ACOUSTIC ANALYSIS OF BENGALI SPEAKING HEARING-IMPAIRED CHILDREN

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Reg. No.: M 9705

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*"When you take what you have for granted;
you fail to perceive how precious it was. . . . . . .Till the day you lose it"*

"I long to hear the sounds of water gushing through a stream, and hitting against the rocks, the sounds of the wind rustling through the leaves, the tinkling of church bells, the gurgling sounds of a *baby, little children playing and shouting in the fields, the song of a bird, the clouds roaring, the thunder and the pitter patter of raindrops, . . . the voice of a human being..." just for once".*

"HELLEN KELLER"
(Deaf Blind)

Mummy, Daddy & Nataraja Sir…

CERTIFICATE

This is to certify that this dissertation entitled

ACOUSTIC ANALYSIS OF BENGALI SPEAKING HEARING-IMPAIRED CHILDREN

is the bonafide work in part fulfillment for the degree of

Master of Science (Speech & Hearing) of the student with

Register No. M9705

Mysore
May, 1999

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CERTIFICATE

This is to certify that the dissertation entitled **"Acoustic Analysis of Bengali Speaking Hearing-Impaired Children"** has been prepared under my supervision and guidance.

Mysore
May, 1999

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DECLARATION

I hereby declare that this dissertation titled **"Acoustic Analysis of Bengali Speaking Hearing-Impaired Children"** is the result of my own study under the guidance of Dr. N.P. Nataraja, Professor & H.O.D., Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other Diploma or Degree.

Mysore
May, 1999

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INTRODUCTION

Hearing impairment either at birth or soon after birth and during early childhood, results in a concomitant deficiency in comprehension and usage of speech.

The vowels most commonly used by young hearing impaired children include the central vowels, /ʌ, ə /, and the low front vowels /æ, ɛ /

Hearing impaired children are delayed in phonemic acquisition (Oiler et al, 1978; Stoel-Gammon, 1982).

Numerous independent investigations (Hudgins and Numbers, 1942; Markides, 1970; Smith, 1975; McGarr, 1980) have been remarkably consistent in identifying typical articulatory errors in the speech of hearing-impaired children who were trained in many different programs. Most of these investigations are of a descriptive nature; that is, either listener judgements or phonetic transcriptions were used to obtain measurements of intelligibility or to describe the articulatory characteristics of speech ("subjective evaluation"). Any comprehensive analysis of the articulatory skills of hearing impaired children must begin with the classic work of Hudgins and Numbers (1942) . They found that the most common error types involving consonants were confusion of the voiced-voiceless distinction, substitution of one consonant for another, added nasality, misarticulations of consonant blends, misarticulation of abutting consonants, and omission of word-initial or word-final consonants. This overall pattern of consonant errors has been replicated in numerous studies (Brannon, 1966, Geffner, 1980; Gold,1978; Levitt, Smith and Stromberg,1976; Markides, 1970; Nober, 1967; Smith,1975). The vowel errors seen were,

1. Substitution of one vowel for another.
2. Neutralization of vowels.
3. Diphthongization of vowels.
4. Nasalization of vowels.
5. Errors involving diphthongs: splitting or dropping of the constituents.

The same pattern has been replicated in other studies of hearing impaired speakers (Angelocci, Kopp and Holbrook, 1964; Calvert, 1961).

Suprasegmental errors, such as improper intonation, improper rhythm and other prosodic features were also observed.

However, due to the limitations of subjective analysis, objective measurements of different parameters of speech started to gain its importance. Among the first studies done on the Acoustic analysis of speech included those by Calvert (1961); Monsen (1974, 1976 a-d) and Rothman (1976).

Acoustic analysis of hearing impaired speech permits a finer grained consideration of some aspects of both correct and incorrect productions than would be possible using subjective analysis (Osberger and Mc.Garr, 1982).

Without a clear understanding of the underlying nature of the deaf child's unintelligible speech, the development of effective clinical strategies would be limited (Metz,1982). Development of effective remedial strategies would be enhanced by analyzing normal and deviant speech production from an acoustical perspective (Zimmerman et al, 1981).

Acoustical analysis of speech production is extremely useful to researchers since the methodologies employed are typically noninvasive, relatively basic with regard to instrumentation, and maybe used routinely to depict changes in the physical characteristics of frequency, intensity and the duration of speech segments.

Various studies have been carried out to understand the speech of the hearing impaired (Hudgins and Numbers, 1942; Angelocci, 1964; Rajanikanth, 1986, Shukla, 1978; Sheela, 1988; Jagadish, 1989; Whitehead, 1991; Sowmya, 1992; Rasitha, 1994; Rahul, 1997; Nober, 1967; Mc Garr, 1978; Geffner, 1980; Stoel-Gammon, 1982; Sonia, 1998; Poonam, 1998; Priya, 1998) But the knowledge in this area is far from complete.

The present study was undertaken:-

* Since the speech related parameters are language specific, there is a need for such studies in all languages. No studies in this direction have been conducted in Bengali language.

Therefore.it was considered that it will be useful to study the acoustic aspects of speech of Bengali speaking hearing impaired children, as it would contribute to our knowledge of teaching speech to the hearing impaired, specifically to Bengali language.

AIM OF THE STUDY

This study was undertaken to obtain objective data for the speech of the hearing impaired children in Bengali. After reviewing the literature, 7 speech related variables were selected for the study because of their probable relationship with speech intelligibility.

HYPOTHESIS - 1

It is hypothesized that there is no significant difference in the utterance of normal hearing and hearing impaired children in terms of,

a) Vowel duration
b) Consonant duration
c) Intersyllabic pauses
d) Total duration of the words

e) Fundamental frequency (F_0)

f) Formant frequencies

g) Bandwidth

HYPOTHESIS - 2

2(a) There is no significant difference in the utterance of normal males and normal females on all the parameters measured.

2(b) There is no significant difference in the utterance of hearing impaired males and hearing impaired females on all the parameters measured.

Deaf subjects and their speech characteristics have been extensively studied in many South Indian languages like Kannada, Tamil, Malayalam, etc. No such studies have been done in Bengali, Hence, the present investigation was undertaken. Twenty congenitally deaf children in the age range of 7-10 years were selected who were matched in terms of age and sex to twenty normally hearing children. The deaf subjects for the study were chosen from those attending therapy at "SHIRC" Calcutta, and "NIHH" Calcutta.Eight bisyllabic (VCV) words containing all the vowels in Bengali language were chosen for the present study.

All the subjects were asked to read the words and their utterances were recorded using a portable taperecorder (AIWA)

The recorded speech samples were analyzed using computer software to determine the following parameters.

I) Temporal parameters

i) Vowel duration (preceding & following vowel duration)

ii) Consonant duration

iii) Total word duration

iv) Pause duration

II) Spectral parameters

i) Average fundamental frequency

ii) Formant frequencies (Fl, F2, F3)

iii) Bandwidths (Bl, B2, B3,)

The obtained results were subjected to statistical analysis in order to determine the mean, standard deviations and the significance of difference between the two groups.

IMPLICATIONS OF THE STUDY

Speech samples (8 VCV Bengali words) from 20 hearing impaired, Bengali speaking children were taken and matched for their age and sex to 20 normal Bengali speaking children. 7 acoustic parameters (vowel duration, consonant duration, intersyllabic pauses, total duration of the words, fundamental frequency, formant frequencies and Bandwidth) were analysed.

1. The results of this study would help in better understanding of the speech of the hearing impaired Bengali speaking children.

2. The results of this study would provide data regarding the acoustic characteristics of speech of the hearing impaired children in general.

3. Methods used in the study and findings of the study would help in planning and developing therapy programs for the hearing impaired.

LIMITATIONS OF THE STUDY

1. Individual difference existed in the hearing impaired group, in terms of,

* Hearing aid usage
* Therapy duration
* Parental participation in therapy
* Motivation for therapy

2. The study was limited to only twenty hearing impaired and twenty normal subjects.

3. The speech samples mere limited to eight VCV combinations only.

REVIEW OF LITERATURE

Communication is the crux of our survival in this world. Communication is a two way process involving the encoding and decoding of information. Thus, this is the only way by which we can express our inner feelings, ideas, views, etc to others. The ability to communicate is what makes all the difference between 'living' and 'surviving'. Communication, is not just exclusive to the human race. Even animals communicate, but what distinguishes human communication from animal communication, is the highly skilled function of "SPEECH". Speech is frequently cited as a most important human faculty, and sometimes, as a "uniquely" human faculty.

Stetson(1928) states that speech is movement made audible (Stetson, 1928). The movements of the speech organs -structures such as the tongue, lips, jaw, velum, and vocal folds - result in sound patterns, that are perceived by the listener. Speech is a form of communication in which one of the essential links is the transmission of information by means of sound waves. While talking, we hear sounds, and on the basis of these sounds, we recognize the string of phonenemes, the intonations and rhythms, that make up the spoken message. Every thing else is inferred and constructed by the brain (Ross and Giolas, 1978).

The part played by the ear in speech communication is the perceiving of sounds, the application of acoustic cues in placing these sounds in phonemic classes, and the use of those same cues in the control of articulation through auditory feedback. Our ears play an indispensible role in speech.The auditory channel is thus vitally important during the learning period; and is the foundation of the language system. It is through the auditory mode, that speech and language are normally and usually, effortlessly, developed (Ross and Giolas, 1978) .

Normal speech production requires auditory reception for monitoring of speech (Monsen, 1974) . Hearing is the most important sensory modality for speech and language acquisition. It is through continous auditory stimulation of speech and other sounds in the environment that a child is able to acquire language (Whetnall and Fry, 1964).

The hearing mechanism is also essential for monitoring one's own speech production. In addition, hearing also enables an individual to make judgements regarding the location of the different sound sources in the environment.

Auditory feedback is particularly important in the early stages, in that, it allows the child to develop the same speech characteristics as those around him. Normally, attempts to produce speech, follow with the development of the phonemic system and are the result of social pressures upon the child. Naturally, he wants to take advantage of the power of speech, and he can do this only by speaking to himself. His first word is amply rewarded by the approval and attention of his mother and other adults and it is not long before his speech productions are reinforced by getting what he wants or at least evoking a verbal response. This is the period during which the mother acts as interpreter between the baby and the world, and there is continous pressure on the child to shape his articulation so as to bring it more and more in line with that of adults. That he is able to do so, is just one more result of his use of acoustic cues. During the learning period, the child is trying to reproduce the sound patterns that he receives from adult speakers, primarily from his mother. "It takes considerable practice and hence time for this process of auditory stimulation, to cause an adaptation to adult like speech to take place in a normal child" (Ross and Giolas, 1978) . The task is however very difficult for a child who is born deaf. Thus hearing controls speech, and without hearing, speech fails to develop. Hearing impairment has a marked effect on the child's ability to acquire speech. (Whetnall and Fry, 1964).

Only when the faculty of hearing is absent, one realises its importance at every walk of life. Loss of hearing results in communication problems, as it not only signals difficulty in understanding the sounds of the environment, but also correlates with serious language, voice and articulation deficits. The normal hearing child is continuously exposed to sounds from birth or even before birth. It has frequently been noted that babies with hearing impairment enter the babbling stage in the normal way and their babbling is not perceptibly different from that of hearing babies (Lenneberg, Rebelsky, and Nichols, 1965; Lenneberg, 1966). What is reported almost equally often is that after the lapse of some time, the babbling fades. This is usually, at about the time, when the trigger action of incoming speech begins to take effect. Because the sound of adult speech is not loud enough to the child, to start him babbling, this motor activity ceases before the control mechanism in the brain has been established. For this reason alone, therefore, the early diagnosis of a hearing loss, and providing adequate amplification at an early stage are essential to the proper management of a hearing impaired child. If these requirements are met, then the normal development of speech from the babbling period onwards becomes a real possibility. In some cases, it has been reported that, even where babbling has faded, the provision of a hearing aid after an interval has resulted in a resumption of babbling activity.

Hearing impairment has a marked effect on a child's ability to acquire speech. This effect is related to the extent and type of hearing loss; thus the child who is profoundly deaf, is most likely to have difficulty in both understanding speech and producing speech that is intelligible. (Stark 1979). One of the most devastating effects of congenital hearing loss is that normal development of speech is often disrupted. As a consequence, most hearing impaired children must be taught the speech skills that normal hearing children readily acquire during the first few years of life. Although some hearing impaired children develop intelligible speech, many do not (Osberger and Mc. Garr, 1982).

For many years, it was believed that profoundly hearing impaired children were incapable of learning to talk. Carrying this belief to the extreme (Froeschels, 1932) even suggested that all deaf children exhibited some behaviour problems, "due to the fact that the profuse motor release connected with speech is impossible in their case".

As reported by (Gold, 1980) one of the major considerations in the education of the deaf, is to achieve a level of speech competence such that the individual can make himself understood to the "person-on-the-street'. However, the ultimate goal of aural rehabilitation, is, for the hearing impaired individual to attain, as far as possible, the same communication skills, as those of the normal hearing individual. However, every hearing impaired child is entitled to speech training services, even if a realistic goal of such training maybe only the development of functional (survival) speech skills. Within the last decade, advances have been made in studying the speech of the hearing impaired. This is largely due to the development of sophisticated processing and analysis techniques, in speech science, electrical engineering, and computer science, that have increased the knowledge of normal speech production. In turn, these technological advances have been applied to the analysis of the speech of the hearing impaired and also, to the development of clinical assessment, and training procedures. The oral communication skills of the hearing impaired children have long been of concern to educators of the hearing impaired, Speech Pathologists, and Audiologists, because the adequacy of such skills, can influence the social, educational and career opportunities available to the hearing impaired individuals (Osberger and Mc. Garr, 1982).

Speech can be studied under three major aspects (Kent and Read, 1995) . They are physiological, acoustical and perceptual.

1. The physiological arena (or physiologic phonetics. (Metz et al., 1985).

2. Acoustic (Monsen, 1976 a, 1976b, 1974, 1978; Angellocci, et al, 1964; Gilbert, 1975; Calvert, 1962; Shukla, 1987; Rajnikantha, 1986; Sheela, 1988; Jagdish 1989; Rasitha, 1994; Rahul, 1997; Elizabeth, 1998; JayPrakash, 1998; Kanaka, 1998; Poonam, 1998).

3. Perceptual; typically, called speech perception (Levitt, et al, 1976; Stevens et al, 1983; Hudgins and Numbers, 1992, Markides, 1970; Geffner, 1980.

The power of modern computer methods in analyzing speech can be appreciated by taking a brief look at the acoustic analysis of speech. Review of the acoustic analysis of speech begins well before the 20th Century. "Modern analytic techniques" involve digital techniques. This offers several advantages as it is non-invasive, needs relatively simple instrumentation, and may be used routinely to depict changes in the physical characteristics of frequency, intensity, and the duration of speech segments. (Leeper, et al, 1987). Acoustic analysis of speech of the hearing impaired permits analysis of both correct and incorrect productionS^using subjective procedures. (Osberger and Mc. Garr, 1982). It provides an objective description of speech of the hearing impaired.

Human beings are equipped at birth to detect certain acoustical features that are important for communication. (Stark, 1979). There are three general categories of phonetic features, that are important for speech reception, namely:

1. temporal cues (eg: vowel duration)
2. spectral cues (eg. formant frequencies)
3. Both temporal and spectral cues. (vowel formant transitions accross a range of frequencies over time).

The classic investigation of errors in phoneme production by deaf children is that of Hudgins and Numbers

(1942). Their main findings were nonfunction of the initial or final consonant, errors in clustered consonants, errors in voicing and nasality, substitutions, and either neutralization or diphthongization of vowels. Vowel production by deaf children shows overlap and poor definition of formant areas. (Angelocci, Kopp, and Holbrook, 1964). There is a lack of correct timing in the movement from one articulatory position to another (Calvert, 1961, Martony, 1966). The speech is characterized by poor breath control (Hudgins, 1937, 1946), and errors of intonation, duration, and rhythm (Lafon et al, 1967; John and Howarth, 1965; Hood, 1966).

In recent years, considerable attention has been given to the possible use of electronic devices to facilitate speech training by providing visual or tactual representations of speech sounds, to compensate for the auditory feedback, that the deaf child lacks (Pickett, 1971; Pronovost, 1967). With the advent of the high speed digital computer and sophisticated signal processing and display generation techniques, it is now possible to develop a great variety of training displays designed to convey information about many aspects of speech (Nickerson and Stevens, 1973). Before this technology can be used with maximal effectiveness, however, more information is needed about the characteristics of the speech of deaf persons, and in particular, about how the acoustic parameters of speech relate to its perceptual properties. Thus, analysis of speech of hearing impaired becomes important (Nickerson, 1975).

So far, little work has been done to study the normal and abnormal speech patterns in Bengali language. Bengali is the native language of 'West Bengal' in India. Although the language bears similarities with many other Indian languages, there are some typical differences which may be reflected in the speech of the hearing impaired. Considering the large population of hearing impaired children in West Bengal, it was considered worthwhile to make an attempt to understand the segmental features of normal and hearing impaired Bengali speaking children.

INTELLIGIBILITY OF SPEECH IN THE HEARING IMPAIRED

Subtelny (1975) has stated that speech intelligibility is the single most practical index of hearing impaired person's oral communication abilities. Oral speech intelligibility of hearing impaired individuals, refers to the intelligibility of their speech to normally hearing listeners, i.e. how much of that subjects (deviant) speech is understandable to other listeners (Monsen, 1983).Further he states that the term "speech intelligibility" is rather ambiguous, because it has only a vague meaning until it is applied to a particular talker and a particular listener in a known context. To study the speech intelligibility of hearing impaired talkers with a greater degree of rigor, the term must be defined precisely. The intelligibility, of the speech of hearing impaired talkers would seem to be dependant on the following:

1. The speaking proficiency of the talker.
2. The listener's prior experience in listening to hearing impaired persons talk.
3. The visibility of the talker to the listener.
4. The complexity of the material spoken.
5. The context in which the utterance occurs.
6. The possibility of repetition of the utterance.

The above factors are all known or suspected to influence the intelligibility of a hearing impaired person's speech. (Monsen, 1983).

On the average, the intelligibility of profoundly hearing - impaired children's speech is very poor. Only about one in every 5 words they say can be understood by a listener who is unfamiliar with the speech of this group. (Brannon, 1966; John and Howarth, 1965; Markides, 1970; Mc Garr, 1978; Smith, 1975). It is difficult to determine the exact nature of speech errors that reduce the speech intelligibility without a clear understanding of the underlying nature of the unintelligible speech of the deaf (Metz, 1982). The intelligibility measures in most studies have been based only on a listeners auditory judgements of a child's productions. While this approach may be the most appropriate for quantifying the intelligibility of speech, it does not necessarily provide an accurate assessment of a child's ability to communicate in a face to face situation.

A review of the literature indicates that an important factor determining the intelligibility of a hearing impaired child's speech is the degree of the child's hearing loss (Boothroyd, 1969; Elliot, 1967; Markides, 1970; Montgomery, 1967; Smith, 1975) . Broothroyd (1969) found a positive correlation between percent intelligibility scores and hearing level at all frequencies, particularly at 1KHz and 2KHz.

Smith (1975) observed a systematic decrease in intelligibility with poorer hearing levels to a level of about 85 dBHTL, after which the relationship was not clear. Monsen (1978) found that all the children he studied with hearing losses of 95dBHTL or less, had intelligible speech, but children with losses greater than 95dBHTL did not always have poor or unintelligible speech. These data indicate that even though a child has a profound hearing loss, he or she still has the potential to develop functional speech skills.

Studies by Smith (1975) and Gold (1978) reveal that even when, the same test materials and procedures were used in these studies, children with similar hearing levels, in different educational settings, showed an average difference of 20% in intelligibility scores. Average intelligibility scores of 70-76% have been reported for the hard of hearing

(Gold, 1978, Markides, 1970). Monsen (1978) did a study which revealed a score of 91% for severely hearing impaired children, and a score of 76% for the profoundly hearing impaired children. Monsen (1978) has attributed the difference in intelligibility scores between his and other studies to differences in the speech material that the children were required to produce. The sentences in his study were shorter, contained a more familiar vocabulary, and were syntactically less complex than those used by other investigators. The above studies indicate that it is not hearing level *per se* that is most important for the development of intelligible speech, but rather the ability of the hearing impaired child to make use of the acoustic cues that are available to him/her.

The overall speech intelligibility does not, on the average improve with age, i.e.; 16 year olds are not, on the average, more intelligible, than 10 year olds (Jensema et al, 1978). Hudgins (1960) studied the intelligibility of deaf children over time. On the average, speech intelligibility was 35% at the beginning of a 5 year period and 40% at the end. John and Howarth (1965) found the average intelligibility of 29 hearing impaired children to be 29% before a special training session in speech improvement, and 45% afterwards.

Markides (1970) found the average speech intelligibility of his talkers to be 19% to laypersons and 31% to teachers.

The effect of listener experience has been cited in several studies. Thomas (1963) found a difference of approximately 24% between experienced and inexperienced listeners. He also found that listeners were able, on the average, to understand about 16% more if they were able to see as well as hear the speaker. Markides (1970) showed an advantage of about 12% for experienced over inexperienced listeners for the speech of profoundly deaf and severely hearing impaired subjects and about 7% for the speech of the "partially hearing".

Monsen (1978) found that experienced listeners, on the average, understood 9% more than their naive counterparts. There is some evidence that this listener advantage is not particularly difficult to acquire, since it accounts to about 5% after a fairly brief exposure to hearing impaired talkers (Monsen, 1978). Mc Garr (1981) studied the intelligibility of test words, said by hearing impaired children in sentence and in isolation. The intelligibility of the words in sentences was greater than in isolation, and experienced listeners, scored from 3% to 11% higher than inexperienced listeners.Hudgins and Numbers (1942) who were the first to report data on the speech intelligibility of hearing impaired children, had, both hard of hearing and deaf children read special sentences, and asked the children's teachers to listen to their speech and give them a score for the number of words correctly produced. The mean score for the group of 8-19 year olds was about 29%.

For normal speech, the redundancy of the context is usually unimportant, but for deviant speech, it can be essential to its comprehension (Monsen, 1983). Words and sentences which are spoken directly to listeners, in a face to face situation, are more intelligible than sentences that are taperecorded (Hudgins, 1949, Thomas 1964).

Various studies have shown differences in terms of intelligibility of speech of the hearing impaired. According to Osberger and Levitt (1982), on the average, the intelligibility of speech of the hearing impaired children is very poor. On the other hand, Metz et al (1982) are of the opinion that the speech produced by many deaf persons is frequently intelligible to even inexperienced listeners. The speech of profoundly hearing impaired children is usually less than 30% intelligible (Ling, 1976).

Poor speech intelligibility achievement in the hearing impaired has been correlated to several variables related to the reception and production of speech. Among the perceptual variables, residual hearing (Montgomery, 1967; Elliot, 1969; Markides, 1970; Smith, 1975; Ravishankar, 1985; Vasantha, 1995) and lip reading (Vasantha, 1995) abilities have been studied. The results have indicated that both residual hearing as well as one's lip reading ability affect intelligibility. Hearing impaired children tend to have a better speech intelligibility when their lip reading abilities were better.

From the production point of view, speech intelligibility has been studied in relation to segmental and suprasegmental errors. It has been generally found that as the overall frequency of segmental or phonemic errors increases in the speech of the hearing impaired, intelligibility decreases. (Brannon, 1966; Gold, 1978; Hudgins and Numbers, 1942; Markides, 1970; Smith, 1975). Hudgins and Numbers, (1942), and Smith (1975) found a high negative correlation between intelligibility and total number of vowel errors (-0.61) and total number of consonant errors (-0.70). Of the seven consonant error categories, considered in the Hudgins and Numbers (1942) study, three categories (omission of initial consonants, voiced-voiceless confusions, and errors involving compound consonants) had the most significant effect on intelligibility. The other four categories concerned, (substitution errors, nasality errors, omission of final consonants, and errors involving abutting consonants) had a lower correlation with intelligibility and contributed to a much lesser extent to the reduced intelligibility of hearing impaired children's speech.

In a recent study, Monsen (1978) examined the relationship between, intelligibility and four acoustically measured variables of consonant production, three acoustic variables of vowel production, and two measures of prosody, three variables showed high correlation with intelligibility.

1) The difference in voice-onset time between /t/ and /d/.

2) Difference in 2nd formant location between /i/ and /I/.

3) Acoustic characteristics of the nasal and liquid consonants.

Other segmental errors that have been observed to have a significant negative correlation with intelligibility are omission of phonemes in the word initial and medial position; consonant substitutions involving a change in the manner of articulation; substitutions of non-English phonemes such as the glottal stop, and unidentifiable or gross distortions of the intended phoneme (Levitt, et al, 1980). At the suprasegmental level, timing errors, and errors involving poor phonatory control have been found to have a negative effect on intelligibility. The correlation between speech rhythm and intelligibility was 0.73, i.e. the sentences spoken with correct rhythm were substantially more intelligible than those that were not (Hudgins and Numbers, 1942). Gold (1980) has stated that,the lack of intelligibility among the hearing impaired children is associated with frequently occuringsegmental and suprasegmental errors. The common articulatory problems observed were:-

* errors of voicing
* omission of consonants
* vowel substitutions

Suprasegmental errors were associated with problems of timing, intonation and voice quality.

Speech production performance was found to be good for children of higher socio-economic status, and better hearing aid users (Weisel, and Reichstein, 1986).

Thus, the results of various studies suggest that overall levels of speech intelligibility are utterly inadequate for oral communication (Ling, 1976). Hence, the parameters such as vowel duration, formants, bandwidths were taken up for the study.

So far, no investigations have been done to study the speech characteristics of Bengali speaking hearing impaired children. The purpose of the present study is to compare, speech of the hearing impaired to that of the normals. This will be of help in improving the speech intelligibility of the hearing impaired children.

TIMING:

Since the early 1900's investigations have repeatedly shown that the speech of deaf children contain numerous timing errors. Such errors include a decreased speaking rate (Voelkar, 1935, 1938; John and Howarth, 1965; Hood, 1966; Nickerson, Stevens, Boothroyd and Rollins, 1974); excessive prolongation of speech segments (Calvert, 1961; Hood, 1966; Levitt, Smith and Stromberg, 1976), insertion of long pauses, often at syntactically inappropriate boundaries (Boothroyd, Nickerson and Stevens, 1974; Nickerson et al, 1974); introduction of adventitious sounds between phonemes and syllables (Hudgins and Numbers, 1942; John and Howarth, 1965; Smith, 1975); failure to temporally differentiate stressed and unstressed syllables (Boothroyd et al 1974; Nickerson et al, 1974); and failure to modify segment duration as a function of phonetic environment (Calvert, 1961; Monsen, 1974). Because of such errors, the speech of the deaf has often been described as slow, labored, and lacking in rhythm.

Hearing impaired speakers have been described as having faulty coordination between various components of the speech mechanism (Mc. Garr & Harris, 1983; Levitt, 1971). Their speech characteristics seem to relate to a mismanagement of the respiratory, phonatory and articulatory system and their relationship to the temporal ordering of speech (Forner and Hixon, 1977, Monsen, 1979, Osberger and Levitt, 1979, Harris and Mc. Garr, 1980).

1. RATE:

On the average, deaf speakers speak at a much slower rate than normal speakers (Rawlings, 1935, 1936; and Voelkar, 1938; Calvert 1962; Boone, 1966; Brannon, 1966; Hood, 1966; Martony, 1965, 1966; Colton and Cooker, 1968; Boothroyed, Nickerson and Stevens, 1974; Nickerson et al, 1974). In 1938, Voelkar compared 98 deaf and 13 normal hearing children in grades 'one' to 'three' on reading rate. He found that the fastest deaf reader was slightly slower than the average normal reader. The average reading rates for the two groups were 69.6 and 164.4 words / minute for the deaf and normal hearing children, respectively.

Nickerson et al (1974) tested slightly older deaf and control groups on reading rate and still found large differences between the groups, although the mean rate for the deaf group was as high as 108 words/minute. This seems in keeping with Boone's (1966) findings that the rate of the speech of the deaf increases with age but still remains considerably slower than that of normal speakers. In addition to measuring the number of words/minute, Nickerson et al (1974) studied their subject's utterances in terms of number of syllables per second. They reported an average of 2.0 syllables or 4.7 phonemes / sec. for the deaf as compared with 3.3 syllables and about 8.0 phonemes/sec for normal speakers. The number of syllables per second for the normal group is identical with the predicted number suggested by Pickett (1968).

The decreased speaking rate may be attributed to:

1. Excessive prolongation of speech segments (increased duration of phonemes).

2. Insertion of improper and often prolonged pauses within utterances (Gold, 1980).

With few exceptions, the speech of the, severely and profoundly hearing impaired is perceived as being too slow and sounding very laboured. Physical measures of speaking rate have shown that profoundly hearing impaired speakers, on the average, take 1.5 to 2.0 times longer to produce the same utterance as do normal hearing speakers (Boone, 1966; Heldinger, 1972; Hood, 1966; John and Howarth, 1965; Voelkar, 1935, 1938).

INCREASED DURATION OF PHONEMES AND VOWELS:

Prolongation of speech segments may be present in the production of phonemes, syllables, and words. Calvert (1961), was among the first to obtain objective measurements of phonemic deviations in the speech of the hearing impaired by spectrographic analysis of bisyllabic words. The results showed that hearing impaired speakers extended the duration of vowels, fricatives and the closure period of plosives upto five times the average duration for normal speakers. Osberger and Levitt (1979), observed that syllable prolongation in the speech of the hearing impaired was due primarily to prolongation of vowels. The duration of a phoneme bears important information in the perception of a speech message. Durational changes in vowels seem to differentiate not only between vowels themselves, but also between similar consonants adjacent to the vowels (Gold, 1980).

There is a general tendency towards a lengthening of vowels and consonants (Angelocci, 1962; Calvert, 1962; John and Howarth, 1965; Boone, 1966; Levitt, Smith and Stromberg, 1974, Parkhurst and Levitt, 1978). Acoustic analysis of normal speech have shown that the duration of vowels is systematically influenced by effects operating at the level of phonetic segments. Since vowels form the nuclei of the larger segments of speech, these differences in vowel duration exert substantial effects on both the production and perception of the temporal and segmental aspects of speech. Vowels have been described as having an intrinsic duration (Peterson and Lehiste, 1960), and, in comparable contexts, some vowels are consistently shorter than other vowels (House, 1961). The vowel duration has been found to vary the meaning of the word and also acts as a prosodic feature in a language (Fairbanks, 1960).

According to O' Shaughnessy (1981) "vowel duration varies directly with tongue height, nasality, voicing, position of the syllable within the word, number of syllables within the word and manner of articulation of the ensuing consonants". Vowel duration performs different functions in different languages (Jensen and Menon, 1972).

Vowels are generally longer in the presence of voiced stops and continuants (House and Fairbanks, 1953, Denes, 1955, Raphael, 1972) . This lengthening of the vowel contributes to the perception of the consonant.

Unfortunately, however, the duration of phonemes is distorted in the speech of the deaf. Lengthening or shortening of a vowel or any speech segment can be done by altering the particular context. House and Fairbanks (1953) showed that the duration of a vowel in English varies systematically from shorter to longer in the following order; a stressed vowel preceding a voiceless stop, less than voiceless fricatives, less than nasals, less than voiced stops, less than voiced fricatives.

Disimoni (1974) based on oscillographic measurements of vowel and consonant durations in CVC and VCV utterances of 3, 6, 9 year old children concluded that:

1. Variability of the duration tended to decrease with age.

2. The vowel duration in the voiceless consonant environments remained relatively constant for all ages tested, while in voiced consonant environments, it was found to increase with age.

3. Vowel duration values for both voiced and voiceless consonant environments were found to be significantly different in 6 and 9 year old subjects, but not in 3 year old subjects.

The vowel duration also varies with reference to the voice-voiceless distinction of the following consonant. The hearing impaired fail to produce the appropriate modifications in the vowel duration as a function of voicing characteristics of the following consonant. Hence the frequent voiced/voiceless confusions observed in their speech may actually be due to vowel duration errors (Calvert, 1961; Monsen, 1974).

Raphael (1971), studied the effect of preceding vowel duration as a cue to the perception of the voicing characteristics of word final consonants in American English. It was found that, regardless of the cues for voicing/ voicelessness, listeners perceived the final segments as voiceless when they were preceded by vowels of short duration and as voiced when they were preceded by vowels of long duration. Early research by House and Fairbanks (1953); Peterson and Lehiste (1960) ; Lindblom (1968) ; and Di Simoni (1974a, b) indicated that vowels in voiceless consonant environments had shorter durations than did vowels in voiced consonant environments.

Angelocci (1962) claimed that his deaf subjects took four to five times as long to produce fricatives as did his normal hearing subjects. The closure periods for plosives were also considerably prolonged. According to Hood (1966), training on duration of phonemes would improve intelligibility significantly if articulation was good.

Monsen (1976) studied 12 deaf and six normal hearing adolescents as they read 56 CV(C)'s containing the vowel /i/ and /I/. He found that the deaf subjects tended to create mutually exclusive durational classes for the two vowels such that the duration of one vowel could not approximate that of the other even when they occurred in the presence of different consonants. For the normal subjects, the duration of /i/, was always longer than /I/, for a particular consonant environment, but the absolute durations of the two vowels could overlap if the accompanying consonants differed. Thus, although the vowels produced by the deaf subjects were distinct in terms of duration, they were still less intelligible, since the listener could not rely on normal decoding strategies to interpret what he heard.

