SPECTROGRAPHIC ANALYSIS OF SPEECH OF THE HEARING IMPAIRED

Reg. NO. M. 9019

Dissertation submitted as part fulfilment for the second year

M.Sc. (Speech and Hearing) to the University of Mysore

All India Institute of Speech and Hearing
MYSORE-570 006
1992

To

My Guide

CERTIFICATE

This is to certify that the Dissertation entitled: **"SPECTROGRAPHIC ANALYSIS OF SPEECH OF THE HEARING IMPAIRED"** *is a bonafide work, done in part fulfilment for the Second Year M.Sc. (Speech and Hearing) of the student with* **Reg.No.M9019.**

DR.(MISS).S.NIKAM

MYSORE
1992

DIRECTOR
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CERTIFICATE

This is to certify that the dissertation entitled

"SPECTROGRAPHIC ANALYSIS OF SPEECH OF

THE HEARING IMPAIRED"

has teen prepared under my supervision and guidance.

Dr.N.P.NATARAJA 29/10/91
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DECLARATION

This dissertation entitled: **"SPECTROGRAPHIC ANALYSIS OF SPEECH OF THE HEARING IMPAIRED"** *is the result of my own study under the guidance of* **Dr.N.P.NATARAJA,** *Professor and HDD, Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any other University for any other Diploma or Degree.*

MYSORE **Reg.No. M.9019**
1992

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C O N T E N T S

INTRODUCTION

"I am just as deaf as I am blind wrote Helen Keller. The problems of deafness are deeper and more complex, if not more important than those of blindness. Deafness is a much worse misforture. For it means the loss of the most vital stimulus the sound of the voice that brings language, sets thoughts astir, and keeps us in the intellectual company of man" (Stevens and Warshofsky, 1971).

Human speech production is diverse and fascinating endeavour, the diversity of which is highlighted by the capacity for human communication by speech to be examined at several levels: physiological, acoustical, psychophysical, linguistic and psycholinguistic levels underlying both production and perception of speech (Weinberg, 1986).

"Long ago the function of hearing became the building stone upon which our intricate human communication was built. If Pre-dawn man had not inherited an ear, he might have resorted instead to signing with his fingers or scratching masks upon the sand, to share his thoughts with others. The result would have an awkward method of communication that could have slowed, for millennia our so called progress. For good or bad, we have developed the ear and the vocal mechanism as the media through which lanaguage is communicated" (Northern, J.L. and Downs M.P., 1978).

"The auditory linked acquisition of language is further unique to human beings because it is a time locked function, related to early maturational periods in the infants life" (Northern, J.L. and Downs M.P., 1978).

"Early hearing impairment has definite effects on language development. As shown by Quigley and Thomure (1968), Goetzinger (1962), Harrison (1964) and others, even very mild impairments of hearing (less than 30dB) are often related to language and other educational deficits. This relation of hearing impairment and language deficit is evident in all a spects of lnguage-phonological, morphological, syntactic and semantic" (Quigley, 1978).

"The longer auditory language is delayed, the less efficient will be the language facility" (Northern, J.L. and Downs, M.P. 1978).

"The speech of the deaf differs from that normals in all regards (Balck 1971). In all studies of speech of the hearing impaired, attention is drawn to the fact that, to a greater or lesser degree, the hearing impaired individuals do not produce speech as well as those who hear" Monsen (1974).

Various studies have been carried out in understanding the speech of the hearing impaired (Hudgins and Numbers 1942, Nober, 1967, Mc Garr, 1978, Geffner, 1980, Stoel Gammon, 1982, Rajanikanth, 1986, Shukla, 1987, Sheela, 1988, Jagadish, 1989, Whitehead, 1991). But the knowledge in this area is far from complete.

AIM OF THE STUDY

This study was undertaken to study the speech characteristics of Kannada speaking hearing impaired children spectrographically in terms of formant frequencies, vowel duration, voice onset time and closure duration.

HYPOTHESIS

The following hypotheses were proposed for the study:

1) There is no significant difference in terms of the speech of the hearing impaired children to that of the normal hearing children in terms of

a) Formant frequencies of vowels

b) Vowel duration

c) Formant frequencies of stop consonants

d) Voice onset time of stop consonants.

e) Closure duration of stop consonants.

METHODOLOGY

The speech samples were collected from the five normal and five hearing impaired children (age range 5-10 years). Speech sample involved the elicitation of ten CVCV nouns with the carrier phase "idu". The stimuli words were presented through picture cards.

Best three out of five trails were analyzed using a PC/AT computer with the necessary software to obtain spectral parameters. The data was been subjected to statistical analysis and results have been discussed.

IMPLICATIONS OF THIS STUDY

The results of this study would help in better understanding of the speech of the hearing impaired children in an Indian language.

The results of the study would provide data regarding the spectrographic characteristics of speech of the hearing impaired children.

This information would hlep in planning and developing therapy programmes for the hearing impaired.

LIMITATIONS OF THIS STUDY

1. The study was limited to only 5 subjects in both the control as well experimental groups.

2. The study was limited to only male children.

3. Individuals differences existed in the hearing impaired children in terms of hearing aid usage, therapy duration, parental participation in therapy, motivation in therapy etc.

