FUNDAMENTAL FREQUENCY TRANSFORMATION IN THE *SPEECH* OF THE HEARING IMPAIRED

REGISTER NO. M 9919

A dissertation submitted in part fulfillment of the Final Year
M.Sc. (Speech and Hearing), University of Mysore,
Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING,
MANASAGANGOTHRI, MYSORE-570006

MAY, 2001

Dedicated

To

Dear Parents-In-Law

And

Parents

for the care

&

encouragement

you have given

Certificate

This is to certify that this dissertation entitled ***"Fundamental** *Frequency Transformation in the Speech of the Hearing-impaired"* is the bonafide work in part fulfillment for the degree of Master of Science (Speech & Hearing) of the student (Register No.M 9919).

Mysore,

May, 2001

Director

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Certificate

This is to certify that this dissertation entitled *"Fundamental Frequency Transformation in the Speech of the Hearing-impaired"* has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any other Diploma or Degree.

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Declaration

This dissertation entitled ***"Fundamental Frequency Transformation in the Speech of the Hearing-impaired"*** **is** the result of my own study under the guidance of Dr. S.R.Savithri, Reader & Head of the Department, Department of Speech Sciences, All India Institute of Speech & Hearing, Mysore, and has not been submitted earlier in any other University for the award of any other Diploma or Degree.

Mysore, Register No. M 9919

May, 2001.

ACKNOWLEDGEMENTS

1 would like to extend my sincere and heartful thanks to Dr. S.R. Savithri, Reader and H.O.D, Department of Speech Sciences, for constant help,support and guidance.

I extend my thanks to Dr. M.Jayaram, Director, AIISH, for permitting me to carry out the study.

I am indebted to all the Speech Science staff for helping me throughout the project. A special thanks to Sreedevi Ma'm- for your suggestions, Rohini Ma'm - for making up time for me, Yashoda & Lalitha.

I thank all the speech pathology staff for guidance, concern, timely help and the faith they have in me. A special thanks to Manjula Ma'm, Prema Ma'm, Pushpa Ma'm, Geetha Ma'm and Swapna.

A special thanks to all my normal and hearing impaired subjects who actively participated in my study.

Thanks to all the library staff for their kindly help.

Mahesh - You are the eternal inspiration, certainly you made it less than it might be.

Lots of thanks to my parents and in-laws without whom I could never reach this stage.

Sis Kavi - Not to forget your 15 days of help during data collection and analysis, Thanks a lot!

A million thanks to my Father-in-law, you are really great and hats off to your patience.

Purnima N. - Thanks for the concern and for considering me as a guest. Don't change, Be like this for ever for at least for the sake of few.

Java & Anshula - Studying together has really helped me a lot. Thank 'U'.

Poornima - Everyone needs a good, innocent and cute friend like you. Hope your dreams are fulfilled and please RELAX !!

Baru - Thanks for the special concern which you always have towards your 'anna\ Be a good SIL too.

Prachi, Kaveri, Raashi, Swaroopa, Harneesh and all II M.Sc girls - 1 admire your extraordinary talents, Thanks for making my stay in hostel memorable. Good friends are precious and rare. I enjoyed the fun we shared together.

Suresh. Vinay , II M.Sc. Guys; Remember 'SS' group, Thanks for the fun & for being good friends.

I thank Mr. Shivappa & Mr. Basavaraju for helping throughout the project and for xeroxing the material.

Thank you Mrs. Manjula for your excellent and quick typing.

Lastly, I thank "BHAGWAN" for "EVERYTHING"

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PAST ME ON THE MILLION YEARS,

I WOULD NEVER HAVE GUESSED,

THAT THEY HAD SOUND,

IF YOU HADN' T TOLD ME

CHAPTER-I

INTRODUCTION

Speech is the most efficient means of communication known to man. Speech and language are normally and usually effortlessly developed through auditor}' mode (Ross and Giolos, 1978). 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 expression of this language response as further spoken or written words (Morley, 1972).

It is through continuous auditory stimulation that a normal child attains speech. The task is however, difficult in the hearing impaired child. Loss of audition has a marked effect on the child's ability to acquire speech (Whetnall and Fry, 1964). A prelingually deaf child has to rely almost entirely on process information (Povel. 1974a, 1974b). There is a shift in modality from auditory sense to tactile, kinesthetic and visual sense & hence speech errors increase in the hearing impaired.

Since the early 1900's investigation have repeatedly shown that the speech of deaf children contains numerous segmental and supra segmental errors. The segmental errors include reduced speaking rate (Voelker, 1938; Boothroyd, Nickerson and Stevens, 1974), excessive prolongation of speech segments (Calvert, 1961; Levitt. Smith and Stromberg. 1976), insertion of long pauses at inappropriate boundaries (Boothroyd. el al, 1974), introduction of adventitious sounds between phonemes and syllables (Hudgins and Numbers 1942; Smith,

1975) and failure to modify segment duration as a function of phonetic environment (Monsen, 1974). Due to such errors, speech of the deaf often is described as slow, labored and lacking in rhythm (Osberger and Levitt, 1979).

Another major source of suprasegmental problems is inappropriate pitch, due to improper control of phonation (Levitt, Smith and Stromberg, 1976). According to Sussman and Hernandez (1979), pitch control in the deaf speaker is inadequate for marking stress. Deaf speech is characterized by a monotonic pitch contour (Hudgins and Numbers, 1942; Levitt, et al 1976). Owing to insufficient control of the vocal cords, FO variations are often restricted to those variations that by physiological properties of the speech organs, directly result from changes in duration and intensity. The monotony gives the speech an unnatural quality. In addition, deaf speaker's pitch is often too high (Calvert, 1961; Angelocci, kopp and HolbrooL 1964; Smith, 1975; Rajanikanth 1986; Sheela, 1988; Apama 1996; Rahul, 1998; Anusha, 1999), this being mainly caused by an increased subglottal pressure and tension of the vocal cords.

The speech produced by deaf is frequently unintelligible even to experienced listeners. Speech intelligibility refers to how much an individual says can be understood by a listener (Osberger and Mc Garr, 1982). 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 on intelligibility of the various errors and abnormal speech patterns that are typical of deaf speech (Parkhurst and Levitt, 1978).

