been mentioned earlier. This line of investigation has been there in the field for over a century now. Helmholtz(1885), synthesized the vowel sounds with the help of a resonator, by using the vowel formant frequencies. The importance of vowel formants was also shown by Fry et al.(1962), who demonstrated with the help of a continuum of synthetic vowels.

Soft palate and the lips are areas of mouth where most of the vowel articulation coincides with most of the consonant articulations. This might influence the vowel articulation. F2 articulation is also affected by this. The front back distinction only depeds on a very little acoustic space, i.e. Front, central and backness. Backness of vowels, as shown by many languages is highly influenced by the lip articulations (Neural, compressed (F2 raising) and Protruded(f2 lowering)). Both height and the backness are predicatable in many of the world's languages, with the help of lip rounding.

Other vowel properties;

1. Nasalization
2. ATR : because of toungue route and the entire phyrangeal cavity might influnces the vowel height. It can affect both F1 (lowering of F1) and F2 (slightly raising the F2)
3. Phonation processes; a) Creaky voice, b) Modal, c) Breathy voice- all these have a very noticeable effect of F1 and F2.

1.6 About the Research Work

Forensic speaker identification is a long and dull process. It includes the analysis of each sound uttered in the speech sample. The analysis of all these sounds is done on the basis of auditory and acoustic features. Yet again, there are a number of such auditory

and acoustic features. The task of the forensic linguist becomes very complex when a choice of parameters is to be made.
This research focuses on understanding the job of a forensic linguist and extracting such acoustic features which are more fruitful and which yield a more accurate conclusion.

Speaker identification involves the acoustic analysis of both consonants and vowels. The current research deals only with the vowels. Since we presume that voice has both unchangeable and changeable features, we will try to understand which of these features carry more information potential about the voice of an individual. By unchangeable features, we mean those features which are always a part of an individual's voice. It is because of these unchangeable features that even after a child becomes an adult and then moves towards old age, one can easily recognize him/her by his/her voice. One can assume that these unchangeable features of voice are genetically determined. On the other hand, our voice also has some changeable features which are acquired with time as we are exposed to a new language or society. The changes in voice are also due to physical and psychological factors. These are called acquired features.

The acoustic parameters that we will deal with include, pitch which is a voice parameter, formants which are resonance parameters and duration and amplitude which are acquired features. The aim of this research is to hierarchically arrange these parameters on the basis of their significance in the process of forensic speaker identification. But, we cannot do away with the auditory features completely as the acoustic analysis is preceded by auditory analysis. Therefore, auditory features will also be discussed in brief.

Pitch is considered to be a very important characteristic of voice since pitch is a result of the vibrations of the vocal cords. The rate at which the vocal cords vibrate depends on the mass, area and length of the vocal cords therefore it is different for different individuals. No two speakers can have the same set of vocal cords. The area, mass and length of vocal cords is determined genetically. How it will develop in a child as he/she grows under normal conditions is also determined genetically. It is possible that those features which are genetically determined remain with an individual for a longer period of time and they have the component of distinctiveness of a speaker. We can , therefore, presume that pitch is one such parameter which may carry those information about

voice which are genetically hard-wired. But, it is wrong to say that it is one of those parameters which remains unchangeable because with time and with exposure to different languages and different physical and psychological situations, we acquire many features. It is because of this reason that the pitch of a child is higher than that of an old person. Singers generally increase their pitch range with continuous practice. So, pitch might be one of those parameters which has the potential to carry genetic information about voice although it is not such a parameter which carries only genetic information about voice.

Formants are also counted amid strong acoustic parameters. They are produced by the resonance which is created in the laryngeal cavity, oral cavity and the nasal cavity during the production of vowels. The areas of the three cavities are also different for different people. thus, we can again presume that the areas of these cavities are genetically determined. Therefore, on the basis of this presumption we can state that resonance parameters also have the potential to carry information about genetically hard-wired features of voice. However, we must not forget that formants are not produced due to resonance alone. They also depend on the tongue movement and movement of lips and jaws. The movement of these articulators is an acquired habit and it can be modulated with ease. Consequently, we can state that formants carry both genetic as well as acquired features of voice.

Duration and amplitude are entirely acquired features. They are largely dependant on what kind of articulatory habits are acquired as a part of the process of acquiring L1 phonology. It also depends on individually acquired articulation habits as we know that every speaker of the same language does not have the same manner of articulation. By this we are suggesting that, parameters such as, duration and amplitude carry information only about the acquired features of voice, the L1 phonology of the an individual to which he/she has been exposed to.

As a researcher, our work is to find that which of these parameters carry genetically hard-wired information about voice, and whether they are strong parameters for speaker identification or not and which of them can yield accurate results so that voice recordings can gain greater acceptability in courts. Once this task is done, our next work is to arrange these parameters in a hierarchy on the basis of their significance. This information will be useful to the forensic experts as they will know which parameters

should be analyzed first in order to get greater accuracy in result. That will save both their energy and time.

1.6.1 Theoretical Framework

The ultimate goal of forensic speaker identification is to prove that voice of an individual is unique just like fingerprint and that it is a robust evidence which is reliable enough to decide cases in courts. We know that voice of an individual changes with time. It may vary due to physiological and psychological factors. The physiological factors may include age, health, smoking and drinking habits etc. Whereas, the psychological factors may include emotional state of an individual, situational factors such as extreme hot/cold weather, background noise etc. Speaker identification aims at discovering those features of voice which remain unaffected by these factors. We can say that those features which are inherent in voice of an individual are not subjected to change by physiological and psychological factors.

This argument leads us to the direction of associating voice with genes. It has been established that in humans, FOXP2 is one of the genes which is responsible for language. Similarly, we might not be completely wrong if we assume that there is any such gene which is also responsible for uniqueness of voice of an individual. In this area, a step has already been taken by Prof. Vaishna Narang and Dr. R. N. K Bamezai. In the volume III, Voices and Genes, of their project report " Mapping Language Mind and Brain: Studies in Biolinguistics" they have talked about the heritability of voice. Another such study " Voice Traits: Inherited or Acquired" was conducted by Steven D. Gray who examined the hypothesis that "vocal traits are determined by genes or environment" . However, whether voice quality of an individual is determined by his/her genes or not is yet to be established.

So, we understand that ultimately any research in speaker identification is done within this framework where the final goal is to establish that every individual's voice is unique, to find out those features which are responsible for this uniqueness and to discover a technique which can measure these features. Every research in speaker identification is a step ahead in bringing voice recordings closer to fingerprints as evidence in courts.

1.7 Objective and Scope of Research

1.7.3 Area of Study:

Speaker Identification has always been an area with numerous applications but the major component in any speaker identification study is to believe and try to prove that voice is unique for every individual. This proof is required to make speaker identification a valid field, so that voice samples can be treated as admissible evidence. Among the various applications of speaker identification, is speaker profiling. Just by hearing the voice we can deduce the age, gender, height etc. This type of profiling helps in a criminal case where the identity of speaker is unknown and the only known thing we have about speaker is his or her voice.

1.7.2 Scope for current research

Voice analysis has many parameters but the first step is to divide these parameters on the basis of auditory parameters and acoustic parameters. Auditory analyses consist of various features, for example: speaking mode of the speaker, speaker's respiratory form or pitch level etc. On the other hand, in acoustic analysis the focus is on the visual representation of the voice. When analyzing voice acoustically we focus on the frequency, resonance, and formant harmonics etc.

The current acceptable mode of voice identification is to combine both auditory and acoustic parameters. The current research is also going to combine both auditory acoustic parameters. Auditory analysis always precedes the acoustic analysis. For current research the set parameters for the auditory analysis will be analyzed first. After that we will move towards the acoustic parameters. The main aim in this research is to find out the one unique feature which can improve the accuracy of forensic speaker identification. After distinguishing proper auditory parameters, we will look into the acoustic parameters.

This research is going to help us develop a proper analyzing method for voice recognition. Vowel analysis has always been an important factor in forensic speaker identification. This research will contribute to the vast history of vowel analysis. By combining both auditory and acoustic parameters, the probability of improvement will increase.

1.7.3 Objective of Research

Many scholars have argued that changing the vowel pattern while uttering a sound is very difficult. Consonants can easily be modified but vowels are very speaker specific. Numerous researches have been conducted on the following topic. The objective of current research is to develop on the findings from previous researches by combining two different approaches together.

Many important researchers like Steven Gray, Dr. Vaishna Narang, Dr. Bamezai etc. have tried to test a hypothesis that the voice quality of an individual is determined by his or her genes. . The research revolves around the question that which features of voice are genetically hard wired and which of them are acquired. Both auditory and acoustic analysis will be conducted on the voice samples of the subjects to find out the answers to these questions.

If every individual has a unique articulatory maneuver, then the filters i.e. different articulators should always produce similar results. The formant frequencies will always have the similar results. The genetic features are like the shape of our vocal tract whereas the acquired features are like phonology of our L1, individual acquired articulation habits. Manner of articulation also changes with age. Socio-psychological factors can also affect the way a person utters a particular sound. There are so many factors which can affect our speech production. This research will try to check whether instead of these factors, there are any kinds of features which cannot be modified.

1.7.4 General research Question

We have discussed this field and all the problems associated with it in great extent. So far, the discussion has pointed out that Voice pattern of every human is unique. There are genetically hardwired features which makes it a unique .These genetically hardwired features have major impact on our speech production. No matter what our condition is, changing these features is not possible. When a vowel is produced there are three components which are responsible for its form; height, length and position. When we analyze a vowel acoustically, F1 represents the height of the vowel and F2 represents the position. The difference between F2 and F1 represents how back the vowel is. The current study will look deep into the vowels produced by Marwari speakers at different syllable positions and analyze the change in formant frequencies. There are many articulatory factors which can affect the production of a vowel.

Nasalized vowels are one of them. These vowels along with their articulatory modifications we will see whether their formant frequencies have changed. The features like pitch, tone and accent can easily be modified but a person cannot change his or her articulator. These formant harmonics are the representation of the filters which are affecting voice productions. These formant frequencies should be unchangeable. This study will try to identify formant values for vowels and see if we change the pitch , tone these formants remains constant or not. Phone recordings will also be taken into account in order to check the variations in formant frequencies.

The relevant research questions for the proposed dissertation are :

1. How do the genetically hardwired features make the voice pattern of every human unique?
2. What aspects of F1 and F2 are helpful in identifying language specific or variety specific sections of an ethnic group?
3. How does F0 measure help in increasing the accuracy of identifying these ethnic groups?
4. How do parameters vowel height, vowel position and nasalization can affect the identification process of the given ethnic groups?
5. Are the formant frequencies affected by the position of vowels (syllable positions)?
6. What is the role of F2 and F2-F1 in increasing the accuracy of speaker identification?

Hypothesis

The values of F2 and F2-F1 determine the position of vowels in the vocal cavity. Changing this position consciously is very difficult, which means that F2 and F2-F1 should be unchanging for every individual. Considering the constancy of these measures (negligible change which is statistically non-existent), improvement in the accuracy of speaker identification is possible by checking for these. By looking at the acoustic analysis of speech data of two distinct ethnic groups of Marwari speakers, we will attempt to justify the hypothesis.

1.8 Structure of the dissertation

This dissertation is divided into five chapters followed by references and bibliography.

The first chapter is comprised of introduction to the research topic i.e., "Role of Formants, f1 & f2 in Speaker Characterisation: A Study of Marwari speaking Monolinguals in Bikaner the chapter is followed by the second chapter i.e. a study on the literature already available on it which has been put under 'Review of Literature'.

It is followed by the third chapter which is 'Research Methodology'. This chapter gives an account of the available methodologies for research in forensic speaker identification. It also discusses the method and process of data collection adopted for the current research and the problems faced during this process.

Next comes the chapter on 'Analysis'. The whole chapter is dedicated to analysis of the speech samples using Praat. Various acoustic parameters have been measured in Praat and the speakers in the Suspect sample have been matched with the speakers in the Question sample. For every acoustic parameter used in the speaker identification process, the observations have been noted down.

This is followed by the concluding chapter which presents the result of the research conducted.

Chapter 2. Literature Review

2.1 History and Various Theories

2.1.1 Traditional " Articulatory" Phonetic Theory

People have been working on speech acquisition and identification for decades. Language labs were established before during world wars but their primary function was to teach second languages. It was Melville Bell (1867) who contributed the most in developing phonetic theory. His students later worked on in his theories and the sound spectrograph was first developed during the 1940s in Bell laboratories. Mellvile Bell's theory is known as Traditional articulatory theory. (Lieberman and Blumstein, 1988). Bell's primary concern was to find out the articulatory maneuvers so that he could teach to deaf people how to talk. He majorly focused on the articulators which could provide instructions for producing various sounds. Around the time Bell was working on his theory, the lack of X-Ray techniques and MRI techniques made a lot of his assumptions false. But some of the articulators which he observed were right also. For example the position of lips while producing the /u/ sound. (Lieberman and Blumstein, 1988).This particular sound can be found without any particular instrument. But there are many sounds whose production cannot be observed by naked eye. For example the velar sounds or the phyrangeal sounds. One of the examples given by Lieberman and Blumstein is the way in which larynx produces and regulates the phonation. The phonetic theory which Bell gave became the classic phonetic theory and helped a lot in various advances in phonetics, phonology and acoustics.

2.1.2 Vowels

Bell said that the phonetic quality of vowels is derived from the position and height of the point of constriction of the tongue. The height of the tongue constriction was supposed to be low for a vowel like /a/ and

supposed to be high for vowels like /i/ and /u/.The position of the point of constriction with respect to front-back was also specified. Bell's theory was used by Chomsky and Halle (1968) in their distinction of binary features. As mentioned earlier all of the Bell's presumptions were not accurate because of the lack of an understanding of the pharyngeal cavity's role in speech production.

Radiographic techniques made X-Rays of supralaryngeal vocal tract possible by 1919 (Jones, 1919). Russell (1928) made use of Radiographs of sustained vowels produced by speakers of American English. After these techniques were available, many linguists and physicists tested this theory and came up with two hypotheses.

1.Formant frequency patterns that differentiate many speech sounds are determined by the areal function of the vocal tract. A particular areal function will always result in a specific unique formant frequency pattern (Lieberman and Blumstein, 1988).

2. The X-Ray studies showed us that different speakers use different articulatory maneuvers to produce similar phonetic contrast.

2.1.3 Quantal Theory of Vowels

Stevens (1972b) introduced the term quantal factor with respect to the acoustic signals used for vocal communications. Stevens (1972b) stated that certain speech sounds are more distinctly recognizable than the others. He focused on three major vowels, [i], [u] and [a]. Acoustically speaking for [i] the second and the third formants, F_2 and F_3 are both high; [a] has low , F_2 and F_1 is high whereas [u] has a low , F_1 and F_2 . Articulatory and Acoustic analysis have shown that these vowels are the limiting articulations of a vowel triangle which constitutes a Language-universal.

And all these three vowels have well defined spectral properties. A central spectral peak occurs at the above 1KHz for[a], a High frequency spectral peak occurs for [i] and a low frequency spectral peak occurs for [u].

2.2 Brief overview of speech research after 1950s.

The second half of the twentieth century was the pioneering era for speech research (Gunnar, 2004). Gunnar Fant in his paper '*Speech research in historical perspective'* has extraordinally classified various stages of speech research in four parts.

1.1950-1965- Fant stated this time as a pioneering era for speech research. The first part marks the beginning of interdisciplinary contacts i.e. when linguists started combining their research with physicists, biologists and various experts from other fields.

2. 1965-1980- In this second period computers had become a a very important factor for any laboratory, which marked the transition from analog to digital processing in all aspects of speech research, and was the foundation for text to speech synthesis and speech recognition.

3. 1980-1995-In the third period statistically oriented methods of speech processing, HMM and analog neural networks became standard tools for speech recognition and in man-computer dialog systems. This technology provided valuable tools for the visually challenged as well as for speech and language-deficient people.

4.1995-2004- Ken Stevens' book *Acoustic phonetics* was published in 1998 and has provided valuable insights for speech production researches. A main trend in the fourth period has been a shift towards speech technology applications from computer science, applied linguistics and psychology,.

2.3 The Current Approaches on speaker Identification

The paper " *Parson Authentication by voice : A need for caution*" mentions the brief overview of the contemporary state of scientific knowledge and technological development in the field of voice identification. Paper states that even though there have been extraordinary scientific advancements in this area, the certainty of the accuracy of voice identification is still very limited. The current classification of the aural recognition procedures has been elaborated by the authors. It states that there are six things which determines the accuracy of the Aural recognition;

1. Familiarity with the speaker
2. Duration of the sample
3. Context
4. Contemporaneous samples
5. Lack of vocal stress and disguise
6. Training

Another article, " forensic speaker identification based on spectral moments", 2002 mentions different approaches used for speaker identification.

1. Long term approach : in this approach, the analyst observes and analyzes the average of acoustic features, like filter spectral coefficient, pitch, cepstral coefficient (Doddington,1985) for a very time. The overall result is then accepted as a final conclusion.
2. Use of Neural Networks to determine Speaker Drawback: Neural Networks require excessive amount of data needed to train the speaker models. In this approach when a new speaker enters, the entire neural network must be trained again.

3. Segmentation Method: this method compares speakers based on similar utterances and then measures differences that originates with speakers rather than the utterances.

Voice

" Communication has long been recognized as one of the most fundamental component of human behaviour." (Peterson,1958)

" The act of speaking is a very specialized way of using the vocal mechanisms. The act of speaking is even more so. Speaking or singing demand a combination or interaction of the mechanism of respiration, phonation, resonance and speech articulation. (Boone,1972)

"Voice play a musical accompaniment to speech, rendering it tuneful, pleasing, audible and coherent, and is an essential feature of efficient communication by the spoken word"

The sounds which humans use can be served at many level, less one percent of the sound produced by humans is useful for linguistic purposes, others give us many information, like the characteristics of speaker, both physiological as well as environmental. Voice carry both linguistics and non-linguistic functions. The degree of the importance of these functions depends on the language. For example, tonal language depends on the voice more specifically than the others.

The voice is a very important factor in speaker identification. Perkins (1971) identified that there are at least five non-linguistics elements associated with voice i.e. voice can give information regarding the sex, height, age and weight. Lass(1980) reported in his studies that it is possible

to identify the age, sex, race, socio-economic status, facial features, height and weight according based on the voice.

“The aspect of voice has received considerable attention and has been found to be useful in criminology. The ability of the voice to provide information regarding the speaker is from well perfected implicit code. (Voicers, 1964). This code is gaining importance, which is evident from the rapidly interest in voice printing, the telecommunication analogue of finger printing” (Perkins,1971)

2.3.1 Voice and Personality

The relationship between voice and personality has always been dwelling with the minds of the reseachers. It was not before Stark Weather (1961), Ostwald (1963), Mankel, Meisels and Hauk (1964) and Rousey and Moriarty (1965) conducted several investigations with positive outcomes, to prove the relationship between Voice and personality of a person. Fairbanks

(1938,39,41,66) ,Pronovost (1938) and Huttar (1967) showed that there is direct connection between a person’s voice and his or her emotional condition.

2.3.2 Voice and Physiology

Voice can also reflect the physiological condition of a person. For example, a very slow or weak voice can be an indication of bad health, a nasalized voice can reflect person suffering from cold.

Other than these factor a person’s voice can also reflect the shape of their articulatory system, their respiratory, phonatory and resonatory mechanisms. A specific abnormality or distinguished feature in any of these might result into a very unique speech production.

An attempt was made to identify the relationship between physiological condition and voice utterance. Numerous studies was conducted, where

infant cries were analyzed. (Blinik,1971; Fisichelliv,R et.al.1963,66; Illingworth,1981; Indira,N 1982). These studies proved that it is possible to identify abnormalities in the neonates by analyzing their cries just after birth and a few hours after that.

2.3.3 Voice and Race

Studies have shown that it is possible to identify the race of an individual's race (Stroud,1956; Hibler,1960; Dickens and Sewyer,1962; Larson and Larson,1966) . An individual's socio-economic background, their personality, region specific identity and even the facial features can be associated with their voice features.

2.3.4 Voice and Sex

Identifying speaker's sex is one of the most easy and common usage of speaker identification. But, even this has many variables. The male speaker might have a high pitched sound or a female speaker can have a very masculine sound. There are some cases where speakers often try to produce a mimicry of the sound, which, if analysed can give mixed results. To ensure the sanctity of the results, voice analysis is often done using auditory and acoustic analysis both. For the purpose of speaker's sex identification studies have often used , voice-less fricatives, isolated spectral noise and whispered vowels (Schwartz, 1968; Ingerman,1968; Colemon,1971). All these studies have shown that speaker's sex can be determined accurately(dennis, 1980). The result of (dennis, Ingressano, Gray Weismer and Gordon H. Sehucker, 1980) study on sex identification is children has shown that vocal tract resonance characteristics give us most accurate result for speaker's sex perception.

" In a study of spontaneous speech of five and six year old children, Murray (1975) – Listeners, were able to identify the speaker's sex with 71 to 78% accuracy for male and female separately". (Dennis,1980).

Sachs (1973) found that 81% of adult speaker identification was correct. Fundamental frequencies in males was significantly higher than in females. For vowels, /i/ and /u/ lower formant values were seen in males than that

of female voices. They concluded that the correct results are not based on fundamental frequencies then the difference in the formant frequency values of male and females.

2.4 Speech Acoustics: Source-Filter Theory

"Acoustics Theory of Speech Production" (Fant,1960) came up with a new theory, which was later named as Source-Filter Theory.

This theory explains the acoustics of voice in terms of the vocal mechanism that produces them. It is a received theory that is largely responsible for 'raising the field of acoustic phonetics toward the level of a quantitative science' (Stevens, 2000). Source-filter theory is yet to be falsified.

It has two components– a source of energy and a filter which modifies that energy. The theory relates acoustics to production in terms of the interaction of these two components.

The larynx is the source of energy input in the production of oral vowels. The production of voice takes place due to the structure of the vocal cords, the air-stream mechanism and the Bernoulli's effect. The structure of the vocal cords, the process of phonation and the Bernoulli's effect behind the process of phonation has been discussed in detail under the section "what is voice and how is it produced?" The air-stream is initiated by the lungs and gets modulated by the vocal cord activity. As the air flows through the glottis, the vocal cords start oscillating. The cords come together, stay together for an instant, and then come apart. The rate at which which the vocal cords vibrate is called the fundamental frequency. The overtones that are produced along with the fundamental frequency are called harmonics.

After the vocal cords start oscillating, the process of abduction and adduction goes on. This cycle is then repeated as long as the aerodynamic and muscular tension conditions for phonation are met. As a result of this, a sequence of high velocity jets of air is injected into the supralaryngeal vocal tract. This makes the already present air in the supralaryngeal tract vibrate. The three resonance cavities, pharyngeal cavity, oral cavity and nasal cavity act as a filter. The frequency and the amplitude at which this air vibrates depend on the shape of the container which is the supralayngeal vocal tract.

The supralaryngeal vocal tract, which contains the oral cavity, the nasal cavity and the pharyngeal cavity, acts like a tube which can produce resonance. Hence, when the air stream moves through this tract, it gets modified by the shape of these three cavities and produces resonant frequencies which is responsible for the quality of a vowel. This resonance leads to the formation of formants , F1, F2, F3…during the production of vowels. So, we can say that the source is the energy input to the system, and is associated with vocal cord vibration. The filter is associated with the shape of the supralaryngeal vocal tract, and modifies the source energy.

It has been mentioned earlier that the two components–source and filter are independent of each other. The independence of vocal cord activity and supralaryngeal activity permits the independent control of pitch through fundamental frequency, and of vowel quality (i.e. the production of different vowels) through formant frequencies. It allows us to say different vowels on the same pitch, and say the same vowel with different pitches. For example , we can change the first vowel in 'faster' and make it 'foster'. But, when we utter 'faster' at different pitches in sentences like, 'I ran faster than him' and 'do you want me to speak faster', there is also a difference.

The independence of these two components can also be seen in the articulation of consonants. For example, in production of the alveolar plosives [t] and [d], the filter, or supralaryngeal vocal tract, is the same for both consonants with constriction at the alveolar ridge, but in [d] the vocal cords are vibrating supplying a periodic energy source at the glottis, while in [t] the cords are not vibrating, and there is no periodic energy source at the glottis. (Rose, 2002)

We must now recollect the factors which are responsible for uniqueness in human speech, as suggested by Cain. The first factor takes into account the shape and size of the vocal cords and the resonators, i.e., oral cavity, pharyngeal cavity and the nasal cavity which are different for different people. The second factor which determines the uniqueness of human voice is the manner in which the articulators produce speech. Cain has tried to capture the physical component of human speech.

On the other hand, Laver talks about the social component of human speech. He has defined voice as a emblem of a speaker. He says that with the help of voice, we can not only communicate our messages from one person to another, but it also acts as our

individual, physical and psychological identity. It is a marker of our mood and it also conforms that we are members of a particular society.

What is a Spectrogram?

Now when we know that human voice is unique for every individual, we try to analyze it. We can study human voices visually. A sound spectrogram is a visual representation of an acoustic signal. It is a convenient way to diagram the changes in a sound's spectrum overtime. In a spectrogram, the horizontal axis represents time and the vertical axis corresponds to frequency. The relative intensity of the sound at any particular time and frequency is indicated by the color of the spectrogram at that point. Darker areas show higher amplitudes in comparison to the lighter ones.

Chapter summary

Forensic speaker identification is about attempting to discriminate between same-speaker and different-speaker voice samples. Voices are characterisable in an exceedingly large number of dimensions, and, because it is likely that they occupy separate regions in multidimensional speaker space, it is also likely that speakers of a given language all have different voices. However, the reduction in dimension number, and increase in within-speaker variation that is imposed by the realities of forensic-phonetic investigation mean that discrimination is not absolute, but must be probabilistic. The probabilities refer to the evidence. That is, one attempts to say how much more probable the observed difference between questioned and suspect samples is, assuming that they have come from the same speaker, and assuming they have come from different speakers. Further limitations obtain as a function of the amount of questioned and suspect data available for comparison, and whether separate unknown samples can be pooled. These limitations all affect the strength of the evidence.

Chapter 3 Research Methodology

3.1 Introduction

This chapter is going to discuss the different approaches and methods used for the current research work. The chapter is going to discuss every important factor for the following research including the profile of the participants of this research. At the end of this chapter various ethical concerns concerning this research will be elaborated.

3.1.1 What is Research ?

There have been many definitions around about what is research? From " quest for knowledge" to " a scientific investigation" people have defined research in various ways. The word research is derived from Middle French "*recherche*", which means "to go about seeking", the term itself being derived from the Old French term "*recerchier*" a compound word from "re-" + "cerchier", or "sercher", meaning 'search'. Godwin Colibao defined research as "In the broadest sense of the word, the definition of research includes any gathering of data, information, and facts for the advancement of knowledge". John W. Creswell states that a "Research is a process of steps used to collect and analyse information to increase our understanding of a topic or issue". It consists of three steps: Pose a question, collect data to answer the question, and present an answer to the question.

All these definitions have one thing in common which is every single one of them states that research is a "search for new information".

Just like the definitions there are enormous numbers of viewpoints on how a research should be conducted and how what kind of research it should be?

To answer these questions, the first thing a researcher should postulate is that what is the purpose of the current research. There can be infinite number of reasons to conduct a research. but there are certain general objectives to conduct a research which are mentioned below:

1. Exploratory or Formulative Research Study: To gain familiarity with the phenomenon or to gain insights into it.
2. Descriptive Research Study: to portray accurately the characteristics of an individual, a group or a situation.
3. Diagnostic Research Study: to determine the frequency with which something occurs or with which it is associated with something else.

4. Hypothesis testing Research Study : to test a hypothesis of a causal relationship between variables .

3.1.2 Types of Research

I. *Descriptive vs Analytical*: Descriptive research involves a descriptions of affairs as it exists at present. The major point in this research is that the researchers has no control over the variables, he or she can only present what has happened or what is happening. In social sciences and business this kind of research is called Ex Post Facto Research. Some examples of this kind of research is current trends in market, the most spoken language etc. the methods involved in descriptive research are survey methods of all kinds. In analytical research on the other the researcher has to use the information available and analyze that information to make the critical claim regarding it.

II. *Applied Vs Fundamental*: applied research aims to finding a solution for an immediate problem faced by the society or any particular industry. Whereas fundamental research is concerned with the theories and generalizations. Research conducted for only knowledge's sake is fundamental research for example, research related to the study of human behavior etc. whereas if a research requires any particular kind of conclusions it is called applied research. Research to identify any particular trends which may affect the current marketing strategy is one of the examples of applied research.

III. *Quantitative Vs Qualitative*: Quantitative research is based on the quantitative measurements of certain characteristics whereas Qualitative research asserts the qualitative phenomenon. For example, if the research is trying to figure out the motives behind certain behavior it will be considered qualitative research. There are many techniques employed in qualitative research for example, depth interviews, sentence completion tests, word association tests etc.

IV. *Conceptual Vs Empirical* : Conceptual research is generally used by philosopher or thinkers to develop new concepts or theories in their areas or to reinterpret

the existing idea. This kind of research is related to abstract ideas or theories. The empirical research only accounts for the observations or experience, it often disregards the existing system or theory. It is a data based research. This kind of research comes up with the conclusions which can be further verified by experiments and observations.

3.2 A brief Historical Perspective on Methods Employed for Present Study

As mentioned in chapter one the current research in analytical study of the role of first three spectral peaks of the vowel spectrogram of a recorded voice. These three spectral peaks involve, fundamental frequency (F0) , F1 and F2. F1 and F2 have always been used to identify vowels. Even though F1 and F2 helps us a lot deciding between two vowels, but there are some occurrences when these two readings are similar for two different vowel.

The role of F0 in vowel recognition has been widely analyzed and discussed in many papers presented by the experts. Umeda and Teranishi (1966) showed that vocal tract length has to be correlated with the F0 to preserve the naturalness of the vowel quality. Fujisaki and Kawashima (1968) the perceptual boundary of F1 shifts upwards as the F0 is raised in Japanese /u/-/e/ and /o/- /a/ continua and that the boundary shifts are much larger when the F0 and the third formant vary concurrently. Fant (1974) reported that the same formant structure can result in the perception of two different vowels, depending on the F0. Scott(1976) found the perceptual boundary between /i/ and /I/ shifts towards /I/ when F0 increases. Traunmuller (1981) showed that the distance between F1 and F2 is critical in Bark to phonetic judgement related to the vowel openness in a Bavarian dialect. Di Benedetto (1987 a, b) also reported that perceptual boundary between /i/ and /e/ is affected by F0 in American English.

Analytical study of natural vowels also show that correlation between F0 and formants (Peterson and Barney,1952) i.e the higher the F0s are the higher the higher the vowel formant frequencies. The analysis of the singers' voices also shows that the they adjust their jaw opening in accordance with the F0 so as to preserve the vowel intelligibility. Gottfried and Chwe (1986) showed that the octave change in F0 show less than 10% increase in F1. All these studied both perceptual and analytical shows that F0 plays a very important role in vowel recognition.

Syrdal (1985) and Syrdal and Gopal (1986) , reported that the Bark- Difference scale (a frequency scale on which equal distances correspond with perceptually equal distances. Above about 500 Hz this scale is more or less equal to a logarithmic frequency axis. Below 500 Hz the Bark scale becomes more and more linear.), F1-F0 vs F3-F2 offers a powerful and comprehensive means to classify vowels.

All these studies show the three main important features in vowel recognition studies. The present study is going to further address the importance of these three features and how these features can help us improvise the field of Speaker identification through recorded voice.

The next section is going to describe how this current research has been organized.

3.3 Overview of Research Design

the current research was conducted using Sampling Method i.e a small group of participants were selected and they were considered as the representatives of their respective communities. These participants were selected on the basis of many parameters. Their age groups, their knowledge of the given variety of the language, their knowledge of the dominant language in the area they belong to, their literacy etc. were the few of the parameters which affected the selection of the participants.

3.3.1 Tools and Instruments

There are many data gathering tools which can be used for the purpose of a research. Selection of the proper tools can help a researcher to test his or her hypothesis for the given research. For the purpose of this research two word list were constructed. Since all the participants understood the dominant language i.e. Hindi ; word lists in Hindi were developed and they were asked to translate those words in their own variety of Marwari. The major goal of this questionnaire was to acquire words which involved a specific vowel, in between two stop consonants. A pilot study was done with four participants in order to create a very specific word list. The pilot study involved a long conversational interview of the four participants, two from each community, and specific words(which served the purpose of the current research) were chosen from their conversations. Since there were many constant variables which needed to be satisfied in order to conduct this experiment, the word lists only involved those words which had the translations resulting a vowel in a medial position ,between two stops.

For example the participants were requested to translate the word /k / (crow) which gives the translation of /kaglo/ the /a/ vowel here is in a nuclear position having /k/ as an onset and /g/ as a coda. The main purpose of this study is to acknowledge the importance of the first three formants of a given vowel sound and the test whether the difference between them remains constant. Since the two different varieties were taken, two separate word lists were created.

The word list was presented to the participants in the interview method. They were asked to translate the word in their own variety and speak it clearly in front of the recording device. To ensure the clarity of the sound each participant was asked to utter the translated word three times.

Instrument : the instruments used in the current study are:

- A portable voice recorder (Sony Stealodeal SO-ICD-PX440 4 GB Voice Recorder (2.5 inch Display)
- Praat Analyzer

3.3.2 Data Elicitation

As mentioned in chapter 1, this is study of two different varieties of Marwari spoken in Bikaner District (Rajasthan, India). These two varieties are based on the caste distinction of the speakers i.e. Speakers from a particular ethnic group (Caste) speaks a distinct variety of Marwari. Two different Ethnic groups chosen for this study are, Bishnoi and Brahmins. The study was conducted on the data acquired from the speakers of these two ethnic groups' recorded voices.

For the current research, which is determining the role of F0, F1 and F2 in speaker identification, a primary data was collected from these two ethnic groups. There are many methods which can be used for primary data collection, observation method, interview method, through questionnaire or schedules etc. For the current study a questionnaire based on the observational data collection method was developed. This questionnaire was later answered by the participants in through the help of interview method.

As mentioned before, this study is done in the domain of Forensic speaker identification, the current study incorporates a question sample or a subject sample. This is an analytical data based study which will use the observations and conclusions to help the field of Forensic speaker identification, to become more reliable. The

purpose of this research is to highlight a particular feature which can be very crucial in speaker identification.

The task of data elicitation was done in Bikaner district. Voice samples were collected from 40 speakers, 20 from each ethnic group. The choice of Finite universe was made for the collection, which is in line with the forensic enquiries. The choice of 40 speakers was to create a rich corpus for an analytical enquiry.

To start any research the first step is to establish the research plan. This plan we help the researcher to deal with all the possible confusions and failures in the given research. The first step to start a research is writing the objectives and the scope of research. Every other possible step comes after the researcher knows, what he or she is try to find through the research. Kothari (2004) in his book Research Methodology has laid down 10 questions which must be answered by the researcher for carrying out any research. The questions are given below :

(i) What is the study about?

(ii) Why is the study being made?

(iii) Where will the study be carried out?

(iv) What type of data is required?

(v) Where can the required data be found?

(vi) What periods of time will the study include?

(vii) What will be the sample design?

(viii) What techniques of data collection will be used?

(ix) How will the data be analyzed?

(x) In what style will the report be prepared?

Any research design works as the blueprint for the collection, measurement and analysis of data. The following section, thus, discusses the answers to the above questions in order to prepare a proper overview for the current research.

The present research, as mentioned in the title "Role of F0, F1 and F2 in Forensic Speaker Identification" , deals with the acoustic aspects of speech sounds in the domain of Forensic Speaker Identification. The research methods employed by the previous researchers have reviewed and followed by the researcher for the present study. After reviewing all the previously used research methods a research design has been constructed which suits the needs of current research.

The main goal of forensic speaker identification is to compare two sets of samples together, the first set is called question sample, i.e. a set of speech sounds acquired by the investigator, from the offender. Question samples are usually acquired without the knowledge of the offender, so it might contain long conversation, telephonic or face to face. The Second set of data is called suspect samples, Suspect samples are obtained by the researcher, in a artificially modified environment. A predetermined conversation or a questionnaire is developed by the researcher which is usually based on the question sample. Obtaining suspect sample is a complicated job, because investigator first has to listen and notice all the particular speaker specific features from the question samples. Then a script is prepared which might contain some words or the entire conversation from the question sample. This script should contain all the peculiarities which will help us mark the speaker specific verification. These peculiarities might contain, pitch, any specific word or any other specific feature of the offender. In India, the CFSL, which is the major forensic laboratory that deals with most gruesome and important criminal enquiries of the country, the script which is prepared as suspect sample contains the entire question sample repeated. This kind of script is avoided by lots of researchers because there might be cases where the suspect, who himself/herself is the offender modifies his or her speech after hearing the exact conversation again. For example, while giving the voice recording as a suspect the real offender might make his or her voice more nasalized, which will make it harder for the researcher to determine the perfect match between two samples.

To avoid any manipulation sometimes investigators create an environment where the suspect has to interact with others, so that an environment is created where they talk fluently and without any modification. In the present study such environments were created by the researcher. While getting the Suspect sample, the researcher also asked them some personal questions about their lives. The Question Sample for the current study was retrieved this way. The speech produced in this manner is often spontaneous and has very little modification risks.

Once the sound recordings are obtained, Question sample and Suspect Samples are fed to the computer for further analysis. Every institute has their own software for analysis purposes. For the purpose of current study Praat was used.

Then the process of voice analysis begins with auditory analysis being the first stage of it. For the purpose of auditory analysis, researcher listens to the samples carefully and

then marks the auditory feature step by step. These auditory features are later compared to the question samples. The features used for auditory analysis usually includes, pitch, loudness, speech rate, fluency, nasality etc. The current study used the standardized list provided by the CFSL for any forensic linguistic investigation. The table of the auditory features made by CFSL is given below;

S.No.	PARAMETERS	EXHIBIT	EXHIBIT	EXHIBIT	EXHIBIT	EXHIBIT
1.	Sex					
2.	Speaking Mode i. Disguised ii. Normal					
3.	Stylistic Feature i. Simple ii. Polite iii. Emotional iv. Expressive v. Ironical					
4.	Respiratory Form i. Nasal ii. Oral					
5.	Pitch Level i. High ii. Normal iii. Low					
6.	Striking Features of Voice i. Coarse ii. Hoarse iii. Creak iv. Pressed voice v. Normal voice					
7.	Fluency i. Hasty ii. Very fluent iii. Normal fluent iv. Sluggish v. Stopping					
8.	Understandability i. Easily ii. Hard iii. Hardly					
9.	Loudness i. Very loud ii. Loud iii. Medium iv. Soft					
10.	Speech Rate i. Very fast ii. Fast iii. Medium					

	iv. Slow v. Very Slow					

Table 3.1 Parameters For Auditory Analysis

The auditory analysis provides an idea about identical or atleast similar sounding utterances in both SS and QS(For the purpose of economy, the current study is often going to use SS for Suspect Sample and QS for Question Sample). The similar sounding utterance are further taken for the acoustic analysis. In acoustic analysis, spectrograms of extracted utterances are acquired with the help of voice analysis software. As mentioned earlier, Praat was the software used for the present study. After this SS is compared with the QS for different parameters set by the researcher. These parameters can be, fundamental frequency, formant frequency distribution, amplitude, duration, etc. Acoustic analysis makes a very vivid and detailed comparison of two different samples, which makes it scientifically reliable.

The probability of two voice samples belonging to the sample speaker increases when the two spectrogram match with each other and on the other hand, the probability decreases for the dissimilar spectrograms. The speech analysis research is still not that developed, that one can be 100 percent sure about the accuracy of the results.

The methods used in the current study was learnt by the researcher from the Central Forensic Science Lab, New Delhi. The researcher worked with the CFSL for a limited time period and learned how to conduct any forensic investigation. While solving the cases for CFSL, she learnt a great deal from their team. The difference between the methods used in the CFSL and the current is research is that for suspect sample, CFSL sometimes provides the entire copy of the script to the suspect. There are some cases where suspect refuses to provide the samples after looking at the exact same conversations, or sometimes they might intentionally start modifying the speech. So, to avoid these modifications a spontaneous conversation was choses and vowels were extracted from it.

The research design for the current study was same as mentioned above. Both Suspect Sample and Question samples were obtained and later compared by the researcher. The voice samples were acquired in the mp3 format, which is readable in Praat and later the extracted sounds were saved as 32 bit .wav files. The "Sony Stealodeal SO-ICD-PX440 4 GB Voice Recorder" was used for recording the data. All the QS files were jumbled by another fellow linguist, to avoid any biases since the recordings were taken by the researcher herself and she knew which question sample belonged to whom. The

extracted question sample were jumbled and assigned new names by the same fellow linguist. The aim of the current study is to identify the Suspect Sample and match it to respective Question Sample. Both auditory and acoustic analysis methods mentioned above are going to help in this investigation.

Difficulties Faced in Data Elicitation : Data collection was a tedious task for the researcher. She faced problems in convincing people to participate in her data elicitation process. There were also a few people who grew skeptical about their voices being recorded, on the other hand there were some who were excited on this very idea of their voice being recorded and used in a research work. Since the Bishnoi Participants belonged to rural areas, letting them know why the following research is being conducted was very difficult.

A common question that the researcher faced was "what will you do with my voice sample?" It was not an easy task for the researcher to satisfy the participants with an answer because the participants failed to understand what a spectrogram is. They were also very skeptical about the fact their voice was being compared to this particular variety Most of them had probably no idea about formants, resonance, fundamental frequency, etc. The researcher tried to explain to them in a simplistic way, but they were keen to know the technicalities involved in a forensic speaker identification process. As a result, many people simply refused to participate in the research.

The researcher met more and more people and tried to convince them. Finally, she managed to collect data from 40 participants.

The voice samples were to be recorded under controlled conditions. Hence, all the voice samples were recorded in a closed room with fans and mobile phones switched off.

The researcher received immense support from her mother and her friends in looking for subjects for her research. Though she was a little nervous before the recording session, it was a proud moment for her when the participants exclaimed with wonder that such research was being carried out by a girl on their variety. The participants showed great excitement and enthusiasm which helped in motivating the researcher.

It is not that only the researcher was nervous, but the participants too grew very nervous before the recording sessions. The next problem was to ask them translate the word list in Marwari. Some words chosen by the researcher were very variety specific and out of use by the current youth. The participants being above forty, knew those words but were either hesitant or laughing at them the researcher tried to calm them down. She

explained it to them that laughing in between the recording might affect the quality of voice, so please stay as calm as possible while the recorder is on.

3.3.3 Selection of the participants

Rajasthan is located in the western side of india. This state of india i nhabits large groups of different religious groups speaking different varieties of Marwari. But in this work the focus is on two varieties that is the brahmans and the bishnois.

Bishnoi or "Vishnoi" is a religious group that is different from other groups in terms of language and religious customs that they follow. They are also referred to as nature worshippers. They have to follow 29 tenets which was prescribed by Guru Jambheshwar, the founder of this group. These tenets were documented for which the Nagri script known as the Shabdwani was used. This script has 120 shabds. These tenets are formed keeping in mind certain basic rules like out of 29 tenets 10 of them deals with personal hygiene and how one should maintain good health of one's own and seven tenets talks about healthy social behaviour. The remaining eight tenets directs towards ways to preserve bio-diversity and encourages good animal-husbandry i.e. ban on killing animals and cutting down of green trees and providing protection to all kind of life forms. The community also makes sure that when they use firewoods then they are devoid of small insects. They are also prohibited from wearing blue clothes as they are dyed by cutting a large quantity of shrubs. This group is also known for playing the most important part in Chipko movement where young or old men or women, married or unmarried stood to protect the trees.

Brahmins are another religious group that speak the Brahmin variety of marwadi. This group is involved into worshipping and performing spiritual rites. During the British raj these groups were formed. The brahmins secured the number one slot in the table. The brahmins are further known by different names like Dadheechs, Pareeks, Saraswats etc. Though initially they were involved into religious rituals in temples but later they were found involved into other sectors like agriculture, warriors etc. The Rajasthani Brahmans are involved into either religious ritual or they get into academics.

All the participants selected for the current research are monolinguals. All these participants have spoken that particular variety of Marwari throughout their lives. Everyone one of them falls under the age group of, above 40. This particular age limit was established because, the frequent migrations and other kinds of interactions with the other ethnic groups has resulted in a new variety of Marwari in the present youth. People who are above usually didn't get affected by this change and still protect their monolithic variety of Marwari.

Ten male and ten female participants were chosen from each ethnic group. Even though all these participants are from Bikaner district, most of the Bishnoi speakers still reside in small villages of the district, whereas the Brahmin participants have migrated to the main city.

Most of the male participants were high school graduates whereas most of the female participants are uneducated or have acquired primary level education.

There were many parameters which were required for the purpose of the participant selections. These parameters are given in the following table.

Inclusion of the Participants	Exclusion of the Participants
1. Age : above 40 2. Gender : both 3. Education : primary (female) Secondary (male) 4. Ethnicity : Bishnoi and Brahmin 5. Place : Bikaner	1. Multilinguals 2. Highly educated (which includes above matriculation) 3. Age : Below 40

Table 3.2 Participants Information

A survey questionnaire was given to the participants prior to the interview. This questionnaire was created in order to acquire the background information on the participants. The questionnaire involved a table to check their linguistics background, a series of general questions about their personal backgrounds, involving whether they belong to a rural area or an urban area, which ethnic group they belong to, their educational qualifications etc. The questionnaire is included in the appendix section of the current research.