4. The stimulus materials used for study were only ten 'CVCV' nouns.

METHODOLOGY

INTRODUCTION

The main objective of this study was to analyze the speech of Kannada speaking hearing impaired children. The spectrographic analysis of speech was done to obtain values of formant frequencies (Fl, F2, F3) in vowels and stop consonants, vowels duration, closure duration of consonants and voice onset time. Vowels /a/, /a:/, /i/, /i:/, /u/ /u:/, /e/, /e:/, /o/, /o:/ and stop consonants /p/, /b/, /t/, /d/, /k/; /g/ were selected for this purpose. But for the measurement of closure duration only /p/, /b/, /t/, /d/, /t/, /d/ were used.

The study also involved the investigation of five normal male hearing children of age five to ten years (Mean age - 7.4 years) as control group. The hearing imparied children were selected from the clinic of All India Institute of Speech and Hearing, Mysore based on the ctiteria that
The child should a) bein the age range of 5 to 10 years

(b) be having Congenital bilateral hearing loss (PTA of greater than 70dB - ANSI, 1969, in the better ear).

(c) have abilities to name the pictures or read.

(d) have no additional handicaps other than that directly related to hearing impairment.

It must be noted that all the hearing impaired children chosen had receive(d) speech therapy at AIISH. All the

children used oral speech mode for communication. The children of the control group had hearing within normal limits on audiological testing and they were chosen from within the institute campus and they too did not have any such problems.

Table showing age and hearing thresholds for the subjects of control group.

a) Normal hearing group:

Sl. No.	Age	Audiological/screening (at 500, 1K, 2K)
1	7 years	Normal limits
2	10 years	- do -
3	7 years	- do -
4	7 years	- do -
5	6 years	- do -

Mean age group was 37/5 = 7.4.

Table showing age and hearing thresholds for the subjects of Experimental group.

b) Hearing impaired group:

Sl.No.	Age	PTA Right	Left
1	10 years	110	110 (500,1K,only)
2	9 years	73	86
3	5"	107	108
4	5"	75	80
5	8"	90	85

Mean age group was 37/5 - 7.4.

MATERIAL

To elicit the speech, commonly spoken nouns (CVCV combination), along with the carrier phrase "idu_____" were used.

The target sounds used for spectrographic analysis are presented below with their respective words:

	words	Consonant	Vowel
1	paṭa	/p/	/a/
2	ba:tu	/b/	/a:/
3	giḍa	/g/	/i/
4	di:pa	/d/	/i:/
5	tuṭi	/t/	/u/
6	gu:be		/u:/
7	kere		/e/
8	ge:ṭu		/e:/
9	koḍe		/o/
10	ko:ti	/k/	/o:/

Recording procedure:

The subject was seated comfortably in the sound treated room at the Department of Speech Sciences, AIISH and audio recordings were made with the tape recorder (model Philips -AW739 Stereo Ampli Deck). The microphone used for this purpose (model AKG-D222 Cardioid type) was kept six inches away from the subjects mouth. The stimulus materials comprised of picture cards. The stimulus materials were presented in a predetermined random order in all five trials by the experimenter. Before every trial a calibration tone

As stated in the study of Abraham.S and Weiner.F (1987) that the consonant production is facilitated with more precision in nouns than in verbs, this study utilized ten common meaningful, picturizable words of Kannada Language.

of 1KHz tone was generated by using a Heterodyne analyzer (Model B&K type 2010) and recorded for 30 secs. Between two successive trials, a gap of minimum 24 hours was allowed to eliminate possible practice effect.

Best three trails out of five (which were considered to be more intelligible) were selected for analysis purpose for all subjects of both the groups.

INSTRUCTION

The children were requested to name in Kannada the picture cards with the carrier phrase "idu".

The subject was made to repeat after the experimenter, whenever the subject had difficulty in finding the target word.

INSTRUMENTATION

Analysis principally involved the following instruments:

1) Antialiasing filter (low pass filter having cut off frequency at 3-5/7.5KHz) with speech interfacing unit.

2) A-D/D-A converter (sampling frequency 8/16KHz, 12 bit)

3) Personal computer AT Inter 80 386 microprocessor (80837 numerical data processor).

4) Software for analysis of speech developed by Voice Speech System, Bangalore.

5).Amplifier and speaker (2011 SOIS Ampli speaker).

PHOTOGRAPH-A: Set up of equipment for analysis of data

PARAMETERS

The speech samples were digitized using 12 bit ADC/DAC board at the sampling frequency of5000Hz and were stored in computer memory. The acoustic parameters were measured using wide band spectrography (300Hz/600Hz). Spectrogram s were derived based on 1024 points FFT calculation for every 3 msec for both vowels and consonants the following parameters were measured:

1) Formant frequencies (Fl, F2 and F3 in Hz) of vowels /a/, /a:/, /i/, /i:/, /u/, /u:/, /e/, /e:/, /o/, /o:/.

2) Vowel duration of /a/, /a:/, /i/, /i:/, /u/, /u:/, /e/, /e:/, /o/, /o:/.

3) Formant frequencies (Fl, F2 and F3) of stop consonants /p/, /b/, /t/, /d/, /k/, /g/.

