TRANSFORMATION OF SPEECH OF THE HEARING IMPAIRED

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CERTIFICATE

'This is to certify that the dissertation entitled Transformation of ***Speech of the Rearing impaired*** *is a bonafide work done in part fulfillment for the degree of Master of Science (Speecb and Hearing) of the student with Reg. No. M.9513*

Mysore
May 1997

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This is to certify that the 'Dissertation entitled transformation of Speech of the Hearing impaired has been prepared under my supervision and guidance.

Mysore
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DECLARATION

I hereby declare that the dissertation entitled Transformation of Speech of the Hearing impaired is the result of my own study under the guidance of Dr. N.P.Nataraja, Professor and Head, 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.

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INTRODUCTION

Communication is fundamental to human society as the very existence of the human society is largely dependent upon effective communication . The communication ability of humans are highly developed and this has been a big leap from those of his nearest neighbours on the evolutionary scale . Such enhanced communication abilities are through the medium of "speech" , which is an ability exclusive to humans .

The importance of speech in society need not be emphasized . The dependence upon speech for communication is so high , that efforts are on in full swing , to make speech , a medium of communication even between men and machines . However , such frequent and easy use of speech often makes people to give only a trivial thought about the complexities that go into the production of speech .

Speech arises out of controlled and coordinated activity over several muscles . The cognitive process and the sensory - motor activity occurring in the brain, which lead to speech are even more complex. An infant acquires speech as he grows, refining it from a gross to very fine and accurate productions Children learn to speak by hearing others around them speak. Disorders of speech may thus arise as a result of inability to hear in infancy .

The fact that there are over 3 million hearing impaired children in India, makes it a very important task to study the effect of hearing impairment on speech abilities and to determine ways and means of correcting the problem. Rehabilitation of the hearing impaired will be successful only if their speech abilities can be corrected, since this enables them to interact with their community.

Speech correction in the hearing impaired has long been under study throughout the world. In fact, attempts to teach speech to the hearing impaired span several centuries. Yet, the competence of the hearing impaired to make himself understood remains to be poor (Ling , 1976) . Only about 20 % of the speech of the hearing impaired may be understood by the person on the street (Gold, 1980). Such results have made it evident that speech may not be a viable communication medium for the hearing-impaired leading to frustrations and unrewarding experiences to them (Smith, 1975)

Research to determine the factors responsible for poor intelligibility of speech in the hearing-impaired is not new. Several efforts have been made to determine the most important factors, the correction of which would improve intelligibility (Krunger et al 1972, Lang 1975; Bernstein 1975; Maassen and Povel 1985 ; and several others). In comparison to the older studies which were mainly correlation studies , the recent studies tend to be more of those which use computer svnthesis to determine the role of certain factors in speech intelligibility .

Use of speech synthesis is a major development in speech sciences and offers several advantages over the traditional correlational studies. (Dorman and Harnley 1985) , primarily the fact that it offers the researcher complete control over the speech stimulus. One may vary a specific parameter to the desired level , without modifying any other parameter. On the other hand, in natural speech it is almost impossible to vary only one parameter without affecting any other .

The importance of studies of speech correction of the hearing impaired , using speech synthesis , lies in the fact that they may be able to indicate which factors in speech contribute most to intelligibility. Once identified , these factors maybe given special focus during therapy for speech correction in the hearing impaired

In India , such studies have been carried out by Sheela (1988) and Jagdish (1989) in Kannada and by Rasitha (1994) in Malayalam .

Aims of the present study :

This study aims to study the following hypothesis :

1 . There is no significant difference in the speech of hearing impaired and that of age and sex matched normal hearing speakers in terms of :

a) Fundamental frequency

b) Vowel duration

c) Formant frequencies (F1 , F2 and F3)

2 . There is no significant difference in the intelligibility of speech of the hearing impaired and that of the same utterance when it is corrected in terms of

a) Vowel duration

b) Fundamental frequency

c) Vowel duration and fundamental frequency , together

to approximate the values of the age and sex matched normal hearing speakers.

Purpose of The Study

This study has been proposed to determine the role of vowel duration, and fundamental frequency of speech, alone and in combination, on the speech of the hearing impaired . Besides giving a better understanding of how intelligibility of speech in the hearing impaired varies from that of the normal hearing speakers, this study is expected to help in giving direction to speech therapy aimed at improving intelligibility of speech of the hearing impaired . By determining the individual contribution of vowel duration and fundamental frequency of speech, alone, and in combination, it would be possible to know the role of each parameter for the intelligibility of speech. These parameters may then be focused for correction in speech therapy , thereby improving the intelligibility of speech of the hearing impaired .

REVIEW OF LITERATURE

Communication, as it is in today's world, makes the human race different from animals. The bulk of communication, around the world uses speech. Speech is the most efficient medium of communication known to man ; so much so, that efforts are on to make speech as a medium of communication even between men and machines.

Speech is an integrated function involving the reception of words by the ear or the eye , their interpretation and synthesis as language within the brain and the expression of this language response as further spoken or written words. It includes the whole of this receptive, formative and expressive activity. Words are composed of sequences of sounds. They are symbolic and have a consistent range of meaning (Morley, 1972). "Speech and language are normally and usually effortlessly developed through the auditory mode". (Ross and Giolas, 1978).

The normal hearing child is continuously exposed to sounds from birth or even before birth. It is through this continuous auditory stimulation that a normal child attains speech. The task is however very difficult for a child 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).

Hearing is essential for the seemingly natural development of speech and language, and communication is interfered with by the presence of a hearing loss (Stark, 1979)The oral communication skills of the hearing - impaired children have long been of concern to educators of the hearing - impaired, speech pathologist and audiologists, because the adequacy of such skills can influence the social, educational and career opportunities available to these individuals (Osberger and McGarr, 1982).

The ultimate goal in aural rehabilitation for the hearing - impaired individual, is to attain, as far as possible, the same communication skills as those of the normal hearing individuals. The poor oral communication skills of the hearing - impaired are evident to anybody who may have heard their speech. However those can be overcome. But a very few deaf individuals achieve good speech quality. Many more deaf children could be trained to speak proficiently if we had greater insight into the essential problems (Levitt , 1974)

Several methods have been employed to study speech production in the hearing - impaired . These include physiological (Metz et al . 1985), acoustic (Monsen , 1976 a, 1976 b. 1974, 1978 ; Angelocci , et al 1964 ; Gilbert . 1975 , McClumphe , 1966 ; Calvert . 1962 ; Shukla , 1985 ; Rajnikanth , 1986 ; Sheela , 1988 ; Jagdish , 1989 ; Rasitha . !994) & perceptual methods (Levitt , et al . 1976 ; Stevens , et al . 1983 ; Hudgins and Numbers 1992 ; Markides . 1970 ; Geffner , 1980 , etc.).

Use of acoustic analysis of speech for studying the speech production skills, offers several advantages as it is non-invasive , needs relatively simple instrumentation , 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 hearing - impaired permits a finer grained consideration of some aspects of both correct and incorrect production than would be possible using methods applied in the subjective procedures (Osberger and McGarr , 1982). It provides objective description of speech of the hearing - impaired . More information about the characteristics of the speech of the hearing - impaired would help in making use of the advances in the technology with maximal effectiveness in the facilitating the oral production skills of the hearing - impaired .

In order to develop more effective speech training procedures for deaf children, it is necessary to know how their speech deviates from that of normally hearing children and the effect of various errors and abnormal speech patterns on the intelligibility (Levitt, 1978). Thus , analysis of speech of hearing - impaired becomes important .

Intelligibility of speech of the hearing - impaired :

One of the most recognized but least understood concomitants of deafness is a deficit of oral communication skills. The speech produced by many deaf persons is frequently unintelligible to even experienced listeners . Moreover it is frequently difficult to determine the exact nature of speech errors that reduce the speech intelligibility . Without a clear understanding of the underlying nature of unintelligibility speech of deaf , the development of effective clinical statement is limited (Metz , 1982).

Speech intelligibility refers to how much of what a child says can be understood by a listener (Osberger and McGarr , 1982).In a study of intelligibility of 192 hearing - impaired subjects ranging 8-19 years of age , a group of experienced listeners were asked to listen to the speech samples of the hearing impaired and write down whatever was understood by them . The mean score for the group was found be only 29 % (Hudgins and Numbers , 1942).

Brarson (1964) found that only 20-25 % of the words in the speech of hearing impaired subjects were intelligible to listeners unfamiliar with hearing impaired children speech . The subjects had a hearing impairment of greater than 75 dB HL , had normal intelligence and no other known handicap . Markides (1970) studied 58 hearing impaired children aged 7 to 9 years only about 31% of their words were intelligible to their teachers whereas 19% intelligible to naive listeners .Smith (1972) studied 40 hearing-impaired children in the age group 8-10 and 13-15 years and found the word intelligibility , as assessed by 120 listeners unfamiliar with the speech of hearing - impaired was 18 7 %. Gold (1980) found that only about 20 % of the speech output of the deaf is understood by the person on the street . This lack of intelligibility may be attributed to several frequently occurring segmental and suprasegmental errors .Monsen (1978) reported a relatively high mean intelligibility score of 76 % however the attributes such high scores to the simpler test materials used to study the speech intelligibility .

According to Ling (1976) , intelligibility ratings can vary not only with the type of judge employed but also with the materials used and with the methods of analysis applied . However , the results of various suggests that the overall level of speech intelligibility is grossly inadequate for oral communication

Intelligibility rating have been reported to be 10-15 % higher when judged by teachers or experienced listeners than those by the naive listeners (Geffner et al , 1978 ; Mangan , 1961 ; Monsen , 1978)

Sentences , when used as test materials tend to be more intelligible than words and sentences which are spoken directly to listener in a face to face situation are more intelligible than sentences that are tape recorded (Hudgins , 1949 ; Thomas , 1964). This suggests that contextual cues also affect the intelligibility of speech.

Poor speech intelligibility achievement in the hearing-impaired has been correlated to several variables related to reception and production of speech .Among the perceptual variables , residual hearing (Montgomery , 1967 ; Elliot , 1969 ; Boothroyd , 1969 ; Markides , 1970 , Smith , 1975 ; Stoker and Lake , 1980 ;

Ravishankar , 1985 ; Vasantha , 1995) and lip reading (Stoker and Lake , 1980; Vasantha ,1995) abilities have been studied . The results have indicated that both residual hearing as well as ones lip reading ability effect intelligibility. Children with lesser degree of hearing loss were found to have a better speech intelligibility. Also, hearing impaired children tend to have a better speech intelligibility when their lip reading abilities were better.

On the production side speech intelligibility has been studied in relation to segmental and suprasegmental errors Errors involving individual speech phonemes , i.e. segmental errors have been studied by Hudgins and Numbers, 1942 ; Nober, 1963 , Markides , 1970 ; Smith , 1973 , McGarr , 1980 ; Ravishankar , 1985 , etc. These studies suggest a negative correlation between the frequency of segmental errors and intelligibility , i.e. the higher the incidence of segmental errors the poorer the intelligibility of speech (Parkburst and Levitt, 1980). However, most of these studies have been correlational studies, where the effect of correction of certain errors in speech, has been studied. In such studies, the researcher does not have full control over speech. It is likely that, parameters other than those under study also varied with therapy, and these contribute to the intelligibility of speech. These findings have been supported by several studies on acoustic features of speech of the hearing-impaired (Calvert, 1961 ; Monsen , 1974 , 1976 a, b, c ; Rothman , 1976).

Both consonant and vowel errors have long been recognized in the speech of the hearing - impaired . Consonant errors include , voicing errors , substitution & omission , while vowel and diphthong errors include , substitution , neutralization of vowels , dipthongization of vowels , etc.

Monsen (1978) examined the relationship between intelligibility, and (a)four acoustic variables of consonant production,

(b) three acoustic variables of vowel production, and,

(c) two measures of prosody,

to find the variables which were highly correlated with intelligibility . He found VOT and the second format frequency to be significant .

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 positions consonant substitution and unidentifiable or gross distortions of the intended phonemes (Levitt, et al 1980) .

TIMING

1. Rate :

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 utterances as do normal hearing speakers (Boone, 1966 ; Hood, 1966 ; Howorth , 1965 ; Voelker , 1935). Hearing-impaired speakers have been found to speak more slowly than even the slowest speakers with normal hearing when hearing - impaired speakers and normals have been studied under similar conditions the measured rates of syllables or word production have often differed by a factor of two or more (Hood , 1966). Nikerson , et al . (1974) studied deaf and control groups on reading rate and found large differences between the groups although the mean rate for the deaf was as high as 108 words / minute.