Sussman and Hernandes (1979) did spectrographic analysis of several suprasegmental aspects of the speech of 10 hearing - impaired adolescents. Among other findings, they observed that the speakers did produce longer vowels before voiced stops than before voiceless stops. However, they noted that the increase in vowel duration due to the presence of voicing was considerably smaller than for normal speakers.

Rashmi (1985) determined the vowel duration of /i/ in /idu/ in children and reported the following results:

Age (years)	Vowel duration (msec)
5 - 6	158.07
6 - 7	121.79
7 - 8	111.32
8 - 9	88.31
9 - 10	87.28

According to Rashmi (1985), males and females showed a consistent decrease in the vowel duration as a function of age.S^vithri (1984) found that a low vowel had longer duration than a high vowel in kannada.

Vowel duration performs different functions in different languages. In American English, for example, variations in vowel duration are phonetic in nature. House (1961), established that the lax vowels [I], [ɛ], [ʌ], [ʊ], are characteristically shorter than their tense counterparts /i/, /e/, /a/, and /u/. It was also demonstrated in the same study that there is an effect of phonetic environment on vowel duration. Vowels preceding voiceless consonants are, in general, shorter than those preceding voiced consonants.

Jensen and Menon (1972) demonstrated that the average duration of long vowels were approximately twice that of their short vowel counterparts. It was concluded that the linguistic distinction between short and long vowels may reside in the single parameter of duration, which may lead to change in meaning.

Potential durational cues include the duration of the previous segment and the duration of the plosive itself. In English, a vowel or consonant followed by a voiceless plosive is significantly shorter in duration than it would be before a voiced plosive (House and Fairbanks, 1953; Peterson and Lehiste, 1960). The durational difference in the segment preceding the plosive is as much as 34% in phrase final syllables, but the contrast is not as great in other positions. (Klatt, 1973 b; 1975). In prestressed position, voiced and voiceless plosives have about the same duration (Lisker, 1969, Klatt, 1973a). However, in post stressed intervocalic phonetic environments, the closure duration for the voiced consonants is shorter (Lisker, 1957).

0' Shaugnessy (1981), studied the duration of french vowels and consonants. He found that vowel durations were highly variable with respect to the phonetic features of ensuing consonants, with voiced fricatives greatly lengthening, and unvoiced obstruents, shortening the vowel. Nasalized vowels were much longer than corresponding oral vowels in closed syllables, but had similar durations in open syllables. Smaller effects included, duration being inversely proportional to vowel height, and duration being longer after stops than after other consonants.

Among the consonants, the consonants in the word initial position were shorter than the consonants in the word final positions. Unvoiced fricatives had the longest duration, at the word initial positions. Most post-vocalic consonants lengthened before and after short/high vowels and shortened next to long/low or nasalized vowels.

The differential effect of vowel environment on the duration of consonants was first shown by Shwartz (1969). In his study, Shwartz varied the phonetic context in which each consonant was embedded. The vowels he chose were one high front vowel, /i/, and one low back vowel, /a/. He found that duration of the consonants were significantly lengthened when the final vowel was /i/., regardless of what the initial vowels were. He reasoned that the primary effect on durations of the consonant element in a VCV utterance was caused by the relative tongue positions between the consonant and the final vowel, and that the effects of the initial vowel were negligible. Lindblom (1968) reported the tendency for the duration of a stop consonant in the initial position of a word to vary inversely with the number of syllables in the word.

Whitehead and Jones (1976, 1978), noted that, for hearing impaired adults, vowels were significantly longer in duration in a voiced than in a voiceless consonant environment and were longer in duration in a fricative than a plosive consonant environment. Unlike normal speakers, however, Whitehead and Jones (1978) found that hearing impaired speakers produced longer /s/ and /ʃ/ segments in the /a/ vowel environment than the /i/ environment.

Raphael (1971) is of the opinion that:-

1. Preceding vowel duration is a sufficient cue to the perception of the voicing characteristics of a word final stop/fricative, or cluster.

2. The presence of voicing during the closure period of a final consonant or cluster does have some cue value, although it is minor compared to that of vowel duration.

3. The cue of preceding vowel duration is more effective before stops and clusters than before fricatives.

4. The perception cues for the preceding vowel duration is continuous, rather than categorical.

Smith (1978) found that even children (4 year olds, and 2 year olds), like adults showed final syllable vowel lengthening than non-final syllable vowel.

The positional effects on segment duration have been studied by several investigators in order to describe the duration of speech segments in different positions in words and phrases. (Cooker et al, 1973; Gaitenby, 1965; Klatt, 1975 a, b, Lehiste, 1972; Lindblom et al, 1976; Noote boom; 1972; Oiler, 1973). The greatest positional effect is final lengthening that appears to be of considerable generality as a phonetic phenomenon.

Lyberg (1981) studied vowel duration depending on its position in the word. It was found that vowel duration is more sensitive to the number of following syllables than to the number of preceding syllables. Leeper et al (1987) studied the influence of utterance length upon temporal measures of syllable production in hearing impaired children. They found that, the hearing impaired children always exceeded the normals in average initial vowel duration (VCV). Same results were obtained for final vowel duration also. The hearing impaired differed from the normal hearing children by about 95 ms., in final vowel duration. In addition, the hearing impaired showed twice the variability of the normals across all utterance lengths. Even the "total word duration" was found to be longer in the hearing impaired group compared to normals.

Another manifestation of the problem of duration of phonemes relates to the differentiation between stressed and unstressed syllables. Nickerson et al (1974), measured the duration of syllables in four short utterances, read by 25 deaf and 25 normal hearing children. They calculated the ratio of the duration of the stressed syllable to that of the unstressed syllable adjacent to it. The results showed that the deaf children failed to produce differences between the durations of the stressed and unstressed syllables. Although both the deaf and the normal children tended to prolong the syllable in phrase or sentence final position, the deaf subjects also produced the unstressed syllables with increased duration. Several investigations have shown that while hearing impaired speakers make the duration of unstressed syllable shorter, the proportional shortening is smaller, in the speech of the hearing impaired than in the speech of normal hearing subjects (Levitt, 1979; Stevens et al, 1978).

Boothroyd, Nickerson, and Stevens (1974) have reported that the unstressed syllables take twice as long for the deaf as for the normals. Angelocci (1962) found that the duration of the unstressed vowels produced by the deaf speakers in his study were 4-5 times as long as the average of that produced by hearing speakers. This lack of differentiation between the length of stressed and unstressed syllables, contributes to the distances perception of improper accent or stress in the speech of the deaf as reported by Hudgins (1946) and Levitt (1971). Duration is not only increased for unstressed syllables but for stressed syllables as well. John and Howarth (1965) found that the duration of monosyllabic words spoken by their deaf subjects was nearly twice that for the same words spoken by hearing children.

Osberger and Levitt (1979) found the mean ratio for the duration of the stressed and unstressed vowels to be 1.49 and 1.28 for the normal hearing children and the deaf children respectively. The reduced ratio for the deaf children indicates that while the average duration of unstressed vowels is shorter than the duration of stressed vowels in the speech of the deaf children, the proportional shortening of unstressed vowels is lesser, in the deaf child's speech than the in the speech of normal subjects.These studies have shown that the hearing impaired produce mostly stressed syllable and that there is an overall tendency for increasing the duration of all phonemes in the speech of the hearing impaired. In contrast to this finding, Reilly (1979) , found longer than normal duration differences between vowels in primary and weak stress syllables produced by a group of profoundly hearing impaired children.

Mc.Garr and Harris (1980) found that, although intended stressed vowels were always longer than unstressed vowels in the speech of profoundly hearing impaired speakers, the intended stress pattern was not always perceived correctly by a listener. Thus, the hearing-impaired speaker was using some other suprasegmental feature to convey contrastive stress. Variation in fundamental frequency would be a likely alternative but Mc Garr and Harris (1980) also found that while the hearing impaired speakers produced the systematic changes in F_o associated with syllable stress, perceptual confusions involving stress pattern were still observed.

The overall tendency for increased duration of all phonemes in the speech of the deaf (Calvert, 1961; Hood, 1966) is felt to be related to the teaching of articulation of individual isolated elements rather than longer more meaningful units of speech. (Rawlings, 1935, 1936; John and Howarth, 1965; Boone, 1966).

Total word duration, vowel duration, the number of pauses and pause duration are higher in the hearing impaired children compared to the normal children [Kanaka (1998), Poonam (1998), Jayaprakash (1998), Priya (1998), Rathnakumar (1998); and Rahul (1997)].

Konefal et al (1982) studied the children's syntactic use of vowel duration. It was found that vowels appearing in the prepausal conditions were longer than vowels in the polysyllabic and monosyllabic positions. The prepausal lengthening effect identified by Umeda (1975) for adults also appeared in young children's spontaneous sentences. When a syllable occurs before a pause that marks a major syntactic boundary, it is longer in duration than when it occurs in other positions in a phrase (Klatt, 1975).

Stevens et al (1978) observed that when there was evidence of prepausal lengthening in the speech of profoundly hearing impaired talkers, the increase in the duration of the final syllable was much smaller, on the average, for the hearing impaired speakers than for the normal hearing speakers. In contrast to this finding, Reilly (1979) found that profoundly hearing impaired speakers used duration to differentiate prepausal and nonprepausal syllables. Reilly(1979) observed a larger than normal difference between the duration of syllables in the prepausal and nonprepausal position in the samples produced by the hearing impaired children.

The deaf do not move their articulators correctly in proceeding from one phoneme to the next (Angelocci, 1962; Calvert, 1961, 1962; John and Howarth, 1965; Martony, 1965, 1966; Brannon, 1966; Levitt and Nye, 1971; Smith 1972; Stevens et al, 1976; Parkhurst and Levitt, 1978).

Intrusive elements are often joined to the intended vowel or consonant. Smith (1972) noted the presence of added attack consonants on vowels and added release vowels on consonants. Parkhurst and Levitt (1978) found adventitious sounds to affect speech intelligibility of the deaf. They reported the presence of unexpected adventitious sounds, i.e. adventitious sounds other than those linked to normal articulatory movements to be highly correlated with reduction in speech intelligibility. Calvert (1962) referred to an intrusive glide, usually a /ə/ to describe the audible on and off glides of vowels in deaf speech. Rawlings (1935, 1936) proposed that part of the problem had to do with the fact that all phonemes were learnt as releasing sounds and this adds extra syllables when the sounds should be arresting. Levitt (1971) suggested that while moving from one articulatory position to the next, the deaf child unintentionally omits extra sounds. Other transitional problems include the timing of voice onset relative to release of voiceless stops (Angelocci, 1962), of the onset of nasalization for nasal consonants (Stevens et al, 1976) and of the end of nasalization on nasal consonants (Martony, 1965, 1966).

Oiler (1974) suggested that final syllable lengthening supplies important cues to the listener for the location of word, phrase, and sentence boundaries.

PAUSES

In addition to the altered durational patterns of the speech of the deaf, there are noted increases in 'within' and "between phrase' pauses which contribute to overall rate problems and thus to decrease intelligibility (Hudgins, 1946; John and Howarth, 1965; Boone, 1966; Boothroyd et al, 1974; Levitt et al, 1974; Nickerson et al, 1974; Forner and Hixon, 1977) . Profoundly hearing impaired speakers typically insert more pauses and pauses of longer duration than do speakers with normal hearing (Boone, 1966; Boothroyd, Nickerson, and Stevens, 1974; Heidinger, 1972; Hood, 1966; John and Howarth, 1965; Stevens, Nickerson and Rollins, 1978).

Stark and Levitt (1974) reported that their deaf subjects tended to pause after every word and stress almost every word. According to John and Howarth (1965) the silences between the words often accounted for one half the total time taken in saying test sentences. Hudgins (1946) noted that part of the problem of pausing was related to its inappropriate placement. Pauses may be inserted at syntactically inappropriate boundaries such as between two syllables in a bisyllabic word or within phrases. The greatest difference between normal hearing and hearing impaired speakers has been observed in the durations of inter and intraphrase pauses (Stevens et al, 1978) . Boothroyd et al (1974) found within phrase pauses to be a more serious problem than between-phrase pauses when they compared deaf to normal hearing speakers. On the average, within phrase pauses lasted eight times longer for the deaf than the normal subjects. Nickerson et al (1974) reported that total pause time for hearing children constituted 25% of the time required to produce their test sentences while pause time for the deaf was 40%. The results of Hudgins' (1934, 1937, 1946) early investigations have indicated that the frequent pauses observed in the speech of the hearing impaired maybe the result of poor respiratory control. Specifically, Hudgins(1934,1937,1946) found that deaf children used short, irregular, breath groups often withonly one or two words, and breath pauses that interrupted the flow of speech at inappropriate places.

There has been some evidence to indicate that pauses do not have a very strong negative effect on intelligibility. Parkhurst and Levitt (1978) looked at the effects of adventitious syllables, excessive duration, pitch breaks, and pauses, on overall speech intelligibility. They reported that excessive or prolonged pauses have a secondary effect on intelligibility. They even noted that short pauses may actually aid in increasing intelligibility. One interpretation of these findings is that these prolonged pauses provide the listener with additional time to process the distorted speech that they are hearing. The excessive and inappropriate use of pauses leads to the perception of improper groupings of syllables (Hudgins, 1946, Nickerson, 1974).

Hudgins (1937) blamed these problems on poor breath control. He claimed that the deaf used too much breath per syllable and that they did not group syllables into breath groups and phrases as normals would. Stark and Levitt(1974), found that hearing impaired children produced stress and pause, but not only in the intended locations. In other words, they tended to put equal stress on most words and to pause between most words. MC. Garr (1976) states that pause was correctly produced about 70% of the time and stress about 65% of the time in the speech of hearing impaired children.

Homma (1980) studied the durational relationships of between Japanese stops and vowels. He concluded that:

1) As in English, vowel duration was longer before voiced consonants than voiceless consonants, but the extent differed drastically. One of the reasons for this may be that vowel duration in Japanese is more influenced by the preceding consonant than the following one.

2) Vowel duration was independent from accent.
3) The place of articulation of the adjacent stops affected the vowel duration. As the place of closure moved toward the back, both VOT and vowel duration became longer in the

1st syllable. On the contrary, vowel duration became shorter in the 2nd syllable. Shukla (1987) compared vowel duration and consonant duration in 30 normal and hearing impaired individuals matched for age and sex. The results indicated the following.

a) On the average, the duration of vowel /a/ was longer when followed by a voiced consonant than when followed by a voiceless consonant in both the groups of subjects. However, in both the groups, the difference was less than the "Just Noticeable Difference" for duration.

b) In both the groups, vowel /a/ was longest in duration when followed by a nasal sound within the voiced sounds category and when followed by fricative /s/ in the voiceless sound category.

c) The duration of the vowel /a/ in the medial position was longer in the speech of the hearing impaired than in the speech of the normal hearing speakers.

d) In normal hearing subjects, the mean duration, of the vowels /a/, /i/ and /u/ in the final position, preceded by different consonants were around 200 msecs, 195 msecs and 185 msecs respectively. In the hearing impaired speakers, /i/ and /u/ tended to be longer than in normal speakers and vowel /a/ tended to be either longer or shorter, when compared to the length of vowel /a/ in normal speakers.

e) Hearing impaired speakers showed a greater variation in vowel durations than normal hearing speakers.

f) In the normal hearing speakers, vowel /a/ in the final position was longer than vowel /i/ and /u/ whereas in the hearing-impaired speakers, vowel /a/ was shorter than vowel /i/ and /u/ .

g) The vowel lengthening phenomenon was observed in Kannada language. "Vowel lengthening phenomenon" is the increment in duration of the final syllable vowel by 100 msec or more. It was first described in English language for phrase final and utterance final positions. (Klatt, 1975a, 1976).

h) Both the groups of subjects did not show any consistent changes in the duration of the vowels depending on the preceding consonants.

i) In both the groups, the durations of consonants were longer in vowels /i/ and /u/ environments, than in the /a/ environment.

j) In both the groups, velar sounds tended to be longer than bilabal consonants in both voiced and voiceless categories

k) In normal hearing subjects, the voiceless consonants were significantly longer than the voiced consonants, whereas, in the hearing-impaired, the durational difference between voiced and voiceless consonants were considerably decreased.

l) In the normal hearing the affricates /tʃ/ and /dʒ/ were the longest, whereas in the speech of the hearing impaired /ṭ/ and /d/ were the longest in voiceless and voiced categories of sounds respectively.

m) Durations of all the consonants were longer in the speech of the hearing impaired than in the normal hearing speakers.

n) Hearing impaired speakers showed a greater variation in controlling the length of all the consonants than the normal hearing speakers.

Sheela (1988) studied vowel duration in four normal and four hard of hearing individuals, and the results indicated that on the average, the hearing impaired group had significantly longer durations for vowels than that of the normal hearing group.

Thus, hearing impaired speakers distort many temporal aspects of speech. These distortions such as excessively prolonged speech segments, and the insertion of both frequent and lengthy pauses, are perceptually prominent, and distruptthe rhythmic aspects of speech. However, in spite of these deviances, there is evidence that suggests that the hearing impaired talker manipulates some aspects of duration, such as those involving relative duration, in a manner similar to that of speakers with normal hearing.

The factors related to particular difficulties with timing of speech events, prolonging them and producing apparently high variability of timing in the speech of the hearing impaired are not known. One possibility is that auditory feedback is necessary for rapid smooth production of complex motoric sequences of speech (Lee, 1950) and that hearing impairment limits the necessary information too severely, requiring a general slowing of the mechanism of production and imposing high instability upon timings.

VOICE QUALITY:

Those experienced in working with the deaf claim that they can readily identify the speech of deaf individuals (Bodycomb, 1946; Boone, 1966) and differentiate it from that of a normal speaker (Calvert, 1962). However in a study by Calvert (1962) where teachers of the deaf were asked to mark a checklist of the characteristics that most closely described the voice quality of the deaf; there was much variety among the 15 teachers in the adjectives they chose. Of 52 suggested terms, 33 were checked. Thus, although it would seem that the voice quality is highly recognizable, for running speech, the attributes which contribute to the perception are not clearly definable. The teachers chose such terms as tense, harsh, flat, breathy, and throaty.

Calvert (1961) also attempted to determine if the speech of deaf persons is distinguishable on the basis of quality from that of people with normal hearing. He selected 10 experienced listeners who said they could identify a deaf speaker by voice quality alone. He exposed them to recordings of vowels, diphtongs, mono and bisyllabic words, and sentences read by deaf and normal hearing speakers, speakers with harsh and breathy voices, and speakers simulating deaf speech. For utterances involving vowels alone, the listeners achieved only 5% accuracy in judging what group the speaker belonged to. As the length of the utterance increased to include transitional elements between phonemes and words, accuracy of judgements improved until a score of 70% was achieved for sentences. Calvert (1961) concluded that identification of the deaf speaker is dependant upon dynamic factors of speech i.e., the movement from one articulatory position to the next.

There seems to be a general agreement that the deaf speakers have a distinctive voice quality (Calvert, 1962, Boone, 1966). However it is not easy to define this characteristic voice quality of the hearing impaired. Hearing impaired are often reported to have a breathy voice quality. Hudgins (1937) and Peterson (1946) attributed this largely to inappropriate positioning of the vocal cords and poor control of breathing during speech. A large glottal opening in the hearing impaired may be due to the failure of the vocal cords to close properly. This results in a large expenditure of air and a voice with poor quality (Hudgins, 1937).

In a recent study, Monsen (1979) quantified some of the characteristics of deaf voice. Acoustic analysis of duration, fundamental frequency, and phonatory control were correlated with ratings of voice quality for monosyllables produced by young hearing impaired children. The results of this study showed that the fundamental frequency contour appeared to be the most general acoustic characteristics which differentiated the children with better voices from those with poorer voices. Children with good voice quality ratings had fundamental frequency contours which fell in an appropriate range and which varied over time in an appropriate manner. In contrast to this finding, children with poor voice quality produced intonation contours which were excessively flat or excessively changing. Monsen (1979) concluded that while other deviations such as poor vowel quality, breathiness and duration errors may exert a strong influence on perceived voice quality in individual cases, these do not appear to be the major factors in determining the quality of the voice.

Thus it appears, that the distinctive voice quality of the hearing impaired may be due to both poor articulatory timing control and inadequate control of fundamental frequency. (Osberger and Mc. Garr, 1982).

Deaf voice has been described by Jones (1978) as having, characteristic monotone peculiarity that immediately strikes the ear upon first hearing it, lack of accent and rhythm, poor resonance, and unnatural quality. Breathy voice and glottalization are characteristic of a hearing impaired child's speech. These problems are caused by improper adjustment of the vocal folds. (Osbeger and Mc. Garr, 1982). There is also a tendency for hearing impaired children who insert many glottalizations in their speech to have lower intelligibility than those who do not (Stevens et al, 1978).

CONSONANT ARTICULATION:

Hudgins and Numbers (1942), who did the first quantitative assessment of the speech of hearing impaired children, classified their data of consonantal errors into errors of omission, substitution and consonant clusters. They also observed that the most common error in the consonants was in voiced and voiceless distinctions. Markides (1970) reported that deaf children misarticulated nearly 72% of all consonants attempted, whilst the partially hearing children misarticulated a little over 26%. The study showed that in deaf individuals omissions were more than substitutions and distortions. Among the partially hearing impaired individuals substitutions were more than omissions and distortions. Analysis of the position of errors showed that the final consonant errors were more numerous than errors involving the initial and medial positions. The most frequently misarticulated consonants were the fricatives /s/, /ʃ/ and the nasal /n/.

Smith (1975) found the omission of consonants to be the commonest error in the speech of hearing impaired individuals. In her study, an analysis of position of errors indicated that there was no difference in the mean proportion of errors in initial and medial positions; however, there was a marked increase of errors in the final position.

Geffner (1980), in her study of the spontaneous production of phonemes in sixtyfive six-year old hearing impaired children, found omissions to be the most frequent problem (91%), followed by substitutions (7%), distortions (1%) and finally additions (0.1%). The frequency of omission errors, when analyzed according to place of articulation, indicated that the velar consonants (/g/, /k/) which are not visible were omitted in a greater proportion than the more visible front consonants (/f/, /p/ and /b/) and other bilabial and labiodentals. The errors when analyzed according to manner of production, showed that lateral and glide phonemes were elicited more accurately than the affricates. When the errors were analyzed in terms of place of articulation, the labiodental and bilabial consonants were correctly produced more often than velar consonants. The voiced and voiceless phonemes were differentiated only minimally.

The initial consonants were produced more correctly than those in the medial position, which were produced more correctly than those in the final position. From these data Geffner (1980) hypothesized that a "phonological system" for the deaf does exist, governed by features of intensity, visibility and frequency".

In summary, the studies (Hudgins and Numbers, 1942; Nober, 1967; Markides, 1970; Smith, 1975; and Geffner, 1980) are generally in agreement, and the most frequent consonant errors are incorrect productions of the palatal and alveolar fricatives, the affricates, and the velar nasals. In addition the results also indicate a better production of bilabials, glides, and labiodental fricatives. The most common error types are omissions, and voiced and voiceless distinctions. Omission of the final consonant is more frequent than that of the initial consonant.

In all these studies, normal listeners listened to the speech of the hearing impaired individuals, and described it as they heard it. However, by listening to the speech of hearing impaired individuals, it is not always possible "to extract the source of a speech error, that is, the 'real acoustic reason[1] and its articulatory counterpart, because speech is a complicated, coarticulated code rather than a simple linear string of symbols". (Monsen, 1978) .

Studies on "CONSONANT DURATION" have revealed that, in general the hearing impaired speakers have longer durations when compared to normally hearing speakers (Rothman, 1967; Calvert, 1962; Shukla, 1987). Therefore, recently there have been a few attempts to measure the acoustic characteristics of speech of hearing impaired individuals.

FUNDAMENTAL FREQUENCY (F_Q):

It is well known that the F_o of children and adult females are higher than those of the adult male. The fundamental frequencies of the vowels of an adult female are about one octave higher than that of the adult male. Children have a fundamental frequency of about 800 Hz even upto the age of 8 and 10 years. The regulation of F_Q in voice is dependant on many factors, including the length of vocal cords, and the regulation of movement of peripheral voice and speech musculature by the Central Nervous System (Pressman, 1942, Kirikae, 1943). In normal hearing speakers, the average F_o decreases with increasing age until adulthood for both male and females (Fairbanks, 1940; Gopal, 1980). Hearing impaired speakers often tend to vary the pitch much less than the normal hearing speakers and the resulting speech has been described as flat or monotone (Calvert, 1962; Hood, 1966; Martony, 1968) .

The poor pitch control in the hearing impaired individual may be due to two reasons:

1. Inappropriate average F_o.
2. Improper intonation - this may be characterised by:
   a. Little variations in F_o resulting in flat and monotonous speech.
   b. Excessive or erratic pitch variations.

Among the noticeable speech disorders of the hearing impaired are those involving fundamental frequency (F_o). Reported F_o values range from 100 to 175 Hz for adult males and from 175 to 250 Hz for adult females. (Fairbanks, 1940; Fairbanks, Wiley and Sassman, 1949b; Fairbanks, Herbert and Hammond, 1949; Hollien and Paul, 1969). Recent data (Hasek, Singh and Murray, 1981) suggest that a significant difference between the average F_o of preadolescent male and female children with normal hearing begins to emerge by 7 or 8 years of age, with the sex difference attributable to a reduction in F_o for male children only, beginning around age 7. If these is a problem with a hearing impaired speaker's average F_o, more often the voice pitch is characterised as too high rather than too low (Angelocci et al, 1964; Boone, 1966; Martony 1968) .

Several investigators have reported that the hearing impaired speakers have a relatively high average pitch than the normal hearing speakers of comparable ages. (Angelocci, 1962; Calvert, 1962; Thornton, 1964; Boone, 1966; Campbell, 1980) . Also, the variability of F_o is much greater in the hearing impaired, than in the normal hearing speakers, (Angelocci, et al, 1964). Whitehead and Maki (1977) reported that on the average the speaking F_o was higher for deaf adults, than for the normal hearing adults, a majority of the deaf adults had speaking F_o values which fell within the normal range. These findings have also been supported by the findings of other studies such as by Ermovick (1965). Martony (1968) compared the pitch (F_o) between severely hard of hearing children and normal children. Differences were noted in terms of range and distribution i.e., monotonous pitch and pitch breaks. Abnormal pitch average higher than normal in the hearing impaired group. The mean F_o for deaf subjects is considerably higher for all vowels than for normal hearing subjects (Angelocci, Kopp and Holbrook, 1962). Some differences in average F_o have been found as a function of the age and sex of the hearing impaired speakers. The results of several studies have shown that there are no significant differences in average F_o between young hearing and hearing impaired children in the 6-12 year age range (Boone, 1966; Green, 1956; Monsen, 1979). Differences have been reported between groups of older children but it is not clear if pitch deviation is greater for hearing impaired females or males. Boone (1966) found a higher average F_o for 17 to 18 year old males than females. Osberger (1978) found that the difference in F_o between hearing and hearing impaired speakers in the 13-15 year age range was greater for females than for males. The F_o for the female hearing impaired speakers ranged between 250 and 300 Hz. This value is about 75 Hz higher than that observed for the normal hearing females. The average F_0 value of the utterances of the male hearing impaired speakers is slightly lower than that of the hearing males for the first part of the utterance. The F_o values for the hearing and hearing impaired male speakers overlap for the last half of the utterance.

Rajanikanth (1986) reported that when compared to normals, the hearing impaired, in general, showed a higher F_0. He also noted that there was a significant difference between males and females and also between the two age groups studied i.e., 10-15 years and 16-20 years. Sheela, (1988) reported that on the whole, the hearing impaired children exhibited higher average F_o than that of the normal hearing group. Several studies done on F_o have shown, that on an average the F_0 of the hearing impaired children are higher than the normals (Kanaka, 1998; Poonam, 1998; Jayaprakash, 1998; Priya, 1998; Rathnakumar, 1998; Sonia, 1998; Rahul, 1997). A significant difference was also found between males and females among the normals as well as the hearing impaired group (Kanaka, 1998; Rajesha, 1998). However, some have found no difference between the F_0 values of normals and hearing impaired children (Rajesha, 1998; and Roopa, 1998). According to Eguchi, S, and Hirsh I. J. (1969) Fv starting from about 300 Hz at 3 years of age, decreases slightly with age. Thirteen years old boys had an average F_o of 221.1 Hz, still an octave higher than that of adult males (124.2 Hz). Thirteen years old girls on the other hand, had an average F_0 of 239.8 Hz, not very different from that of adult females (220.9 Hz). This variation in F_0 could be due to changes in the length of the vocal cords (as reported by Negus, 1949), and the development of the larynx. There are important changes and a rapid decease of F_0 after about 13 years in boys. (Eguchi and Hirsh, 1969) This evidence agrees with the results reported by Naider (1965).

Nataraja and Jagadish, (1984), studied the relationship between F_0 and vowel duration. The duration and fundamental frequency of /i/ and /u/ were averaged for each subject, as at normal pitch, high pitch, and low pitch (fundamental frequencies). Results showed that there was a greater increase in the duration of vowels /i/ and /u/ at higher F_0 when compared to lower F_0 in the case of females. In case of males, there was a greater increase in the duration of vowels /i/ and /u/ at lower F_0 than at higher F_0 Thus, it can be concluded that the duration of vowels varies with F_0 This study confirms the statement of Wang (1981) and Lyberg(1981), that the duration of vowel varies with F_0 and rejects the observation of Nooteboom (1972); Cooper (1976); Lindblom et al, (1976); and Lehiste (1976), that duration is independent of F_0 Meckfessel and Thornton (1964) reported values of fundamental frequency while speaking (FFS), in post pubescent hearing - impaired males to be higher than those for normal hearing post pubescent males. However, Greene (1956) found similar values for the 2 groups. Gilbert and Campbell (1980) studied FFS in 3 groups (4-6 years, 8-10 years, 16-25 years) of hearing impaired individuals, and reported that the values were higher in the hearing impaired groups when compared to values reported in the literature for normally hearing individuals of the same age and sex.

The inability to control FFS contributes to the low intelligibility of hearing impaired speech (Boothroyd and Decker, 1972) , and may be a factor contributing to the unusual voice quality. Monotony, pitch breaks, and the use of inappropriate registers by hearing impaired speakers also have been reported by Martony (1968).

Meckfessel (1964) and Thornton (1964) reported FFS data for 7 and 8 year old speakers that were higher than values for normally hearing speakers.

Ermovick (1965) and Gruenewald (1966) reported values that were equal to or lower than values for normally hearing speaker. Green (1956) reported higher post pubescent values for hearing impaired females than those obtained for normally hearing females, while Ermovick (1965) and Gruenewald (1966) reported values that were similar. Pinto and Hollien (1982) studied FFS characteristics of Australian women. He found that, the FFS of these women became substantially lower with age (35 years later).

From the results of various studies for speaking fundamental frequency, it is expected to be higher than normals Angelocci, Kopp, and Holbrook (1964) compared the mean F_o of normally hearing and hearing impaired adolescents between 11 and 14 years and found that the mean F_o of the hearing impaired subjects (236 Hz) was 43 Hz higher than that of the normally hearing subjects (193 Hz). However, Monsen et al (1979) said that a mean F_o of 236 Hz cannot necessarily be considered abnormal in males between 11 and 14 years old. In his study the mean values fell within the range that appeared to be normal. Thus, with respect to F_o, the normal range among hearing subjects is quite broad and the hearing impaired subjects appear in most cases to fall within it. In cases where they do not, the mean F_o is higher than normals.

Whitehead (1977) found that while the FFS was higher for deaf adults than for normally hearing adults, on the average, actually a majority of the deaf adults, had speaking fundamental frequency which fell within a normal range. The pitch deviancy of profoundly hearing impaired children has been evaluated perceptually by Mc Garr and Osberger (1978) using a 5 point rating scale. The scale was used with approximately 50 children, 10-11 years of age. The results of this study showed that a large number of children received pitch ratings that were either appropriate for their age and sex or differed only slightly from optimal levels. There was, however, a small group of children who could not sustain phonation and whose speech was characterized by pitch breaks or large fluctuations in pitch. On the whole, these findings are in agreement with earlier studies which indicate that the pitch of many pre - adolescent hearing impaired children is within the normal range. However, it is possible, that rather large differences in F_0 can exist between normal and hearing impaired speakers before pitch is perceived as deviant and remedial training is indicated.