One of the continuing questions posing those interested in speech of the hearing impaired is to assess the importance of different error types. Two methods frequently used are (a) correlational method and (b) speech transformation method. In the correlational method, errors in the speech are divided into distinct articulatory and auditory dimensions. The significance of the different dimensions are assessed by calculating multiple correlations with intelligibility scores. Those error types are considered most damaging, which best predict unintelligibility.

Speech transformation is a method where the errors are artificially corrected with the help of computer programs, after which the improvement is measured in perception experiments. This is possible due to the recent developments in the digital speech technology. Speech transformation method derived part of its attractiveness from the fact that it directly stimulates speech training without bothering patient and the therapist with a restricted, experimentally controlled training programs.

A few investigators have conducted experiments to study the effect of segmental and suprasegmental correction on intelligibility of deaf speech (Hudgins and Numbers, 1942; Markides, 1970; Smith, 1975; Osberger and Levitt, 1979; Maassen and Povel, 1985; Komshian and Bunnell, 1998). In general, the results indicated that speech signal will be interpreted by the listener within the framework of temporal patterns that are determined by the rules for specific language. The literature diverges widely with respect to segmental and supra segmental aspects in hearing impaired speech. The results are equivocal in nature.

This is mainly due to the fact that no reliable phonetic transcription system exists for suprasegmental aspects.

The scarcity of studies in the transformation of prosodic aspects of the hearing impaired has led to lack of understanding of the suprasegmental aspects. Especially with respect to Kannada language only one unpublished study (Rahul, 1997) was carried out. The results of this study indicated decrement in intelligibility when fundamental frequency in deaf speech was corrected. In this context the present study was planned. It aimed at investigating the perceptual effect of correcting FO pattern and duration in the speech produced by Kannada speaking hearing impaired children. This would further enable us to highlight on rehabilitative measures in hearing impaired population. Though most of the researchers emphasize on deviant FO in hearing impaired , the question arises whether it is feasible to correct the same or not. Hence the present study would throw light on intelligibility' improvement, if any, when fundamental frequency alone was altered and when combination of FO and duration was altered.

CHAPTER- II

REVIEW OF LITERATURE

Most studies of the human voice source have been concerned with stationary voice qualities and only a limited amount of work has been devoted to dynamic variations and influence of a linguistic - phonetic frame including prosody. In practice it is necessary to take into account the covariation and high degree of interaction between source and filter functions. The mutual influence is best understood in terms of an overall articulatory gesture oriented model in which lung pressure and glottal adjustments are included. Changes in supraglottal articulation, as in voiced consonant, can cause major changes in amplitude and shape of glottal flow pulses (Perrehumbert, 1981).

It is well known that intonation in speech plays a major role in communication and deviant intonation affects speech output markedly. For example speech of the hearing impaired is highly unintelligible due to erroneous intonation patterns. Speech communication by profoundly hearing impaired individuals suffer not only from the fact that they cannot hear other people's utterances, but also from the often poor quality of their own productions. The lack of adequate perceptual feedback of hearing impaired children's own speech during their early years prohibits them from establishing good fluency. Both the intelligibility and the naturalness of their speech suffer, and as a result, many hearing impaired children are unable to use speech to communicate effectively with family, friends and others (Allen & Arndorfer. 2000).

Deaf speak much more slowly than normals, lengthening by a factor of 1.5 to 2 (Nickerson, Stevens, Boothroyd and Rollins, 1974). They produce voiceless plosives and fricatives with longer durations than their voiced cognates (Monsen, 1974). They fail to produce a difference between the durations of stressed and unstressed syllables. Angelocci (1962) and Boothroyd, Nickerson and Stevens (1974) report "Stacatto" speech in the hearing impaired subjects. Moreover, deaf speakers insert pause in inappropriate places, not only between words but even within words. As a consequence, the grouping of syllables is incorrect and they are often spoken separately. This 'syllabic speech' strongly affects intelligibility (Levitt, Smith and Stromberg, 1976).

Although there is some disagreement as to exactly when young children begin to use intonation grammatically (Galligan, 1987), most normal hearing children passively acquire the necessary rules to use intonation correctly and consistently at a very young age (Levitt, 1971). This is not the case who lose their hearing prelingually. This population must actively learn the mechanics of intonation production without the benefit of adequate auditory feedback. Intonation is particularly difficult for hearing impaired, perhaps because they do not understand the concept of pitch. They may not have an auditory referent for the terms high/low pitch in the frequency domain (Nickerson, 1975). Often they tend to increase their intensity, when asked to raise their pitch (Nickerson, 1975; Phillips, Renillard, Bass and Pronovost, 1968). Incorrect location of word and sentence accent is not only caused by temporal distortions, but to an even larger extent by incorrect pitch movements. Some common characteristics of the intonation produced by hearing impaired talkers include limited pitch variation (Calvert, 1962; Green 1956; Stathopoulos, Duchan, Somenmeics and Bruce, 1986); excessive or erratic pitch fluctuations (Parkhurst and Levitt, 1978; Smith, 1975) and inappropriate average FO (Angelocci, Kopp and Holbrook, 1964; Boone, 1966; Picket, 1968). Rising intonation at the end of the question appears to be particularly difficult for hearing impaired adults and children to produce (McGarr and Osberger, 1978; Sussman and Hernandez, 1979). Frequently reported problems with deaf speaker's voice are monotonous character and elevated fundamental frequency (Boone. 1966; Calvert, 1961; Angelocci et al, 1964; Smith, 1975). Higher pitch level found is due to increased tension of the vocal cords, thus giving the deaf speaker an increased awareness of onset and progress of voicing (Pickett, 1968). Martony (1968) described laryngeal tension as extra effort devoted to the articulators. Monsen (1979) interpreted it as a side effect of the increased subglottal pressure and tension, deaf speakers exert in compensating for inadequate breaking techniques. Few investigators report deaf speech as monotonous and produce equal stress on most words by changing intensity and duration, while FO remains constant (Hudgins and Numbers, 1942: Stark and Levitt 1974; Gold, 1980). Owing to insufficient control of vocal cords. FO variations are often restricted, variations in physiological properties of the speech organs result in changes of duration, intensity and frequency. This monotony of speech gives an unnatural quality. The pitch is often too high, mainly caused by an increased subglottal pressure and tension of the vocal cords (Calvert. 1961; Smith. 1975). Willemain and

Lee (1971) hypothesized that the reason for the high pitch is that deaf speaker uses extra vocal effort which provides them awareness of the onset and progress of the voicing. In contrast, a minority of deaf speakers produce excessive pitch changes (Martony, 1968; Smith, 1975; Parkhurst and Levitt, 1978).