The problem of reduced rate of speaking in the deaf speaker seems to be related to two separate problems :

1. Increased duration of phonemes , and

2. Improper and often prolonged pause within utterances (Gold , 1980)

2. Increased duration of phonemes :

The duration of a phonemes bears important information in the perception of a speech message. Duration changes in vowels serve to differentiate not only between vowels themselves but also between similar consonants adjacent to those vowels (Raphel , 1972 ; Gold , 1980). There is a general tendency towards lengthening of vowels and consonants in the deaf (Angelocci , 1962 ; Boone , 1966 ; Levitt , et al . 1974 ; Levitt and Parkburst, 1978 ; Sheela, 1988; Rasitha , 1994).

Calvert (1961) was among the first to obtain objective measurements of phonemic duration in the speech of hearing-impaired by spectrographic analysis of bisyllabic words. This study showed that hearing-impaired speakers extend the duration of vowels, fricatives and the closure period of plosives upto 5 times the average duration for normal speakers.

Monsen (1946) studied 12 deaf and 6 normal hearing adolescents as they read 56 CVCs words containing the vowels / i / or /I / . He found that the deaf subjects tend 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 consonantal 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 the speech that was heard .

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 voice-voiceless confusion observed in their speech may actually be due to vowel duration errors (Clavert, 1961)

Shukla (1987) compared vowel duration and consonant duration in thirty norma! 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 JND 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 / within 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 the vowel / a / tended to be either longer or shorter when compared to the length of the vowel / a / in normal speaker.

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

1) In normal hearing the affricates / ch / and / j / were the longest , whereas in the speech of the hearing-impaired / t / 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 .

impaired speaker , the intended stress pattern was not always perceived correctly by a listener . Thus , the hearing-impaired speaker use some other suprasegmental features to convey contrastive stress . Variation in fundamental frequency would be a likely alternative , but McGarr and Harris (1980) also found that while the hearing-impaired speaker produced the systematic changes in the fundamental frequency associated with syllable stress, perceptual confusions involving stress pattern were still observed .

3. Pauses :

Pauses have been found to be inserted at syntactically inappropriate boundaries, such as between two syllables in a bisyllabic word or within phrases by the hearing-impaired speakers (Osberger and McGarr, 1980; Sheela,1988; Jagdish,1989) .Profoundly hearing-impaired speakers insert more pauses , and pauses of longer duration than do speakers with normal hearing (Boone , 1966 ; Boothroyd , et al . 1974 ; Stevens , et al . 1978 etc .). Strok and Levitt (1974) reported that the deaf subjects tended to pause after every word and stress almost every word .

Nickerson et al . (1974) reported that the total pause time in the speech of normal hearing children constituted 25% of the time required to produce the test sentences , whereas it was 40% in the speech of the deaf Boothroyd , et al . (1974) considered that within phrase pauses were more serious problem them between phrase pauses in deaf speakers .

The inappropriate use of pauses along with the timing errors leads to the perception of improper grouping of syllables and contributes to the poor rhythm perceived in the speech of the hearing-impaired (Hudgins , 1946 ; Nickerson , et al . 1974). Hudgins (1934, 1937, 1946) suggested that the frequent pauses observed in the speech of the hearing-impaired may be the result of poor respiratory control . It was found that the deaf children used short , irregular breath groups , often with only one or two words per breath , and breath pauses that interrupts the flow of speech at inappropriate places . Also there was excessive expenditure of breath on single syllables, false grouping of syllables and misplacement of syllables.

Thus hearing-impaired children distort many temporal aspects of speech . In spite of these deviencies . there is evidence suggesting that hearing-impaired talkers manipulate some aspects of duration such as those involving relative duration , in a manner similar to that of a speaker with normal hearing .

4. Voice quality

There seems to be general agreement that the deaf speakers have a distinctive voice quality . (Bodycomb . 1946 ; 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 result in a large expenditure of air and a voice of poor quality (Hudgins , 1937).

Calvert (1962) found 52 different adjectives that had been used in the description of deaf persons speech , A few of them include tense , flat, breathy , harsh, throaty , etc. . He 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 had teachers of the deaf attempt to determine by listening whether the recorded speech sounds (vowels and diphthongs in isolation , non-sense syllables , words and sentences) had been produced by profoundly deaf speakers , normal hearing speakers imitating deaf speakers , speakers simulating harsh and breathy voice or by normal hearing speakers . Isolated vowels from which onset and termination characteristics had been clipped could not be distinguished as to source , but the sources of the sentences were identified with 70% accuracy . Clavert (1971) concluded that deaf voice quality is identified not only on the basis of relative intensity, fundamental frequency and the harmonics , but also by the dynamic factors of speech such as transition gestures that change from one articulatory position into another.

5. Pitch and Intonation :

Fundamental frequency :

In normal hearing speakers, the average fundamental frequency (Fo) decreases with increasing age until adulthood for both males and females (Fairbanks, 1940 ; Usha. 1979 ; 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 individuals may be due to two reasons :-

1) Inappropriate average Fo.

2) Improper intonation - This maybe characterized by :

a) Little variation in Fo resulting in flat and monotonous speech .

b) Excessive or erratic pitch variation .

Average fundamental frequency :

values reported in the literature for normally hearing individuals of the same age and sex .

" The average Fo value of the utterances of the male hearing-impaired speakers was slightly lower than that of the normal hearing males for the first part of the utterance . The Fo values for the hearing and hearing-impaired male speakers overlapped for the last half of the utterance" (Osberger , 1981).

Rajanikanth (1986) reported that when compared to normals the hearing-impaired , in general, showed a higher FFS . He also noted that there was a significant different 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 Fo than that of the normal hearing group .

Several explanations have been offered to explain the pitch deviation 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 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 structure . 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 .

Fo variation

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 Fo is much greater in the hearing-impaired, than in the normal hearing speakers (Angelocci ,et al ,1964).Whitehead and Make (1977) reported that on the average the speaking Fo was higher for deaf adults, than for the normal hearing adults, a majority of the deaf adults had speaking Fo values which fell within the normal range. These findings have also been supported by the findings ofother studies such as by Ermovick (1965), Gruanewald (1966), Shukla (1987) etc.

These differences may vary as a function of the age or sex of the hearing-impaired speakers. While these were no significant differences in average Fo between young normal hearing and hearing-impaired children aged 6-12 years (Boone. 1966 ; Green, 1956 ; Monsen, 1979), differences have been reported between groups of older children (7-18 years old males). Osberger (1981) found that the difference in Fo between hearing-impaired speakers in the 13-15 years age range was greater for females than for males. The Fo for female hearing-impaired speakers ranged between 250-300 Hz. which is about 75 Hz higher than that observed for the normal hearing females.

Meckfessel and Thornton (1964) reported the Fundamental frequency while speaking (FFS), values in post - pubertal hearing - impaired males to be higher than those for normal hearing post - pubertal males . However , Greene (1956) found similar value for the two groups.Gilbert and Campbell (1980) studied FFS in three 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 average Fo value of the utterances of the male hearing-impaired speakers was slightly lower than that of the normal hearing males for the first part of the utterance . The Fo values for the hearing and hearing-impaired male speakers overlapped for the last half of the utterance" (Osberger , 1981).

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Fo variation

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

a) Lack of variation of Fo , or

b) Excessive variation of Fo .

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

A particular problem is that of inappropriate or insufficient pitch change at the end of a sentence (Sorenso , 1974) . A terminal pitch rise such as occurring at the end of some questions may be more difficult to produce for the deaf them a terminal fall (Phillips, et al. 1968).

Hearing-impaired speakers who tend to produce each syllable with equal duration may also generate a similar pitch contour (.Monopitch) on each syllable (Nickerson , 1975). It has been suggested that some of the unusual pitch variations seen may result from attempts to increase the amount of proprioceptive feedback during speech (Martone , 1968).

Pitch problem 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 somewhat exaggerated but , rather , pitch breaks and erratic changes that do not serve the purpose of intonation . These speakers may raise or lower the Fo by 100 Hz or more , within the same utterance These are reports that often , after a sharp rise in Fo the hearing-impaired speaker loses all phonatory control and thereafter there is a complete cessation of phonation (Smith , 1975 ; Stevens , et al. 1978).

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

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

b) A short falling contour, occurring on words of short duration . The Fo change may be more than 10 Hz per 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, characterized 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 speaker.

" The hearing - impaired showed almost double the frequency ranges as compared with normals , accompanied with large individual variations" (Rajnikanth , 1985) .

6. Segmental Influence on Fo Control :

It is seen that some hearing - impaired children produce the vowels /i/ /I/ and / u / with a higher Fo than the other vowels of English . It has been shown that there is a systematic relationship between vowels and Fo in normal speech . High vowels are produced with a higher Fo than lower vowels ; resulting in an inverse relationship between Fo and frequency location of the first format of the vowel (House and Fairbanks , 1953 ; Peterson and Barney , 1952).

Angelocci, et al . (1964) first examined some of the vowel changes in Fo in the speech of the hearing - impaired . They found that the average Fo and intensity for all vowels were considerably higher for the hearing - impaired than for norma! hearing subjects . In contrast , the range of frequency and amplitude values for the vowel formants were sreater for the normal hearing than for the hearing - impaired speakers . So they suggested that the hearing - impaired subjects attempted to differentiate vowels by excessive laryngeal variation rather than by articulatory maneuvers as in normal hearing speakers .

Bush (1981) found that 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 . Bush has postulated that because of the nonlinear nature of the stress strain relationship for vocal fold tissue , increase in vocal fold tension may be greater in magnitude when the tension on the vocal fold is already relatively high (as in the case with hearing - impaired) resulting in some what larger increases in Fo during the articulation of high vowels

From the above studies it is clear that pitch deviation is present in the speech of the hearing - impaired . The abnormal pitch variation have been considered to be the major cause of faulty intonation in the hearing - impaired . There are also evidences which suggest that the hearing - impaired individuals know and use some of the rules as used by the normal speakers .

7. Velar Control

Improper control of velum has long been recognized as a source of difficulty in the speech of the deaf (Beehm , 1922 ; Hudgin , 1934) . Miller (1968) had speculated that the type of hearing loss may be a causative factor in some nasalization problems . Hyponasality , he suggests , may be more prevalent among people with conductive loss than those with sensori-neural loss because nasal sounds may appear excessively loud to the former due to the transmittability of nasal resonances via bone conduction Individuals with sensory-neural loss on the other hand may welcome the additional cues provided by the nasal resonances and therefore tend to nasalize sounds that should not be nasalized.

Learning velar control is difficult for a hearing-impaired child because :

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 .

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 . Some researchers have suggested that such factors as misarticulation , pitch variation and speech tempo affect the proper judgment (Colton and Cooper,, 1968).

For these reasons , objective measures that correlate with the velar activity are put forward . Acoustic properties of nasal sounds that have been investigated include shifted and split first formant (Fujimura , 1960 ; House , 1961) and enhanced amplitude of the lower harmonics (Deiattre , 1955) . Attempts to detect nasalization directly have included the measurement of acoustic energy radiated from the nostrils

(Fletcher , 1970 ; Shelton , Knox , Anidt and Elbert, 1967) and measurement of the vibration on the surface of the nose (Holbwook and Crawford , 1970 , Stevens , Kalikow and Willemain , 1974).

Ravishankar (" 1985) found that the intonation errors were most frequent followed by errors in pitch , rate of speech , nasality and voice quality

The role of suprasegmental features of speech in the intelligible verbal discourse has been well documented by several investigators (Eisenson , 1971 ; Lieberman , 1972 ; Geers , 1978) . The suprasegmental errors that are studied in relation to speech intelligibility are timing errors , pitch and intonation errors and errors in nasality . Most of these errors have been found to be detrimental to speech intelligibility .

Studies that have attempted to determine the role of deviant suprasegmental production and unintelligible speech are of two types :

1. Correlational studies i.e. where the intelligibility of speech is correlated with the number of errors in speech.

2. Causa! studies i.e. studies that attempted to determine the cause and effect relationship . These studies can be sub-divided into two major categories: a) Studies in which hearing - impaired children receive intensive training for the correction of a particular type of error .

b) Studies in which the errors are corrected in hearing - impaired children's recorded speech samples using modern signal processing techniques .