Several explanations have been offered to explain the pitch deviations noted in the hearing impaired. "One possible reason for the difficulty is that deaf children may lack a conceptual appreciation of what pitch is". (Anderson, 1960; Martony, 1968; Boothroyd, 1970) . Martony (1968) proposed that laryngeal tension noted in the hearing impaired is a side effect of the extra effort put into the articulators. He opined that since the tongue muscles are attached to the hyoid bone, and the cricoid and thyroid cartilages, extra effort in their use would result in tension, and change of position in the laryngeal structures. This would ultimately cause a change in pitch. Willeman and Lee (1971) hypothesized that the deaf speakers use extra vocal effort to give them an awareness of the onset and progress of voicing and this becomes the cause for the high pitch observed in their speech. The auditory feed back system is the main channel for appropriate establishment and production of pitch (F_o), F_0 or pitch, has been a particularly difficult property of speech for deaf children to learn to control (Boothroyd, 1970). The average F_0 for long vowels is slightly higher than its short vowel counterpart (Jensen and Menon, 1972). This effect, which occurred for most speakers, was expected to be the result of increased vocal effort associated with the production of long vowels. Thus there will be an increase in the vocal fold tension which results in higher F_0 for phonation.

Pickett (1968) said that the high pitch produced by the hearing impaired speakers to due to increased tension in the cricothyroid muscle and by increased subglottal air pressure. The extra vocal effort that is needed to generate high pitched sounds leads to an increased Kinesthetic awareness of voicing beyond that possibly available from residual hearing.

Fundamental frequency correlates of voiced stop consonants was studied in the speech of the preadolescent children by Ohde (1985). The utterances contained voiceless aspirated, voiceless unaspirated, and voiced stop consonants produced in the context of /i, e, u, o, a/ by 8 to 9 year old subjects. The results revealed that F_o significantly contrasted voiced with voiceless aspirated and unaspirated stops. F_o consistently differentiated vowel height in alveolar and velar stop consonant environments only. He also suggested that F_o is still at an emerging stage in the age group of 8-9 years.

F_0 at voicing onset is higher in utterances beginning with voiceless aspirated stops than in utterance beginning with voiced stops (House and Fairbanks, 1953; Lehiste and Peterson, 1961; Mohr, 1971; Lea, 1973; Umeda, 1981), and F_0 decreased faster after voicing onset for voiceless than for voiced stops (Haggard et al, 1981; Umeda, 1981; Ohde, 1984; Silverman, 1984) . F_0 tends to be higher following voiceless consonants than voiced consonants (House and Fairbanks, 1953; Umeda, 1981; Ohde, 1984).

Vowels with high tongue positions have a higher F_0 than vowels with low tongue positions (Peterson and Barney 1952, House and Fairbanks, 1953). Monsen, Engebretson and Vemula, 1978, stated that the medial stressed syllable always has the highest peak F_0 The F_o of a vowel placed between voiceless plosives is about 5% higher than in a vowel placed between voiced plosives. (House and Fairbanks, 1953). The difference is greatest, about 15%, immediately following voicing onset (Lehiste and Peterson, 1961a; Lea, 1973) . A much smaller difference is found in the vowel preceding the stop. The difference in onset F_o is due in part to the greater transglottal pressure and greater vocal fold stiffness at voicing onset for a voiceless plosive (Halle and Stevens, 1971).

Fundamental Frequency Variations:

The speech of hearing impaired individuals is characterized by the extremes of F_0 variations, i.e., either:

a) Lack of variation of F_0, or

b) Excessive variation of F_0.

Hearing impaired speakers who tend to produce each syllable with equal duration may also generate a similar pitch contour (mono pitch) on each syllable (Nickerson, 1975). It has seen suggested that some of the unusual pitch variations seen may result from attempts to increase the amount of proprioceptive feedback during speech (Martony, 1968). Several investigations have shown that the hearing impaired speakers do produce pitch variations, but the average range was less than the range of the normal speakers. (Green, 1956; Calvert, 1962; Martony, 1968; Nandyal, 1981). This would result in the monopitch observed in the speech of the hearing impaired.

"The hearing impaired showed almost double the frequency ranges as compared with normals, accompanied with large individual variations" (Rajanikanth, 1985). There is a problem of inappropriate or insufficient pitch change at the end of a sentence (Sorenso, 1974). It is more difficult for the deaf to produce a terminal pitch rise such as that, occurring at the end of some questions as compared to a terminal fall (Phillips et al, 1968).

Monsen (1979), while studying the manner in which F_0 changes over time, using a spectrographic technique observed four types of F_0 contours in the speech of the hearing impaired children of 3-6 years of age. They are:

a) A falling contour, characterized by a smooth decline in F_0 at an average greater than 10 Hz per 100 msec.

b) A short, falling contour, occurring on words of short durations. The F_0 change maybe more than 10 Hz / 100 msec, but the total change may be small.

c) A falling flat contour, characterized by a rapid change in frequency at the beginning of a word, followed by a relatively unchanging flat portion.

d) A changing contour, characterised by a change in frequency, the duration of which appears uncontrolled, and extends over relatively large segments.

Monsen (1962) found that the types of contours appeared to be an important characteristic separating the better from poorer hearing impaired speakers.

Pitch problems vary considerably from speaker to speaker. While insufficient pitch variation has been noted as a problem for some speakers, excessive variations has been reported for others (Martony, 1968) . Such variations are not simply normal variations that have been some what exaggerated but rather, pitch breaks and erratic changes that do not serve the purpose of intonation. These speakers may raise or lower the F_0 by 100 Hz or more, within the same utterance. There are reports, that often after a sharp rise in F_o the hearing impaired speaker loses all phonatory control, and thereafter there is a complete cessation of phonation (Smith, 1975; Stevens, et al, 1978).

Segmental influence on F_0 control:

A common clinical observation is that some hearing impaired children produce the vowels, /i, I, u/ at a higher F_0 than the other vowels of English. It has been shown that there is a systematic relationship between vowel production and F_0 in normal speech. High vowels are produced on a higher F_0 than low vowels, resulting in an inverse relationship between F_o and the frequency location of the first formant of the vowel (House and Fairbanks, 1953; Peterson and Barney, 1952).

Angelocci et al (1964) first examined some of the vowel changes in F_0 in the speech of the hearing impaired. Their results showed that the average F_o for all vowels was considerably higher for the hearing impaired than for the normal hearing subjects. Measures of vowel amplitude were also found to be higher in the samples of the hearing impaired speakers than in those of the normal hearing children. In contrast, the range of frequency and amplitude values for the vowel formants was greater for the normal hearing than for the hearing impaired speakers. This finding, combined with the high F_0. and amplitude values, led Angelocci, et al (1964) to suggest that the hearing impaired subjects attempted to differentiate vowels by excessive laryngeal variations, rather than with articulatory maneuvers, as do normal hearing speakers.

Bush (1981) observed that a close relationship exists between vowel related variability in F_o and articulatory skill in a majority of the profoundly hearing impaired subjects. Greater F_o variability was observed for the hearing impaired speakers who produced a wide range of vowel sounds (in terms F_1 and F_2 values) than for speakers with limited articulatory skills. The larger vowel to vowel variations in F_o also tended to be associated with better speech intelligibility. The direction in which the F_o varied as a function of vowel height was similar for both normals and hearing impaired children.

Bush (1981) concluded that the vowel to vowel variations produced by the hearing impaired speakers, were in some way, a consequence of the same articulatory maneuver used by normal speakers in vowel production. The mechanism proposed by Bush (1981) to explain the segmental variations in F_o by the hearing impaired was an extension of a vocal fold tension mechanism developed by Honda (1981), to account for normal vowel related variations in F_0.Honda's mechanism assumed that moving the tongue root forward for the production of high vowels, causes the thyroid bone to move forward, tilting the cartilage anteriorly. As a result, there is increased tension on the vocal folds, resulting in an increase in F_0. Bush has postulated that because of the nonlinear nature of the stress - strain relationship for vocal fold tissue, increases in vocal fold tension may be greater in magnitude when the tension on the vocal folds is already relatively high (as is the case with hearing impaired speakers), resulting in somewhat larger increases in F_0 during the articulation of high vowels.

Thus, it appears that profoundly hearing impaired speakers encode and organize some aspects of F_0 with respect to syntactic considerations in much the same manner as do normal speakers. There are obvious deviations in F_0 control in the speech of the hearing impaired, but there is evidence to suggest that they know and use some of the same rules applied by normal hearing speakers.

FORMANT FREQUENCY CHARACTERISTICS OF VOWELS:

Vowels are the simplest sounds to analyze and describe acoustically. They are associated with a steady state acoustic pattern and steady state articulatory configuration. In addition, vowels often have been characterized with a very simple set of acoustic descriptors, namely, the frequencies of the first 3 formants.

Lehiste and Peterson (1961) found that vowels differ from one another in the following ways:

1. Vowels have inherent differences in duration. Long/tense vowels have greater durations than short/lax vowels, and vowels produced with a relatively open jaw position are longer than vowels produced with a relatively close jaw position.

2. When vowels are produced in context with other sounds, they differ in their formant trajectories eg: tense vowels tend to have proportionately short off glides (vowel to consonant transitions) and long steady states. Lax vowels, on the other hand, tend to have proportionately long offglides and short steady states.

The vowel production in an individual is influenced by vocal tract configuration. The shape of the vocal tract and the location of the formants are closely interrelated.Three characteristics of the vocal tract that are of particular importance in determining the formant frequencies are:

1. The diameter of the vocal tract at the point of maximum constriction between the tongue and the roof of the mouth.

2. The distance of this tongue constriction from the glottis, and;

3. The area of the month opening relative to the degree of lip rounding (Stevens and House, 1955).

Vocal tract configuration modifies the spectrum of the vowels in the following way:

1. Length - the frequency of all formants become low as the length of the vocal tract increases.

2. Lip rounding -increased constriction of the labial port also lowers all formant frequencies.

3. Anterior oral constriction - elevation of the front of the tongue lowers the first formant and raises the second formant.

4. Posterior oral constriction - raising the posterior part of the tongue tends to lower the second formant.

5. Pharyngeal constriction - narrowing the pharynx raises the frequency of the first formant.

6. Nasalization - the effects of coupling the nasal resonant space to the vocal tract are very complex. Not only are the resonant frequencies altered, but antiresonances are introduced. The overall result is highly variable.

It has been recognized that the vowel formants represent the acoustical resonant properties of vocal tract as shaped in articulation by the tongue (Potter, Kopp and Green, 1947; Joos, 1948.; Peterson and Barney, 1952; Peterson, 1951, 1959; Peeter and Steinberg, 1950; Stevens and House, 1961).

Identification of the vowels is cheifly dependant on the first and the second formant.

Joos (1948) had postulated that F1 corresponds to the back cavity and F_2 corresponds to the front cavity of the mouth. However it has also been reported that the formants generated by different speakers uttering the same vowel have different frequencies, and that formants generated in producing different vowels may have the same frequency. A theory based on absolute values for vowel formant frequency has great difficulty (Stevens and House, 1963). However, recent studies reveal that F_1 and F_2 are not simply acoustic features of front cavity and back cavity in the vocal track (Fant, 1960).

Eguchi and Hirsh (1969) report that F_1 is generally dependant more on the back cavity volume than on the volume of other cavities. An exception is the vowel */a/*, where F_1 is affected equally by changes in both the front and back cavity volumes. F_1 of the vowels /e/ and /i/ is almost completely determined by the back cavity volume. Vowels /u/ and /o/ are some what more dependant on the front cavity constriction.

There are only a few studies of vowel formant frequency of children (Potter and Steinberg, 1950, Peterson and Barney, 1957), especially on the development of formant frequencies (Potter and Peterson, 1948; Okarmura, 1966). The only known data is that the formant frequencies of 8 year old children are about 25% higher than that of adult males and 20% higher than that of adult females. Okamura (1966) reported that Japanese vowel formant frequencies can be differentiated from each other by the age of 9.

From results and the work done by Eguchi and Hirsh (1969), Negus (1949), and Fant (1960), the following conclusions may be drawn:

1. The development of the front cavity will have a greater influence on changes in formant frequencies than the development of the back cavity.

2. F_1 of /a/ is not so clearly influenced by the development of the vocal tract, but indirectly or mutually influenced by development of front and back cavities and also other factors (i.e, F_o,etc) .

3. Variability of formant frequencies for given vowels between subjects is independent of age and sex.

Further, the perception of vowels is dependant not only on formant frequency, but also on many other information bearing elements of speech (Peterson, 1952) .

Peterson and Barney (1952) evaluated a population of 33 men, 28 women and 15 children (ages unspecified) that had been studied earlier by Potter and Steinberg (1950). Each speaker did two readings of a list of 10 words, i.e. heed, hid, head, had, hod, hawed, who'd, hud, and heard. The data for children are depicted below:

	i	I	ɛ	æ	a	ɔ	U	u	ʌ	ɝ
F_o	272	269	260	251	256	263	276	274	261	261
F_1	370	530	700	1000	1030	680	560	430	850	560
F_2	3200	2750	2600	2300	1350	1050	1400	1150	1600	1650
F_3	3700	3600	3550	3300	3200	3200	3300	3250	3350	2150

Eguchi and Hirsh (1969) studied formant frequencies of vowels of children of both the sexes and age between 3 to 13 years. The mean formant frequencies of vowels produced by children of 7 to 10 years are tabulated.

	i		ɛ		æ		a		ɔ		u	
Age	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
7	411	3204	664	2280	136	2299	950	1652	817	1398	481	1525
8	397	3104	585	2195	685	2222	921	1729	743	1359	450	1437
9	403	3106	608	2296	647	2295	1053	1785	836	1352	469	1392
10	403	3028	645	2193	735	2255	997	1709	814	1336	469	1351

With age as a principle variable, Potter and Steinberg (1950) reported no correlation between the F_o and formant frequency for three groups of adult males, adult females and children.

Eguchi and Hirsh (1969) did a study of the formant frequency characteristics of vowels. Results showed that with age, 2nd formant frequency tended to drop more than did the 1st formant frequency, with the exception of F_1 for /a/ (especially between 3-5 years of age). Formant frequencies of 13 year old girls were close to those of adult females, while 13 year old boys had higher formant frequencies than did adult males. Formant frequencies of adults showed almost the same values as those found in the literature (Peterson and Barney, 1952; Fairbanks and Grubb, 1961; Potter and Steinberg, 1950). The first formant frequency of /a/ was independent of age. The between subject standard deviations of formant frequencies are unrelated to age and sex.

In children, the formant frequencies of vowels were studied mainly by Peterson and Barney (1952) and Eguchi and Hirsh (1969). The formant frequencies especially the first (F_1) and second (F_2) formants are traditionally used to provide an acoustic description of vowels. The higher formants, other than F_1 and F_2 are of less importance to determine the phonetic quality of vowel sounds. For speech intelligibility F_2 is more important as it lies within the most sensitive range of human hearing. F_1 represents the tongue height. F_1 increases and then decreases as the vowels go from /i/ to /u/. F_2 decreases from /i/ to /u/ which represents the constriction of the tongue in the front back plane.

Angelocci, Kopp and Holbrook (1964) studied the vowel formants of deaf and normal hearing 11-14 year old boys. The results showed that the means of F_1 for the deaf are higher than for the normal hearing for the vowels /i/, /I/, /æ/, /u/, /ʌ/'and /ɝ/, and lower for the vowels, /ɛ/,/a/,/ /ɔ/ and /U/.

Potter et al, 1947, and Fairbanks et al, 1961, reported that F_1 rose in frequency as it progressed from /i/ to /a/, where it reached its maximum frequency position, and then it lowered in frequency as it progressed from /a/ to /u/. The exception to this pattern is seen in F_1 of ,/æ/ for the normal hearing subjects.

Vision is a particularly useful supplement to residual hearing for vowels because tongue and lip placement are directly related. The child with residual hearing extending upto 1000 Hz can be expected to hear F_1 of all vowels. However, in order to discriminate between back and front vowels which have similar F_1 values, the child must supplement F_1 information with cues provided by lip shape. (Ling, 1976).

The rules by which such a child could learn to differentiate vowels on an auditory visual basis, might be explained as follows:

* low F_1 + lips rounded = /u/
* low F_1 + lips spread = /i/
* high F_1 + lips neutral = /a/

Jensen and Menon (1972) indicated that there is relatively small difference in F_1 and F_2 respectively between the short and long members of a vowel pair. Also, whatever difference that exist tended to be variable from speaker to speaker. He concluded that formant frequency lacks significance with respect to the perception of the short and long vowel distinction. Bennett (1980) compared the formant frequency characteristics of preadolescent males and females (7-8 years of age). Results showed that the vowel resonances of male children were consistently lower than those of females. The range of differences extended from about 3% for F1 of /i/ to 16% for F_1 of /æ/'. With respect to F_2 values, 84% of the boys and 82% of the girls had F_2 values which fell in areas of nonoverlap. Thus there was substantial sex separation across all 5 vowels in terms of F_2. Also, for F_3, the difference between male and female was approximately 296 Hz, while for F_4, it was 466 Hz.

FORMANT TWO FREQUENCY:

The mouth cavity was found to be an essentially determinant of F_2 only in case of /i/. F_2 of /i/ is a half wavelength resonance of the back cavity. F_2 of the back vowels /u/, /o/ and /a/ are somewhat more dependent on the front cavity than on the back cavity (Fant, 1960).

Angelocci, Kopp and Holbrook (1964) revealed that F_2 for the deaf was lower than for the normal hearing for the front vowels /i/, /I/, ,/ɛ/ and ,/æ/ ; F_2 for the deaf was higher than for the normal hearing for the back and neutral vowels, /a/, /ɔ/ , /U/, /u/, /ʌ/ , and /ɝ/ . The range of F_2 means for the normal hearing subjects was higher (1715 cps) than for the deaf (1148 cps).

Ling (1976) suggested that the F_2 values increases systematically as the tongue moves forward in the mouth. F_2 is therefore lower for the back than for the front vowels. Since hearing impairment is usually greater for high frequencies, the errors made by hearing impaired listeners in speech identification tasks are more frequently associated with front than with back vowels (Rosen, 1962; Schultz, 1964).

Geffner (1980) who studied the feature characteristics of spontaneous speech production in young deaf children, revealed that, vowels with lower F_2 were more easily produced. According to Levitt (1978) the lowest two formants play a dominant role in identifying vowels and are differentiated not on the basis of absolute formant frequency, but by the ratio of the first and second formant frequencies, i.e., the F_2/F_1 ratio.

The direction, the extent, and the duration of F_2 transitions have been shown to be important in the correct perception of adjacent consonants (Delattre, Liberman, and Cooper, 1955; Liberman, et al, 1956; Sharf and Hemeyer, 1972). F_2 transitions in particular, appear to be an important acoustic cue to the place of consonantal articulation, as for example, between such sounds as /b/ and /d/.

Monsen (1976) measured the nature and extent of differences of 2nd formant transitions between deaf and normal hearing speakers. It was found that the F_2 transitions were reduced both in time and in frequency in the speech of the hearing impaired subjects. Since formant transitions are important acoustic cues for the adjacent consonants, decreased F_2 transitions may be an important factor in the low intelligibility of the speech of the deaf.

FORMANT THREE FREQUENCY:

Angelocci, Kopp and Holbrook, (1964), found that F_3 for the deaf was higher than for the normal hearing for all vowels except /i/, /u/ and /ʌ/. The position of F_3 offered less information with respect to normal differentiation than did F_1 and F_2. In the normal hearing children, F_3 values were in the following order:

/i/ > /I/ > /u/ > /ɝ/

Other investigators (Fairbanks et al, 1961; Potter et al, 1947), have reported similar findings. In contrast, F_3 for the deaf did not follow the pattern reported above. Between /i/ at 3099 cps and /I/ at 3091 cps, there was a drop of only 8 cps. In the transition from /u/ at 2748 cps to /ɝ/ at

2948 cps there was a 200 cps increase rather than the expected decrease of approximately 800 to 1000 cps. There was a difference of 1342 cps between /i/ and /ɝ/ for the normal hearing; while for the deaf, this difference was only 151 cps. This may be due to the difficulty encountered by the deaf in the production of the /ɝ/ sound.

The mean frequencies of the fundamental and first three formants of vowels for normal hearing and deaf subjects as given by Angelocci et al (1964) is as follows:

		i	I	ɛ	æ	a	ɔ	U	u	ʌ	ɝ
F_o	N	199	191	189	187	188	189	194	204	195	194
	D	254	245	214	234	230	223	242	248	227	241
F_1	N	262	410	606	588	917	762	500	363	671	396
	D	421	447	536	609	694	681	484	364	682	463
F_2	N	2776	2300	2079	2231	1376	1067	1216	1061	1427	1459
	D	2325	2173	1946	1799	1576	1177	1563	1377	1433	1946
F_3	N	3251	2974	2908	2961	2705	2750	2791	2757	2813	1909
	D	3099	3091	3019	2966	2825	2805	2798	2748	2793	2948

Levitt (1976), from a study of the acoustic and perceptual characteristics of speech of the deaf children concluded that the formant frequency values were typical of the schwa vowel. Most vowels spoken in isolation can be identified by normal listeners if both the F_1 and F_2 are audible, although identification of the high front vowels may be improved if F_3 can also be heard. (Delattre, Liberman, Cooper and Gerstman, 1952).

Sheela (1988) studied 4 congenital deaf children of 8-10 years. She found that the hearing impaired had higher F_1 and F_2 and low F_3 values than those of the normal group. The hearing impaired group showed higher variability than normals.

Kanaka (1998) studied the difference in formant frequency between hearing impaired and normal children. She found that the F_1 and F_3 in the hearing impaired was less than the normal children for both short and long vowels. In terms of F_2, it was more than normal for both short and long vowels. Poonam (1998) found that F_1 was more than normals for /i/, /i:/, /u/, /u:/ and /o/ whereas it was less than normals for /a/, /a:/, /e/, /e:/ and /o:/. F_2 was found to be more for /a/, /u/, /u:/, /o/, and /o:/ and less for /a:/, /I/, /i:/, /e/, /e:/. F_3 values were more in the hearing impaired subjects than the normals except for /i/ and /i:/. Jayaprakash (1988), and Priya (1998) found an increase in the F_1, F_2, F_3 values for the deaf subjects as compared to the normal subjects. Rahul (1997), revealed that the F_1 and F_3 values of the deaf were higher than that of the normal children. However in 11/20 subjects, the F_2 values were found to be decreased compared to the normals. The rest 9/20 showed an increase in the F_2 values. Rathnakumar (1998) showed no significant difference between the deaf and normal hearing children for F_1, F_2 and F_3 values.

VELAR CONTROL:

The velum or soft palate functions as a gate between the oral and nasal cavities. It is lowered to open the passage to the nasal pharynx when a sound such as one of the nasal consonants is made which requires that the air be emitted through the nose. It is raised, thus sealing off the passage, for non-nasal sounds, and in particular for those requiring the build up of pressure in the mouth (obstruent consonants) . Improper control of the velum has long been recognized as a source of difficulty in the speech of the deaf (Brehm, 1922, Hudgins, 1934) . If the velum is raised when it should be lowered, the speech may be described as hyponasal; if it is lowered, when it should be raised, hypernasality is the result. Miller (1968) has speculated that the type of hearing loss may be a causative factor in some nasalization problems. Hyponasality may be more prevalent among people with conductive loss than among those with sensorineural loss because nasal sounds may appear excessively loud to the former, due to the transmittability of nasal resonance via bone conduction. Individuals with sensorineural loss, on the other hand, use the additional cues provided by the nasal resonances and hence tend to nasalize sounds that should not be nasalized.

Nasality has been described as a "quality" problem because improper velar control can give the speech a characteristic sound. In addition to affecting quality, however, poor control of the velum can also lead to articulatory problems. Stevens, Nickerson, Boothroyd and Rollins, (1974) said that deaf persons tend to raise the velum when it should be lowered, or lower it, when it should be raised, leading to confusions between nasal and non nasal sounds.

Learning velar control is difficult for a deaf child for two reasons:

1. Raising and lowering the velum, is not a visible gesture and is therefore not detectable by lip reading.

2. The activity of the velum produces very little proprioceptive feedback.

The movement of the velum must be timed accurately when producing words with abutting nasal and stop consonants, if the appropriate sounds are to be produced and the resulting speech is to be fluent. Deaf speakers often have considerable difficulty producing such clusters (Stevens, Nickerson, Boothroyd, and Rollins, 1974) . Ravishankar (1985) found that the intonation errors were most frequent followed by errors in pitch, rate of speech, nasality and voice quality.

Colton and Cooker, (1968) studied perceived nasality in the speech of the deaf. Statistically significant differences in mean ratings of nasality were found between the deaf and the normal hearing individuals and also between reduced tempo and normal tempo groups. In general, deaf speakers were perceived to be more nasal than normal speakers. Furthermore normal speakers are perceived as more nasal when speaking at a reduced tempo than when speaking at a normal tempo, thus, much of the perceived nasality in the speech of the deaf may be a natural consequence of reduced speaking tempo. Improper velar control may affect the resonant properties of speech and also may result in articulatory errors (Osberger and Me Garr, 1982) . Hypernasality has been reported to be present in the speech of many hearing impaired individuals (Hudgins and Numbers, 1942; Boone, 1966; Co ton and Cooker, 1968)

Deviant nasalization characteristics in the speech of the hearing impaired has been reported to be the result of improper posture of velopharyngeal structures (Hudgins, 1934, Mc Clumphe, 1966; Stevens et al, 1976), inappropriate timing of the opening and closing gestures of the velum (Stevens et al, 1976) and faulty palato-pharyngeal valving. The studies have pointed that for many deaf speakers, the velum remains lowered much of the time and thus many vowels are nasalized. Another deviation reported is the way the tongue body is positioned in the mouth. Boone (1966), Seaver et al (1980) pointed out that nasalization in the speech of the hearing impaired is due to the perceived resonance brought about in the pharyngeal cavity by an inferiorly retracted tongue position during speech and not due to velopharyngeal insufficiency.

Improper velar control is difficult to judge subjectively, in part because the distinctive perceptual features of nasalization have not been clearly defined and in part because the perception of nasality may be affected by factors in addition to the activity of the velum, like a a deliberate constriction of the nasal pathways, may produce a type of nasal speech, which does not necessarily involve improper velar control.

Also, some researchers have suggested that the perceptional of nasality may be influenced by such factors as misarticulation, pitch variation, and speech tempo (Co ton and Cooker, 1968). Acoustic properties of nasal sounds that have been investigated include shifted and split first formants. (Fujimara, 1960; House, 1961), and enhanced amplitude of the lowest harmonic (Delattre, 1955) . Attempts to detect nasalization directly have included the measurement of the flow of air though the nose (Lubker and Moll, 1965; Quigley, Shiere, Webster and Cobb, 1964), measurement of the acoustic energy radiated from the nostrils (Shelton, Knox, Arndt and Elbert, 1967) and measurement of the vibration on the surface of the nose (Holbrook and Crawford, 1970; Stevens, Kalikow and Willemain, 1974) .

In terms of intelligibility, the difference in the degree of nasalization of sounds that should be nasalized, and those that should not be, and the adequacy of the velar adjustments that are required in order to produce nasal consonants in the context of other sounds is important. Stevens, Nickerson, Boothroyd, and Rollins (1974) have defined an index to indicate the ability of the speaker to differentiate nasal consonants and non nasal vowels in running speech. Normally hearing speakers produced values of this index in the range 10-20 dB. Values close to zero would suggest a failure to differentiate nasal from non-nasal sounds which could result from either excessive hyper or hypo-nasality. Using this index, Stevens et al (1974) found that 76% of the profoundly hearing impaired children studied had excessive nasalization in at least half of the vowels produced in monosyllabic words. Excessive nasalization on at least eight of the ten vowels studied was observed for 3 6% of the children. The greatest difficulty in velopharyngeal control was evidenced in the hearing impaired children's production of nasal stop clusters which required closely coordinated movements of the velopharynx and oral articulators.

FORMANT BANDWIDTH AND AMPLITUDE

Each formant can be described by two additional and interacting features, bandwidth and amplitude. Bandwidth is related to damping which is the rate of absorption of sound energy. The greater the damping, greater is the bandwidth of the sound. Sounds that are generally damped, tend to die quickly; and their energy gets quickly dissipated. Sounds that are associated with very little damping tend to be sustained.

Each formant of the vocal tract during vowel production has a bandwidth. The usual convention in bandwidth is to measure the width of the formant (or any resonance) between two points that are 3dB below the peak on either side of it. The figure of 3 dB corresponds to the "half-power point", or the points corresponding to half of the acoustic power of the sound as determined by the peak. Formant bandwidth increases with formant numbers, so that higher formants have larger bandwidths than does F_1.

Experiments have shown that changing the bandwidth of the formants has very little effect on vowel perception. In fact, it appears that the ear is not very sensitive to such changes . But even when the effect of bandwidth reductionis perceptually obvious as when the bandwidth approaches zero, listeners can still identify vowel sounds. The primary perception effect of formant bandwidths is the unnaturalness of the vowel sound. Vowels that have unusually narrow bandwidths sound artificial even though listeners usually can identify these vowels. At the other extreme, increasing formant bandwidth eventually can reduce the distinctiveness of vowels, because the energy of the different formants, begins to overlap. In such an existence, the vowel spectrum loses the sharpness of its peak and valleys.

Formant amplitude is related to formant bandwidth in so far as increase in band width often lead to reduction in over all amplitude. That is so long as source energy remains constant, increase in formant bandwidth are accompanied by-reduction in formant amplitude. The relative amplitude of the formants in a vowel are determined by the formant frequencies of the formants, the bandwidth of the formants, and the energy available from the source. It has been noted that there is an interaction between formants and vowel production. When two formants are drawn closely together, they reinforce one another or both of their amplitudes increase. When the two formants are more apart, their interaction is reduced and both of their amplitude decreases. When F_1 moves up in the frequency, the higher formants are in effect boosted by the high-frequency tail of the F_1-curve and when F_1 moves down, the higher formants are not as strongly influenced by the high frequency tail.

Nataraja, Savithri and Venkatesh (1993) have reported formant frequency values, duration of vowels and the average fundamental frequency in the speech of the hearing impaired. Fifteen congenitally hearing impaired individuals served as subjects. Results indicated that:

1) There is significant difference between normal hearing and the hearing impaired in terms of the first three formant frequencies. Hearing impaired subjects frequently misarticulate the vowels and thus F_1 and F_2 fall into

areas normally associated with other vowels resulting in more extensive scattering of F_1/F_2 ratio.

2) On the average the hearing impaired had significantly longer duration for vowels than that of normal hearing.

3) On the whole, hearing impaired exhibited higher average F_Q than that of normal hearing subjects.

To summarize the review in general, many temporal and frequency characteristics of speech have been identified and measured in different languages, in order to understand the normal process of speech production and speech perception. In the process, researchers found that speech parameters are dependent on many factors, either linguistic or non linguistic. This resulted in measurement of different temporal and frequency characteristics of speech in different languages of the world. Similarly temporal and frequency characteristics have been measured in disordered speech like hearing impaired, stuttering, misarticulation etc.

Simultaneously, research in similar lines using acoustic, aerodynamic and physiological procedures also have been carried out in the speech of the hearing impaired subjects, with the aim of contributing to the teaching methodologies, and in turn to achieve better results. Until then, an attempt at understanding the speech of the hearing impaired subjects were based only on subjective judgements.

Most of the work in the area of speech of the hearing impaired, is done in U.S.A. using American English Speakers. Since the speech parameters are languages specific, there is a need to carry out research to measure and describe different parameters of speech in the hearing impaired speakers of Bengali language.

Rahul (1997) studied the speech pattern of Kannada speaking hearing impaired children in the age range of 5 to 8 years. Results of his study revealed that,

1) The vowel duration is greater in the speech of the hearing impaired as compared to the normal hearing speakers for vowels /a/, /a:/, /e/, /e:/, /i/, /i:/, /o/, /o:/, /u/ and /u:/ in the word initial and word medial positions.

2) The vowel formant frequencies, in the speech of the hearing impaired vary from that of the normal hearing speakers, such that,

a) F_1 may be either higher, lower, or similar to the normal hearing speakers.

b) The F_2 is lower than normals for the front vowels, and higher than normals for the back vowel.

c) The F_3 tends to be higher than the normal hearing speakers.

Rasitha (1994) studied speech pattern on Malayalam speaking hearing impaired children in the age range of 5-9 years. She found that

1) The hearing impaired group had significantly longer vowel duration than that of the normal hearing group.

2) Normal hearing children did not show any inter syllabic pauses (intra word) whereas 4 out of 5 children in the hearing impaired group inserted inter syllabic pauses at least once in each word.

3) The total durations of the words uttered by the hearing impaired children were significantly longer than that of the normal hearing group.

4) Higher average F_0 than that of the normal hearing group was exhibited by the hearing impaired children.

5) The hearing impaired children had higher F_1 and lower F_2 than that of the normal hearing group.

Balasubramanyan (1980), studied native Tamil speakers who were asked to pronounce different words, all embedded in the test sentence /inda va:rtte/. Spectrographic analysis were made for these utterances and the duration of vowels and consonants was measured. It was found that the duration of a segment (be it a vowel/consonant) depends on the structure of the syllable in which it occurs. Vowels in syllables of the structure VC were found to be invariably shorter than those in the syllable of the structure CV.

Balasubramanyan (1981) studied the duration of vowel in Tamil for native speakers of Tamil (3 of whom had no linguistic background). Seven hundred Tamil words occurring in various positions were taken. The four subjects were asked to pronounce the words, 3, 6 and 9 times each, embedded in a test sentence /inda varitte/. Thus, in all, 3000 words were examined. Spectrographic analysis was done and he concluded that,

a) Open vowels are longer than closed vowels.

b) Vowels in monosyllabic utterances are longer than those in words of more than one syllable.

c) The more segments there are in a syllable, the less is the duration of the vowel in them.

d) The syllables of VCV vowels are longer when followed by voiced consonants than when followed by voiceless consonants.

e) There is no appreciable difference between the duration of vowels followed by dental, palato alveolar and velar consonants.