Among the suprasegmental parameters, most of the studies are on timing and the least on stress, intonation and rhythm. Few Investigators have synthesized temporal and spectral parameters to determine its effect on intelligibility (Levitt, 1973; Sheela, 1988; Komshian and Bunnel,1998)

Levitt (1973) synthesized various versions of the word 'better' using parameters modelled after recordings from deaf children. Some of the synthetic versions included adjustments of timing and formant trajectories so that their speech nearly resembled normal speech. Ten versions included both normal and synthetic versions. A paired comparison task was used and the listeners were instructed to indicate the member of pair which sounded most like natural speech. The results suggested that the durational adjustments had the strongest effects on natural ratings. However, unaltered versions were ranked as being more natural sounding than synthetic one.

Monsen and Leiter (1975) studied two measurements of prosody from the connected speech of 37 hearing impaired and six normally hearing adolescents. The average word duration and amount of variation in FO was determined. The study had 50 normal listeners as the judges to detect intelligibility. A significant negative correlation was found between average word duration (especially, function words) and intelligibility. In contrast, linguistically appropriate pitch control as measured by FO variation, does not correlate with speech intelligibility. This indicates that both speech of intelligible and unintelligible speakers may exhibit a large amount of FO variation. Probably its an inadequate measure of pitch control since it takes into account neither the appropriateness of FO variation nor the deviations like FO discontinuity and diplophonia.

Parkhurst and Levitt (1978) recorded 15 sentences and instances of four types of prosodic errors; adventitious sounds, excessive phoneme duration, pitch breaks and pauses of 40 deaf children. A trained speech pathologist listened to the recordings and determined the intelligibility score. The judgements were made regarding the occurence of the four categories of prosodic errors. The prosodic distortions were analysed as they could be detected by the ear. The study was concerned with evolving a system to identify features that could be evaluated by speech pathologist while routing testing condition. A multiple linear regression was performed relating intelligibility to the prosodic distortions. The results indicated that an increase in the frequency of the prosodic distortion corresponded to decrease in intelligibility. But an exception with short pauses were observed as they found insertion of short pauses at syntactically appropriate boundaries had a positive effect on intelligibility. Excessive/ prolonged pauses are perceptually very prominent, they nevertheless provide the listener with additional time to process the distorted speech that has been heard. Adventitious sounds had the greatest negative effect, followed by very long duration and pitch breaks on intelligibility'.

McGarr and Osberger (1978) determined the relationship between pitch deviancy and other aspects of speech production that affect intelligibility. The purpose was also to examine relationship of poor phonatory control on segmental and suprasegmental errors in deaf children's speech. The speech production of 57 eleven to twelve year old deaf children was analysed. The speech skills assessed included pitch register, prosodic features i.e., stress, juncture or pause and intonation, segmental features and overall intelligibility. Three listeners familiar with speech of the deaf rated on a scale. The results revealed pitch register to be either appropriate for their age and sex or differed only slightly from optimal level. Children with poorer hearing have a lower average score. They were most successful at producing the intended feature of pauses and less well on production of stress. They did slightly better in producing a stressed form that occured near the end of a sentence than one that occured near the beginning. Only a small proportion of the children were able to control intonation contour sufficiently well enough to produce a recognizable question. Among segmental features, the most frequent error type was omission of target phoneme, which occurred 29% of the time. Pitch deviancy and intelligibility were significantly correlated. High correlations were obtained for factors related to speech production skills, namely intelligibility and production of prosodic features and production of phonemic features and prosodic features. Ryalls and Lieberman (1982) proposed that vowel intelligibility is reduced at higher FO because formant peaks are under sampled by the relatively wide spacing between source harmonics.

Osberger and Levitt (1979) aimed at quantifying the effect of timing errors on the intelligibility of six deaf children. They used six stage of approximation procedure to correct the deviant timing patterns in sentences, (1) original utterance (2) correction of pauses only (3) correction of relative timing only (4) correction of absolute syllable duration (5) correction of relative timing and pauses and (6) correction of absolute syllable duration and pauses. In addition, two degrees of stress (stressed/unstressed) were assigned by two experienced listeners. The responses of three listeners was scored word by word as a measure of intelligibility for each sentence. The results showed highest intelligibility score when relative timing errors only were corrected, for both stressed and unstressed words within a phrase. On the average, fewer the number of phonemic errors, greater the improvement in intelligibility. In their study, the correction of pauses always led to detrimental effect on intelligibility. This could be due to the changes in FO which occur when a normal speaker pauses, are not always present in deaf speech. The fall in FO which is normally present at the end of breath group was not always evident in deaf speech. It is possible that after the pauses were removed, the intonation contour was such that the speech did not sound 'normal' or 'natural' which in turn may have adversely affected intelligibility.

Sitler . Schiavetti & Metz (1983) investigated contextual effects in hearing impaired speakers intelligibility. The study comprised of two groups, normal and hearing impaired subjects. They read monosyllabic words and CID evervdav sentences. Five listeners wrote down each word and sentence they heard from the speakers and also to guess if they were unsure of any words. The results suggested contextual measurements of hearing impaired speakers intelligibility to be more appropriate. It may be that it is a measure of maximal performance that can usually be expected of hearing impaired speakers. It is more generalizable to real world applications, since speech is more often produced in a coarticulatory context than as single, isolated words. Suprasegmental errors also contributed to the degradation of contextual intelligibility. Speakers may afford more opportunity for suprasegmental errors that may impede improvement in intelligibility.

Maasen and Povel (1984 , 1985) examined the effects of various computer based corrections on the intelligibility of sentences produced by ten Dutch deaf children. The three dimensions modified were timing, FO and spectral components of both the vowel and consonants. They used intonation grammar of Hart and Cohen (1973) implemented on a computer. This rule generated stylized sequences of FO movements covering most intonation patterns occuring in most naturally spoken Dutch sentences. They used only five pitch movements.

(1) A prominence lending rise of four semitones in 100ms, immediately at the beginning of the vowel of stressed syllable.

(2) A prominence lending fall of four semitones in 75ms late in the vowel

(3) A nonprominence lending rise of four semitones in 100ms, very late in the vowel.