Correctional studies - The suprasegmental errors examined most extensively in relation to intelligibility have been those involving timing . One of the earliest attempts to determine the relationship between deviant timing patterns and intelligibility is the study by Hudgins and Numbers (1942) .

Although they correlated rhythm errors with intelligibility , many of these errors appear to be due to poor timing control and erroneous Fo (Osberger and McGarr, 1982) . They found that sentences spoken with correct rhythm were substantially more intelligible than those that were not . The correlation between speech rhythm and intelligibility was 0.73. The other correlational studies have shown a moderate negative correlation between excessive prolongation of speech segments and intelligibility (Monsen , Leiter , 1975 ; Levitt, 1978) .

Reilly (1979) reported that the better the profoundly hearing - impaired speaker was able to produce the segmental, lexical and syntactic structure of the utterance , the more intelligible the utterances likely to be .

Parkburst and Levitt (1978) indicated that another type of timing error , the insertion of short pauses at syntactically appropriate boundaries had a positive affect on intelligibility . The presence of these pauses actually helped to improve the intelligibility . They added that excessive or prolonged pauses appeared to have a secondary effect in reducing the intelligibility

Studies have also been done to determine the relationship between errors, involving Fo control and intelligibility. The inability to control Fo while speaking contributes to the low intelligibility of the speech of the hearing - impaired (Boothroyd and Deacker , 1975).

"Suprasegmental aspects of phonation have been emphasized by some investigators as indicators of speech intelligibility" (Levitt, 1974).

McGarr , et al , (1976) found that the hearing - impaired children who were unable to sustain phonation and showed pitch breaks and marked fluctuations in pitch were consistently judged to have poor intelligibility . Such children were also reported to show timing errors and very low phoneme production scores in continuous speech . They found a significant correlation between speech intelligibility and rated pitch deviancy on subjective evaluation in their hearing - impaired subjects .

McGarr and Osberser (1978) found that for the majority of the children studied , there seemed to be no simple relationship between pitch deviancy and intelligibility . some children whose pitch was judged appropriate for their age and sex had intelligible speech , while others did not The exception to this pattern were the children who were unable to sustain phonation and whose speech contained numerous pitch breaks . Their speech was consistantly judged to be uninteligibility .

Monsen (1979) found that pitch contours correlate significantly with voice quality ratings , and suggested that significant correlation with intelligibility will only be found when intonation patterns are taken into account

" The speech intelligibility scores showed a high negative correlation with suprasegmental errors" (Shukla 1985) . His study indicated that the suprasegmental errors were strong deterrents to speech intelligibility . Among the error types , intonation errors showed the highest correlation followed by errors in pitch . errors in rate of speech , errors in voice quality , and the presence of nasality .

The effect of prosody on intelligibility has been evaluated mainly by correlational techniques . In studies using subjective ratings of all prosodic features combined (Fo , temporal structure and intonation) it was found that errors in rhythm (Hudgins and Numbers , 1942) poor phonatory control (Smith , 1975) and staccato

Science the timing modifications for this condition involved only the correction of the duration ratio for stressed - to - unstressed vowels , the overall durations of the vowels (e.g. syllables) were still longer than the corresponding duration in normal speech . "These data indicate that the prolongation of syllables and vowels , which is one of the most obvious deviancies of the speech of the hearing - impaired . does not in itself hence a detrimental effect on intelligibility (Osberger and McGarr , 1982)

Maassen and Povel (1984, a) changed the syllable and phoneme duration such that thev were either absolutely or relatively equal to durations of the corresponding segments in the norma! utterances . Intelligibility improved from 25 % to 30 % when a phonemic relative correction was performed for 26 out of 30 sentences . Here , each phoneme got the same relative duration as the corresponding phoneme in a normal utterances . Improvement in speech intelligibility was 11 % to 17 % when syllabic relative correction was done . for eight sentences out of thirty sentences where the syllable was the unit of transformation. For five sentences largest increase resulted from a phonemic absolute correction (intelligibility improved from 21 % - 28 %)

Maassen and Povel (1985) conducted three experiments to study the effect of segmental and suprasegmenta! corrections in the intelligibility and judged quality of the speech of the deaf. By means of digital signal processing segmental and intonation corrections were carried out on 30 Dutch sentences spoken by 10 deaf children . The transformed sentences were tested for intelligibility and acceptability by presenting them to inexperienced listeners . A complete segmental correction improved the intelligibility from 24 % to 72 % which for a major part was due to correction of vowels . The correction of temporal structure and intonation caused only a small improvement from 24 % to 34 %. Combination of segmental and suprasegmental prosody (McGarr and Osbrger , 1978) or syllable speech (Levitte , et al . 1976) all show moderate to high negative correlations with speech intelligibility (Povel, 1984)

Studies that attempted to determine the cause and effect relationship between speech intelligibility have dealt primary with timing (Osberger and McGarr , 1982).

John and Howarth (1965) reported significant improvement in the intelligibility of profoundly hearing - impaired children's speech after the children had received intensive training focussed only in the correction of timing errors

Houde (1973) observed a decrement in intelligibility when timing errors of hearing-impaired speakers were corrected , similar results were obtained by Boothroyd et al. (1974) .

A major problem with the training studies is that the training may result in changes in the child's speech other than those of interest. In addition to this , the effect of phoneme production and of prosodic feature production upon intelligibility have not been separated sufficiently in these studies (Osberger and McGarr , 1982) .

Recent investigations have attempted to eliminate this confounding variables by using modern techniques such as " Analysis - by - Synthesis" .

In such studies speech is either synthesized with timing distortion (Lang ; Hudgins , 1977 ; Bernstein , 1977) or synthesized versions of the speech of the hearing-impaired are modified so that the errors (timing or pitch and intonation errors) are corrected selectively (Osberger and Levitt , 1979 ; Povel , 1984 ; Oster , 1985 ; Maassen , 1986 ;Jagdish, 1988; Sheela, 1988; Rasitha ,1994).

Gold (1980) gave a detailed review of a large number of studies dealing with the production characteristics of hearing - impaired individual. He concluded -

" Whereas there is much documentation of the kinds of segmental and suprasegmental errors in the speech of hearing - impaired , there is far less evidence of the direct effects of each of these errors types on overall speech intelligibility" . " Thus although we may be able to identify' those errors to occur most frequently in the speech of the deaf , we need further research to indicate how these errors types interact to reduce speech intelligibility and to determine which error types should be the first to be considered when planning a training program for improved speech production in the hearing - impaired children" .

Through the use of modern speech synthesis techniques , it is possible to determine the causal relationship between the errors and the intelligibility without the presence of the confounding variables than are seen in the training studies (Osberger and Levitt . 1979)

In digital manipulation techniques it is easy to correct errors in the time domain (suprasegmental) but more difficult to correct segmental errors (Hudsins , 1977 ; Kruger. et al .1972 ; Osberger and Levitt . 1979) If speech synthesis techniques are used . both types of errors can easily be corrected or inserted . especially if a synthesis-by - rule system is used (Bernstein . 1977)

Lang (1975) used an analysis-synthesis approach to correct timing errors in the speech samples produced by hearing - impaired speakers , and also to introduce timing distortions in the samples of normal speakers. Minimal improvements in intelligibility were observed for the speech of the hearing - impaired and minimal decrements in intelligibility were observed for the normal speakers

Bernstein (1977) found no reduction in the intelligibility of speech samples produced by a normal speaker when synthesized with timing errors. In contrast to this

Science the timing modifications for this condition involved only the correction of the duration ratio for stressed - to - unstressed vowels, the overall durations of the vowels (e.g. syllables) were still longer than the corresponding duration in normal speech . "These data indicate that the prolongation of syllables and vowels , which is one of the most obvious deviancies of the speech of the hearing - impaired . does not in itself hence a detrimental effect on intelligibility (Osberger and McGarr , 1982)

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Higgins (1977) found that when normal speech was synthesized with the durational relationship between stressed and unstressed syllables reversed , there was a substantial reduction in intelligibility . Greater reductions in intelligibility occurred when the stress assignments for both pitch and duration were incorrect.

In an attempt to resolve some of the conflicting information in this area , Osberger and Levitt (1979) quantified the relative effect of timing errors on intelligibility by means of computer stimulation . Speech samples produced by hearing - impaired children were modified to correct timing errors , only , leaving all other aspects of the speech unchanged . Three types of corrections were performed , relative timing , absolute syllable duration and pauses . Each error was corrected alone and together with one of the other timing errors . Six stage approximation procedure was used to correct the deviant timing patterns in the speech of six deaf children . They were :-

a) Original unaltered sentences

b) Correction of pause only

c) Correction of relative timing

d) Correction of relative timing and pauses

e) Correction of relative pauses

f) Correction of absolute duration and pauses .

An average improvement in intelligibility was observed only when relative timing errors alone were corrected . The second highest intelligibility score was obtained for the original , unaltered sentences . The intelligibility scores obtained for the other four forms of timing modification were poorer than those obtained for the original sentences , on the average . However , the improvement was very small (4%).

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Osler (1985) took speech samples from three hearing -impaired children and analyzed them individually to find errors in vowels , consonants and prosody . Based on this analysis , a phonetic system for each child was established and a synthetic speech containing different combination of errors was generated . A group of normal hearing subjects listened to the synthetic deaf speech could understand . The results of the study showed that synthesis by rule system can be used to establish the relative impact on intelligibility of different types of speech errors and to develop an individualized program for speech improvement . The individualized program suggested for the three deaf children imply that the segmental errors should be given more emphasis and should be corrected first and then the suprasegmental errors. The segmental error correction will improve the intelligibility up to 66 % to 97 % .

Sheela (1988) studied the effect of computer correction of some of the temporal aspects in the speech of the hearing - impaired on speech intelligibility. She studied eight children , 4 normal and 4 hearing - impaired . The age group was 8-10 years . The hearing - impaired children were having bilateral hearing loss of 70 dB or greater . The test materials consisted of 8 bisyllabic Kannada words. The recorded words were digitized and acoustic analysis was carried out to obtain of the vowel duration , word duration , Fo , f1 , f2, f3, BW1, BW2, and BW3 . Later the correlation of vowel duration , pauses and Fo were made in the speech of the hearing - impaired for those words where in these parameters were deviant from the normal individuals mean value in order to match the mean values of the normals

Results revealed that on the average the hearing - impaired subjects had:-

1) Longer vowel duration when compared to the normals .

2) Intersyllable pauses were present in three of the hearing - impaired children ,

3) Total duration of words was longer,

4) Average fundamental frequency was higher,

5) F1 and F2 was higher than normals and F3 was smaller

The correction of timing errors and average Fo did effect the intelligibility of speech of the hearing - impaired . The correction of different types of errors either in isolation or in combination had differential effect on the intelligibility It was seen that the maximum improvement in intelligibility was observed when only the vowel duration was corrected. It was noticed that when pauses alone were corrected, and when the combination of vowel duration and pauses were corrected the scores were less .

Jagadish (1989) studied the effect of computer correction of some of the temporal aspects in the speech of the hearing - impaired on speech intelligibility. He studied 6 children, 3 norma! hearing and 3 hearing - impaired aged between 9-12 years The hearing - impaired children were having bilateral hearing loss of 70 dB or greater and without only additional handicaps . The test material consisted of eight bisyllabic words in Kannada . Speech samples were recorded and the acoustic analysis was done to find the vowel duration , word duration , Fo , formant frequencies and bandwidth . The corrections of those parameters where there were significant differences between the values of the normal hearing group and the hearing - impaired group were done . The parameters corrected were , vowel duration and pause and the combination of these two parameters .

The results of the study indicated that :-

1) Vowel duration were longer in the speech of the hearing - impaired subjects than for the normal hearing subjects .

2) Intersyllabic pauses were present in hearing - impaired and were absent in the normals.

3) Total duration of words produced by the hearing - impaired subjects were longer .

The intelligibility rating indicated that speech intelligibility improved when the vowel duration was altered with the elimination of pauses and there was only slight improvement when only one condition was changed .