Thus, the results of various studies suggest that the overall levels of speech intelligibility are completely inadequate for oral communication (Ling, 1976). Hence, the above spectrographic parameters such as formants, vowel duration etc were taken up for the study.

Very few investigators have studied the speech characteristics of hearing impaired i.e., Rajanikanth (1986), Shukla (1985), Sheela (1988), Jagadish (1989), Rasitha (1994), Rahul (1997), Priya (1998), Kanaka (1998), Sonia (1998), Poonam (1998), Jayaprakash (1998), Rajesha (1998), Roopa (1998) and Rathnakumar (1998). There have been no such studies done in Bengali. Therefore, the present study was undertaken to acoustically analyse the speech of Bengali speaking hearing impaired children between the age group of 7-10 years.

METHODOLOGY

As shown in the previous chapter it necessary to know the speech characteristics both in normals and hearing impaired to plan effective and efficient therapy for the hearing impaired. This study has been carried out with the aim of comparing the speech of normal Bengali speaking children with that of Bengali speaking hearing impaired children, who are using hearing aid and undergoing therapy. The temporal and spectral parameters, which play an important role in the perception of speech sound have been studied.

The following parameters have been considered in the present investigation:

I TEMPORAL PARAMETERS

1. Preceding Vowel Duration
2. Consonant duration
3. Following vowel duration
4. Pause duration
5. Total word duration

II SPECTRAL PARAMETERS

1. Fundamental frequency of the vowels.
2. Formant frequencies (F_1, F_2, F_3,) of the vowels.
3. Bandwidths (B_1, B_2, B_3) of the vowels.

SUBJECTS:

Two groups of 20 subjects each were selected for the study. **Group I:** consisted of hearing impaired children and group II had normal hearing children, all aged between 7-10 years of age. (mean age of Group I was 8.4 years and the mean age of Group II was 8.9 yrs) . Group I, consisted of 20 hearing impaired children, 10 males and 10 females, selected from those attending therapy at "SHIRC" and "NIHH" Calcutta, for at least a period of 1 year. They all satisfied the following conditions:

1. Had congenital bilateral severe hearing loss (PTA of greater than 70 dBHL - reference, ANSI, 1969, or more in the better ear).

2. Had Bengali, as their mother tongue, and were exposed to the same, in their daily environment.

3. Had no additional problems or deviations other than those which are directly related to the hearing loss.

4. Have been using a hearing aid, suited for their hearing loss, for at least a period of 1 year.

5. Were able to read simple bisyllabic words (VCV) in Bengali.

6. Were able to follow simple commands and instructions.

GROUP II: Consisted of normal hearing children, with normal speech and language abilities, and who were matched to the children in Group I, in terms of their age and sex.

MATERIALS:

The test material consisted of 8 commonly spoken bisyllabic (VCV) Bengali words. (Words are listed in Appendix I). Words were simple, so that both normal and hearing impaired children could read them. All the words were chosen based on familiarity to the subjects. All the words were meaningful to the subjects. Each of these words were written on flash cards, for presenting to the subjects. The words (VCV) consisted of all the vowels of Bengali /ɔ/, /a:/, /i/, /i:/, /u/, /u:/, /e/ and /o/ in the initial position and consonants. Thus, a total of 8 words were chosen for the study.

DATA COLLECTION:

The speech samples for the normal group was recorded in a quite room, away from noise. The speech samples were recorded using a portable tape recorder, with an unbuilt microphone.

The speech samples for the hearing impaired were recorded in a sound treated room. All subjects were comfortably seated at a distance of 15cms, from the microphone.

The following instructions were given: The children were asked to read the words writen on the cards. Before each word, they were given a carrier phrase "/eita:/" meaning "THIS IS". The children were given an opportunity to be familiar with the list. One card at a time was presented to each child. If they were unable to follow, then the instructions were repeated. The subjects were made to repeat after the experimenter, whenever they had difficulty in reading particular words. As each word was uttered, by the child, it was recorded using the portable taperecorder. Each subject uttered each word three times. The best out of three trails, (which was considered to be the most intelligible) was selected for analysis.

INSTRUMENTATION:

Analysis principally involved the following instruments:

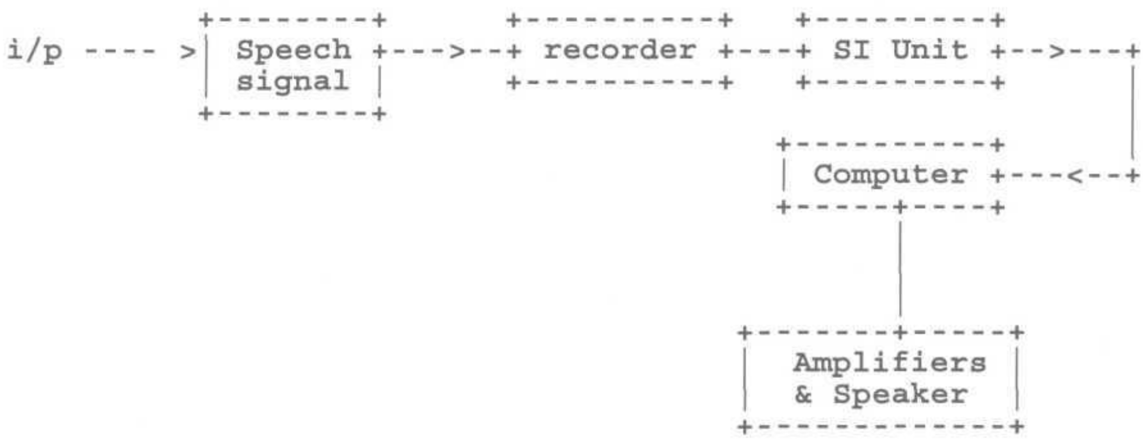
1. Portable tape recorder (AIWA)
2. Sukawa stereo headphone.
3. Antialiasing filter (low pass filter having cut off frequency set at 7.5 KHz), with Speech Interface Unit (SIU).
4. Analog to Digital / Digital to Analog converter (sampling frequency rate set at 16KHz, 12 bit).
5. Personal computer with Intel Pentium 200 MHz processor.

6. Printer Epson Fx 1000.

7. Software for analysis of speech (developed by Voice speech system, Bangalore).

8. Amplifier and Speaker, (2011, SOIS Ampli Speakers).

BLOCK DIAGRAM SHOWING ARRANGEMENT OF INSTRUMENTS FOR THE PURPOSE OF RECORDING AND ANALYSIS OF SPEECH:



ANALYSIS OF DATA:

The recorded samples, that is, each word at a time, as fed through the speech interface unit (12 Bit A/D converter), and digitized at a sampling rate of 16,000 Hz. The block duration and resolution were 50 msec and 10 msec respectively digitised and stored in the hard disc of the computer, using SSL software, developed by Voiced Speech Systems, Bangalore. Before digitising, each sample was passed through the anti-aliasing filter at 3.5 KHz with a role-off of 48 dB/octave. The level indicators of the SI unit was used to monitor, the intensity level to avoid any distortion while digitising the signal.

The words were analyzed using SPGM program of SSL software for total word duration, vowel duration, consonant duration, formant frequency (initial and final), (Fl, F2, F3) of only the preceding vowels and the mean fundamental frequency (of the preceding vowel), and the Bandwidth values (Bl, B2, B3) of the preceding vowel.

I. TEMPORAL PARAMETERS:

1. Total Word Duration: refers to the time between the initiation and termination of a word, and was measured using the speech wave-form and the spectrogram. The waveform was displayed on the computer monitor using the "DISPLAY" programme of SSL and the spectrogram using SPGM. The words were identified based upon the continuity of the wave-form. The word duration was considered to extend from the beginning of the periodic signal to the end of the periodic signal. This duration was highlighted through the use of cursors. The highlighted portion was played back through headphones, to confirm that it contained the word under study. Once this was confirmed, the duration of the highlighted portion was read from the display, and considered as the duration of that particular word.

2. **Vowel Duration:** was measured using waveform and spectrogram displayed on the screen of the computer. The vowels were identified based upon the regularity of the wave-form. The vowel duration was considered to extend from the beginning of the periodic signal and formant frequency to the end of the periodicity and formant frequency (for the vowels in the word initial position as well as for the vowels in the word final position) . The duration was highlighted through the use of cursors. The highlighted portion was played back, through headphones/speakers to confirm that it contained, the vowel under study. Once this was confirmed, the duration of the highlighted portion was read form the display.

3. **Consonant duration:** The length of time during which any consonant sound occurs is termed the duration of that consonant sound. Duration of the consonant in the medial position were measured from the wide bar spectrograms taken for the words. This resulted in duration of five consonants followed by three vowels, **(/aː/,** /u/, */o/* . On a wide band bar spectrogram, consonant boundary was determined as follows:

a) Duration of stop consonants was measured using as reference points the cessation of vocal periodicity of the preceding vowel and the onset of vocal periodicity of the final vowel (Parnell et al, 1977) eg: /t/ as in /oto/.

b) Duration of fricatives was measured using as reference points the observable onset cessation of turbulent noise (Klatt, 1974). eg: /ʃ/ as in /i:ʃa:/ /u:ʃa:/ /eʃo/

c) The duration of affricates included both the burst noise and the frication noise till the onset of the glottal vibration of the following vowel. eg: /tʃ/ as in /itʃa/ and /utʃu/

d) Duration of the nasal /n/ was determined by the presence of extremely rapid spectral change (Monsen, 1978). Using the cursor the identified consonant portion, i.e., cessation of previous vowel to the beginning of the following vowel was highlighted and played back, only after confirming that the consonant has been highlighted. Then the measurement of the highlighted portion was taken. This provided the consonant duration.

4. **Pause duration:** The **"DISPLAY"** program of SSL was used. Pause duration is defined as the time between the initiation and termination of a silence. The pause duration was measured directly from the speech waveform, using the DISPLAY program of SSL, as explained earlier. The speech waveforms were visually inspected for silent intervals, and the duration of the silence was then calculated by placing the cursors at the points of pause onset and termination. Pause onset was defined as the point where the waveform stopped crossing the zero axis on

the display screen, and the pause termination was defined as the point where the waveform next crossed the zero axis. The portion was highlighted every time and listened through headphones for confirmation and better validity. When pauses were identified, their location and duration was noted (intra-word). Locations were confirmed by an acoustic playback of the portion of the signal surrounding the pause.

II. SPECTRAL PARAMETERS:

1. Determining the average fundamental frequency:

To extract the vowel from the fundamental frequency (F_0) a spectrogram of only the preceding vowel was obtained using the "SPGM" program of the software "Speech Science Lab" . After extracting the target vowel, the utterances were first analyzed and then displayed to obtain the Fo contour. Thus, the, speech statistics were displayed to obtain the mean fundamental frequency.

2. Extraction of formant frequencies (Fl, F2, F3):

To extract the vowel formant frequencies (Fl, F2, F3) a spectrogram of only the preceding vowel was obtained using the "SPGM" programme of the software "Speech Science Lab". After extracting the target vowel, the cursor was placed, in the middle of the vowel portion, so as to avoid the formant transitions. The formant frequencies were determined by using the sectioning method through the use of Linear Predictive Coding (LPC). This was done with 12 LPC coefficients. The frequencies at the peaks representing the formants were noted using the cursor.

3. Determining the Band width values Bl; B2; B3 :

The 'PATPLAY 1' programme of software SSL was used to measure the bandwidth, Bl; B2; and B3. The cursor was placed at the point where the bandwidth were found to be in the increasing order.

Thus, all the utterances of all the subjects of both the groups were analysed to obtain, total word duration, vowel duration (preceding as well as following), pause duration, consonant duration, mean fundamental frequency, formant frequencies (Fl, F2, F3) and the bandwidths (Bl, B2, B3). Thus, a total of 8 parameters were analyzed.

STATISTICAL ANALYSIS:

Descriptive statistics consisting of mean, standard deviation, minimum and maximum values, were obtained for all the parameters analyzed. To check whether there were any significant differences between the values of normal hearing group, and hearing impaired group, the independent 't' tests was applied. All the statistical analysis were carried out using the statistical software package "SPSS".

PROBLEMS FACED DURING ANALYSIS:

1. Children had misarticulations of vowels, due to which, some of the words were unintelligible.

2. Though familiarity with the material was made, they pronounced the words with uncertainty.

3. As substitutions, distortions, and omissions were present, it was difficult to identify the vowel.

RESULTS AND DISCUSSION

The aim of the present study was to investigate the acoustic characteristics of the speech of Bengali speaking hearing impaired children, and compare it with that of the normal hearing speakers to find out if there was a significant difference between the 2 groups.

Acoustic Analysis:

Eight bisyllabic (VCV) words uttered by 20 severely hearing impaired and 20 normal hearing children were analyzed to obtain the following acoustic parameters.

1. Vowel duration
2. Consonant duration
3. Total word duration
4. Average fundamental frequency
5. Formant frequencies (F_1, F_2, F_3)
6. Pause duration
7. Bandwidths (B_1, B_2, B_3)

The descriptive statistics was obtained for all the measures. The mean, and standard deviation values were calculated for all the parameters.

1. Vowel Duration:

The duration of the vowels in the initial (preceding vowel duration), and in the final (following vowel duration) positions were measured for both the normal hearing and the hearing impaired speakers. The results are tabulated in Table 1 and Table 2 respectively. A study of Tables 1 and 2, and of Figures 1 and 2 show that the mean vowel duration are much higher in the hearing impaired speakers than in the normal hearing speakers, both in the initial and the final positions.

(a) Preceeding vowel duration:

As shown in table 1 (a) and (b) the vowel duration for the hearing impaired group was longer than the normal hearing group for all the 8 vowels.

In the normal female group, among the 8 vowels studied, the vowel /u:/ had the longest duration (161.70msec); followed by /u/ (153.70msec); /e/ (153.60msec); */i:/* (148.50msec); /ɔ/ (141.80msec); /a:/ (138.60msec), /o/ (137.60msec), /i/ (99.10msec).

So, among the normal females, the preceding vowel duration was in the following (decreasing) order:

/u:/ > /u/ > /e/ > /i:/ > /ɔ/ > /a:/ > /o/ > /i/

In case of the hearing impaired females, the vowel /e/ had the longest duration (639.5 msec), followed by /u:/ (638.5msec), /i/ (571-8 msec), /ɔ/ (564.5 msec), /o/ (560.5 msec), /i:/ (545.2 msec), /u/ (541.7 msec), /a:/ (540.6msec).

Thus, the hearing impaired females had the preceeding vowel duration in the following (decreasing) order:

/e/ > /u:/ > /i/ > /ɔ/ > /o/ > /i:/ > /u/ > /a:/

Table 1 (a) : Mean and SD for preceeding vowel duration (in msec) for both normal and hearing impaired groups "FEMALES".

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
ɔ	141.80	22.51	564.5	185.59	422.7	*
a:	138.60	16.33	540.60	201.55	402	
i	99.10	12.55	571.80	128.54	472.7	*
i:	148'.50	41.10	,545.2	188.36	396.7	
u	153.70	34.02	'541.7	183.22	388	*
u:	161.70	54.95	638.5	141.12	476.8	*
e	153.60	42.28	'639.0	135.23	485.4	*
o	137.60	6.69	560.50	38.94	422.9	*

* - Significant difference between means at P-0.05 level.

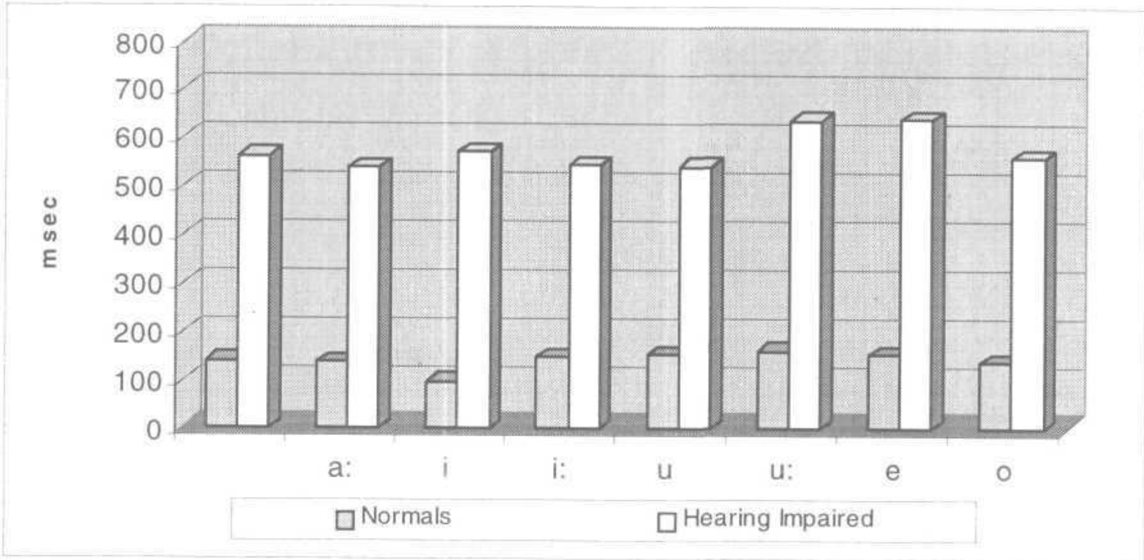
Similarly in the normal male group, the vowel /u:/ had the longest duration (207.1 msec), followed by /i:/ (183.3 msec), /o/ (178.8 msec), /e/ (176.9 msec), /u/ (170.1 msec), /a:/ (155.5 msec), /i/ (134.3 msec) and /ɔ/ (129.8 msec).

Table 1 (b) : Mean and SD for preceding vowel duration (in msec) for both normals and hearing impaired group "MALES".

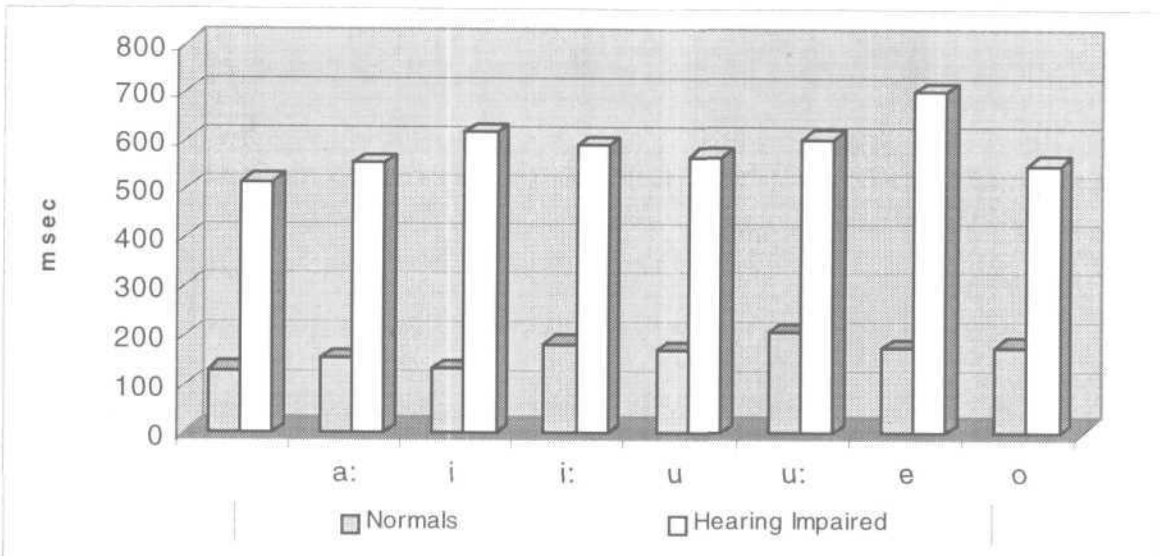
Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
ɔ	129.8	39.82	516.3	224.84	386.5	*
a:	155.5	40.82	556.0	305.86	400.5	*
i	134.3	28.49	619.4	218.34	485.1	*
i:	183.3	55.28	593.6	148.34	410.3	*
u	170.1	61.35	568.3	176.17	398.2	*
u:	207.1	57.64	605.7	262.47	398.6	*
e	176.9	56.00	703.0	216.74	526.1	*
o	178.8	56.33	552.2	213.47	373.4	*

* - Significant difference between means at P-0.05 level.

Graph 1(a): The Means of preceding Vowel duration (in msec) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 1(b): The Means of preceding Vowel duration (in msec) for both Normals and Hearing-Impaired groups "MALES"



Among the male hearing impaired group, the vowel /e/ had the longest duration (703 msec), followed by /i/ (619.4 msec); /u:/(605.7 msec); /i:/(593.6 msec); /u/ (568.3 msec), /a:/ (556.0 msec); /o/ (552.2 msec), /ɔ/ (516.3 msec).

In decreasing order, the preceding vowel duration, among the male hearing impaired group is as follows:

/e/ > /i/ > /u:/ > /i:/ > /u/ > /a:/ > /o/ > /ɔ/

In both the hearing impaired groups (males and females), the vowel /e/ had the longest duration.

The hearing impaired group thus, did not follow the same pattern as that of the control group, for both males and females.

It was seen that normal males and females more or less followed the same pattern in terms of vowel duration. The same was true of the males and females in the hearing impaired group also.

For the normal female group, minimum and maximum mean values ranged from 99.10 to 161.70 msec and for the hearing impaired female group, the mean values ranged from 540.6 to 639 msec. For the normal male group, minimum and maximum mean values ranged from 129.8 to 207.1 msec, and for the hearing impaired male group, the mean values ranged, from 516.3 to 703 msec.

The mean vowel duration produced by the hearing impaired females were found to be higher than that of normals by 388 to 485.4 msec. The mean difference between hearing impaired females and normals for the vowels, /ɔ/, /a:/, /i/, /i:/, /u/, /u:/, /e/, /o/, were 422.7 msec, 402 msec, 472.7 msec, 396.7 msec, 388 msec, 476.8 msec, 485.4 msec, 422.9 msec, respectively.

The mean vowel duration produced by the hearing impaired males were found to be higher than that of normals by 373.4 to 526.1 msec. The mean difference between hearing impaired males and normals for the vowels /ɔ/, /a:/, /i/, /i:/, /u/, /u:/, /e/, /o/, were 386.5 msec, 400.5 msec, 485.1 msec, 410.3 msec, 398.2 msec, 398.6 msec, 526.1 msec, 373.4 msec, respectively.

Independent 't' - test performed showed a significant difference between the :

1. hearing impaired females and normal females, and

2. hearing impaired males and normal males, at 0.05 level of significance, both males and females of hearing impaired group showing longer durations than the males and females of the normal group.

Independent 't' - test performed showed no significant difference between the,

(i) Hearing impaired females and hearing impaired males, and

(ii) Normal females and normal males at 0.05 level of significance.

Thus, the hypothesis (1) stating that there is no significant difference between the normal and hearing impaired subjects in terms of preceding vowel duration is rejected.

Hypothesis (2) stating that there is no significant difference between hearing impaired males and hearing impaired females, as well as normal males and normal females in terms of preceding vowel duration is accepted.

(b) Following vowel duration:

In the present study, three vowels namely /a:/, /o/, and /u/ were studied in the final position. Table 2 (a) and (b) shows the mean durations and standard deviations of these 3 vowels in the final position of 8 bisyllabic words.

Among the 8 bisyllabic words chosen, the vowel /u/ occurs only once in the final position (in the word, /utʃu/) However /a:/ has occurred four times in the final position; /a:ta:/, /itʃa:/, /iʃa:/, /uʃa:/. The vowel /o/ has

n

occurred three times in the final position (/ɔṇo/, /eʃo/, /oto/). It was observed that the duration of the vowels /a:/, /u/ and /o/ did not vary systematically depending upon the type of preceding consonant in both the normal as well as the hearing impaired group. Hence, the average values have been presented in the table 2(a) and (b).

As shown in table 2 (a) and (b), the following vowel duration for the hearing impaired group was longer than the normal hearing group for all the 3 vowels.

In the normal female group, among the 3 vowels studied, the vowel /a:/ had the longest duration (182.47 msec), followed by /u/ (170.7 msec), and /o/ (165.3 msec).

Table 2 (a) : Mean and SD for following vowel duration (in msec) for both normal and hearing impaired groups "FEMALES".

Vowels	Normals		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/a:/	182.47	40.42	460.85	178.83	278.38	*
/o/	165.3	20.34	423.66	120.98	258.36	*
/u/	170.7	49.13	380.0	149.14	209.3	*

* - Significant difference between means at P-0.05 level.

So, among the normal female group, the following vowel duration in the decreasing order was, /a:/ > /u/ > /of

In case of the hearing impaired females, again the vowel /a:/ had the longest duration (460.85 msec) followed by /o/(423.66 msec) and /u/(380 msec). In decreasing order, the vowel duration was as follows: /a:/ > /o/ > /u/

Table 2 (b) : Mean and SD for following vowel duration (in msec) for both normals and hearing impaired group "MALES".

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/a:/	212.37	67.31	455.47	155.85	243.1	*
/o/	197.8	56.02	443.9	155.28	246.1	*
/u/	208.5	73.02	393.0	156.11	184.5	*

* -Significant difference between means at p-0.05 level.

Similarly, in the normal male group, the vowel /a:/ had the longest duration (212.37 msec), followed by /u/ (208.5 msec), and /o/ (197.8 msec).

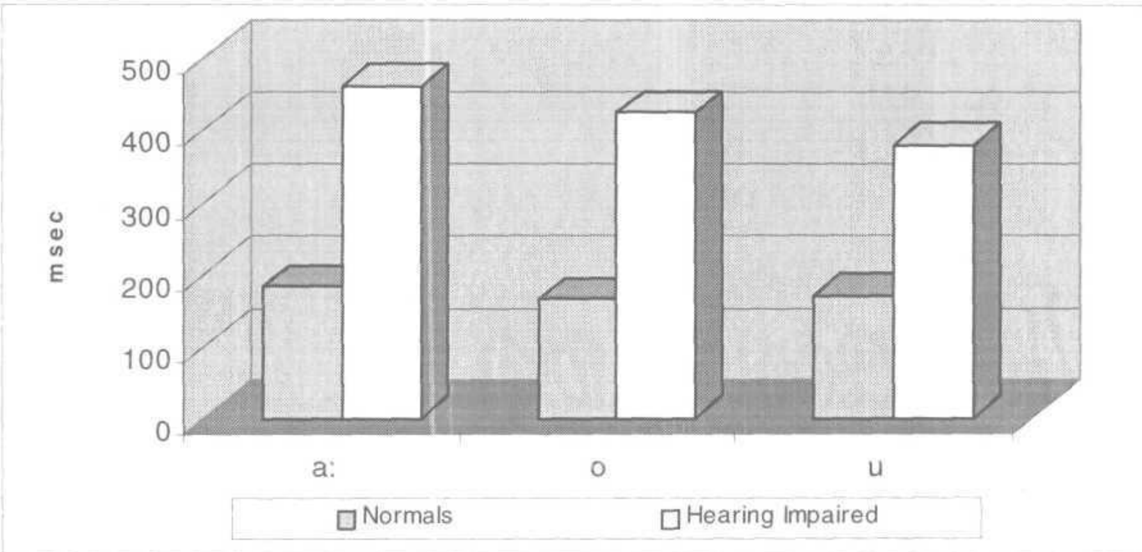
The normal male group, thus, had the following vowel duration, in the (decreasing) order as: /a:/ > /u/ > */o/.*

Thus, the normal male group followed the same pattern as that of the normal female group.

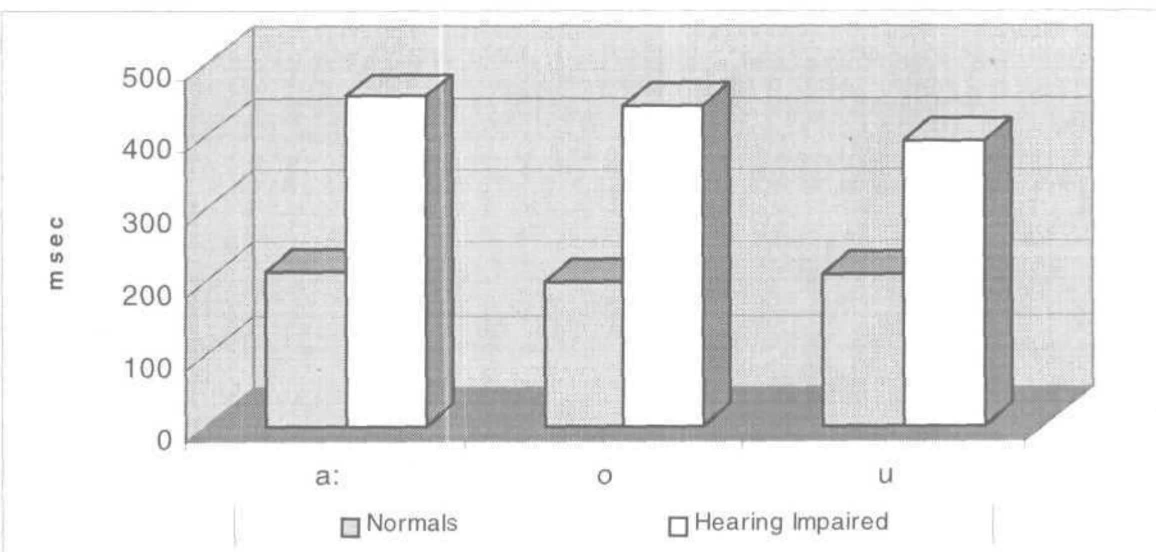
In the hearing impaired male group, the vowel /a:/ had the longest duration (455.47 msec), followed by /o/ (443.9 msec) and /u/ (393 msec). In decreasing order,
/a:/ > /o/ > /u/.

Again, the hearing impaired male and female group seem to follow the same pattern in terms of the duration of the final vowels.

Graph 2(a): The Means of following Vowel duration (in msec) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 2(b): The Means of following Vowel duration (in msec) for both Normals and Hearing-Impaired groups "MALES"



On analyzing the results, it is seen that /a:/ had the longest duration compared to /o/ and /u/ in both the normal and hearing impaired groups. This finding, that is, vowel /a/ being longer than /o/ and /u/ has also been observed in Tamil language (Balasubramanian, 1981). Balasubramanian suggested that "other things being equal, open vowels are longer than close vowels". This seems to hold true for Bengali also.

For the normal female group, minimum and maximum mean values ranged from 165.3 msec to 182.47 msec, and for the hearing impaired female group, the mean values ranged from 380 msec to 460.85 msec. For the normal male group, minimum and maximum mean values ranged from 197.8 to 212.37 msec, and for the hearing impaired male group, the mean values ranged from 393 to 455.47 msec.

The mean vowel duration (following vowel duration) produced by the hearing impaired females were found to be higher than that of normals by 209.3 to 278.38 msec. The mean difference between hearing impaired females and normals for the vowels /a:/, /o/ and /u/ were 278.38 msec, 258.36 msec and 209.3 msec, respectively. The mean vowel duration produced by the hearing impaired females were found to be higher than that of normals by 184.5 to 246.1 msec. The mean difference between hearing impaired males and normals for the vowels /a:/, */of,* and /u/ were 243.1 msec, 246.1 msec and 184.5 msec respectively.

Independent 't' test performed showed, a significant difference between the :

1. hearing impaired females and normal females.
2. hearing impaired males and normal males, at 0.05 level of significance, both males and females of hearing impaired group showing longer duration than the males and females of normal group.

Independent 't'-test performed showed no significant difference between the

(i) hearing impaired females and hearing impaired males, and

(ii) normal females and normal males, at 0.05 level of significance.

Thus, the hypothesis (1) stating that there is no significant difference between the normal and hearing impaired subjects in terms of following vowel duration is rejected.

Hypothesis (2) stating that there is no significant difference between the hearing impaired males and hearing impaired females, as well as normal males and normal females, in terms of following vowel duration is accepted.

On analysing the results, obtained from data on both the preceding, and following vowel durations, it can be concluded that, the vowel duration of the hearing impaired, is in general almost 2 to 3 times greater than that of the normal hearing speakers. This finding is in agreement with several other studies which have tried to map the differences in the speech of the 2 groups (Angelocci, 1962; Calvert, 1962; John and Howarth, 1965; Boone, 1966; Levitt et al, 1974; Monsen, *1914;* Parkhurst and Levitt, 1978; Osberger and Levitt, 1974; Sheela, 1988; Leeper et al, 1987; Shukla 1987; Vasantha, 1995; Rahul, 1997) .

Monsen (1974) has stated that the deaf subjects produced vowels which were longer by one and a half times when compared to the normally hearing speakers. Osberger and Levitt (1979) observed that the syllabic prolongation in the speech of the hearing impaired subjects was primarily due to the prolongation of the vowels.

Zimmerman and Rettaliata (1981) in their cineflourographic study demonstrated that the deaf subjects had longer utterance durations. These studies reported a general tendency towards lengthening of vowels and consonants in the speech of the hearing impaired.