4) Voice onset time of stop consonants /p/, /b/, /t/, /d/, /k/, /g/.

5) Closure duration of consonants /p/, /b/, /t/, /d/, /ṭ/, /ḍ/.

Formant Frequencies:

Definition: A formant was operationally defined as the local maximum in the vocal tract transfer function detected, only during the transmission of acoustic energy and displayed in the form of a peak in the amplitude spectrum that is not due to source spectrum parameters.

By FFT analysis the cursor was placed at the steady state portion of the vowel and the section was taken at that point and the most prominent peaks were taken as Fl, F2, F3 respectively and it is measured in Hertz (Hz).

The burst frequencies of the stop consonants were also obtained in the same manner.

Vowel Duration

The vowel duration was defined as the time between the onset and cessation of glottal vibration (House, 1961; Whitehead and Jones, 1976).

The vowel duration was measured from the spectrogram as the time duration between the initial regular glottal vibration to the final regular vibration associated with that vowel formed the vowel duration. The unit of vowel duration is in milliseconds (msec).

Voice onset time (VOT)

VOT was defined as the time equivalent space from the onset of the stop release burst to the first vertical striation representing glottal pulsing (Liberman, Delattre, and Cooper, 1952; Lisker and Abramson, 1964, 1967).

The VOT was measured for the six stop consonants in the target word from the spectrograms. The cursor was moved to the first indication of energy associated with the stops oral release and that point was marked. Then the cursor was moved

to the beginning of the regularly appearing waveform of the vowel following that stop. The real time value (in msec) between these two markings provided the VOT. VOT was measured for the stop consonants in the following target words:

1 /p/ - in paṭa

2 /b/ - in ba:tu

3 /k/ - in ko:ti

4 /g/ - in giḍa

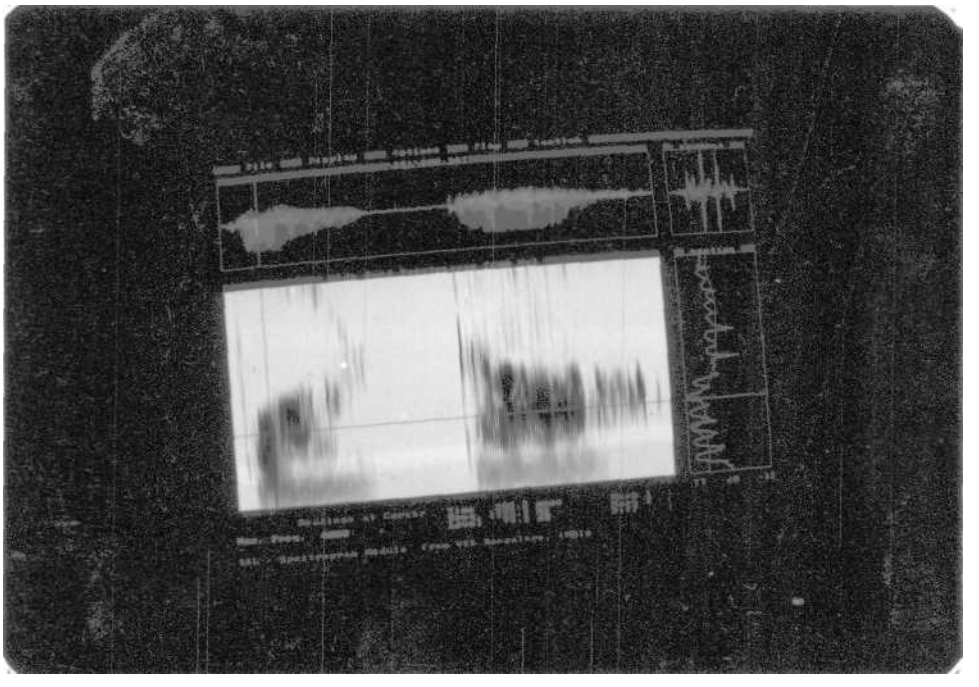
5 /t/ - in tuṭi

6 /d/ - di:pa

CLOSURE DURATION:

The consonant closure duration indicated the time for which the articulator is held in position for stop consonant. Closure duration was the duration between the offset of resonance for the preceding vowel and the onset of burst for the stop consonant in intervocalic condition and duration from the regular vertical striation on the baseline to the onset of burst for the voiced stop in the initial position. The consonant closure duration was determined by placing the cursor at the terminal point of the preceding vowel to that of the onset of burst following it is the spectrogram. The time value thus obtained was the consonant closure duration of that consonant.

The consonant closure duration of the following sounds were determined with their respective words as follows:



PHOTOGRAPH-B: Spectrogram display used for the measurement of Formant Frequencies (Fl, F2 & F3), Vowel Duration (VD), Voice Onset Time (VOT) and Closure Duration (CD)

/p/ - di:pa

/b/ - gu:be

/t/ - ba:tu

/d/ - idu of di:pa

/ṭ/ - paṭa

/ḍ/ - giḍa

STATISTICAL ANALYSIS

Descriptive statistics consisting of mean, standard deviation, range were obtained for all the parameters. Mann-Whitney two sampled U test matched, along with t-test was performed for finding out the significance of means of the experimental group to that of the control group for comparison purpose.