Thus it is seen that the speech of the hearing impaired is characterized by several errors, which make it highly unintelligible. While several investigators have attempted to determine the contributions of the various errors to the poor speech intelligibility, it is through modern speech analysis and synthesis techniques that the researchers have found it possible to finely control the many variables in speech. The present study is aimed at analysing the speech of the hearing impaired, to see how it varies from that of the normal and to determine the effect of correction of vowel duration, and that of the fundamental frequency, alone, and in combination, on the intelligibility of speech of the hearing impaired, using modern digital signal processing techniques.

METHODOLOGY

The study was carried out with the aim of comparing the speech of the hearing impaired with that of the normals and to see the effect of the correction of some parameters on the intelligibility of speech of the hearing impaired. It has been shown that vowels play an important role in the intelligibility of speech, in normals and in the hearing impaired (Kent and Read, 1994; Massen and Povel 1985). Hence, this study has been done on vowels only. Further, the time constraints, prevented the study of segemental aspects in the speech of the hearing impaired.

I. PARAMETERS STUDIED :

The following parameters have been studied -

Acoustic Parameters : 1) Fundamental frequency of speech.

2) Formant frequencies (F1, F2, and F3) of the vowels /a/, /a:/, /e/, /e:/, /i/, /i:/, /o/, /o:/, /u/, and /u:/ in the word initial and the word medial positions.

3) Duration of the vowels /a/, /a:/, /e/, */e:/, /*i*/,/i./, o/*, /o:/, /u/, and /u:/ in the word initial and the word medial positions.

Psychoacoustic Parameters : 1) Word Identification.

2) Speech Clarity rating.

The following parameters were corrected in the speech of the hearing impaired

1) Vowel duration, in both, the word initial and word final position.
2) Fundamental frequency in vowels.
3) Both, vowel duration and the fundamental frequency, together.

II. SUBJECTS:

Two groups of five subjects each were selected for the study. Group 1 consisted of hearing impaired children and Group 2 of normal hearing children, all aged between five to eight years of age (mean age of Group 1 = 6.4 years, and Group 2 = 6.9 years)

Group 1 consisted of five hearing impaired speakers, four males and one female, selected from those attending therapy at the All India Institute of Speech and Hearing, for at least a period of one year. They all satisfied the following conditions -

1 Had congenital bilateral severe hearing loss (PTA of 70 dB HL -reference ANSI 1969, or more, in the better ear)

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

3. Had Kannada as their mother tongue and were exposed to the same in their daily environment.

4. Had been using a hearing aid, appropriately suited for their hearing loss, for at least a period of one year.

5. Were able to read simple words in Kannada.

6. Were able to follow simple commands, and instructions,

Group 2 consisted of normal hearing children, with normal speech and language abilities and who were matched to the children in Group 1 in terms of their age and sex.

III. MATERIALS :

The test materials consisted of twenty simple VCV and CVCV words (words are listed in Appendix 1). These words consisted of ten vowels / a /, / a: /, / e /, / e: /, / i /, / i: /,/ o /, / o: /, / u /, and / u; / in the word initial position and ten vowels / a /, / a: /, / e /, / e: /, / i /, / i: /,/ o /, / o: /, / u /, and / u: / in the medial position. Thus a total of twenty words were chosen for the study All words were chosen based on familiarity to the subjects All words were meaningful to the subjects. Each of these words were written on flash cards, for presenting to the subjects.

IV.DATA COLLECTION :

The speech samples of all the subjects were recorded in a sound treated room, with a 100 MHz. Pentium computer, using an "Analog - to - Digital Converter" (ADC), using a dynamic cardioid microphone with a flat frequency response (AKG - D75) The speech utterances were digitized at a sampling rate of 16000 Hz., with 12 bit quantization.

All subjects were comfortably seated at a distance of 15 cms from the microphone. They were instructed to read out the word written on the card presented to them, at a comfortable loudness level, One card at a time was presented to the children. If the children were unable to follow, then the instructions were repeated. As each word was uttered bv the child, it was recorded on the hard disk of the computer. Thus all the words read by all the subjects were recorded. Each utterance of each of the ten subjects were thus recorded and saved as a separate digitized file.

V. ANALYSIS OF THE DATA :

The computer software "Speech Science Lab" (SSL) and "Vaghmi" (both from "Voice and Speech Systems") loaded on a 100 Mhz Pentium computer was used for analysis of the data. For all analyses a block duration of 30 msec, and a block shift of 10 msec was used. The words were analyzed for vowel duration, vowel formant frequency (F1, F2, and F3), and their mean fundamental frequencies (Fo).

1) Vowel Duration :

The vowel duration was measured directly from the speech waveform. The waveform was displayed on the computer monitor using the 'DISPLAY" programme of SSL. The vowels were identified based upon the regularity of the waveform. The vowel duration was considered to extend from the beginning of the periodic signal to the end of the periodicity (for the vowels in the word initial position), and from the end of one aperiodic portion to the beginning of the next aperiodic portion (for vowels in the word medial portion). This duration was highlighted through the use of cursors. The highlighted portion was played back through headphones, to confirm that it contained the vowel under study. Once this was confirmed, the duration of the highlighted portion was read from the display.

2) Extraction of Formant Frequencies :

To extract the vowel formant frequencies (F1, F2, F3), a spectrogram of each utterance using the "SPGM" programme of the software "Speech Science Lab", was obtained. After identifying the target vowel, the cursor was placed in the middle of the vowel portion so as to avoid the formant transitions, and the formant frequencies were determined by using the sectioning method through the use of Linear Predictive Coding (LPC). This was done with 18 LPC coefficients.

3) Determining the Fundamental Frequency :

For measurement of fundamental frequency, the "INTON Off-line" program, in the Voice diagnosis module of the software "Vaghmi" was used. The utterances were first analyzed and then displayed to obtain the Fo contour. Then the speech statistics were displayed to obtain the mean Fo

Thus all the utterances of all subjects of both the groups were analysed to obtain vowel duration, formant frequency, and the fundamental frequency.

VI. STATISTICAL ANALYSIS :

Descriptive statistics consisting of mean , standard deviation , minimum and maximum values, were obtained for all the parameters analysed To check whether there were any significant differences between the values of the normal hearing group and hearing impaired group, the Wilcoxon Signed Ranks Test was applied. All statistical analyses were carried using the statistical software package "SPSS"

VII. CORRECTION OF ERRORS :

The following parameters were corrected

1) Vowel duration,

2) Fundamental Frequency,

3) Both, vowel duration and Fundamental frequency, in combination

In all instances , corrections were made to match the value of the age and sex matched normal hearing subjects

CORRECTION PROCEDURES :

1 . Correction of the vowel duration only :

Here, the vowel durations of the words in the utterances of the hearing impaired children's speech samples were modified so as to match those of the age and sex matched normal hearing subject . The corrections were done only in the stable portions of the waveforms , so as to preserve the transitions. These corrections were done by cutting the required duration from the vowel waveform, using the "DISPLAY" programme of the SSL. The duration required to be reduced was highlighted, and then deleted from the word. Care was taken to preserve the formant transition and to prevent abrupt splicing, which would lead to the perception of a burst Unaltered and duration corrected waveforms are shown in Figure 1 These corrections were done in 44 words.

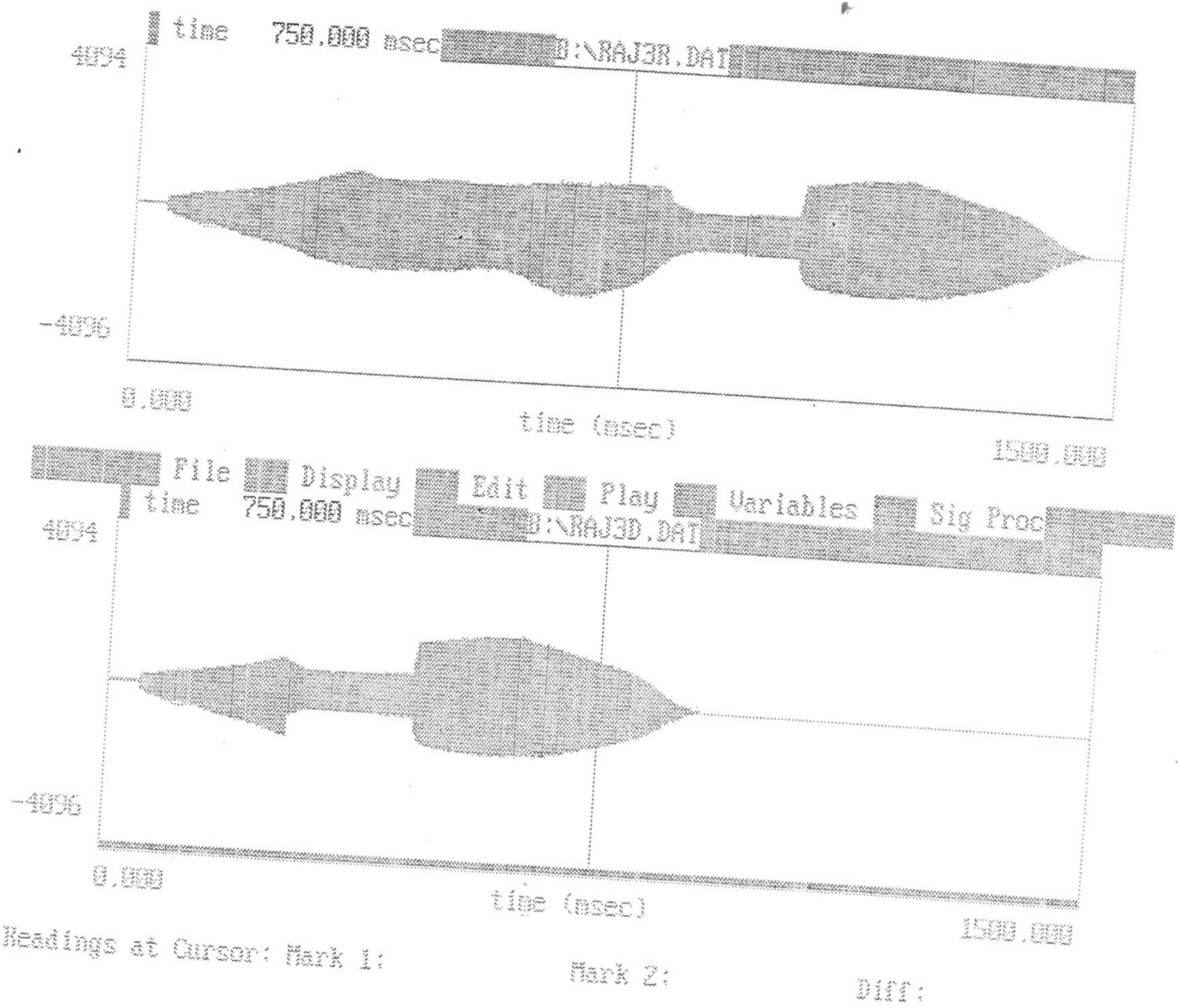
2. Correction of Fundamental Frequency (Fo):

The Fo was modified using the "analysis - by - synthesis" technique available on the "Acoustic-Phonetics I" (ACOPHON - I) module of the software "Speech Science Lab". The utterance to be modified was first analysed, in order to determine its various speech parameters. After analysis, using the "PATPLAY" programme, the Fo was appropriately scaled to approximate the mean Fo for the matched normal hearing speaker. Thus, the Fo contour was preserved as it was in the speakers natural utterance. Following this correction, the utterance was resynthesised.

3. Correction of both Fo and duration :

For this, the samples were first corrected for their vowel durations (as described in "Correction of Vowel Duration") and then their Fo was modified using the analysis- by -synthesis method (as described in the "Correction of Fo").

Thus the utterances of four hearing impaired subjects were corrected for Vowel duration, Fundamental Frequency, and both, vowel duration and Fundamental frequency, in combination.


time 750,000 msec
D:\RAJ3R.DAT
4094
-4096
0.000
time (msec)
1500.000
File
Display
Edit
Play
Variables
Sig Proc
time 750,000 msec
D:\RAJ3D.DAT
4094
-4096
0.000
time (msec)
1500.000
Readings at Cursor: Mark 1:
Mark 2:
Diff:

VIII. RE-RECORDING THE SPEECH SAMPLES :

The unaltered and altered speech samples were transferred from the computer to a cassette tape . There were 44 unaltered utterances and 132 altered utterances All the 176 words, along with 10 words which were repeated, to find out the intrajudge reliability in terms of perceptual evaluation, were randomised so as to eliminate practice effect

IX. MEASURES OF SPEECH INTELLIGIBILITY :

Five listeners, all post-graduate students in Speech and Hearing, native speakers of Kannada, and experienced to the speech of the hearing -imnaired, were asked to listen to the speech samples and to write down the words that they have heard (Word Identification task) . They were also requested to rate the clarity of the words on a 5 point interval scale, from I, denoting very clear to 5, denoting highly unclear speech (Clarity rating task). Both these tasks were carried out in a sound treated room The tape, with 186 words recorded on it was played using a "Sony" tape recorder and each listener was delivered the speech samples through a headphone at a comfortable loudness level.