(4) A nonprominence lending fall of four semitones, very early in the syllable.

(5) A prominence lending half fall of two semitones in 25-50ms during the second half of the vowel.

Three judges experienced in intonation research identified the focus domains and termed as 'linguistic accent structure'(LAS). An accent structure produced by deaf was termed as 'deaf accent structures' (DAS). Three versions of intonation corrections were produced. In version 1. LAS was realised with a FO stylization making use of five above mentioned pitch movements of intonation grammar. In version 2, the same accent structure was produced by using only a rise fall pattern on each stressed syllable. Version 3 was also a contour of peaks, located on the stressed syllables of DAS. Finally a combined temporal and intonation corrections were performed. Twelve judges who had no experience with deaf speech wrote down as much as they understood. Percentage of words correctly understood was intelligibility score. Following intelligibility test, they judged relative quality of different versions of same sentence using paired-comparison method. An analysis of variance was used to study possible learning effect and differences between groups of listeners. It was concluded that neither of the two significantly affected intelligibility scores. To compare the corrected and uncorrected versions, Fisher's test of significance was used. The results suggested small, but significant improvement was noted for corrections of suprasegmental aspects. However major improvement was noted when segmental aspects were corrected. Corrections of speech sounds caused largest increase in intelligibility from 24% to 72%

whereas suprasegmental corrections yielded gain from 24% to 37% only. Hence, the authors emphasize that it is more important to work on improving articulation than in timing and intonation. It was suggested that in instances where maintaining phonation is a problem, the relative contribution of suprasegmental corrections should be enhanced.

Yorkston , Beukelman & Bell (1988) argued that prosody is important in the perception of segmental information. This is a reasonable assumption given that FO has been implicated as an important perceptual cue to vowel identity (Traunmuller, 1981), stop consonant voicing (Haggard, Ambler and Callow 1970), syllable stress (Lehiste, 1970) and marking lexical boundaries (Liss, Spitzer, Caviness, Adler and Adwards 1998). A monotonic pitch has detrimental effect on intelligibility of speech.

Rubin-Spitz and Me Garr (1990) investigated the relationship between acoustic measurements and perceptual judgements of hearing impaired children's utterances. Stimuli included five declarative sentences, four interrogatives and three had more than one clause. FO measurements and their temporal locations were made for each utterance at utterance onset, peak of the sentence contour, peak in the final syllable and utterance offset. Perceptual measures were made to judge whether each utterance had a falling, rising or flat contour. The results indicated that the hearing impaired participants failed to use terminal FO contour appropriately to differentiate between declarative and interrogative sentences. In fact, in agreement with Sussman and Hernandez (1979), none of their hearing talkers produced any rising contours, either perceptually or acoustically.

Komshian and Bunnell (1998) focussed on the range and extent of spectral and temporal modifications that was needed to judge deaf speech perceptually normal. Recordings of passages read by three deaf talkers were used as a material. The word 'beautiful' was extracted from the rainbow passage, analyzed using LPC and syllabic time warping. The intonation contour was varied linearly from deaf to normal. A ten step spectral continuum was created which approximated 10% to 90% normal LPC parameters. Listeners were instructed to judge the synthesized speech tokens of deaf as 'normal' or 'disordered'. It was seen that all the responses to the stimuli that were not modified spectrally were rated as 'disordered' which demonstrates that simply correcting the timing of the deaf speech samples to normal, without making any changes in the spectrum, does not make the stimulus sound normal. However, there was an ordered increase in the proportion of 'normal' responses corresponding to spectral modification in the stimuli. Two way ANOVA revealed significant interaction between talkers and spectral steps, main effects on only talkers and on only spectral steps. A significant spectral steps factor revealed that the spectrum of the stimuli approached that of the normal speech, there was a concomitant perceptual shift in the direction of normal. In later stages of experiment, corrections were extended to phrase length speech token, 'when the sunlight strikes raindrops in the air' as timing effects could be better assessed. The results of loglinear analysis showed significant spectral and temporal effects but the interaction of the two was not significant. However, the magnitude of spectral effects was sufficiently greater than the magnitude of the temporal effects.

In general, they conclude that spectral features contribute more to the perception of normality than temporal feature. It was never possible to produce a criterion level of 70% normal judgements by altering temporal structure of deaf speech without spectral modifications as well. A combination of the two produced 70% or higher normal ratings. The distinction between spectral and temporal features in speech is somewhat arbitary. Applying the results to clinical practice suggests that it is more important to achieve improvements at the segmental level rather than in speech timing as the outcome of clinical treatment.

The experiment by Loures and Weismer (1999) was designed to study the effect of flattened F0 contours and by implication, monotonic pitch on sentence level speech intelligibility produced by normal speakers. Results indicated that flattened F0 contour decreased intelligiblity both in terms of listeners scaled ratings and transcription accuracy. LPC based resynthesis technique used to modify F0 contour. Results suggested that suprasegmentals are crucial to sentence comprehension. The rise and fall of F0 contour directs the listeners attention to the content words of an utterance, which are typically stressed. The location of words that are more highly stressed are predicted by the form of the preceding F0 contour and therefore receive higher processing priority, resulting in better comprehension. This suggests that if F0 contour is flattened, the listener would have more difficulty comprehending high content components of an utterance because an important cue to their location has been deleted.

Allen & Arndorfer (2000) examined the relationship between certain acoustic parameters and listener's perceptions of intonation contours produced by hearing impaired children. Six severe to profound hearing impaired children and six normal hearing children were the subjects. Test material included ten declarative sentences and ten phonemically matched interrogative sentences within the context of a script. Each sentence ended with a carefully chosen disyllabic (target) word. Twelve adult listeners, inexperienced with the speech of hearing impaired listened to a randomized utterances and categorized as statement, question or other. Fundamental frequency and duration measurements were obtained for the target (final) word of each sentence and intensity measures were recorded for each entire sentence. Acoustic analysis showed that both the groups had acoustically different intonation contours for declarative V/S interrogative sentences. In general, hearing impaired children's productions were similar to normal hearing children, in that they used F0, duration and intensity cues to mark the distinction. Their contrastive use of these acoustic cues, however was less pronounced than for the normal group. Multiple logistic regression of listener's responses to the hearing impaired children's utterances showed that 4 acoustic measures all derived from the sentence-final word, were significantly predictive: 1) sentence-final F0 2) slope between target word's initial and final F0 3) duration of the target word 4) dB difference between the target words 1^{SI} and 2^{nd} syllables. The two groups differed slightly in their durational correlate. For the hearing impaired group, it was the overall length of the target word, whereas for normal group, it was the relative lengths of the words two syllables. Hearing impaired children often resorted in producing higher final pitch. Their interrogatives were, on average 39% longer than declaratives, whereas in normal group the difference was only 14%. Thus to conclude, many children could produce intonation contours that are distinctive enough for linguistic purposes. Hence it is suggested that many hearing impaired children have the ability to benefit substantially from training in the production of intonation.