Also, the hearing impaired speakers show a much greater inter speaker variability in vowel duration than the normal hearing speakers. Thus, while the normal hearing speakers, show a maximum variability of 73.02 msec (for the vowel /u/ in the final position), the hearing impaired show a maximum variability of 305.86 msec (for the vowel /a:/ in the initial position). These findings are in agreement with the reports of Monsen (1974), Osberger (1978), Osberger and Levitt (1979), Rajanikanth (1986), Shukla (1987), Jagdish (1988), Rasitha (1994), Vasantha (1995). Similar findings have been reported by physiological studies as well. (Rothman, 1977; Zimmerman and Rettaliata, 1981). Rothman (1977) stated that the deaf, as a group were more variable in their articulatory behaviour than were normal speakers.

It is not clear why the deaf should have particular problems with the timing of speech events like prolonging them and producing high variability in the timing. One possibility is that they depend heavily on vision and that vision simply does not operate in as rapid a time frame as audition (Carlson, 1977; Gannong, 1979). Another possibility is that auditory feedback is necessary for rapid smooth production of complex motoric sequences of speech (Lee, 1950) and that hearing impairment limits the necessary information too severely, requiring a general slowing of the mechanism of production and imposing high instability upon timing.

Lyberg (1981) reported a strong relationship between vowel duration and the fundamental frequency. Nataraja and Jagadish (1984) found that vowel duration of /i/ and /u/ were longer at higher and lower fundamental frequencies than that at normal fundamental frequency since the hearing impaired tended to have a greater fundamental frequency than the normal hearing, the increased vowel duration may be an effect of this.

2. Consonant Duration:

The time during which any consonant sound occurs is termed as the duration of that consonant sound. Many factors seem to affect the duration of a consonant. There were variations in the durations of the consonants. In the present study, the durations of five consonants namely, /n/, /t/, /t[/, /(// and /t/ were measured. Table 3 shows the mean durations and standard deviation values of these five consonants in the normal and hearing impaired groups for both males and females.

Among the eight bisyllabic words chosen, the consonants /n/, /t/ and /t/ occurred only once. However /t(/ has occurred two times (/it [a:/, /utju/) and /[/ had occurred three times (/i: [a:/, /u: la:/, /ejo/). Hence, the average values have been presented in the table 3(a) and (b).

As shown in tables 3(a) and 3(b), the consonant duration for the hearing impaired was longer than the normal hearing group for all the five consonants studied.

Table 3 (a): Mean and SD for consonant duration (in msec) for both normal and hearing impaired groups "FEMALES".

Consonants	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/n/	136.4	46.24	243.00	52.13	106.6	*
/t/	120.6	21.72	189.6	73.74	69.0	*
/tʃ/	151.5	19.11	347.10	184.45	195.6	*
/ʃ/	172.1	12.61	352.10	117.78	180.6	*
/t/	141.10	23.16	214.10	78.99	73	*

* - Significant" difference between means at P-0.05 level.

In the normal female group, among the five consonants studied, the consonant /[/ had the longest duration (172.1 msec), followed by /tf/ (151.5 msec), /t/ (141.10), /n/ (136.4 msec), and /t/ (120.6 msec). Among the normal female group, the consonant duration was in the following (decreasing) order: /(/ > /t[/ > /t/ > /n/ > /t/

'In case of the hearing impaired females, again the consonant / //, had the longest duration (352.70 msec) followed by /tf/ (347.10 msec), /n/ (243 msec) /t/ (214.10 msec), and /t/ (189.6 msec). In decreasing order, it showed the following pattern: /[/ > /t[/ > /n/ > /t/ > /t/

Table 3 (b): Mean and SD for consonant duration (in msec) for both normals and hearing impaired group "MALES".

consonants	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ṇ/	89.40	14.64	20i:27	108.77	111.87	*
/t̪/	87.59	14.21	156.0	27.06	68.41	*
/tʃ/	170.0	25.31	*259.1*	17.44	89.7	*
/ʃ/	225.7	47.64	348.7	166.10	123.0	*
/t/	144.6	24.92	328.5	180.77	183.9	

* - Significant difference between means at P-0.05 level.

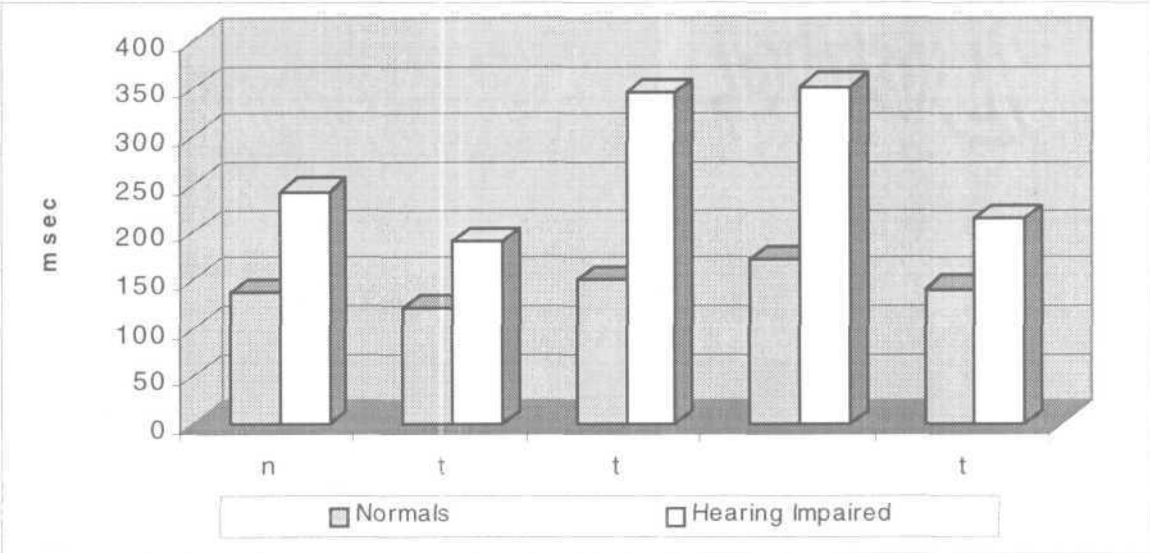
Similarly, in the normal male group, /ʃ/ had the longest duration (225.7 msec) followed by /tʃ/ (170.0 msec), /t/ (144.6 msec), /n/ (89.4 msec), /t/ (87.59 msec). Among the normal male group, the consonant duration was in the following (decreasing) order: /ʃ/ > /tʃ/ > /ṭ/ > /ṇ/ > /t̪/

Among the hearing impaired male group, /ʃ/ had the longest duration, (348.7 msec) followed by /t/(328.5 msec), /tʃ/ (259.7 msec), /n/ (201.2 msec),/t/ (156.0 msec).

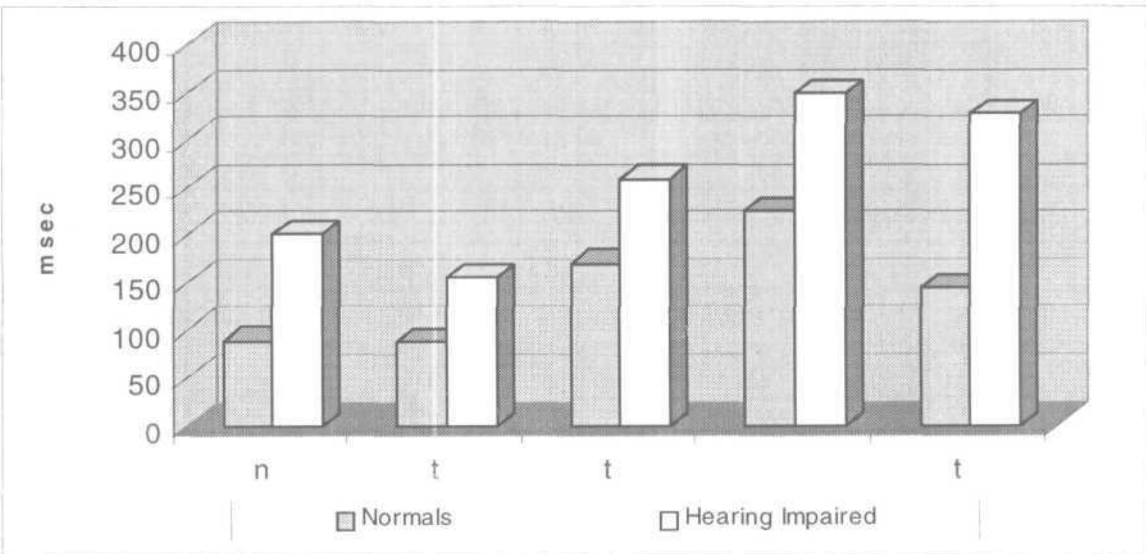
The hearing impaired male group showed the following pattern (in the decreasing order):

/ʃ/ > /ṭ/ > /tʃ/ > /ṇ/ > /t̪/

Graph 3(a): The Means for consonant duration (in msec) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 3(b): The Means for consonant duration (in msec) for both Normals and Hearing-Impaired groups "MALES"



On analysing the results, it is seen that among the normal group, both the males and the females show similar pattern in terms of consonant duration. Although the same pattern is not established, for the hearing impaired group, among the males and females of both the groups, /ʃ/ has the longest duration and /t̪/ has the shortest duration. For both the male and female group among the normals, the following pattern was observed: /ʃ/ > /tʃ/ > /ṭ/ > /ṇ/ > /t̪/

This can be explained in terms of the place of articulation of the above consonants. From the above pattern it can be seen that the duration of the consonant increases as the point of articulation moves backward in the oral cavity. Thus, the duration of the consonant increased from /t̪/ to /ṇ/ to /ṭ/ to /tʃ/ to /ʃ/ (longest). This increase in duration of consonants as the point of articulation moved backward in the oral cavity may be explained by Fant's (1960) finding that bilabial stop consonants tend to be released more rapidly than the lingua alveolar or the lingua velar stop consonants.

There seems to be some controversy in this regard. Fischer-Jorgenson (1964) and Lehiste (1970) observed that labial stops are 10-20 msec longer in duration than the dental or the velar stops. Subtelny et al, (1966) reported that both the voiced and voiceless stop dentals are 30-50 msec longer than the labials. In any case, "such a difference is less than the difference limits for the perception of duration. The particular difference is probably a function of biomechanical aspects of the production mechanism (Smith, 1978) .

The reason why /t̪/ has shown the shortest duration in males and females of both the normal and the hearing impaired group can be explained in terms of the effect of the vowel environment on the duration of the consonant.

Several researchers (Schwartz, 1969; Disimoni, 1974; Whitehead and Jones, 1978) have reported that the duration of the consonants is mainly determined by the following vowel. In the present study, /t̪/ has been examined in the word /a:t̪a:/. Thus the following vowel /a:/ has contributed to the short duration of /t̪/. This finding supports the findings of Schwartz (1969), Disimoni (1974) and Whitehead and Jones (1978), who found that the /s/ and /ʃ/ were longer in the vowel /i/ environment when compared to /s/ and /ʃ/ in vowel /a:/ environment.

Shwartz (1969) , who found that /s/ and /ʃ/ were longer in the vowel /i/ environment, suggested that, "shorter consonant durations before the vowel /a/ resulted from an earlier release of consonant constriction". He opined that this earlier release was the result of an anticipatory response of the greater distance which must be covered by the articulators when proceeding from the alveolar position to the low back vowel "/a:/". Thus the reason for /t̪/ having the shortest duration, because of the large distance to be covered when moving from the alveolar /t̺/ position to the low back vowel /a:/ in the word /a:t̺a:/

The mean consonant duration produced by the hearing impaired females were found to be higher than that of the normals by 13 to 195.6 msec.

The mean consonant duration produced by the hearing impaired males were also found to be higher than that of the normals by 68.41 to 183.9 msec.

Thus, in general, the hearing impaired group had higher consonant durations when compared to the normal group. This is supported by the results ofthe studies done on consonant duration by previous researchers. Rothman (1977) did an electromyographic investigation of articulation and phonation patterns in the speech of the deaf. The results indicated that the deaf speakers extended the durations of speech segments and exhibited difficulty co-ordinating articulation with phonation. Calvert (1962), examined the duration of selected consonants and vowel phonemes in deaf children and compared it with that of normal hearing children (15-18 years of age) . The results show that the deaf speakers typically distorted the duration of the phonemes 1st by extending their duration several times that of normal hearing speakers, and second by not following the effect of one sound upon another that is commonly found among normally hearing speakers. Calvert (1962) opined that in distorting the duration of the consonants, the deaf speakers destroy cues which may help us in understanding their speech. The results of the present study are also similar to the study done by Shukla (1987) on the speech of deaf speakers. He has stated that:

(i) Duration of the consonants is longer in the speech of the hearing impaired than in the normally hearing speakers.

(ii) The hearing impaired speakers showed a greater variation in controlling the length of the consonants than normally hearing speakers.

There was also a lot of variability in the consonant durations from one speaker to the other among the deaf children. This was mainly because the hearing impaired children had a lot of misarticulations in their speech. The common errors seen were in terms of distortion of the speech sounds, and substitution.

In the above sample containing five different consonants in eight CVC words, the most frequently noted errors were substitution of /n/, /tʃ/, and /ʃ/ by /t̪/. Most of the hearing impaired children used /t̪/ to substitute for the fricative, affricates and nasal sounds. This findings is in agreement with the findings of Markides (1970) who revealed that the most frequently misarticulated consonants were the fricative /s/, /ʃ/, and the nasal /n/.

Geffner (1980) also said that according to the manner of articulation, laterals and glide phonemes were elicited more accurately than the afficates. She also found that the initial consonants were produced more correctly than those in the medial position.

In summary, the studies (Hudgin and Numbers, 1942; Nober, 1967; Markides, 1970; Smith, 1975; and Geffner) are generally in agreement, and the most frequent consonant errors are incorrect productions of the palatal and alveolar fricatives, the affricates and the nasals.

Independent 't' - test performed showed, a significant difference between the :

1. Hearing impaired females and normal females.

2. Hearing impaired males and normal males, at 0.05 level of significance, both males and females of hearing impaired group showing longer duration than the males and females of normal group.

Independent 't' - test performed showed no significant difference between the:

(i) Hearing impaired females and hearing impaired males, and

(ii) Normal females and normal males, at 0.05 level of significance.

Thus, the hypothesis, (1) stating that there is no significance difference between the normal and hearing impaired subjects in terms of consonant duration is rejected.

Hypothesis (2) stating that there is no significant difference between the hearing impaired males and hearing impaired females, as well as normal males and females, in terms of consonant duration is accepted.

Total Word Duration:

The words spoken by the hearing impaired subjects had longer durations in general, when compared to the normal hearing group. Table 4(a) and (b) depict the mean, and standard deviation values for "Total word duration" in both the groups.

Table 4 (a) : Mean and SD for total word duration (in msec) for both normal and hearing impaired groups "FEMALES".

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔṇo/	557.9	60.7	1566.8	404.37	1008.9	*
/a:ṭa:/	529.5	77.9	1445.5	298.15	916.0	*
/itʃa:/	586.6	51.92	1631.0	697.01	1044.5	*
/i:ʃa:/	557.3	89.32	1416.10	473.83	858.8	*
/utʃu/	533.5	70.73	1332.7	300.12	799.2	*
/u:ʃa:/	578.0	68.68	1611.3	400.07	1033.3	*
/eʃo/	544.8	53.22	1598.0	261.75	1053.6	*
/oṭo/	550.8	15.69	1457.4	125.3	906.6	*

* - Significant difference between means at P-0.05 level.

Among the normal female speakers, the word /itʃa:/ had the longest duration (586.5 msec); followed by /u:ʃa:/ (578 msec); /ɔṇo/ (557.9 msec); /i:ʃa:/ (557.3 msec); /oṭo/ (550.8 msec), /eʃo/ (544.4 msec); /utʃu/ (533.5 msec); /a:ta:/ (529.5 msec).

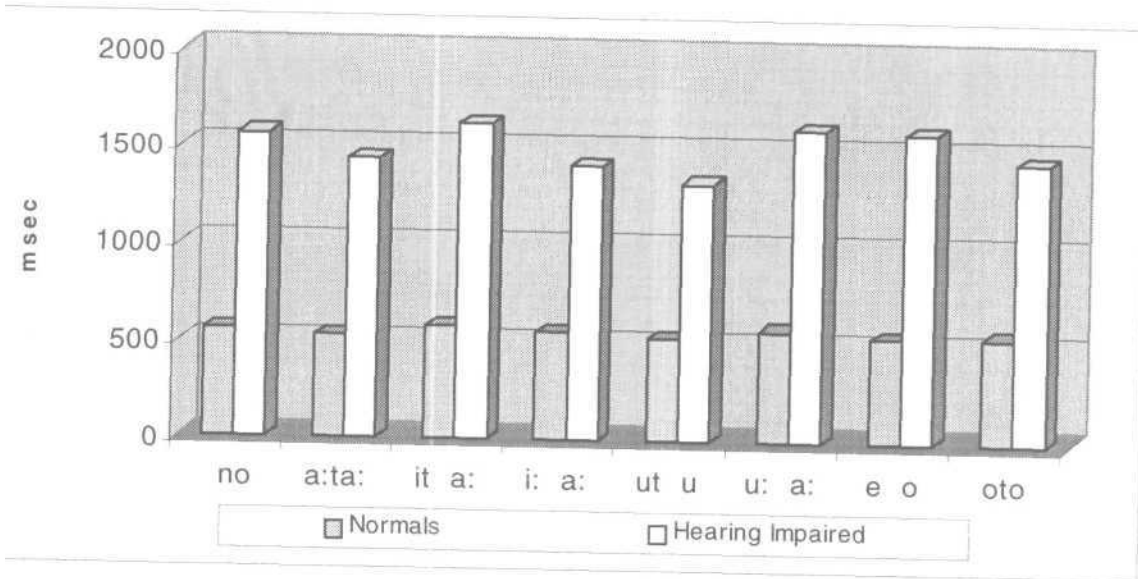
Among the hearing impaired female speakers, the word /itʃa:/ had the longest duration (1631.0 msec); followed by /u:ʃa:/ (1611.3 msec); /eʃo/ (1598 msec); /ɔṇo/ (1566.8 msec); /oṭo/ (1457.4 msec); /a:ta:/ (1445.5 msec); /i:ʃa:/ (1416.1 msec); /utʃu/ (1332.7 msec).

Table 4 (b): Mean and SD for total word duration (in msec) for both normal and hearing impaired groups "MALES".

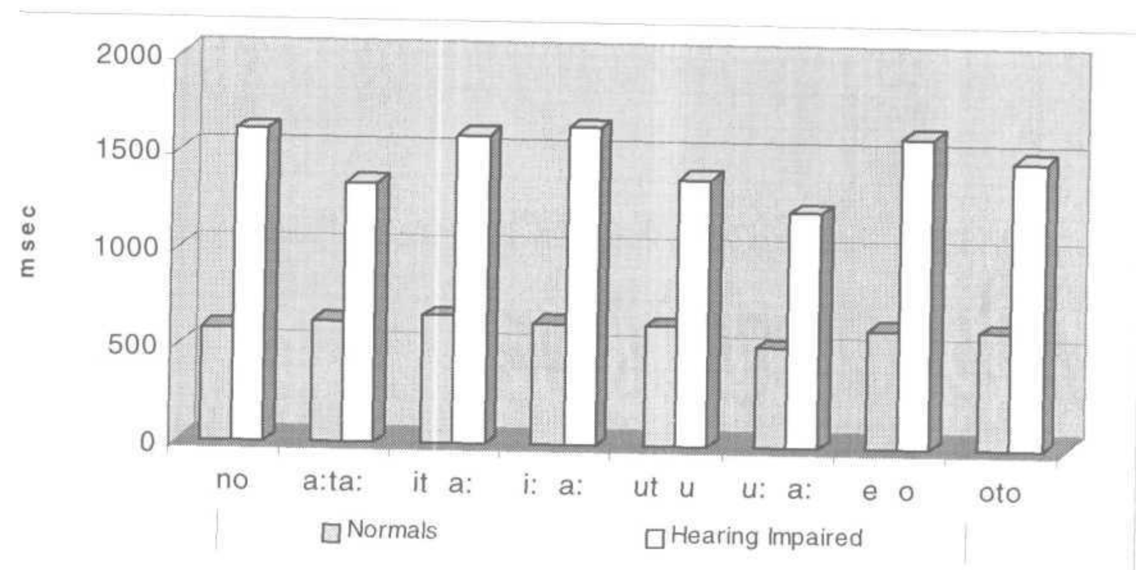
Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔṇo/	590.4	61.13	1612.8	532.16	1022.4	*
/a:ta:/	631.9	188.39	1343.1	438.26	711.2	*
/itʃa:/	664.6	154.49	1596.10	479.4	931.4	*
/i:ʃa:/	632.3	110.32	1639.5	499.02	1007.2	*
/utʃu/	624.0	135.99	1381.2	385.23	757.2	*
/u:ʃa:/	518.62	101.47	1219.4	312.55	700.78	*
/eʃo/	619.7	111.36	1604.7	374.49	985.0	*
/oṭo/	613.7	106.46	1488.3	382.12	874.6	*

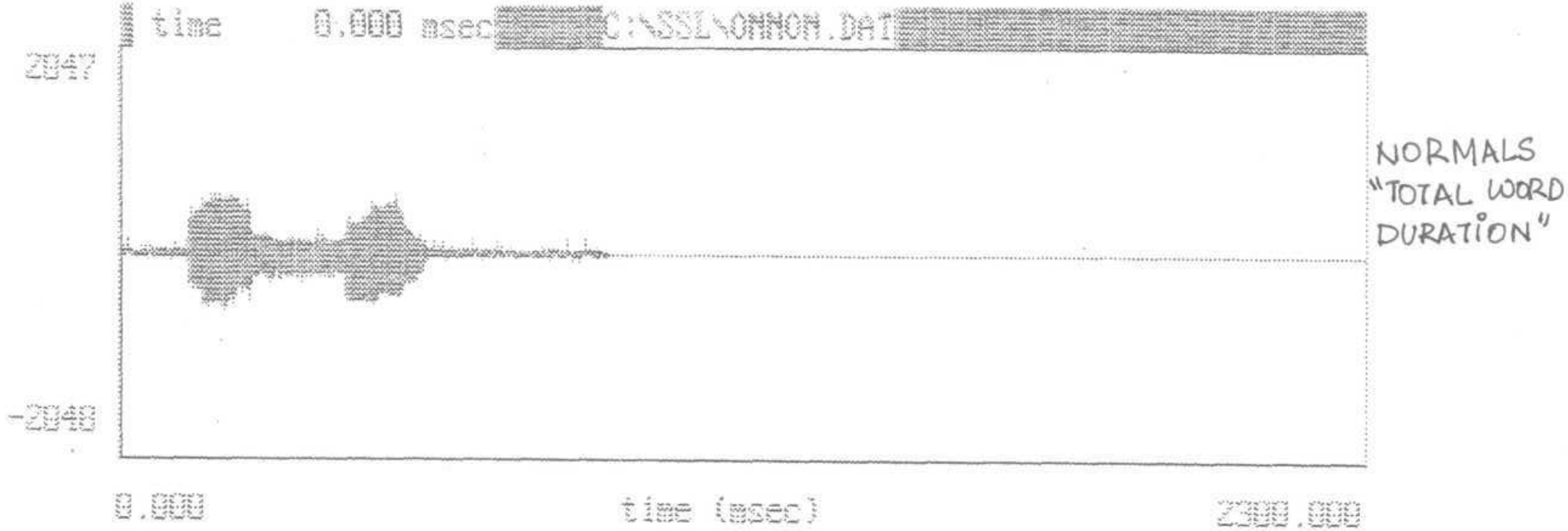
* -> Significant difference between means at P-0.05 level.

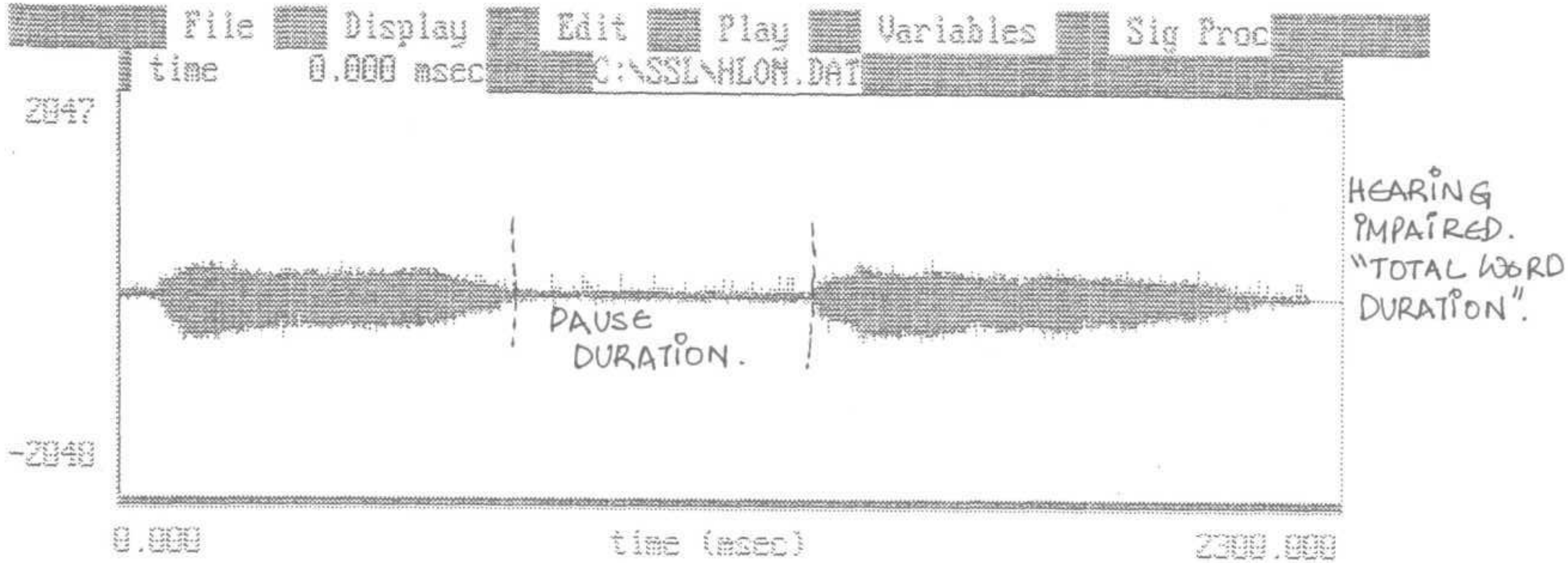
Graph 4(a): The Means for "Total word Duration" (in msec) for both Normals and Hearing Impaired groups "FEMALES"



Graph 4(b): The Means for "Total word Duration" (in msec) for both Normals and Hearing Impaired groups "MALES"




time 0.000 msec C:\SSL\OMNOM.DAT
2047
-2048
0.000
time (msec)
2300.000
NORMALS
"TOTAL WORD DURATION"


File Display Edit Play Variables Sig Proc
time 0.000 msec C:\SSL\HLON.DAT
2047
-2048
PAUSE DURATION.
0.000
time (msec)
2300.000
HEARING IMPAIRED.
"TOTAL WORD DURATION".

WORD : |ɔṇo|

In the normal hearing male group, the word /itʃa:/ had the longest duration (664.7 msec) followed by /i:ʃa:/ (632.3 msec); /a:ṭa:/ (631.9 msec); /utʃu/ (624 msec); /eʃo/ (619.7 msec); /oṭo/ (613.7 msec) /ɔṇo/ (590.4 msec); /u:ʃa:/(518.62 msec).

In the hearing impaired male group, the word /i:ʃa:/ had the longest duration (1639.5 msec); followed by /ɔṇo/ (1612.8 msec); /eʃo/ (1604.7 msec); /itʃa:/ (1596.1 msec); /oṭo/ (1488.3 msec); /utʃu/ (1381.2 msec); /a:ṭa:/ (1343.1 msec); /u:ʃa:/ (1219.4 msec).

In both the normal male and female groups, the word /itʃa:/ had the longest duration. Also, in the hearing impaired male group, the word /itʃa:/ had the longest duration. In both the normal hearing as well as the hearing impaired male groups, the word /u:ʃa/ had the shortest duration. The mean difference between the hearing impaired females and the normals for the words /ɔṇo/, /a:ṭa:/, /itʃa:/, /i:ʃa:/, /utʃu/; /u:ʃa:/, /eʃo/ and /oṭo/ were 1008.9; 916.0; 1044.5; 858.5; 799.2; 1033.3; 1053.6 and 906.6 msec respectively. The mean word duration produced by the hearing impaired females were found to be higher than that of normals by 799.2 to 1053.6 msec.

The hearing impaired females had greatest variations compared to that of the normal hearing group. The minimum and maximum mean values ranged from 529.5 to 586.5 msec, for the normal female group. In case of the hearing impaired female group, the minimum and maximum mean values ranged from 1332.7 to 1631 msec.

The mean difference between the hearing impaired males and normals for the words, /ɔṇo/, /a:ṯa:/, /itʃa:/, /i:ʃa:/, /utʃu/, /u:ʃa:/, /eʃo/ and /oṭo/, were 1022.4, 711.2, 931.4, 1007.2, 757.2, 700.78, 985.0 and 874.6 msec. The mean word duration produced by the hearing impaired males were found to be higher than that of normals by 700.78 to 1022.4 msec.

The hearing impaired males had greater variations than that of the normal hearing group. The minimum and maximum mean values ranged from 518.62 to 664.7 msec, for the normal male group. In case of the hearing impaired male group, minimum and maximum mean values ranged from, 1219.4 to 1639.5 msec.

Independent 't' - test performed showed significant between the :

1. Hearing impaired females and normal females.
2. Hearing impaired males and normal males, at 0.05 level of significance both males and females, of the hearing impaired group showing longer duration than the males and females of the normal group, in terms of word duration.

Independent 't' - test performed showed no significant difference between the :

(i) Hearing impaired females and hearing impaired males, and

(ii) Normal females and normal males at 0.05 level of significance.

Thus, the hypothesis, (1) stating that there is no significant difference between the normal and hearing impaired subjects in terms of "total word duration" is rejected.

Hypothesis (2) stating that there is no significant difference between the hearing impaired males and hearing impaired females, as well as, normal males and females, in terms of "Total word duration" is accepted.

On analysing the results, obtained from the data about total word duration, it can be concluded that the "Total word duration" of the hearing impaired, is in general greater than that of the normal hearing speakers.

Similar findings have been reported by Leeper (1987); Sheela, (1988); Rasitha, (1994). Total duration of words would be more in hearing impaired children as they prolong the speech segments and insert several intersyllabic pauses. Osberger and Mc. Garr (1982), reported that prolongation of speech segments is present in the production of phonemes, syllables and words in the speech of the hearing impaired.

Nickerson et al (1974) measured the duration of 4 short utterances read by 25 normal hearing and 25 deaf children, in stressed and unstressed conditions. They found that in general, the deaf subjects tend to prolong the duration of the utterances.

The overall tendency for increased duration of all phonemes in the speech of the deaf (Calvert, 1961, Hood, 1966) is felt to be related to the teaching of articulation of individual isolated elements rather than longer, more meaningful, units of speech (Rawlings, 1935, 1936; John and Howarth, 1965; Boone, 1966).

Total word duration was found to be higher in hearing impaired children compared to normal children even in recent Indian studies done by Kanaka (1998), Poonam (1998), Sonia (1998), Jayaprakash (1998), Rajesha (1998), Roopa (1998), Priya (1998), and Rathnakumar (1998).

Fundamental Frequency:

The mean fundamental frequency (F_o) was measured for all the words for each of the hearing impaired and the normal hearing subjects.

Table 5(a) and (b) show the mean, and standard deviation values of fundamental frequency of normal and hearing impaired subjects. On scrutiny of these values, it is seen that, all the hearing impaired subjects had a much higher F_o than their age and sex matched controls. As a group, the hearing impaired subjects had a statistically significant higher F_0 than heir age and sex matched controls.

Among the normal hearing subjects, it was seen that the females and the males had almost similar F_0 values, the values for females being slightly higher than that of the males. This could be attributed to the age of the subjects. The reduction of pitch among the males normally take place only after publicity, but till then their pitch remains as high as that of the females matched in terms of age.

Table 5 (a): Mean and SD values for fundamental frequency (in Hz) for both normal and hearing impaired groups "FEMALES".

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	250.20	20.10	353.30	64.16	103.1	*
/a:/	251.10	33.07	348.30	78.14	97.2	*
/i/	258.8	28.80	355.5	48.22	96.7	*
/i:/	259.70	17.44	341.90	52.12	82.2	*
/u/	274.4	14.37	358.7	53.13	84.3	*
/u:/	260.5	11.60	360.4	64.65	99.9	*
/e/	256.8	27.72	351.3	72.06	94.5	*
/o/	249.4	7.09	349.4	19.60	100.0	*

* - Significant difference between means at P-0.05 level.

As shown in table 5 (a) and (b), among normal females, the vowel /u/ had the highest F_0, (274.4 Hz), followed by /u:/ (260.5 Hz), */i:/* (259.7 Hz), /i/ (258.8 Hz), /e/ (256.8 Hz), /a:/ (251.1 Hz), /ɔ/ (250.2 Hz) and /o/ (249.4 Hz).