X. STATISTICAL ANALYSIS :

a) Word Identification :

When the word identified by the listener was the same as the one uttered by the speaker, it was considered to be correct. Words wrongly identified, or those not identified at all, were considered to be wrong. The number of correct identification by each judge for each subject was converted into percentage of scores , as follows :

$$\text{Intelligibility Score} = \frac{\text{Number of correct identification}}{\text{Total number of utterances}} \times 100$$

b) Clarity rating :

The judges were asked to rate the utterances on a 5 point rating scale (1-good to 5-poor).The ratings made by majority of the judges was considered to be the Clarity rating of that particular word . Descriptive statistics was obtained for both altered and unaltered utterances The Wilcoxon Signed Ranks Test was performed to check whether there was any significant differences between unaltered and each, type of altered sets.

Interiudse and Intrajudge reliability was checked using Pearson's rank correlation method to determine the correlation between and within the judges

Thus from the speech of five hearing impaired impaired and five normal hearing subjects, the vowel analysis yeilded

1. Vowel duration for ten vowels (/ a /, / a: /, / e /. e: /, / i /, / i:/, / o /, / o : /, / u / , and *l*u:/) in the word initial position, and ten vowels (/ a /, / a: /, / e /, / e: /, / i /, / i:/, / o /, / o: /, /u/ and / u: /) in the word medial position.

2. Fundamental freouency.

3. Formant Frequencies - First formant frequency . Second formant frequency , and Third formant frequency - for ten vowels (/a/, /a:/, e/, /e:/, /i/, / i : /, /u/, and /u:/) in the word initial position, and ten vowels (/a/, /a:/ ,/e/, /e:/, /i/, /i:/, /o/, /o:/, /u/, and /u:/) in the word medial position.

A total of five parameters in 200 words were extracted. A total of 132 words were then corrected

RESULTS AND DISCUSSIONS

This study was planned to compare certain parameters of speech of the hearing impaired speakers with that of the norma! hearing speakers, to determine the differences between the two, and also to determine the effects of computer correction of some of these parameters to find out their effect on the intelligibility and clarity of the speech of the hearing impaired.

The results of analysis of 200 words in terms of a totaJ of 20 vowels /a/, /a:/, /e/, /e:/, /i/, /i:/, o/, /o:/, /u/, and /u:/ in the word initial and the word medial positions and synthesis of 132 words with correction of vowel duration, fundamental frequency, and both these together are presented here.

SPEECH ANALYSIS

Speech samples of both the normal hearing speakers and the hearing impaired speakers were analyzed to obtain various parameters . These were -

1. Vowel duration

The duration of the vowels in the initial and the medial 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 Table 1 and Table 2, and of Figures 1 and 2 show that the mean vowel duration are much higher in the hearing impaired speakers than in the norma! hearing speakers, both in the initial and the medial positions. While these range from 64.5 msec to 224.5 msec for the normal hearing, the range for the hearing impaired is 134.0 msec to 575.34 msec.

The Wilcoxon signed rank test was done to determine if the differences between the two groups were statistically significant . The results of the test indicates a statistically significant difference for all the samples . with the vowel duration of hearing impaired being 2 to 3 times greater than that of the normal hearing speakers . 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 68.21 (for the vowel / i /) the hearing impaired show a maximum variability of 283.14 (for the vowel / e /) .

The hearing impaired children tend to have a significantly longer vowel duration than normal hearing children of the same age and sex . The study indicates that the hearing impaired tend to have vowel duration 2 to 3 times greater than that in the norma! hearing children . These results are similar to the reports of several other studies which have tried to map the differences in the speech of the two groups (Angelocci .1906 ; Calvert, 1962 ; John and Howarth. 1065 . Boone . 1966 ; Levitt et al. 1974 ; Monsen , 1974 ; Parkburst and Levitt 1978 . Osberger and Levitt . 1974 ; Sheeia 1988 . Leeper et a!.. 1987 ; Shukla 1987 ; Vasantha 1995}.

The hearing impaired were also found to have a greater variability in their vowel duration . This too. is consistant with the results of other studies such as those of Monsen (1974), Osbergar (1978). Osberger and Levitt (1979), Rajnikanth (1986), Shukla (1987), Jagdish (1988), Rasitha (1994), Vasantha (1995). Physiological studies also report similar findings , of a greater variability in the articulatory behavior in the hearing impaired .

Vowel	Hearing Impaired		Normal hearing		
	Mean	SD	Mean	SD	
a	134	37.89	64.5	23.38	*
a:	471.66	235.10	188.20	24.82	*
i	276.30	141.44	79.30	38.06	*
i:	289.40	135.63	188.20	68.21	*
u	258	115.78	100.40	30.83	*
u:	436	262.75	155.75	61.29	*
e	394.58	283.14	137.40	39.96	*
ɐ	447.20	219.88	204.88	35.13	*
0	393.40	125.26	113.20	25.31	*
o:	575.34	240	225.40	63.40	*

Note ; * Indicates statistically significant difference between the two groups at P<0.05 level

Table 1 : Mean and SD for vowel duration in initial position (in msec.) for both normal hearing and hearing impaired groups.

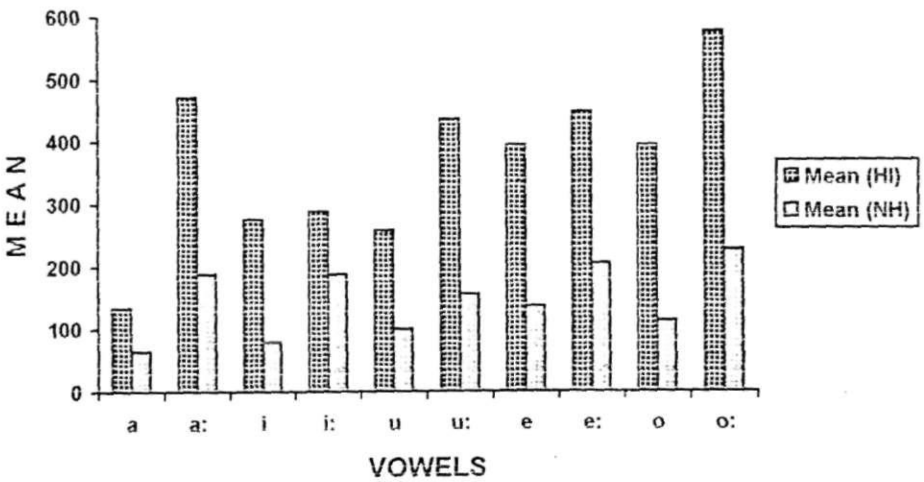


Figure 1 : Mean duration of vowels in initial position for norma! hearing and hearing impaired speakers

Vowel	Hearing impaired		Normal Hearing		
	Mean	SD	Mean	SD	
a	268.60	164.42	99	17.12	*
a:	448.88	150.38	203.40	26.16	*
i	210.86	173.97	84.20	17.04	*
i:	516	278.33	335.25	150.06	-
u	296.20	129.84	95.25	41.13	*
u:	439.40	221.54	89.60	34.12	*
e	300.80	177.05	97.76	31.35	*
e:	480.98	214.70	188.20	30.24	*
o	224.32	91.73	101.40	20.51	*
o:	518.20	172.53	181.25	45.85	*

Note : * Indicates statistically significant difference between the two groups at $P < 0.05$ level

Table 2 : Mean and SD for vowel duration in medial position (in msec.) for both norma! hearing and hearing impaired groups.

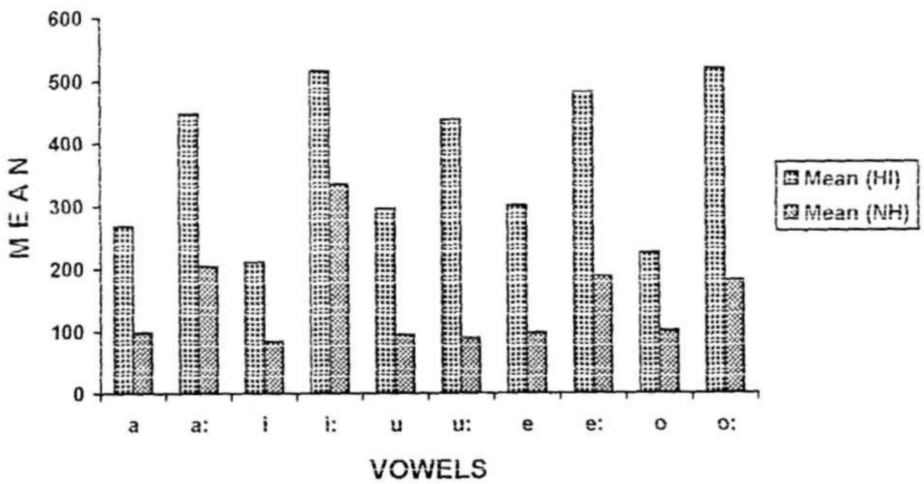


Figure 2 : Mean duration of vowels in medial position for normal hearing and hearing impaired speakers

It is not clear why the deaf should have particular problems with the timing of speech events . Prolonging them and producing a high variability of 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 Jagdish (1984) found that vowel duration of /i/ and /u/ were longer at higher and lower fundamental frequencies than that at norma! fundamental frequency . Since the hearing impaired tended to have a greater fundamental frequency than the norma! hearing . the increased vowel duration may be an effect of this .

2 . Fundamental Frequency :

The mean fundamental frequency (Fo) was measured for all the words for each of the hearing impaired and the normal hearing subject . These are listed in Table 3 and presented in Figure 3. On scrutiny of these it is seen that, four of the five hearing impaired subjects had a much higher Fo than their age and sex matched controls One subject had Fo about the same as his age and sex matched control . As a group , the hearing impaired subjects had a statistically significantly higher Fo than their age and sex matched controls .

Subject	Normal Hearing		Hearing Impaired	
	Mean	SD	Mean	SD
1	271	30.4	364	39.6
2	265	28.7	341	43.4
3	268	13.2	310	32.2
4	252	144	351	29.1
5	241	12.4	238	23.5

Table - 3 : Mean and SD for Fo of Speech of the Hearing Impaired and Normal Hearing groups

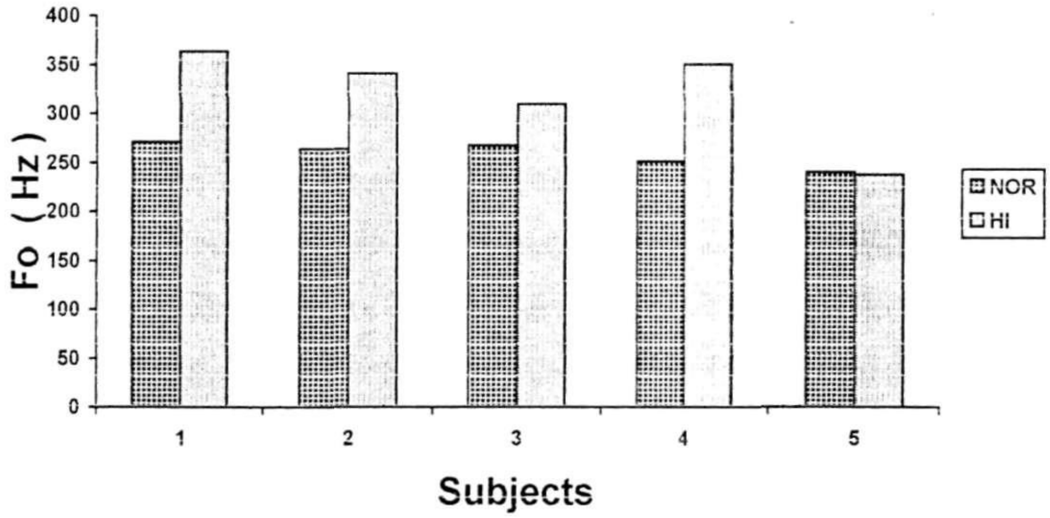


Fig - 3 : Mean Fo of Speech for Normal Hearing and Hearing Impaired Subjects

Average Fundamental Frequency :

Average fundamental frequency (Fo) decreases with increasing age until adult hood for both males and females (Fairbanks , 1940 ; Hollien and Paul , 1964 ; Samuel, 1973 ; Usha , 1979 ; Gopal , 1980) In this study . the hearing impaired subjects as a group were found to have a relatively higher Fo than their age and sex matched controls This is in conformity with the findings of Angeoccci, (1962) : Calvert (1962) ; Engelberg , (1962) ; Angeolcci et al... (1964) ; Thronton (1964) , Boone (1966) ; Martony (1968) ; Rajnikanth . Jagdish (1989) ; Sheela (1988) ; and Rasitha (1994).