On the basis of this a participant background information were acquired from them. These Information are summed up in a tabular form and attached to the appendix section of the research work.

3.3.4 Data Assessment

In the case of experimental data or a survey, researchers has to depend on the estimation of the values of known parameters of the subjects and deduct a hypothesis out of it in order to draw some inferences. Analysis can be categorized as descriptive analysis and inferential analysis. Descriptive analysis is largely the study of distributions of one variable. For example, in some linguistic studies, researchers try to find the availability

of a particular feature in a given age group and its distribution among male and female. This feature can have different variant in different groups, for example, the usage of the colloquial word 'Yeah'. It has been noticed that the word 'yeah' has different representations in different age groups, which varies from 'Yes' to 'Yo'. This a unidimensional research aims at finding only a specific variable or only one type of a variable among a group of speakers, among people of different age groups, social class, or any other group. When the research is done in respect of two or more than two variables respectively it is called bivariate or multivariate respectively.

Sometimes, research requires that variables are compared or correlated to figure out the amount of correlation between two or more variables. Such analysis is called correlation analysis. In some other cases, researchers look into the effect of a variable on other dependent variables. It is thus a study of functional relationships existing between two or more variables. This type of analysis is termed Causal analysis. This analysis can be termed as regression analysis. Causal analysis is considered relatively more important in experimental researches, whereas in most social and business researches our interest lies in understanding and controlling relationships between variables then with determining causes per se and as such we consider correlation analysis as relatively more important.

The present research is largely correlational analysis, where the researcher is interested in gauging the accuracy of results found through different variables. the correlation analysis of the data is involved here as we try to establish the relationship between different parameters in order to find which parameters together will help in finding more accurate results. Further, we have discussed the analysis process in brief here and we will describe it in detail in the next chapter.

Analysis of speech samples for speaker identification is generally done at the word level.But for the present study the analysis was done at the syllable level. So, there was a need for some software that could help slice sentences and words into disparate audio files. The software, namely Praat, have the option of clipping audio samples into small files. Therefore, It was used to clip out the particular vowels from their words. The words selected for comparison will be extracted from the sentences and will be saved as .WAV files. Praat will also be used for generating spectrograms of the extracted words and with the help of the software, voice, resonance and manner features like pitch, frequency, duration, intensity, formant values and others will be measured. A

comparison of these features, as the researcher believes, will help in identifying the relationship between the voice, resonance and manner features and this may have implications for speaker identification. In the next chapter, we have discussed the process of segmentation of sentences, words, sounds and their analysis using Praat in detail.

3.3.5 Ethical Considerations:

While conducting the data, collection process a consent form was prepared by the researcher to ensure the ethics of the research process. The participants were supposed to sign the consent form before any kind of data was collected from them. The copy of the consent form is attached to the appendix section of the research. The form talks about the purpose of the research and it also explains the role of the participants in the research. To ensure the identity of the participants in the research, a close has been added which promises them that their identity will be kept confidential from everyone. It also assures them that their speech samples will only be used for the academic purposes. Researcher made sure that the informed consent was taken from each participant before collecting any data.

Participants were not offered any monetary incentive to avoid any wrong expectation or modification of the sample. All the participants were aware at the time about the motive of the research and that this research was solely based on the academic grounds, and would not be used to acquire any kind of profit.

Participants were informed beforehand that they can withdraw their participation from the research any time they want and that it is completely voluntary work. They were also informed by the researcher that they can withdraw their data or participation, if they had any objection with the work or the way research was being conducted.

Though this is not stated in the consent form, the participants were informally conveyed that they could ask the researcher not to use their data if they had any objection to the use of their voice samples.

The contact details of researcher's supervisor were also shared with the participants, to make them feel confidence on the subject and the researcher and she asked them to contact her supervisor, if they had any issues with any aspect of the research.

The next chapter is going to examine step by step analysis of the voice samples collected from 40 speakers. The acoustic parameters which include, pitch, and manner parameters, will be listed down and their values will be measured with the help of Praat

for different speakers. The following chapter also gives a detailed analysis of each acoustic parameter and discusses their information potential. On the basis of these parameters, an attempt will be made to identify the speakers in the Suspect sample and to match them with the speakers in the Question sample. The accuracy with which these parameters identify the suspects will help us answer the importance of F1 and F2 in forensic speaker identification.

Chapter 4 Analysis

This chapter includes the auditory and acoustic analysis of the voice samples acquired from the participants. The samples were analysed on the basis of auditory parameters set by CFSL, by another fellow Scholar, Miss Stuti Bhagat, who after marking the characteristics of every participant, jumbled the data altogether. This was done to ensure that no further biases were involved in the given research. Since the researcher, herself collected the entire data set, she knew what was said by which speaker, So, jumbling of the data helped her avoid these factors.

After auditory analysis, a match set for each participant was created, which involved one question sample and one suspect sample. It was hypothesized that the particular SS belongs to the respective QS.

Acoustic Analysis was conducted to check the accuracy rate of auditory analysis and it also helped making the data more scientifically presentable.

4.1 Pilot Study

A pilot study was conducted on four people, two from each variety; one male and one female. Participants were asked to translated words from Hindi basic word list given to them, to Marwari. Each participant was supposed to translate the word in Marwari and then utter the translation three times. Out of these words, thirty-five words from each variety was chosen for further enquiry. Another set of vowel sounds were extracted from the same participants, from the conversational manner. These selections were made on the basis of the position of vowels. In every word, the vowel had to occupy the medial position where, it is both followed and preceded by a stop consonant. An auditory and acoustical analysis was conducted on the seventy words from the basic word list and the vowels extracted from the random conversations. As mentioned earlier, the first set of data, which is retrieved in a controlled environment, where the investigator has the control over all the variables, is called the suspect sample and the second set of data which is context dependent and cannot be controlled by the investigator is called question sample. Auditory analysis, which was conducted on the basis of chart given by **Central Forensic Science Laboratory** (CFSL), showed that the Brahmin variety has more nasalized and rounded vowels whereas the no nasalization was visible in Bishnoi variety. The Acoustical analysis showed that the in Both Brahmin and Bishnoi Variety the F2 values for each vowel from suspect sample showed the minimal distinction to the mean F2 value from the question sample. This

consistency was not visible in the other formants. A hypothesis was created on the basis of this enquiry. Which is given below;

"The values of F2 and F2-F1 determine the position of vowels in the vocal cavity. Changing this position consciously is very difficult, which means that F2 and F2-F1 should be unchanging for every individual. Considering the constancy of these measures (negligible change which is statistically non-existent), improvement in the accuracy of speaker identification is possible by checking for these. By looking at the acoustic analysis of speech data of two distinct ethnic groups of Marwari speakers, we will attempt to justify the hypothesis."

The hypothesis is going be tested in the present study, which as mentioned earlier is conducted on 40 Marwari speakers from two different varieties. The two varieties belong to different ethnic groups, Bishnoi and Brahmins.

4.2 General research Question

We have discussed this field and all the problems associated with it in great extent. So far, the discussion has pointed out that Voice pattern of every human is unique. There are genetically hardwired features which makes it a unique .These genetically hardwired features have major impact on our speech production. No matter what our condition is, changing these features is not possible. When a vowel is produced there are three components which are responsible for its form; height, length and position. When we analyze a vowel acoustically, F1 represents the height of the vowel and F2 represents the position. The difference between F2 and F1 represents how back the vowel is. The current study will look deep into the vowels produced by Marwari speakers at different syllable positions and analyze the change in formant frequencies. There are many articulatory factors which can affect the production of a vowel. Nasalized vowels are one of them. These vowels along with their articulatory modifications we will see whether their formant frequencies have changed.The features like pitch, tone and accent can easily be modified but a person cannot change his or her articulator. These formant harmonics are the representation of the filters which are affecting voice productions. These formant frequencies should be unchangeable. This study will try to identify formant values for vowels and see if we change the pitch , tone these formants remains constant or not. Phone recordings will also be taken into account in order to check the variations in formant frequencies.

The relevant research questions for the proposed dissertation are :

7. How do the genetically hardwired features make the voice pattern of every human unique?
8. What aspects of F1 and F2 are helpful in identifying language specific or variety specific sections of an ethnic group?
9. How does F2-F1measure help in increasing the accuracy of identifying these ethnic groups?
10. How do parameters like amplitude, vowel duration and syllable duration affect F1 and F2 in case of the given ethnic groups?
11. Is the formant frequencies affected by the position of vowels (syllable positions)?
12. What is the role of fundamental frequency in increasing the accuracy of speaker identification?

Hypothesis

The values of F2 and F2-F1 determine the position of vowels in the vocal cavity. Changing this position consciously is very difficult, which means that F2 and F2-F1 should be unchanging for every individual. Considering the constancy of these measures (negligible change which is statistically non-existent), improvement in the accuracy of speaker identification is possible by checking for these. By looking at the acoustic analysis of speech data of two distinct ethnic groups of Marwari speakers, we will attempt to justify the hypothesis.

4.3 Analysis

This chapter is going to discuss the auditory and acoustic parameters, which were used for the following study. As mentioned earlier, the following study is comparison of two varieties of Marwari, with reference to their question samples and suspect samples. A question sample was acquired by the interview method and a suspect sample was acquired on the basis of questionnaire provided to the participants in a quite environment. The present study tries to find out the importance of the F2 in Forensic Speaker Identification, in order to do that, a comparative method was developed, where each suspect sample was compared to the entire question sample and the nearest possible match was deducted.

As mentioned by the guideline of Indian Supreme Court, an auditory analysis was conducted first and then it was followed by the acoustic analysis. For the purpose of auditory analysis, the parameters provided by the Central Forensic Science Laboratory (CFSL) were used. Even though these parameters do not focus on sociolinguistics cues of the speaker, in order to avoid going off track, the preliminary analysis showed the Brahmin variety had more rounded and nasalized vowels. The sociolinguistic cues are avoided by the investigators because it has been noticed that these cues, such as tone, accent etc. can be easily be modified. Even though they are articulatory features, a conscious modification is possible for them. For example, a Bishnoi can speak with high intonation, which is a prominent marker of Brahmin variety. So, exclusively depending on the auditory analysis for the purpose of variety distinction is not reliable. This makes the acoustic analysis important. The second half of this chapter is going to deal with that. Since, the main aim of this study is to find out the importance of F2 in Speaker Identification, there are few parameters, which will play an important role in the current study. To determine the importance of F2, first the acoustic space charts for all the suspect samples and question samples were created and compared. Then to determine the role of F2, the values of F2, F2-F1, F3-F2 were tabulated and compared with the question samples, which were found to be the nearest match to the question sample and the previous results were re-examined. A separate comparison of F0 was conducted to see the effect of F0 on F2.

4.3.1 Auditory Analysis

During the auditory analysis, all the known sample i.e. The suspect samples were listed carefully and remarks were made by the listener. Since the research knew all the suspects personally, these remarks were conducted by two other different linguists, in order to avoid any predetermined biases. These biases can affect the remarks on suspects, in a way that the suspect might be more talkative or outspoken but while giving the recording he or she became more conscious. This kind of situation might result to researcher writing his or her own remarks, rather than being true to the recording. This problem was because the analysis was conducted by other linguists.

The recordings were played for the researchers and they were asked to assign the auditory details given in the table for each participant. This analysis was conducted for both suspect sample and question sample.

The auditory analysis was divided into four tables. The first table represents the auditory analysis of known Brahmin speakers. The second table represents the Auditory Analysis of known Bishnoi Speakers. Both of these tables contain data from twenty speakers from each variety. The data is divided into ten categories, the sex of the speaker, Speaking Mode, Stylistic Feature, Respiratory Form, Pitch Level, Striking Features of Voice, Fluency, Understandability, Loudness, Speech Rate. The table is arranged in such a way that, the first ten speakers are male and the other ten speakers are females, for each variety.

The next two tables contain the question samples obtained by random conversations from each speaker. The third table, has all the question samples for the male participants, the forth table has the auditory analysis of question samples of all the female speakers.

The parameters designed by the CFSL, gives an extensive overview of auditory features of the speakers.

S.No.	PARAMETERS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.	Sex	M	M	M	M	M	M	M	M	M	M	F	F	F	F	F	F	F	F	F	F
2.	Speaking Mode Disguised Normal	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
3.	Stylistic Feature Simple Polite Emotional Expressive Ironical	SIMPLE	EXPRESSIVE	EXPRESSIVE	POLITE	EXPRESSIVE	EXPRESSIVE	SIMPLE	IRONICAL	POLITE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	SIMPLE	POLITE	SIMPLE	SIMPLE	EXPRESSIVE	POLITE	SIMPLE	SIMPLE
4.	Respiratory Form Nasal Oral	ORAL	NASAL	NASAL	NASAL	ORAL	ORAL	ORAL	NASAL	ORAL	NASAL	ORAL	NASAL	NASAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL
5.	Pitch Level High Normal Low	HIGH	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	HIGH	HIGH	HIGH	HIGH	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
6.	Striking Features of Voice Coarse Hoarse Creak Pressed voice Normal voice	NORMAL	CREAK	CREAK	CREAK	NORMAL	NORMAL	HOARSE	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	PRESSED	NORMAL	NORMAL
7.	Fluency Hasty Very fluent Normal fluent Sluggish Stopping	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL	NORMAL	HASTY	HASTY	FLUENT	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL	FLUENT	FLUENT	NORMAL	NORMAL
8.	Understandability Easily Hard Hardly	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY

9.	Loudness Very loud Loud Medium Soft	VERY LOUD	LOUD	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOUD	LOUD	MEDIUM	MEDIUM	VERYLOUD	MEDIUM	MEDIUM	MEDIUM	LOUD	LOUD	MEDIUM	MEDIUM	MEDIUM	MEDIUM
1zz z0.	Speech Rate Very fast Fast Medium Slow Very Slow	MEDIUM	MEDIUM`	MEDIUM	FAST	FAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM	FAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM

Table 4.1 : Auditory Analysis of Known Brahmin Speakers (Brahmin Suspect Samples)

Observations:

1. The most important feature in this variety is that, many speakers had a nasalized voice. This feature is prominent in many Brahmin variety across the Indo-Aryan language families.
2. The loudness feature is medium for most of the speakers. Which is going to be an important distinction between Bishnoi and Brahmin variety.

S. No.	PARAMETERS	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1.	Sex	M	M	M	M	M	M	M	M	M	M	F	F	F	F	F	F	F	F	F	F
2.	Speaking Mode Disguised Normal	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
3.	Stylistic Feature Simple Polite Emotional Expressive Ironical	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	SIMPLE	SIMPLE	EXPRESSIVE	POLITE	EXPRESSIVE	SIMPLE	IRONICAL	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	SIMPLE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE
4.	Respiratory Form Nasal Oral	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	NASAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL
5.	Pitch Level High Normal Low	HIGH	HIGH	HIGH	HIGH	HIGH	NORMAL	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	NORMAL	NORMAL	HIGH	NORMAL	HIGH
6.	Striking Features of Voice Coarse Hoarse Creak Pressed voice Normal voice	HOARSE	HOARSE	NORMAL	PRESSED	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	PRESSED	NORMAL	PRESSED
7.	Fluency Hasty Very fluent Normal fluent Sluggish Stopping	HASTY	HASTY	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	FLUENT	FLUENT	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL
8.	Understandability Easily Hard Hardly	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY

9.	Loudness Very loud Loud Medium Soft	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	MEDIUM	MEDIUM	VERYLOUD	LOUD	LOUD	LOUD	LOUD	LOUD	LOUD	LOUD	MEDIUM	MEDIUM
10.	Speech Rate Very fast Fast Medium Slow Very Slow	VERY FAST	VERY FAST	MEDIUM	FAST	FAST	MEDIUM	VERY FAST	VERY FAST	MEDIUM	FAST	VERY FAST	VERY FAST	VERY FAST	VERY FAST	FAST	FAST	FAST	FAST	FAST	FAST

Table 4.2 : Auditory Analysis of known Bishnoi Speakers (Suspect Samples)

Observations:

1. There is only one nasalized voice identified by the listener for this variety.
2. There are only two voices which is identified with medium tempo of loudness. The Bishnoi speakers tend to sound very loud in recorded voice.
3. The Speech rate is fast or very fast for Bishnoi speakers, which was normal for the Brahmin speakers.

S. No .	PARAMETERS	3	10	1	6	9	2	8	5	7	4	22	26	27	23	21	30	29	25	28	24
1.	Sex	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
2.	Speaking Mode Disguised Normal	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
3.	Stylistic Feature Simple Polite Emotional Expressive Ironical	SIMPLE	EXPRESSIVE	EXPRESSIVE	POLITE	EXPRESSIVE	EXPRESSIVE	SIMPLE	IRONICAL	POLITE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	SIMPLE	SIMPLE	EXPRESSIVE	POLITE	EXPRESSIVE	SIMPLE	IRONICAL
4.	Respiratory Form Nasal Oral	ORAL	NASAL	NASAL	NASAL	ORAL	ORAL	ORAL	NASAL	ORAL	NASAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL
5.	Pitch Level High Normal Low	HIGH	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	NORMAL	HIGH	HIGH	HIGH	HIGH
6.	Striking Features of Voice Coarse Hoarse Creak Pressed voice Normal voice	NORMAL	CREAK	CREAK	CREAK	NORMAL	NORMAL	HOARSE	NORMAL	NORMAL	NORMAL	HOARSE	HOARSE	NORMAL	PRESSED	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
7.	Fluency Hasty Very fluent Normal fluent Sluggish Stopping	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL	NORMAL	HASTY	HASTY	FLUENT	HASTY	HASTY	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
8.	Understandability Easily Hard Hardly	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY

9.	Loudness Very loud Loud Medium Soft	VERY LOUD	LOUD	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOUD	LOUD	MEDIUM	MEDIUM	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	VERY LOUD	MEDIUM	MEDIUM
10.	Speech Rate Very fast Fast Medium Slow Very Slow	MEDIUM	MEDIUM`	MEDIUM	FAST	FAST	MEDIUM	MEDIUM	MEDIUM	MEDIUM	FAST	VERY FAST	VERY FAST	MEDIUM	FAST	FAST	MEDIUM	VERY FAST	VERY FAST	MEDIUM	FAST

Table 4.3 : Auditory Analysis of 20 Unknown Male Speakers (Question Samples)

Observations:

1. Speaker SS 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 belongs to the Brahmin variety. Their closest match identified in QS by the linguist are, 3, 10, 1, 6, 9, 2 ,8, 5, 7 and 4 respectively.
2. Speaker SS 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30 belongs to the Bishnoi Variety. Their closes match identified in QS are, 22, 26, 27, 23, 21, 30, 29,25, 28, and 24.
3. Just like the SS of Brahmin speakers, QS also showed highly nasalized voice. And similarly, just like SS of Bishnoi speakers, QS were identified as very loud and fast by the researcher.
4. There were some speaker specific features, like the speaker 3, 4, 5 had a creaky voice for SS samples and their counter parts, had the same features in their.

S. No.	PARAMETERS	12	14	17	16	11	13	15	18	19	20	33	35	40	37	39	31	38	32	36	34
1.	Sex	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
2.	Speaking Mode Disguised Normal	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
3.	Stylistic Feature Simple Polite Emotional Expressive Ironical	EXPRESSIVE	EXPRESSIVE	SIMPLE	POLITE	SIMPLE	SIMPLE	EXPRESSIVE	POLITE	SIMPLE	SIMPLE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	SIMPLE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE	EXPRESSIVE
4.	Respiratory Form Nasal Oral	ORAL	NASAL	NASAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	NASAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL	ORAL
5.	Pitch Level High Normal Low	HIGH	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	HIGH	HIGH	HIGH	HIGH	HIGH	NORMAL	NORMAL	HIGH	NORMAL	HIGH
6.	Striking Features of Voice Coarse Hoarse Creak Pressed voice Normal voice	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	PRESSED	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	PRESSED	NORMAL	PRESSED
7.	Fluency Hasty Very fluent Normal fluent Sluggish Stopping	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL	FLUENT	FLUENT	NORMAL	NORMAL	FLUENT	FLUENT	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	FLUENT	NORMAL	NORMAL
8.	Understandability Easily Hard Hardly	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY	EASILY

9.	Loudness Very loud Loud Medium Soft	VERYLOUD	MEDIUM	MEDIUM	MEDIUM	LOUD	LOUD	MEDIUM	MEDIUM	MEDIUM	MEDIUM	VERYLOUD	LOUD	LOUD	LOUD	LOUD	LOUD	LOUD	LOUD	MEDIUM	MEDIUM
10.	Speech Rate Very fast Fast Medium Slow Very Slow	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	VERY FAST	VERY FAST	VERY FAST	VERY FAST	FAST	FAST	FAST	FAST	FAST	FAST

Table 4.4 : Auditory Analysis of 20 Unknown Female Speakers (Question Samples)

Observations:

1. Brahmin female speakers, unlike male speaker showed a fewer number of nsalaized voice. Two to be exact.
2. Unlike male Bishnoi speaker, female speaker's voice was identified as loud. But it is still one tempo higher than Brahmin females.

Discussion

1. The data was analyzed in such a way that, speaker, 1 to 10 from suspect samples were Brahmin males, and speaker 11 to 20 twenty were Brahmin Females. Similarly, speaker 21 to 30 were Bishnoi males and 31 to 40 were Bishnoi females.
2. The primary analysis done by the fellow linguist had good results, she almost matched every SS to its respective QS. But there were some problems. For example, a lot of voices had similar features for more than two of them. An individual assessment can give a plot to start our research but concluding 100 percent accurate result is not possible with auditory analysis. Speaker 11 and 12 from Suspect Sample and 14 and 17 from Question sample had only one auditory difference marked between them. The researcher marked the number 11/14 as expressive, which is a subjective feature. So, a researcher can never solely depend on the auditory analysis of any voice sample.
3. The 'very loud' or 'loud' feature was very dominating in Bishnoi variety. Which is helpful in differentiating between two varieties. But, marking individual speaker's voices on the basis of that is very difficult. Some additional information is required.
4. Auditory analysis helped us differentiating the two varieties, and their voices separately. It also helped identifying the usable and unusable sounds from the entire set of recorded data. Which means that, not all sounds can be taken further for forensic enquiry, some sounds have extra background noise, so are extremely slow, and some might be so nasalized that extracting vowel out of them can be next to impossible. Auditory helped differentiation those unwanted elements from other. There are individual characteristics which can be marked by auditory analysis, but conducting a full forensic study on it in not wise. Auditory analysis should be the first step of many steps of Forensic Speaker Identification. Which should be followed by the pitch analysis of a person.

Auditory analysis helped creating a new hypothesis which was based on the data acquired through auditory investigation. The matches found through the auditory analysis is going by treated as the preliminary data and would be further analyzed acoustically to see the accuracy of the results.

The next section is going to talk about the pitch or F0 of the suspects. The researcher has tried matching two separate F0, one from SS and one from QS, on the basis of their mean F0, their speaker specific F0 and its standard deviation.

SUSPECT SAMPLE 1	168.5980458
SUSPECT SAMPLE 2	153.5932177
SUSPECT SAMPLE 3	107.2371207
SUSPECT SAMPLE 4	107.1278928
SUSPECT SAMPLE 5	148.8725529
SUSPECT SAMPLE 6	191.3015512
SUSPECT SAMPLE 7	137.1995728
SUSPECT SAMPLE 8	163.245018
SUSPECT SAMPLE 9	177.1379419
SUSPECT SAMPLE 10	170.1728775
SUSPECT SAMPLE 11	166.4968299
SUSPECT SAMPLE 12	231.8832411
SUSPECT SAMPLE 13	215.1516555
SUSPECT SAMPLE 14	198.4419609
SUSPECT SAMPLE 15	165.3266804
SUSPECT SAMPLE 16	240.3425258
SUSPECT SAMPLE 17	234.6983841
SUSPECT SAMPLE 18	269.7167526
SUSPECT SAMPLE 19	274.9273508
SUSPECT SAMPLE 20	235.2649086

Table 4.5 Mean Pitch of Suspect Sample Brahmin Variety

SUSPECT SAMPLE 1	168.5980458
SUSPECT SAMPLE 2	153.5932177
SUSPECT SAMPLE 3	107.2371207
SUSPECT SAMPLE 4	107.1278928
SUSPECT SAMPLE 5	148.8725529
SUSPECT SAMPLE 6	191.3015512
SUSPECT SAMPLE 7	137.1995728
SUSPECT SAMPLE 8	163.245018
SUSPECT SAMPLE 9	177.1379419
SUSPECT SAMPLE 10	170.1728775
SUSPECT SAMPLE 11	166.4968299
SUSPECT SAMPLE 12	231.8832411
SUSPECT SAMPLE 13	215.1516555
SUSPECT SAMPLE 14	198.4419609
SUSPECT SAMPLE 15	165.3266804
SUSPECT SAMPLE 16	240.3425258
SUSPECT SAMPLE 17	234.6983841
SUSPECT SAMPLE 18	269.7167526
SUSPECT SAMPLE 19	274.9273508
SUSPECT SAMPLE 20	235.2649086

Table 4.6 Mean Pitch of Suspect Sample Bishnoi Variety

SUSPECT SAMPLE 1	168.5980458
SUSPECT SAMPLE 2	153.5932177
SUSPECT SAMPLE 3	107.2371207
SUSPECT SAMPLE 4	107.1278928
SUSPECT SAMPLE 5	148.8725529
SUSPECT SAMPLE 6	191.3015512
SUSPECT SAMPLE 7	137.1995728
SUSPECT SAMPLE 8	163.245018
SUSPECT SAMPLE 9	177.1379419
SUSPECT SAMPLE 10	170.1728775
SUSPECT SAMPLE 11	166.4968299
SUSPECT SAMPLE 12	231.8832411
SUSPECT SAMPLE 13	215.1516555
SUSPECT SAMPLE 14	198.4419609
SUSPECT SAMPLE 15	165.3266804
SUSPECT SAMPLE 16	240.3425258
SUSPECT SAMPLE 17	234.6983841
SUSPECT SAMPLE 18	269.7167526
SUSPECT SAMPLE 19	274.9273508
SUSPECT SAMPLE 20	235.2649086

Table 4.7 Mean Pitch of Question Sample Male Speakers

Table 4.8 Mean Pitch of Question Samples Female Speakers

The above tables are important to distinguish between male and female speakers. This observation helps the researcher in a way that, now the investigation will only precede between two male speakers or between two female samples.

4.3.2 Acoustic Analysis

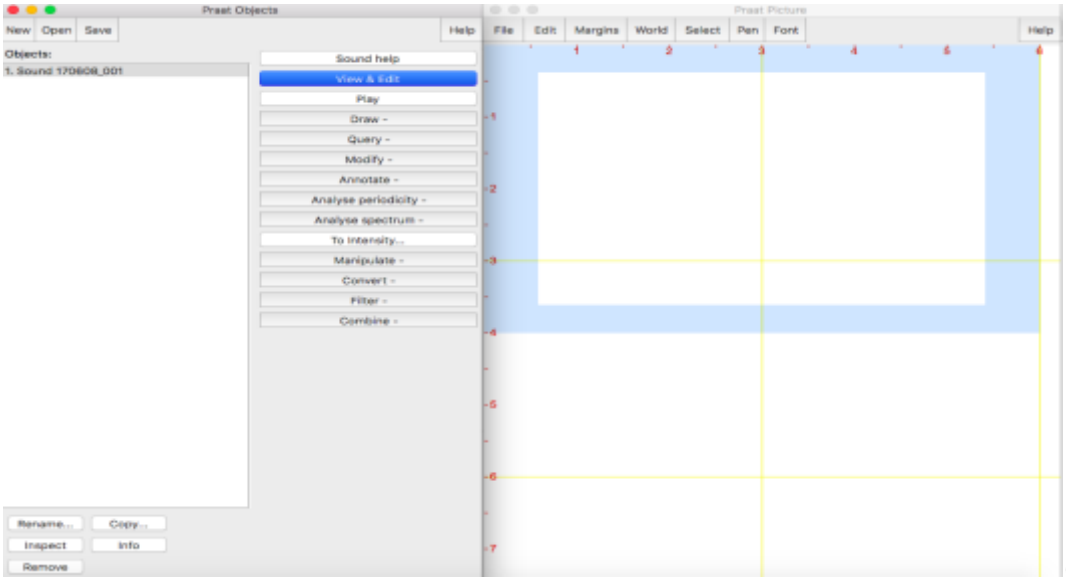
For acoustic analysis seven vowels were selected which were common for both the varieties. Every speaker had to utter five words of the given vowel, from the questionnaire provided by the researcher and the recording was made. The same seven vowels were also extracted from the same speakers, as question samples, out of their random conversation with the researcher. These question samples were extracted by another linguist in such a way that; the researcher did not know the identity of their speakers. To check the possibility of identifying unknown speakers from known speakers, these random question sample were compared with the suspect samples and then the accuracy rate was checked. The seven vowels which were selected for the purpose of following study are; five cardinal vowels, [i], [e],[u],[o] and [a] and two central vowels, [I], [ə]. two separate word lists were prepared for both varieties in order to achieve accurate results. These two varieties have lexical and morphemic differences for a lot words, and asking them to read out the same word list would result in a conscious and modified utterance. The two separate word lists were prepared to avoid these modifications. The Word lists are given in the table below,

Brahmin Variety	English	Bishnoi Variety	English
pəɖʰaɪ	To study	kiɽi	ant
kətʰɛ	Where	kitʰ	where
bətaɳo	To say	bitʰ	there
pəkgjo	To ripe	mɪndi	Terrace walll
bəɖɖo	Big	bɪdʒ	seeds
ʈaber	Kid	ətik	This much
bap	Father	tikʰi	spicy
mʌtʰo	Head	dʒiko	that
maco	Cot	biʃnoi	Bishnoi
kaglo	Crow	dʒisi	Like that
gitɳo	To eat	kɛɽ	Kind of seed
ʈikki	Bindi	kɛɽo	how
dʒiko	That	bɛɽo	That's how
dʒiti	That much	tʰɛtʰ	All the way
kitta	How much	retʰ	sand
tɪkʰo	Spicy	bəɖɖo	big
pɪtʰ	Back	bəɖʰarno	To cut
bɪl	Type of fruit	pəɖʰjora	educated
kʰɪcro	Porridge	pəʈekɳo	To drop
dɪgo	Tall	dʰɔ̃ver	Fog
pɛt	Tummy	ʈaber	Kid
pesa	Money	badəlvai	Clouds
kɛvo	To talk	mandʒo	cot
bɛn	That guy/ girl	kaglo	Crow
kɛs	Hair	bap	Father
cʰoɖɛ	To leave	bodo	Old
bʰogəl	Door knob	cʰoʈok	Small
ʈokri	Basket	ɖobʰa	Eyes
pothi	Book	moʈok	Fat / big
coti	Braid	kʰodaɳo	To dig
dukʰɛ	To pain	dudʰ	Milk
dudʰ	Milk	kud	To jump
lut	To steal	pʰul	Flower
tʰuk	spit	kuteɳo	To smash
pucaɳo	To ask	sutʰ	dress

Table 4.9 Word list

In order to analyse the voice samples, Praat was used. First, the recordings were opened in the Praat by using the command, "Read from File". This command listed all the voice

samples as Praat objects. The next step was, using the command " View and Edit". A picture of Praat window is given below,



e

Figure 4.1 Praat Window

The left half of the window was majorly used for the purpose of this study. This half represents the Praat object window, where we can read sound files, and analyse them. The right half of the window is called Praat object window. Spectrograms for the sound files can be drawn on this side of the software.

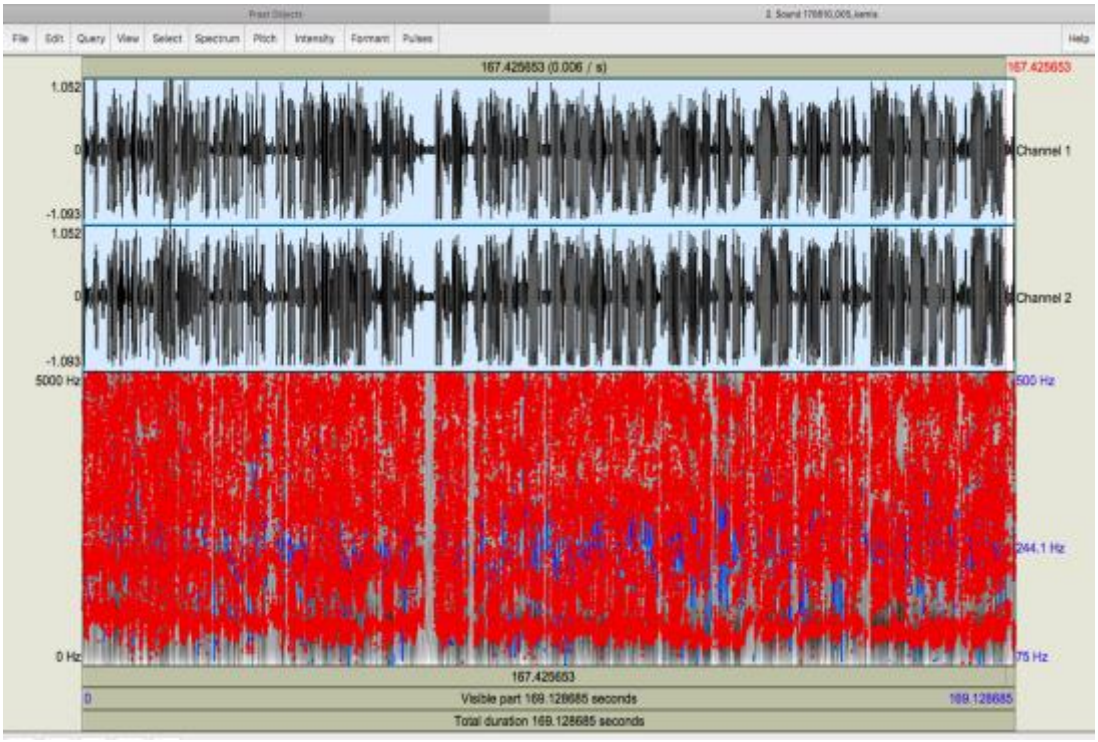


Figure 4.2 spectrogram of full conversation done with speaker 'Kamla'

The image above shows a spectrogram of complete voice sample, taken from a speaker called Kamla. There are three visible layers in this window. The first layer represents the entire conversation; each peak is a representation of a syllable. The second layer represents the same sound file along with the noises which were surrounding it. The first layer tries to reduce the noise and other problems as much as possible. The third layer contains and demonstrates the formants, pitch listing and other important features. The third half also represents the spectrogram of the sound wave.

In order to extract vowel, each word was sliced out of the wave files and then the word was repeated again and again in order to find out the starting and ending point of the vowel required. Then the vowel was segregated out of it and analysed. The required features like, Formant listings, pitch listing and spectrograms were segregated and saved.

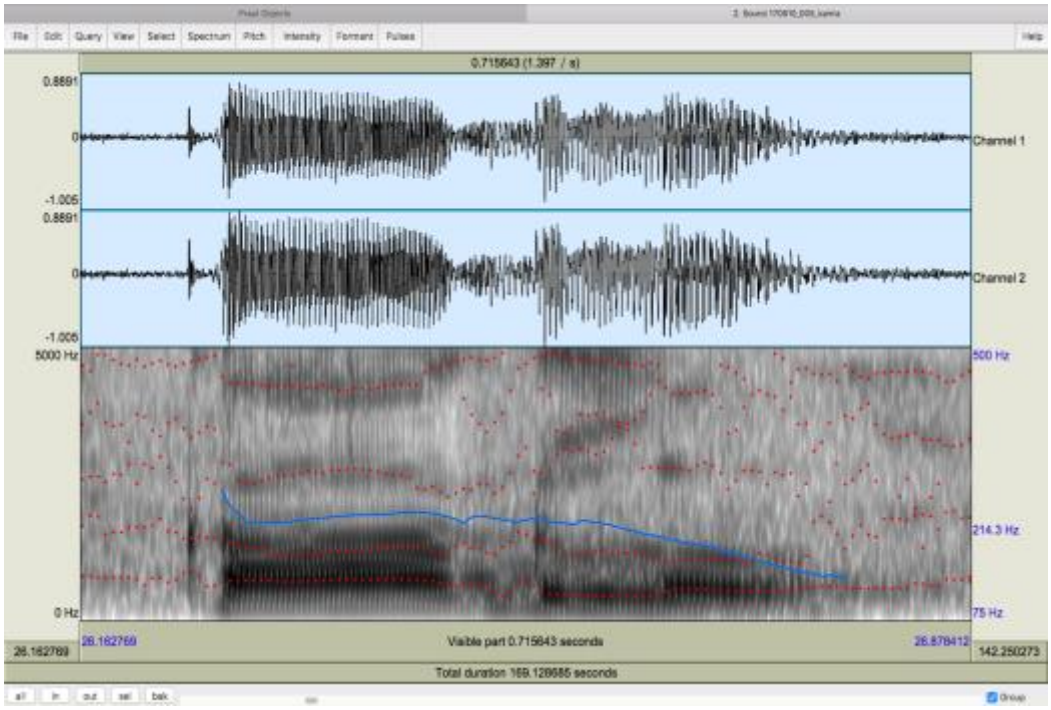


Figure 4.3 kamla/kaglo/ spectrogram

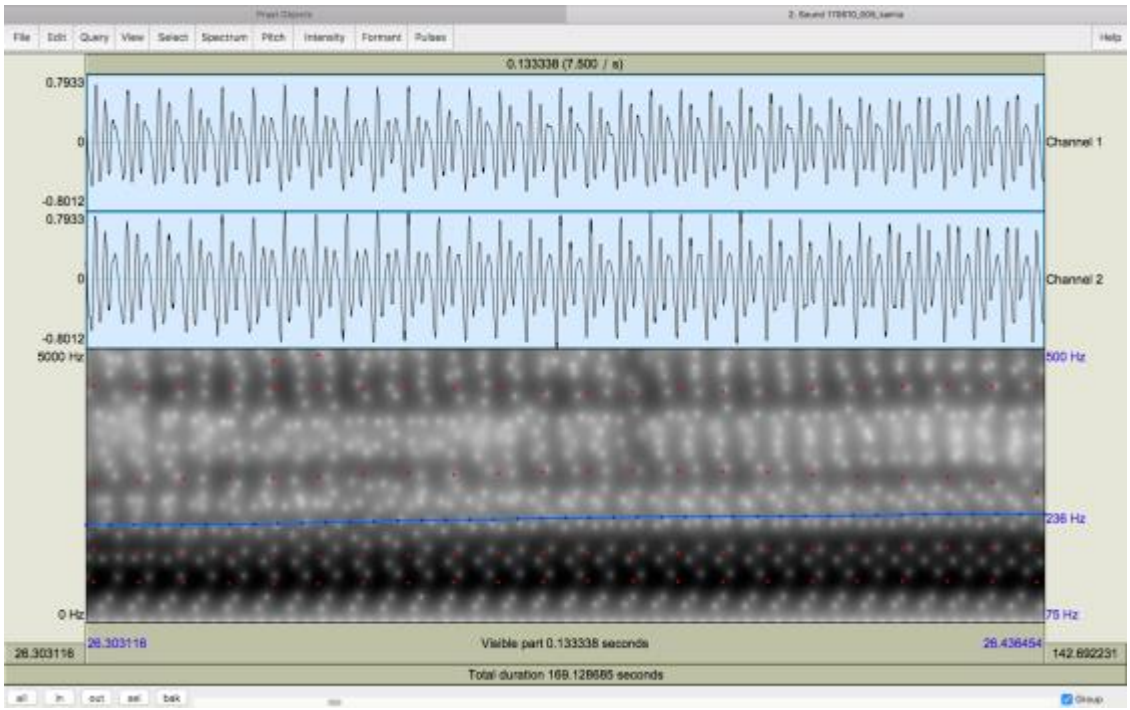


Figure 4.4 kamla/a/Kaglo/spectrogram

Figure 3 is the Praat picture of 'Kamla' uttering word /*kaglo*/ i.e. crow in Marwari. The Figure 4 is the /a/ vowel and its spectrogram extracted from the word /*kaglo*/ . Every sound was extracted the same way for the rest of the forty speakers. After all the vowels were the same way, from both question sample and suspect sample they were analysed

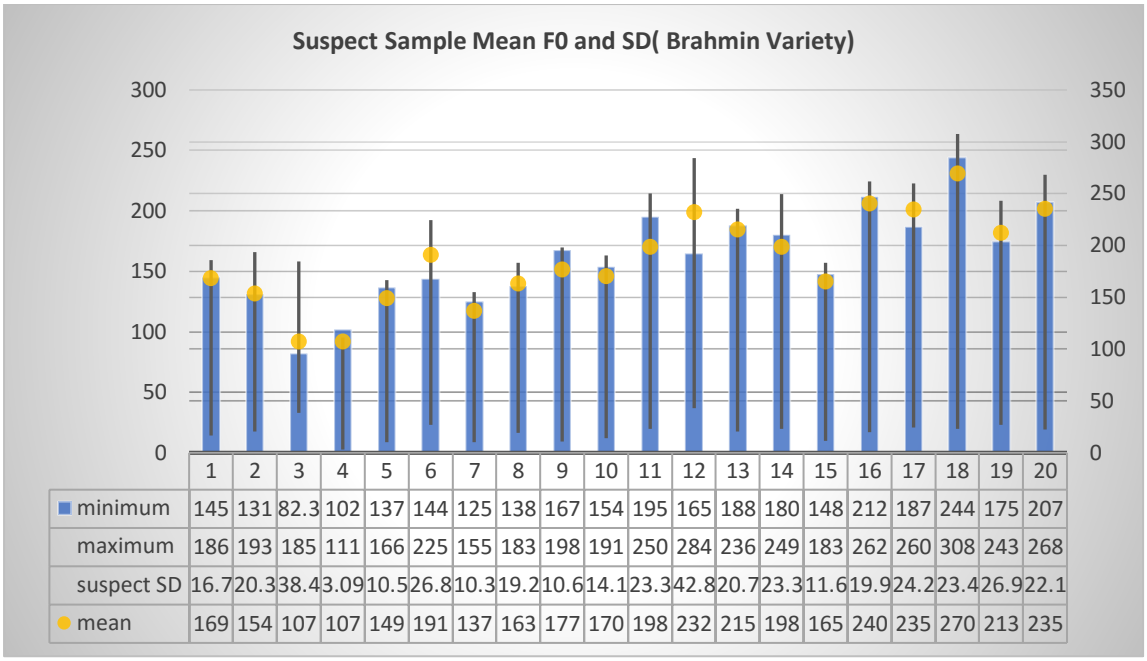
based on the parameters set by the researcher. The values for every parameter was extracted from Praat. The master excel sheet containing both Question Samples and Suspect samples is attached in the Appendix.

Once all the values were noted on MS Excel, they were analysed in order to match the suspect sample to their respective question samples. Four lists were created which contained, F3-F2, F2-F1, F2 and F1 values of every speaker. Two separate lists were also created to draw acoustic spaces for every speaker. These lists contain the negative F1 and negative F2-F1 which is required to form an acoustic space chart for any speaker. To narrow down the search each acoustic chart of the suspect sample was compared to the same charts for the question samples. The subjects, which showed the same or similar charts were grouped together. Their values from the later lists were then analysed. Each list was analysed one by one and matched with their relative subjects.

As mentioned in the auditory analysis, the suspect sample was divided into two lists, first contain the values from Brahmin variety and the later has the values from the Bishnoi variety. Each list is organized in such a way that the first ten speakers are male and the next ten speakers are females.