RESULTS AND DISCUSSION

Ten CVCV nouns uttered by five hearing impaired speakers and five normals on three out of five trials were used for specrographic analysis. The parameters noted were:

1) Formant frequency characteristics (Fl, F2 and F3). of short vowels /a/, /i/, /u/, /e/, /o/ and long vowels /a:/, /i:/, /u:/, /e:/ and /o:/.

2) Duration of above mentioned vowels.

3) Formant frequency characteristics (Fl, F2 and F3) of stop consonants /p/, /b/, /t/, /d/, /k/, /g/.

4) Voice onset time of stop consonants /p/, /b/, /t/, /d/, /k/, /g/.

5) Closure duration of stop consonants /p/, /b/, /t/, /d/, /ṭ/, /ḍ/.

Descriptive and inferential statistical analyses were carried out. The results are presented below.

FORMANT FREQUENCY CHARACTERISTICS OF VOWELS

Table-1 and Graph-1 provide mean, standard deviations and range of Fl for short vowels in the speech of the hearing impaired and normals. The mean Fl values of all short vowels produced by the hearing impaired were found to be higher than that of the normals, varying from 25-131Hz. For /a/ the difference between the means of hearing impaired to that of

normals was 25Hz; for /i/ - 131Hz, for /u/ - 96Hz, for /e/ -93Hz and for /o/ 30Hz. However, a significant mean difference between the groups was found only for the vowels /i/ and /u/.

Table-1.1: The mean, S.D., Range and Mean differences values of Fl of short vowels in hearing impaired and normal groups (in Hz).

Vowels	Hearing Impaired			Normals			Mean diff. HI&normal
	Mean	(SD)	Range	Mean	(SD)	Range	
/a/	940	(175)	627-1176	915	(132)	627-1160	25
/i/*	842	(104)	407-784	511	(115)	266-658	131
/u/*	656	(110)	502-909	560	(68)	398-643	96
/e/	716	(160)	392-941	623	(94)	517-784	93
/o/	654	(164)	392-941	624	(103)	517-900	30

* significant difference between the means at 0.05 levels

Table-1.2 and Graph-1 show the mean Fl values of long vowels for both the groups. The mean Fl values for the hearing impaired was found to be higher than that of the normals (by 9-182Hz) except for /a;/ (lower by 7Hz) and /e:/ (lower by 6Hz). Sheela (1988) also reported similar results i.e., higher Fl values in the vowels produced by hearing impaired group than in vowels produced by normal group. But the significant difference was present only for high vowel /i:/ (182Hz).

Table-1.2: The mean, S.D., Range and Mean differences values of Fl of long vowels in hearing impaired and normal groups (in Hz).

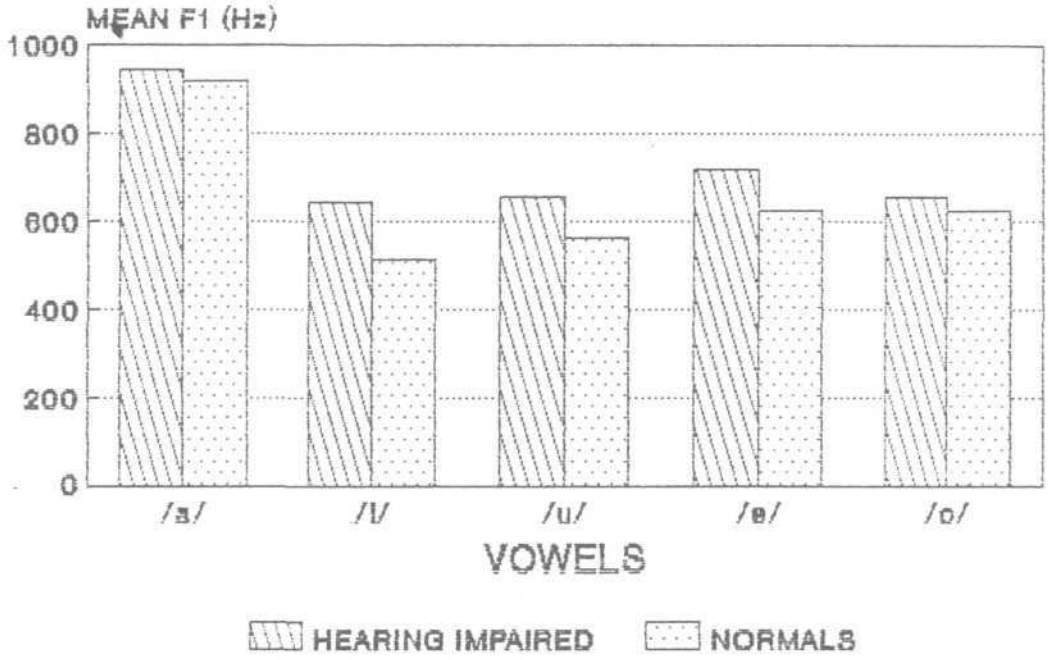
Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI and Normal
/a:/	1006 (203)	643-1317	1013 (123)	784-1237	-7
/i:/*	595 (196)	266-925	413 (112)	235-643	182
/u:/	545 (106)	390-784	536 (77)	382-658	9
/e:/	594 (106)	390-784	600 (54)	502-643	-6
/o:/	619 (105)	392-784	598 (76)	503-784	21

* Significant difference between means 0.05 level

The hypothesis that there is no significant difference between the means of Fl values of the hearing impaired and normal children was accepted for /a/, /e/, /o/, /a:/, /u:/, /e:/ and /o:/ and rejected for /i/, /u/ and /i:/. However it may be generally concluded that the vowels produced by hearing impaired group has Fl similar to normals.