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) . A lack of the intuitive gray of the concept may help explain why deaf children often attempt to raise their pitch by increasing their vocal intensity (Phillips Rebillard Bass and Pronovost , 1968)

However , one of the five subjects studied . was found to have a Fo which was nearly the same as that of the matched control This mav be a result of therapeutic intervention .

Several explanations have been suggested to explain the higher Fo in the hearing impaired . Angelocci et al ., (1964) suggested that the hearing impaired attempted to differentiate vowels by excessive laryngeal variation rather than with articulatory variations as in the normal hearing subjects . This led to an increased Fo. Witleman and Lea (1971) hypothesised that the deaf speaker uses extra vocal effort to give him an awareness of the onset and progress of voicing and this leads to a higher

Fo. Pickett (1968) explains increased pitch as being due to increased sub-glottal pressure and tension of the vocal cords . This is directed to the laryngeal mechanism in order to obtain a greater kinesthetic feedback Martony (1968) and Honda (1981) opine 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 and the cricoid and thyroid cartilage, an extra effort on the articulators would result in tension and change of the vocal cords . leading to an increased Fo .

Non of the suggested explanations may be able to explain the increased Fo for all the hearing impaired. It is likely that several of these reasons interact to lead to an increased Fo .However, it is evident that a higher Fo in the hearing impaired indicates a lack of laryngeal control due to absence of auditory feedback

3. Formant Frequency :

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 Shangnessy , 1978) . The primary acoustic correlate of vowel quality is the frequency-position of formants . or energy concentrations in the spectrum (Fant. 1960) . As a genera! rule , the frequency of the first formant raises as the mouth becomes more open and that the frequency of the second formant raises as the tongue is retracted and raised (Fant, 1960) . 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 articulators. Monsen & Shangnessy (1978)-are of the opinion that the vowel articulation is difficult for the deaf since the clues for it are insufficient. Unlike many consonants, vowels do not have articulatory reference points that can be easily described

a) First Format Frequency (Fi) :

The first format frequency (Fi) was measured for a total of 20 vowels / a /, / a: /, / e /, / e: /, / i /, / i: /,/ o /, / o: /, / u /, and / u: / in the word initial and the word medial positions position . The results are tabulated in Tables 4 and 5 and shown graphically in Figures 4 and 5 respectively An examination of these show that the subjects of the hearing impaired group had a high F1 for vowels in the initial and the media! position, except for the vowels / a / and / o/ in the initial position and the vowel / o / in the media! position. The FI ranged from 489.42 Hz. to 1070.46 Hz. in the hearing impaired, as compared to a range of 450.96 Hz. to 1119.94 Hz. in the norma! hearing group. Further the SD clearly indicates that the hearing impaired subjects had a greater variability than the normal hearing subjects.

On comparing the two , through the Wilcoxon Signed rank test, a statistically sianificant difference was obtained only for a few vowels conditions. These are - / a /, / a: /, /i /, / u: /, / o: / in the initial position and / a: /, / i /, / u: / , / e /, / e: / in the media! position. In all these, the hearing impaired were found to have a greater F1 than the normal hearing except for vowel / a: / in the initial and the medial positions and / o / in the medial position which had values of F1 lesser than that of the normal hearing group .

F1 is known to be correlated with the degree of opening. Since out of the 20 vowels studied, 10 did not vary significantly from the normal hearing group, it can be concluded that the hearing impaired do not differ significantly from normal in their range of mouth opening for these vowels. This finding is in agreement of the reports of Nataraj and Rohini (1992). However, the hearing impaired do differ in the range of mouth opening for some other vowels. No regular pattern of could be established.

Vowel	Hearing impaired		Normal Hearing		
	Mean	SD	Mean	SD	
a	1071.46	138.34	969.32	73.09	*
a:	809.56	333.29	1069.26	367.02	*
i	529.90	114.55	493.50	104.40	*
i:	489.42	144.81	473.10	113.26	-
u	555.30	226.69	450.96	93.20	-
u:	680.60	329.50	548.03	127.13	*
e	679.29	162.61	647.38	95.26	-
e:	680.60	192.34	644.78	75.80	-
o	693.28	194.25	731.08	103.24	-
o:	680.64	155.90	586.68	40.94	*

Note : * Indicates statistically significant difference between the two groups at P<0.05 level

Table 4 : Mean and SD for Fl in initial position (in Hz..) for both normal hearing and hearing impaired groups.

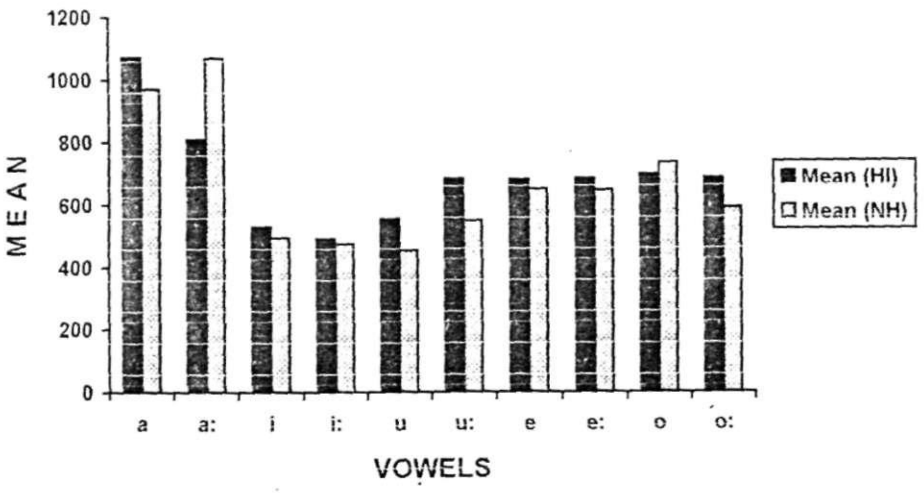
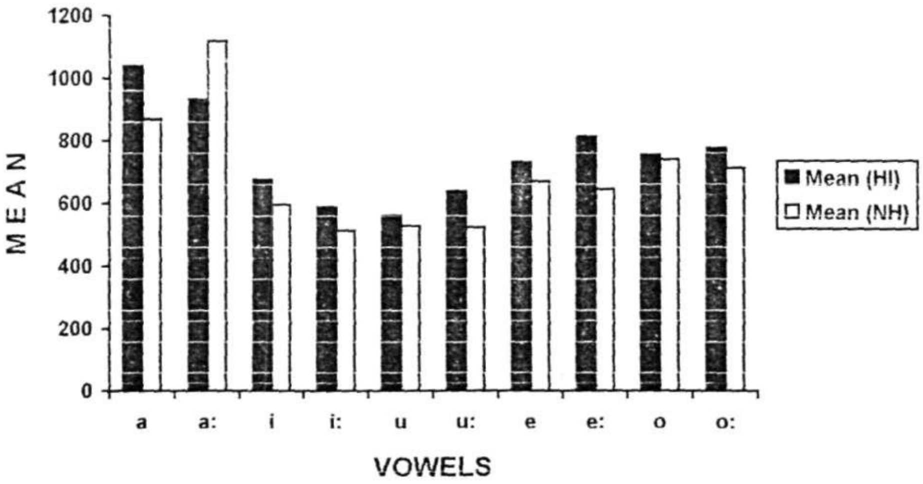


Figure 4 : Mean First Format frequency for vowels in the initial position for norma! hearing and hearing impaired speakers

Vowel	Hearing impaired		Normal Hearing		
	Mean	SD	Mean	SD	
a	1039.06	456.63	868.94	294.58	-
a	931.78	262.85	1119.44	171.15	*
i	674.92	249	596.04	106.38	*
i:	588.25	118.45	511.84	90.18	*
u	560.75	210.98	527.84	71.87	-
u:	636.86	195.86	522.32	90.39	*
e	731.70	188.66	668.22	97.73	*
e:	811.52	245.59	643.10	90.79	*
o	755.96	144.79	740.38	108.89	-
o:	774.92	247.40	709.80	322.10	-

Note : * Indicates statistically significant difference between the two groups at P<0.05 level

Table 5 : Mean and SD for Fl for vowels in medial position (in Hz.) for both normal hearing and hearing impaired groups.



b) Second Format Frequency (F_2)

F2 measures for all vowels in both initial and final position were studied and are tabulated in Table 6 and 7 and shown on Figures 6 and 7 respectively. On studying these graphs it is evident that, 11 out of the 20 vow els studied showed the F2 in the hearing impaired to be lower than that of the normal hearing group, and 9 out of the 20 to have a higher F2 than the normal hearing group. Further, the hearing impaired also showed a greater variability than the normal hearing group

A comparison through the Wilcoxon Signed ranks tests showed a statistically significant difference between the two groups for all vowels except for / a: / in both initial and medial positions and for / i. / in the media! position. A closer look at the obtained values reveal that the F_2 values for hearing impaired speaker are lesser than those for normal hearing speakers for the front vowels / i / , / i: / , / e / , / e: / in both initial and media! positions, and greater than those for norma! hearing speakers in the back vowels. / u / , / u: / , / o / and / o. / in both initial and medial positions . This suggests a neutralization of F_2 in hearing impaired speakers , such that the F_2 tends to resemble that of the schewa vowel.

c) Third Format Frequency (F_3)

The F_3 values , measured for both the groups are tabulated in Tables 8 and 9 and shown in Figures 8 and 9 respectively. An examination of these show that the hearing impaired have a higher F3 for al! the vowels except for the vowels / e / and / o / in the initial position and the vowels / i /, / i: /, / o /, / o: /, in the media! position. It also becomes evident that the hearing impaired show a higher variability in the F3 than the norma! hearing speakers, in the word initial position. However, this variability is lesser in the medial position.

Vowel	Hearing Impaired		Normal Hearing		
	Mean	SD	Mean	SD	
a	1007.84	211.60	1589.06	160.82	*
a:	1731.38	465.98	1191.50	670.33	-
i	2625.90	891.87	2943.60	99.37	*
i:	2435.66	908.58	3018.08	272.58	*
u	1634 44	334.02	877.64	188.55	*
u:	1603.14	559.74	918.60	46.44	*
e	2391.62	358.35	2522.84	689.74	*
e:	2340.16	332.72	2888.72	119.17	*
0	1653.22	293.54	1502.72	301.61	*
o:	1979.66	707.79	1163.94	211.15	*

Note : * Indicates statistically significant difference between the two groups at $P < 0.05$ level

Table 6 : Mean and SD for F2 for vowels in initial position (in Hz.) for both normal hearing and hearing impaired groups.