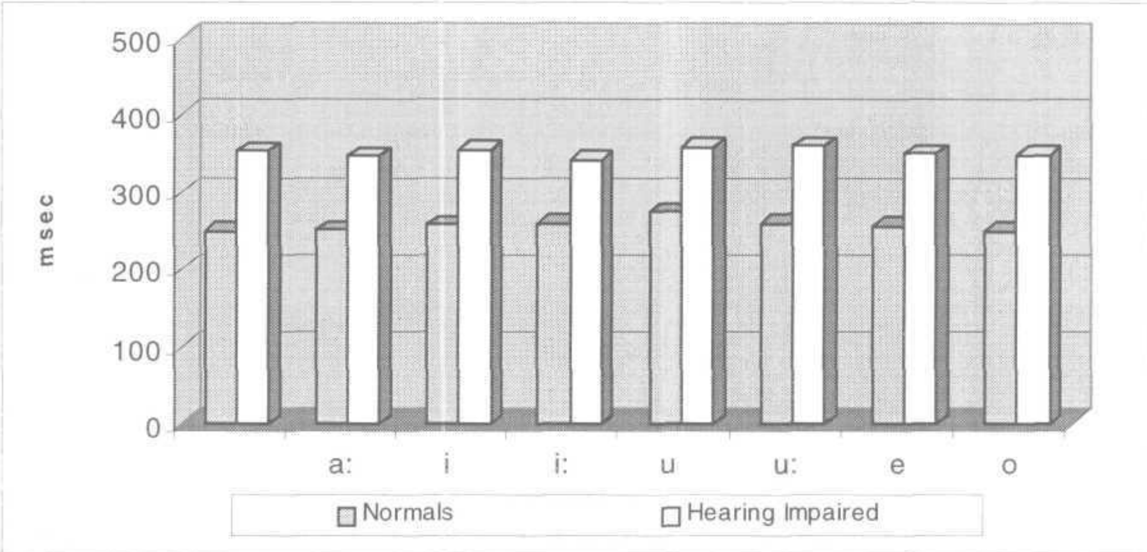
In the hearing impaired female group, the highest F_0 was for the vowel, /u:/ (360.4 Hz), followed by /u/ (358.7 Hz), /i/ (355.5 Hz), /ɔ/ (353.3 Hz), /e/ (351.3 Hz), /o/ (349.4 Hz), /a:/ (348.3 Hz), /i:/ (341.9 Hz).

Table 5 (b): Mean and SD values for fundamental frequency (in Hz) for both normal and hearing impaired groups "MALES".

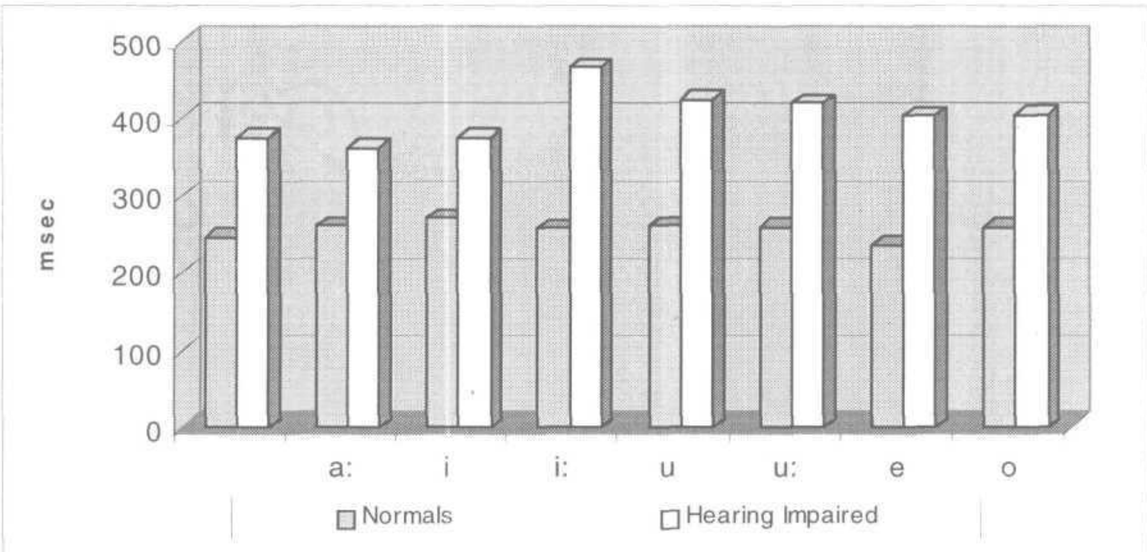
Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	246.9	26.48	374.9	49.46	128.0	*
/a:/	262.3	31.81	362.7	41.79	100.4	*
/i/	271.8	34.92	375.2	54.47	103.4	*
/i:/	258.8	26.72	465.5	38.41	206.7	*
/u/	260.9	30.35	425.5	32.551	164.6	*
/u:/	259.3	30.77	420.91	55.93	161.61	*
/e/	237.2	31.62	403.4	42.27	166.2	*
/o/	259.9	18.31	404.61	139.81	144.71	*

* - Significant difference between means at P-0.05 level.

Graph 5(a): The Means for fundamental frequency (in Hz) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 5(b): The Means for fundamental frequency (in Hz) for both Normals and Hearing-Impaired groups "MALES"



As shown in table 5(b), among the normal hearing male group, the vowel /i/ had the highest F_0 (271.8 Hz), followed by /a:/ (262.3 Hz), /u/ (260.9 Hz), /o/ (259.9 Hz), /u:/ (259.3 Hz), /i:/ (258.8 Hz), /ɔ/ (246.9 Hz), /e/ (237.2 Hz).

In the hearing impaired male group, the higher F_o was seen for the vowel /i:/ (465.5 Hz), followed by /u/ (425.5 Hz) /u:/ (420.91 Hz), /o/ (404.61 Hz), /e/ (403.4 Hz), /i/ (375.2 Hz), /ɔ/ (374.9 Hz), /a:/ (362.7 Hz).

In the normal groups, the minimum and maximum mean values ranged from 237.2 Hz to 274.4 Hz, whereas, in the hearing impaired group, the minimum and maximum mean values ranged from 341.9 Hz to 465.5 Hz. So, variations in the range of the mean values was seen to be more in the hearing impaired group than in the normal hearing group.

Independent 't' - test indicated significant difference between the groups, i.e.

1. Hearing impaired females and normal females.

2. Hearing impaired males and normal males, at 0.05 level of significance, both males and females of the hearing impaired group showing higher F_o, than the males and females of the normal group.

Independent 't' - test performed showed no significant difference, between the:

(i) Hearing impaired females and hearing impaired males, and

(ii) Normal females and normal males, at 0.05 level of significance.

Thus, the hypothesis (1) stating that there is no significant difference between the normal and hearing impaired subjects in terms of Average fundamental frequency is rejected.

Hypothesis (2) stating that there is no significant difference between hearing impaired males and hearing impaired females, as well as normal males and normal females, in terms of average F_o is accepted.

On analysing the data and the results obtained above, it can be concluded that the hearing impaired subjects have a relatively higher F_0 values than normal hearing subjects. This is inconformity with the findings of Angelocci, (1962); Calvert, (1962); Engelberg, (1962); Angelocci et al, (1964); Thorntan, (1964); Boone, (1966); Martony, (1968); Rajanikanth and Jagadish (1989); Sheela (1988); Rasitha (1994); Rahul, (1997); Priya (1998); Kanaka (1998); Poonam (1998).

"If there is a problem with the hearing impaired speakers average F_0, more often the voice pitch is characterised as too high rather than too low". Angelocci, (1962); Angelocci, et al, (1964); Boone, (1966); Calvert, (1962); Engelberg, (1962); Kopp and Holbrook, (1964); Martony, (1968); Meckfessel, (1964); Thornton, (1964);

Gilbert and Campbell, (1980) ; Rajanikanth, (1986) ; Shukla, (1987).

There have been a few explanations put forward in order to explain the higher F_o in case of the hearing impaired. Angelocci, et al (1964) suggested that the hearing impaired subjects attempted to differentiate vowels by excessive laryngeal variations rather than with articulatory maneuvers, as done by normal hearing speakers.

Willemain and Lee (1971) hypothesized that the deaf speakers use extra vocal effort, to give himself an awareness of the onset and progress of voicing and this becomes the cause for the high pitch observed in their speech.

Pitch is a difficult aspect of speech for deaf children to learn to control (Boothroyd, 1970). One possible reason for the difficulty is that deaf children may lack a conceptual appreciation of pitch (Anderson, 1960; Martony, 1968) . This lack of concept may help explain why deaf children often attempt to raise their pitch by increasing their vocal intensity (Phillips, Rebillard, Bass and Pronovost, 1968) .

Pickett (1968) had suggested that the increase in pitch was due to increased subglottal pressure and tension of the vocal cords. Thus, the general opinion has been that the increased vocal effort is directed at the laryngeal mechanisms for kinesthetic feedback.

Bush (1981) has not supported the view that greater F_o variability was observed for the hearing impaired speakers who produced a wide range of vowel sounds. She attributed age related factors such as laryngeal growth accompanied, by adolescent voice change, which are not auditorily detected, to the pitch deviations.

Average fundamental frequency (F_0) decreases with increasing age until adulthood for both males and females (Fairbanks, 1940; Hollien and Paul, 1964; Samuel, 1973; Usha, 1979; Gopal, 1980). Martony (1968) and Honda (1981) opined that the laryngeal tension is a side effect of the extra effort put in the articulators. Since the tongue muscles are attached to the hyoid bone, the cricoid and the thyroid cartilages, an extra effort in their use would result in tension and a change of position in the laryngeal structures. This would cause a change in pitch.

Although, none of the above explanations would alone be sufficient to provide the exact reason behind the increased F_0 for the hearing impaired subjects, an interaction of several of these explanations would be more appropriate.

However, in summary, it may be stated that the high F_0 indicates lack of laryngeal control due to the absence and auditory feedback.

FORMANT FREQUENCY CHARACTERISTICS OF VOWELS:

The quality of vowels depends mainly on the position and shape of the tongue and quite small changes in these markedly affect vowel quality (Monsen and Shaughnessy, 1978). The primary acoustic correlate of vowel quality is the frequency position of formants, or energy concentrations in the spectrum (Fant, 1960) . As a general rule , the frequency of the first formant raises as the mouth becomes more open and the frequency of the second formant raises as the tongue is retracted and raised (Fant, 1960) i.e, F_1 varies mostly with tongue height and F_2 varies mostly with tongue advancement (that is, with variation in the antero-posterior position of the tongue). There could be exception to this rule, however, multidimensional scaling experiments confirm the general accuracy of the rule (Fox, 1983, Rakerd and Verbrugge, 1985) In general, low vowels have a high F_1 frequency and high vowels have a low F_1 frequency. Back vowels have a relatively higher F_2 frequency.

Since it is not easy to describe or categorize the quality of vowels by listening alone, acoustic analysis, to a great extent, would provide the information regarding the behaviour of the articulators. One of the purposes of this study was to analyse and compare the vowel formants of the hearing impaired speakers and normal hearing Bengali speakers.

Monsen and Shaughnessy (1978) are of the opinion that the vowel articulation is difficult for the deaf since clues for it are insufficient. Unlike many consonants, vowels do not have particular reference points that can be easily described.

Previous researchers (Potter et al, 1947, Angelocci et a, 1964), have indicated that the first three formants contribute to the greatest part of vowel information.

Thus, in the present study, three formant values namely F_1, F_2 and F_3 for each vowel were obtained.

FIRST FORMANT FREQUENCY (F_1):

The first formant frequency (F_1) was measured for all the eight vowel, in the word initial position.

Tables 6(a) and 6(b) depict the mean and standard deviation values of Fl for normal and hearing impaired subjects. In general, the results show that the hearing impaired subjects had a higher Fl than those of the normal hearing group.

The means of the first formant frequency (F_1) for the hearing impaired female subjects were higher than for the normal hearing subjects for the vowels /i/, */i/ /,* /u/, /u:/ and /0/, and lower for the vowels, /ɔ/, /a:/ and /e/. The mean difference of the F_1 values for these vowels varied from 87.9 to 209.4 Hz. The mean difference of F_1 values between hearing impaired females and normals for the vowels were, /ɔ/ (-143.3 Hz) /a:/ (-164.3 Hz), /i/ (118.2 Hz), /i:/ (209.4 Hz) /u/ (100.1 Hz), /u:/ (154.7 Hz) /e/ (-87.9 Hz) and /o/ (88.9 Hz).

Independant 't' -test performed showed a significant mean difference between the hearing impaired females and normal females only for the vowels /ɔ/, /a:/ /i:/, /u:/ and /o/

Table 6 (a): Mean and SD values for the first formant frequency (in Hz) for both normal and hearing impaired groups:"FEMALES"

Vowels	Normal		Hearing Impaired		Mean diff. (HI Sc N)	
	Mean	S.D	Mean	S.D		
/ɔ/	772.5	59.97	629.20	109.19	-143.3	*
/a:/	1121.80	70.63	957.50	91.34	-164.3	*
/i/	587.80	86.57	706.00	107.31	118.2	
/i:/	389.30	53.04	598.70	79.95	209.4	*
/U/	555.0	44.73	655.10	78.63	100.1	
/u:/	485.9	79.41	640.6	92.61	154.7	*
/e/	689.2	70.53	601.3	81.0	-87.9	
/o/	582.3	18.81	671.2	31.32	88.9	*

* -> Significant difference between means at P-0.05 level.

Table 6 (b): Mean and SD values for the first formant frequency (in Hz) for both normal and hearing impaired groups: "MALES"

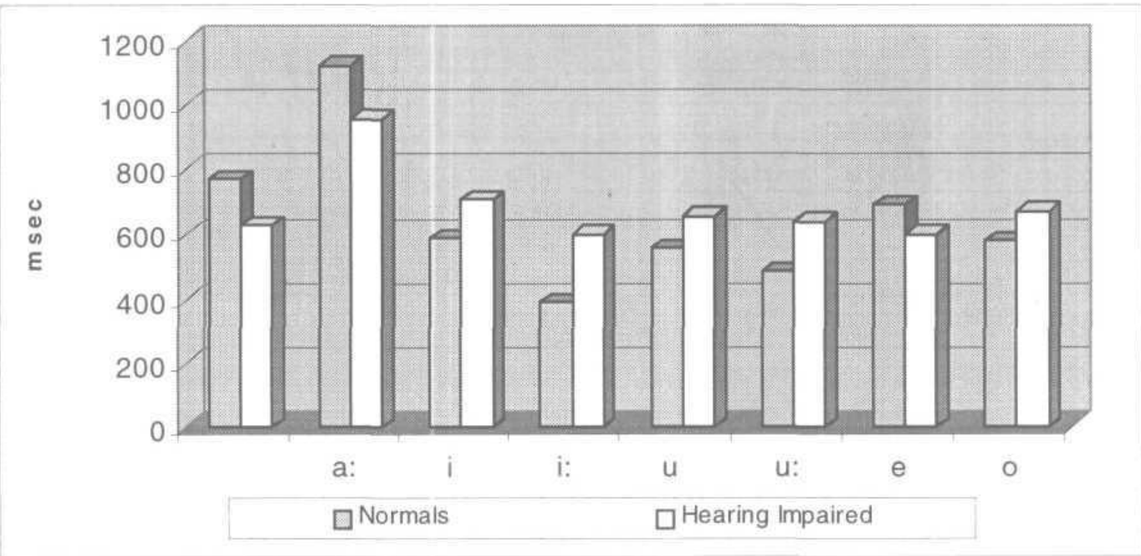
Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	667.3	91.35	571.6	134.99	-95.7	
/a:/	1105.5	89.61	989.1	168.09	-116.4	*
/i/	599.9	89.10	756.7	102.58	156.8	*
/i:/	325.5	38.41	429.0	62.63	103.5	*
/u/	587.2	72.98	684.8	85.43	97.6	
/u:/	514.1	97.49	658.3	109.99	144.2	*
/e/	679.5	69.72	604.78	75.80	-74.72	
/o/	579.7	45.31	689.5	157.14	109.8	*

* -> Significant difference between means at P-0.05 level.

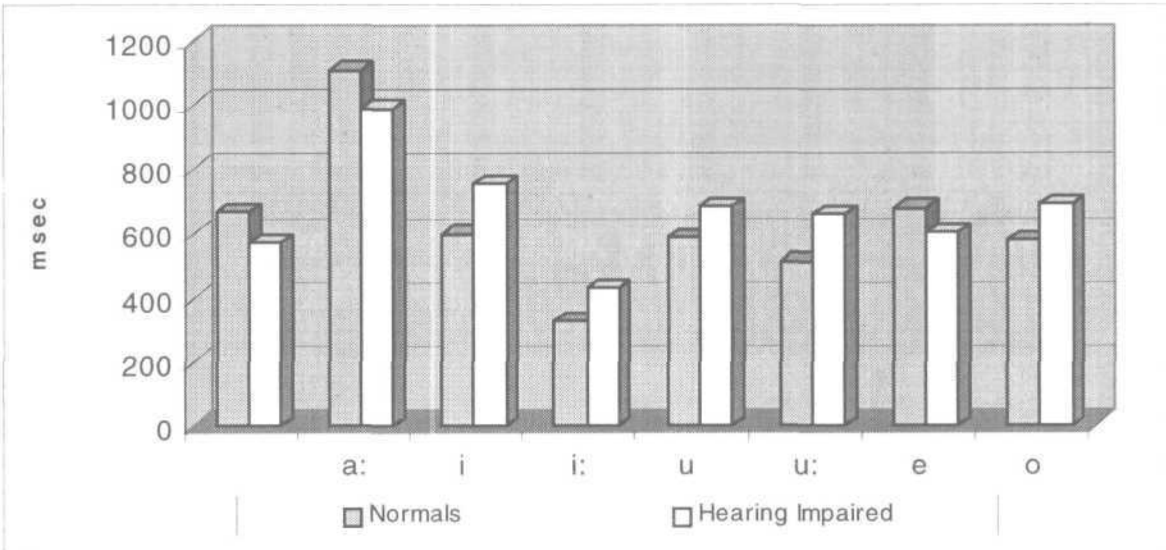
It was found that the hearing impaired males had higher F_1 values than that of normals for the vowels /i/, /i:/ /u/ /u:/ and /o/ and lower for the vowels ,/ɔ/, /a:/, and /e/. The mean difference of the F_1 values between the normal and hearing impaired males for these vowels varied from -116.4 to 156.8 Hz. The mean difference of F_1 values between the hearing impaired males and normals, for the vowels were /ɔ/ (-95.7 Hz), /a:/ (-116.4 Hz) , /i/ (156.8 Hz) /i:/ (103.5 Hz) and /o/ (109.8 Hz)

Independant 't'- test performed showed significant mean difference between the hearing impaired males and normal males, only for the vowels, /a:/, /i/, /i:/, /u:/, and /o/.

Graph 6 (a): The Means for first formant frequency (in Hz) for both Normals and Hearing Impaired groups "FEMALES"



Graph 6 (b): The Means for first formant frequency (in Hz) for both Normals and Hearing-Impaired groups "MALES"



The pattern found among the males and females for F-]_ was similar. For both males and females, F_1 was higher for the vowels /i/, /i:/, /u/, /u:/, and /o/ in the hearing impaired speakers, whereas F_1 was lower for the vowels ,/ɔ/, /a:/ and /e/ among the hearing impaired when compared to the normals.

In the hearing impaired group, (males and females), the mean value of F_1 ranged from 429 Hz to 1989 Hz as compared to a mean range of 325.5 Hz to 1121.8 Hz among the normal hearing group. Further the SD clearly indicates that the hearing impaired subjects had a greater variability than the normal hearing subjects.

Comparison between males and females

On comparing between the males and females, it was found that vowels /a:/,/i:/, /u:/, and /o/ in both the groups showed significant mean difference between hearing impaired and normal hearing speakers. In all these, the hearing impaired speakers were found to have a speaker were found to have a greater F_1 than the normal hearing speakers, except for the vowel /a:/, which had values of F_1 lesser than that of the normal hearing group.

Thus, the hypothesis that there is no significant difference between the means of F_1 values of vowels of the hearing impaired females and normal females was rejected for the vowels /ɔ/, /a:/, /i:/, /u:/ and /o/ and accepted for the vowels /i/,/u/ and /e/.

The hypothesis that there is no significant difference between the means of F_1 values of vowels of the hearing impaired males and normal males was rejected for the vowels /a:/, /i/, /i:/, /u:/ and /o/ and accepted for the vowels /ɔ/, /u/, /e/.

The hypothesis (2) there is no significant difference between males and females has been accepted for both the normal as well as the hearing impaired group.

F_1 is known to be correlated with the degree of mouth opening. On scrutinizing the results obtained, it can be concluded that although in general the F_1 values of the deaf speakers were found to be higher than the normal hearing speakers, around four out of the eight vowels studied did not vary significantly from the normals. Hence it can be concluded that in terms of their range of mouth opening for these vowels, the hearing impaired group did not differ significantly from normals. This finding is in agreement with the reports of Nataraja and Rohini (1992) . However , since for some of the other vowels, the hearing impaired speakers tended to differ from the normals in the range of mouth opening, it can be concluded that no regular pattern could be established in terms of F_1

SECOND FORMANT FREQUENCY (F_2):

Table 7 (a) and (b) depict the mean and standard deviation values of the second formant frequency of normal and hearing impaired subjects. On analysing these values, it is seen that in general the F_2 values of the hearing impaired subjects was higher than the normal hearing subjects.

Among the female group, the mean F_2 values were found to be higher in the hearing impaired speakers when compared to the normal females, for the vowels, /ɔ/, /a:/ /u/, /u:/ and /o/. The mean difference between normals and hearing impaired for the vowels were, /ɔ/ (228.9 Hz), /a:/ (121.7 Hz), /i/ (-235.2 Hz), */i:/* (-247.5 Hz), /u/ (197 Hz) /u:/ (263.2 H), /e/ (-363.4 Hz), and /o/ (276.9 Hz). The mean difference for these vowels ranged from -363.4 Hz to +276.9 Hz.

Thus, among the female group, F_2 values for the hearing impaired speakers were found to be higher than the normal hearing speakers for the vowels /ɔ/, /a:/,/u/, /u:/ and /o/ and lower for the vowels /i/, /i:/ and /e/. Thus in general, higher F_2 was seen in the hearing impaired speakers for the back and neutral vowels, whereas lower F_2 was seen for the front vowels.

However, significant differences between the means among the hearing impaired females and normals was found only for the vowels /ɔ/, /a:/, /i:/ ,/e/, and /o/.

Table 7 (a): Mean and SD values for the second formant frequency (in Hz) for both normal and hearing impaired groups:"FEMALES"

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	1192.70	123 .59	1421.6	131.15	228.9	*
/a:/	1540.5	75.00	1662.20	113.27	121.7	*
/i/	2779.5	91.39	2544.3	135.10	-235.2	
/i:/	3203.4	145.55	2955.9	150.16	-247.5	*
/u/	1499.8	112 .37	1696.8	175.88	197.0	
/u:/	1185.6	92 .11	1448.8	120.00	263.2	
/e/	2582 .1	137.45	2218.7	266.94	-363.4	*
/o/	1066.40	23 .2	1343.3	52.56	276.9	*

* -> Significant difference between means at P-0.05 level.

Table 7(b) reveals that the mean of the hearing impaired males were higher than that of the normal male group for the vowels /ɔ/, /a:/, /u/, /u:/, and /o/ and lower for the vowels /i/, /i:/ and /e/. The mean difference between normals and hearing impaired for the vowels were /ɔ/ (254 Hz), /a:/ (214.3 Hz), /i/ (-199 Hz), */i:/* (-145 Hz), /u/ (242.9 Hz), /u:/ (203 Hz), /e/ (-409.8 Hz) /o/ (324.9 Hz). The mean difference for these vowels, ranged from -409.8 Hz to + 324.9 Hz. Thus among the male group a similar pattern as that of the female group was seen in terms of the F_2 values, i.e., F_2 was higher for the hearing impaired males for the vowels /ɔ/, /a:/, /u/, /u:/ and /o/, (back vowels) and lower for the vowels /i/, /i:/ ,and /e/ (front vowels). However, significant difference between the means among the hearing impaired males and normals was found only for the vowels /ɔ/, /i/, /u/, /e/,and /o/.

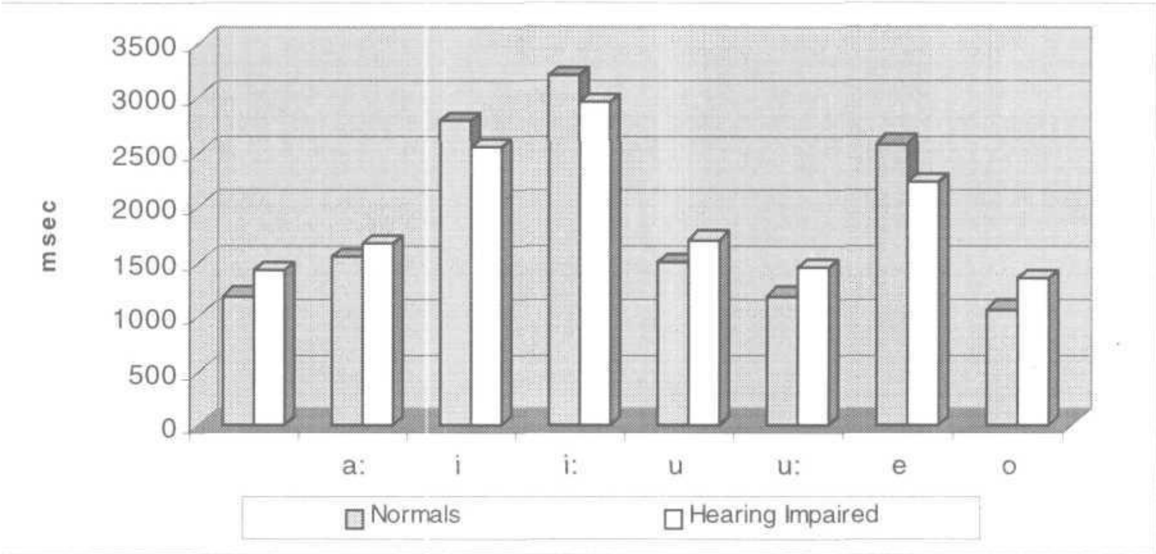
Table 7 (b) : Mean and SD values for the second formant frequency (in Hz) for both normal and hearing impaired groups: "MALES"

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	1168.6	86.13	1422.6	222.25	254	*
/a:/	1474.4	114.19	1688.7	181.53	214.3	
/i/	2743.0	114.35	2543.9	246.24	-199.1	*
/i:/	3176.4	78.29	3031.4	253.72	-145	
/u/	1467.4	94.10	1710.3	132.24	242.9	*
/u:/	1195.7	161.47	1398.7	168.88	203	
/e/	2580.7	235.1	2170.9	392.5	-409.8	*
/o/	1054.9	151.65	1379.8	200.25	324.9	*

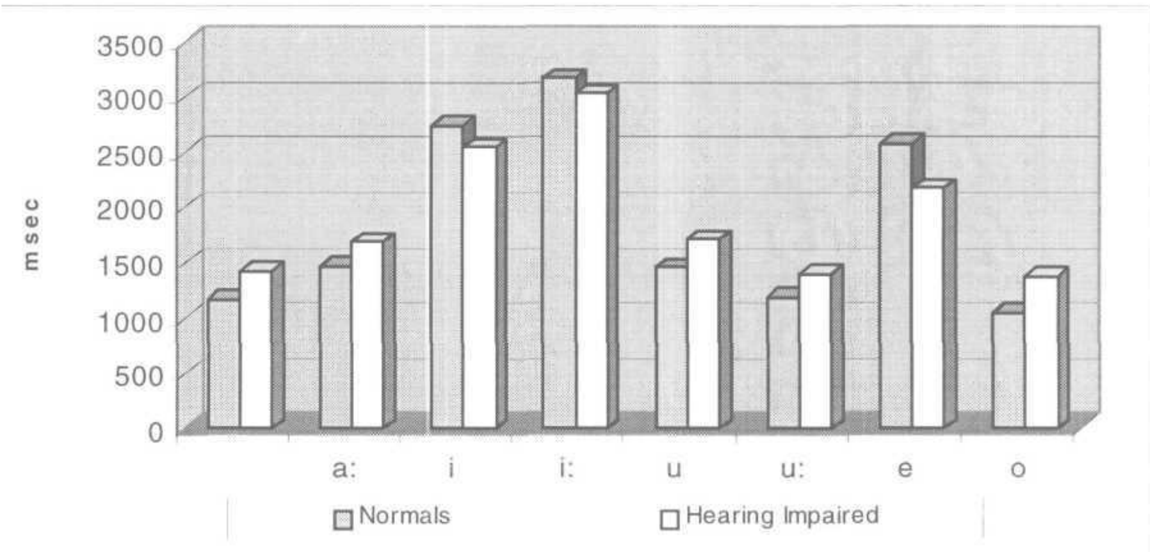
* -> Significant difference between means at P-0.05 level.

Both the groups, showed an overall similar pattern for the mean F_2 among males and females of both the normal and the hearing impaired groups. Both the hearing impaired males and females showed a higher mean F_2 for the back vowels /ɔ/, /a:/, /u/, /u:/ and /o/ compared to the normal hearing group. Both the hearing impaired males and females had lower mean F_2

Graph 7 (a): The Means for second formant frequency (in Hz) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 7 (b): The Means for second formant frequency (in Hz) for both Normals and Hearing-Impaired groups "MALES"



than the normal hearing group for the front vowels /i/, /i:/, and /e/. In general, the hearing impaired males and females showed a higher value of F_2 for the back vowels compared to the normal hearing group and lower F_2 values for the front vowels.

Thus, the hypothesis (1) stating that there is no significant difference between the mean F_2 values of the hearing impaired and normal females Was rejected for the vowels for /ɔ/, /a:/, /i:/, /e/ and /o/ and accepted for the vowel/i/, /u/, /u:/. Among the above mentioned vowels, higher F_2 for the hearing impaired groups was for the vowels /ɔ/, /a:/ and */of* and lower for the vowels, /i:/ and /e/.

Among the males, the hypothesis stating that there is no significant difference between the mean F_2 values of the hearing impaired and normal males, was rejected for the vowels /ɔ/ , /i/, /u/, /e/ and /o/ and accepted for the vowel, /a:/, /i:/ and /u:/, among which, significantly higher F_2 for the hearing impaired group was seen for the vowels ,/ɔ/, /u/ and /o/, and lower F_2 values were *seen* for the vowels, /i/ and /e/.

However no gender effects were seen in terms of F_2 in both the normal and hearing impaired groups. Thus, the hypothesis (2) stating that there is no significant difference between the hearing impaired females and hearing impaired males as well as between the normal females and males in terms of the second formant frequency is accepted.

Thus, it can be concluded that in spite of the differences seen between the F_2 values of the front and back vowel, there is a general tendency for the hearing impaired group to have higher F_2 values compared to the normal hearing group.

The results of the present study are in agreement with the report of Sheela(1988), Sowmya Narayanan (1992), Rasitha (1994), Rahul (1997), Kanaka (1998),i.e., the hearing impaired produced a higher F_2 compared to the normal hearing speakers. Similar findings have also been reported by various investigators (Angelocci et al, (1964), Potter et al (1947), Fairbanks et al(1961) and Levitt (1976).

THIRD FORMANT FREQUENCY (F3) :

Table 8 (a) and (b) depict the mean and standard deviation values of F_3 for normal and hearing impaired subjects. In general, it was found that, the third formant frequency is higher in the hearing impaired group compared to the normal group. Among the females, the hearing impaired females had a higher F_3 when compared to the normal females for all the vowels except for /e/. The mean difference of the F_1 values for these vowels varied from - 6.1 Hz to +352.1 Hz. By far the greatest group difference in the mean of F_3 values among the female group was for the vowel /o/, in which the normal hearing females had an F_3 of 1996.9 Hz and the hearing impaired females had an F_3 of 2349.0 Hz.

Table 8 (a) : Mean and SD values for the third formant frequency (in Hz) for both normal and hearing impaired groups:"FEMALES"

Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	3243.8	119.73	3474.10	137.27	230.3	*
/a:/	3249.3	99.51	3538.4	219.55	289.1	*
/i/	3632.6	98.67	3839.5	145.74	206.9	*
/i:/	3794.6	90.26	3803.8	126.17	9.2	
/u/	3362.9	122.68	3620.1	177.47	257.2	*
/u:/	3219.9	115.29	3348.8	230.59	128.9	*
/e/	3603.0	110.45	3596.9	449.81	-6.1	
/o/	1996.9	21.07	2349.0	43.91	352.1	*

* - Significant difference between means at P-0.05 level.

The mean difference of F_3 values between hearing impaired females and normal females for the vowels, were, /ɔ/ (230.3 Hz), /a:/ (289.1 Hz), /i/ (206.9 Hz), /i/ (9.2 Hz),/u/ (257.2 Hz), /u:/ (128.9 Hz), /e/ (-6.1 Hz) and /o/ (352.1 Hz).