Table-1.3 and 1.4 and Graph-2 show the mean F2 values of short vowels and long vowels respectively. The mean F2 values of back vowels /a/, /u/ and /o/ were found to be higher i.e., the mean difference between normals and hearing impaired were 177Hz, 191Hz and 329Hz respectively. Whereas for front vowels /i/ and /e/ mean difference values were found to be lower in impaired by 657Hz and 740Hz respectively. However significant difference between means was present for front vowels /i/ and /e/ and back vowel /o/.

GRAPH-1: SHOWING THE MEAN F1 OF HEARING IMPAIRED AND NORMAL GROUPS FOR SHORT VOWELS



GRAPH-1: SHOWING THE MEAN F1 OF HEARING IMPAIRED AND NORMAL GROUPS FOR LONG VOWELS

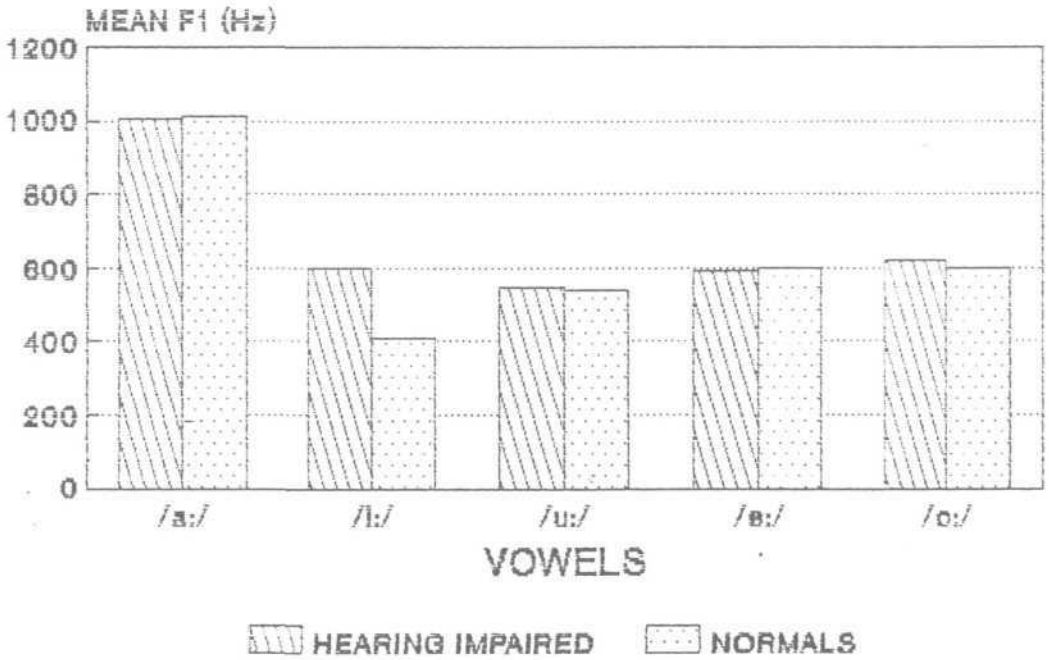


Table-1.3; The mean, S.D., Range and Mean differences values of F2 of short vowels in hearing impaired and normal groups (in Hz).

Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a/	1837 (192)	1529-2070	1660 (128)	1412-1819	177
/i/*	2470 (698)	1239-3730	3127 (251)	2698-3498	-657
/u/	1591 (318)	1176-2327	1400 (279)	1035-1960	191
/e/*	2226 (517)	1647-3702	2966 (153)	2713-3231	-740
/o/*	1526 (250)	1050-1960	1197 (154)	894-1443	329

* significant difference between the means at 0.05 level

The study of Table-1.4 and Graph-2 revealed that the long vowels followed the same pattern as that of short*vowels but greater difference in terms of mean values were present for /a:/ - 242Hz, for /o:/ - 383Hz, for /u:/ - 489Hz. For /i:/ and for /e:/ the values were lower by 778Hs and 636Hz respectively in the hearing impaired group.

These differences were found to be significant for all long vowels. The results of the present study are in agreement with study by Sheela (1988) i.e., high F2 values in vowels produced by hearing impaired but only with respect to back vowels /a/, /o/, /u/ and /a;/, /o:/ and /u:/.

Table-1.4: The mean, S.D., Range and Mean differences values of F2 of long vowels in hearing impaired and normal groups (in Hz).