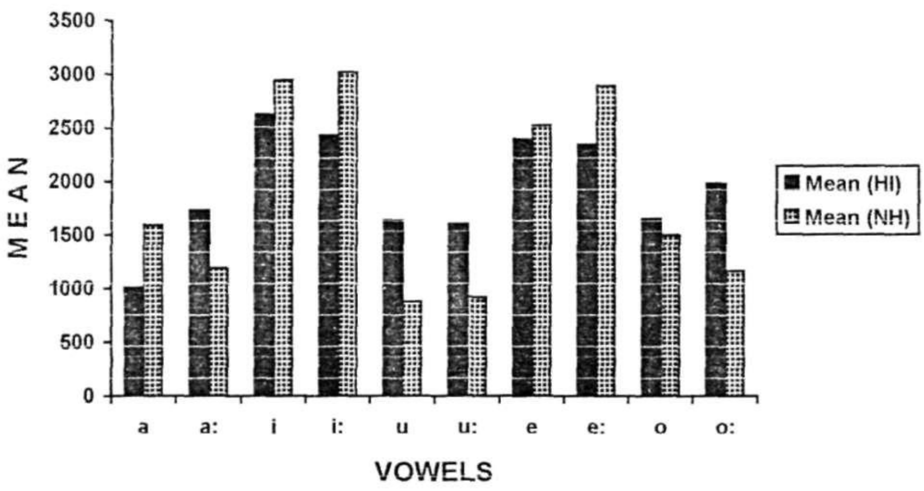


Figure 6 : Mean F_2 for vowels in initial position

Vowels	Hearing	Impaired	Normal Hearing		
	Mean	SO	Mean	SD	
a	1436.02	382.03	1772.52	185.63	*
a:	1791.38	126.66	1794.36	342.67	-
i	2374.96	964.52	2976.52	140.61	*
i:	2682.35	780.34	2959.94	268.03	-
u	1725.45	141.46	1141.18	123.79	*
u:	1584.34	216.16	1253.24	315.64	*
e	2180.48	303.36	2497.20	375.16	*
e:	2224.22	306.30	2467.90	276.06	*
o	1929.12	165.96	1781.94	223.91	*
o:	1766.30	188.79	1401.98	250.77	*

Note : * Indicates statistically significant difference between the two groups at

Table 7 : Mean and SD for F2 for vowels in medial position (in Hz.) for both norma! hearing and hearing impaired groups.

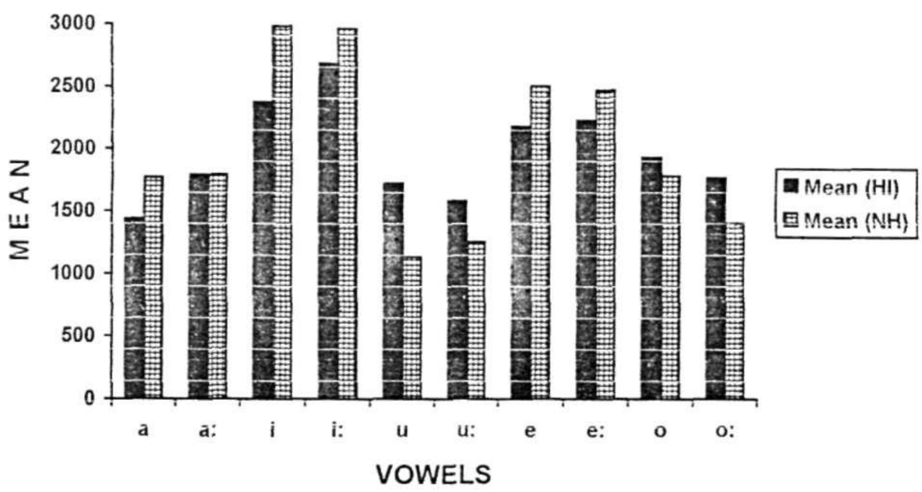


Figure 7 : Mean F_2 for vowels in medial position

The Wilcoxon Signed Ranks tests , when administered showed a statistically significant difference between the two groups for the following vowels - / i: /, / o / , / o: /. / e: / and / u: / in initial position and / a: /, / e / , / e: / , / i / , and / u: / in media! position. For all these vowels , the mean F;, for hearing impaired speakers was higher than that for normal hearing speakers except for / o./ in initial position and / i / in medial position, which maybe considered exceptions.

These differences can be considered as indicating that the degree of constriction in the vocal tract is lesser in the case of hearing impaired, as F3 is correlated with the desree of constriction of the tongue. Such findings have also been reported by Natraja and Rohini (1992).

Thus it maybe concluded that :

1. The vowel duration in the word initial and medial position is greater for the hearing impaired than the normal hearing speakers.

2. Fundamental frequency is higher in the hearing impaired.

3. The formant frequencies vary as follows -

a. First formant frequency tends to be higher than the normal hearing subjects.

b. Second formant frequency tends to be neutrlaized, to resemble that of the schewa vowel.

c. Third formant frequency tends to be higher than the normal hearing subjects

Vowels	Hearing	Impaired	Norrnai Hearing		
	Mean	SD	Mean	SD	
a	3693.14	502.11	3516.72	342.66	-
a:	3505.54	590.24	3422.62	451.22	-
i	3993.74	1045.14	3772.14	320.72	-
i:	4031.38	1103.89	3792.18	409.95	*
u	3309.93	561.85	3278.38	402.48	-
u:	3364.58	335.36	2881.03	332.50	*
e	3242.73	223.37	3319.35	285.62	-
e:	3883.82	433.06	3672.52	157.87	*
o	3504.98	159.96	3297.10	356.71	*
o:	3353.66	305.44	3535.68	364 77	*

Note : * Indicates statistically significant difference between the two groups at $P< 0.05$ level

Table 8 : Mean and SD for F3 for vowels in initial position (in Hz.) for both normal hearing and hearing impaired groups.

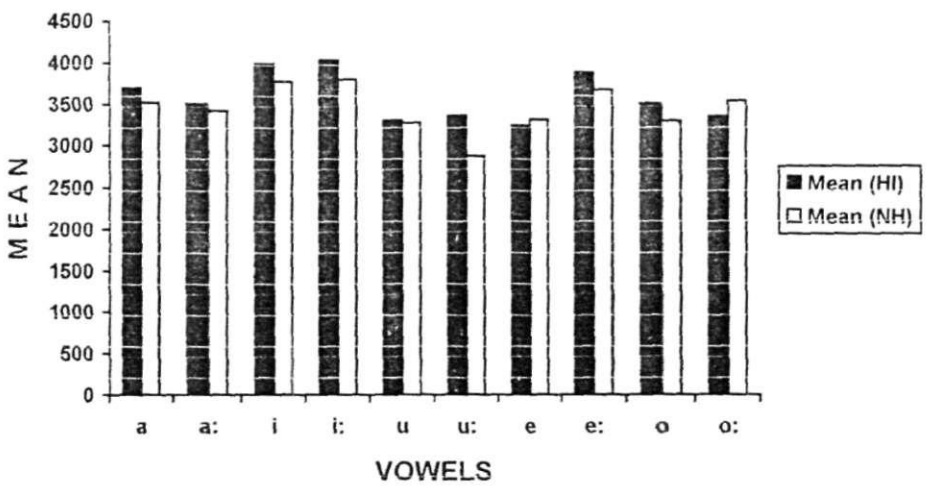


Figure 8 : Mean F_2, for vowels in initial position

Vowels	HEARING Impaired		Normal Hearing		
	Mean	SD	Mean	SD	
a	3323.14	447.94	3301.90	536.74	-
a:		181.99	3425.14	370.88	*
i	3617.12	102.89	3806.40	304.13	*
i:	3900.87	850.90	3951.04	402.93	-
u	3176.45	235.30	3145.86	575.12	-
u:	3359.94	371.42	2911.75	747.40	*
e	3417.56	266.41	3424.78	339.07	*
e:	3541.96	362.23	3259.66	346.13	*
o	3265.44	324.40	3375.68	301.44	-
o:	3490.08	401.66	3669.23	348.27	-

Note : * Indicates statistically significant difference between the two groups at $P < 0.05$ level

Table 9 : Mean and SD for F3 for vowels in medial position (in Hz.) for both normal hearing and hearing impaired groups.

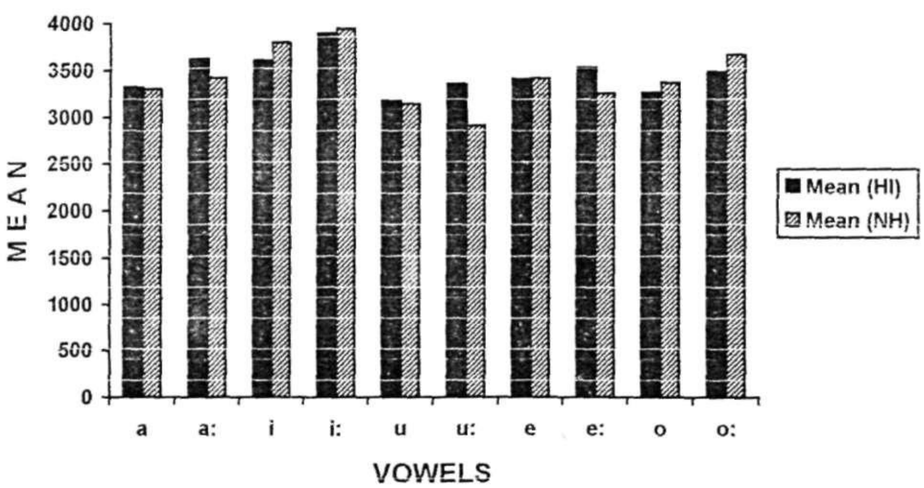


Figure 9 : Mean F3 for vowels in the medial position

Based on the results of the analysis , the hearing impaired speech samples were corrected for certain parameters and resynthesized . The parameters corrected were :

i . Duration only

ii Fundamental Frequency only

iii Both, duration and fundamental frequency together

These corrections were made only for those words which had their values differing from those of the age and sex matched norma! hearing controls. All corrections were made to match the value for the corresponding utterances in the age and sex matched norma! hearing control for that particular subject. All the synthesized words , along with an unaltered sample were randomly presented to five listeners , who were asked to identify the words and rate the clarity on a five point rating scale . The results are as follows

1 . Intelligibility and Clarity rating task

The judges were presented 44 unaltered words and 132 altered words which were corrected for either the vowel duration, the fundamental frequency or both together. Ten words were repeated to check reliability of the ratings made by the judges. The judges were asked to rate their clarity on a 5 point scale , from I, indicating good to 5, donating highly unclear speech They were also asked to write what they hear. The obtained results were tabulated and the most common rating for each sample was determined. This rating was assumed to be reflective of the claritv rating of that particular sample .

These values were then subjected to the Wilcoxon Signed Rank Test to determine if correction of duration , Fundamental frequency and simultaneous correction of both had any effect on the clarity and the intelligibility of the word

2 . Inter-judge reliability :

The Pearson's rank correlation method was used to determine the interjudge and the intrajudge reliability. The mean interjudge reliability was 0.689 and ranged from 0.543 to 0.799. The mean intrajudge reliability was 0.83 1 and ranged from 0.734 to 0.913. The results show a high positive correlation indicating that the results of this part of the study were valid.

3 . Word identification task

The mean word identification score for the unaltered utterances of the hearing impaired was found to be 38.6 % and ranged from a low of 19 % for subject 4, to a high of 76 % for subject 2. These scores are tabulated in Table 10 and shown in Figure 10

The general finding that speech intelligibility is poor in the hearing impaired speech is in agreement with several other studies such as those of Hood (1966), Angelocci (1962), John & Howrath (1965). Sheela (1988), Rajanikanth (1986), Rasitha(1994).

However, the exact intelligibility scores obtained in this study varied from those of other studies. This maybe due to the fact that the intelligibility varies depending upon several factors such as the type of judges (experienced vs. in experienced), the type of speech sample (words vs. sentences), the method of presentation, the method

Subject	Mean word identification score
1	23 %
2	76%
3	31%
4	19%
5	44 %

Table 10 : Mean word identification scores of five judges for the unaltered speech samples of hearing impaired speakers

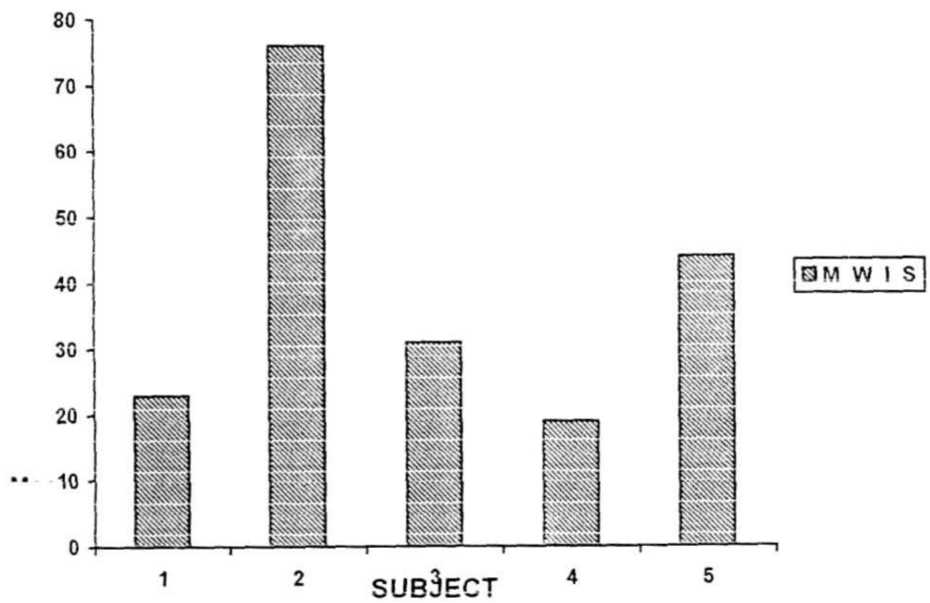


Figure 10 : Mean word identification scores of five judges for the unaltered speech samples of hearing impaired speakers

of analysis etc. (Ling, 1976). It also depends upon the amount of training of the deaf child, his residua! hearing, and his lip reading ability (Vasantha, 1995).