The parameters used to identify each subject is given below;

F0 (Pitch) : As discussed earlier F0 is a voice feature, which according to the previous studies carries the genetic information about the speakers. F0 represents the frequency at which the vocal cords start vibrating. Which depends on the length, shape and mass of vocal cord. Every speaker has his or his own unique dimensions of vocal cords, so the values of F0 can be the marker of a genetically endowed feature. For this the mean pitch of every speaker was measured and then the standard deviation for this was calculated. Standard deviation is calculated by the distance of each observation from the mean and then squared. The First parameter which was selected to match suspect sample with question sample is mean pitch and its standard deviation.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
minimum	145	131	82.3	102	137	144	125	138	167	154	195	165	188	180	148	212	187	244	175	207
maximum	186	193	185	111	166	225	155	183	198	191	250	284	236	249	183	262	260	308	243	268
suspect SD	16.7	20.3	38.4	3.09	10.5	26.8	10.3	19.2	10.6	14.1	23.3	42.8	20.7	23.3	11.6	19.9	24.2	23.4	26.9	22.1
mean	169	154	107	107	149	191	137	163	177	170	198	232	215	198	165	240	235	270	213	235

Observations:

The observations made by the above four charts are as Fellow;

1. In Figure 1 we can see that there is a difference between first ten speakers and the next ten speakers. This male and female distinction is visible with the fact that males are showing lower mean for F0 whereas the female speakers are showing the higher F).
2. The minimum F0 for speakers 1. 2. 5. 6, 8 and 10 is almost same. The SD is also similar for these speakers. Whereas speakers 12, 13, 14, 16, 17, 19 and 20 show the similar SD and minimum pitch. This was helpful in creating distinction between male and female speakers

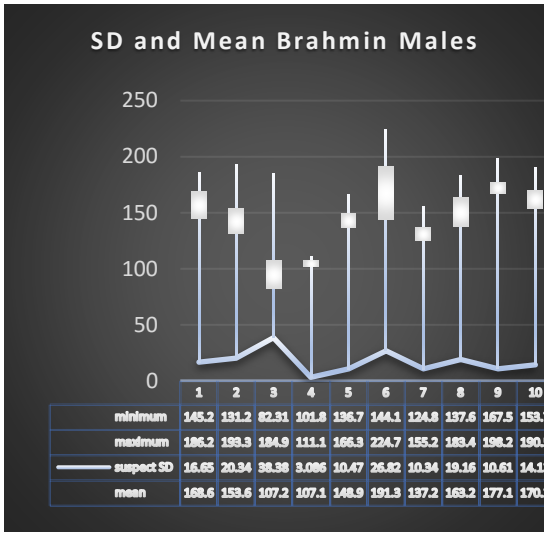


Chart 4.2 Standard deviation and Mean first Brahmin Males

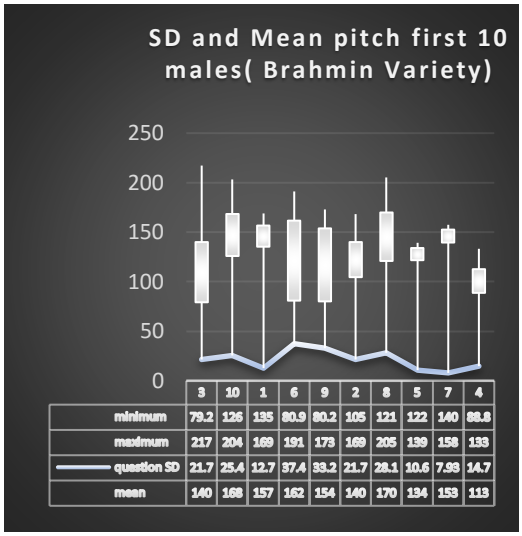


Chart 4.3 Standard Deviation and Mean QS 1-10

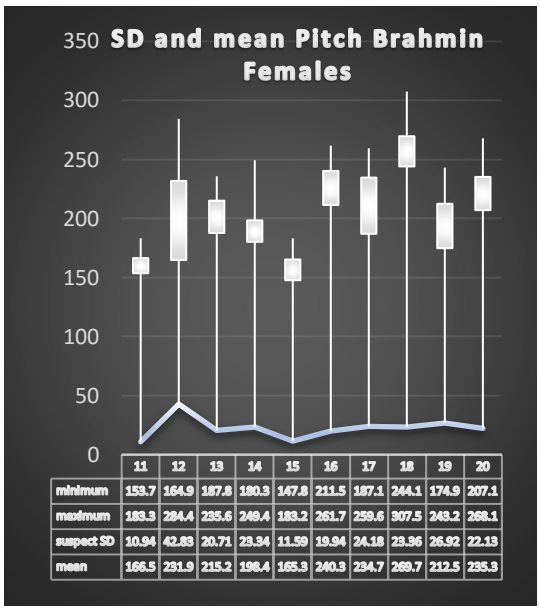


Chart 4.4 SD and Mean Pitch(Brahmin Female)

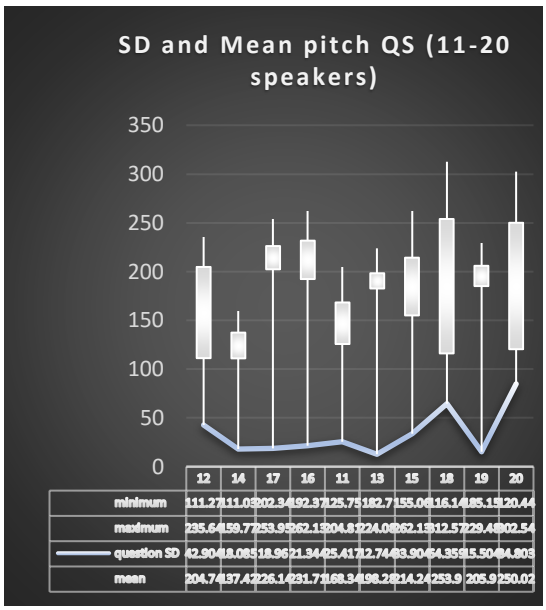
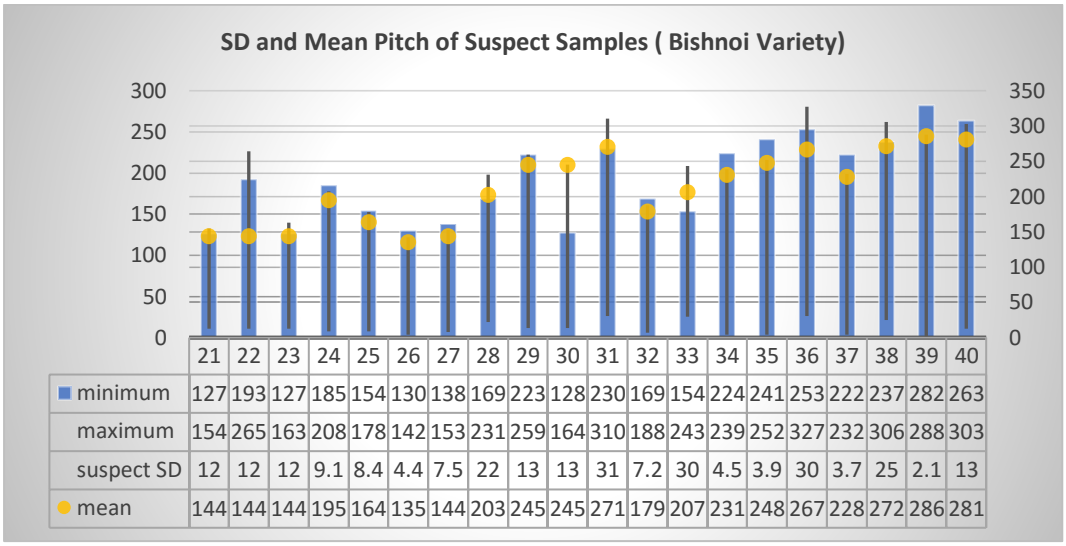


Chart 4.5 SD and Mean pitch QS (11-20 speakers)

Observations:

1. On the basis of this distinction two separate graphs were created for speaker 1 to 10 and 11 to 20
2. The F0 of Suspect sample 2 and Question sample 10 shows similar mean values and the standard deviation.

3. The F0 values of Suspect Samples 8, 9, 10 and Question Samples 5, 7, 4 have similar values for Standard deviation and mean pitch. Their minimum and maximum mean pitch values also match with each other.
4. The F0 values and SD of Suspect Sample 12, 13, 14, 15, 16, 17, 18 and 19 are showing the similar values to Question Sample 14, 17, 16, 11,13,15,18 and 19.
5. Suspect Sample 2 and Question Sample 10 has been placed on the similar positions because both of these values are not matching to any other speaker profile.
6. Suspect Sample 11 and 20 have similar SD and mean values to Question Sample 12 and 20 respectively. But both of these speakers are showing different values for minimum and maximum F0 with their respective Question Samples.



	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
minimum	127	193	127	185	154	130	138	169	223	128	230	169	154	224	241	253	222	237	282	263
maximum	154	265	163	208	178	142	153	231	259	164	310	188	243	239	252	327	232	306	288	303
suspect SD	12	12	12	9.1	8.4	4.4	7.5	22	13	13	31	7.2	30	4.5	3.9	30	3.7	25	2.1	13
mean	144	144	144	195	164	135	144	203	245	245	271	179	207	231	248	267	228	272	286	281

Chart 4.6 SD and Mean Of Suspect Samples (Bishnoi Speakers)

Observations:

The observations made by the above four charts are as Fellow;

1. In Figure 1 we can see that there is a difference between first ten speakers and the next ten speakers. This male and female distinction is visible with the fact that males are showing lower mean for F0 whereas the female speakers are showing the higher F).

2. The minimum F0 for speakers 21, 23, 25, 26, 27 and 30 is almost same. The SD is also similar for these speakers. Whereas speakers 31,34,35,36,37,38,39,and 40 show the similar SD and minimum pitch. This was helpful in creating distinction between male and female speakers

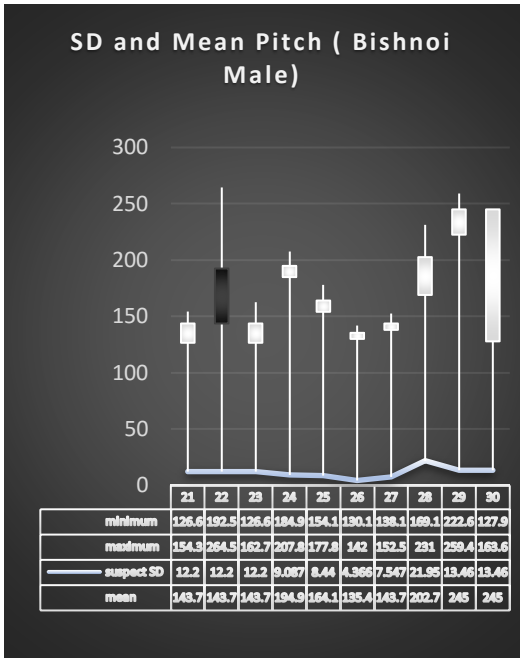


Chart 4.7 Standard deviation and Mean first Bishnoi Males

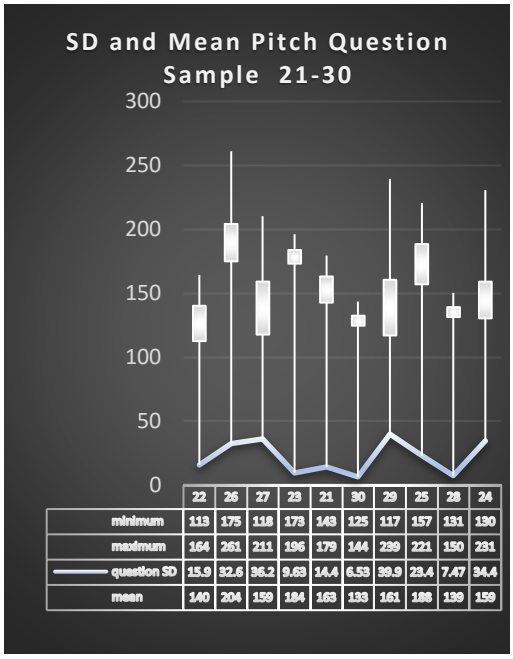


Chart 4.8 Standard Deviation and Mean QS 20-30

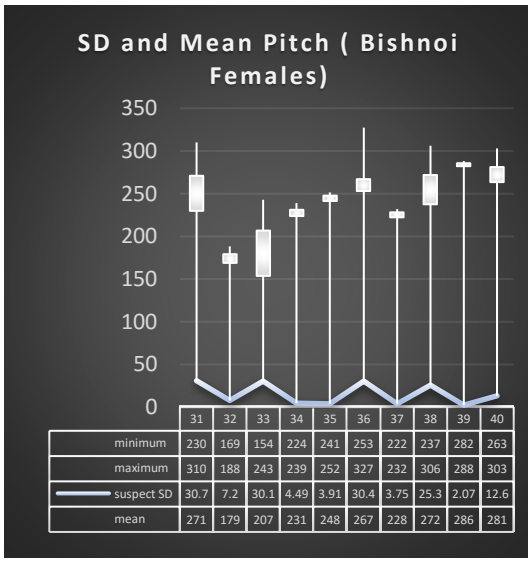


Chart 4.9 SD and Mean Pitch (Brahmin Female)

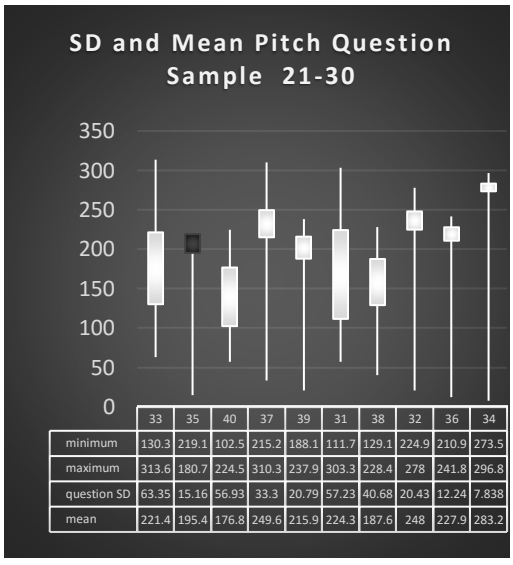


Chart 4.10 SD and Mean pitch QS (11-20 speakers)

Observations:

1. On the basis of this distinction two separate graphs were created for speaker 20 to 30 and 30 to 40
2. The F0 of Suspect sample 22 and Question sample 26 shows similar mean values and the standard deviation.
3. The F0 values of Suspect Sample 21, 23,24,25 and Question Sample 22, 27,23 and 21 have similar values for Standard deviation and mean pitch. Their minimum and maximum mean pitch values also match with each other.
4. The F0 values of Suspect Sample 32,33,34,35,36,37,38,39,40 and Question Sample 35,40,3739,31,38,32,36,34 have similar values for Standard deviation and mean pitch. But their F0 minimum and maximum gap is very high.
5. Speaker 31 and speaker 33 are put at the matching position because they are not matching to any other speaker's SD and mean.

Discussion:

Suspect Sample is retrieved in a controlled environment and Question Samples are retrieved from a, everyday conversations. Which makes it very difficult to analyse data. This can also develop the biases in any investigator. The F0 analysis gives an investigator a platform to divided these samples acoustically. The similar values of mean F0 shows that sound belongs to the same person. F0 analyses serves as the founding factor for any forensic query. The results of this F0 analysis has also once again proven the previous studies, F0 is one of the most important governing factor while doing any Forensic Phonetic enquiry. From the given study following conclusions can be made;

1. The average means of both varieties, Brahmin and Bishnoi were 152.44858 - 220.17699, 163.0643- 246.84121 for male and female respectively.
2. Bishnoi Speakers showed a slightly higher mean values than that of Brahmin Speakers
3. The minimum to maximum range for F0 was higher for Bishnois than that of Brahmins.

4. Only mean F0 or Standard deviation separately failed to give any clue about the speaker identification. It was the combination of both along with the minimum and maximum pitch values, which provided the conclusive results.

This way of comparing Suspect Sample and Question samples is giving positive results. But there are some speakers who didn't provide the expected outcomes. The reason can be both, bad recording or the sound belongs to different speakers. But to achieve irrefutable results we need to look at the other factors as well. The next section is going look at the acoustic space of every participants along with the question samples matched individually based on the previous enquires.

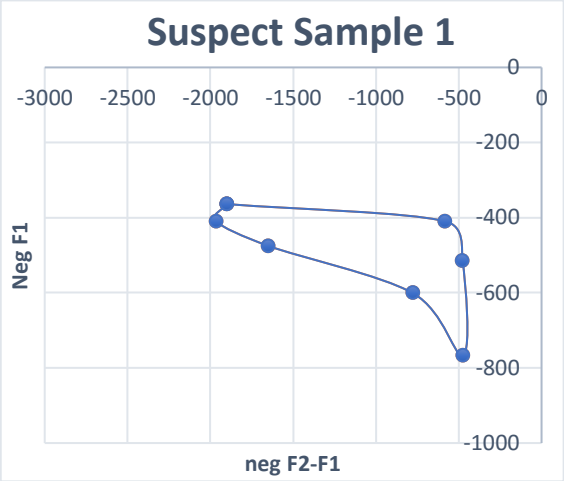


Chart 4.11 : Acoustic Space of Speaker 1

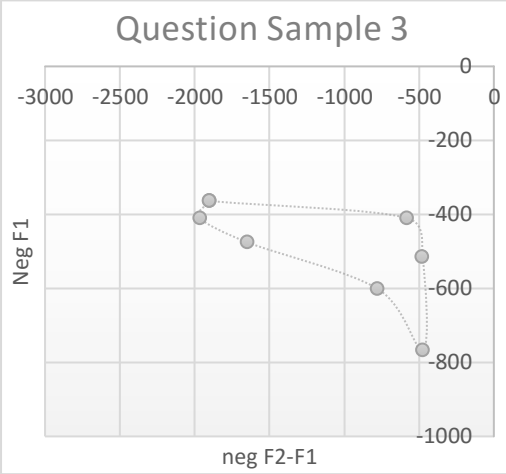


Chart 4.12 : Acoustic Space of Question Sample 3

The Acoustic Space of SS1 and QS is almost the same.

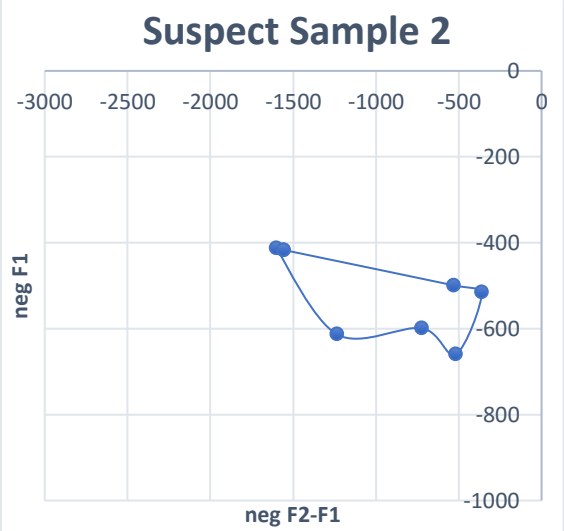


Chart 4.13 : Acoustic Space of Speaker 2

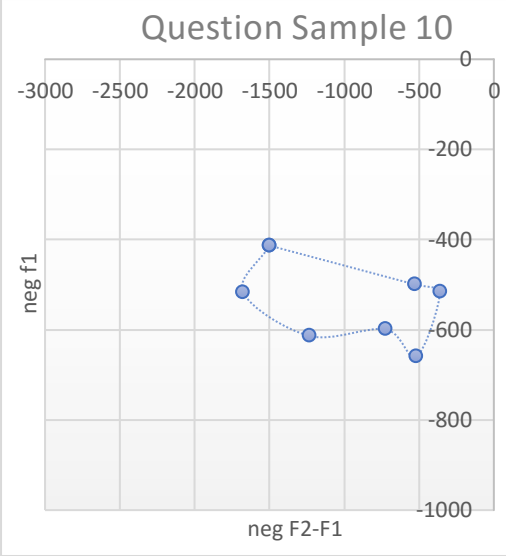


Chart 4.14: Acoustic Space of Question Sample 10

The Acoustic Space of SS2 and QS10 is almost the same, with some variation between the cardinal /i/and centralized/I/

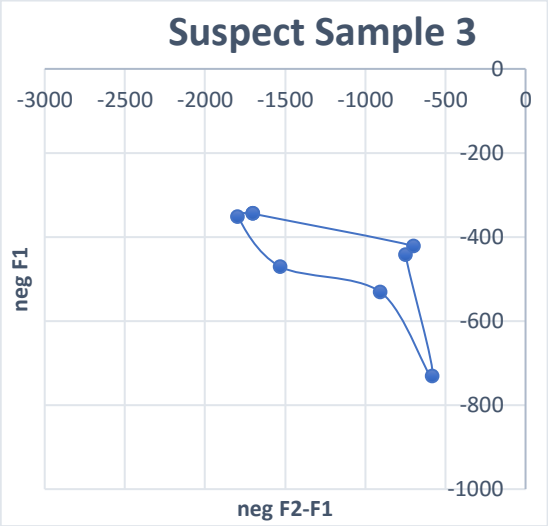


Chart 4.15 : Acoustic Space of Speaker 3

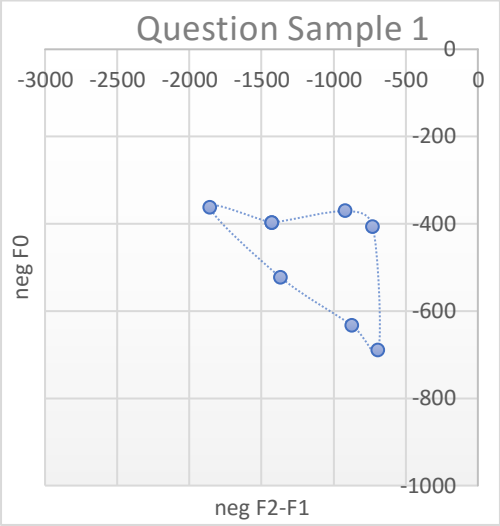


Chart 4.16 : Acoustic Space of Question Sample 1

The Acoustic Space of SS3 and QS1 is almost the same. The values of vowel /o/and /u/ in suspect sample shows a little variation, which is negligible.

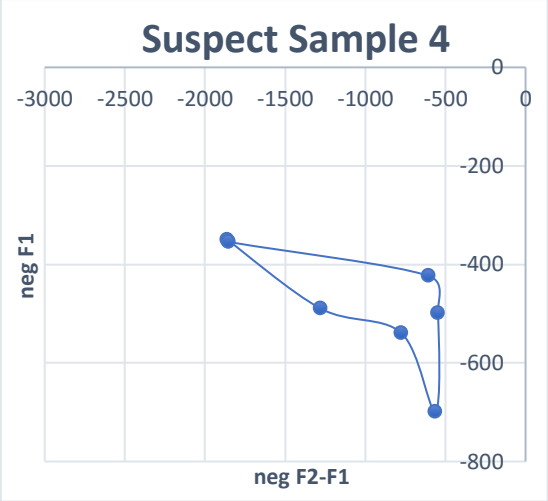


Chart 4.17: Acoustic Space of Speaker 4

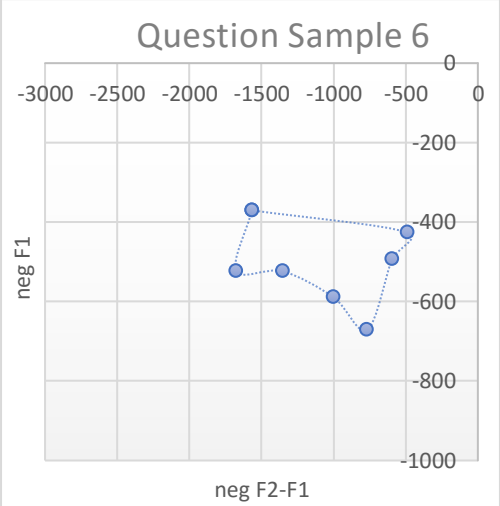


Chart 4.18: Acoustic Space of Question Sample 6

The Acoustic Space of SS4 and QS6 does not look the same because their /i/ and /I/ values have some differences.

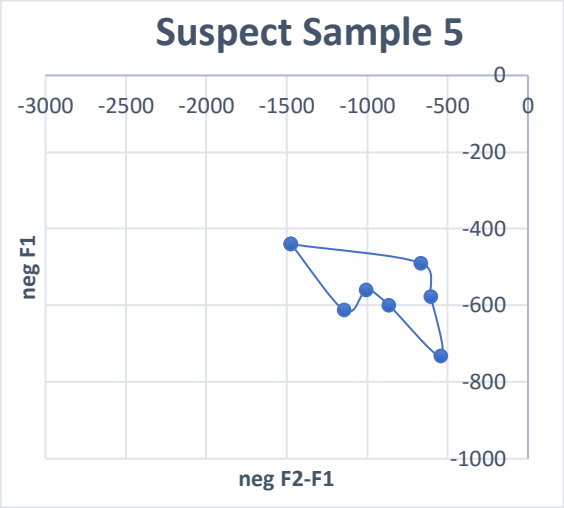


Chart 4.19 : Acoustic Space of Speaker 5

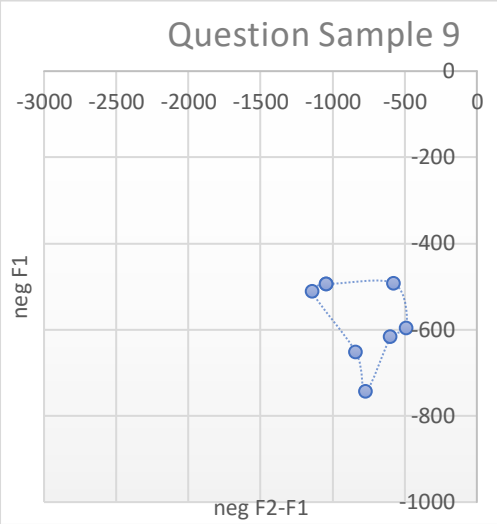


Chart 4.20 : Acoustic Space of Question Sample 9

The Acoustic Space of SS5 and QS9 is almost the same.

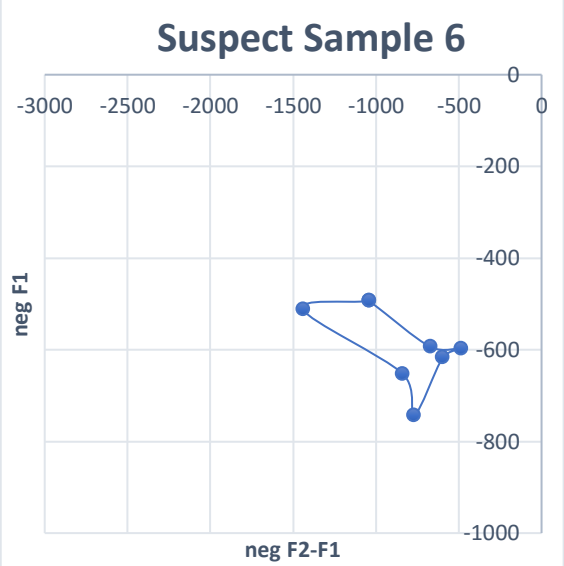


Chart 4.21 : Acoustic Space of Speaker 6

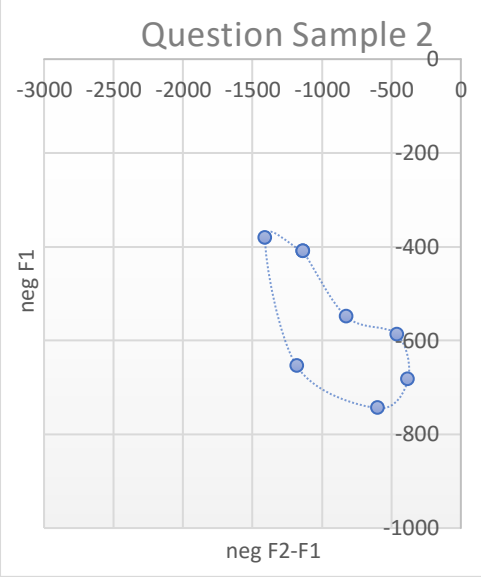


Chart 4.22 : Acoustic Space of Question Sample 2

The Acoustic Space of SS6 and QS2 are the nearest match to each other.

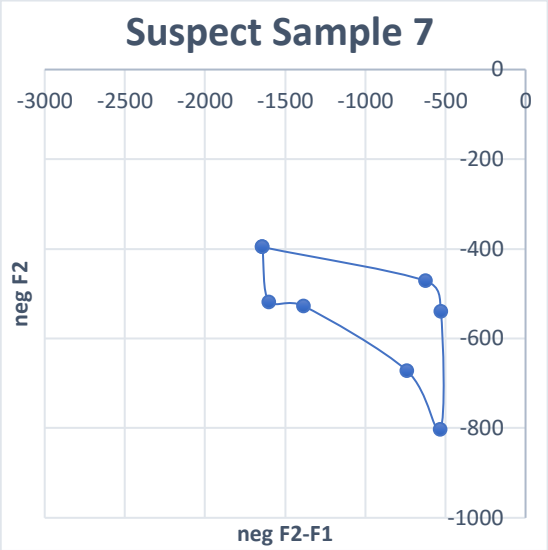


Chart 4.22: Acoustic Space of Speaker 7

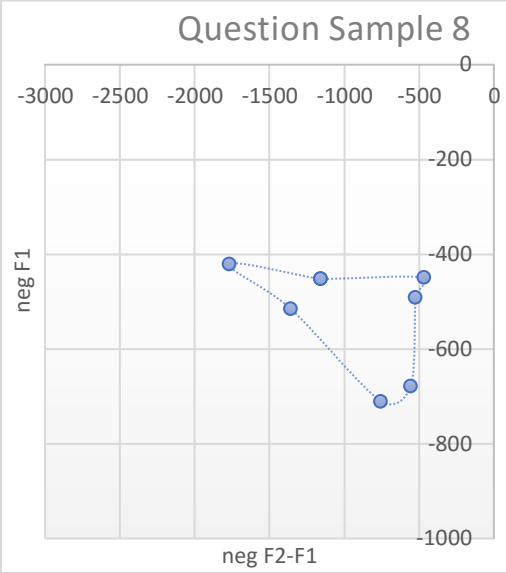


Chart 4.23: Acoustic Space of Question Sample 8

The Acoustic Space of SS7 and QS8 is almost the same. The position of /i/ is little different for both of them.

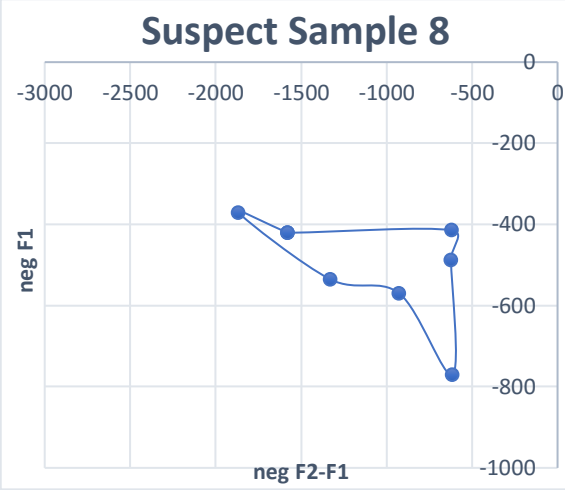


Chart 4.24 : Acoustic Space of Speaker 8

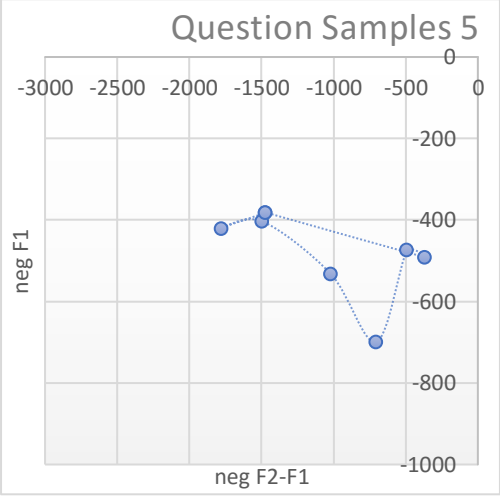


Chart 4.25 : Acoustic Space of Question Sample 9

The Acoustic Space of SS8 and QS9 is almost the same.

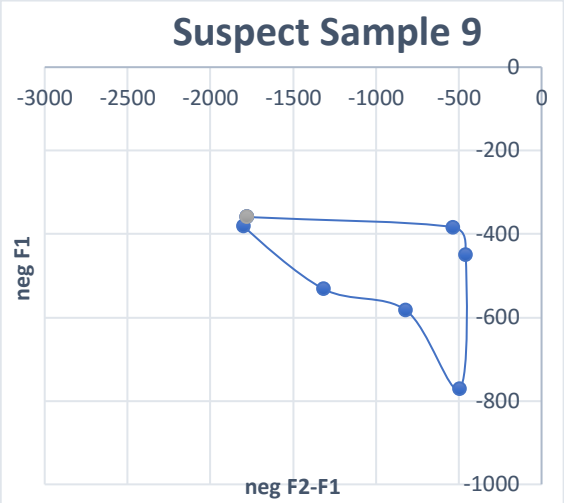


Chart 4.26 : Acoustic Space of Speaker 9

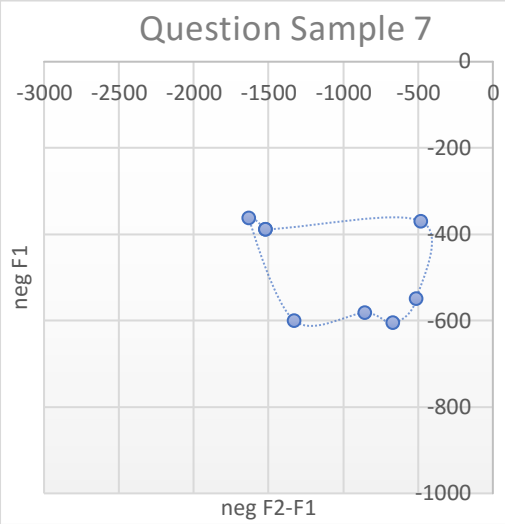


Chart 4.27: Acoustic Space of Question Sample 7

The Acoustic Space of SS9 and QS7 is almost the same. The /a/ vowel is little lower for QS7.

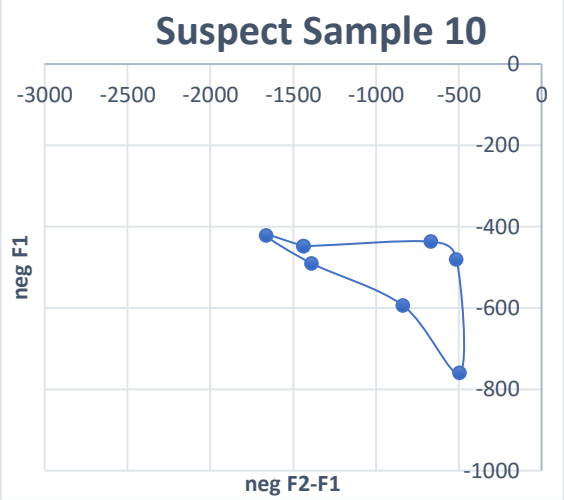


Chart 4.28 : Acoustic Space of Speaker 10

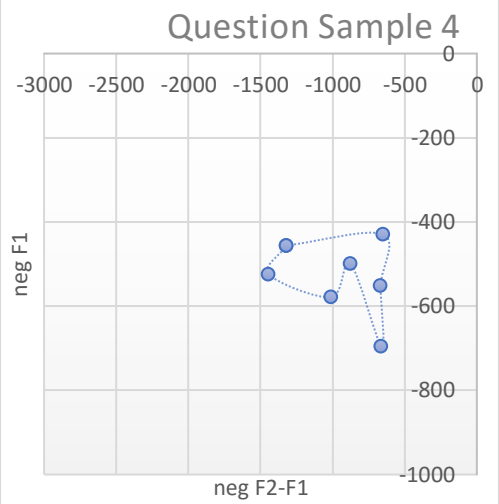


Chart 4.29 : Acoustic Space of Question Sample 4

The Acoustic Space of SS10 and QS4 is almost the same. The /i/ is at different position for both of them.

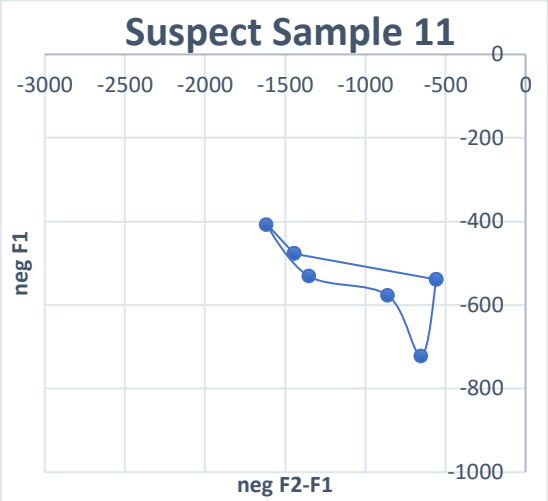


Chart 4.30 : Acoustic Space of Speaker 11

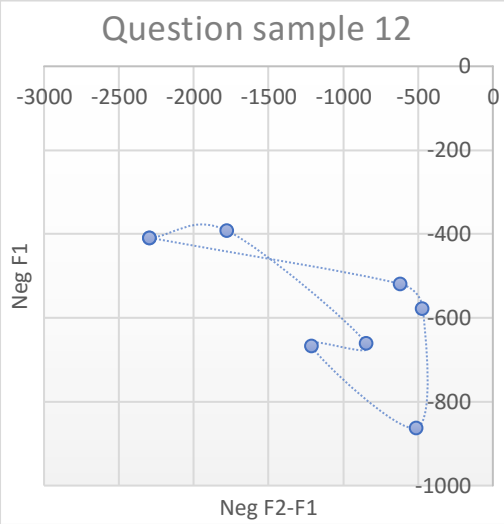


Chart 4.31 : Acoustic Space of Question Sample 12

The Acoustic Space of SS11 and QS12 is almost the same. Even though they look different, while looking closely at the values we can see they have similar characteristics.

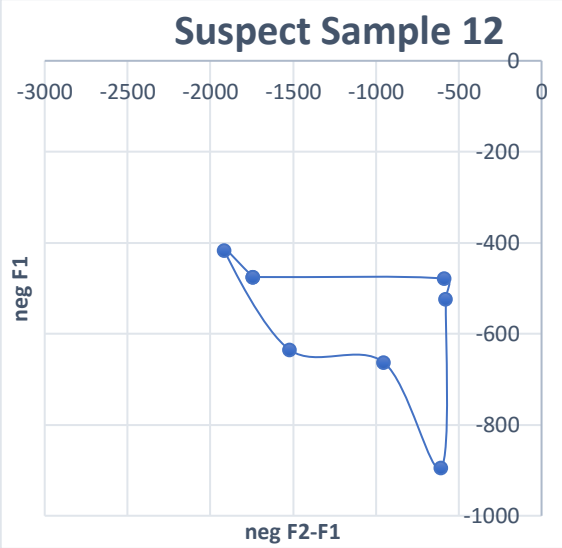


Chart 4.32 : Acoustic Space of Speaker 12

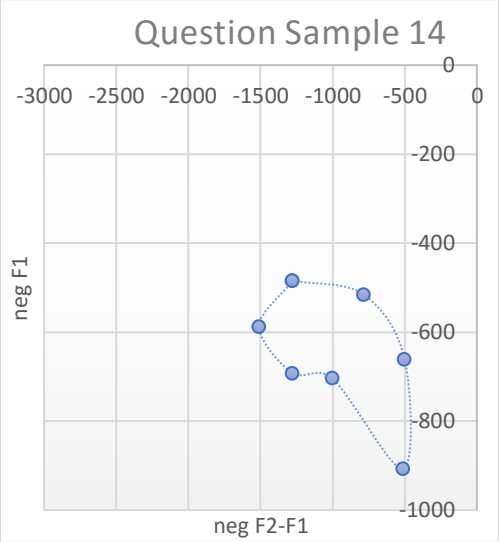


Chart 4.33: Acoustic Space of Question Sample 14

The Acoustic Space of SS12 and QS14 is almost the same. The /i/ vowel is again different for these two samples

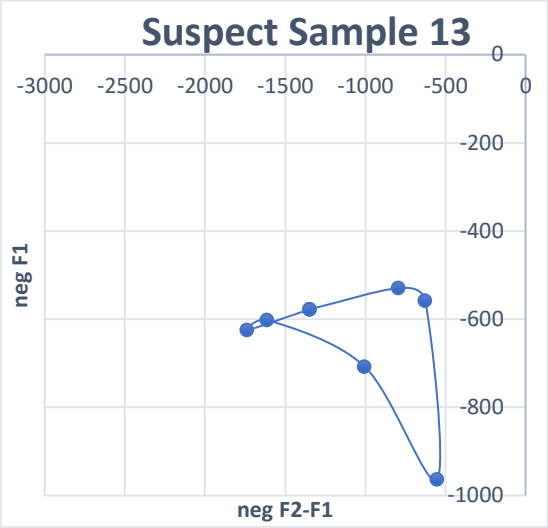


Chart 4.34 : Acoustic Space of Speaker 13

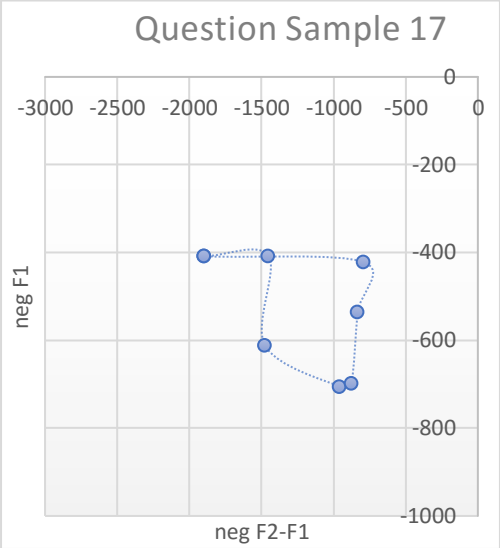


Chart 4.35: Acoustic Space of Question Sample 17

The Acoustic Space of SS13 and QS17 is almost the same. The /a/ vowel is at the lower position for QS17

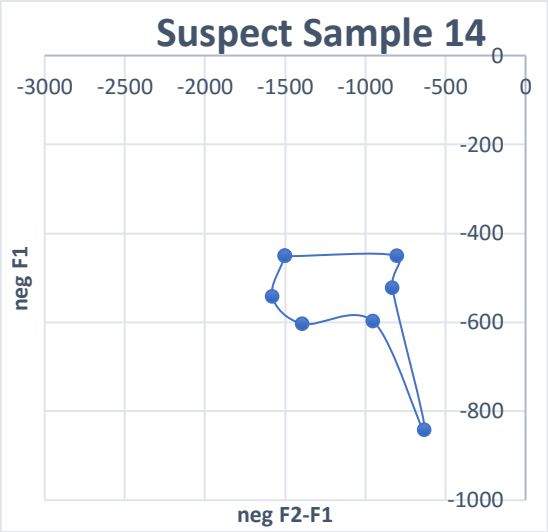


Chart 4.36 : Acoustic Space of Speaker 10

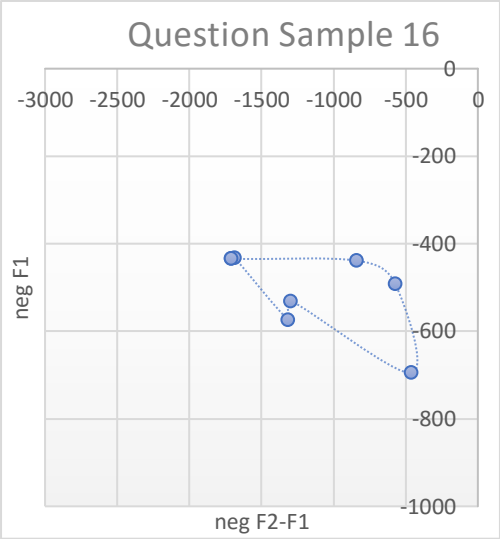


Chart 4.37 : Acoustic Space of Question Sample 16

The Acoustic Space of SS13 and QS16 is almost the same.

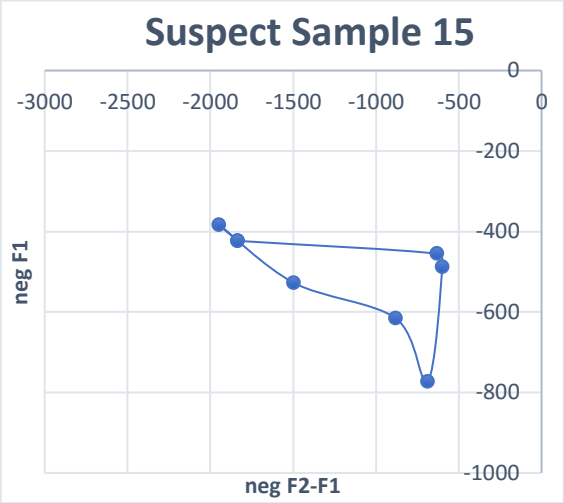


Chart 4.38 : Acoustic Space of Speaker 15

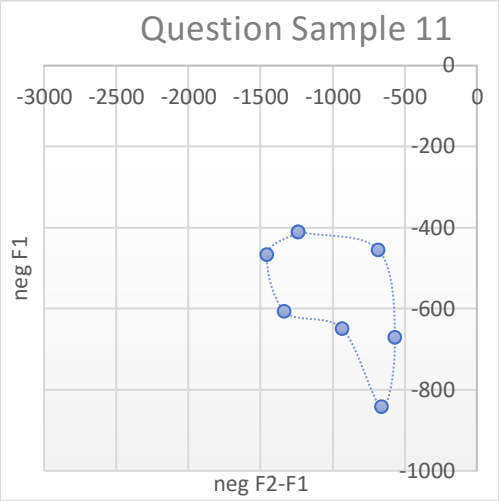


Chart 4.39 : Acoustic Space of Question Sample 11

The Acoustic Space of SS15 and QS11 is almost the same. Other than the /i/ vowel every other vowel appears to be at the identical positions in both samples.