Independant 't' test performed showed a significant difference between the hearing impaired females and the normal females for all the vowels except /i:/ and /e/. i.e., the values of F_3 were increased in the hearing impaired speakers compared to the normal hearing speakers for all the vowels, except /i:/ and /e/.

Table 8 (b) : Mean and SD values for the third formant frequency (in Hz) for both normal and hearing **impaired groups: "MALES"**

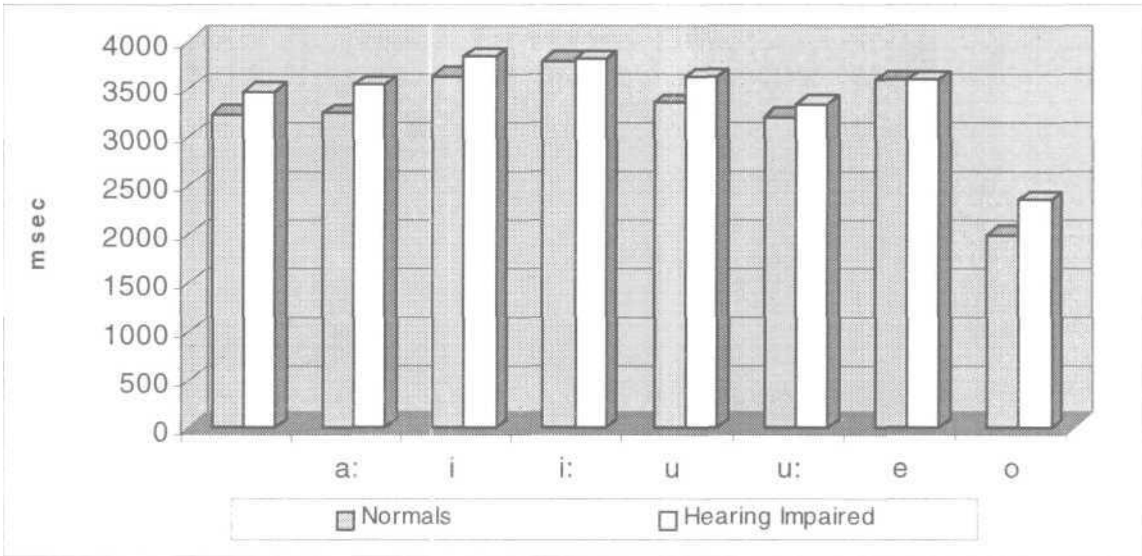
Vowels	Normal		Hearing Impaired		Mean diff. (HI & N)	
	Mean	S.D	Mean	S.D		
/ɔ/	3146.3	174.79	3356.70	307.13	210.4	*
/a:/	3262.4	197.72	3456.3	278.95	193.9	*
/i/	3582.3	256.51	3749.9	256.9	167.6	*
/i:/	3786.4	74.44	3729.3	108.25	-57.1	
/u/	3313.3	172.93	3408.3	301.99	95.0	
/u:/	3215.7	109.51	3288.8	189.01	73.1	
/e/	3578.6	166.32	3557.3	587.6	-21.3	
/e/	1889.6	286.93	2550.5	522.19	660.9	*

* - Significant difference between means at P-0.05 level.

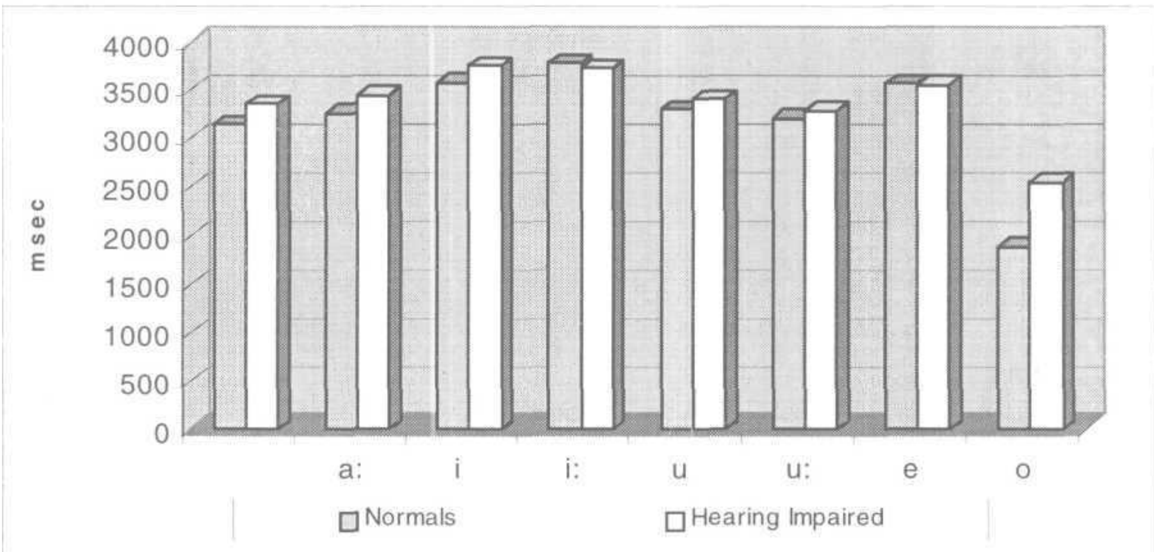
Among the male group, it was seen that the hearing impaired males had a higher F_3 than the normal hearing males, for all the vowels, except for /i:/ and /e/. The mean difference of the F_3 values for these vowels varied from -57.1 Hz to +660.9 Hz.

The greater group difference in the mean of F_3 values, among the male group, was for the vowel /o/, in which the normal hearing males had an F_3 of 1889.6 Hz and the hearing impaired males had an F_3 of 2550.5 Hz.

Graph 8 (a): The Means for the third formant frequency (in Hz) for both Normals and Hearing-Impaired groups "FEMALES"



Graph 8 (b): The Means for the third formant frequency (in Hz) for both Normals and Hearing-Impaired groups "MALES"



The mean difference of F_3 values between hearing impaired males and normal males for the vowels, were, /ɔ/ (210.4 Hz), /a:/ (193.9 Hz) /i/ (167.6 Hz), /i:/ (-57.1 Hz), and /u/ (95.0 Hz) /u:/ (73.1 Hz), /e/ (-21.3 Hz), and /o/ (660.9 Hz).

Independant 't'- test performed showed a significant difference between the hearing impaired males and normal males for the vowels, /ɔ/, /a:/, /i/, and /o/. For all these vowels, the mean F_3 for the hearing impaired speakers was higher than that of the normal hearing speakers. It can be concluded that the males also followed nearly the same trend as that of the females, i.e., both hearing impaired males and females had higher F_3 values than the normal hearing speakers for nearly all the vowels.

Thus, the hypothesis (1) stating that there is no significant difference between the means of F_3 values for vowels of the hearing impaired females and normal females is rejected for the vowels /ɔ/, /a:/- /i// /u/, /u:/, and /o/ and accepted for the vowels, /i:/ and /e/.

The hypothesis stating that there is no significant difference between the means of F_3 values for vowels of the hearing impaired and normal hearing males is rejected for /ɔ/, /a:/, /i/, and /o/, and accepted for the vowels, /i:/, /u/, /u:/ and /e/.

The hypothesis (2) stating that there is no significant difference between males and females has been accepted for both the normal hearing as well as the hearing impaired group.

It also becomes evident that the hearing impaired show a higher variability in the F_3 than the normal hearing speakers. The individual differences and the high variability observed among the hearing impaired group can be considered as indicating that the degree of constriction in the vocal tract is lesser in the case of the hearing impaired, as F_3 is correlated with the degree of constriction of the tongue. Such findings have also been reported by Nataraja and Rohini (1992). Angelocci et al., (1964) reported that F_3 was generally higher for vowels produced by the hearing impaired children than that of normally hearing children which is consistent with the results of the present study. Similar findings have also been seen in the studies done by Rahul (1997); Priya (1998); and Poonam (1998) and Jayprakash (1998).

BANDWIDTHS

The 1st three band widths, Bl, B2 and B3 were determined for all the 8 vowels. The hearing impaired children had smaller values of band widths as compared to the normal hearing children.

The standard deviation values did not show any consistent pattern. Similar findings were obtained both in males and females.

Independent 't'- test performed showed a significant difference between the two group, at 0.05 level of significance for Bl, B2 and B3 i.e., the values of Bl, B2 and B3, for almost all the vowels were found to be significantly lower in the hearing impaired group compared to the normal group. The above results are in agreement with previous studies done by Sheela (1988) and Poonam, (1998) .

Thus, the hypothesis (1) stating that there is no significant difference between the normal and hearing impaired subjects (both males and females) is rejected.

The hypothesis(2) stating that there is no significant difference between the males and females of both normal and hearing impaired group is accepted.

PAUSES

The analysis of intraword (or inter syllabic) pauses revealed that normal subjects did not show any intersyllabic (or intraword) pauses. Pauses were observered in the utterances of most of the hearing impaired subjects. It was found that 18 out of 20 hearing impaired subjects exhibited pauses in their utterance (10 males, and 8 females). Generally, it was observed that male hearing impaired children had more intraword pauses as compared to female hearing impaired children.

This result is in agreement with the results obtained by Poonam, (1998). Among the females, pauses were observed in the utterances of eight hearing impaired subjects. Two of the subjects did not show any pauses.

The mean pause duration ranged from 179.3msec (for the word /i:ʃa/) to 279.5msec for the word /oto/. among the hearing impaired females. Among the females, the word with the maximum number of pauses was for /utʃu/ (8/8), and /oto/ (8/8), followed by /ɔṇo/, /itʃa:/ and /u:ʃa/ (7/8) /eʃa/ and /i:ʃa:/ (6/8) and /a:ṭa:/ (5/8). In general, almost all the subjects exhibited pauses for most of the words. Five subjects showed pauses in all the eight words, the other three showed pauses in at least five words.

Among the male hearing impaired group, all the 10 subjects exhibited intraword pauses. The maximum number of subjects exhibiting pauses were as follows: on the word /i:ʃa:/ (10/10) followed by /ɔṇo/, /itʃa:/ and /oṭo/ (9/10), /eʃo/ and /utʃu/ (8/10) with minimum number of pauses for /u:ʃa:/ and /a:ṭa:/ (6/10). Again, it was observed that almost all the subjects exhibited pauses for most of the words. Seven out of ten subjects exhibited pauses for all the eight words, two subjects showed pauses for 6 words and the remaining are one subject showed pauses in only 5 out of the 8 words.

The mean pause duration ranged from 127 msec (for the word /u:ʃa:/ to 328msec (for the word /i:ʃa/), among the hearing impaired males. So, in the present study, the results revealed that the hearing impaired males exhibited more frequent intraword pauses as compared to the hearing impaired females. However, the intelligibility of the male hearing impaired speakers was found to be better than the female hearing impaired speakers. No pauses were found either in males or females of the normal group.

So, the hypothesis (1) stating that there is no significant difference between the hearing impaired and normal hearing subjects in terms of pauses is rejected for both male and females.

The hypothesis (2) stating that there is no significant difference between the hearing impaired males and hearing impaired females as well as between the normal males and females is accepted.

The results of this study are in agreement with several other studies done by previous researches on pause duration. It has been observed that the profoundly hearing impaired speakers typically insert more passes and pauses of longer durations than do speakers with normal hearing Boone(1966) Boothroyd et al (1974), Heidinger (1972J, Hood (1966), John and Howarth, (1965), Stevens et al (1978) Sheela, (1988), Jagadish (1989), Rasitha, (1994), Kanaka (1998), Priya (1998), Poonam (1998).

Obserger and Mc Garr (1982), while considering the speech of the hearing impaired state that "pauses maybe inserted at syntactically inappropriate boundaries such as between two syllables in a bisyllabic word or within phrases". "The frequent pauses observed in the speech of the hearing impaired maybe the result of poor respiratory control (Hudgins, 1934, 1937, 1946). Hudgins (1946) reported that the deaf children used short, irregular breath groups, often with only one or two words, and breath pauses that interrupted the flow of speech at inappropriate places. Also , there was excessive expenditure of breath of single syllables, false grouping of syllables, and misplacement of accents. Forner and Hixon (1977) found the muscle activity to be normal for deaf individuals, during quiet breathing, but noted that they do not take enough air while breathing for speech.

Consistent with the results found in the present study, there has been some evidences to indicate that pauses do not have a very strong negative effect on intelligibility (Parkhurst and Levitt, 1978). They noted that short pauses may actually aid in increasing the intelligibility as it provides additional time to the listener to process the distorted speech that they are hearing.

ACCORDING TO THE FINDINGS OF THIS STUDY:

I. Hypothesis (1) stating that there is no significant difference in the utterences of the hearing impaired and the normal hearing Bengali speaking children in terms of

l.(a) Vowel duration (preceding and following) is "REJECTED"

(b) Constant duration is "REJECTED"

(c) Total word duration is "REJECTED"

(d) Average Fundamental Frequency (F_0) is "REJECTED"

(e) Formant frequencies (F_1, F_2, F_3)

(i) First formant frequency (F_x) is "REJECTED"

(ii) Second formant frequency (F_2) is "REJECTED"

(iii) Third formant frequency (F3) is "REJECTED"

(f) Bandwidths (B_1, B_2, B_3) is "REJECTED"

(g) Intersyllabic pause duration is "REJECTED"

II. HYPOTHESIS (2) stating that,

(a) There is no significant difference in the utterances of normal males and normal females on all the parameters measured is "ACCEPTED"

(b) There is no significant difference in the utterance of the hearing impaired males and females on all the parameters measured is "ACCEPTED"

Thus, the results of the present study indicates the need for correcting vowel duration, formant frequencies, and elemination of pauses in the speech of the Bengali speaking hearing impaired children. Attempts may be made to incorporate these in therapy with the hearing impaired.

SUMMARY AND CONCLUSION

Within the last decade, advances have been made in studying the speech of the hearing impaired. This is largely due to the development of sophisticated processing and analysis techniques, in speech science , and computer science, that have increased our knowledge of normal speech production. In turn, these technological advances have been applied to the analysis of the speech of the hearing impaired as well as to the development of clinical assessment training procedures.

Several researchers (Voelkar, 1938, Hudgins and Numbers, 1942, Boone, 1966; Nober, 1967; Colton & Cooker, 1968; Markides, 1970; Smith, 1975; Geffner, 1980; and Angelocci et al, 1964; Ravishankar, 1985; Shukla, 1987; Sheela, 1988; Rasitha, 1994; Vasantha, 1995; Rahul, 1997; Kanaka,1998; Priya,1998; Poonam, 1998; and Jayaprakash, 1998) have attempted to describe the speech characteristics of the individuals with severe to profound hearing impairement. The speech characteristics studies include articulation errors, high pitched voice, improper intonation, improper rhythm, slow rate and nasality.

Several researchers (Calvert, 1962; Angelocci et al., 1964; Monsen, 1974, 1976a, 1976b, 1976c, 1978; Rothman, 1976; Whitehead & Jones, 1976, 1978; Leeper et al, 1980, and Shukla, 1987) have recognized the need for describing the speech of the hearing impaired individuals, using objective parameters like vowel duration, consonant duration, voice onset time, fundamental frequency formant frequencies, transitional patterns, oral & nasal airflow, Shimmer & Jitter. This would aid in objective assessment as well as in developing effective therapeutic procedures. Many of the speech parameters which are related to speech intelligibility are language specific.

Deaf subjects & their speech characteristics have been extensively studied in many South Indian language like Kannada, Tamil, Malayalam etc. No such studies have been done in Bengali. Hence, the present investigation was undertaken. Twenty congenitally deaf children in the age range of 7-10 years were selected who were matched in terms of age and sex to twenty normally hearing children. The deaf subjects for the study were chosen from those attending therapy at "SHIRC" Calcutta, and "NIHH" Calcutta. Eight bisyllabic (VCV) words containing all the vowels in Bengali language were chosen for the present study.

All the subjects were asked to read the words and their utterances were recorded using a portable taperecorder (AIWA) The recorded speech samples were analyzed using computer software to determine the following parameters.

I) Temporal parameters

i) Vowel duration (preceding & following vowel duration)

ii) Consonant duration

iii) Total word duration

iv) Pause duration

II) Spectral parameters

i) Average fundamental

ii) Formant frequencies (F_1, F_2, F_3)

iii) Bandwidths (Bl, B2, B3,)

The obtained results were subjected to statistical analysis in order to determine the mean, standard deviation and the significance of difference between the two groups.

The present study revealed the following findings;-

1) On an average, the hearing impaired group (both males and females) had significantly longer duration for vowels than the normal hearing group.

2) Hearing impaired speakers showed a greater variation in vowel duration than normally hearing speakers.

3) There was a vowel lengthening phenomena observed in Bengali language.

4) Both the groups of subjects (normal hearing and the hard of hearing group) did not show any consistent change in the durations of the vowels depending upon the consonant context.

5) Duration of all the consonants were longer in the speech of the hearing impaired than in the normally hearing speakers.

6) Hearing impaired speakers showed a greater variation than normals, in controlling the length of the consonants.

7) Common articulatory errors seen in the hearing impaired children during consonant production were distortion & substitution errors.

8) Substitution errors most often observed was the substitution of fricatives, affricates & nasals by /t/. thus the s o /ʃ/, /tʃ/ d /n/ were frequently substituted by ,/t̪/.

9) The total word durations of the words uttered by the hearing impaired children were significantly longer than that of the normal hearing group. Both the males and females of the hearing impaired group had nearly 1.5 to 2 times longer word durations than normal hearing subjects.

10) Normal hearing children did not show any intersyllabic (intraword) pauses, where as, among the male hearing impaired speakers, all the children revealed significant intersyllabic pauses, and around 8/10 females hearing impaired children exhibited pauses.

11) On the whole, significantly higher average F_0 was exhibited by the hearing impaired subjects than that of

the normal hearing group (for both males and females). Larger variations were seen in the hearing impaired group.

12) The hearing impaired males and females showed significant differences in their F_1 as compared to normal hearing controls, i.e., F_1 values were higher in the hearing impaired group, when compared to the normals.

13) The F_2 values were higher in case of the hearing impaired group, when compared to the normal hearing group for both males and females.

14) All the hearing impaired subjects including males and females, revealed a significantly higher F_3 than that of the normal hearing control group.

15) Bandwidths (B_1, B_2, B_3) of hearing impaired subjects were reduced than that of the normal hearing subjects.

16) No gender effects were noticed for any of the parameters studied, i.e. there is no significant mean differences seen between the normal males and normal females, nor between the hearing impaired males and females.

17) The speech intelligibility for the deaf speakers was poorer than for the normal speakers.

CONCLUSIONS

Although the basic differences that characterize normal speech from deaf speech remain the same in different languages, there are some notable differences in terms of vowel lengthening , higher pitch, effect of word accent , stress, intonation, etc which are typical to the speech of the Bengali speaking hearing impaired children. Thus, to a certain extent, speech parameters are language specific. On analysing the results, it is seen that certain speech parameters seem to behave similarly in different languages for example, just like in Bengali language, vowel lengthening phenomena has also been reported in English language. Thus , it would be useful to study the different parameters in various languages. The results of the present study provides normative data varies parameters studied in Bengali language. The results of this study indicate that the hearing impaired individuals differ from normals in certain temporal & spectral characteristics of their speech. Further increased variability was also seen , in the hearing impaired speakers, than in the normally hearing speakers that is , the hearing impaired speakers not only behaved differently from the normals, but they also were different from each other. Thus, the deviant features present in the speech of the hearing impaired need to be modified to improve & enhance speech intelligibility.

RECOMMENDATIONS:

- Similar studies can be carried out using a larger number of subjects, which would thus give more reliable results.

- To minimise the high variability among the hearing impaired subjects, a more homogeneous group of subjects can be chosen.

- Various spectral parameters & their relations to the factors affecting speech intelligibility, in the hearing impaired children may be studied. Such information will be useful in planning therapy for children with hearing impairement.

- The study maybe done across ages to delineate the developmental stages of speech acquisition in the hearing impaired.

- The extent to which the deviant features maybe modified in order to improve speech intelligibility using visual feedback system, like spectrographs, visible speech patterns and/or biofeedback system is of interest for future research.

- Research maybe also focussed on to assess the effect of different types of oral training on speech production by the hearing impaired.

- Results of this study can help in determining the error types & the kinds of errors that should be considered first when planning a training programme for the improvement of speech in the hearing impaired child.

- Similar studies using sentences as the speech material maybe carried out .

- A study to find out the effect of correction of the various deviant parameter maybe undertaken.

BIBLIOGRAPHY

Anderson, F. (1960). cited in Nicerkson, R.S. (1975). Characteristics of the speech of deaf persons. The Volta Review, 77, 342-362.

Angelocci, A., Kopp, G., and Holbrook, A. (1964). The vowel formants of deaf and normal hearing 11 to 14 year old boys. Journal of Speech and Hearing Disorders, 29, 15 6-170.

Angelocci, A.A. (1962) . Some observations on the speech of the deaf. The Volta Review, 64, 403-405.

Angelocci, A.A., Kopp, G., and Holbrook, A. (1991). Cited in readings in clinical spectrography of speech. R.J. Baken and R.C. Daniloff (Ed.) Publishing Group Inc., New Jersey, 510-523.

Balasubramanian T. (1980). Timing in Tamil. Journal of Phonetics, 8(4), 449-469.

Balasubramanian, T. (1981). Duration in Tamil. Journal of Phonetics, 9, 151-162.

Behrens, T. (1978) . cited in Ross, M. and Giolas, T.G. (1978). Auditory Management of Hearing impaired children. University Park press, Baltimore, XV.

Bennet, S. (1980) . cited in Readings in clinical spectrography of speech. R.J. Baken and R.C. Daniloff (Ed.) . Singular publishing Group Inc., New Jersey, 384-391.

Black J.W. (1971). Speech Pathology for the Deaf, Speech for the Deaf Child: knowledge and use. L.E. Connor (Ed.) Washington, D.C.: A.G. Bell Association for the deaf, 154-169.

Bodycomb, M. (1946). cited in Gold, T. (1980). Speech production in the hearing impaired children. Journal of Communication Disorders, 13, 397-418.

Boone, D.R. (1966) . Modification of the voices of deaf children. The Volta Review, 68, (686-694) .

Boothroyd A., Nickerson, R., and Stevens, K. (1974). Temporal patterns in the speech of the deaf: A study in remedial training. Northampton Mass: C.V. Hudgins Diagnostic and Research Centre, Clarke School for the

Deaf, as cited by Osberger, M.J. and McGarr, N.S. (1982) in "Speech Production Characteristics of the Hearing Impaired", Status report on speech research, Jan.-March, Haskins Lab, New Haver Conn, 227-290.

Boothroyd, A. (1969). cited in Osberger, M.J. and McGarr,N.S. (1982).Speech production characteristics of the hearing impaired. Status reports on speech research, Jan-Mar. Haskins Lab, New Haver, Conn. 227-290.

Boothroyd, A. (1970). Concept and control of fundamental voice frequency in the deaf. An experiment using a visible display paper presented at the International Conference of the Deaf, Stockholm, Sweden.

Boothroyd, A. (1985). Evaluation of speech production of the hearing impaired and some benefits of forced - choice testing. Journal of Speech and Hearing Research, 28, 85-196.

Boothroyd, A. (1989). Hearing aids, cochlear implants, and profoundly deaf children. In E. Owens & D. Kessler (Eds.), Cochlear implants in young deaf children, Boston: College-Hill, 81-100.

Boothroyd, A., (1984). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Boothroyd, A., and Decker, M. (1972). Control of voice pitch by the deaf: An experiment using a visible Speech Device. Audiology, 11, 343-353.

Boothroyd, A., Springer, N., Smith, L., and Schulman, J. (1988). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Boothyord, A. (1978). Discussion Summary. Ross, M., and Giolas, T.G. (Eds). (1978). Auditory Management of Hearing-Impaired Children. University Park Press, Baltimore, 332.

Borden, G.S., and Harris, K.S. (1980). Speech Science Primer. Physiology, Acoustics, and Perception of speech. Baltimore, U.S.A.

Brannon, J.B. (1964). Visual feedback of glossal motions and its influence upon the speech of deaf children. Unpublished Ph.D. Dissertation, Northwestern University.

Brannon, J.B. (1966). The speech production and spoken language of the deaf, as cited in Ling, D. (1976) . Speech and the hearing impaired child: Theory and practice: First edition. The A.G. Bell Association for Deaf, Inc., Washington D.C.

Brehm, F.E. (1922). Speech correction. American Annals of the Deaf. In Nickerson, R.S. (1975), 67, 361-370.

Broad & Peterson (1971). The acoustics of speech. Travis (Ed.)(1971). Handbook of speech pathology and Audiology, Prentice Hall Inc: Englewood Cliffs, New Jersey.

Bush, N. (1981). Vowel articulation and Laryngeal control in the speech of the deaf. Unpublished doctoral dissertation. Massachusetts Institute of Technology, cited by Osberger,M.J. and McGarr, N.S. (1982).

Calvert, D.R. (1961). Some acoustic characteristics of the speech of profoundly deaf individuals. Ph.D., Thesis, Stanford University. As cited by Harris, K.S.,and McGarr, N.S. (1980).

Calvert, D.R. (1962). Speech sound duration and the consonant error. The Volta Review, 64, 401-403.

Campbell, M.I. (1980). Speaking fundamental frequency in three groups of hearing impaired individuals. Journal of communication disorders, 13, 195-205.

Carney, A.E. (1993). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Carney, A.E., Osberger, M.J., Miyamoto, R.T., Karasek, A., Dettman, D., and Johnson, D.L. (1991). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Chermak, G.D. (1981). Handbook of audiological rehabilitation. Illinois: Charles, C. Thomas, 9-7.

Colton, R.H., and Cooker, H.S. (1968). Perceived nasality in the Speech of the deaf. Journal of Speech and Hearing Research, 11, 553-559.

Cooper, M. (1976). cited in Nataraja, N.P., and Jagadish, A. (1984). Vowel duration and fundamental frequency. Journal of A.I.I.S.H., 15, 57-63.

Cowie, R.I.D., and Cowie, E.D. (1983). Speech production in profound post lingual deafness cited in M.E. Lutman, and M.P. Haggard (Eds.). Hearing Science and Hearing disorders. London: Academic Press, 183-231.

Davis, J.M., Elfenbein, J.L., Schum, R., and Bentler, R. (1986). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Delattre, P.C. (1955). Two acoustic correlates of Nasality studied by Synthesis. In Nickerson R.S., (1975). Paper presented at Modern language Association, Chicago.

Delattre, P.C, Liberman, A.M., Cooper, F.S., and Gerstman, L.J. (1952) . An experimental study of the acoustic determinants of vowel color. Word, 8, 195-210.

Denes, P. (1955) . Effectiveness of duration of the perception of voicing. Journal of Acoustical Society of America, 27, 769-773.

Di Simoni, F.G. (1974) . Effect of Vowel Environment on the Duration of Consonants in the Speech of three, six and nine-year old children. Journal of Acoustical Society of America, 55, 360-361.

Di Simoni, F.G. (1974b). Influence of Consonant Environment on Duration of Vowels in the Speech of three, six and nine-year old children. Journal of Acoustical Society of America, 55, 693-703.

Di Simoni, F.G. (1974c). Influence of Utterance length upon bilabial closure duration for /p/ in three, six and nine-year old children. Journal of Acoustical Society of America, 55, 1353-1354.

Eguchi, S., and Hirsh, I.J. (1969). Development of speech sound in children. Acta Otolaryngology, Supplement, 257.

Elizabeth, J.A. (1998). Analysis of Speech of Malayalam Speakers. Unpublished Master's dissertation, Mysore University, Mysore.

Elliot, L.L. (1967) . cited in Osberger, M.J. and McGarr,N.S. (1982) . Speech production characteristics of the hearing impaired. Status report on Speech research, Jan-March, Haskins Lab, New Havens, Conn., 227-290.

Engelberg, M. (1962). Correlation of Falsetto voice in a deaf adult. Journal of Speech and Hearing Disorders, 27, 162-164.

Erber, N.P. (1982). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Erber, N.P. and Allencewicz, C. (1976) . cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Ermovik, D.A. (1965). A spectrographic analysis for comparison of connected speech of deaf subjects and hearing subjects. Masters thesis, University of Kansas, as cited by Shukla, R.S. (1987).

Fairbanks, G. (1940). Recent experimental investigations of Vocal pitch in Speech. Journal of Acoustical Society of America, 11, 457-466.

Fairbanks, G. (1960). Voice and Articulation Drill Book, New York, Harper.

Fairbanks, G., and Grubb, P.A. (1961).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Fairbanks, G., Herbert, E.L., and Hammond, J.M. (1949). cited in Gilbert, H.R., and Campbell, M.I. (1980). Speaking fundamental frequency in three groups of hearing impaired individuals. Journal of Communication disorders, 13, 195-205.

Fairbanks,G., Wiley,J.H., and Lassman, F.M.(1949b). cited in Gilbert, H.R., and Campbell, M.I, (1980). Speaking fundamental frequency in three groups of hearing impaired individuals. Journal of Communication disorders, 13, 195-205.

Fant, G. (1960). Acoustic Theory of speech production, Mounton, The Hague.

Fant, G. (1973). Speech sounds and features, Cambridge, Massachusetts, MIT Press.

Fisher-Jorgenson, L. (19 64). Sound Duration and Place of Articulation. Zeitschrift for Phonetikeprachwissen Schaft and Kommunikation Storschung, 17, 175-207.

Forner, L., and Hixon, T.J. (1977). Respiratory Kinematics in profoundly hearing impaired speakers. Journal of Speech and Hearing Research, 66, 373-408.

Froechels, E. (1932). cited in, Osberger, M.J., and McGarr,N.S. (1982). Speech production characteristics of the hearing impaired. Status report on speech research, Jan-Mar., Haskins Lab, New Haver, Conn., 227-290 .

Fujimura, O. (1960). Spectra of Nasalized Vowels, Quarterly Program Report, Research Laboratory of Electronics, MIT, 214-218.

Geffner, D. (1980) . Feature characteristics of spontaneous speech production in young deaf children. Journal of communication Disorder, 13, 443-454.

Gilbert, H.R. (1975). Simultaneous Oral and Nasal Airflow during stop consonant production by hearing impaired speakers, Folia Phoniatrica, 27, 423-437.

Gilbert, H.R., & Cambell, M.I. (1978). Voice onset time in speech of hearing impaired individual. Folia Phonetic, 30, 67-81.

Gold, T. (1980). Speech production in hearing impaired children. Journal of Communication Disorders, 13,397-418.

Gold. T. (1978). Speech and Hearing skills: A comparison between hard-of-hearing and deaf children. Unpublished Doctoral Dissertation, City University, New York.

Gopal, H.S. (1980). Relationship for locating optimum frequency in the age range of 7 to 25 years. Unpublished Master's dissertation, Mysore University, Mysore.

Green, D.S. (1956). Fundamental frequency of the speech of profoundly deaf individuals. Unpublished doctoral dissertation, Purdue University, cited.

Green, D.S., (1956). A comparison between vocal characteristics of deaf and normal hearing individuals. Unpublished Doctoral dissertation, University of Kansas.

Gruenewald, B.E. (1966). A comparison between vocal characteristics of deaf and normal hearing individuals. Unpublished Doctoral Dissertation, University of Kansas.

Gruenewald, B.E. (1966). cited in Gibert, H.R., and Campbell, M.I. (1980). Speaking fundamental frequency in three groups of hearing impaired individuals. Journal of Communication Disorders, 13, 195-205.

Haggard, B. (1981). cited in Ohde, R.N. (1985). Fundamental frequency correlates of stop consonant voicing and vowel quality in the speech of preadolescent children. Journal of Acoustical Society of America, 78(5), 1554-1561.

Halle, M. and Stevens, K.N. (1971). cited in Klatt, D.H. (1975). Voice Onset Time, Frication and Aspiration in word-initial stop consonant clusters, Journal of Speech and Hearing Research, 18, 686-706.

Hallien, H., and Paul, P. (1969). cited in Gilbert, H.R., and Campbell, M.I. (1980). Speaking fundamental frequency in three groups of hearing impaired individuals. Journal of Communication disorders, 13, 195-205.

Hasek, C, Singh, S., and Murray, T. (1981). cited in Osberger, M.J., and McGarr,N.S. (1982). Speech production characteristics of the hearing impaired, Jan-March, Haskins Lab, New Haver, Conn. 227-290.

Heidinger, V.A. (1972). An explanatory study of procedures for improving temporal patterns in the speech of the deaf children. Unpublished doctoral dissertation, teachers college, Columbia University, as cited by Ling, D. (1976) .

Holbrook, A., and Crawford, G.H. (1970). cited in Nickerson, R.S. (1975). Characteristics of the speech of Deaf Persons. The Volta Review, 77, 342-362.

Homma (1981). Durational relationships between Japanese stops and vowels. Journal of phonetics, *9,* 273-281.

Honda, H. (1981). cited in Osberger, M.J., and McGarr,N.S. (1982) . Speech production characteristics of the hearing impaired, Jan-Mar., Haskins Lab, New Hover, Conn. 227-290.

Hood, R.B. (1966) . Some physical concomitants of the perception of Speech rhythm of the deaf: Ph.D. thesis, Stanford University, as cited in Nickerson, R.S. (1975) .