Subtelny (1977) cautioned that speech intelligibility assessment cannot be used with confidence for training purposes without knowledge of the properties of speech that can influence intelligibility. Stevens et al (1973, 1983) supported this notion by stating that the fundamental problem of speech assessement with hearing impaired persons is to identify those propoerties of speech that determine its intelligibility. Metz et al (1980) and Nickerson and Stevens (1980), suggested that identification of those properties of speech that determine intelligibility is a methodologically complex task but it clearly has utility for the development of effective remedial strategies for improvement of speech of hearing impaired.

Gold (1980) has opined that although there was much documentation of the kinds of segmental and suprasegmental errors in the speech of the hearing impaired there was far less evidence of the direct effects of each of those error types on overall speech intelligibility. Having knowledge in this regard will help in planning suitable training program for each hearing impaired child for improving the speech production ability.

Manipulation of deaf speech by means of digital speech processing or speech synthesis techniques to study the direct effect of various segmental and suprasegmental errors on speech intelligibility of the hearing impaired children's speech is of recent origin. There have been a few studies in this regard so far. (Kruger et al, 1972, Lang, 1975). The present study is also similar to those studies and aimed at checking the effect of some timing errors and the average F0 correction on the speech intellligibility of the hearing impaired children's speech.

CORRECTION OF VOWEL DURATION :

The correction of vowel duration was found the improve the clarity of speech of the hearing impaired. The mean clarity rating on the five point scale (1 denoting good to 5 denoting highly unclear) dropped from 4.29 of the unaltered sample to 3.00 for those whose duration was corrected. This difference was statistically significant. A total of 29 out of the 44 words corrected for vowel duration were correctly identified. This finding is in agreement with that of Masser & Povel (1985), Jagadish (1989) and Rasitha (1994). This indicates the importance of vowel duration in the perception of speech.

Studies on vowel duration production and perception in normals (Nooteboom, 1973) suggest that listeners are extremely sensitive to the duration that a vowel should have in a given context. It has been shown by Calvert (1961) that listeners experienced to the speech of the deaf speech can not identify speech as deaf unless they hear at least syllable length productions. "This shows that the effect of the characteristic deaf syllable prolongation were to make the deaf conspicuous and tedious to listen to". (Harris & Mc Garr. 1980). Thus it can be concluded that the reduction in the vowel duration in the speech of the deaf, improves the intelligibility of their speech.

CORRECTION OF FUNDAMENTAL FREQUENCY :

The correction of fundamental frequency also had a positive effect on the clarity of speech the hearing impaired. When the Fo of the words were corrected, 23 out of the 44 words were correctly identified. While the improvement was not as much as that seen by the correction of duration, the mean intelligibility score improved to 3.69 from a poor 4.29 for unaltered samples. While this improvement in clarity with correction of Fo has been reported by Maassen and Povel (1984b, 1985), others such as Jagdish (1988) and Sheela (1988) have found a reduction in the speech intelligibility with a correction of Fo. These differences maybe due to the speech abilities of the subjects used for this study. However the other differences that can be noticed across these studies are as follows :

Firstly, it is seen that both Jagdish (1989) and Sheela (1988), while correcting the Fo, did not attempt to preserve the intonation contour. The intonation contour has been found to be an important factor, separating the better from the poorer hearing impaired speakers (Monsen, 1979). However in this study, care has been taken to presereve the original Fo contour by merely scaling the Fo to match that of the normal hearing speaker.

Secondly, in the previous studies, (Sheela, 1988; Jagdish, 1989) the corrections were made to match the mean value of the normal hearing group In doing so. individual variations may be lost. In this study, all corrections were made to match the values of the age and sex matched normal hearing control for each hearing impaired speaker.

Lastly, the past decade since the other studies have seen major technological advancements. The instruments used for speech analysis and synthesis have undergone several improvements and maybe able to synthesize more natural sounding speech. Thus, for example, while Sheela (1988) used a sampling rate of 8000 Hz. with a block duration of 50 msec, this study uses a sampling rate of 16000 Hz. with a block duration of 30 msec. Thus, the resolution achieved with modem state-of-the-art instruments is much better than what was achieved earlier., and these factors may be affecting the results.

CORRECTION OF BOTH Fo AND VOWEL DURATION :

Since the correction of duration, and the correction of Fo, in isolation, improved clarity it is logical to assume that a correction of both simultaneously, would improve clarity further This was found to be true as the mean clarity score improved to 2.71, when both Fo and vowel duration were corrected together. A total of 29 out of 44 words were correctly identified when both vowel duration and Fo were corrected together. These scores are better than that achieved after correction of either the Fo or the vowel duration, in isolation.

Thus it maybe concluded that, both Fo and vowel duration, have an important role in the perceived clarity of speech of the hearing impaired. The correction of these show an improvement of intelligibility rating, with a maximum improvement occuring with the correction of vowel duration, and a somewhat lesser improvement due to the correction of the Fo. Simultaneous correction of both, improves clarity more than either of them in isolation.

The mean clarity rating, as measured by 5 judges was found to be best for samples corrected for F_0 and duration and worst for unaltered samples . These results are tabulated in Table 11 .

Condition	Mean Clarity rating
Unaltered	3.29
Duration corrected	3.00
Fo Corrected	3.09
Both Fo and duration corrected	2.71

Table 11 : Mean intelligibility ratings across 44 unaltered and 132 altered samples
(1 - denotes good <-> 5 denotes highly intelligible)

Samples corrected for duration alone , those corrected for F_0 alone and those corrected for both duration and F_0 , all showed a statistically significant improvement in intelligibility when compared to the unaltered sample . Sample corrected for duration alone , when compared with samples corrected for F_0 alone showed a statistically significant difference , with samples corrected for duration only being more intelligible than those corrected for Fo only . Samples corrected for both Fo and duration were found to be significantly more intelligible than either of the other conditions These results are tabulated in Table 12 .

	Duration Corrected	Fo Corrected	Both Corrected
Duration Corrected			
Fo Corrected			
Both Corrected			

Note : * indicates statistically significant difference at $P < 0.05$ level

Table 12 : Comparison of unaltered and three corrected conditions for their intelligibility

The improvement in intelligibility with a correction of the vowel duration has also been shown by other studies such as those of Sheela (1988), Jagdish (1989), and Rasitha (1994). However, these studies do no report an improvement in intelligibility with a correction of Fo, or with simultaneous correction of the two. This maybe due to the reasons as explained earlier.

The results of the correcton of the vowel duration and the Fo, indicate that both these parameters are important contribuers to the intelligibility of speech of the hearing imaaired. The correction of vowel duration has a greater positive effect on the intelligibility, than the correction of Fo. Simultaneous correction of bothhas the greatest positive effect on speech intelligibility of the hearing impaired.

The study, therefore shows that:

1. The vowel duration is greater in the speech of the hearing impaired,as compared the norma! hearing speakers, for vowels / a /, / a: /, / e /, / e: /, / i / ! i: / / o /. / o: / / u / and / u: / in the word initial and the 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) the first formant frequency maybe either higher, lesser or similar to the normal hearing speakers,

b) the second formant frequency is lesser than normals for the front vowels, and higher than normals for the back vowels.

c)the third formant frequency tends to be higher than the normal hearing speakers.

4. Correction of vowel duration, improves the intelligibility of speech of the hearing impaired.

5. Correction of Fo , improves the intelligibility of speech of the hearing impaired , but the improvement is not as much as seen with the correction of vowel duration .

6. Correction of both Fo and vowel duration together improves the speech intelligibility. This improvement is better than that achieved bv correction of either Fo or vowel duration alone .

SUMMARY AND CONCLUSIONS

Speech training for the hearing impaired must be efficient enough to achieve intelligible speech. An efficient training program requires that there will be methods to assess childs errors as well as to estimate the effect of these errors on intelligibility (Oster, 1985).

In order to study the effect of various errors in the speech of the hearing impaired , several studies have been done. These may be of two types

a) Where the children are trained to correct specific errors, and the effect of this training on intelligibility is seen .

b) Errors in the hearing impaired childrens recorded speech samples are corrected through modem signal processing techniques to see its effect on intelligibility .

Recent investigators have attempted to eliminate the confounding variables present in studies using training, by using computer processing techniques. In such studies, speech is either synthesized with timing distortions (Lang 1975 ; Hudgins 1977 ; Bernstein 1977) or synthesized vertions of the speech of the hearing impaired are modified so that the errors (timing / or pitch and intonation errors) are corrected selectively . (Osberger & Levitt 1979 ; Massen & povel 1984a ; 1984b ; 1985 ; Oster 1985 , Massen 1986 ; Sheela, 1988 ; Jagdish, 1989 ; Rasitha, 1994)

This study was done with an aim of analysing the speech of the hearing impaired and then to study the effect of correction of vowel duration and Fo on the intelligibility , individually and in combination.

Five hearing impaired subjects, 4 male and I female attending speech therapy at the All India Institute of Speech and Hearing were taken up for study . Five normal hearing children , matched for age and sex formed the controls .

Twenty Kannada words (VCV and CVCV) were used as speech samples These words contained the vowels / a /, / a: / / i /, / i: / / e / / e: /, / u / / u: / / o /, /o: / All vowels were studied in word - initial as well as word final positions . All the subjects were asked to read the words and their utterences were digitised and recorded on a computer.

The recorded speech samples were analysed using computer software to determine the following parameters :

1. Vowel duration
2. Fundamental frequency (Fo)
3. First formant frequency (FI)
4. Second formant frequency (F2)
5. Third formant frequency (F3)

Statistical analysis was done to determine significant differences exist between normal hearing and the hearing impaired groups. Based on the results it was concluded that :

1. The vowel duration is significantly higher in the utterences of the hearing impaired when compared to that in the norma! hearing group . The hearing impaired produced 2 to 3 times longer vowels , in word initial and medial positions.
2. The hearing impaired , as a group , tend to have a higher fundamental frequency than the normal hearing group .

3. The hearing impaired do not have much differences in their Fl as compared to the normal hearing speakers .

4. The hearing impaired tend to have a "neutralized" F2 ; i.e they tend to keep the F2 similar to that of the neutral schewa vowel , when compared to normal hearing speakers.

5. The hearing impaired tend to have a higher F3 than that of the normal hearing speakers

6. Correction of vowel duration , improves the intelligibility of speech of the hearing impaired .

7. Correction of Fo , improves the intelligibility of speech of the hearing impaired , but the improvement is not as much as seen with the correction of vowel duration .

8. Correction of both Fo and vowel duration together improves the speech intelligibility . This improvement is better than that achieved by correction of either Fo or vowel duration alone .

Hence it would be appropriate to aim for correction of vowel duration and Fo in speech therapy for the hearing impaired .

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APPENDIX - 1

Words used to study the vowels in the initial position :

| a| |appa|

| a:| - | a:ne |

|e| - |entu|

|e:| - |e:nu|

| i | - |idu|

|i:| - |i:ga|

| o | - |ole|

|o:| |o:le|

|u| - |uppu|

|u:| - |u:ta|

Words used to study vowels in the medial position -

| a | - | mane|

| a: | - | Ka:lu |

| e| - |bekku|

|e:| - |be:da|

| i | - | tindi |

| i : | - |bi:ga|

|o| - |dodda|

|o:| - |do:sa|

I u | - | Kuni |

|u:| - |ku:su|