In most research on timing in speech, results are reported in the form of the effects of various contextual factors on segmental duration (Klatt, 1976; Umeda, 1975). These contextual factors typically involve features of phonological units; prominence of words, locations of words in phrases, and stress of syllables, though there are slight disagreement about these factors (Sitler,et al. 1983).

In Indian context there are a few studies related to correcting prosodic parameters and determining its contribution towards intelligibility. Sheela (1988) found the effect of some timing errors and average FO corrections on the intelligibility of four hearing impaired children's speech. Eight bisyllabic kannada words formed the test material. The parameters corrected were, (1) vowel duration (2) pauses (3) FO of all the phonemes. Totally seven types of corrections were obtained when combination was tried. Five listeners wrote down the words (word identification task) and rated in a 5-point scale. Wilcoxon Signed Rank test was performed to check for the significance. The results suggested maximum improvement in intelligibility when vowel duration alone was corrected. This may be probably due to the importance of vowel duration in the perception of speech. Correction of pauses had a detrimental effect on speech intelligibility. The correction of FO either alone or in combination with a pause, vowel duration and pauses and vowel duration (combined) showed a detrimental effect on intelligibility'. This could be due to synthetic speech which sounds 'monotonous' and also due to limitations of programs used for synthesis. Hence it was concluded that no dramatic gain in intelligibility may be expected, if speech pathologists succeed in training the hearing impaired children to have better control over the suprasegmental aspects of speech.

Jagadish (1989) investigated the relationship between suprasegmental errors and speech intelligibility of three hearing impaired subjects. The test material consisted of eight bisyllabic kannada words. The parameters measured were vowel duration (both in initial and final position) duration of pauses and word duration. Vowel duration (corrected in steps 25%, 50%, 75% 100%) and pauses were then corrected to match the mean values of normal group. Three listeners were the judges for word identification task, in two sets (open and closed set). Wilcoxon Signed Rank test was performed to check significant difference between the altered and unaltered words. The results suggested that intelligibility improved when vowel duration was corrected both in initial and final position (25%, 50% and 75%) along with the pauses . There was decrement in intelligibility when pauses alone was altered, duration alone was altered and when duration was altered by 100% with diminition of pause.

Sreedevi and Savithri (1999) investigated the effect of changing FO in the sentences uttered by nine hearing impaired children. The test material consisted of meaningful Kannada sentence of six words from a story 'Capseller and the Monkies'. The FO contours of the normal child's utterances were transposed onto the hearing impaired child's utterances which was then synthesized. The recorded samples were evaluated perceptually by ten normal adults. They were instructed to indicate whether the two sentences in a pair were the same or different, if they were different which of the two had better intelligibility. The results indicated 70% intelligibility score for unaltered sentences and a 12% score for synthesized sentences. This finding suggests that limiting the correction of speech of hearing impaired to intonation alone will not improve intelligibility. Rather it had a detrimental effect. However, the combination of transposition of spectral and temporal parameters may yield better results.

The review indicates that literature diverge widely with respect to suprasegmental factors of deaf speech. The role of impaired intonation in hearing impaired children's speech has not received a great deal of study to date, nor is the published literature entirely consistent in what has been found. One set of studies have included intonation as a factor influencing the perceived intelligibility of deaf speech (Hudgins and Numbers, 1992; McGarr and Osberger, 1978; Maasen and Povel, 1984, 1985; Monsen 1978; Smith 1975). Another set of studies have analyzed acoustic correlates of deaf speech (Green, 1956; Rosenhouse, 1986; Sussman and Hernandez, 1979) and found few acoustic differences between utterances that supposedly differed in intended intonation. A recent study by Allen and Arndorfer (2000) related physical measures to perceptual properties which revealed few measures to be correlated with four parameters.

To summarize, there are only few studies on the effect of FO change on intelligibility of hearing impaired speech. Of these, four studies have used words and six have used sentences. Only one study used dynamic time warping algorithm to match frames of spectral information between deaf and normal pairs of words. Only two studies report improvement in intelligibility when prosodic parameters were altered. The results are equivocal in nature. This is mainly due to the fact that no reliable phonetic transcription system exists for suprasegmental aspects. While in the area of speech production, there are several studies, research in the area of speech intelligibility is scanty. The scarcity of studies in the transformation of prosodic aspects of the hearing impaired has led to lack of understanding of the suprasegmental aspects. In this context, the present study was planned. It aims at investigating the perceptual effect of correcting FO pattern in the speech produced by the hearing impaired children. It is hypothesized that the speech intelligibility will improve after FO transformation.

CHAPTER -III

METHODOLOGY

Subjects : Two groups of subjects were considered in the present study. Group I had seven hearing impaired subjects , selected based on the following criteria.

The subjects.

1. had congenital bilateral severe hearing loss (PTA of 70dB HL - reference ANSI 1969, or more in the better ear),
2. had no other associated sensory/ motor handicap,
3. had Kannada as their mother tongue,
4. were in the age range of 8 - 11 years, and
5. were able to read simple Kannada sentences.

Group II consisted of age matched normal subjects.

Material: Five simple familiar four to five - word sentences (Appendix 1) from the study " The Capseller and the Monkeys" formed the material. Each sentence was printed on a card size 16 X 4cms of which consisted of the respective picture.

Method : Subjects were tested individually in the sound treated room of the Speech science laboratory. The stimulus card was presented to the subjects who was instructed to utter the sentence thrice into the microphone kept at a distance of l0cms from the mouth. All these were audio recorded using the tape deck.