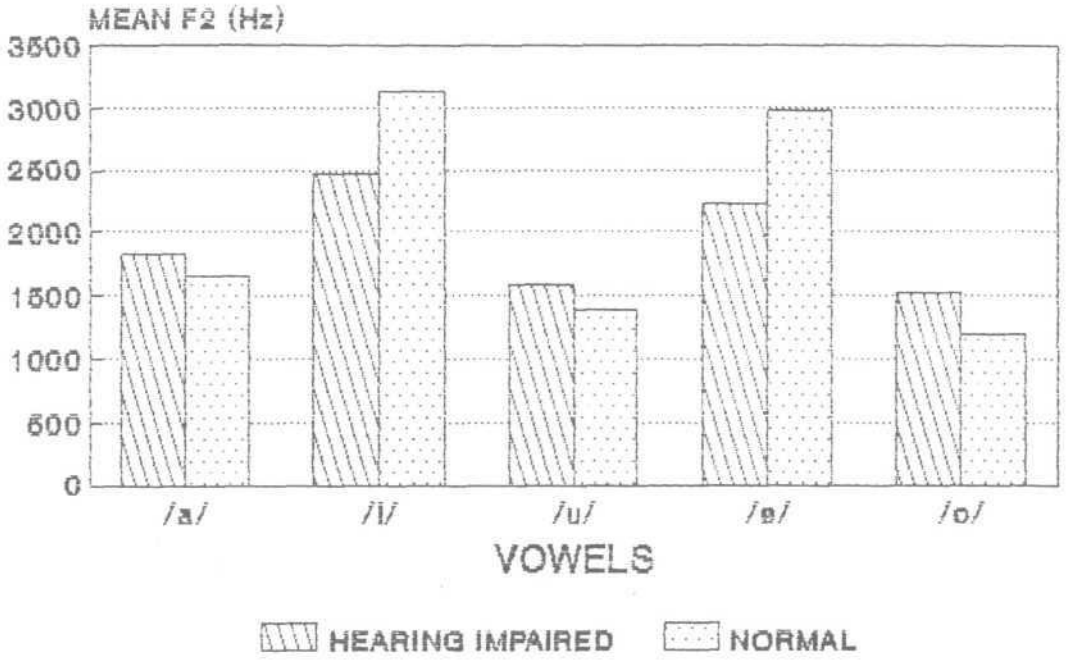
Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a:/*	1805 (286)	1427-2305	1563 (123)	1427-1803	242
/i:/*	2465 (626)	1552-3639	3243 (252)	2893-3858	-778
/u:/*	1524 (263)	1176-2164	1035 (87)	900-1223	489
/e:/*	2311 (571)	1678-3790	2947 (161)	2588-3200	-636
/o:/*	1538 (281)	1035-1945	1155 (170)	862-1427	383

* Significant difference between means at 0.05 level

The hypothesis that there is no significant difference between the means of F2 values of the hearing impaired and normal children was accepted for /a/, /u/, /o/ and rejected for /e/, /i/, /o/, /a:/, /i:/, /u:/, /e:/ and /o:/. Thus it can be concluded that the mean F2 is significantly higher in the vowels produced by hearing impaired.

Tables 1.5 and 1.6 and Graph-3 depict the mean F3 values of short and long vowels respectively. The mean F3 values of all the short and long vowels are found to be lower than that of the normals by 3Hz to 190Hz except for the long vowel /o:/ (261Hz).