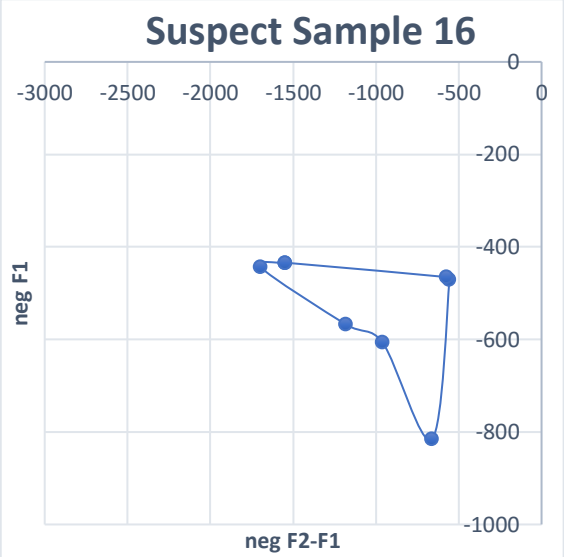


Chart 4.40 : Acoustic Space of Speaker 16

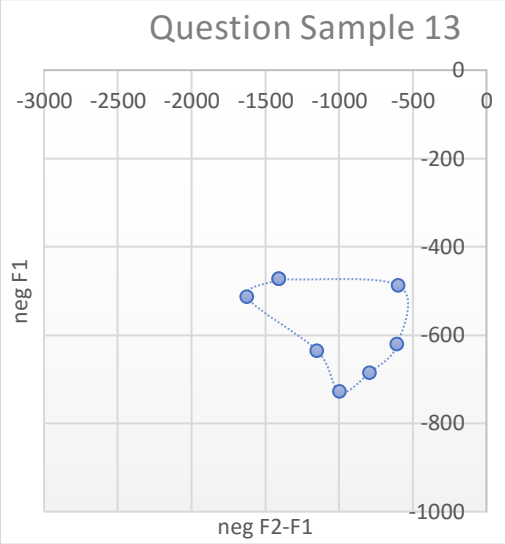


Chart 4.41: Acoustic Space of Question Sample 13

The Acoustic Space of SS10 and QS4 is almost the same.

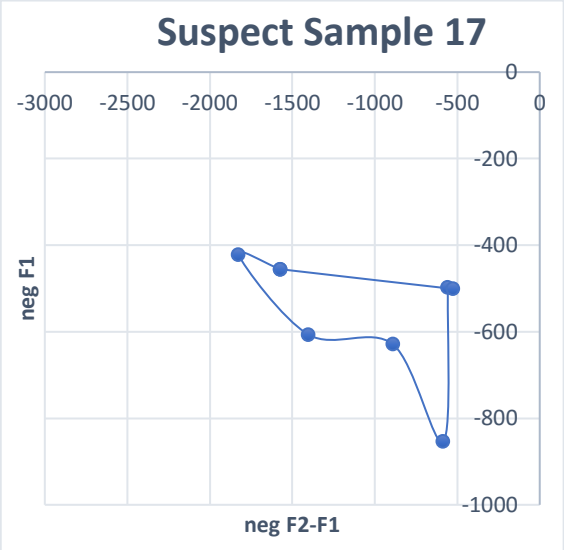


Chart 4.42 : Acoustic Space of Speaker 17

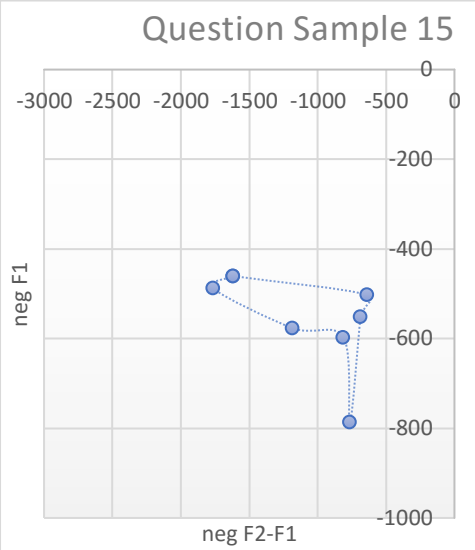


Chart 4.43 : Acoustic Space of Question Sample 15

The Acoustic Space of SS17 and QS15 is almost the same.

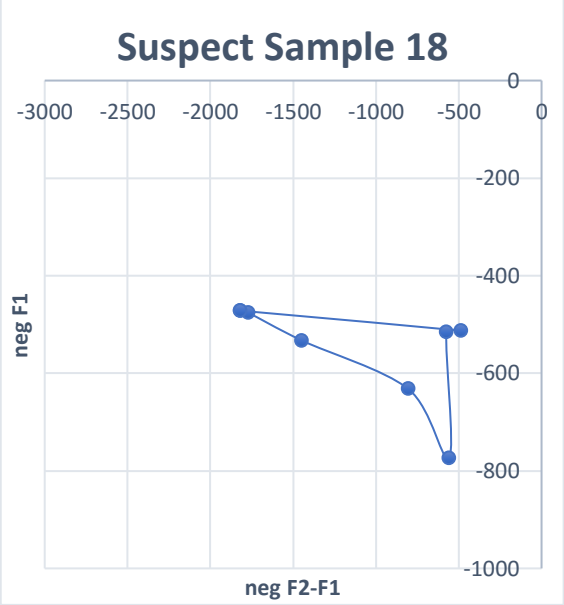


Chart 4. 44 : Acoustic Space of Speaker 10

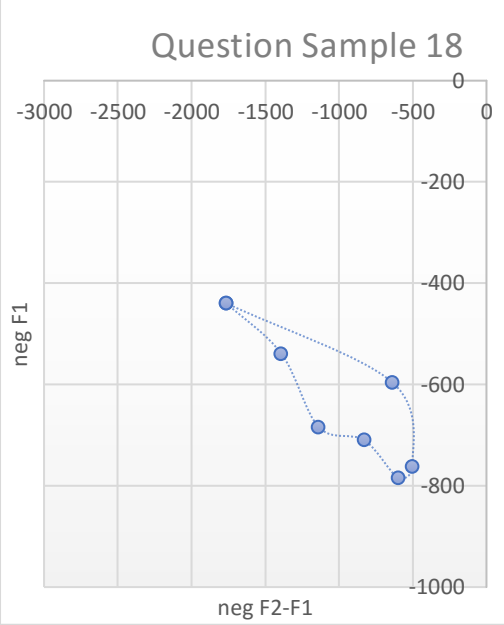


Chart 4.45: Acoustic Space of Question Sample 4

The Acoustic Space of SS18 and QS18 appears to be, not matching with each other. But other than the /o/vowel every other vowel is placed at the similar position to its counterpart in another chart.

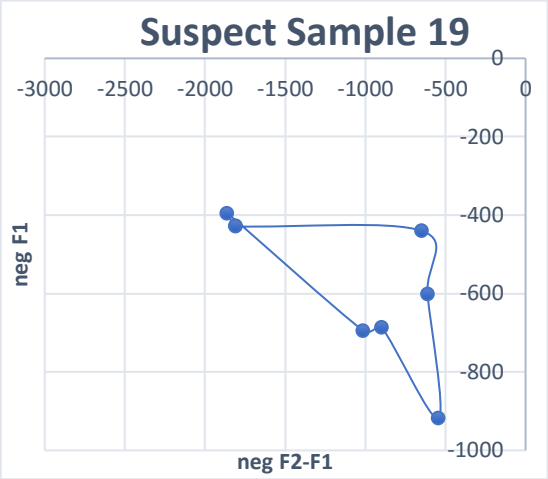


Chart 4.46: Acoustic Space of Speaker 19

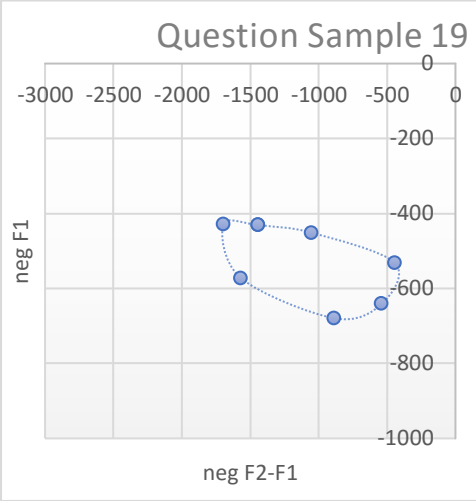


Chart 4.47: Acoustic Space of Question Sample 19

The Acoustic Space of SS19 and QS19 is almost the same, with /a/ being the exceptionally different values for SS and QS

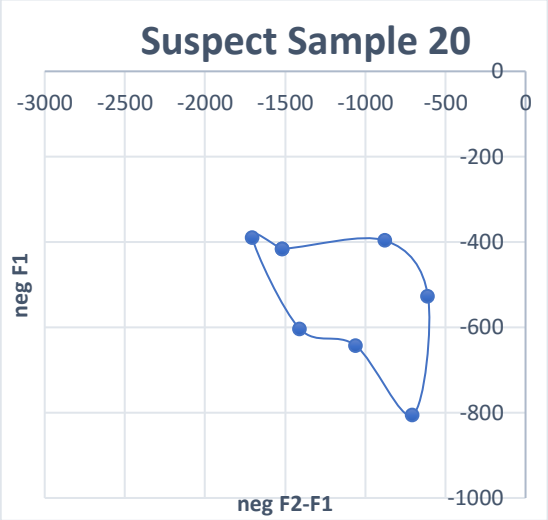


Chart 4.48 : Acoustic Space of Speaker 20

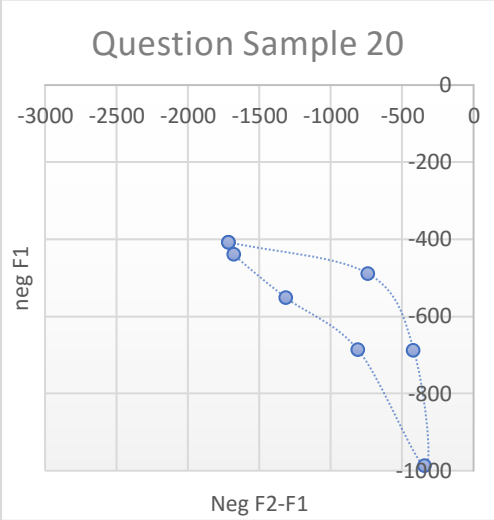


Chart 4.49: Acoustic Space of Question Sample 20

The Acoustic Space of SS20 and QS20 is almost the same.

Observations :

Vowel /i/ And /I/are not matching for many speakers. At some positions, vowel /a/ was lower than expected. All these are individual characteristics of the speakers. This might help us differentiate two speakers apart from each other. Other four vowels were usually constant with reference to their positions in the chart. Both Question samples and Suspect Samples of individual speakers occupied the similar positions in the charts.

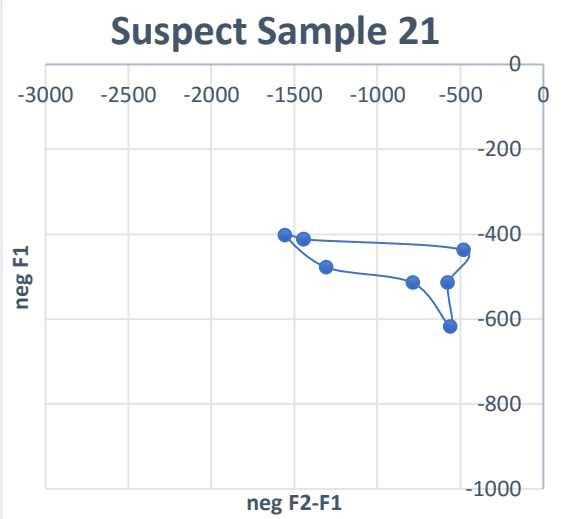


Chart 4.50 : Acoustic Space of Speaker 21

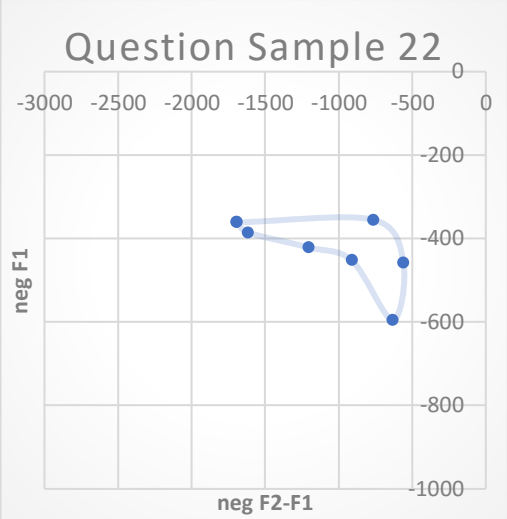


Chart 4.51 : Acoustic Space of Question Sample 22

The Acoustic Space of SS21 and QS22 is almost the same.

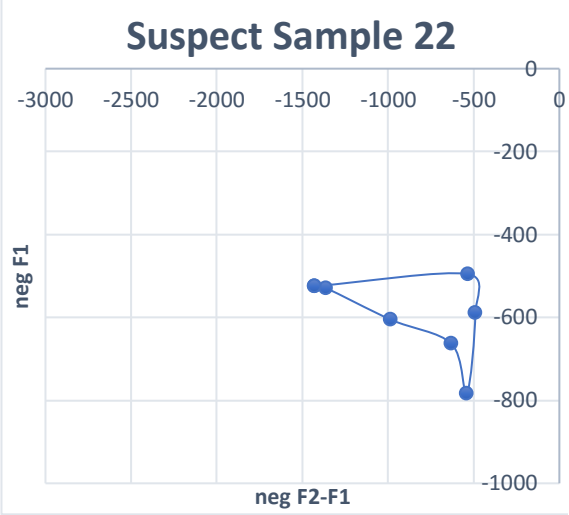


Chart 4.52: Acoustic Space of Speaker 22

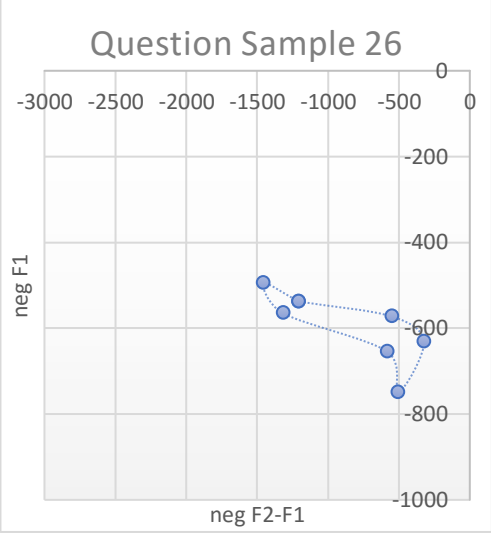


Chart 4.53 : Acoustic Space of Question Sample 26

The Acoustic Space of SS20 and QS20 is almost the match.

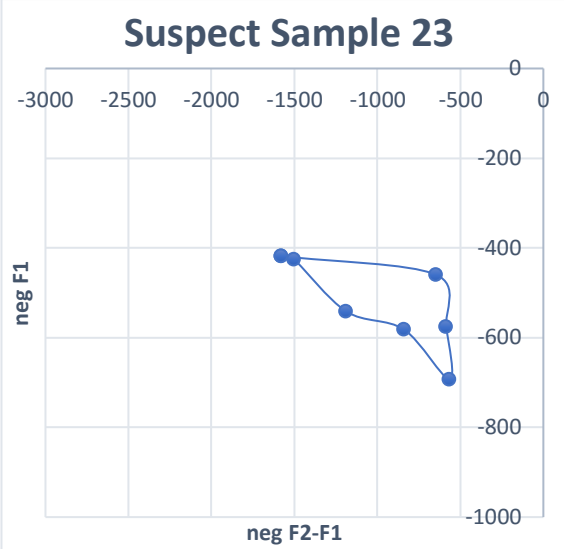


Chart 4.54 : Acoustic Space of Speaker 23

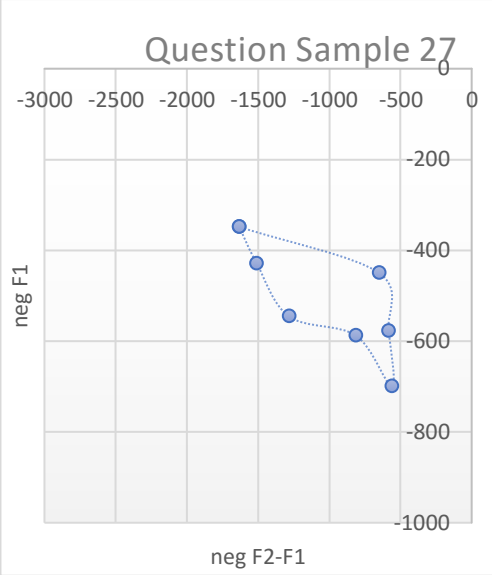


Chart 4.55: Acoustic Space of Question Sample 27

The Acoustic Space of SS20 and QS20 is almost the same.

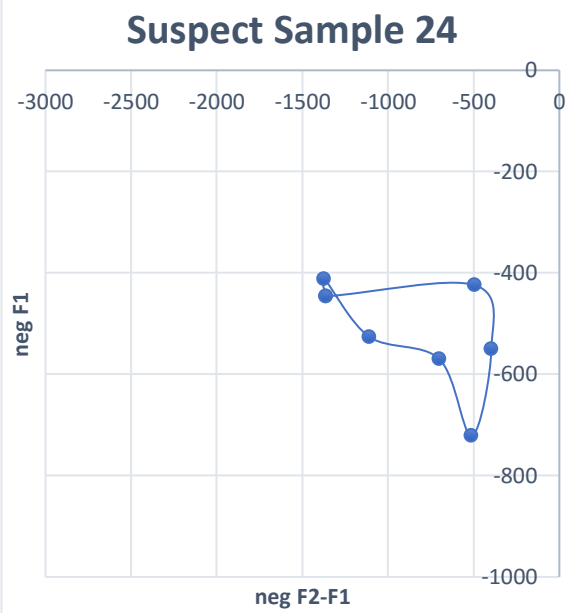


Chart 4.56 : Acoustic Space of Speaker 24

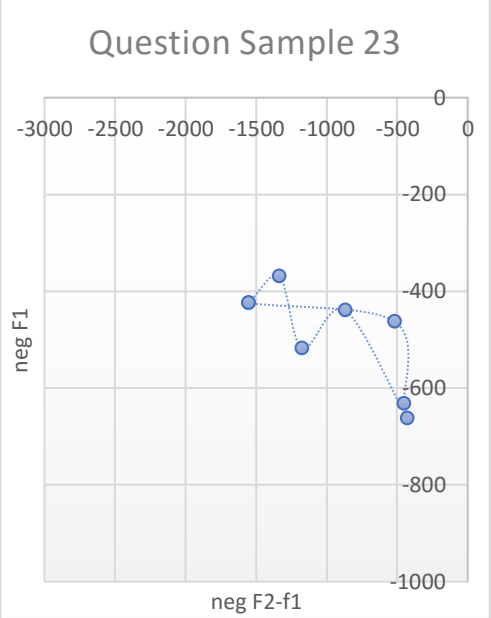


Chart 4.57: Acoustic Space of Question Sample 23

The Acoustic Space of SS24 and QS23 is almost the same.

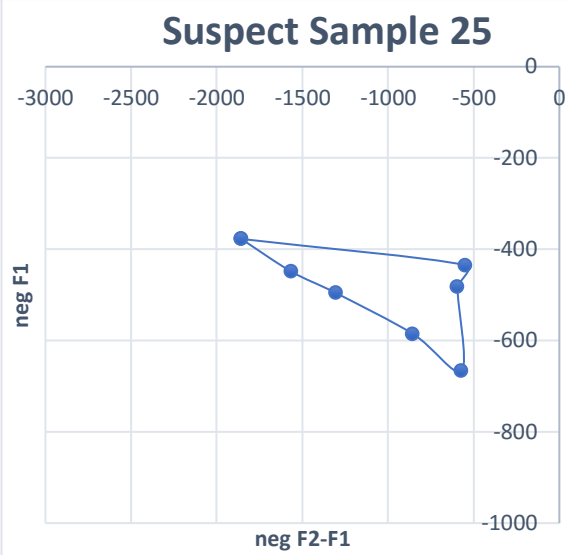


Chart 4.60: Acoustic Space of Speaker 25

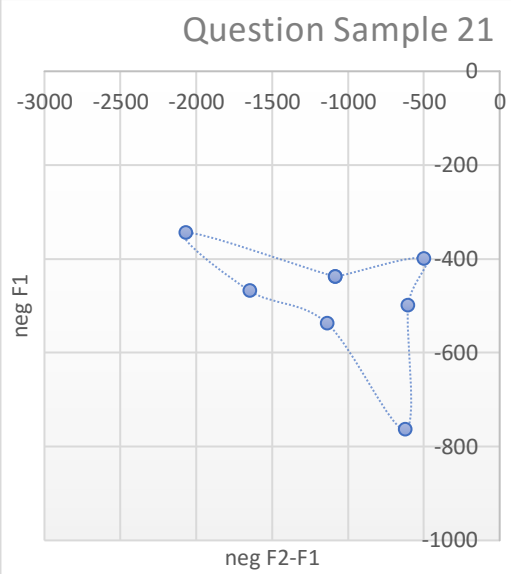


Chart 4.61 : Acoustic Space of Question Sample 21

The Acoustic Space of SS25 and QS21 is almost the same.

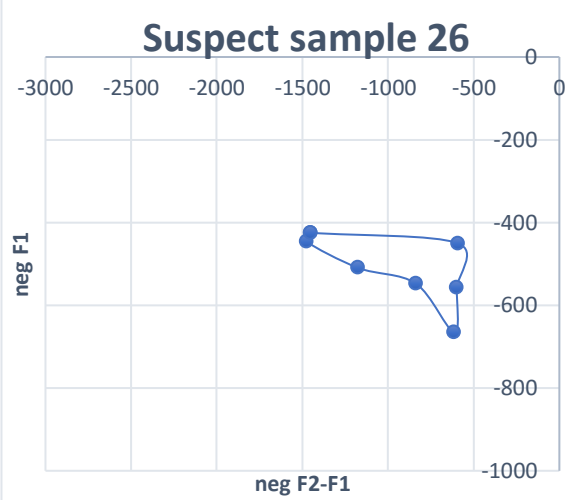


Chart 4.62: Acoustic Space of Speaker 26

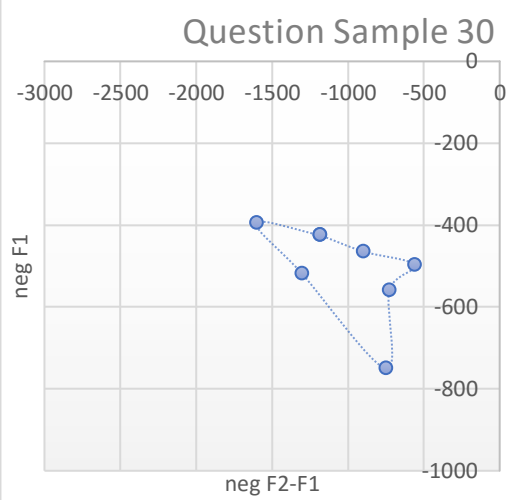


Chart 4.63: Acoustic Space of Question Sample 30

The Acoustic Space of SS20 and QS20 is almost the same.

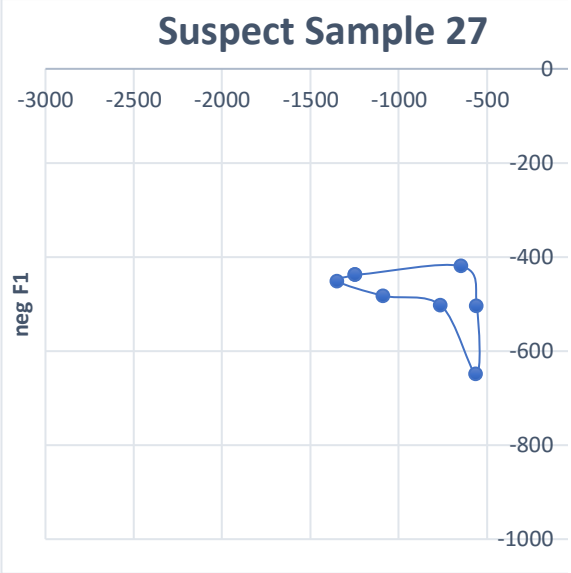


Chart 4.64: Acoustic Space of Speaker 27

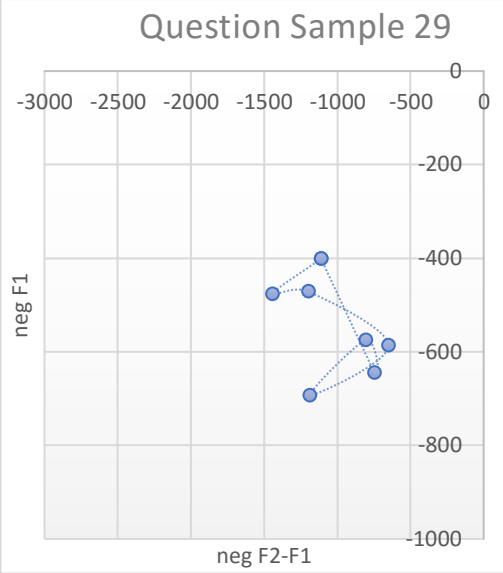


Chart 4.65: Acoustic Space of Question Sample 29

The Acoustic Space of SS27 and QS29 doesn't appear to be matching..

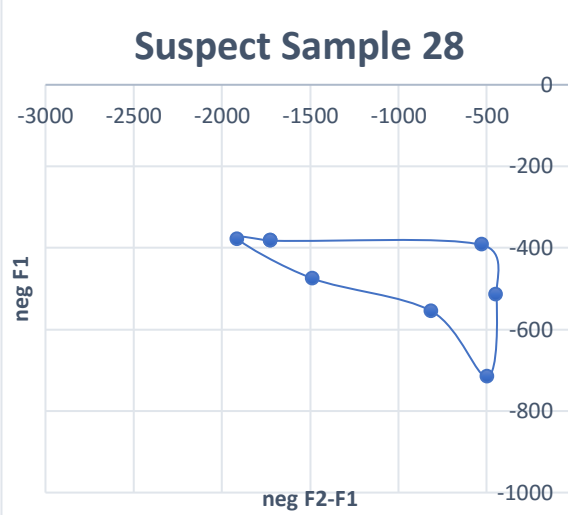


Chart 4.66: Acoustic Space of Speaker 28

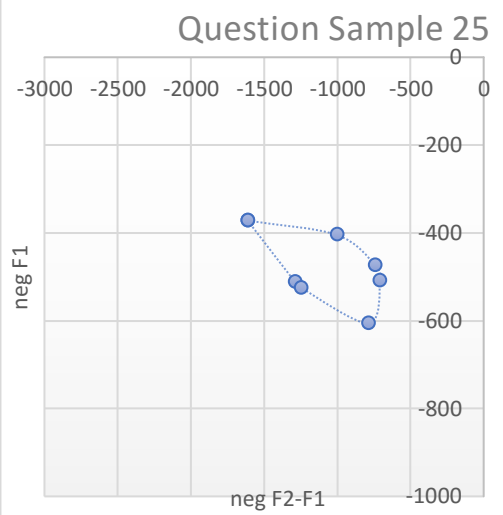


Chart 4.67: Acoustic Space of Question Sample 25

The Acoustic Space of SS28 and QS25 is almost the same.

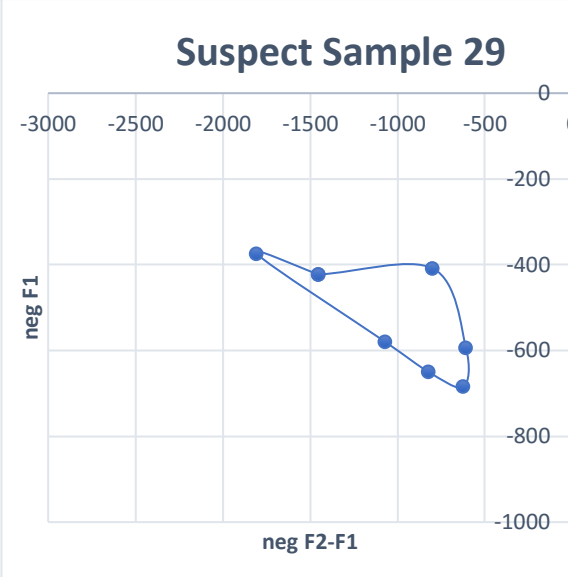


Chart 4.68: Acoustic Space of Speaker 29

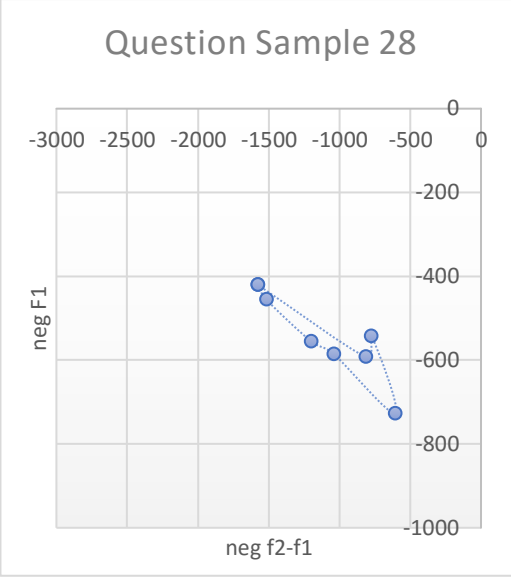


Chart 4.69: Acoustic Space of Question Sample 28

The Acoustic Space of SS29 and QS28 is almost the same.

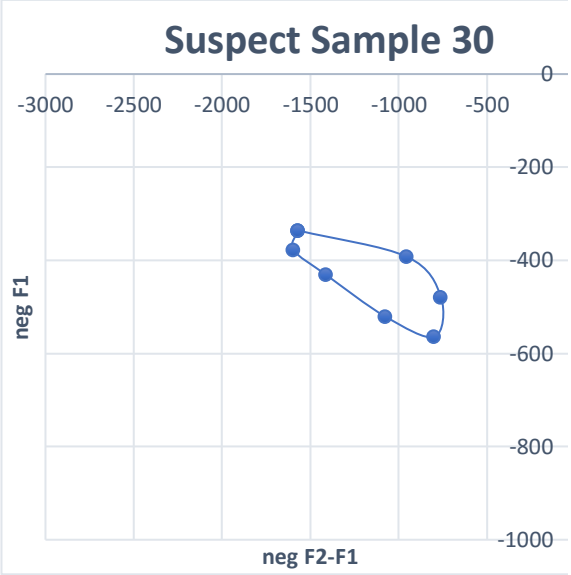


Chart 4.70: Acoustic Space of Speaker 30

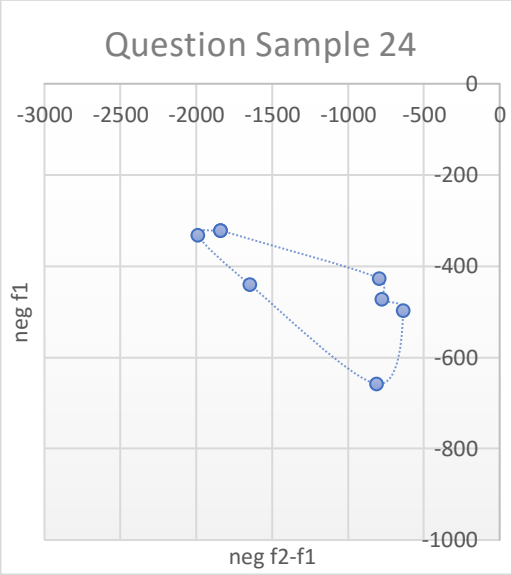


Chart 4.71: Acoustic Space of Question Sample 24

The Acoustic Space of SS30 and QS24 is almost the same.

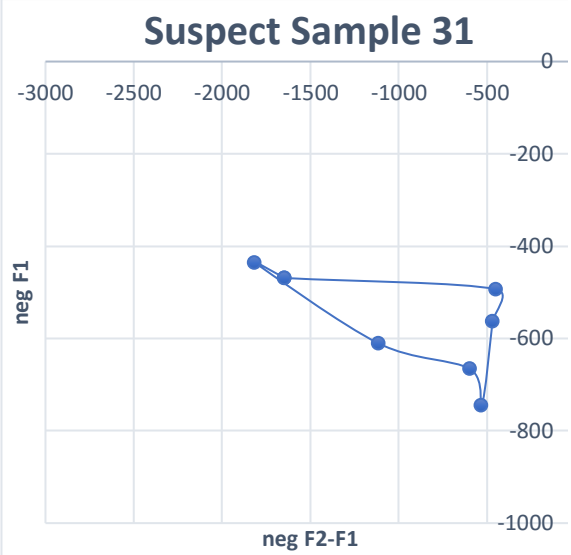


Chart 4.72: Acoustic Space of Speaker 31

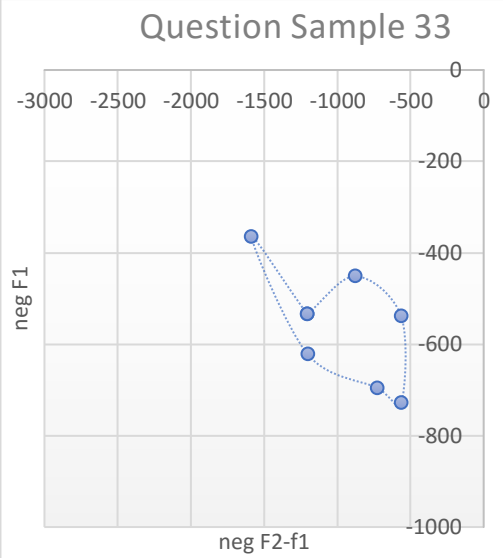


Chart 4.73: Acoustic Space of Question Sample 33

The Acoustic Space of SS31 and QS33 is almost the same.

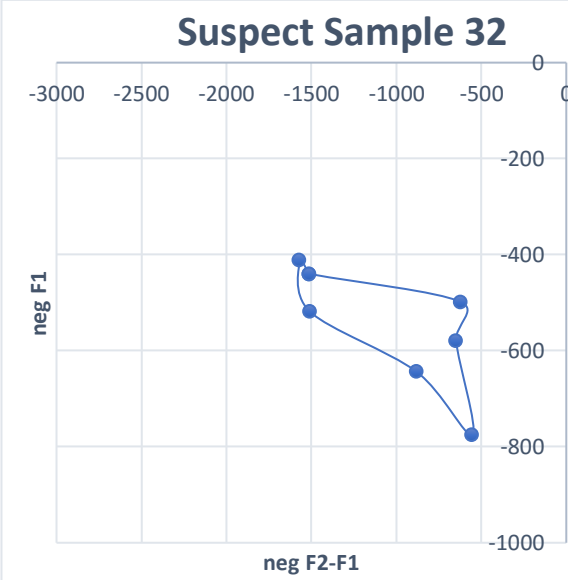


Chart 4.74: Acoustic Space of Speaker 32

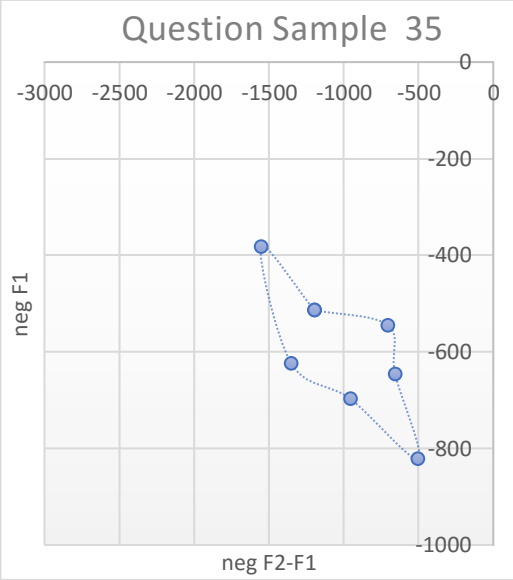


Chart 4.75: Acoustic Space of Question Sample 35

The Acoustic Space of SS32 and QS35 is almost the same.

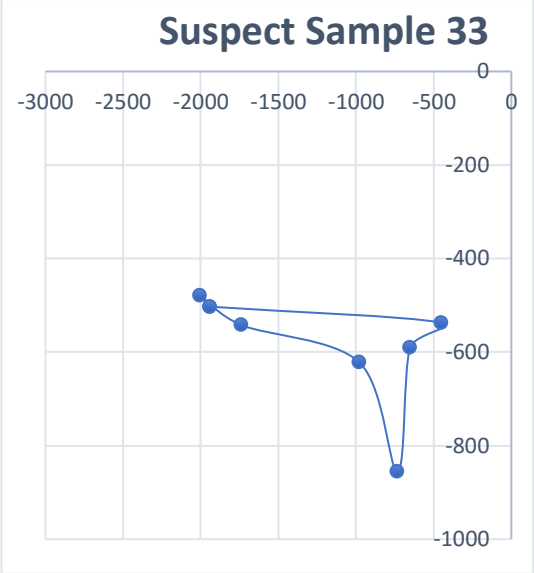


Chart 4.76: Acoustic Space of Speaker 33

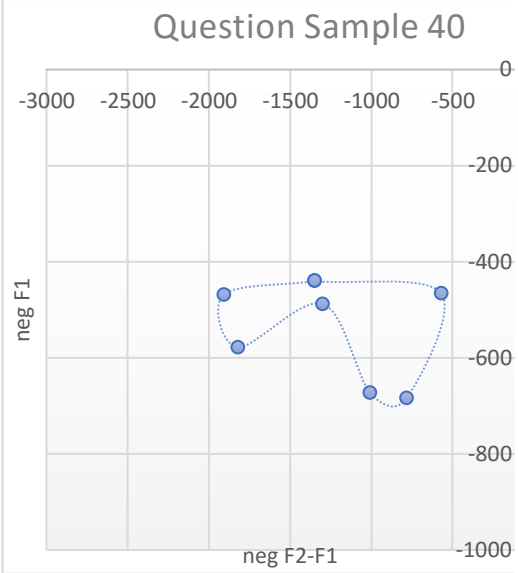


Chart 4.77: Acoustic Space of Question Sample 40

The Acoustic Space of SS33 and QS40 is almost the same.

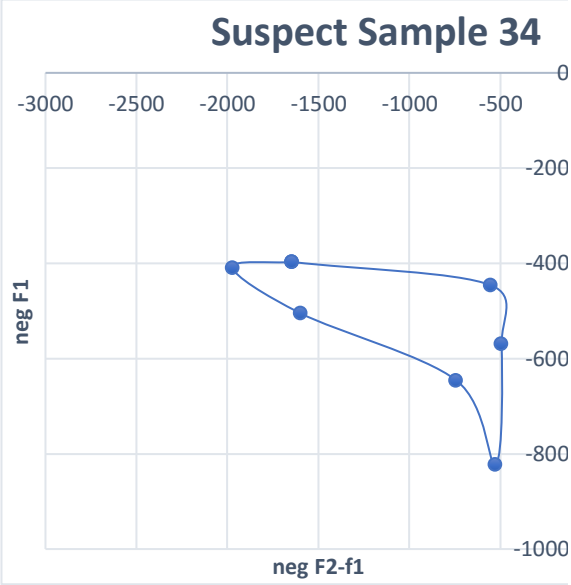


Chart 4.78: Acoustic Space of Speaker 34

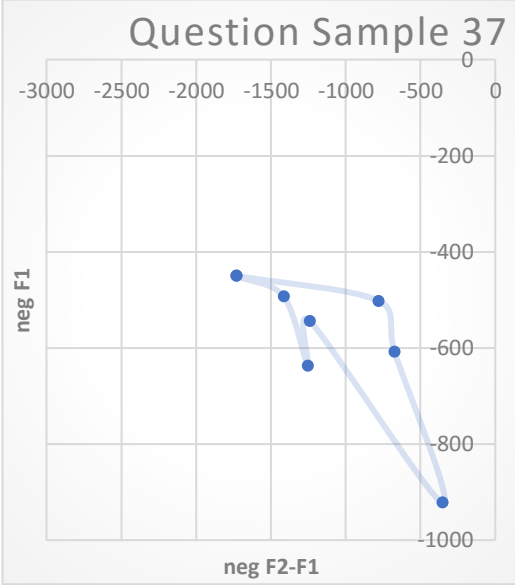


Chart 4.79: Acoustic Space of Question Sample 37

The Acoustic Space of SS34 and QS37 is almost the same.

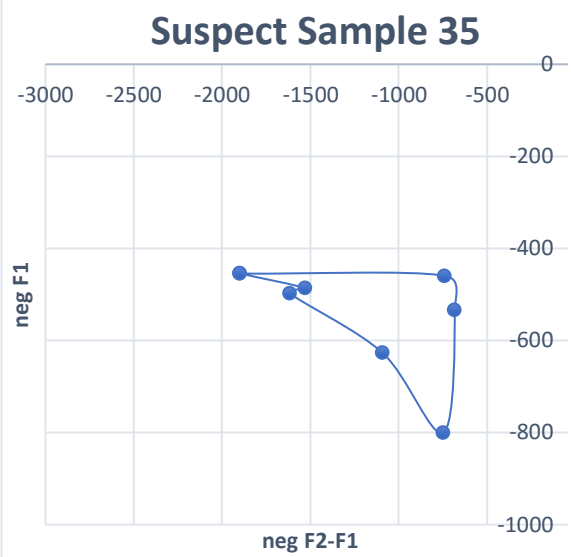


Chart 4.80: Acoustic Space of Speaker 35

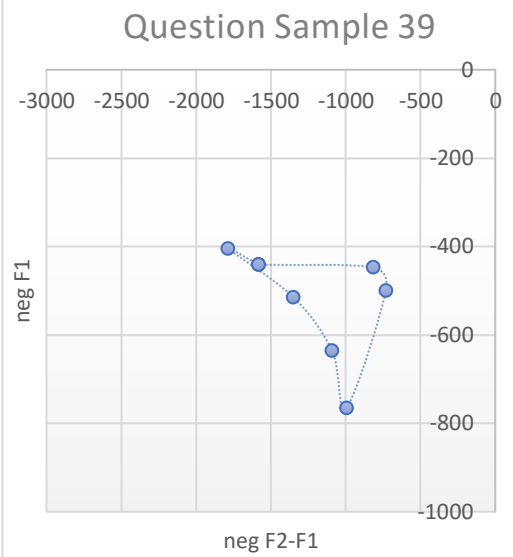


Chart 4.81: Acoustic Space of Question Sample 39

The Acoustic Space of SS35 and QS39 is almost the same.

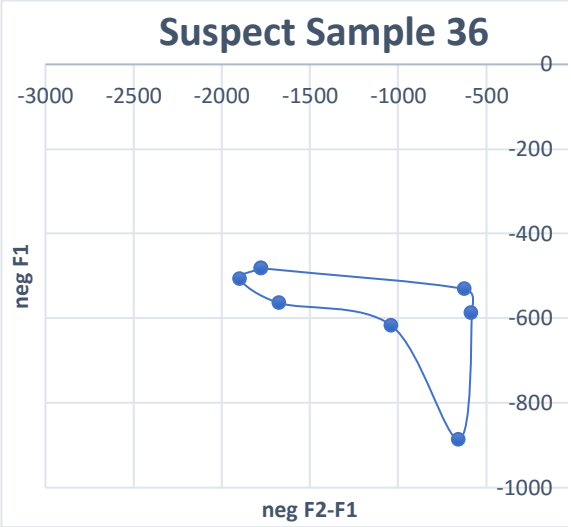


Chart 4.82: Acoustic Space of Speaker 36

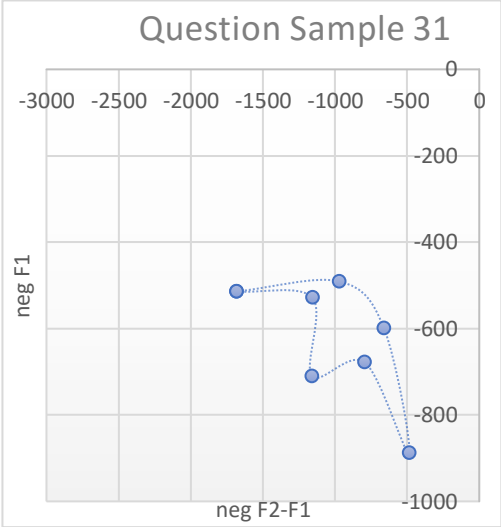


Chart 4.83: Acoustic Space of Question Sample 31

The Acoustic Space of SS36 and QS31 is almost the same.