The audio recorded samples were listened to and best of the three utterance was selected. The best utterance was then fed to the Computer through the CSL 4300 B external module and stored in the Computer memory. The Software "Computerized speech lab" was used for analysis. Using the waveform display of the 'CSL' , the duration of each sentence was measured. Sentence duration is defined as the time duration between the onset of voicing/ frication/ burst and the offset of the same. Using the 'pitch extraction' the FO movement over the sentence was extracted and the FO at every 10ms was noted. Dynamic Time-warping (DTW) was used to match the normal value. DTW was done when the sentence duration was greater than 50% compared to that of normal sentence duration. The two options provided in the program "CSL" was either to reduce the duration to half or to double the duration. Using ASL (acoustic speech lab) program correction of FO was performed on the time-warped signal. The FO of the sentences in the hearing impaired was modified at every 10ms keeping the F0 of the age matched subject as the reference. If the sentence duration was two times lesser than the matched normal duration, DTW was not performed and only F0 was corrected. Following F0 transformation, the sentences were synthesized.

Figures 1, 2 and 3 depicts the waveform before and after transformation.

23a

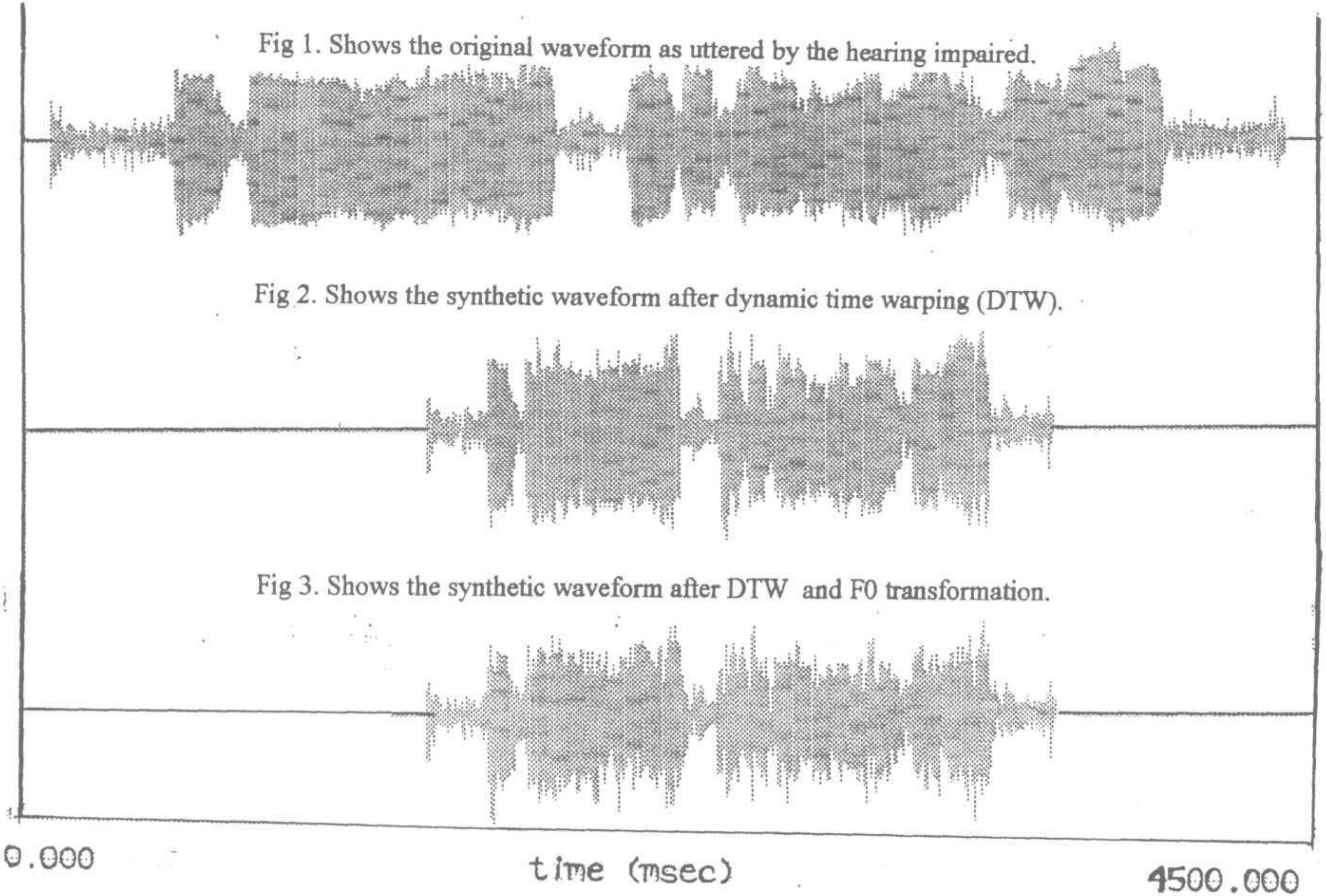


Fig 1. Shows the original waveform as uttered by the hearing impaired.

Fig 2. Shows the synthetic waveform after dynamic time warping (DTW).

Fig 3. Shows the synthetic waveform after DTW and F0 transformation.

Perceptual evaluation :

Ten judges who were native speakers of Kannada, participated in the study. Judges were instructed to rate intelligibility in two tasks. A session of thirty minutes each was alloted to each of the tasks.

Task 1: The synthesized and original sentences uttered by all the six hearing impaired subjects was randomized, iterated and audio recorded. It consisted of twenty sentences with FO only synthesis and twenty five sentences with combination of warping and FO synthesis. This resulted in a total of forty five sentence pairs. The judges were instructed to record whether the paired sentences were 'same' (S) or different (D) in terms of intelligibility on a response sheet. If they record the pair as 'different' they had to indicate whether the first (1) or the second (2) sentence was better in terms of intelligibility.

Task 2: The original sentence uttered by the hearing impaired subjects and the transformed sentence were randomized, iterated and audio recorded to form a total of forty sentences. The listeners were provided with a closed set of five sentences. They were instructed to listen to the audio recorded sentences and print the respective number of the sentence.

Statistical analysis :

Task 1 : In this task, the percentage 'Same/ Different' for each sentence pair was calculated and averaged.

Task 2 : In this task, the percentage of correct identification for each of synthetic sentence was calculated by the following formula,

$$\% \text{ Intelligibility} = \frac{\text{No. of sentences correctly identified}}{\text{Total No. of sentences}} \times 100$$

On the basis of % intelligibility the role of suprasegmentals in improving intelligibility was calculated.