House, A. & Fairbanks, G. (1953). The influence of consonant environment upon the secondary acoustical characteristics of vowels. Journal of Acoustical Society of America, 25, 105-113.

House, A.S. (1961) . On vowel durations in English. Journal on Acoustical Society of America, 33, 1174-1175) .

Hudgins, C. V., and Numbers, F.C. (1942) . An investigation of the intelligibility of the speech of Deaf and Normal Subjects. Genetic Psychology Monograph, 25, 289-392.

Hudgins, C.V. (1934). A comparative study of the Speech Coordination of Deaf and Normal Subjects. Journal of Genetic Psychology, 54, 3 (as mentioned in Nickerson, 1975) .

Hudgins, C.V. (1934). cited in Leper, H.A., Perez, D.M., and Mencke, E.O., (1987). Influence of utterance length upon temporal measures of syllable production by selected hearing impaired children. Folio Phoniatrica, 39, 230-243.

Hudgins, C.V. (1937) . cited in Gold, T. (1980) . Speech production in hearing impaired children. Journal and Communication disorders, 13, 397-418.

Hudgins, C.V. (1946) . cited in Gold, T. (1980) . Speech production in hearing impaired children. Journal of communication disorders, 13, 397-418.

Hudgins, C.V. (1949) . cited in Ling, D. (1976) . Speech and the hearing impaired child: Theory and practice. First edition. The A.G. Bell Association for the Deaf Inc: Washington, D.C., 11-19.

Hudgins, C.V. (1960). cited in Monsen, R.B (1983). The oral speech intelligibility of hearing impaired talkers. Journal of Speech and Hearing disorders, 48, 286-296.

Hudgins, C.V., and Numbers, F.C. (1992). cited in Kent, R.D., and Read, C. (1995). The Acoustic Analysis of Speech. Delhi, A.I.T.B.S.

Hudgins, C.V., and Stetson, R.H., (1937) . Relative speed of articulatory movements. Archieva ueerlandaises de phonetique experimentale, 13, 85-94. In supra-segmentals, Lehiste, I (Ed.), MIT Press: Massachusetts (1970) .

Huntington, D., Harris, K.S., & Sholes, G. (19 68) . An electromyographic study of consonant articulations in hearing - impaired and normal speakers. Journals of Speech and Hearing Research, 11, 147-158.

Jagadish (1989). Synthesis of Speech of the Hearing-Impaired. Masters Dissertation, University of Mysore.

Jayaprakash, E. (1998). Temporal and Acoustic Analysis of Speech of Kannada speaking, hearing-impaired children. Unpublished Master's dissertation, University of Mysore, Mysore.

Jensema, C.J., Karchmer, M.A. and Trybus, R.J. (1978). cited in Monsen, R.B (1983). The oral speech intelligibility of hearing impaired talkers. Journal of Speech and Hearing disorders, 48, 286-296.

Jensen, F., and Menon, K. (1972). Physical Analysis of Linguistic Vowel Duration. Journal of Acoustical Society of America, 52, 708-810.

Jerger, S., Stout, G., Kent, M., Albritton, E., Loiselle, L., Blonderay, R., and Jorgenson, S. (1993). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

John, J.D., and Howrath, N.J. (1865). The effect of time distortions on the intelligibility of deaf children's speech. Language and Speech, 8, 127-134, as cited by Osberger, M.J., and McGarr, N.S. (1982).

Jones, C. (1967) . Deaf Voice: A description derived from a survey of the literature. The Volta Review, 69, 507-508.

Joos, M. (1948).cited in Eguchi, S., and Hirsh, I.J., (1969) . Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Kanaka, G. (1998) . Acoustic Analysis of Speech of Tamil Speaking hearing impaired children. Unpublished Master's dissertation, University of Mysore.

Kent, and Read, (1994) . Acoustic Analysis of Speech. All India Travelling Booksellers Publisher, New Delhi.

Kent, R.D. (1976). Anatomical and Neuromuscular Maturation of the Speech Mechanism: Evidence from acoustic Studies. Journal of Speech and Hearing Research, 18, 421-447.

Kirikae, I. (1943). cited in Eguchi, S. and Hirsh, I.J. (1969). Development of Speech sounds in children. Acta Otolaryngology, supplement, 257, 5-48.

Klatt, D.H. (1973, b) . cited in Klatt, D.H. (1975) . Voice Onset Time, Frication, and Aspiration in word-initial consonant clusters. Journal of speech and hearing research, 18, 686-706.

Klatt, D.H. (1975). Voice onset time, frication and aspiration in word initial consonant clusters. Journal of Speech and Hearing Research, 18, 686-706.

Klatt, D.H. (1976). Linguistic uses of segmental duration of English: Acoustic and perceptual evidence. Journal of Acoustic Society of America, 54, 1203-1221.

Konefal, J.A., Folkes, J., & Bond, Z.S. (1982). Children's syntactic use of vowel duration. Journal of Phonetics, 10, 361-366.

Kushal Raj and Nataraja, N.P. (1984) . Voice Onset Time in Children. Journal of AIISH, XV, 29-37.

Lafon, J.C., Dulac, A.M. (1967). cited in Smith, C.R. (1875). Residual hearing and speech production in deaf children. Journal of Speech and Hearing Research, 18, 795-811.

Lass, N.J. (1982) . Speech and Language advances in basic research and practice, 8, 221-283.

Lea, W.A. (1973) . cited in Klatt, D.H. (1975) . Voice Onset Time, Frication and Aspiration in word-initial stop consonant clusters, Journal of Speech and Hearing Research, 18, 686-706.

Leeper, H.A., Perez, D.M., and Mencke, E.D. (1987). Influence of utterance length upon temporal measures of syllable production by selected hearing impaired children. Folia phoniatrical, 39, 230-243.

Leeper, H.A., Perez, D.M., and Mencke, E.D. (1987). The influence of utterance length upon bilabial closure duration of selected deaf children. Journal of Communication Disorders, 13, 373-383.

Lehiste, I. (1976). cited in Nataraja, N.P., and Jagadish, A. (1984). Vowel duration and fundamental frequency. Journal of A.I.I.S.H., 15, 57-63.

Lehiste, I., and Peterson, 6.E. (1961). cited in Klatt, D.H. (1975). Voice Onset Time, Frication and Aspiration in word-initial stop consonant clusters, Journal of Speech and Hearing Research, 18, 686-706.

Lenneberg, E.H., Rebelsky, F.G., and Nichols, I.A., (1965). In Fry, D.B. (1978) . Auditory channel in Speech and Language development. M. Ross and T.G. Giolas (Eds.) Auditory management of hearing impaired children: Principles and prerequisites for Intervention (15-43). Baltimore, University Park Press.

Lenneberg, F.H. (1966) . In Fry, D.B. (1978) . Auditory channel in Speech and Language development. M. Ross and

T.G. Giolas (Eds.) Auditory management of hearing impaired children: Principles and prerequisites for intervention (15-43). Baltimore, University Park Press.

Levitt, H. (1971). cited in Leeper, H.A., Periz, D.M. and Mencke, E.O., (1987). Influence of utterance length upon temporal measures of syllable production by selected hearing impaired children. Folia Phoniatrica, 39, 230-243.

Levitt, H. (1978). The Acoustics of Speech Production. Auditory management of Hearing Impaired Children, (Eds.) T. Giolas and M. Ross, Baltimore, University Park Press, 45-115.

Levitt, H. (1979). cited in Osberger, M.J., and McGarr, N.S. (1982). Speech production characteristics of the hearing impaired. Status Report of Speech Research, Jan-Mar., Haskins Lab, New Haver, Conn., 227-290.

Levitt, H. and Nye, P. (1972). In Levitt, H., Smith, C.R., and Stromberg, H. (1974). Speech Communication Seminar. Fant,G.(Ed.) Speech communication: Proceedings of the speech communication seminars (129-139). Stockholm, Vol. 4, Stockholm, Almquist and Wiksell International.

Levitt, H., and Smith, C.R. (1974). In sensory capability of hearing impaired children. (Ed.) R.E. Stark, University Park Press.

Levitt, H., Smith C.R., and Stromberg, H. (1976). Acoustic, articulatory and perceptual characteristics of the speech of the deaf children. In Fant, G. (Ed.) Speech Communication. Proceeding of the speech communication seminar. Stockholm, Vol. 4, Stockholm, Almquist and Wiksell International, 121-139.

Levitt, H., Stromberg, H., Smith, C, and Gold, T. (1980) . cited in Osberger, M.J. and McGarr, N.S. (1982).Speech production characteristics of the hearing impaired. Status reports on speech research, Jan-Mar. Haskins Lab, New Haver, Conn. 227-290.

Liberman, A., Delattre, P., Gerstman, L., and Cooper, F. (1956) . Tempo of frequency change as a cue for distinguishing classes of speech sounds. Journal of Experimental Psychology, 52, 127-137.

Lindblom, B. (1968). Temporal Organization of Syllable production. Speech transmission laboratory, R. Inst. Technol., 0. Progress Stat. Rep. Stockholm, Sweden.

Ling, D. (1976). Speech and the hearing impaired child: Theory and Practices. First edition. The A.G. Bell Association for the Deaf Inc. Washington, D.C.

Lisker, L. (1957).cited in Klatt, D.H. (1975). Voice Onset Time, Frication, and Aspiration in word-initial consonant clusters. Journal of speech and hearing research, 18, 686-706.

Lisker, L. (1969) .cited in Klatt, D.H. (1975). Voice Onset Time, Frication, and Aspiration in word-initial consonant clusters. Journal of speech and hearing research, 18, 686-706.

Lisker, L., and Abramson, A. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. Word, 20, 384-422.

Lisker, L., and Abramson, A.S. (1967). Some effects of context on voice onset time in English stops. Language and Speech, 19, 1-28.

Lubker, J.F., and Moll, K.L. (1965). cited in Nickerson, R.S. (1975). Characteristics of the speech of Deaf Persons. The Volta Review, 77, 342-362.

Luterman, D., and Ross, M. (1991). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Lyberg, B. (1981). Some observation on the vowel duration and the fundamental contour in Swedish utterance. Journal of Phonetics, 9, 261-273.

Mahshie, J., (1980). Laryngeal Behaviour in Hearing-Impaired Speakers. Unpublished Doctoral Dissertation, Syracuse University.

Markides, A. (1970). The speech of deaf and partially hearing children with special reference to factors affecting intelligibility. British Journal of Communication Disorders, 5, 126-140.

Martony, J. (1965). Studies on speech of the deaf. Quarterly progress and status report. Stockholm: Speech Transmission Laboratory, Royal Institute of Technology, 16-24.

Martony, J. (1966). cited in Nickerson, R.S. (1975). Characteristics of the Speech of deaf persons. The Volta Review, 77, 342-362.

Martony, J. (1966). cited in Osberger, M.J. and McGarr, N.S. (1982). Speech production characteristics of the hearing impaired, Jan-Mar., Haskins Lab, New Haver, Conn. 227-290.

Martony, J. (1968) . One the correction of the voice pitch level for severely hard of hearing subjects. American Annals of the Deaf, 113, 195-202.

McClumpha, S.H. (1966). Cineflourographic Investigation of Velopharyngeal function in selected deaf speakers. Unpublished master's dissertation, Gainesville (as quoted by Gilbert, H.R. and Campbell, M.I., 1978).

McGarr, N.S. (1978). Differences between experienced and inexperienced listeners in understanding the speech of the deaf. Unpublished Ph.D., thesis, City University of New York (as mentioned by Geffner, D. 1980) .

McGarr, N.S. (1981) . The effect of context on the intelligibility of hearing and deaf children's speech. Language and Speech, 24,255-264.

McGarr, N.S., and Harris, K.S. (1980). Articulatory Control in a Deaf Speaker. Haskins Laboratories Status Report on Speech Research, SR-63/64, 309-332.

McGarr, N.S., and Osberger, M.J. (1978). Pitch deviancy and intelligibility of deaf speech. Journal of Communication Disorder, 11, 837-847.

Meckfeasel, A.L. (1964). A comparison between vocal characteristics of deaf and normal hearing individuals. Cited by Gilbert, H.R. and Campbell, M.J. Speaking fundamental frequency in three groups of hearing impaired individuals. Journals of communication disorders, 1980, 13, 195-205.

Metz, D.E., Samar, V.J., Schiavetee, N., Sitler, R.W., Whitehead, R.L. (1985). Acoustic dimensions of hearing impaired speaker's intelligibility. Journal of Speech and Hearing Research, 28, 3, 343-354.

Metz, D.E.# Schiavetti, N., Sitler, R.W., Samar, V. (1990). The speech production characteristics of hearing impaired speakers. The Volta Review, 92, 5, 223-236.

Metz, D.E., Whitehead, R.L., Mahshie, J.J. (1982). Physiological correlates of the speech of the deaf. A preliminary view. In Sims, D.S., Walter, G.G., Whitehead, R.L. (Eds.). Deafness and Communications: Assessment and Training *1st* Edition, Baltimore Williams and Wilkins, 75-89.

Miller,M.A. (1968) . Speech and voice patterns associated with hearing-impairment. Audecibel, 17, 162-167.

Monsen, R.B. (1976a). The production of English stops consonants in the speech of deaf children. Journal of phonetics, 4, 29-42 (b).

Monsen, R.B. (1976b). A taxonomic study of diphthong production in the speech of deaf children. In Hirsh, S.K., Eldrededge, D.H., Hirsh, I.J., and Silverman, S.R. Hearing and Davis: Essay Honoring Hollowell Davis, Washington University Press: St. Louis, Missouri.

Monsen, R.B. (1976d). Second formant transitions of selected consonant-vowel combinations in the speech of deaf and normal-hearing children. Journal of Speech and Hearing Research, 19, 279-289.

Monsen, R.B. (1978) . Toward measuring how well hearing-impaired children speak. Journal of Speech and hearing Research, 19, 279-289.

Monsen, R.B. (1983). The oral speech intelligibility of hearing-impaired talker. Journal of Speech and Hearing Disorder, 48, 286-296.

Monsen, R.B., Engebretson, A.M., and Vemula, N.R. (1979). Some effects of Deafness on the Generation of Voice. Journal of Acoustical Society of America, 66, 1680-1690 .

Monsen, R.B., Engerbretson, A.M., and Vemula, N.R. (1979). Some effects of deafness on the generation of voice. Journal of Acoustical Society of America, 66, 1680-1690.

Monsen, R.B. (1974). Durational aspects of vowel production in the speech of deaf children. Journal of Speech and Hearing Research, 17, 386-398.

Montgomery, G.W.G. (1967). Analysis of pure tone audiometric responses in relation to speech development in profound deaf. Journal of Acoustical Society of America, 41, 53-59.

Montgomery, G.W.G. (1967). cited in Osberger, M.J. and McGarr, N.S. (1982). Speech production characteristics of the hearing impaired. Status report on Speech research, Jan-March, Haskins Lab, New Havens, Conn., 227-290.

Naider, V.J. (1965). cited in Eguchi, S., and Hirsh, I.J. (1969). Development of Speech sounds in children Acta Otolaryngology, Supplement, 257, 5-48.

Nandayal, I. (1981). Comparison of Intonation Patterns of Normal Hearing and Hearing-Impaired subjects. Unpublished independent project, University of Mysore, Mysore.

Nataraja, N.P., and Jagadish, A. (1984). Vowel duration and fundamental frequency. Journal of All India Institute of Speech & Hearing, 15, 57-63.

Nataraja, N.P., and Rohini, S. (1992). Spectral analysis of the speech of hearing impaired. An unpublished research work conducted at AIISH, Mysore

Nataraja, N.P., Savithri, S.R., Venkatesh, C.S. (1993). Speech Oriented Learning System for the Hearing Handicapped, SOLSH - A report unpublished project report.

Negus, V.E. (1949). cited in Eguchi, S., and Hirsh, I.J. (1969). Development of Speech sounds in children Acta Otolaryngology, Supplement, 257, 5-48.

Nickerson, R.S. (1975) . Characteristics of the Speech of Deaf persons. The Volta Review, 77, 342-362.

Nickerson, R.S., and Stevens, K.N. (1973). cited in Nicerkson, R.S. (1975). Characteristics of the Speech of Deaf persons. The Volta Review, 77, 342-362.

Nickerson, R.S., Stevens, K.N., Boothroyd, A., and Rollins, A. (1974). Some observations on timing in the speech of Deaf and Hearing Speakers, BBN Report No. 2905, Cambridge, MA.

Nober, E.H. (1967). Articulation of the deaf. Exceptional Child, 33, 611-621 as cited by Ling, D. (1976).

Nooteboom, S.G. (1972). cited in Nataraja, N.P., and Jagadish, A. (1984) . Vowel duration and fundamental frequency. Journal of A.I.I.S.H., 15, 57-63.

Northern J.L., and Downs M.P. (1978). Hearing in Children.

O' Shoughnessy, D. (1981). French vowel and consonant durations. Journal of Phonetics, 9, 385-406.

Ohde, R.N. (1985). Fundamental frequency correlates of stop consonant voicing and vowel quality in the speech of preadolescent children. Journal of Acoustical Society of America, 78, 5, 1554-1561.

Okamura, M. (1966).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Oiler, D.K., and Eillers, R.E. (1988). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Oiler, D.K., and Kelly, C. A. (1974). Phonological substitutions of a hard of hearing child. Journal of Speech and Hearing disorders, 39, 65-74.

Osberger, M.J. (1978) . The effects of timing errors in the intelligibility of deaf children's speech. Unpublished Doctoral dissertation, University of New York.

Osberger, M.J., and Levitt, H. (1979). The effect of timing errors on the intelligibility of deaf children's speech. Journal of Acoustical Society of America, 66, 1316-1324.

Osberger, M.J., and McGarr, N.S. (1982). Speech Production Characteristics of the Hearing-impaired. Status report on speech research, Jan-Mar. Haskins Laboratories, New Haven, Conn., 227-290.

Osberger, M.J., and McGarr, N.S. (1982). Speech Production Characteristics of the Hearing-Impaired. Speech and Language Advances in Basic Research and Practice, 8, 221-283.

Parkhurst, B., and Levitt, H. (1978). The effect of selected prosodic errors on the intelligibility of deaf speech. Journal of Communication Disorders, 11, 249-256.

Peterson, G.E. (1946). cited in Nickerson, R.H. (1975). Characteristics of the Speech of Deaf persons. The Volta Review, 77, 342-362.

Peterson, G.E. (1951).cited in Eguchi, S., and Hirsh, I.J., (1969) . Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Peterson, G.E. (1959).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Peterson, G.E., and Barney, H.L. (1952). Control Methods used in a study of the vowels. Journal of Acoustical Society of America, 24, 175-184.

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

Philips, E.A., Rebillard, A.T., Bass, H., and Pronovost, W. (1968). Teaching Intonation to the deaf by visual pattern matching. American Annals of the Deaf, 113, 239-246.

Pickett, J.M. (1968). Sound patterns of Speech: An introductory sketch. American Annals of the Deaf, 113, 239-246.

Pickett, J.M. (1971). cited in Nickerson, R.S. (1975). Characteristics of the speech of Deaf persons. The Volta Review, 77, 342-362.

Pinto, O.D. and Hollien, H. (1982). Speaking fundamental frequency characteristics of Australian Women: Then and now. Journal of Phonetics, 10, 367-375.

Pollack, D. (1981) . Acoupedics; An approach to early management. In Mencher, G.I., And Gerber, S.E. (Ed.) Early Management of hearing loss. 1st Edition, New York, Grune and Stratton, 301-318.

Poonam, G. (1998). Acoustic analysis of speech of Punjabi Speaking hearing impaired children. Unpublished Master's dissertation, University of Mysore, Mysore.

Potter, R.K. and Steinberg, J.L. (1950).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Potter, R.K., and Peterson, G.E. (1948).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Potter, R.K., Kopp, G.A., and Green, H.C. (1947).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otolaryngology, Supplement, 257, 5-48.

Pressman, J.J. (1942) . cited in Eguchi, S. and Hirsh, I.J. (1969). Development of Speech sounds in children. Acta Otolaryngology, supplement, 257, 5-48.

Priya, P. (1998) . Acoustic analysis of speaking of Malayalam speaking hearing impaired children. Unpublished Master's dissertation, University of Mysore, Mysore.

Pronovost, W. (1967). cited in Nickerson, R.S. (1975). Characteristics of the Speech of Deaf Persons. The Volta Review, 77, 342-362.

Quigley S.P. (1978). Effects of early hearing impairment on normal language development. In Martin, F.N. (Ed.) Paediatric Audiology, Prentice Hall Inc.: Englewood Cliffs, New Jersey.

Quigley, L.F., Shier, F.R., Webster, R.C., and Cobb, CM. (1964) . Measuring Palatopharyngeal Competence with the Nasal Anemometer. Cleft Palate Journal, 1, 304-313.

Rahul (1997). Acoustic Transformation of Speech and Hearing-Impaired. Unpublished Masters dissertation, University of Mysore.

Rajesha, H. (1998). Analysis of Prosodic Aspects of Kannada in hearing impaired children. Unpublished Master's dissertation, Mysore University, Mysore.

Rajnikanth (1986) . Acoustic analysis of speech of the Hearing-Impaired. Unpublished Master's Dissertation. University of Mysore.

Raphael, L.J. (1972) . Preceding vowel duration as a cue to the perception of the voicing characteristics of word-final consonants in American English. Journal of Acoustical Society of America, 51, 1296-1303.

Raphael, L.J., (1971). Preceding vowel duration as a cue to the perception of the voicing characteristics of word-final consonants in American English. Journal of Acoustical Society of America, 51, 1972-1303.

Rashmi (1985) . Acoustic aspects of the Speech of children. Unpublished Master's dissertation, University of Mysore, Mysore.

Rasitha (1994). Analysis and Synthesis of Speech of Hearing-Impaired. Unpublished Master's dissertation, University of Mysore.

Rathna, K. (1998) . Temporal and Acoustic Analysis of Speech of Telugu in Hearing impaired children. Unpublished Master's dissertation, Mysore University, Mysore.

Ravishankar, K.C. (1985) . An examination of the relationship between speech intelligibility of the hearing impaired on receptive and productive variables. Unpublished doctoral thesis, University of Mysore, Mysore.

Rawlings, C.G. (1935) . A comparative of the movements of the breathing muscles in speech and in quiet breathing of deaf and normal subjects. American annals of the Deaf, 80, 147-156.

Rawlings, C.G. (1936).cited in Nickerson, R.S. (1975). Characteristics of the Speech of deaf persons. The Volta Review, 77, 342-362.

Reichstein, J., and Weisel A. (1986). Hearing Thresholds as predictors of speech production performance. Scandinavian Audiology, 15, 22, 223-229.

Reilly, A.P. (1979). Syllabic nucleus duration in the speech of hearing and deaf children. Unpublished doctoral dissertation. The City University, New York.

Robbins, A.M., Renshaw, J.J.# and Berry, S.W. (1991). cited in Carney, A.E., and Moeller, M.P. (1998). Treatment Efficacy: hearing loss in children, Journal of Speech and Hearing Research, 41, 361-384.

Roopa, J. (1998) . Analysis of Prosody of Punjabi in deaf children. Unpublished Master's dissertation, Mysore University, Mysore.

Rosen, M. (1962). cited in Ling, D. (1976). Speech and the hearing impaired child: Theory and practice first edition. The A.G. Bell Association for the Deaf Inc: Washington D.C., 11-19.

Ross, M., and Giolas, T.G. (1978) . Auditory management of hearing-impaired children. University Park Press, 1-14.

Rothman, H.B. (1977) . An electromyographic investigation of articulation and phonation patterns in the speech of deaf adults. Journal of Phonetics, 5, 369-376.

Rothmans, H.B. (1987). An electromyographic investigation of articulation and phonation patterns in the speech of deaf adults. Journal of Phonetics, 5, 369-376.

Samuel, G. (1973) . Study of the fundamental frequency of voice and natural frequency of vocal tracts on an Indian population of different age ranges, Master's dissertation, University of Mysore.

Savithri, S.R. (1984). Primary effort and quality: An experimental verification. Unpublished doctoral dissertation, University of Mysore, Mysore.

Savitri, and Sridevi, N. (1990). Perception and production of voicing in children from five to eight years. An unpublished Research work conducted at AIISH.

Schwartz, M.F. (1969). Influence of Vowel Environment upon the duration of *Isi* and / /. Journal of the Acoustical Society of America, 46, 480-481.

Seaver, E.J., Andrews, J.R., and Granata, J.J. (1980). A radiographic investigation on velar positioning in Hearing-impaired young adults". Journal of Communication disorders, 13, 239-247.

Sharf, D., and Hemeyer, T. (1972). cited in Monsen, R.B. (1976) . Second formant transitions of selected consonant-vowel combination in the speech of deaf and normal hearing children. Journal of Speech and Hearing Research, 19, 267-278.

Sheela, (1988) . Analysis and synthesis of speech and hearing impaired. Unpublished Master's Dissertation. University of Mysore, Mysore.

Shelton, R.L., Knox, A.W., Arndt, W.B., and Elbert, M. (1967). cited in Nickerson, R.S. (1975). Characteristics of the speech of Deaf Persons. The Volta Review, 77, 342-362.

Shukla, R.S. (1987). Objective measurement of the speech of the hearing impaired. Unpublished Doctoral Thesis, University of Mysore, Mysore.

Shultz, A.R. (1964) . cited in Ling, D. (1976) . Speech and the hearing impaired child: Theory and practice first edition. The A.G. Bell Association for the Deaf Inc: Washington D.C., 11-19.

Silverman, R.S. (1984) . cited in Ohde, R.N. (1985) . Fundamental frequency correlates of stop consonant voicing and vowel quality in the speech of preadolescent children. Journal of Acoustical Society of America, 78(5), 1554-1561.

Smith, B.L. (1978). Temporal Aspects of English Speech Production. A developmental Perspective. Journal of Phonetics, 6, 37-67.

Smith, C.R. (1972). Residual hearing and speech production in deaf children. Unpublished Ph.D., dissertation, City University of New York, as cited by Ling, D. (1976) .

Smith, C.R. (1975). Residual hearing and speech production in deaf children. Journal of Speech and Hearing Research, 18, 795-811.

Stark, R.E. (1979). Speech of the hearing impaired child. In Bradford, L.J., and Hardy, W.G. Hearing and Hearing impaired. 1st Edition, New York: Grune and Stratton, 229-248.

Stein (1980) . A study of articulatory characteristics of deaf talkers. Unpublished Doctoral Dissertation, University of Iowa.

Stetson, R.H. (1928). Cited in Kent, R.D., & Read, C. (1995) . The Acoustic Analysis of Speech. Delhi, A.I.T.B.S., Publishers & Distributors.

Steven, K. (1983). cited in Kent, R.D. & Read, C. (1995). The Acoustic Analysis of Speech, Delhi, A.I.T.B.S.

Stevens, K., Nickerson, R., Boothroyd, A., and Rollins, A. (1976). Assessment of Nasalization in the speech of deaf children. Journal of speech and hearing research, 19, 393-416.

Stevens, K.N. and House, A.S. (1955).cited in Eguchi, S., and Hirsh, I.J., (1969) . Development of Speech Sounds in Children. Acta Otoiaryngology, Supplement, 257, 5-48.

Stevens, K.N. and House, A.S. (1961).cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otoiaryngology, Supplement, 257, 5-48.

Stevens, K.N., and House, A.S. (1963). cited in Eguchi, S., and Hirsh, I.J., (1969). Development of Speech Sounds in Children. Acta Otoiaryngology, Supplement, 257, 5-48.

Stevens, K.N., Kalikow, D.M., and Willemain, T.R. (1974). cited in Nickerson, R.S. (1975). Characteristics of the speech of Deaf Persons. The Volta Review, 77, 342-362.

Stevens, K.N., Nickerson, R.S., and Rollins, A.M. (1978), cited in Osberger, M.J., and McGarr, N.S. (1982). Speech production characteristics of the hearing impaired. Status Report of Speech Research, Jan-Mar., Haskins Lab, New Haver, Conn., 227-290.

Stevens, K.N., Nickerson, R.S., Boothroyd, A., and Rollins, A. (1974). Assessment of Nasality in the Speech of Deaf Children, BBN Report No. 2902.

Stevens, S.S., and Warshofsky,(1971). Sound and Hearing, Time Life Books, New York, 145-154.

Stoel-Gammon, C. (1982). The acquisition of segmental phonology by normal hearing and hearing impaired children. In I. Hochberg, H. Levitt, and H.J. Osberger (Eds.). Speech of the hearing impaired: Research training and personnel preparation. Baltimore, Maryland: Univ. Park Press.

Subtelny, J.D. (1975). cited in Osberger, M.J. and McGarr,N.S. (1982) . Speech production characteristics of the hearing impaired. Status report on Speech research, Jan-Mar, Haskins Lab, New Haver, Conn. 227-290.

Subtelny, J.V., Worth, J.H., and Sakuda, M. (1966) . Intra-oral pressure and rate of flow during speech. Journal of Speech and Hearing Research, 9, 498-518.

Sussman and Hernandez (1979). A spectrographic analysis of the supra segmental aspects of the speech of the hearing-impaired adolescents. Audiology, Hearing and Education, 5, 12-16.

Sykes, J.L. (1940). A study of the spontaneous vocalizations of young deaf children. Psychological Monograph, 1940, 52, 104-123.

Thomas, W.G. (1964) . cited in Ling, D. (1976) . Speech and the hearing impaired child: Theory and practice. First edition. The A.G. Bell Association for the Deaf Inc: Washington, D.C., 11-19.

Thomas, W.G. (1964). Intelligibility of the speech of deaf children Proc. Int. Congr. On Education of the deaf. Washington, D.C.: U.S. Govt. Printing Office, 245-261, as cited by Ling, D. (1976) .

Thornton, A. (1964). A spectrographic comparison of connected speech of deaf subjects and hearing subjects. Unpublished Master's thesis, Lawrence (as quoted by Gilbert, H.R., 1978).

Till and Striveks (1981). Instrumentation and Validity for direct-readout voice onset time measurement. Journal of Communication Disorders, 14, 507-512.

Umeda, N. (1975). Vowel duration in American English. Journal of the Acoustical Society of America, 58, 434-445.

Umeda, N. (1981) . cited in Ohde, R.N. (1985) . Fundamental frequency correlates of stop consonant voicing and vowel quality in the speech of preadolescent children. Journal of Acoustical Society of America, 78(5), 1554-1561.

Vasantha, D. (1995). Phonological space for vowel production in Telugu Deaf Children: A spectrographic study. Journal of Acoustical Society of India, 23, 36-47.

Voelkar, C.H. (1935). A preliminary stroboscopic study of the speech of the deaf. American Annals of the deaf, 80, 243-259.

Voelker, C.H. (1938)1 study of the comparative rate of utterance of deaf and normal hearing speakers. American Annals of the Deaf, 38, 274-284.

Wang, E. (1981). Personal Communications, cited in Nataraja, N.P., and Jagadish, A. (1984). Vowel duration and fundamental frequency. Journal of A.I.I.S.H., 15, 57-63 .

Weisel, A.# and Reichstein, J. (1986). Hearing thresholds as predictors of speech production performance Scandinavian Audiology, 15, 223-226.

Whetnall, E., and Fry, D.B. (1964) . The deaf child. 1st Edition, London: William Heinemann Medical Books Limited.

Whitehead, R. (1982). Some Respiratory and Aerodynamic patterns in the speech of the Hearing Impaired, in I. Hochberg, H. Levitt and M.J. Osberger (Eds.), speech of the hearing impaired: Research, Training and Personal preparation, Baltimore, Maryland, USA, 371-912.

Whitehead, R.L., and Jones, K.D. (1978). The effect of vowel environment on duration of consonants produced by normals, hearing - impaired and deaf adult speakers. Journal of Phonetics, 6, 77-81.

Whitehead, R.L., and Jones, K.O., (1976). Influence of Consonant Environment on duration of vowels produced by normal hearing, hearing impaired and adult deaf speakers. Journal of the Acoustical Society of America, 60, 513-515.

Whitehead, R.L., and Maki, J.E. (1977). Fundamental vocal frequency characteristics of the Adult Hearing impaired. Asha, Chicago cited in Monsen, R.B. (1979b).

Willemain, T.R., and Lee, F.F. (1971). Tactile pitch feedback for deaf speakers. The Volta Review, 73, 541-554.

Wintiz, H., La Riviere, C. (1975). Variations in VOT for English initial stops, Journal of Phonetics, 3, 41-52.

Wood (1971). Terminology and nomenclature. Travis (Ed). Hand book of Speech Pathology and Audiology, Prentice Hall, Inc. Englewood Cliffs, NJ.

Zimmerman, G. and Rettaliata, P. (1981). Articulatory patterns of an adventitiously deaf speaker: Implications for the role of auditory information in speech production. Journal of Speech and Hearing Research, 24, 169-178.

APPENDIX

The following comprised of the list of words used in the study:

/ɔ/	-	/ɔṇo/
/a:/	-	/a:t̪a:/
/i/	-	/itʃa:/
/i:/	-	/i:ʃa:/
/u/	-	/utʃu/
/u:/	-	/u:ʃa:/
/e/	-	/eʃo/
/o/	-	/oṭo/