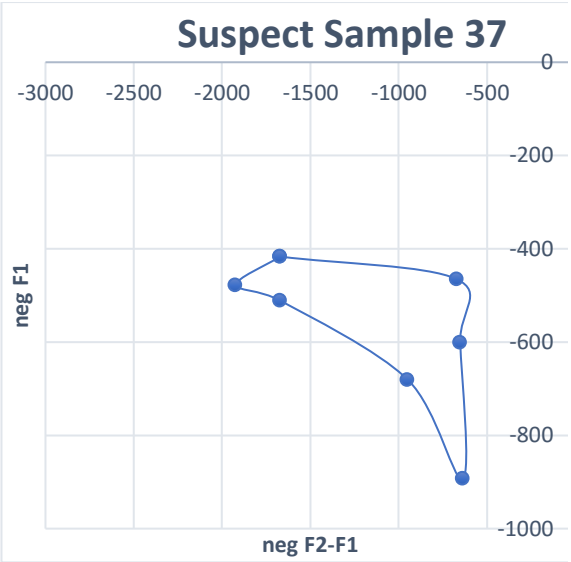


Chart 4.84: Acoustic Space of Speaker 37

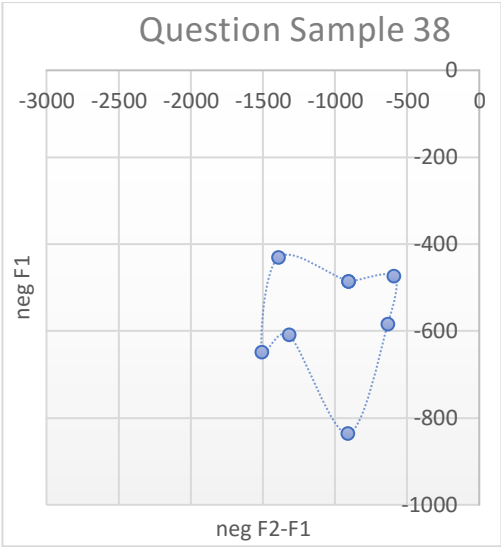


Chart 4.85: Acoustic Space of Question Sample 38

The Acoustic Space of SS37 and QS38 is almost the same.

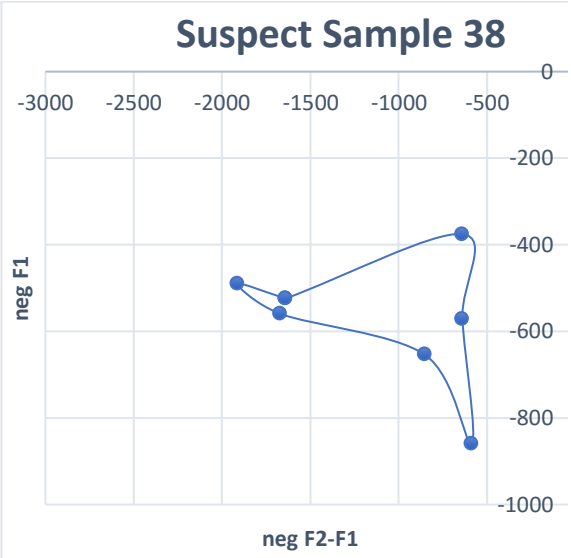


Chart 4.86: Acoustic Space of Speaker 38

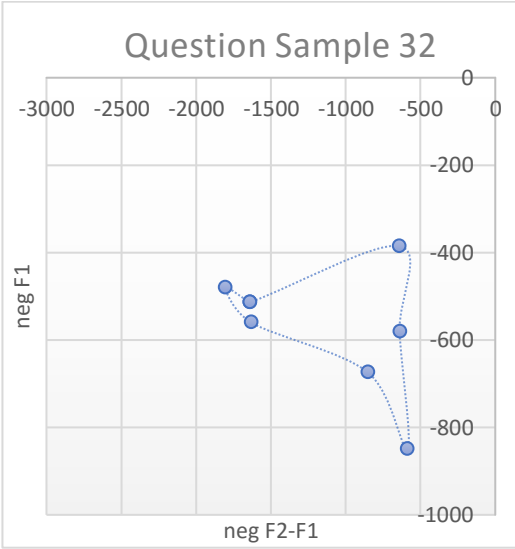


Chart 4.87: Acoustic Space of Question Sample 32

The Acoustic Space of SS38 and QS32 is almost the same.

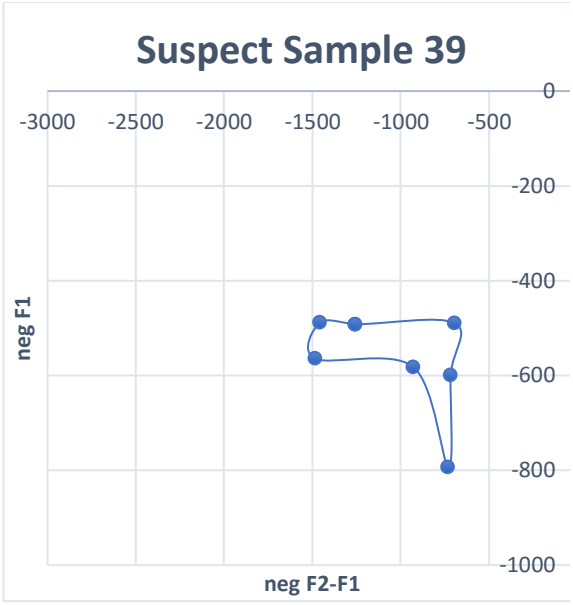


Chart 4.88: Acoustic Space of Speaker 39

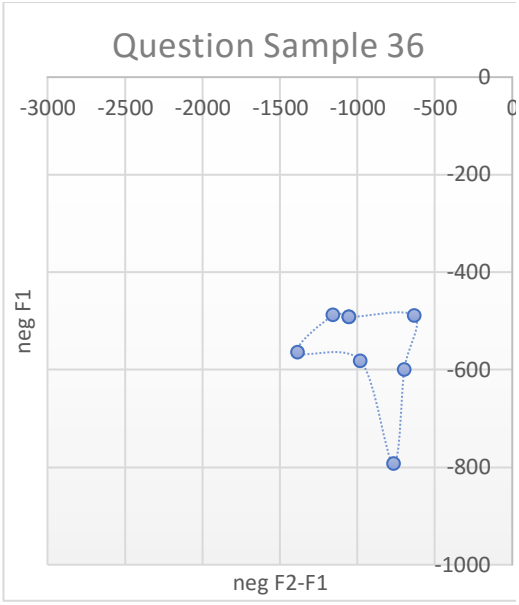


Chart 4.89: Acoustic Space of Question Sample 36

The Acoustic Space of SS39 and QS36 is almost the same.

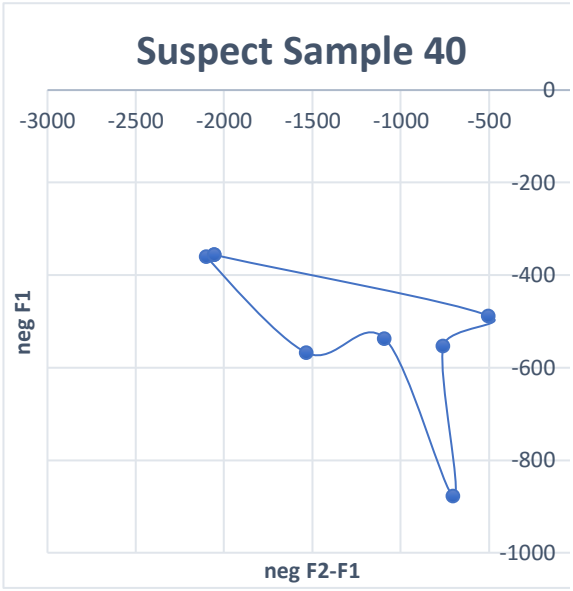


Chart 4.90: Acoustic Space of Speaker 40

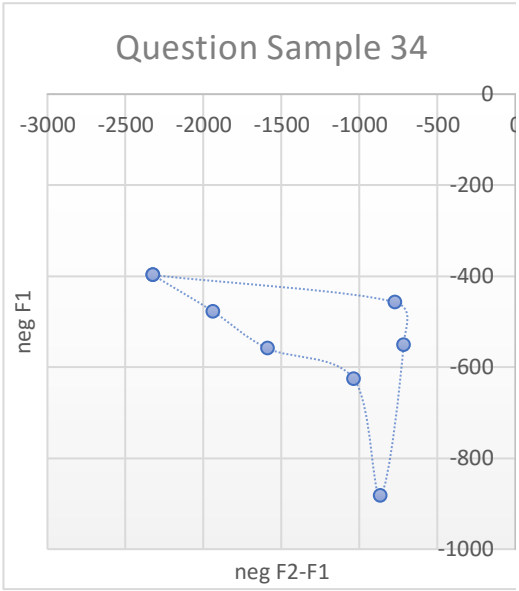


Chart 4.91: Acoustic Space of Question Sample 34

The Acoustic Space of SS40 and QS34 is almost the same.

Observations:

Unlike Brahmin Variety, the speakers of Bishnoi variety had far too many abnormalities, when it come to the vowel position. Their values were constantly mis-matching for the Question sample and Suspect Sample. Suspect sample 24, 29 and 27 were looking different from their respective questions samples, but when looked closely at the values, it was deducted that there were slight changes of values in the chart. But all three were able to be positioned at entire acoustic space of the Variety vowel charts. As mentioned earlier, Bishnoi speakers were speaking very fast, this might affect the extraction of question samples, as they are derived from a conversation.

Discussion

The Acoustic space has been an important factor in any phonetic investigation. It helps the researcher determine the area in our mouth, which the language occupies and This section investigates the size of vowel spaces used by speakers i.e. the size of the "working" vowel space (in the Fl x F2 plane) used by the Brahmin and Bishnoi speakers while pronouncing their vowels. A vowel space is defined as speaker's F1 and F2 frequency. Identification of vowels is done on the basis of patterns formed by their formants within the given acoustic space. As discussed earlier the F1 shows the height of the vowels and F2 or F2- F1 shows the front/back-ness of vowel.

Vowel Space or vowel limit is associated by Catford (1988), with the cardinal vowels of Danial Jones(1917). According to him any vowel production should be limited to a fixed space. Either the vowel should take the approximant space of the vowel itself or it should position at in the vowel space. The acoustic space of both varieties gave us a rough idea about the acoustic space of Brahmin and Bishnoi Vowels. For Brahmin Speakers, the difference between /i/ and /I/ was very low, and because of that the acoustic space derived from it looked at somewhat similar position.

Bishnoi Variety speakers' speaking speed affected the Question Samples drastically, resulting in slightly different graphs for certain vowels, for some people.

The next section is going to analyse the other remaining formants of the speakers. A plot was created in order to find out the importance of these harmonics. These graphs include the F1, F2, F3, F2-F1 and F3- F1. The particular graph template was created to see the role of F2 and F1 in forensic speaker identification of the speakers.

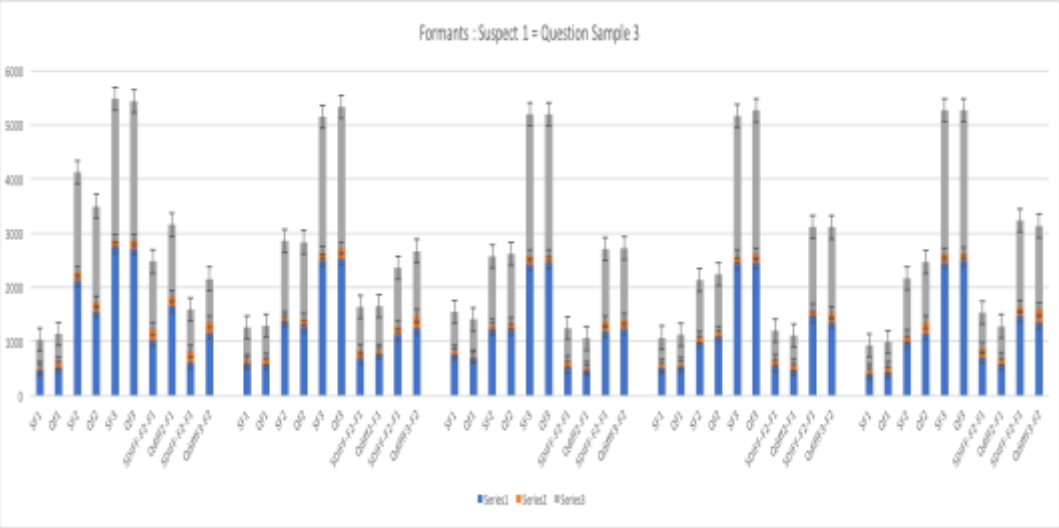


Chart 4.92 : A comparison of F1, F2, F2-F1, F3-F2 between SS1 and QS3 along with language mean values and Standard Deviation

Observation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

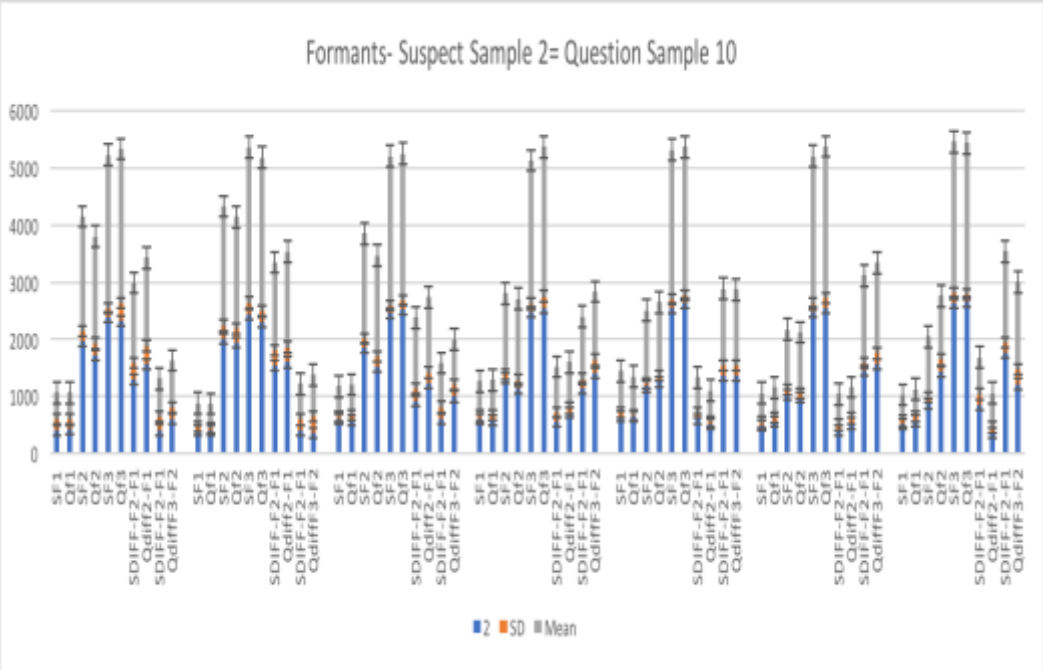


Chart 4.93 : A comparison of F1, F2, F2-F1, F3-F2 between SS2 and QS10 along with language mean values and Standard Deviation

Observation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 2, 4, 5, 6, and 7. Vowel 1and 3 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing. The F2- F1 difference is still matching for the two speakers for some vowels.

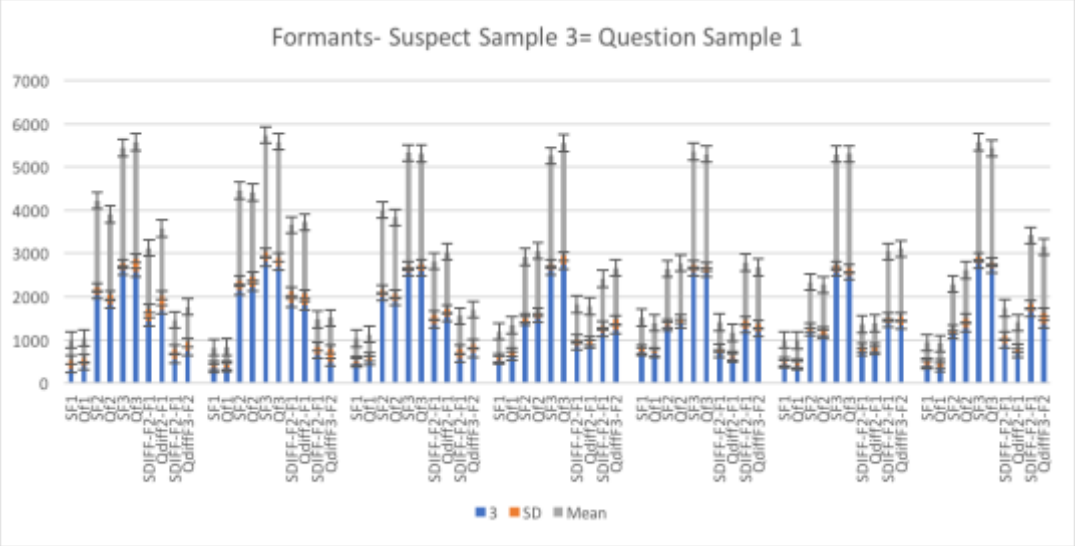


Chart 4.94 : A comparison of F1, F2, F2-F1, F3-F2 between SS3 and QS1 along with language mean values and Standard Deviation

Observation

1. F1 and F2 values are remaining consant for all seven vowels, for this speaker the difference between two sample's f2-f1 is very low.
2. The F3- F1 is different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

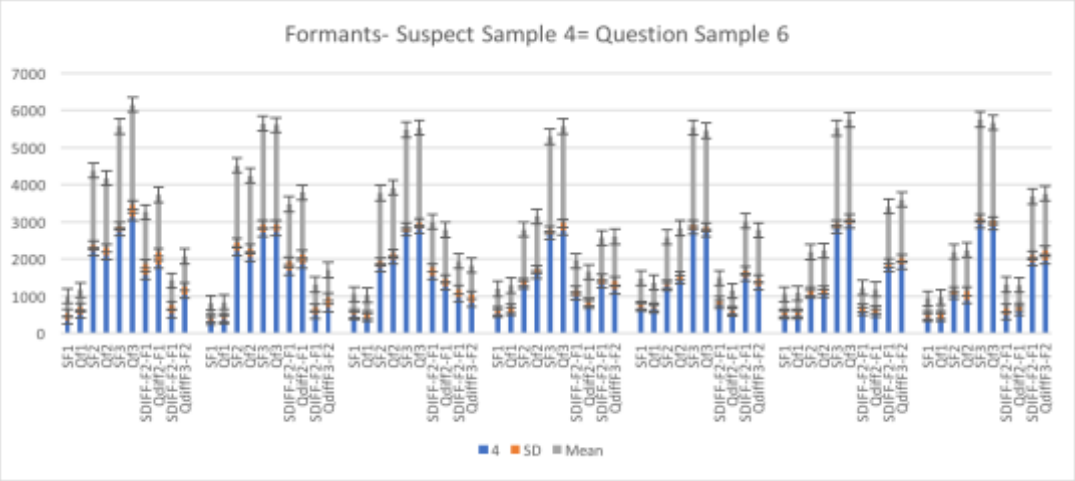


Chart 4.95 : A comparison of F1, F2, F2-F1, F3-F2 between SS4 and QS6 along with language mean values and Standard Deviation

Observation

1. F1, F2 and F2-F1 values are remaining consant for vowel for all sevel vowels.
2. The and F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

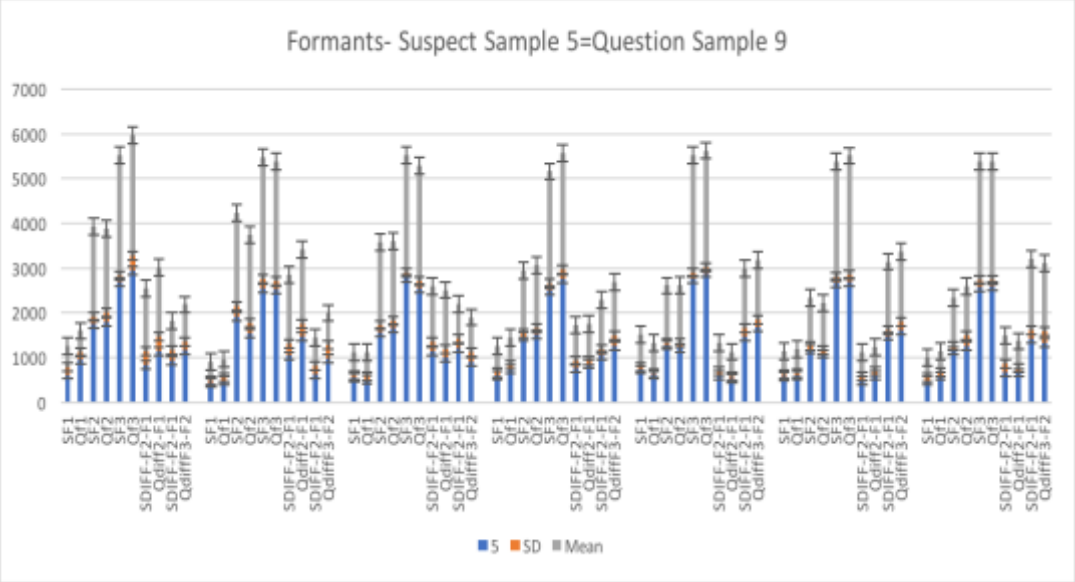


Chart 4.96 : A comparison of F1, F2, F2-F1, F3-F2 between SS5 and QS9 along with language mean values and Standard Deviation

Observation

1. F1, F2 and F2-F1 values are remaining consant for all seven vowels.
2. The and F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is constantly changing.

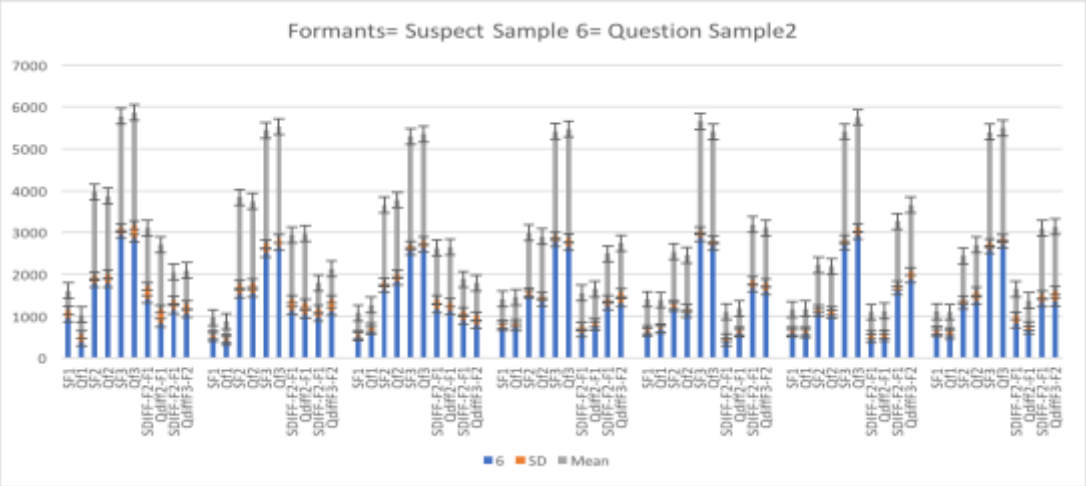


Chart 4.97 A comparison of F1, F2, F2-F1, F3-F2 between SS6 and QS2 along with language mean values and Standard Deviation

Observation

1. F1,F2 and F2-F1 values are remaining consant for all seven vowel.
2. The and F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is constantly changing.

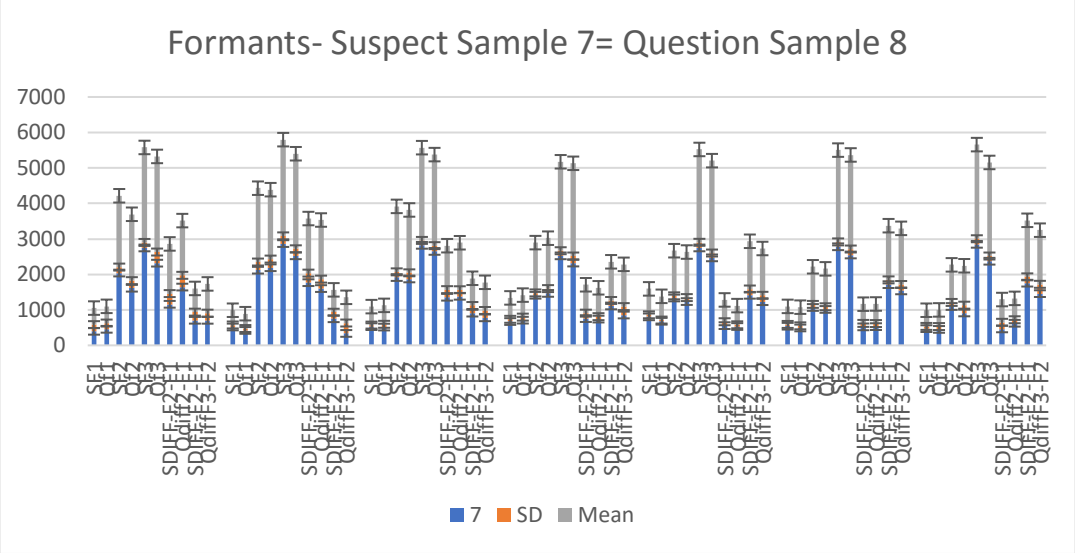


Chart 4.98 : A comparison of F1, F2, F2-F1, F3-F2 between SS7 and QS8 along with language mean values and Standard Deviation

Observation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6 and 7 .Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

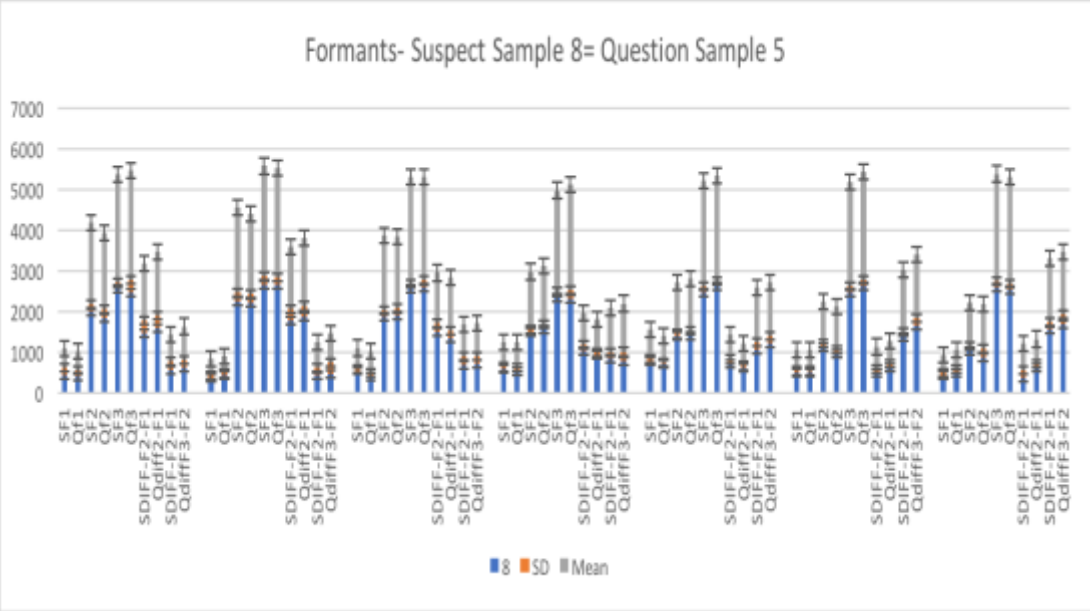


Chart 4.99: A comparison of F1, F2, F2-F1, F3-F2 between SS8 and QS5 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for all seven vowels.
2. The F3- F1 is different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

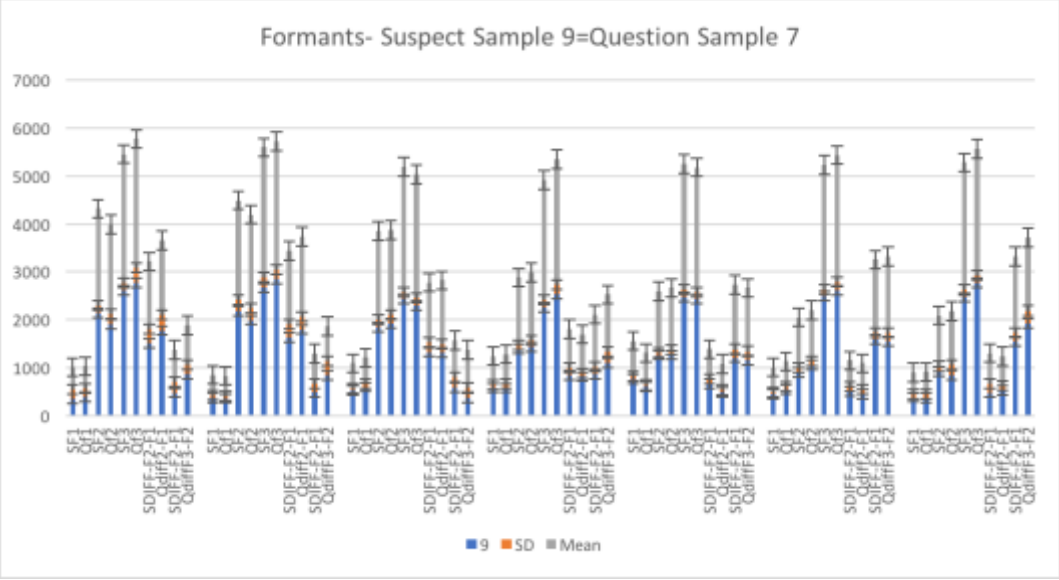


Chart 4.100: A comparison of F1, F2, F2-F1, F3-F2 between SS9 and QS7 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 3, 4, 5, 6, and 7. Vowels 1and 2 are showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 is different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

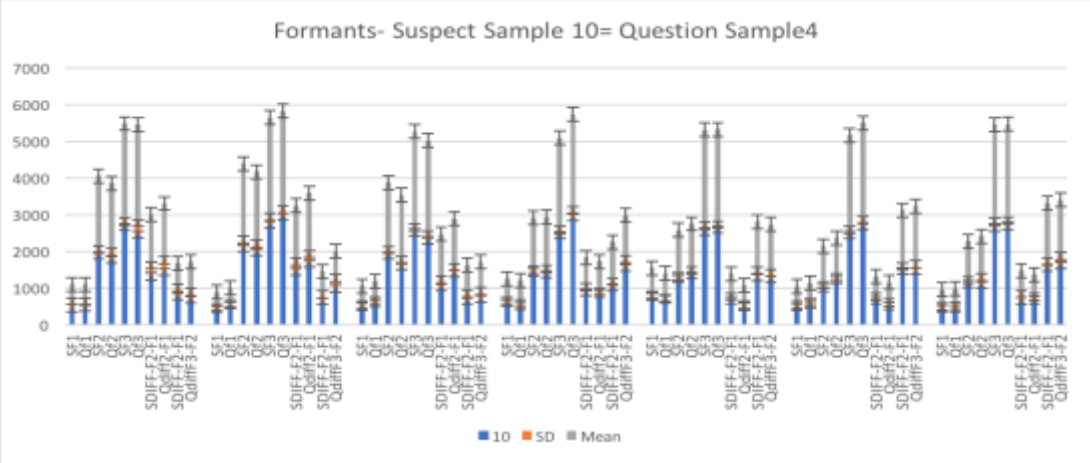


Chart 4.101: A comparison of F1, F2, F2-F1, F3-F2 between SS10 and QS 4 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 1,2, 3, 4, 5, and 7. Vowel 6 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 is different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

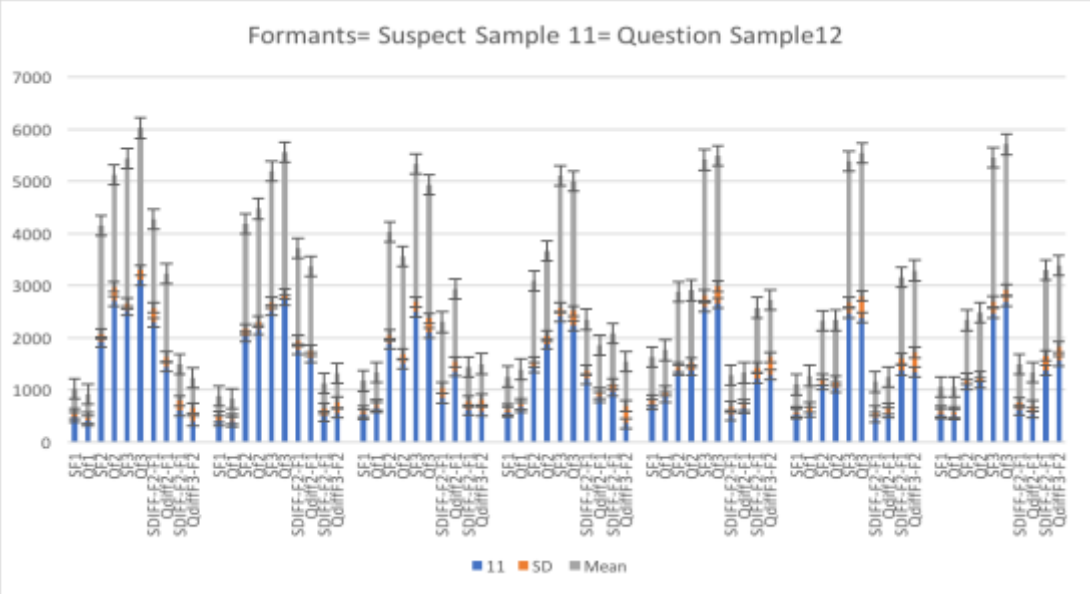


Chart 4.102 : A comparison of F1, F2, F2-F1, F3-F2 between SS11 and QS12 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 5, 6, and 7. Vowels 1,2,3 and 4 are showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

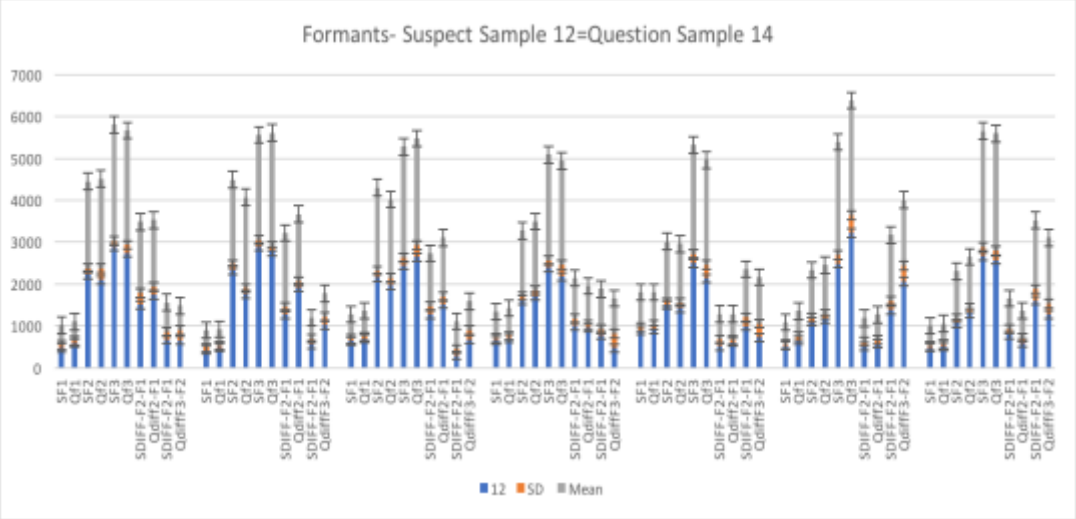


Chart 4.103: A comparison of F1, F2, F2-F1, F3-F2 between SS12 and QS14 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 1, 4, 5, 6, and 7. Vowel 2 and 3 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

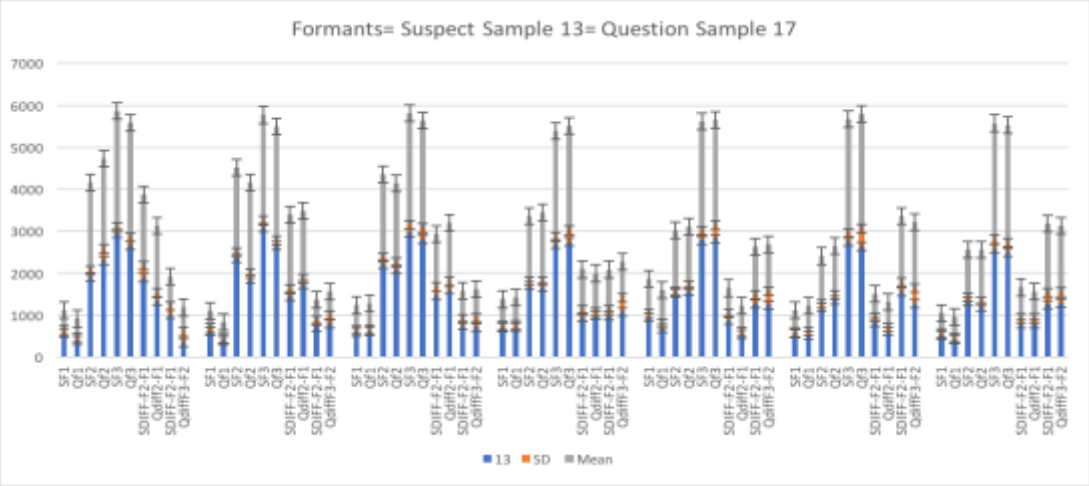


Chart 4.104: A comparison of F1, F2, F2-F1, F3-F2 between SS13 and QS17 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

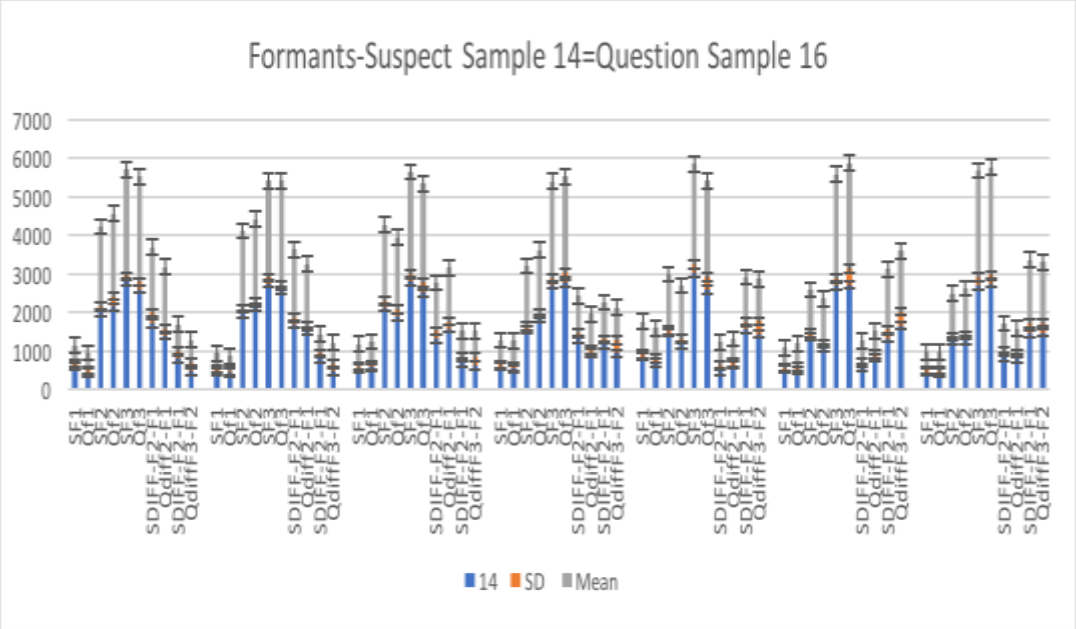


Chart 4.105: A comparison of F1, F2, F2-F1, F3-F2 between SS14 and QS16 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1values are remaining consant for all seven vowels.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

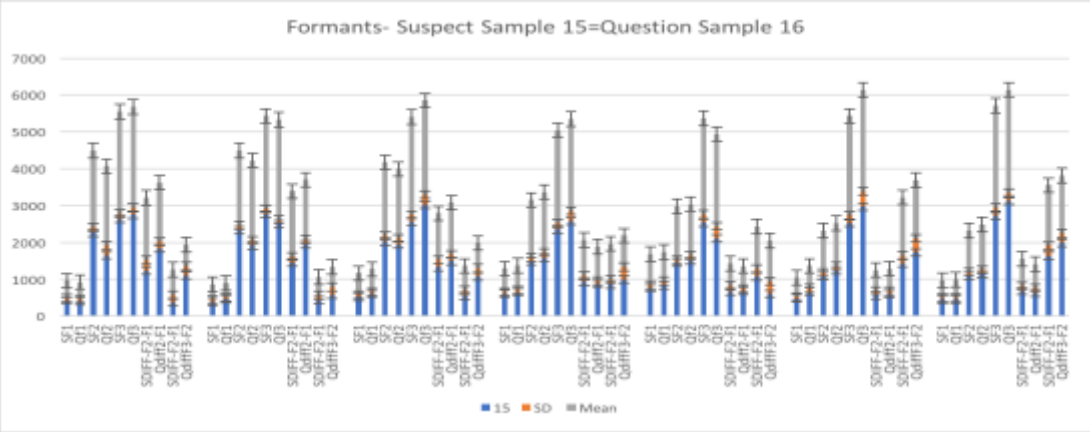


Chart 4.106 : A comparison of F1, F2, F2-F1, F3-F2 between SS15 and QS16 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 is different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

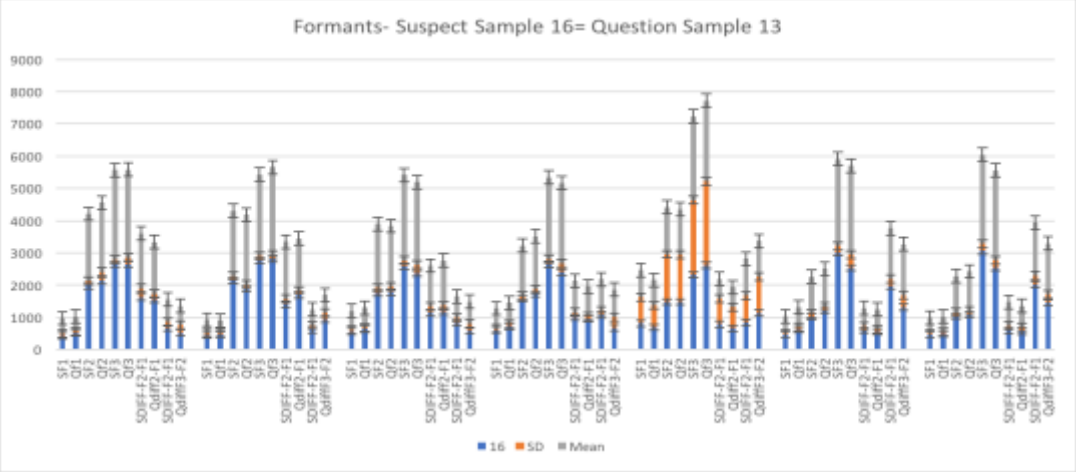


Chart 4.106 : A comparison of F1, F2, F2-F1, F3-F2 between SS16 and QS13 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1values are remaining consant for all seven vowels. Vowel 6 is showing high Standard deviation values than other vowels. Which can be considered as speaker specific feature.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

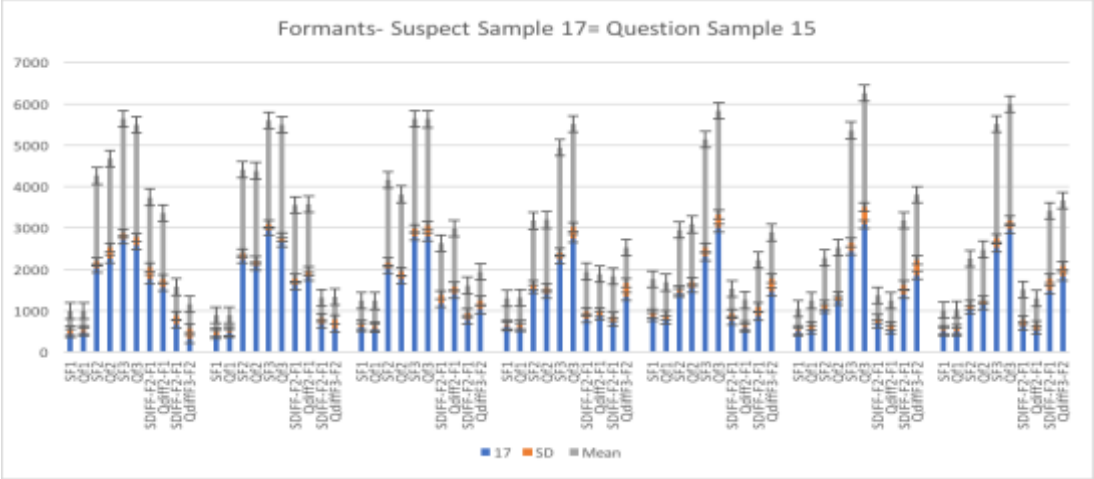


Chart 4.107: A comparison of F1, F2, F2-F1, F3-F2 between SS17 and QS15 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1values are remaining consant for vowel, 2, 3, 5, 6, and 7. Vowels 1 and 4 are showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