CHAPTER-IV

RESULTS

Task **1**: The results of the perceptual analysis when both the parameters (FO and duration) was corrected revealed that 20% of the judges perceived original and synthetic sentences as same and 80% of the judges perceived the two as different. Table 1 indicates the perceptual analysis when both parameters were corrected.

Judges	**Same**	**Different**		**Difference between original & synthetic sentences**
		Original sentence better	**Synthetic sentence better**	
JI	11	11	**3**	**8**
J2	10	7	**8**	-1
J3	0	20	**5**	15
J4	0	22		19
J5	4	20	**1**	19
J6	0	22		19
J7	0	24	**1**	23
J8	2	22	**1**	21
J9	9	14	**2**	12
J10	13	7	5	2
AVERAGE	5	17		14
RANGE	0-13	7-24	1-8	
% AVERAGE	20%	68%	12%	
% RANGE	0-52%	28-96%	4-32%	

Table 1: Scores of the perceptual analysis for F0 and duration transformation.

In general, percent range was higher for original sentences compared to synthetic sentences. Among the original and synthetic sentences, original was perceived better by 68% of the judges. Of the ten judges, J3, J4, J6 and J7 perceived original and synthetic sentences as different, however, J1, J2, J5, J8, J9 and J10 perceived these to be same at least in few tokens. Among all the judges, J2 perceived maximum number of synthetic tokens as better than the original sentences and J7 perceived maximum number of original tokens to be better. Thus the results indicated decrement in intelligibility when both FO and duration were transformed.

Table 2 indicates the results of perceptual analysis when only FO was corrected (when the sentences uttered by hearing impaired was two times lesser than the normal, only FO transformation was done).

Judges	**Same**	**Different**		**Difference between original & synthetic sentences**
		Original sentence better	**Synthetic sentence better**	
JI	12	7	1	6
J2	7	12	1	11
J3	3	14	3	11
J4	[illegible]	17	0	17
J5	2	16	2	14
J6	2	14	4	10
J7	1	18	1	17
J8	1	18	1	17
J9	12	7	1	6
J10	10	8	2	6
AVERAGE	5	13	2	11
RANGE	1-12	7-18	0-4	
% AVERAGE	25%	65%	10%	
% RANGE	5-60%	35-90%	0-20%	

Table 2: Scores of the perceptual analysis for F0 only transformation.

In general, the original sentences were perceived as better by 65% of the judges when FO only was corrected. The percent range was higher for original sentences compared to synthetic sentences. Of the ten judges, J3, J4, J5, J6, J7 and J8 perceived a few tokens as same and majority of the sentences were perceived as different. J4 perceived original sentences to be better compared to synthetic sentences. Majority of the judges perceived only one token to be better among synthetic sentences. J6 perceived a maximum of four synthetic sentences out of twenty five sentences presented. J7 and J8 perceived maximum number of original sentences to be better. Thus the results indicated decrement of intelligibility when only FO was transformed.

Task 2: The results of sentence identification task when both the parameters (FO and duration) were corrected was tabulated. Table 3 provides a detailed description of analysis by judges when both the parameters were corrected.

Judges	**Original sentence better**	**Synthetic sentence better**	**Difference between Original & Synthetic sentence**
Jl	18	12	6
J2	18	16	2
J3	17	12	5
J4	19	14	5
J5	18	13	5
J6	16	15	1
J7	17	14	3
J8	18	15	3
J9	18	14	4
J10	19	17	2
AVERAGE	18	14	4
RANGE	16-19	12-17	
% AVERAGE	72%	56%	
% RANGE	64-76%	48-68%	

Table 3: Scores of the perceptual analysis after FO and duration transformation.

When FO and duration was corrected, 72% of the time judges perceived the original sentences to be better compared to synthetic sentences. The percent range was higher for original compared to synthetic tokens. J10 perceived maximum number of original and synthetic tokens compared to other judges. J6 perceived the least number of original tokens and Jl and J3 perceived the least number of synthetic tokens to be more intelligible. The difference between original and synthetic tokens was minimum for J6 and maximum for J1. Thus the results revealed decrement in sentence identification task when both FO and duration were transformed.

The results of sentence identification task when only FO was corrected are as in Table 4.

Judges	**Original sentence better**	**Synthetic sentence better**	**Difference between Original & Synthetic sentence**
Jl	12	15	-3
J2	14	16	-2
J3	13	13	0
J4	13	14	-1
J5	12	11	1
J6	13	14	-1
J7	13	14	-1
J8	13	14	-1
J9	14	16	-2
J10	14	16	-2
AVERAGE	13	14	-1
RANGE	12-14	11-16	
% AVERAGE	65%	70%	
% RANGE	60-70%	55-80%	

Table 4: Scores of the perceptual analysis when FO only was transformed.

When only FO was corrected, synthesized sentences were perceived better by 70% of the judges. The percent range was higher for the synthesized sentences compared to original sentences. Of the ten judges, J3 perceived no difference between the original and synthesized tokens. Jl perceived maximum number of synthetic sentences to be better compared to original sentences. The judges J4, J6, J7 and J10 perceived minimum number of synthetic sentences. Only J5 perceived original to be better compared to synthetic tokens. Thus the results indicated improvement in sentence identification task when only FO was corrected.

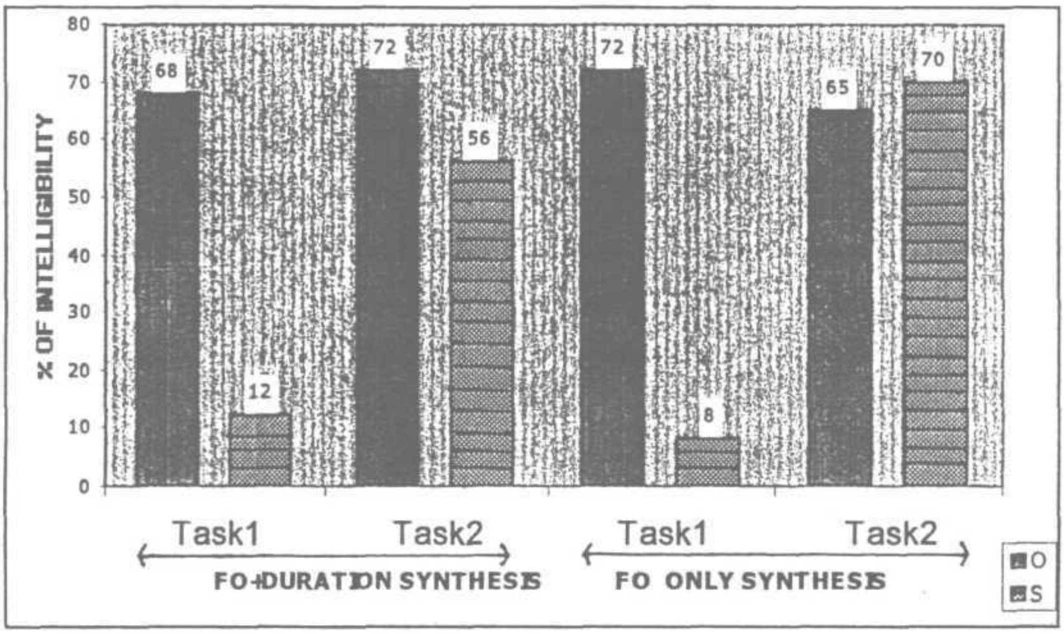
To summarize, the results revealed:

a) In task 1 and 2, FO and duration transformation resulted in decrement of intelligibility.

b) In task 1, FO transformation resulted in decrement in intelligibility. However, FO transformation in task 2 resulted in increment in intelligibility.

Figure ^indicates the summary of perceptual analysis for both the tasks.

Fig.4. Summary of Results



CHAPTER-V

DISCUSSION

The results indicated two points of interest. First of all there was a decrement in intelligibility when FO. FO and duration was transformed. The decrement in intelligibility when FO and duration was corrected and when only FO was corrected are in consonance with other studies.

Maasen (1986), in an attempt to correct the intonation by transposing the normal FO contours on to the deaf utterances also found this method to be unsuccessful. Similar results were obtained by Sheela (1988), Jagadish (1989), Sreedevi and Savithri (2000).

The reasons for a such a decrement in present study may be due to the program 'dynamic time warping" and 'pitch extraction'. After dynamic time warping the sentences sounded mechanical and as a fast dubbed utterance. The sentences after transforming FO was heard as a low pitched breathy voice. This suffix effect resulted in masking the actual sentence, thus reducing the overall intelligibility score.

The second reason for decrement may be due to the nature of synthetic sentences. After dynamic time warping, the individual segment was reduced to half, which resulted in the deletion of release of the segment in the whole sentence. It appears that the sentences uttered by hearing impaired, the prolonged nature may actually provide the listener with additional time to process their speech. The prolongation occurs due to exaggerated articulation and accumulation of greater air pressure behind the articulators (Nataraja, Savithri, Sreedevi and Sangeetha 1999).

The third reason could be the durational aspects considered while performing synthesis. The options provided in dynamic time warping was either to reduce the duration to half or to double the duration. When the sentence duration was twojtimes lesser than the normal, dynamic time warping was not performed. Hence the matching of frame to frame FO could not be applied in synthetic sentences.

The result was not in consonance with studies reported by Maasen and Povel (1985) and Komshian and Bunnel (1998). Their results suggested small, but significant improvement and contribution of suprasegmental features to the perception of normality than the temporal features.

Second, there was a minimal improvement when FO only was corrected in the second task (sentence identification). This could be probably due to the retainment of the duration which resulted in naturally sounding sentence. The judges had enough time to decide the actual sentence presented. Minimal syllable prolongation aided the better perception of sentences. This is in consonance with Maasen and Povel (1985), who reported small, but significant improvement noticed when suprasegmental aspects were corrected.

In the present study perceptual effects after FO transformation was minimal and a decrement when both the parameters (FO and duration) were synthesized. FO has been implicated as an important perceptual cue to vowel identity (Traunmuller 1981), stop consonant voicing (Haggard, Antler and Calloco, 1970), syllable stress (Lehiste, 1970) and marking lexical boundaries (Liss, Spitzer, Caviness, Adler and Edwards, 1998). Though such implications of FO are reported, limiting the correction of speech of hearing impaired to FO did not improve intelligibility significantly.

The results indicate that the segmental training may facilitate the speech of the hearing impaired rather than the suprasegmentals. Intensive training on facilitation of segmental aspects would further enhance percentage of intelligibility.

CHAPTER-VI

SUMMARY AND CONCLUSIONS

The present study aimed at investigating the perceptual effect of correcting FO pattern and duration in the speech produced by Kannada speaking hearing impaired children. It comprised of six normal and seven hearing impaired subjects in the age range of 8-11 years. The test material consisted of five simple familiar sentences. The sentences were audio-recorded and fed to the computer using CSL-4300B external module. The sentences were then analysed for duration and fundamental frequency by using the waveform display and pitch extraction respectively.

Dynamic time warping was performed to match the normal sentence duration using Acoustic speech lab program, FO was corrected for every 1 Oms on the time warped signal and finally synthesized.

The synthetic and original sentences were given for perceptual evaluation to ten judges. In task 1, judge had to rate same/different for the pair of sentences heard. The results suggested decrement in intelligibility for the synthetic sentences compared to original ones. In task 2, judges had to identify the sentence heard from a closed set given to them. The results revealed decrement in intelligibility when both the parameters (FO and duration) were synthesized. There was a slight improvement noticed when only FO was transformed.

Thus, the perceptual effects of FO transformation led to minimal improvement and a decrement in intelligibility when both the parameters were corrected. Hence it could be analyzed that limiting the correction to FO will not improve intelligibility, but the focus while training hearing impaired should be on the segmental aspects.

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APPENDIX-1

TEST MATERIAL

೧. ಒಂದು ಊರಿನಲ್ಲಿ ಒಬ್ಬ ಟೋಪಿ ಮಾರುವವನು ಇದ್ದನು.

೨. ಕೋತಿಗಳ ತಲೆಯ ಮೇಲೆ ಟೋಪಿಗಳು ಇದ್ದವು.

೩. ಆದರೆ ಕೋತಿಗಳು ಟೋಪಿಯನ್ನು ಕೊಡಲಿಲ್ಲ.

೪. ಆಗ ಅವನಿಗೆ ಒಂದು ಉಪಾಯ ಹೊಳೆಯಿತು.

೫. ಅವನು ತನ್ನ ಟೋಪಿಯನ್ನು ಕೆಳಗೆ ಎಸೆದನು.