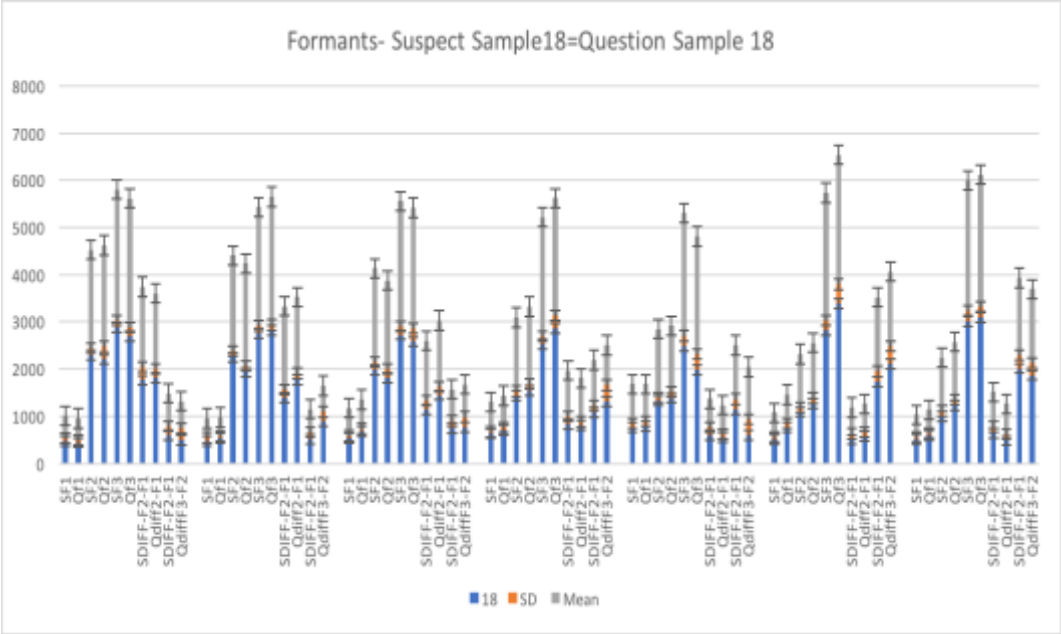


Chart 4.108 : A comparison of F1, F2, F2-F1, F3-F2 between SS18 and QS18 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for all the seven vowels.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

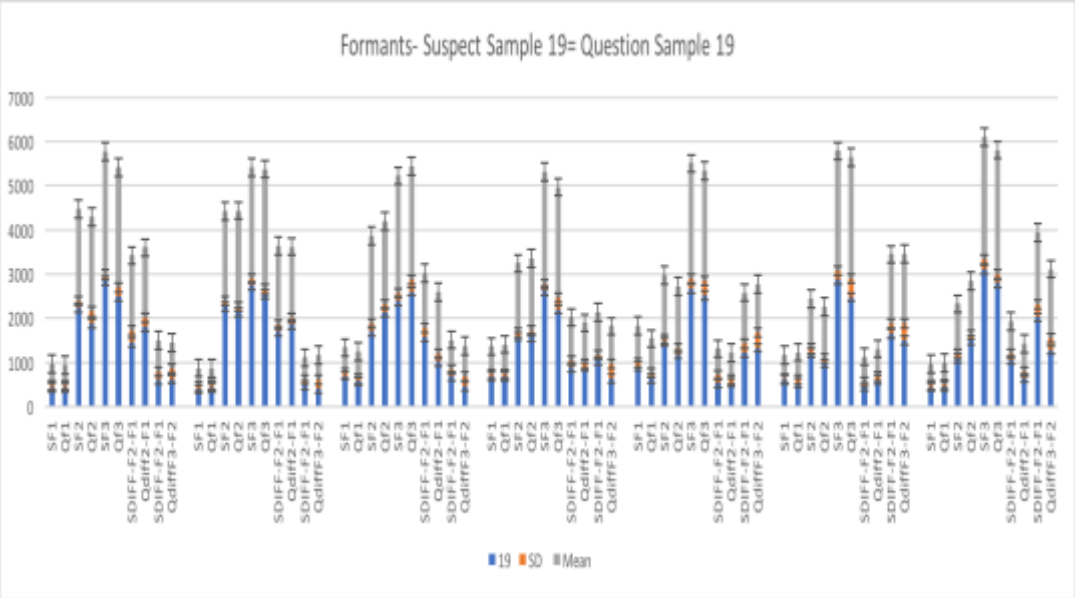


Chart 4,109: A comparison of F1, F2, F2-F1, F3-F2 between SS19 and QS19 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 1,2, 3, 4, 5,and 6. Vowel 7 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

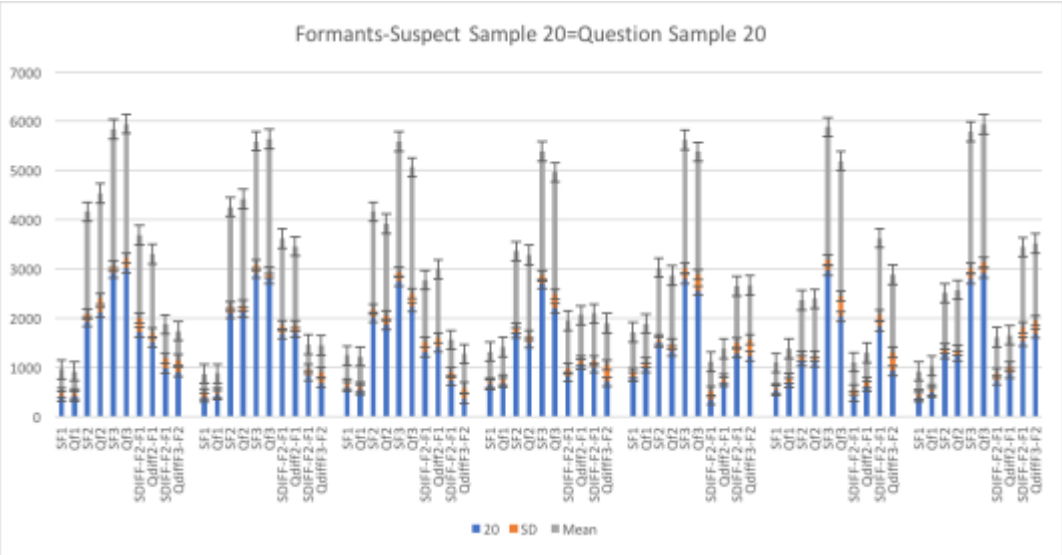


Chart 4.110: A comparison of F1, F2, F2-F1, F3-F2 between SS20 and QS20 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

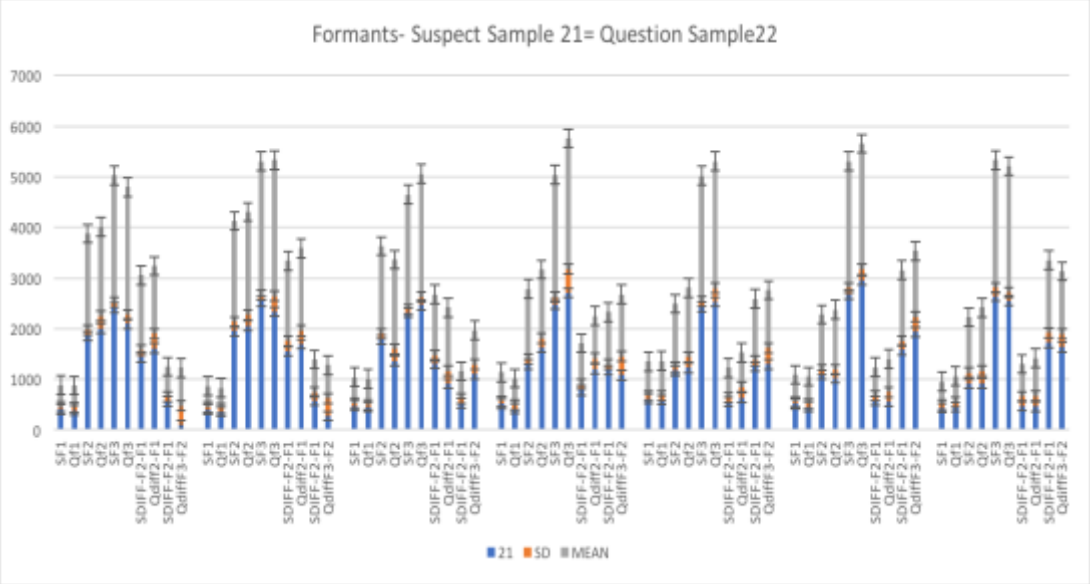


Chart 4.111 : A comparison of F1, F2, F2-F1, F3-F2 between SS21 and QS22 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

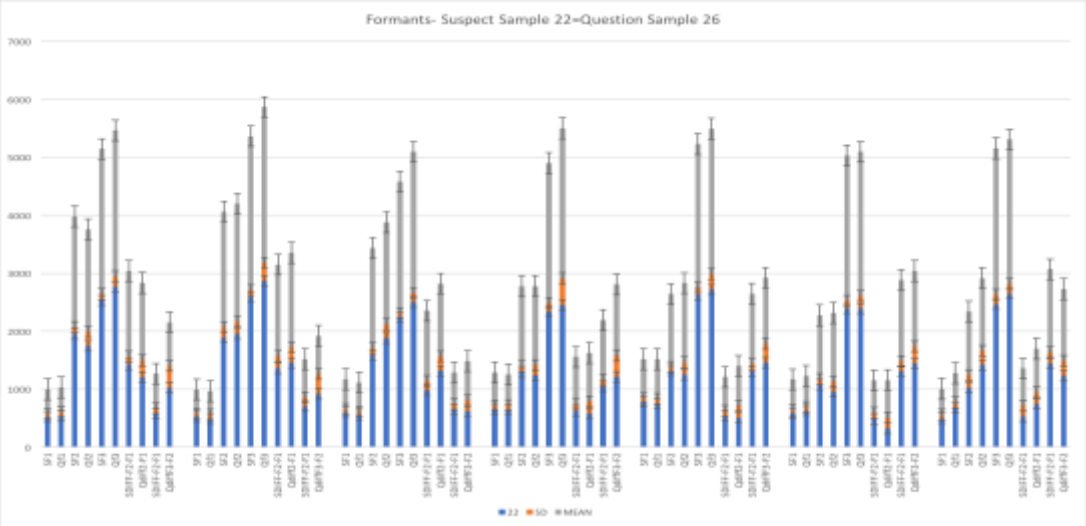


Chart 4.112: A comparison of F1, F2, F2-F1, F3-F2 between SS22 and QS26 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 4, 5, 6, and 7. Vowel 3 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

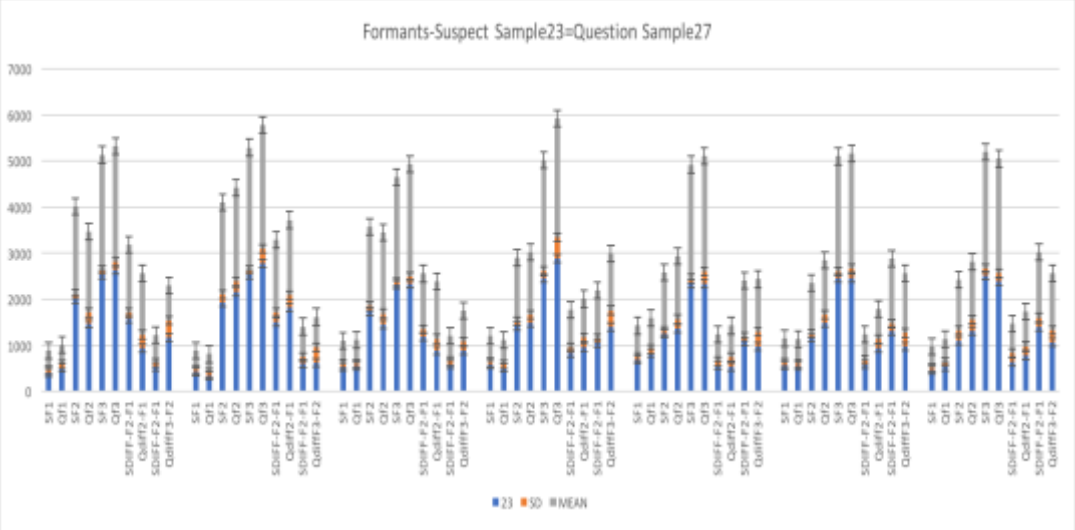


Chart 4.113 : A comparison of F1, F2, F2-F1, F3-F2 between SS23 and QS27 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

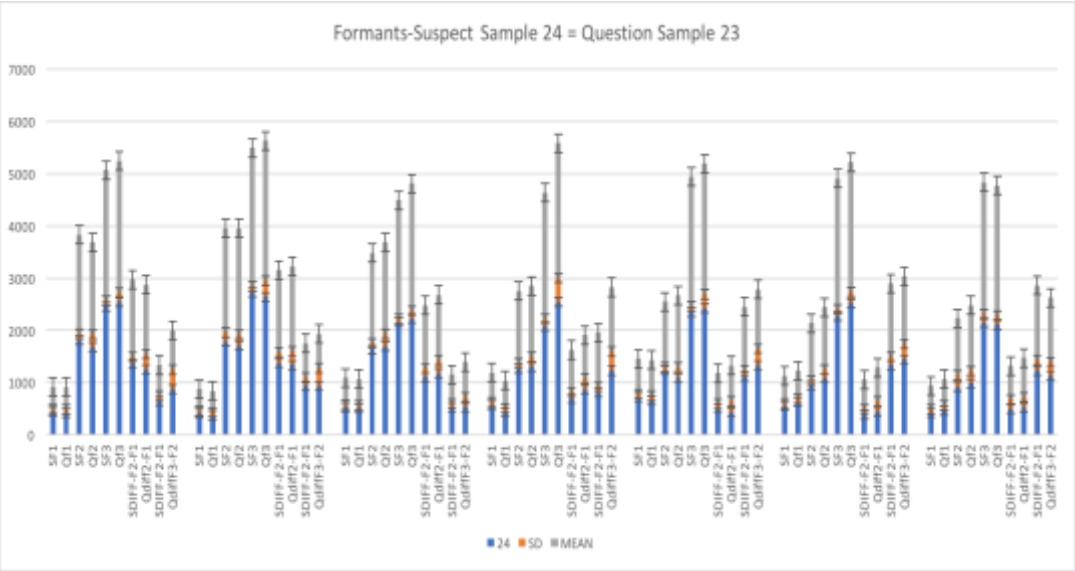


Chart 4.114: A comparison of F1, F2, F2-F1, F3-F2 between SS24 and QS23 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for all seven vowels.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

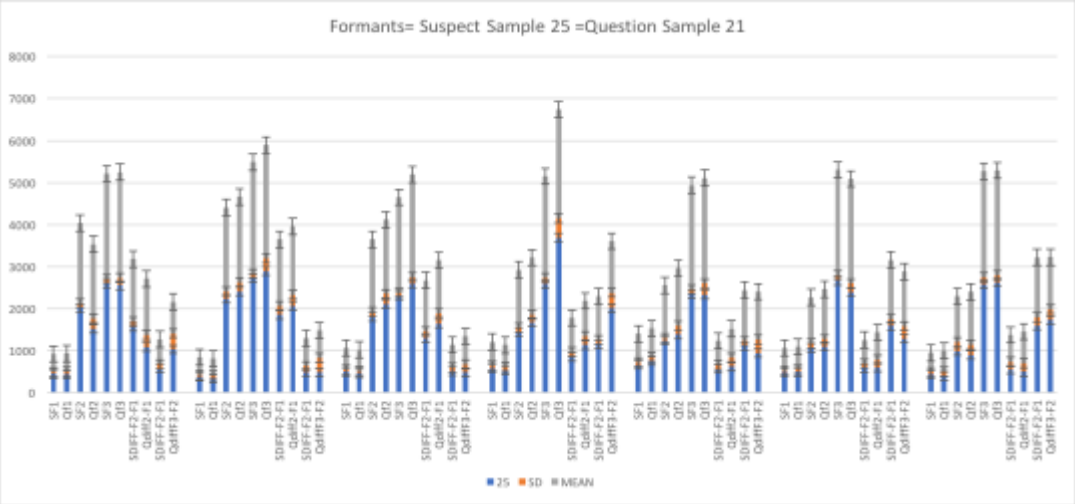


Chart 4.115 : A comparison of F1, F2, F2-F1, F3-F2 between SS25 and QS21 along with language mean values and Standard Deviation

1. F1, F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

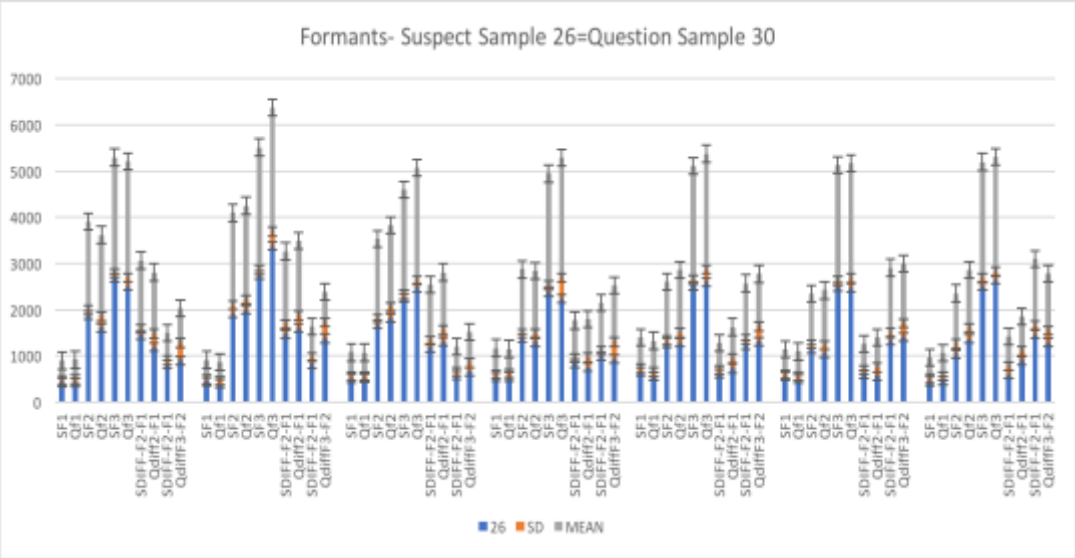


Chart 4.116 : A comparison of F1, F2, F2-F1, F3-F2 between SS26 and QS30 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for all seven vowels.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

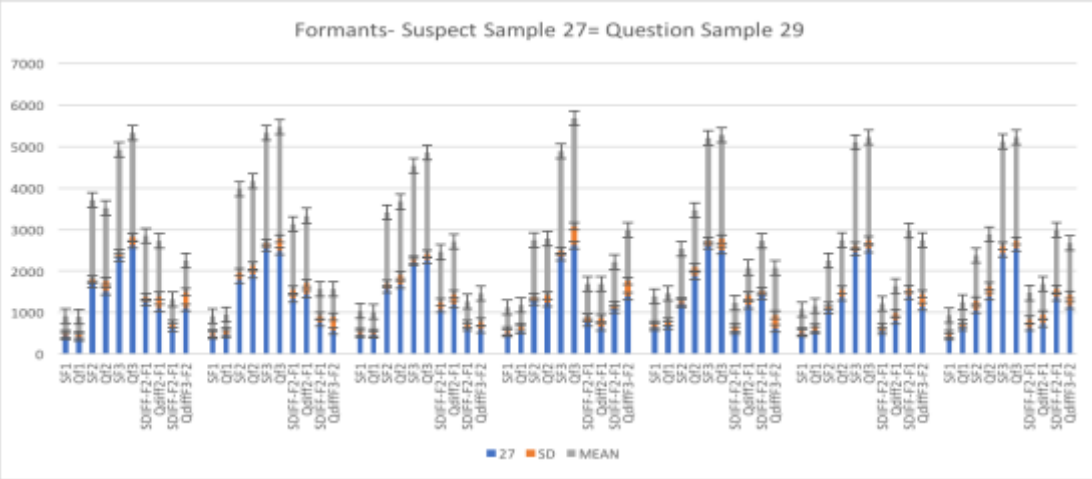


Chart 4.117: A comparison of F1, F2, F2-F1, F3-F2 between SS27 and QS29 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

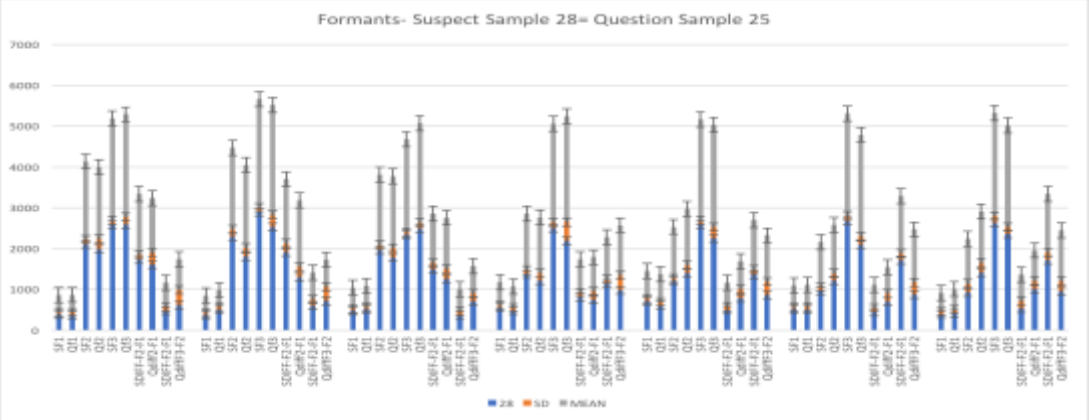


Chart 4.118 : A comparison of F1, F2, F2-F1, F3-F2 between SS28 and QS25 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 1, 3, 4, 5, 6, and 7. Vowel 2 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

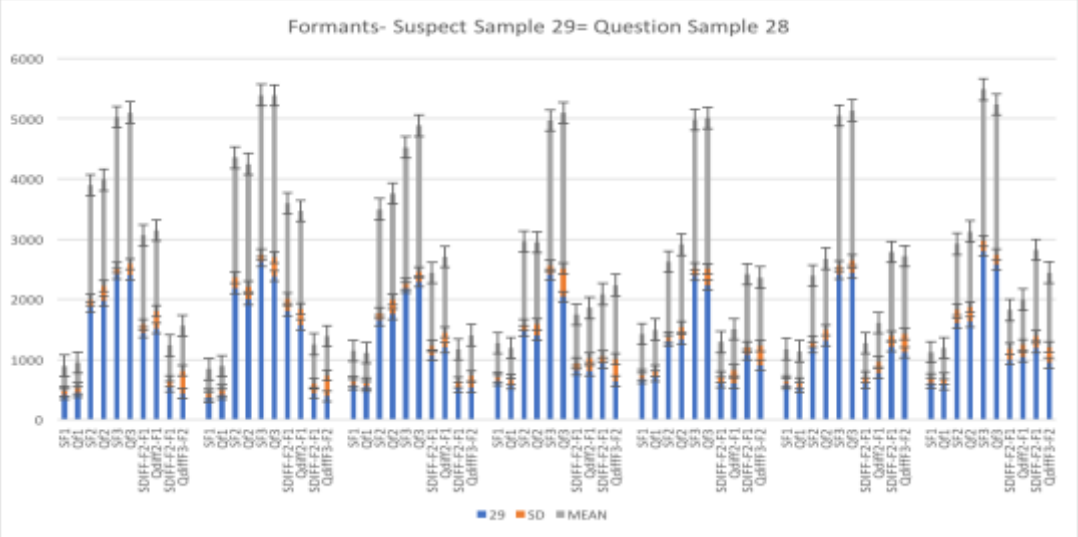


Chart 4.119: A comparison of F1, F2, F2-F1, F3-F2 between SS29 and QS28 along with language mean values and Standard Deviation

1. F1, F2,and F2-F1 values are remaining consant for vowel, 1, 2, 4, 5, 6, and 7. Vowel 3 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

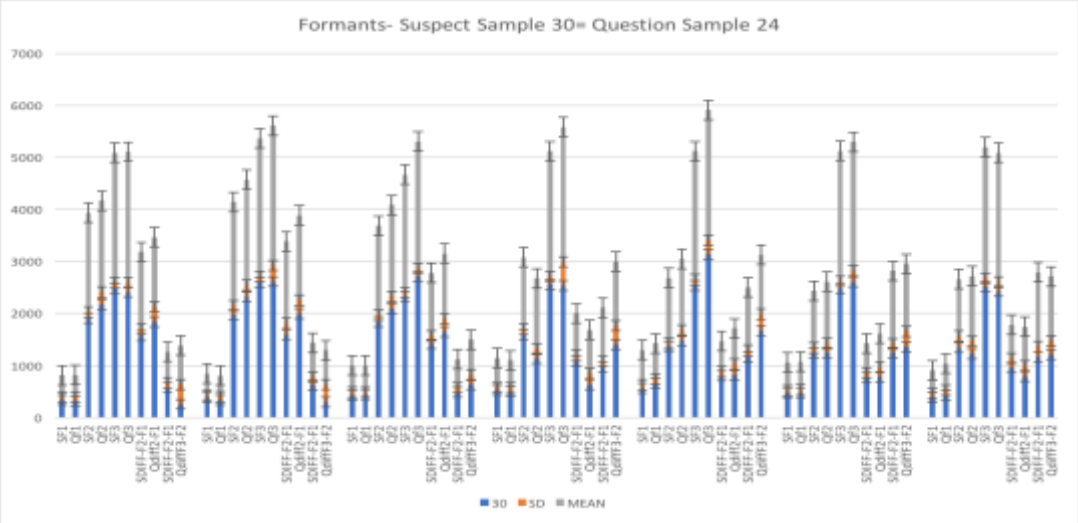


Chart 4.120 : A comparison of F1, F2, F2-F1, F3-F2 between SS30 and QS24 along with language mean values and Standard Deviation

1. F1,F2 and F2- F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

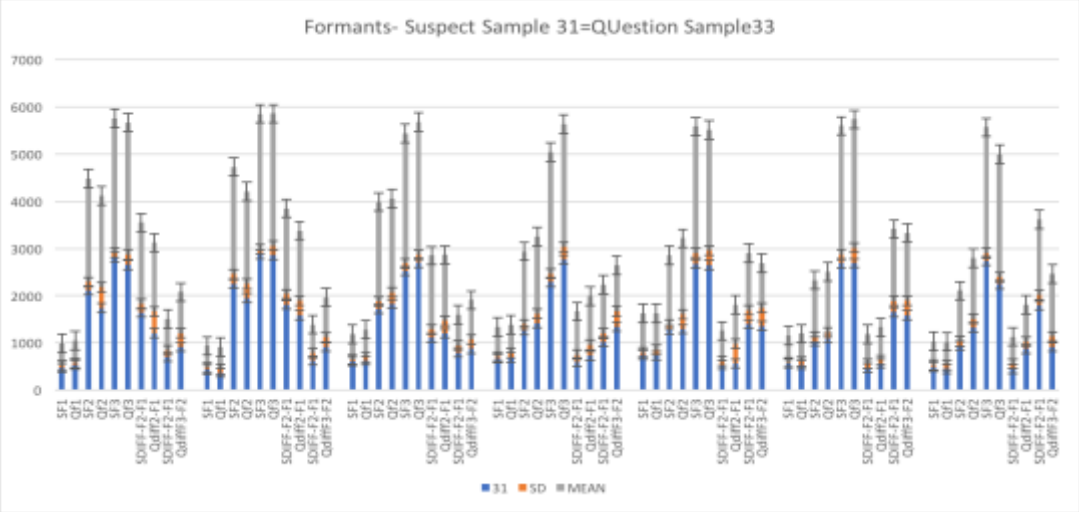


Chart 4.121: A comparison of F1, F2, F2-F1, F3-F2 between SS31 and QS67 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel 1, 2, 3, 4, 5, and 6. Vowel 7 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

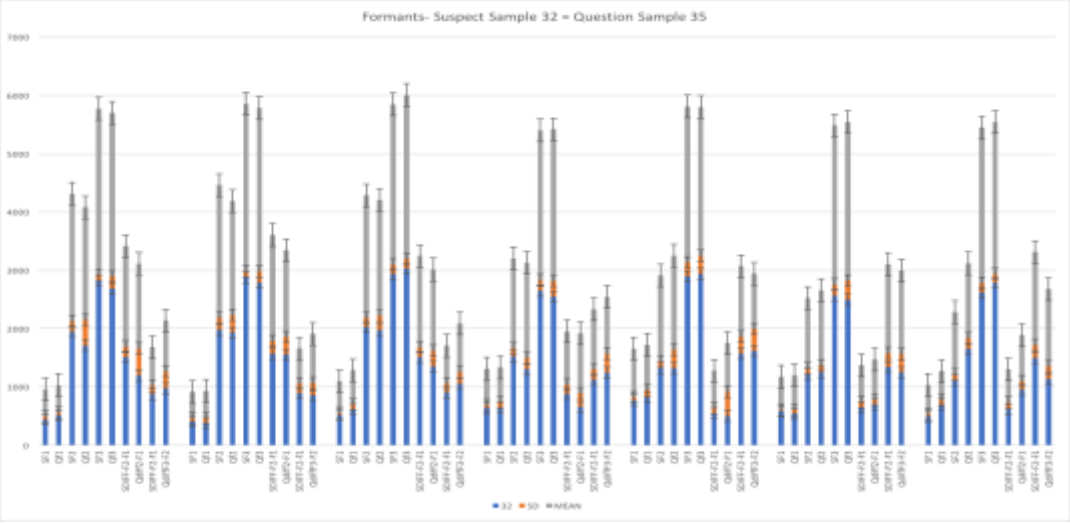


Chart 4,122: A comparison of F1, F2, F2-F1, F3-F2 between SS32 and QS35 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel,1, 2, 3, 4, 5, and 6. Vowel 7 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

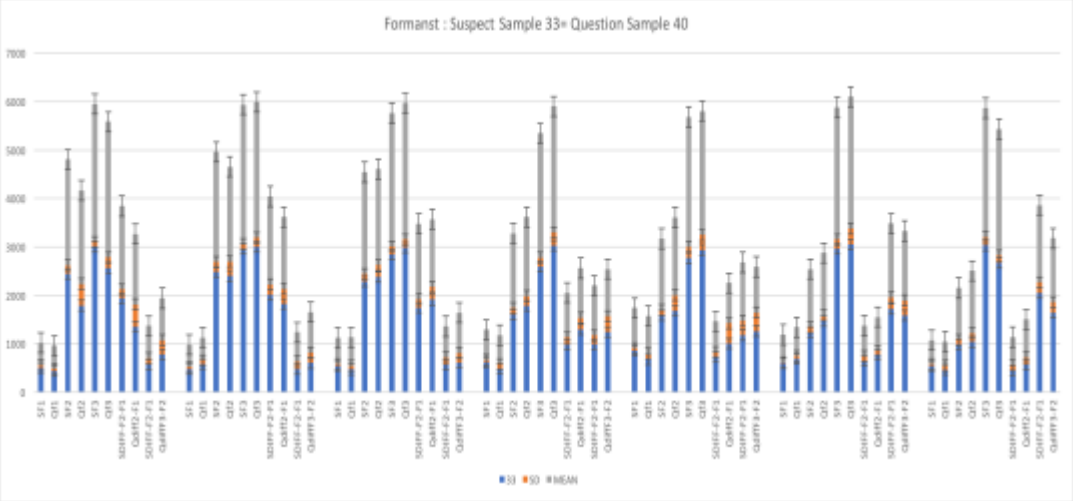


Chart 4.123: A comparison of F1, F2, F2-F1, F3-F2 between SS33 and QS40 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 2, 3, 4, 5, 6, and 7. Vowel 1 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

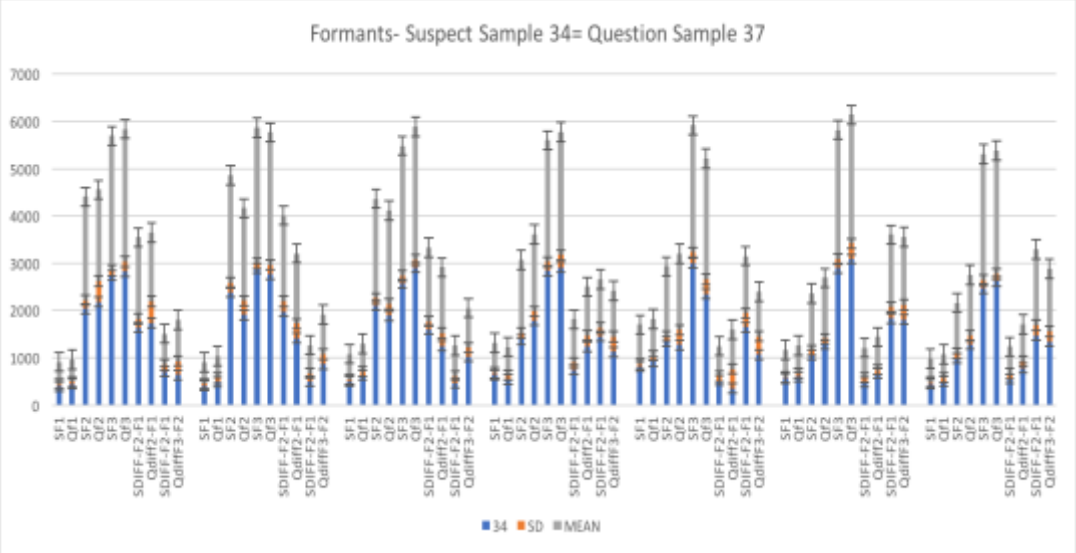


Chart 4.124: A comparison of F1, F2, F2-F1, F3-F2 between SS34 and QS37 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 1, 3, 4, 5, 6, and 7. Vowel 2 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

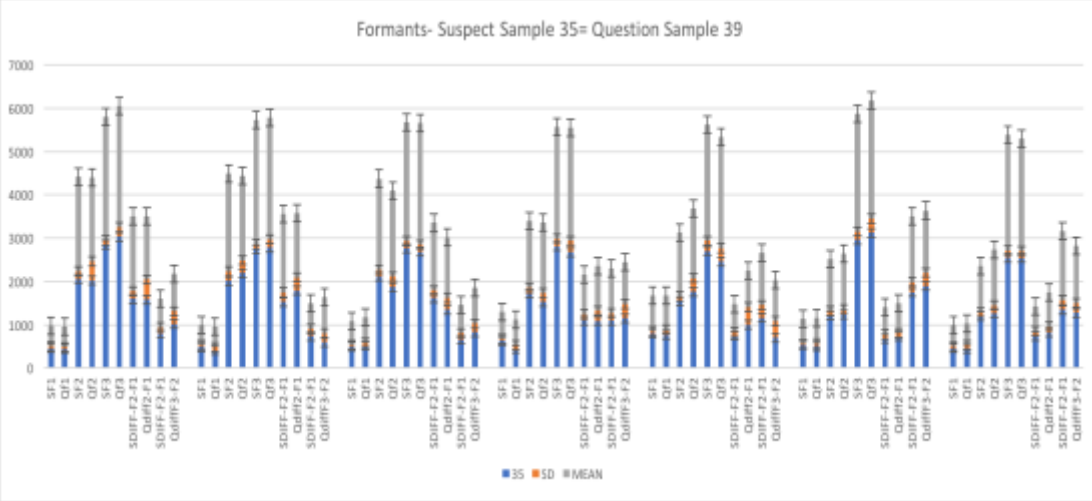


Chart 4.125: A comparison of F1, F2, F2-F1, F3-F2 between SS35 and QS39 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for all seven vowels.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

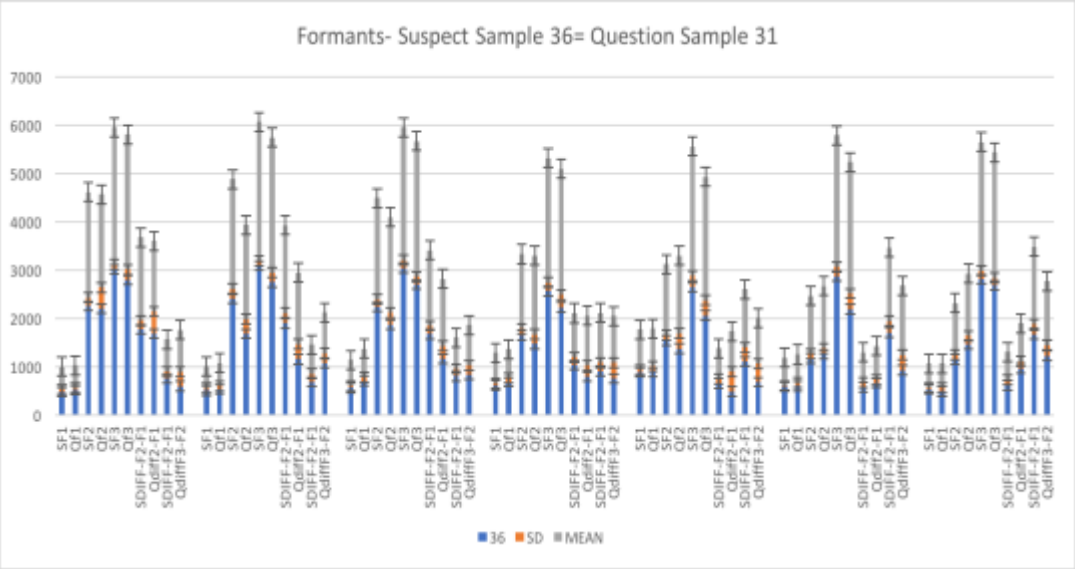


Chart 4.126: A comparison of F1, F2, F2-F1, F3-F2 between SS36 and QS31 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 1, 3, 4, 5, 6, and 7. Vowel 2 is showing very high margin between SS and QS. This can be a speaker specific feature.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

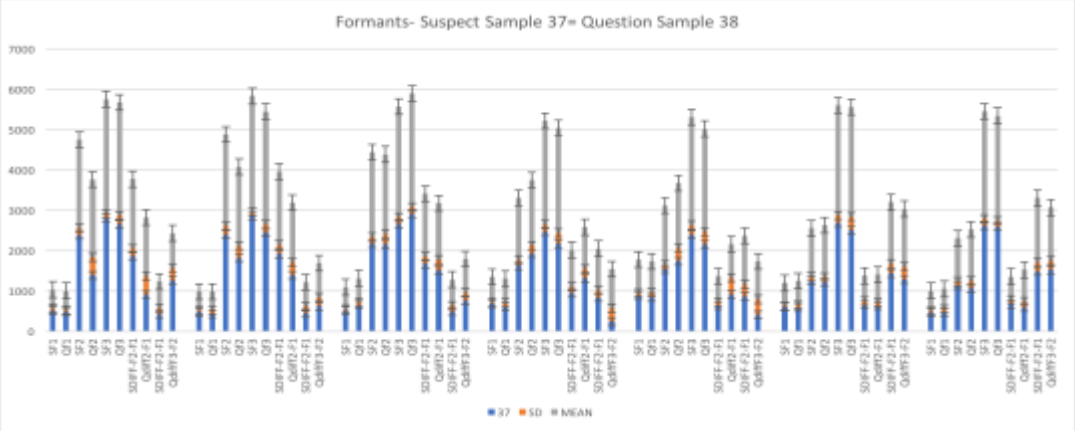


Chart 4.127: A comparison of F1, F2, F2-F1, F3-F2 between SS37 and QS38 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 3, 4, 5, 6, and 7. Vowels 1and 2 are showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

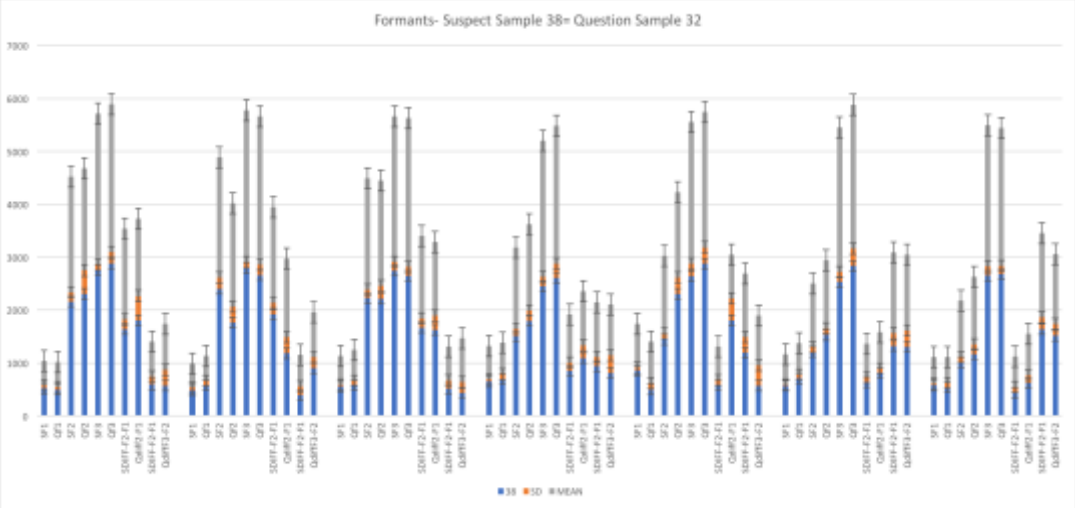


Chart 4.128: A comparison of F1, F2, F2-F1, F3-F2 between SS38 and QS32 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 1, 3, 4, 6, and 7. Vowels 1 and 5 are showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

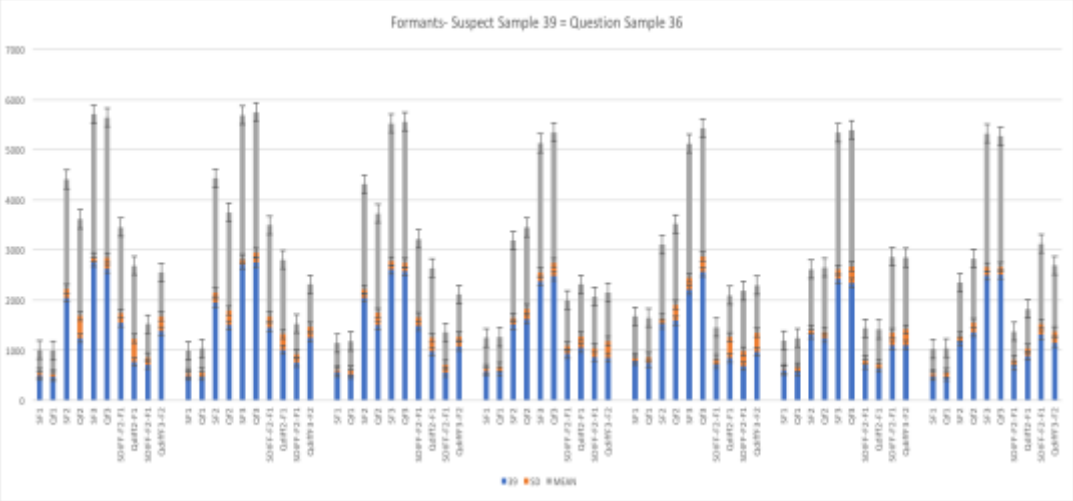


Chart 4.129 : A comparison of F1, F2, F2-F1, F3-F2 between SS39 and QS36 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 4, 5, 6, and 7. Vowels 1, 2, and 3 is showing some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

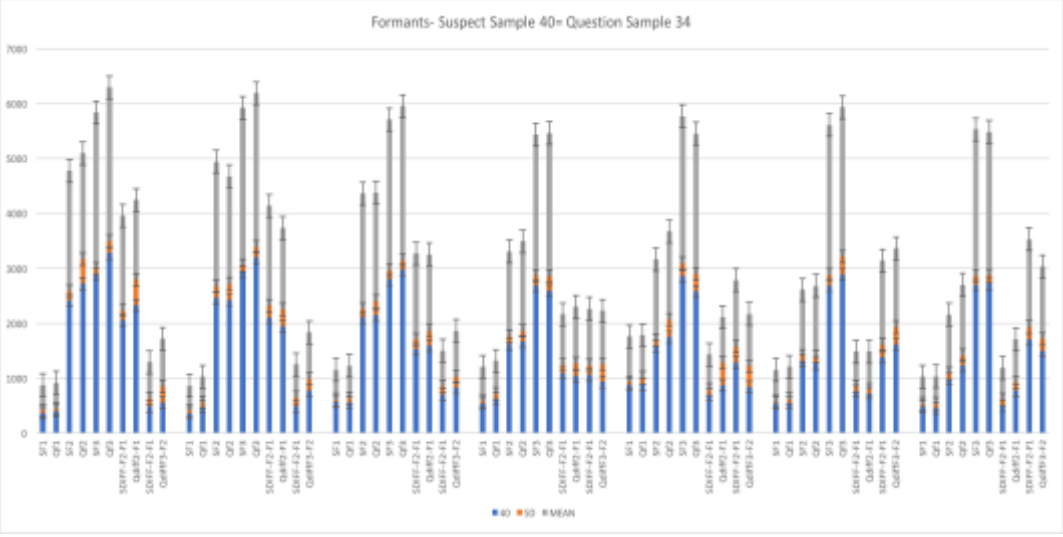


Chart 4.130: A comparison of F1, F2, F2-F1, F3-F2 between SS40 and QS34 along with language mean values and Standard Deviation

1. F1,F2 and F2-F1 values are remaining consant for vowel, 3, 4, and 6. Vowels 1, 2, 5, and 7 showed some differences in Question Sample and Suspect Sample.
2. The F3- F1 are different for two speakers, for almost every vowel. Since the F2 is consistent, the changing difference values shows that F3 is changing.

4.4 Results

After all the required acoustic analyses were conducted, the accuracy of the results was checked. As mentioned in the chapter Research Methodology, two sets of data were created for the purpose of current research. The known sample which is marked as the suspect sample and the unknown sample which is called Question Sample in forensic terms. The suspect sample was retrieved from an ideal environment created by the researchers. They were given a word list and the participants were asked to utter those words. For the second set, Question sample researcher extracted sounds in an interview manner and they were jumbled by another researcher in order to avoid any pre-determined biases. But the original data was also kept aside to check the accuracy results later on. Once the entire analysis was conducted the accuracy was checked.

4.4.1 Effects of Nasalization on Vowel Formants

Nasalization has spectral effects on modifying vowels heights. A person's nasalized voice has often showed acoustic graphs similar to a graph made by a voice, where speaker consciously modifies his or her own voice. Vowel heights are often affected by nasalization of the vowel. Nasalization of vowel happens when the velum is lowered and the air passes through the nasal cavity. A nasalized vowel has quality of changed vowel height. As mentioned earlier, vowel height is perceived with F1 in spectral analysis. The current study had few speakers, whose voices were identified as nasal voice. This section is going to look into the voice analysis of these people, and what effect, if any, did nasalization laid on these particular samples.

Suspect Sample, 2, 3, 4, 8, 10, 12, and 13 from Brahmin Variety and Speaker, 33 from Bishnoi Speakers very identified as nasal voice from the suspect samples and Question

Sample, 10, 1, 6, 5, 4 14 and 17 from Brahmin Variety and Speaker 40 from Bishnoi Variety were identified as nasal voices.

The major effects of vowel nasalization which were notification in these samples were;

1. Difference between vowel height in suspect sample and question for vowel /i/ in all the speakers which were identified as nasal by the listeners. (See chart 4.13, 4.14, 4.15,4.16,4.17, 4.18,4.24,4.25,4.28,4.29,4.32,4.33,4.34,4.35)
2. Vowel /a/ showed height difference between suspect sample and question sample for most of the speakers. (See chart 4.13, 4.14, 4.15,4.16,4.17, 4.18,4.24,4.25,4.28,4.29,4.32,4.33,4.34,4.35
3. The same difference is visible in suspect sample 33 and 40 of Bishnoi speakers. (See chart 4.76)
4. The vowel height is considerably low for these speakers, comparing to other speakers from the same variety. Which is clearly visible in their SD and mean F1 charts. Even though the values of QS and SS are matching in most of them the values are lower than the rest of the speakers' F1.
5. The vowel height has also affected, F2-F1 for these speakers.

Acoustic theory of vowel nasalization states that F1 in an oral vowel is replaced by the shifted nasal vowel F1'(Fant. 1960: FUjimura & Lindqvist. 1971: Stevens. Fant, & Hawkins. 1986), this effects shifts the F1 frequency and which results in decrease of vowel height. The current pattern of decrease in vowel height of Marwari speakers can be explained with this theory. An investigation conducted by Wright (Wright, 1975, 1986) also showed that the presence of a nasal formant affects the vowel height of the perceived nasal formant height.

According to the original sets the following results were discovered;

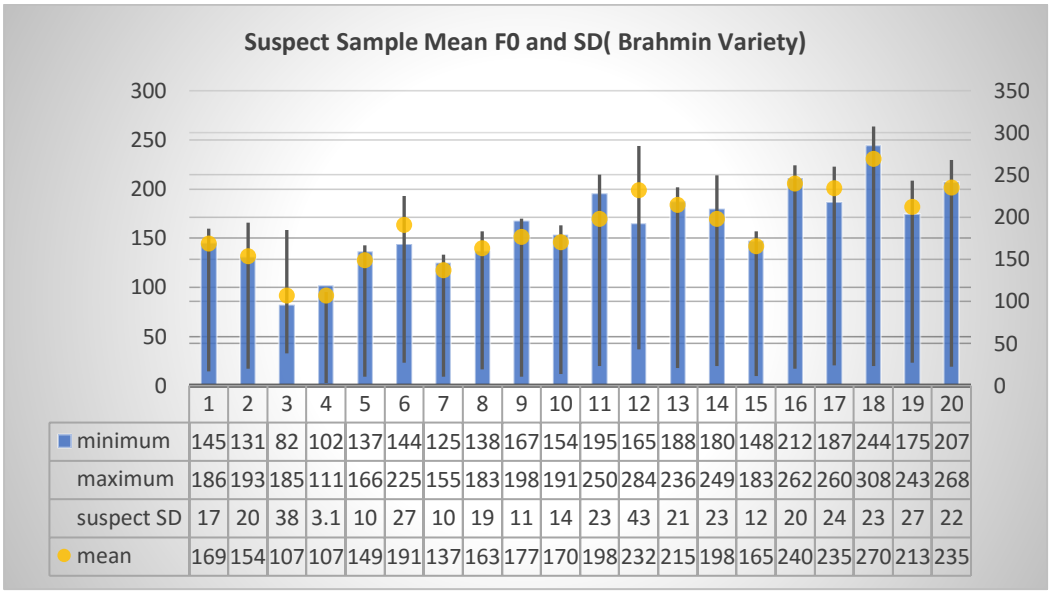
1. Suspect Sample 1 was Question Sample 3
2. Suspect Sample 2 was Question Sample 10
3. Suspect Sample 3 was Question Sample 1
4. Suspect Sample 4 was Question Sample 6
5. Suspect Sample 5 was Question Sample 9
6. Suspect Sample 6 was Question Sample 2
7. Suspect Sample 7 was Question Sample 8
8. Suspect Sample 8 was Question Sample 5

9. Suspect Sample 9 was Question Sample 7
10. Suspect Sample 10 was Question Sample 4
11. Suspect Sample 11 was Question Sample 12
12. Suspect Sample 12 was Question Sample 14
13. Suspect Sample 13 was Question Sample 17
14. Suspect Sample 14 was Question Sample 16
15. Suspect Sample 15 was Question Sample 11
16. Suspect Sample 16 was Question Sample 13
17. Suspect Sample 17 was Question Sample 15
18. Suspect Sample 18 was Question Sample 18
19. Suspect Sample 19 was Question Sample 19
20. Suspect Sample 20 was Question Sample 20
21. Suspect Sample 21 was Question Sample 22
22. Suspect Sample 22 was Question Sample 26
23. Suspect Sample 23 was Question Sample 27
24. Suspect Sample 24 was Question Sample 23
25. Suspect Sample 25 was Question Sample 21
26. Suspect Sample 26 was Question Sample 30
27. Suspect Sample 27 was Question Sample 29
28. Suspect Sample 28 was Question Sample 25
29. Suspect Sample 29 was Question Sample 28
30. Suspect Sample 30 was Question Sample 24
31. Suspect Sample 31 was Question Sample 33
32. Suspect Sample 32 was Question Sample 35
33. Suspect Sample 33 was Question Sample 40
34. Suspect Sample 34 was Question Sample 37
35. Suspect Sample 35 was Question Sample 39
36. Suspect Sample 36 was Question Sample 31
37. Suspect Sample 37 was Question Sample 38
38. Suspect Sample 38 was Question Sample 32
39. Suspect Sample 39 was Question Sample 36
40. Suspect Sample 40 was Question Sample 34

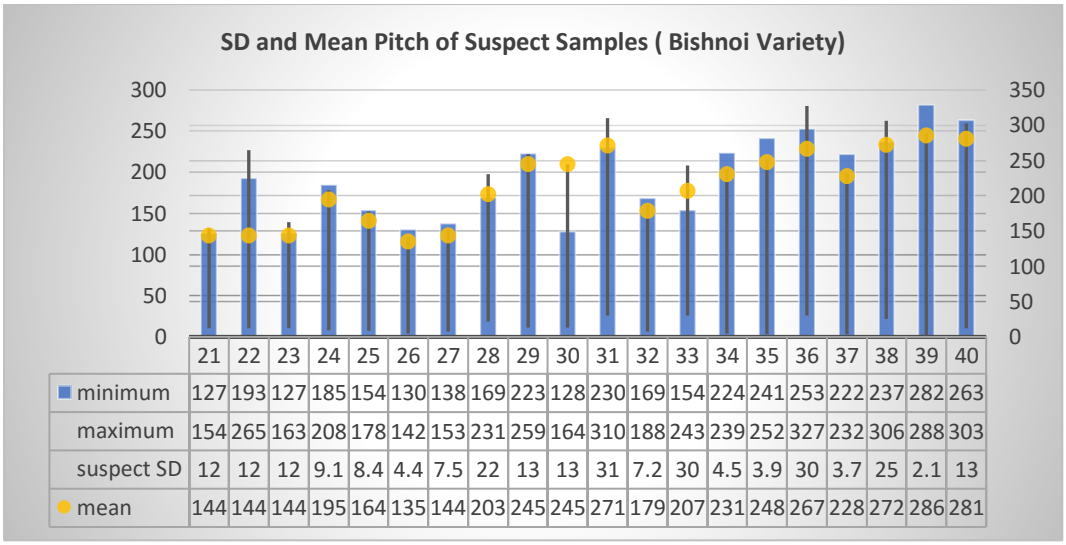
When each and every parameter was observed carefully, following conclusions were made;

The auditory comparison showed us that in a simple conversation, listener can identify the voice of the speaker by their profile. A new hypothesis was formed on the basis of that which included the list of participants, along with their expected question samples. The hypothesis was tested through the help of the acoustic parameters and every participant was individually tested on the basis of various factors. After the analysis, it was revealed that, the accuracy of auditory analysis was not hundred percent for the current research. There was one case when the listener identified the voice of female 82-year-old lady speaker as a male participants. This research was conducted on a very ideal environment, so the results of auditory analysis were quite positive. But in a criminal enquiry, the investigator cannot fully depend on the auditory analysis. Because sometimes the suspects modify their voices intentionally as well.

1. The mean F0 of speakers from varieties helped identifying the gender differences acoustically.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
minimum	145	131	82	102	137	144	125	138	167	154	195	165	188	180	148	212	187	244	175	207
maximum	186	193	185	111	166	225	155	183	198	191	250	284	236	249	183	262	260	308	243	268
suspect SD	17	20	38	3.1	10	27	10	19	11	14	23	43	21	23	12	20	24	23	27	22
mean	169	154	107	107	149	191	137	163	177	170	198	232	215	198	165	240	235	270	213	235



	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
minimum	127	193	127	185	154	130	138	169	223	128	230	169	154	224	241	253	222	237	282	263
maximum	154	265	163	208	178	142	153	231	259	164	310	188	243	239	252	327	232	306	288	303
suspect SD	12	12	12	9.1	8.4	4.4	7.5	22	13	13	31	7.2	30	4.5	3.9	30	3.7	25	2.1	13
mean	144	144	144	195	164	135	144	203	245	245	271	179	207	231	248	267	228	272	286	281

2. The comparison of F0 within the variety helped marking the individual samples to their respective counterparts in the QS. The Speaker 31 and speaker 33 are put at the matching position because they are not matching to any other speaker's SD and mean. Similarly, there were some speakers who showed high range of maximum to minimum F0 values, and different from their Question Samples. This proved that only depending on SD and Mean F0 can be problematic for any forensic enquiry.
3. Almost every acoustic space chart had the vowels occupying the mean vowel space of the language. Even though there were few acoustic space charts which didn't match with their respective QSs.
4. The most conclusive results were acquired with the help of Formant charts, which included F1, F2, F3 diff F2- F1 and diff F3-F2. With almost 90 percent accuracy, the Suspect Samples and Question Samples matched with each other for the F1, F2 and F2-F1 values. Some vowels had a slight difference in their F1 and F2 values but the accuracy of other six vowels made it negligible. All the Suspect Samples matched with their respective Question Samples, on the basis of this.
5. The standard deviation was also constant and minimum for almost all the vowels.

Discussion:

Speaker Identification is an evolving field. People have been working on it for around half century now, but researchers have not achieved hundred percent accuracy in it. People keep comparing voice identification to fingerprint identification, but we have to understand these are two completely different fields. The later has a very few factors which can affect its outcomes but human voice identification is as difficult as finding the same fish in the ocean. There are n number of factors which can affect its results. Human mood, emotions, age, gender, height and even as simple factor as wind can affect voice recording and modify it or damage it drastically. So, a simple method of voice recognition is never going to be good enough for any voice investigation. This research is trying to find out one of those important factor, so that it can strengthen the voice identification process. F0 or pitch analysis has been there since the beginning of voice recognition researches. The importance of vowel height has also been established by the researchers for the forensic speaker queries. The current study takes the formant research one step further by looking at the frontness and backness of vowel identification. F2 or front-back characteristics of vowel depends on the consonant preceding it or following it. The research has been conducted on the grounds that even with all the variables in voice identification, it is F2 which remains constant or at least gives the positive outcomes while comparing two speaker's voices.

Chapter 5 Conclusion

5.1 Area of Study:

This chapter is going to summarize the experiments conducted in chapter four "Analysis" and the results of those experiments. The hypothesis written in the chapter one, section 1.7 is going to be re-examined in the lights of newly achieved results. To reproduce the reference of the hypothesis, the section has been repeated below;

As mentioned earlier, Speaker Identification had always been an area with numerous applications but the major component in any speaker identification study is to believe and try to prove that voice is unique for every individual. This proof is required to make speaker identification a valid field, so that voice samples can be treated as admissible evidence.

Among the various applications of speaker identification, is speaker profiling. Just by hearing the voice we can deduce the age, gender, height etc. This type of profiling helps in a criminal case where the identity of speaker is unknown and the only known thing we have about speaker is his or her voice.

5.1.1 Scope for current research

Voice analysis has many parameters but the first step was to divide these parameters on the basis of auditory parameters and acoustic parameters. Auditory analyses consisted of various features, for example: speaking mode of the speaker, speaker's respiratory form or pitch level etc. On the other hand, in acoustic analysis the focus is on the visual representation of the voice. When analysing voice acoustically we focused on the pitch, frequency and formant harmonics.

The current acceptable mode of voice identification is to combine both auditory and acoustic parameters. The current research combined both auditory and acoustic parameters. Auditory analysis preceded the acoustic analysis. For current research the set parameters for the auditory analysis were analysed first. After that we moved towards the acoustic parameters. The main aim of this research was to find out the one unique feature which can improve the accuracy of forensic speaker identification. After distinguishing proper auditory parameters, we looked into the acoustic parameters. The formant frequencies of vowels were the focus of current study.

This research was going to help us develop a proper analysing method for voice recognition. Vowel analysis has always been an important factor in forensic speaker identification. This research will contribute to the vast history of vowel analysis. By

combining both auditory and acoustic parameters, the probability of improvement will increase. This can help us narrow down the features which might help in future forensic speaker identification.

5.1.2 Objective of Research

as mentioned in chapter one, many scholars have argued that changing the vowel pattern while uttering a sound is very difficult. Consonants can easily be modified but vowels are very speaker specific. Numerous researches have been conducted on the following topic. The objective of current research was to develop on the findings from previous researches by combining two different approaches together.

The research revolved around the question that which features of voice are important for forensic speaker identification. Both auditory and acoustic analysis will be conducted on the voice samples of the subjects to find out the answers to these questions.

If every individual has a unique articulatory manoeuvre, then the filters i.e. different articulators should always produce similar results. The formant frequencies will always have the similar results. The genetic features are like the shape of our vocal tract whereas the acquired features are like phonology of our L1, individual acquired articulation habits. Manner of articulation also changes with age. Socio-psychological factors can also affect the way a person utters a particular sound. There are so many factors which can affect our speech production. This research checked one of these factors i.e. what are features that remains constant while producing a same or similar speech samples in different contexts.

5.1.3 General research Question

We have discussed this field and all the problems associated with it in great extent. So far, the discussion has pointed out that Voice pattern of every human is unique. There are genetically hardwired features which makes it a unique. These genetically hardwired features have major impact on our speech production. No matter what our condition is, changing these features is not possible. When a vowel is produced, there are three components which are responsible for its form; height, length and position. F1 represented the height of the vowel and F2 represented the position. The difference between F2 and F1 represented how back the vowel is. The current study looked deeply into the vowels produced by Marwari speakers at different syllable positions and

analyzed the change in formant frequencies. There are many articulatory factors which affected the production of a vowel. Nasalized vowels are one of them. These vowels along with their articulatory modifications we saw whether that their formant frequencies have changed. The features like pitch, tone and accent can easily be modified but a person cannot change his or her articulator. These formant harmonics are the representation of the filters which are affecting voice productions. These formant frequencies should be unchangeable. This study tried to identify formant values for vowels and see if we change the pitch and other formants remains constant or not.

The relevant research questions for the proposed dissertation are:

1. How do the genetically hardwired features make the voice pattern of every human unique?
2. What aspects of F1 and F2 are helpful in identifying language specific or variety specific sections of an ethnic group?
3. How does F0 measure help in increasing the accuracy of identifying these ethnic groups?
4. How do parameters vowel height, vowel position and nasalization can affect the identification process of the given ethnic groups?
5. Are the formant frequencies affected by the position of vowels (syllable positions)?
6. What is the role of F2 and F2-F1 in increasing the accuracy of speaker identification?

Hypothesis

The values of F2 and F2-F1 determine the position of vowels in the vocal cavity. Changing this position consciously is very difficult, which means that F2 and F2-F1 should be unchanging for every individual. Considering the constancy of these measures (negligible change which is statistically non-existent), improvement in the accuracy of speaker identification is possible by checking for these. By looking at the acoustic analysis of speech data of two distinct ethnic groups of Marwari speakers, we will attempt to justify the hypothesis.

5.2 Conclusion

The F0 and other formants have been the marker of vowel height, position and length. F0 represents the starting frequency of any sound, when it is produced in a human vocal

cavity. It has been proven that every human has his or her own dimensions, shape and a very unique vocal tract. So, when any sound wave is produced by human vocal tract, it gets affected by the person's unique speech mechanisms. The shape of vocal chords, the length of the wind pipe, the shape of oral or nasal cavity etc., all these things are very speaker specific. So, it has been assumed that any sound wave, which is produced by a human should have a unique print associated with it. Which can help the investigator to differentiate it from other's voices. Forensic Speaker Identification is a process which is primarily based on this ideology of voice being speaker specific. The current study was an attempt to see the importance of vowel formants in forensic speaker identification. As explained in the hypothesis, the major aspect of this study was to deal with the role of F2, and F2-F1 and see if it remains constant for the speaker in every context. The two contexts, which were taken for this study were, sound taken by the known speakers in an ideal environment, where there is not disturbance and the participants are provided with a world list and sounds taken by the unknown speakers in a conversation based environment where sounds are extracted from a normal conversation. The differences in these two environments were that, one of them had very few variables and the investigator knew the identity of the participants and in the second one the variables which can affect the quality of selected sound, were way to high and there were chances of the sound being distorted and unusable for the study. Both samples were compared acoustically along with auditory analysis, to see the resemblance and common factors in these samples. And look for the importance of F2 and F2-F1 in these analyses. The pitch analysis and acoustic space analysis was also conducted on the speakers to identify the gender and variety specific features. Standard deviation of every vowel was analyzed with respect to the standard deviation of the entire language's mean vowel frequencies. The closest matches were further analyzed and put in a graphical representation to make it easier to understand. The results found in this study are given below;

1. The first step was, auditory comparison which showed that in a simple conversation, listener can identify the voice of the speaker by their profile. The accuracy of auditory analysis was almost hundred percent for the current research. There was one case when the listener identified the voice of female 82-year-old lady as male speaker. This research was conducted on a very ideal environment, so the results of auditory analysis were quite positive. But in a

criminal enquiry, the investigator cannot fully depend on the auditory analysis. Because sometimes the suspects modify their voices intentionally as well.

2. The mean F0 of speakers from varieties helped identifying the gender differences acoustically.
3. The comparison of F0 within the variety helped marking the individual samples to their respective counterparts in the QS. The Speaker 31 and speaker 33 are put at the matching position because they are not matching to any other speaker's SD and mean. Similarly, there were some speakers who showed high range of maximum to minimum F0 values, and different from their Question Samples. This proved that only depending on SD and Mean F0 can be problematic for any forensic enquiry.
4. Almost every acoustic space chart had the vowels occupying the mean vowel space of the language. Even though there were few acoustic space charts which didn't match with their respective QSs.
5. The most conclusive results were acquired with the help of Formant charts, which included F1, F2, F3 diff F2- F1 and diff F3-F2. With almost 90 percent accuracy, the Suspect Samples and Question Samples matched with each other for the F1, F2 and F2-F1 values. Some vowels had a slight difference in their F1 and F2 values but the accuracy of other six vowels made it negligible. All the Suspect Samples matched with their respective Question Samples, on the basis of this.
6. The standard deviation was also constant and minimum for almost all the vowels.
7. There was difference between vowel height in suspect sample and question sample for vowel /i/ in all the speakers which were identified as nasal by the listeners.
8. Vowel /a/ showed height difference between suspect sample and question sample for most of the speakers who were identified as having a nasalized voice. The same difference is visible in suspect sample 33 and 40 of Bishnoi speakers.
9. The vowel height is considerably low for these speakers, comparing to other speakers from the same variety. Which is clearly visible in their SD and mean F1 charts. Even though the values of QS and SS are matching in most of them the values are lower than the rest of the speakers' F1.

10. Because of the nasalization of the speech the vowel height has also affected F2-F1 for the speakers.

The overall conclusion from the current study is that the speakers of the Brahmin variety had a general nasalized tone for almost 8 speakers. The Bishnoi speakers on the hand had a loud voice. The acoustic analysis for these varieties showed that the vowel /i/ and /I/ occupied a very close position in a vowel chart for the Brahmin variety and because of the nasalization, it becomes very difficult to differentiate between these two. Bishnoi speakers' loud and fast voice output created a higher mean pitch for the variety than that of Brahmin speakers.

Nasalization affected the F1 values of Brahmin speaker a lot. But in all these cases, the F2 remained somewhat unchangeable and provided positive results. In forensic speaker identification, for a nasalized voice it is better to look for the F2, which depicts the position of vowel in the mouth, i.e. how back or front the vowel is. So, we can say that through the help of the current study, it can be shown that F2 shows the highest level of accuracy for a nasalized voice and for a non-nasal oral voice, both F2 and F1 should be taken into consideration and to achieve more accurate results, the analysis should contain both auditory and acoustic analysis.

5.3 Limitations of the Present Study

The current research work has provided a great deal of learning experience to the researcher and hopefully, it will be as helpful for the reader as well. Even though the research was conducted in a very planned manner and with a lot of determination, there are some points which needs improvement. The first point is that, the data set used for the present research was huge and researcher has tried her best to analyse it in a given period of time. But there still a lot which can be done with the given set of data. The second limitation is that to acquire the Question Samples, researcher had to talk to them on random topics, and since the participants didn't know the researcher personally, they were little hesitant, which might affect the spontaneous purpose of the Question Sample. In real life, the accused are usually unware that they are being recorded so they are careless while speaking.

5.4 Future Scope

Though the current study has tried to cover every possible way of analysing the given data and looking for the role of F2 and F2- F1 in it, there were some possible analytical

modules which were not included in it. The most important thing which is missing from the data is the T-testing of the hypothesis, through a statistical programme. Vowel duration and amplitude analysis was also excluded from the research because of the time limitation. The large number of participants and analysing their data made it very difficult to cover every possible way of analysis on for this research.

In future, the researcher can also look for the likelihood ratio for the current study and make it statistically more accurate. LR can improve the strength of the data along with making it more scientifically accurate. One more addition which can be done to this research is that, the context in which the question sample has been collected can be increased, for example, to ensure the authenticity of the recording, a recorded speech from telephone conversation can be used as a question sample.

As it is said earlier there is always a scope of improvement in any study. The future researchers can take these suggestions or choose any other topic from the field of Forensic Speaker Identification, which will help improving the accuracy of voice recording in court and might make it as admissible as finger print. Every research done on this topic takes us to one step closer to the ultimate goal, which is "Making Voice Analysis as reliable as Finger Print Identification".

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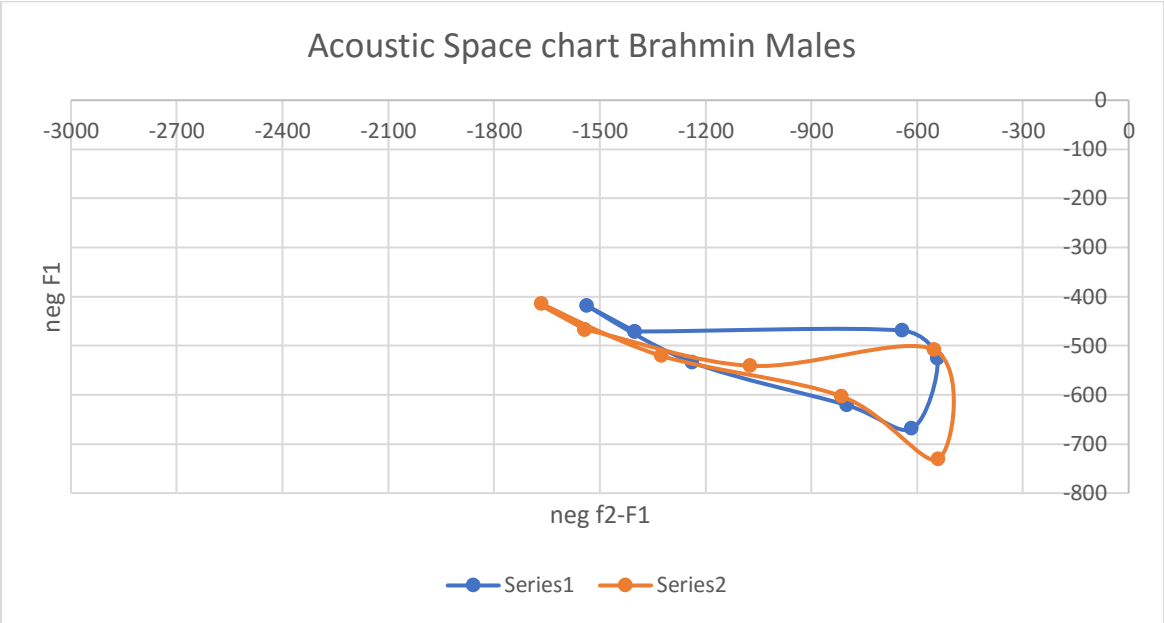
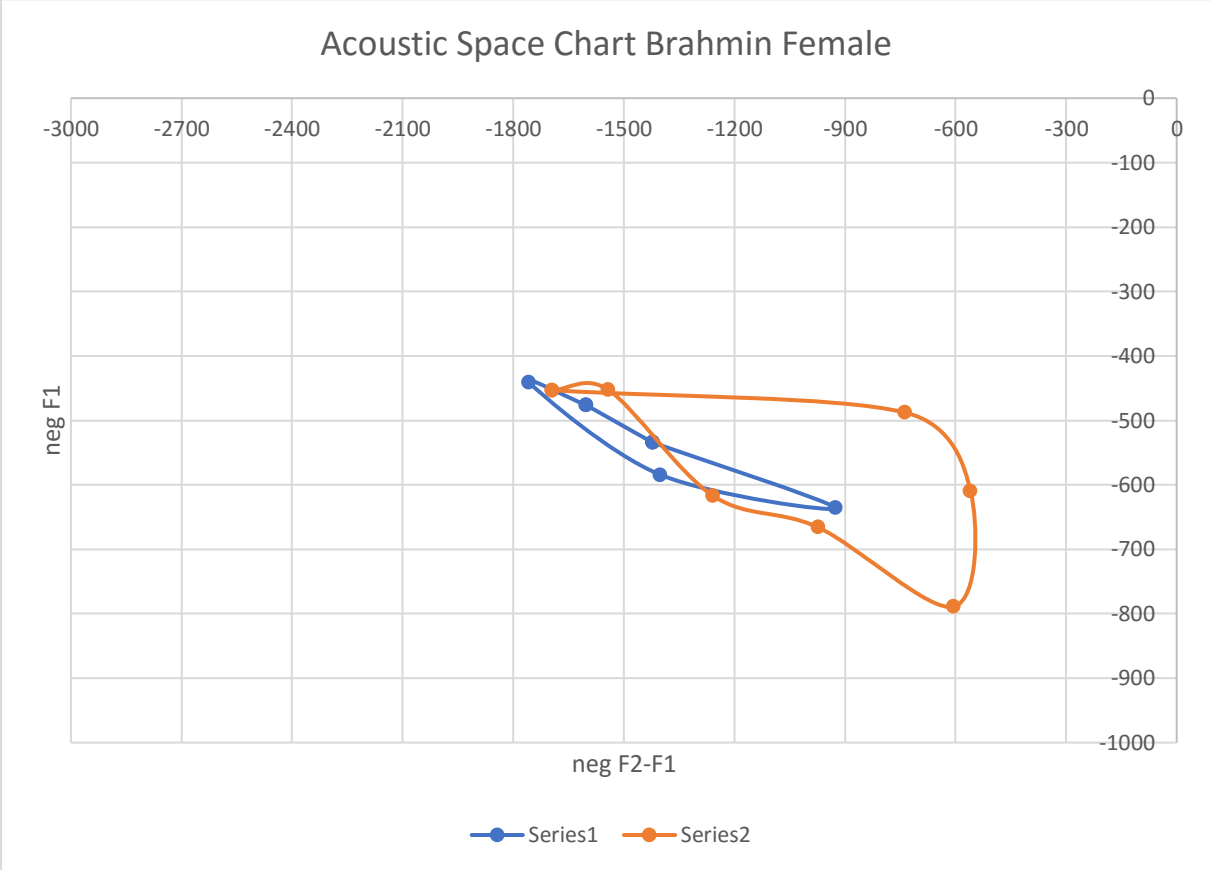
II. Appendix


Acoustic Space chart Brahmin Males
-3000
-2700
-2400
-2100
-1800
-1500
-1200
-900
-600
-300
0
-100
-200
-300
-400
-500
-600
-700
-800
neg F1
neg f2-F1
Series1
Series2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-2400
-2100
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-1500
-1200
-900
-600
-300
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-100
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-400
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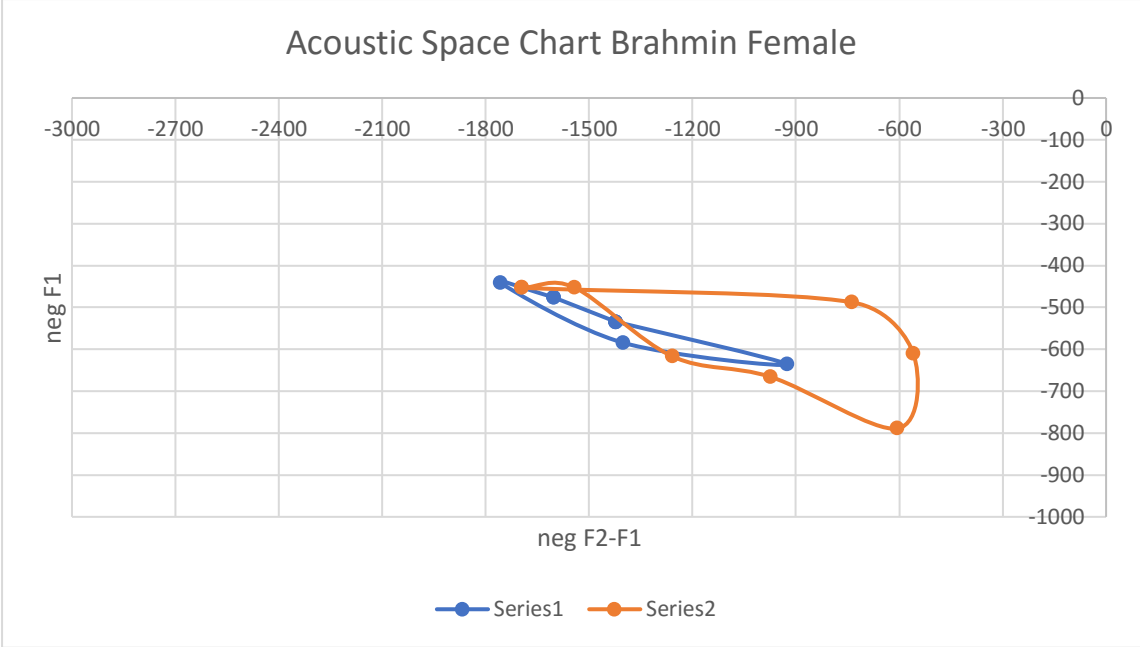
-600
-700
-800
-900
-1000
neg F1
neg F2-F1
Series1
Series2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-700
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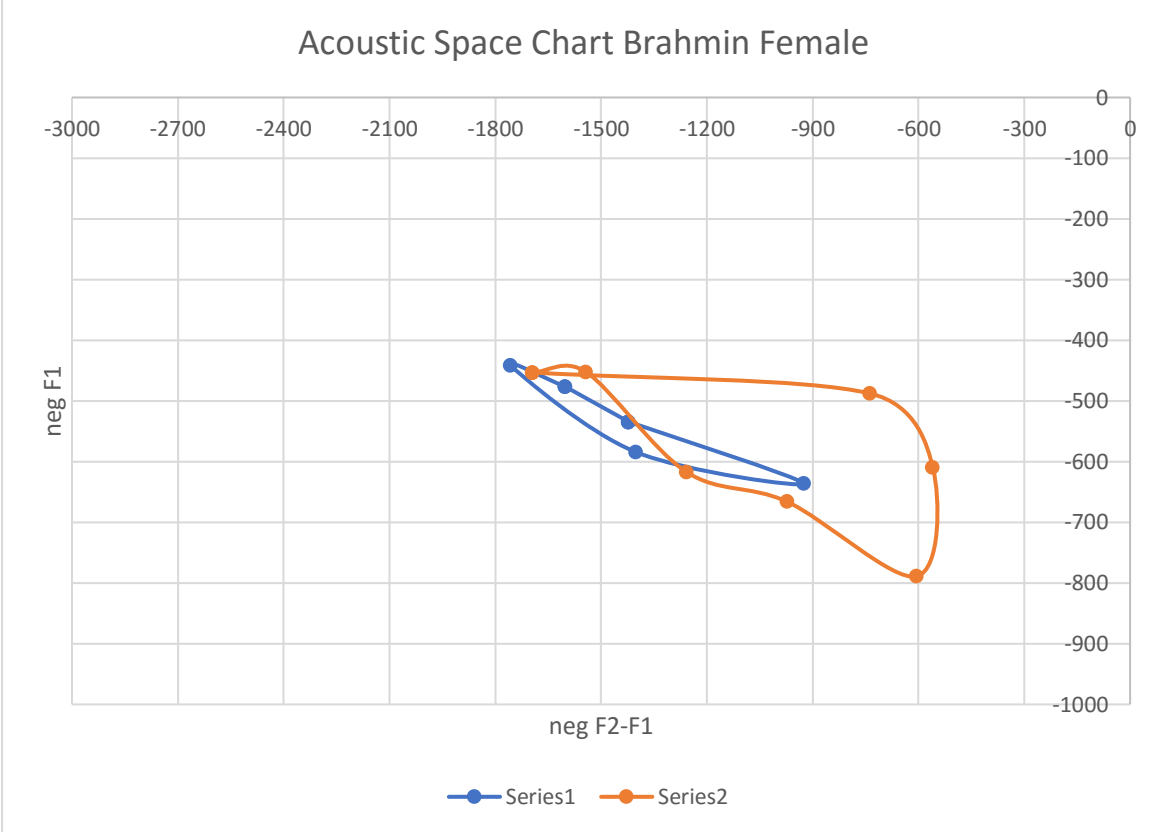
-1000
neg F1
neg F2-F1
Series1
Series2


Acoustic Space Chart Brahmin Female
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-2700
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-2100
-1800
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-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
neg F1
neg F2-F1
Series1
Series2

subject	vowel	sf0	sf1	sf2	sf3	sdiff f2-f1	sdiff f3-f2	qf0	qf1	qf2	qf3	difff 3-f2	difff 3-f2
1	**I**	145.187882	363.804754	2264.271345	2837.561573	1900.466594	573.290228	165.359356	352.090429	2364.665505	3113.853213	2012.575084	749.187708
1	**i:**	175.903096	410.221808	2374.113712	3197.782594	1963.891903	823.668882	168.676768	413.541395	1926.25855	2909.055822	1512.704411	982.797272
1	**ɛ**	175.903096	475.367581	2123.754138	2733.696133	1648.38678	609.941995	166.476110	531.268719	1557.296109	2715.949868	1026.02739	1158.653759
1	**ə**	180.703867	600.913996	1378.031363	2500.92656	777.1173694	1122.895197	148.442605	591.982417	1280.771181	2525.50726	688.7887633	1244.736079
1	**a**	145.187882	766.122135	1239.342672	2428.364117	473.2205365	1189.021445	135.373393	704.409273	1227.127462	2456.840809	522.7181884	1229.713347
1	**o**	171.142098	514.393429	991.0749865	2444.435754	476.6815574	1453.360768	148.153386	541.897048	1100.5972	2448.178059	558.6992952	1347.580859
1	**u**	186.158399	409.532029	992.7781363	2460.474109	583.2461073	1467.695973	164.480646	437.805526	1140.914963	2492.169014	703.1094364	1351.254051
2	**I**	143.846495	416.987821	1972.810675	2390.652223	1555.822854	417.841548	168.512457	423.867102	1714.446016	2318.719233	1290.578914	604.273217
2	**i:**	150.321919	413.320581	2012.207065	2425.148461	1598.886807	412.941396	129.904775	403.041536	1941.555241	2303.822584	1538.513704	362.267343
2	**ɛ**	193.301666	613.707853	1846.603603	2448.827248	1232.895749	602.223645	104.617206	594.500958	1520.697919	2518.176065	926.1969603	997.478146
2	**ə**	163.902073	598.966804	1323.037621	2475.561656	724.0708206	1152.524035	152.283366	582.758294	1149.907408	2555.931839	567.149114	1406.024431
2	**a**	131.234748	659.280704	1175.839225	2540.277746	516.5583546	1364.438521	129.118483	645.795028	1256.741195	2626.552801	610.9461668	1369.811606
2	**o**	139.691389	499.357236	1028.611311	2481.259878	529.2540734	1452.648567	136.627698	572.129115	977.7240438	2552.04501	405.5949281	1574.320966
2	**u**	152.854246	515.116392	875.4083829	2644.559043	360.2967437	1769.15066	159.230221	574.686528	1427.489899	2646.312712	852.8033706	1218.822813
3	**I**	87.3460533	344.583627	2046.210477	2610.104375	1701.62685	563.893898	205.131583	397.893526	1822.789202	2565.032372	1424.895676	742.24317
3	**i:**	91.0258690	351.304720	2145.171461	2806.993136	1793.86674	661.821675	90.3997676	362.829644	2217.537025	2708.179746	1854.707381	490.642721
3	**ɛ**	82.3126974	470.406788	2001.367408	2574.560422	1530.960619	573.193014	151.314166	522.944297	1889.687902	2588.364431	1366.743605	698.676529
3	**ə**	132.471288	531.367987	1435.676719	2609.38442	904.308732	1173.707701	217.309114	633.643760	1503.57406	2741.076802	869.9302999	1237.502742
3	**a**	89.6882395	731.818369	1314.10454	2580.18566	582.2861702	1266.08112	161.165650	689.838968	1377.969676	2558.394484	688.1307072	1180.424808
3	**o**	82.9591039	443.030783	1190.648173	2576.411606	747.6173907	1385.763433	79.2413205	406.450895	1134.289169	2484.493012	727.8382739	1350.203843
3	**u**	184.856592	421.648574	1120.575524	2763.611138	698.92695	1643.035614	170.111258	370.875876	1285.647938	2651.413972	914.7720611	1365.766034
4	**I**	106.669162	354.271868	2208.042466	2734.621866	1853.770598	526.5794	119.246164	523.247047	2088.453052	3141.627167	1565.206004	1053.174115
4	**i:**	111.094766	349.836238	2211.045024	2715.524854	1861.208786	504.47983	117.740812	370.331416	2044.860709	2734.276771	1674.529293	689.416062
4	**ɛ**	107.419092	489.560644	1768.284355	2730.369199	1278.723741	962.084844	88.7616770	423.845129	1977.143438	2806.987152	1553.298308	829.843714
4	**ə**	106.628001	539.140143	1314.285647	2640.157461	775.1455031	1325.871814	132.967760	588.909230	1590.153801	2764.25056	1001.244579	1174.096759

4	**a**	101.815947	698.834805	1261.243461	2767.714449	562.408655	1506.470988	121.999493	671.202104	1438.315991	2719.67296	767.113886	1281.356969
4	**o**	105.829110	498.030357	1044.821993	2803.303169	546.791637	1758.481176	102.703847	492.970968	1087.41643	2929.479825	594.445461	1842.063395
4	**u**	110.43917	423.317544	1028.355363	2945.553239	605.037818	1917.197876	105.371761	426.400515	912.026791	2884.796026	485.626278	1972.769234
5	**I**	166.280292	613.121712	1753.260649	2681.263197	1140.138937	928.002548	121.762035	952.572122	1790.627563	2949.448865	838.055440	1158.821302
5	**i:**	156.840984	440.073683	1913.647955	2546.066485	1473.574272	632.41853	132.370446	493.682867	1533.423921	2513.09725	1039.741054	979.673329
5	**ɛ**	143.845018	559.706569	1562.231906	2770.747982	1002.525349	1208.516076	128.894390	511.938317	1652.311087	2552.855785	1140.372769	900.544698
5	**ə**	136.749650	599.941897	1463.778382	2507.538482	863.836484	1043.7601	154.954515	743.195163	1513.089318	2764.770214	769.894155	1251.680896
5	**a**	138.702620	732.734978	1274.485409	2747.520258	541.750430	1473.034849	130.012883	617.207284	1213.572976	2884.982937	596.365691	1671.409961
5	**o**	147.218945	577.412426	1181.152562	2662.852184	603.740129	1481.699622	139.291923	597.063810	1082.521604	2691.011668	485.457793	1608.490064
5	**u**	152.470356	489.651417	1154.633546	2576.764326	664.982128	1422.13078	130.987335	593.382918	1266.03521	2592.025491	672.652918	1325.990281
6	**I**	187.484827	952.572122	1790.627563	2949.448865	838.055440	1158.821302	176.887475	381.997569	1790.098458	2858.577792	1408.100889	1068.479334
6	**i:**	224.681253	493.628671	1533.423921	2513.09725	1039.741054	979.673329	175.968622	409.456690	1546.209863	2658.561253	1136.753172	1112.35139
6	**ɛ**	209.295383	511.938317	1652.311087	2552.855785	1140.372769	900.544698	168.939501	655.102690	1834.798036	2630.119157	1179.695345	795.321121
6	**ə**	144.096954	743.195163	1513.089318	2764.770214	769.894155	1251.680896	154.428825	744.342318	1343.195173	2665.610839	598.852849	1322.415666
6	**a**	175.182976	617.207284	1213.572976	2884.982937	596.365691	1671.409961	190.896795	682.823598	1062.607871	2672.536812	379.784272	1609.928941
6	**o**	187.987007	597.063810	1082.521604	2691.011668	485.457793	1608.490064	183.796020	587.197789	1045.543576	2937.228012	458.345786	1891.684436
6	**u**	210.382458	593.382918	1266.03521	2592.025491	672.652918	1325.990281	80.9140370	549.880395	1371.188467	2715.919615	821.308071	1344.731148
7	**I**	131.425075	395.959678	2038.475328	2745.664094	1642.51536	707.188766	150.731337	452.581963	1610.4683	2316.26744	1157.886337	705.79914
7	**i:**	144.434005	518.341652	2118.797576	2868.691548	1600.456411	749.893972	139.582755	421.044659	2187.587705	2523.591187	1766.543046	336.003482
7	**ɛ**	132.676215	527.666002	1911.24817	2819.577281	1383.582168	908.329111	153.472495	515.472937	1872.00051	2648.029531	1356.527573	776.029021
7	**ə**	130.617918	671.680739	1412.345507	2522.693533	740.664631	1110.348026	146.855034	710.211971	1464.71486	2320.439303	754.502888	855.724443
7	**a**	124.835291	803.613829	1335.559133	2746.677707	531.945303	1411.118574	156.063191	678.682924	1234.22637	2465.893106	555.543445	1231.666736
7	**o**	141.254125	539.575232	1067.723096	2778.972085	528.147863	1711.248989	164.189145	491.057078	1012.347483	2547.414194	521.290410	1535.066711
7	**u**	155.183219	471.629195	1095.23839	2847.638696	623.609195	1752.400306	157.506947	449.592697	913.1900302	2371.113281	463.597332	1457.923251
8	**I**	154.135705	420.613408	1999.148878	2543.440116	1578.53547	544.291238	120.983046	381.783684	1851.112549	2457.708325	1469.328865	606.595776
8	**i:**	183.416963	370.803480	2237.636168	2653.462337	1866.832687	415.826169	205.456055	420.574848	2198.440297	2650.83768	1777.865449	452.397383

8	**ɛ**	180.033887 3	535.261347 9	1864.494188	2554.210065	1329.23284	689.715877	176.622105 9	402.871274 8	1899.789512	2598.942367	1496.918237	699.152855
8	**ə**	137.592764 1	570.049115 6	1495.599218	2333.809508	925.550102 4	838.21029	145.933029	531.982300 1	1552.068003	2319.649059	1020.085703	767.581056
8	**a**	142.771583	770.181115 4	1385.177576	2451.35224	614.996460 6	1066.174664	176.836765 5	699.041090 8	1403.820983	2616.728903	704.779892 2	1212.90792
8	**o**	162.711370 6	486.991482 7	1110.191748	2476.769581	623.200265 3	1366.577833	189.810037 5	474.492205 2	964.903543 9	2614.447036	490.411338 7	1649.543492
8	**u**	182.052852 6	414.573893 8	1032.137458	2581.797442	617.563564 2	1549.659984	173.876143 4	491.178851 3	859.884954 3	2537.746617	368.706103	1677.861663
9	**I**	176.557032 9	359.113142	2138.229068	2619.111192	1779.115926	480.882124	167.896307 3	388.590931 3	1904.405985	2766.475536	1515.815054	862.069551
9	**i:**	198.219231 1	381.042205 8	2180.35776	2665.867191	1799.315554	485.509431	164.529253 3	362.759923 7	1993.283084	2845.836106	1630.52316	852.553022
9	**ɛ**	179.083700 7	531.877175 2	1847.204021	2434.290082	1315.326846	587.086061	171.857826 6	599.602722 4	1927.03515	2304.761092	1327.432428	377.725942
9	**ə**	167.494287 7	583.087934 6	1400.837358	2265.609843	817.749234 4	864.772485	80.16250422	581.886758 8	1433.413824	2536.348611	851.525148 2	1102.934787
9	**a**	167.796569 8	771.104134 8	1265.937957	2474.551422	494.833822 2	1208.613465	166.991812 4	605.255151 6	1269.452871	2436.617647	664.197719 4	1167.164776
9	**o**	170.897133 5	449.770482 6	907.6194694	2501.056127	457.848986 8	1593.436658	152.761762 7	549.616059 1	1061.15543	2616.598475	511.539370 9	1555.443045
9	**u**	179.917637 8	383.840152 2	918.986231 6	2468.96656	535.146079 4	1549.980328	172.798430 2	369.637959 3	849.369547 5	2778.548569	479.731588 2	1929.179022
10	**I**	160.178508 7	448.203341 9	1882.43701	2658.095186	1434.233668	775.658176	156.299068 7	455.663935	1772.697368	2457.981854	1317.033433	685.284486
10	**i:**	183.340474 2	421.490954 7	2083.533047	2722.487607	1662.042092	638.95456	162.903230 1	524.281770 1	1965.754115	2948.306911	1441.472345	982.552796
10	**ɛ**	179.538172 5	490.629359 9	1877.000489	2517.512711	1386.371129	640.512222	181.271495 2	578.791241	1590.095892	2296.990742	1011.304651	706.89485
10	**ə**	153.675061	593.597843 1	1430.700925	2444.850899	837.103081 9	1014.149974	159.746732 4	499.426208 3	1375.719577	2929.118186	876.293368 7	1553.398609
10	**a**	159.148751	759.615242 6	1252.343546	2543.380496	492.728303 4	1291.03695	125.988131 3	695.129690 6	1356.30802	2589.686713	661.178329 4	1233.378693
10	**o**	164.798421 1	480.493319 5	993.6139514	2452.676814	513.120631 9	1459.062863	188.966820 7	551.733807 5	1218.668789	2687.321264	666.934981 5	1468.652475
10	**u**	190.530754 3	436.714523 5	1105.204188	2649.688725	668.489664 5	1544.484537	203.565227 8	429.686742 7	1080.351591	2694.382228	650.648483	1614.030637
11	**I**	160.178508 7	477.176164 6	1919.66648	2516.082405	1442.490315	596.415925	157.162990 1	409.209201 2	2699.966141	3100.455621	2290.75694	400.48948
11	**i:**	183.340474 2	407.249918 4	2023.346708	2517.517636	1616.09679	494.170928	163.418993	392.616765 9	2166.235528	2717.952854	1773.618762	551.717326
11	**ɛ**	179.538172 5	531.127360 1	1882.183302	2498.44287	1351.055942	616.259568	179.630357 7	661.809908 5	1504.661195	2090.84906	842.851286 5	586.187865
11	**ə**	153.675061	576.782698 1	1436.456903	2409.134042	859.674204 9	972.677139	159.737879 4	667.706083 4	1879.031814	2232.155102	1211.325731	353.123288
11	**a**	159.148751	721.494308	1371.570252	2586.570819	1215.000567	650.075944	125.750603 2	862.671630 3	1372.904344	2661.443512	510.232713 7	1288.539168
11	**o**	164.798421 1	538.682188 4	1095.814264	2469.64117	557.132075 6	1373.826906	187.877997 4	578.111194 9	1046.235166	2384.493774	468.123971 1	1338.258608
11	**u**	164.798421 1	538.682188 4	1095.814264	2469.64117	557.132075 6	1373.826906	204.809724 2	519.417506 7	1134.615603	2691.198847	615.198096 3	1556.583244

12	**I**	254.192249 3	475.355955 3	2217.957067	2885.135626	1742.601112	667.178559	232.007986 4	587.860263	2095.042774	2744.097132	1507.182511	649.054358
12	**i:**	284.383934 1	417.692124 6	2332.83956	2888.264339	1915.147435	555.424779	218.142746 9	484.186807 3	1761.515619	2776.596867	1277.328812	1015.081248
12	**ɛ**	271.21228	635.680686	2154.628135	2442.453177	1518.947449	287.825042	215.442686 8	693.119251 1	1968.410047	2642.164603	1275.290796	673.754556
12	**ə**	223.238237 7	663.110900 3	1615.531225	2394.867435	952.4203247	779.33621	235.636480 8	703.720749 2	1705.355018	2178.654117	1001.634269	473.299099
12	**a**	233.854577 2	895.451851 1	1502.872352	2494.169014	607.4205009	991.296662	199.095503 2	907.228971 8	1418.604779	2139.551653	511.3758072	720.946874
12	**o**	164.896727 6	524.805449 2	1102.814462	2484.33861	578.0090128	1381.524148	111.272447 6	661.444530 9	1161.512037	3219.262902	500.0675061	2057.750865
12	**u**	191.404681 8	479.164926 5	1065.440762	2666.439299	586.2758355	1600.998537	221.590245 7	515.457627 4	1300.012637	2575.412721	784.5550096	1275.400084
13	**I**	234.619870 8	577.474646	1923.161754	2950.49792	1345.687108	1027.336166	224.076355 1	408.673952 5	2306.510708	2662.597377	1897.836756	356.086669
13	**i:**	235.556250 2	625.267862 9	2361.766541	3095.678868	1736.498678	733.912327	198.064863 7	407.750076	1858.973424	2660.009441	1451.223348	801.036017
13	**ɛ**	224.813435 2	602.009070 5	2213.529076	2971.33559	1611.520006	757.806514	198.734926 2	611.406269 7	2087.05784	2802.852468	1475.65157	715.794628
13	**ə**	230.458573 7	707.585252 4	1711.433082	2699.638206	1003.84783	988.205124	191.440533	705.470181 2	1662.121678	2745.23087	956.6514968	1083.109192
13	**a**	195.930925 1	964.032827 8	1517.279945	2793.422199	553.2471172	1276.142254	198.944841 3	698.606997 5	1576.02557	2824.013924	877.4185725	1247.988354
13	**o**	196.879623	558.668781 9	1184.609323	2751.888955	625.9405411	1567.279632	182.695598 6	536.174560 8	1369.525233	2642.220656	833.3506722	1272.695423
13	**u**	187.802910 5	529.694876 2	1323.476177	2584.653463	793.7813008	1261.177286	193.970135 7	421.909366 1	1213.514575	2507.461161	791.6052089	1293.946586
14	**I**	249.364618 3	603.362819 6	1993.329701	2788.941643	1389.966881	795.611942	122.921546	434.881972 7	2141.390152	2598.527525	1706.508179	457.137373
14	**i:**	187.579822 4	451.303186	1952.334407	2742.774822	1501.031221	790.440415	123.361656 9	432.274441 5	2118.124798	2576.248615	1685.850357	458.123817
14	**ɛ**	197.476625 2	542.089675 9	2122.086087	2809.116633	1579.996411	687.030546	146.464207 2	574.002471 7	1886.272123	2499.178624	1312.269651	612.906501
14	**ə**	186.400242 5	598.441884 1	1547.721859	2702.251583	949.2799749	1154.529724	148.963908 5	531.109245 9	1826.075366	2756.716183	1294.96612	930.640817
14	**a**	180.313662 7	843.001297 3	1473.86142	3024.108309	630.8601227	1550.246889	159.768516 8	695.129690 6	1156.30802	2589.686713	461.1783294	1433.378693
14	**o**	189.301870 4	522.310295 5	1352.852788	2677.846344	830.5424925	1324.993556	111.033147 5	492.353285 9	1064.38147	2708.629911	572.0281841	1644.248441
14	**u**	198.656884 7	450.659284	1251.83679	2690.897329	801.177506	1439.060539	149.413299 7	438.660800 8	1277.490061	2745.702435	838.8292602	1468.212374
15	**I**	147.770214	423.208689	2258.324436	2634.081669	1835.115747	375.757233	262.128338 5	410.192659 9	1644.664839	2751.961244	1234.472179	1107.296405
15	**i:**	183.180540 6	382.729493	2330.058883	2760.628525	1947.329389	430.569642	236.282274	466.121383 8	1917.583815	2497.124849	1451.462431	579.541034
15	**ɛ**	168.634371 3	527.452537 1	2024.158666	2567.790969	1496.706129	543.632303	155.061468 6	607.363442 2	1938.213985	3012.898525	1330.850543	1074.68454
15	**ə**	168.860672 7	615.927194 6	1495.434444	2353.681444	879.5072494	858.247	210.085745 3	649.880994 2	1581.837312	2579.135745	931.9563178	997.298433
15	**a**	154.481829 2	772.973439 8	1460.587297	2536.497033	687.6138572	1075.909736	193.267881 5	841.310934 7	1501.648832	2110.226341	660.3378973	608.577509

15	**o**	163.259639 3	488.364675 7	1087.880707	2520.618034	599.516031 3	1432.737327	216.180278 6	670.575410 3	1237.786658	2971.491454	567.211247 7	1733.704796
15	**u**	171.092688 4	455.383347 5	1086.437743	2721.214697	631.054395 5	1634.776954	226.675703 5	454.967521 1	1137.461582	3122.741512	682.494060 9	1985.27993
16	**I**	250.242124	434.109923	1980.668275	2645.294581	1546.558352	664.626306	262.128338 5	514.492613 1	2135.793713	2657.093619	1621.3011	521.299906
16	**i:**	257.844520 1	443.548426 4	2141.016548	2756.394379	1697.468122	615.377831	241.859971 2	472.970211 6	1879.232761	2816.741114	1406.262549	937.508353
16	**ɛ**	247.138362 8	567.087430 5	1750.728908	2580.937262	1183.641478	830.208354	227.680510 4	635.436287 7	1782.277325	2358.542498	1146.841037	576.265173
16	**ə**	214.951740 7	606.853568 4	1567.06398	2643.788505	960.210411 6	1076.724525	225.745814 9	728.716711 5	1724.259774	2395.793223	995.543062 5	671.533449
16	**a**	211.505003 1	816.019462 6	1478.338634	2315.689295	662.319171 4	837.350661	241.873577 4	685.278073 2	1477.721746	2611.44023	792.443672 8	1133.718484
16	**o**	238.979519 4	471.413999 9	1027.920799	2999.24175	556.506799 1	1971.320951	192.365961 6	620.993653 4	1224.198177	2538.333395	603.204523 6	1314.135218
16	**u**	261.736410 4	465.202973 2	1039.438692	3056.138172	574.235718 8	2016.69948	230.293141 8	488.026688 4	1084.364564	2546.092368	596.337875 6	1461.727804
17	**I**	244.412044 9	455.408075 5	2028.906665	2715.278271	1573.49859	686.371606	253.951775 7	487.798999 3	2253.361165	2576.300003	1765.562166	322.938838
17	**i:**	254.813756 5	421.789176 3	2248.383523	2932.687674	1826.594347	684.304151	234.184380 9	460.649637	2076.189974	2653.097288	1615.540337	576.907314
17	**ɛ**	228.695084 5	606.655520 3	2008.271925	2796.875651	1401.616405	788.603726	218.876524 8	576.726097 4	1758.69392	2788.212604	1181.967823	1029.518684
17	**ə**	227.544199 3	629.059355 2	1519.335616	2244.855323	890.276260 8	725.519707	218.991574 6	597.353239 4	1407.922	2749.076494	810.568760 6	1341.154494
17	**a**	187.087446 8	853.491111 6	1437.665305	2308.842513	584.174193 4	871.177208	202.338090 2	786.397762 4	1550.62373	3005.351594	764.259676	1454.727864
17	**o**	240.739929 8	496.973693 3	1052.741444	2447.089403	555.767750 7	1394.347959	209.365301 6	551.181387	1236.56724	3094.376573	685.385853	1857.809333
17	**u**	259.596226 7	501.102173 5	1025.330483	2525.822885	524.228309 5	1500.492402	245.296383 2	502.826684 1	1138.576029	2970.329681	635.749344 9	1831.753652
18	**I**	268.025086 2	471.767551 5	2288.65926	2881.798341	1816.891709	593.139081	312.570011 5	439.578750 9	2202.38726	2689.885566	1762.808509	487.498306
18	**i:**	295.109309 1	476.227514 9	2245.352361	2760.691038	1769.124846	515.338677	261.596940 2	539.274505 2	1929.396676	2812.884604	1390.122171	883.487928
18	**ɛ**	258.007269 9	532.986182 7	1979.525955	2723.884003	1446.539772	744.358048	276.799807 8	684.371764 6	1820.609152	2580.225221	1136.237387	759.616069
18	**ə**	265.055527 7	632.180244 5	1436.58797	2524.152994	804.407725 5	1087.565024	244.450847 4	709.925566 4	1538.456999	2856.794633	828.531432 6	1318.337634
18	**a**	250.145180 2	773.557197 2	1331.317827	2478.565725	557.760629 8	1147.247898	116.143964	784.927213 1	1382.559636	1987.828022	597.632422 9	605.268386
18	**o**	244.142447 9	515.488955 8	1089.637714	2818.317138	574.148758 2	1728.679424	289.298454 6	762.173819 1	1264.796393	3378.272029	502.622573 9	2113.475636
18	**u**	307.532447 2	512.83794	996.955607 6	3009.454827	484.117667 6	2012.499219	276.436406 4	596.119515 8	1232.950453	3097.114122	636.830937 2	1864.163669
19	**I**	243.197111 3	428.713064 2	2238.427114	2841.266744	1809.71405	602.83963	194.251447 3	430.389726 2	1873.266957	2490.669879	1442.877231	617.402922
19	**i:**	236.704937 9	394.986256 6	2256.226557	2733.019749	1861.2403	476.793192	210.146002 9	428.416854 1	2125.80169	2534.146839	1697.384836	408.345149
19	**ɛ**	209.147887 2	694.957401 6	1706.42721	2388.072047	1011.469808	681.644837	216.762981 1	572.349158	2140.72693	2599.663156	1568.377772	458.936226

19	**ə**	174.892525	686.386677	1584.190257	2613.202407	897.803579 3	1029.01215	229.483528 7	679.510805	1565.829014	2197.022887	886.318206 5	631.193873
19	**a**	185.173867 8	918.644845 4	1461.703314	2674.698388	543.058468 6	1212.995074	185.147052 1	640.573119 1	1178.252264	2510.360438	537.679144 9	1332.108174
19	**o**	202.508529 4	601.994396	1213.421185	2869.769045	611.426745 4	1656.34786	193.710056 3	531.697990 2	975.570196 1	2474.219024	443.872205 9	1498.648828
19	**u**	235.887229 8	440.465969 5	1086.197363	3107.784732	645.731393 5	2021.587369	211.826155 2	451.215729 8	1503.20437	2781.844995	1051.98864	1278.640625
20	**I**	233.033420 3	416.202209 2	1933.349399	2915.525419	1517.14719	982.17602	271.703511 8	407.627886 1	2118.880674	3022.449939	1711.252788	903.569265
20	**i:**	240.104530 4	389.786927 7	2094.703351	2921.654539	1704.916423	826.951188	120.437423 3	439.770382 9	2116.423793	2804.143287	1676.65341	687.719494
20	**ɛ**	210.116620 7	603.323300 4	2012.153129	2747.048468	1408.829829	734.895339	260.353148 9	551.677413	1864.623135	2226.650379	1312.945722	362.027244
20	**ə**	207.121534	643.014399 9	1702.547752	2693.083593	1059.533352	990.535841	148.475377 5	686.995062 4	1494.729194	2201.079876	807.734131 6	706.350682
20	**a**	233.033420 3	805.402832 2	1509.359719	2797.585662	703.9568858	1288.225943	354.696366 7	987.608118 4	1327.895145	2555.996175	340.287026 6	1228.10103
20	**o**	255.332323	527.384726 1	1135.808467	2971.452557	608.423740 9	1835.64409	302.541196 3	688.355641 3	1106.249896	2035.71651	417.894254 7	929.466614
20	**u**	268.112502 1	396.790630 9	1272.42678	2797.997963	875.636149 1	1525.571183	291.902000 3	489.036418	1226.88386	2916.788561	737.847442	1689.904701
21	**I**	154.544813 5	412.500959 1	1853.364364	2418.576765	1440.863405	565.212401	164.216482 1	385.770654 3	2001.0169	2099.899834	1615.246246	98.882934
21	**i:**	166.395317 3	403.162237 7	1955.80368	2540.674735	1552.641442	584.871055	134.348136 8	361.202278	2056.649197	2334.630384	1695.446919	277.981187
21	**ɛ**	140.730601 6	478.596720 3	1782.211679	2317.348393	1303.614959	535.136714	147.527969 1	452.362888	1363.734338	2467.995114	911.37145	1104.260776
21	**ə**	127.326484 9	515.140708 8	1299.607631	2480.539548	784.4669222	1180.931917	112.628497 6	421.324814	1624.273446	2709.743773	1202.948632	1085.470327
21	**a**	125.400058 6	617.542504	1175.681524	2430.036173	558.1390736	1254.354649	135.527969 1	595.309537	1229.279951	2529.78387	633.970414	1300.503919
21	**o**	132.823457 7	514.543627 6	1089.421953	2673.949125	574.8783254	1584.527172	148.867479 8	458.123765 2	1017.835505	2954.14385	559.711739 8	1936.308345
21	**u**	147.160254 1	437.87261	915.0112107	2638.541375	477.1386007	1723.530164	138.823679	455.154277 7	918.373667 7	2552.904581	463.21939	1634.530913
22	**I**	264.527055 3	524.497593 3	1953.904144	2535.489414	1429.406551	581.58527	261.093032 5	537.829945 4	1744.78055	2769.741087	1206.950605	1024.960537
22	**i:**	260.497913 8	529.158327 7	1891.775861	2598.71449	1362.617533	706.938629	194.707192 3	494.194919 4	1952.511147	2871.061945	1458.316228	918.550798
22	**ɛ**	243.241496 3	605.505359 5	1588.438913	2247.753446	982.9335535	659.314533	239.392848 7	565.261355 4	1881.921044	2504.06533	1316.659689	622.144286
22	**ə**	192.529158	663.560091 8	1292.904725	2340.106677	629.3446332	1047.201952	184.643069 4	654.392689 2	1237.162116	2449.822512	582.769426 8	1212.660396
22	**a**	197.106477	783.635322 9	1324.497611	2639.440462	540.8622881	1314.942851	175.007185 2	750.162543 9	1255.374724	2716.946712	505.212180 1	1461.571988
22	**o**	212.535624 8	589.867091	1080.301746	2396.480052	490.434655	1316.178306	190.665183 5	631.741709 2	954.8537918	2396.384363	323.112082 6	1441.530571
22	**u**	240.781693 5	495.631213	1027.569222	2468.780656	531.938009	1441.211434	184.152127 8	672.772806 2	1421.121581	2649.931263	748.348774 8	1228.809682
23	**I**	148.700486 2	418.178674 3	1995.954269	2526.549123	1577.775595	530.594854	171.683951 3	521.314978 4	1462.968247	2629.267307	941.653268 6	1166.29906

23	**i:**	162.684886	425.293023	1928.372083	2527.034807	1503.079062	598.662724	152.071267	337.201894	2166.154375	2786.042837	1828.952481	619.888462
23	**ɛ**	138.376821	541.713623	1728.818122	2312.445	1187.104499	583.626878	199.895798	559.824329	1449.974007	2341.951519	890.149574	891.977512
23	**ə**	139.264197	581.783895	1421.929299	2468.02331	840.145403	1046.094011	126.105419	520.265943	1485.741584	2879.043288	965.475640	1393.301704
23	**a**	126.614385	692.545087	1258.8858	2334.070146	566.340712	1075.184346	136.198947	828.727483	1358.543224	2332.442775	529.815737	973.899551
23	**o**	136.226053	576.346163	1161.41357	2468.316064	585.067406	1306.902494	117.729115	545.261331	1490.96643	2462.224572	945.705098	971.258142
23	**u**	154.301656 2	459.745780 8	1106.942831	2507.394445	647.197050 2	1400.451614	210.529584 3	538.288127 2	1319.9188	2390.153127	781.630672 8	1070.234327
24	**I**	207.775959 9	446.28179	1809.616037	2461.632225	1363.334247	652.016188	191.240817 8	424.281026 8	1678.073513	2550.091297	1253.792486	872.017784
24	**i:**	197.151229 7	412.449423 4	1783.981559	2726.336418	1371.532136	942.354859	173.216688 8	369.851383 1	1703.72168	2637.880637	1333.870297	934.158957
24	**ɛ**	202.535434 6	526.048250 3	1635.739065	2159.698464	1109.690815	523.959399	193.310712	518.047766 4	1691.397658	2223.599794	1173.349892	532.202136
24	**ə**	184.942575 2	570.200696 1	1270.026035	2080.627906	699.8253389	810.601871	181.137361 4	439.237981 9	1307.554768	2539.845405	868.316786 1	1232.290637
24	**a**	189.128805 7	721.822315 2	1233.858708	2350.158375	512.036392 8	1116.299667	178.434912 9	662.732610 8	1091.884683	2418.563976	429.152072 2	1326.679293
24	**o**	187.740852 1	549.877427 5	946.5531331	2277.856297	396.675056	1331.303164	173.456966 6	632.153725 2	1081.635077	2522.429867	449.481351 8	1440.79479
24	**u**	201.679777 1	424.249377 8	917.387789	2145.6887	493.138411 2	1228.300911	196.261395 2	462.599920 4	982.233559 4	2113.308921	519.633639	1131.075362
25	**I**	170.735175	449.020755 5	2013.024214	2599.923133	1564.003459	586.898919	168.235691 3	437.961066 9	1521.579947	2553.675991	1083.61888	1032.096044
25	**i:**	177.787502 4	377.369847 3	2234.439035	2719.930898	1857.069188	485.491863	143.381369 5	344.748540 6	2411.012402	2894.384167	2066.263861	483.371765
25	**ɛ**	166.030679 9	495.854105 1	1800.002245	2316.287395	1304.14814	516.28515	142.749164 9	468.350478 2	2113.87894	2597.358538	1645.528462	483.479598
25	**ə**	155.259280 9	585.505528 3	1439.661654	2590.043485	854.1561257	1150.381831	179.414801 1	537.318799 6	1674.782219	3688.424975	1137.463419	2013.642756
25	**a**	154.107932 9	665.751198 7	1236.350497	2347.03394	570.599298 3	1110.683443	170.204482 9	763.698393	1386.636452	2332.913466	622.938059	946.277014
25	**o**	160.347299	482.841231 5	1077.391679	2667.511859	594.550447 5	1590.120185	166.077928 7	499.109222 6	1102.462245	2388.824431	603.353022 4	1286.362186
25	**u**	164.565679 9	434.879648 5	984.7400201	2577.585449	549.860371 6	1592.845429	172.158382 4	399.751483 2	898.820289 3	2626.507067	499.068806 1	1727.686778
26	**I**	141.957837 8	424.712069 4	1876.607868	2686.853375	1451.895799	810.245507	143.785535 2	424.312260 2	1608.308867	2512.023722	1183.996607	903.714855
26	**i:**	138.143871 6	446.378771 6	1921.507374	2744.516836	1475.128602	823.009462	138.351920 1	395.442314 6	1997.786716	3377.364739	1602.344401	1379.578023
26	**ɛ**	132.187713 7	509.981751 7	1683.060192	2264.73224	1173.07844	581.672048	132.637372 2	518.052277 1	1821.571137	2480.695988	1303.51886	659.124851
26	**ə**	131.448040 5	547.498002 9	1385.264867	2384.939601	837.7668641	999.674734	128.376036 9	550.420940 5	1300.285009	2231.532701	749.864068 5	931.247692
26	**a**	135.905666 1	665.616182 5	1280.054827	2521.267698	614.4386445	1241.212871	131.022963 5	559.244908 8	1286.102649	2597.535995	726.857740 2	1311.433346
26	**o**	130.053755	557.704471 1	1155.896885	2492.380899	598.1924139	1336.484014	128.666930 5	497.625948 2	1059.658167	2466.51422	562.032218 8	1406.856053

26	**u**	138.412763	450.469217	1042.357201	2508.824065	591.887983	1466.466864	124.726379	464.626648	1361.916729	2649.521196	897.290082	1287.604467
27	**I**	152.502041	438.090694	1683.861086	2319.533687	1245.770391	635.672601	131.754011	401.071449	1511.99097	2632.038858	1110.919521	1120.047888
27	**i:**	142.750380 4	451.552553	1798.022254	2560.129738	1346.469703	762.107484	179.681412	476.456145 8	1917.669954	2478.271068	1441.213808	560.601114
27	**ɛ**	150.467684 8	482.719972	1568.083219	2213.146225	1085.363247	645.063006	155.096310 5	471.310574	1669.404738	2264.142455	1198.094164	594.737717
27	**ə**	130.528583	503.588382	1263.591671	2336.831833	760.003282 8	1073.240162	150.548813	587.015979 1	1235.721001	2625.174303	648.705021 9	1389.453302
27	**a**	138.074669 3	649.775995 5	1211.562888	2613.899752	561.786884 5	1402.336872	239.392848 7	693.612558 7	1881.921044	2504.065333	1188.308485	622.144286
27	**o**	144.751540 3	504.628412 8	1062.945933	2471.036296	558.317520 2	1408.090363	117.041509	575.195154 4	1381.047527	2528.905526	805.852372 6	1147.857999
27	**u**	147.069797 7	419.769188 1	1065.865457	2433.192023	646.096268 9	1367.326566	150.491613 3	644.553482 4	1388.14972	2561.513165	743.596237 6	1173.363445
28	**I**	227.247247 8	382.378261 6	2105.153497	2579.926683	1722.775235	474.773186	220.798187	371.915885 9	1984.093648	2590.312388	1612.177762	606.21874
28	**i:**	206.892474 8	378.256475 8	2289.455875	2888.514017	1911.199399	599.058142	169.628471 7	511.787249 6	1799.565918	2520.563733	1287.778668	720.997815
28	**ɛ**	194.442811 8	475.382714 1	1959.855934	2337.147657	1484.47322	377.291723	189.995335 8	524.765391 2	1772.596113	2480.432785	1247.830722	707.836672
28	**ə**	186.336384 2	555.711280 4	1366.998653	2499.452296	811.287372 6	1132.453643	157.061518 9	474.155307	1213.966246	2188.584857	739.810939	974.618611
28	**a**	169.066566 8	716.397448	1211.753742	2572.534712	495.356292	1360.780972	184.603911 8	605.953191 1	1391.742385	2253.459517	785.789193 9	861.717132
28	**o**	203.573028 3	515.122718 5	959.9916075	2672.212279	444.868889	1712.220672	180.430435 6	508.560873 6	1216.455746	2086.527434	707.894874 4	870.071688
28	**u**	231.031594 5	392.773447 9	920.2861887	2628.416933	527.512740 8	1708.130744	216.864605 4	404.680835	1406.944681	2351.848947	1002.263846	944.904266
29	**I**	234.333815 6	422.643531 3	1871.998191	2418.08212	1449.35466	546.083929	133.285269 6	455.474006 8	1972.614249	2406.605071	1517.140242	433.990822
29	**i:**	259.420787	374.740891	2180.053128	2625.217716	1805.312237	445.164588	131.422528 2	420.982770 5	1995.594091	2386.031899	1574.611321	390.437808
29	**ɛ**	255.488297 8	580.334214 2	1648.350375	2190.779771	1068.016161	542.429396	139.592936 8	555.711886 9	1754.771324	2292.9779	1199.059437	538.206576
29	**ə**	254.320076 6	650.027170 7	1471.496158	2411.446869 3	821.468987 3	939.950711	146.168248 5	592.561284 4	1405.213053	2045.892691	812.651768 6	640.679638
29	**a**	250.327173 4	684.666651 7	1308.189758	2395.265895	623.523106 3	1087.076137	142.135321 1	727.297135	1332.167006	2236.487018	604.869871	904.320012
29	**o**	238.836033 8	593.695872 1	1201.756908	2418.806953	608.061035 9	1217.050045	131.489430 3	542.073347 1	1316.328904	2438.084692	774.255556 9	1121.755788
29	**u**	222.605656 6	608.913625	1605.718213	2797.526231	996.804588	1191.808018	150.279381 3	585.293695 2	1626.410582	2573.825701	1041.116887	947.415119
30	**I**	163.554488 5	335.723529 5	1906.251817	2482.213653	1570.528288	575.961836	159.401604 4	321.745014 7	2159.067432	2413.196611	1837.322417	254.129178
30	**i:**	156.146776	377.557359 4	1972.940453	2598.704235	1595.383094	625.763782	157.802757 4	331.984897 8	2321.037773	2612.718366	1989.052875	291.680593
30	**ɛ**	158.391291 8	431.451577 3	1841.304747	2335.489537	1409.853163	494.184797	230.839793 6	440.912963 7	2084.815436	2713.888906	1643.902472	629.07347
30	**ə**	127.855710 7	521.105565 9	1595.221364	2560.41507	1074.115798	965.193706	130.419757 5	498.094943 6	1133.518126	2532.143409	635.423182 4	1398.625283

30	**a**	136.445992	564.4149801	1362.444839	2529.430327	798.0298589	1166.985488	163.6412052	657.8038399	1469.962795	3136.854188	812.1589551	1666.891393
30	**o**	143.957625	479.1889103	1240.005527	2488.476319	760.8166167	1248.470792	130.9112223	473.2348399	1248.245132	2602.077668	775.0102921	1353.832536
30	**u**	153.020252	392.4105183	1345.450116	2505.29021	953.0395977	1159.840094	141.0584219	426.6781861	1218.038247	2430.255271	791.3600609	1212.217024
31	**I**	292.130012	468.9405827	2114.700703	2816.487725	1645.76012	701.787022	130.2616533	534.3587436	1740.62236	2654.479734	1206.263616	913.857374
31	**i:**	310.1804856	435.9959273	2249.404768	2874.189034	1813.408841	624.784266	313.6286958	364.9576783	1951.242622	2863.107503	1586.284944	911.864881
31	**ɛ**	282.145014	610.6306876	1724.733169	2522.083593	1114.102481	797.350424	294.0721351	622.0764347	1823.720713	2701.569098	1201.644278	877.848385
31	**ə**	229.769149	666.4196833	1261.736558	2288.427821	595.3168747	1026.691263	191.3742448	695.7950904	1420.559685	2765.973622	724.7645946	1345.413937
31	**a**	237.545147	745.1324063	1275.914707	2672.249134	530.7823007	1396.334427	215.5416988	728.7821036	1291.196874	2650.321368	562.4147704	1359.124494
31	**o**	253.274408	563.5721969	1032.443811	2682.896226	468.8716141	1650.452415	189.5183877	537.8889015	1102.029749	2688.932542	564.1408475	1586.902793
31	**u**	291.0159295	493.4719796	941.1282393	2735.765569	447.6562597	1794.63733	215.4512602	451.3301711	1328.235242	2243.676463	876.9050709	915.441221
32	**I**	184.8261468	439.9907949	1952.087727	2829.69043	1512.096932	877.602703	199.0316179	513.7104555	1709.62081	2684.027205	1195.910355	974.406395
32	**i:**	187.8593686	411.7659519	1980.403576	2875.956084	1568.637624	895.552508	180.73609	382.4420911	1934.587787	2789.185912	1552.145696	854.598125
32	**ɛ**	178.0939344	518.4444309	2027.546574	2935.989129	1509.102143	908.442555	212.1591993	623.3981299	1974.713597	3031.686237	1351.315467	1056.972633
32	**ə**	176.8750661	643.7050714	1525.082712	2649.847475	881.3776406	1124.764763	184.9939803	645.9014295	1302.619348	2550.021076	656.7179185	1247.401728
32	**a**	184.8142842	774.4833657	1327.742777	2899.589781	553.2594043	1571.847011	219.0778325	821.3279559	1323.680755	2938.154211	502.3527991	1614.473456
32	**o**	171.6048148	579.6035383	1228.004602	2569.435813	648.4010637	1341.431211	182.4581676	544.7015781	1248.727867	2498.885594	704.0262889	1250.157727
32	**u**	168.7844417	498.7154557	1118.508411	2615.692447	619.7929553	1497.184036	189.5942932	697.3006539	1652.29922	2787.017128	954.9985661	1134.717908
33	**I**	243.0603487	502.9169829	2443.453515	3005.625485	1940.536527	562.171975	209.65477	440.3328569	1788.978179	2568.025005	1348.645322	779.046826
33	**i:**	196.5014798	479.1865107	2481.477371	2953.799781	2002.29086	472.32241	102.498134	578.0929124	2398.155769	2998.433217	1820.062857	600.277441
33	**ɛ**	204.8434634	542.0840889	2281.174853	2844.186423	1739.090764	563.01157	105.3346427	468.4287315	2376.738413	2987.385557	1908.309682	610.647144
33	**ə**	203.0762879	621.9946572	1600.673077	2595.182395	978.6784198	994.509318	224.538058	487.6612372	1785.800251	3030.103288	1298.139014	1244.303037
33	**a**	153.5451414	854.9360836	1587.538531	2768.440521	732.6024464	1180.901991	224.538058	672.6854818	1679.515975	2939.182552	1006.830493	1259.666577
33	**o**	204.5159253	590.6213541	1242.710446	2962.05507	652.0890919	1719.344624	224.538058	684.2034455	1466.831898	3049.661768	782.6284525	1582.82987
33	**u**	240.8233769	537.3652393	987.3994434	3032.286589	450.0342041	2044.887146	146.7340412	465.9652147	1036.027462	2671.490297	570.0622473	1635.462835
34	**I**	238.618598	397.0750638	2041.123412	2747.872042	1644.048348	706.74863	238.8240659	449.9484028	2180.627583	2819.461346	1730.67918	638.833763
34	**i:**	223.6588083	408.5306373	2380.776127	2886.472662	1972.24549	505.696535	215.1617297	493.2521114	1907.533754	2770.189391	1414.281643	862.655637

34	**ɛ**	228.418325 2	504.985367 9	2102.85142	2567.629892	1597.866052	464.778472	310.32674	636.705257 5	1887.276241	2907.48103	1250.570984	1020.204789
34	**ə**	230.665078	645.540914	1388.537545	2844.066794	742.996036	1455.529249	230.691023	544.025144 6	1783.850779	2908.480923	1239.825634	1124.630144
34	**a**	232.067768 6	822.088943 3	1347.519775	2999.843282	525.430831 7	1652.323507	278.483284	922.154661	1275.777484	2349.704252	353.622823	1073.926768
34	**o**	231.942659 8	569.080018	1062.329711	2901.544315	493.249693	1839.214604	228.356841 7	607.885162 6	1281.72954	3088.836454	673.844377 4	1807.106914
34	**u**	231.523457 4	445.928489 6	998.8427823	2472.180008	552.914292 7	1473.337226	245.201943	502.221216 5	1281.659963	2621.785582	779.438746 5	1340.125619
35	**I**	241.312705 4	454.572327	2051.952585	2850.395799	1597.380262	798.443214	191.045936	441.102457 4	2022.264312	3035.792485	1581.161855	1013.528173
35	**i:**	243.879996 6	486.759102 4	2014.833614	2749.259654	1528.074512	734.42604	237.934199	404.747535 9	2190.269831	2779.494356	1785.522295	589.224525
35	**ɛ**	246.400557 4	497.637287	2112.91564	2767.702185	1615.278353	654.786545	213.553683 5	514.545231 5	1863.762118	2686.076968	1349.216887	822.31485
35	**ə**	248.324780 6	626.750575 6	1718.39547	2810.320254	1091.644894	1091.924784	188.076348	435.939216 7	1526.013903	2673.789236	1090.074686	1147.775333
35	**a**	250.621653	800.058623 3	1547.387885	2706.20273	747.329261 7	1158.814845	234.549146 1	765.157882 4	1760.284128	2461.927116	995.1262456	701.642988
35	**o**	251.545283 2	533.932736 1	1216.403612	2962.758012	682.470875 9	1746.3544	234.549146 1	500.092283 1	1232.181511 1	3125.662363	732.089227 9	1893.480852
35	**u**	251.000844	459.460218 9	1197.325971	2546.884904	737.865752 1	1349.558933	211.901666 8	447.382446 6	1264.878936	2542.026101	817.496489 4	1277.147165
36	**I**	327.299486 4	481.637240 5	2257.251212	3017.523826	1775.613972	760.272614	242.171370 1	514.229999 6	2198.28995	2793.128932	1684.05995	594.838982
36	**i:**	282.908856 8	507.260639 6	2404.840266	3091.882207	1897.579626	687.041941	303.307070 6	528.982914 3	1685.827152	2752.404967	1156.844238	1066.577815
36	**ɛ**	253.006638 6	563.746340 2	2238.140123	3044.569447	1674.393783	806.429324	228.362739 4	710.039532 8	1869.712731	2699.751895	1159.673198	830.039164
36	**ə**	260.093152 2	617.044270 7	1655.422222	2565.434709	1038.377951	910.012487	217.522419 7	678.485884 7	1471.165721	2227.400329	792.6798363	756.234608
36	**a**	232.793287 4	886.167647 9	1541.637677	2646.965569	655.470029 1	1105.327892	224.327573 7	888.666150 4	1375.697752	2061.629665	487.031601 6	685.931913
36	**o**	254.509772 8	587.740875 9	1169.786012	2878.10769	582.045136 1	1708.321678	111.662058 7	599.650679 1	1259.55071	2190.593451	659.900030 9	931.042741
36	**u**	257.550032	531.379014 9	1151.953121	2818.329639	620.574106 1	1666.376518	242.680859 9	490.930601 8	1460.401187	2687.479796	969.470585 2	1227.078609
37	**I**	222.176096 4	516.610196 4	2387.923299	2813.405752	1871.313103	425.482453	203.56268	486.062987 6	1389.772757	2657.311858	903.709769 4	1267.539101
37	**i:**	224.352610 2	478.308129 9	2401.368949	2851.855429	1923.060819	450.48648	130.540104	431.010649 1	1823.927433	2451.904249	1392.916784	627.976816
37	**ɛ**	226.665408	511.229215	2181.549174	2665.423016	1670.319959	483.873842	199.652845	649.757122 7	2158.034877	2916.26489	1508.277754	758.230013
37	**ə**	229.009351 8	680.498391 9	1629.649485	2471.860091	949.151093 1	842.210606	129.095472	609.954114 2	1926.4958	2171.881277	1316.541686	245.385477
37	**a**	230.68897	893.135803 3	1530.679351	2397.376997	637.543547 7	866.697646	217.50232	835.955099 6	1747.271979	2154.60541	911.3168794	407.333431
37	**o**	231.417370 6	600.751264 4	1252.623395	2686.758225	651.872130 6	1434.13483	204.604895 3	585.421247 8	1220.626006	2508.402532	635.204758 2	1287.776526
37	**u**	231.902083 8	465.197229 1	1136.847742	2620.73062	671.650512 9	1483.882878	228.404961 3	474.541072 8	1064.121196	2587.25761	589.5801232	1523.136414

38	**I**	237.438396	524.1095859	2164.539786	2765.506839	1640.4302	600.967053	244.126606	501.2058804	2306.369363	2880.017636	1805.163483	573.648273
38	**i:**	273.235557 4	489.879846 8	2404.024254	2797.432312	1914.144407	393.408058	224.925921	582.630565 9	1764.959305	2666.861622	1182.328739	901.902317
38	**ɛ**	248.162410 6	559.357912 4	2230.09524	2747.982752	1670.737328	517.887512	277.958350 9	587.070413 5	2216.650156	2654.930629	1629.579743	438.280473
38	**ə**	278.775731	653.676263 2	1506.513033	2447.721318	852.8367668	941.208288	230.762041	700.061532 2	1797.036018	2611.782985	1096.974486	814.746967
38	**a**	299.034999 6	859.210485 4	1446.338009	2641.964391	587.1275236	1195.626382	251.613194	501.2058804	2306.369363	2880.017636	1805.163483	573.648273
38	**o**	305.836266	571.034797	1210.513373	2535.641808	639.478576	1325.128435	234.613632 1	714.393317	1531.902564	2836.514259	817.509247	1304.611695
38	**u**	260.009436	575.490023 2	1016.240349	2657.441731	440.7503258	1641.201382	271.863078	542.649413 6	1166.969044	2685.389388	624.319630 4	1518.420344
39	**I**	282.108530 2	492.021217 1	2046.735718	2761.517958	1554.714493	714.782248	238.571886 6	474.837218	1242.471947	2626.760765	767.634729	1384.288818
39	**i:**	285.441684 8	488.317258 8	1946.092798	2708.196027	1457.775539	762.103229	241.832305 7	485.604387 9	1496.094716	2752.636531	1010.490328	1256.541815
39	**ɛ**	288.074426 8	564.50823	2048.755325	2608.329088	1484.247095	559.573763	220.962965 1	519.162211 7	1498.117274	2579.594556	978.9550623	1081.477282
39	**ə**	287.369675 8	581.890752 6	1511.071096	2378.573623	929.1803434	867.502527	235.088080 3	575.356952 4	1623.739137	2479.282994	1048.382185	855.543857
39	**a**	286.908261 6	792.907847 5	1522.772071	2208.751907	729.8642235	685.979836	210.853953 1	744.316767 9	1592.584027	2562.476054	848.267259 1	969.892027
39	**o**	285.090543 4	599.596062 2	1316.725699	2419.852732	717.1296368	1103.127033	214.734928 2	589.031930 5	1241.400121	2345.587907	652.3681905	1104.187786
39	**u**	284.131550 8	489.912114 6	1183.005777	2490.441691	693.0936624	1307.435914	233.075113 8	471.178920 4	1362.411732	2512.01364	891.2328116	1149.601908
40	**I**	302.639641 5	356.365173	2410.500472	2895.09848	2054.135299	484.598008	282.898927 4	397.548666 5	2721.671863	3276.297908	2324.123197	554.626045
40	**i:**	287.047393 9	360.594318 2	2460.149062	2942.620187	2099.554744	482.471125	282.053183 2	477.098297 4	2417.681991	3194.227552	1940.583694	776.545561
40	**ɛ**	281.544445 6	568.291722 1	2098.394645	2798.337557	1530.102923	699.942912	275.541087 6	558.755250 9	2148.203375	2976.770338	1589.448124	828.566963
40	**ə**	271.285657 8	537.329663 4	1627.178785	2683.174156	1089.849122	1055.995371	288.678634 6	625.304177 2	1662.216398	2590.339542	1036.912221	928.123144
40	**a**	263.441175 1	877.564599 6	1578.020448	2857.931492	700.4558484	1279.911044	296.780770 5	881.766045 1	1746.619605	2583.992251	864.8535599	837.372646
40	**o**	275.820768 6	553.123275 6	1312.815223	2690.806693	759.6919444	1377.991473	273.501463 1	550.725909	1267.844054	2884.887322	717.1181 45	1617.043268
40	**u**	285.850209 5	488.178192 2	988.5345189	2697.25436	500.3563267	1708.719841	283.26806	457.281143 3	1231.290277	2723.392523	774.0091337	1492.102246

Participants Background Infomation

1. Name of the Participants:
2. Age
3. Gender
4. Cast
5. Educational Qualification
6. Medium Of Education :
7. The Participant belongs to

(a) Rural area (b) Urban area

i) (if Urban) : How long have he/she been staying in the city :

Linguistic background

	Listening	Speaking	Reading	Writing
Bishnoi Marwari				
Brahman Marwari				
Hindi				
Other regional Varieties				

*Please sign the following consent before you proceed.
I certify that the study has been explained to me, and that participation is absolutely voluntary, that my identity will remain confidential. I agree under no coercion to participate in this study.

Researcher's signature
Participant's signature
Name Nikita Suthar Name ----------

Institution JNU, New Delhi School ------

Date ---------- Date -------