GRAPH-2: SHOWING THE MEAN F2 OF HEARING IMPAIRED AND NORMAL GROUPS FOR SHORT VOWELS



GRAPH-2: SHOWING THE MEAN F2 OF HEARING IMPAIRED AND NORMAL GROUPS FOR LONG VOWELS

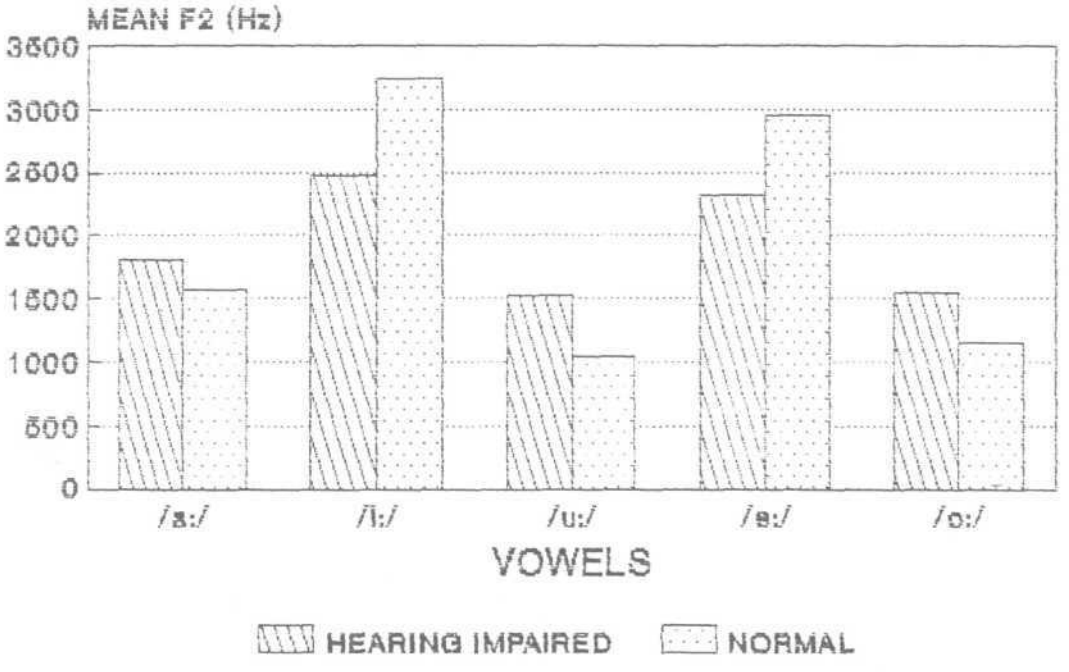


Table-1.5: The mean, S.D., Range and Mean differences values of F3 of short vowels in hearing impaired and normal groups (in Hz).

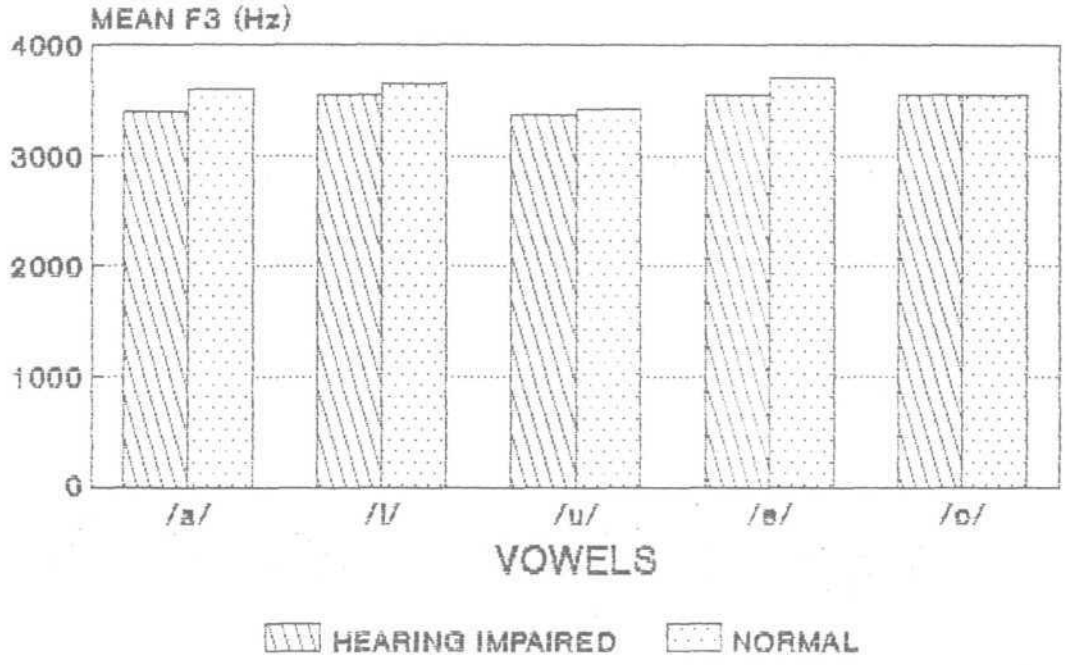
Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a/	3408 (391)	2274-3921	3593 (194)	3209-3858	-185
/i/	3557 (334)	2839-3921	3640 (157)	3366-3874	-83
/u/	3360 (395)	2431-3984	3427 (302)	2823-3937	-67
/e/	3549 (332)	2745-3858	3693 (117)	3482-3890	-144
/o/	3545 (245)	3215-3921	3548 (300)	2760-3874	-3

The result of t-test did not show any significant difference in F3 value produced by hearing impaired and normals. The result of this study supported the results of the study by Sheela (1988) i.e., the F3 of the hearing impaired group in lower than that of the normals. However, long vowel /o:/ was an exception.

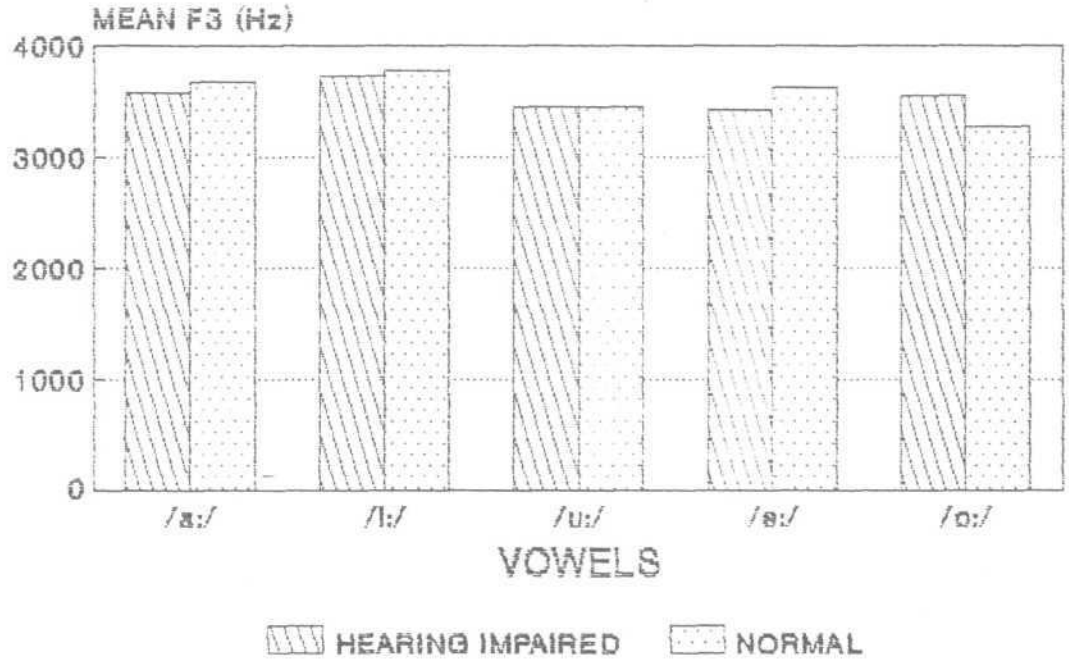
Table-1.6: The mean, S.D., Range and Mean differences values of F3 of long vowels in hearing impaired and normal groups (in Hz).

Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a:/	3577 (268)	3110-3899	3681 (308)	2839-3984	-104
/i:/	3721 (176)	3363-3890	3778 (106)	3707-3893	-57
/u:/	3441 (383)	2666-3984	3449 (268)	2890-3811	-8
/e:/	3429 (421)	2541-3921	3619 (170)	3372-3858	-190
/o:/	3539 (279)	2980-3905	3278 (940)	2960-3874	261

GRAPH-3: SHOWING THE MEAN F3 OF HEARING IMPAIRED AND NORMAL GROUPS FOR SHORT VOWELS



GRAPH-3: SHOWING THE MEAN F3 OF HEARING IMPAIRED AND NORMAL GROUPS FOR LONG VOWELS



The hypothesis that there is no significant difference between the means of F3 values of the hearing impaired and normal children was accepted for both short and long vowels.

Based on the analyses of vowels produced by the hearing impaired group, the following conclusions can be drawn:

1) Fl is similar to normals.
2) F2 is higher than normals.
3) F3 is similar to normals.

FORMANT FREQUENCY RELATIONSHIP OF VOWELS

Tables-1.7 and 1.8 show the mean difference values of in terms of Fl and F2, F2 and F3 and F3 and Fl for short and long vowels respectively both in hearing impaired and normals.

Table-1.7: Showing the difference between formant frequencies in short vowels for hearing impaired group and normal group (In Hz)

Vowels		Hearing Impaired group	Normals groups	Mean difference hearing impaired and normal
/a/	Fl - F2	897	745	152
	F2 - F3	1571	1983	-362
	F3 - Fl	2468	2678	-210
/i/	Fl - F2	1830	2616	-786
	F2 - F3	1087	513	574
	F3 - Fl	2915	3129	-214
/u/	Fl - F2	935	840	95
	F2 - F3	1769	2027	-258
	F3 - Fl	2704	2867	-163
/e/	Fl - F2	1510	2343	-833
	F2 - F3	1323	727	596
	F3 - Fl	2833	3070	-237
/o/	Fl - F2	872	573	299
	F2 - F3	2019	2351	-332
	F3 - Fl	2891	2924	-33

Table-1.8: Showing the difference between formant frequencies in long vowels for hearing impaired group and normal group (In Hz)

Vowels		Hearing Impaired group	Normal group	Mean difference hearing impaired and normal
/a:/	Fl - F2	799	550	249
	F2 - F3	1772	2118	-346
	F3 - Fl	2571	2668	-97
/i:/	Fl - F2	1870	2830	-960
	F2 - F3	1256	535	721
	F3 - Fl	3126	3365	-239
/u:/	Fl - F2	979	499	480
	F2 - F3	1957	2414	-457
	F3 - Fl	2936	2913	23
/e:/	Fl - F2	1717	2347	-630
	F2 - F3	1118	672	446
	F3 - Fl	2835	3019	-184
/o./	Fl - F2	919	557	362
	F2 - F3	2001	2123	-122
	F3 - Fl	2920	2680	240

Inspection of the above tables showed that

1) In short front vowels, Fl was high, the difference between F2 and F3 was low and the difference between Fl and F2 was low. From the acoustic model of speech production given by Fant (1968) these changes may be attributed to tongue retraction. Boone (1966) has also reported similar change in the articulatory position in the hearing impaired.

2) In back vowels it has been found that F2 was high, F3 was low, the difference between F2 and Fl was high.The model given by Fant (1968) these changes may be attributed to mid palatal position of the tongue. Stein (1988) from his cineflrographic study of vowels, produced by hearing impaired speakers, has drawn similar conclusions.

3) In long front vowels Fl was high, F3 was low, the difference between Fl and F2 was low, the difference between and F2 and F3 was high. Again according to Fant, these changes may be attributed to tongue retraction and pre palatal positioning of the tongue.

4) In back vowel /u:/ Fl was high, the difference between Fl and F2 "Was also high, hence tongue fronting is suggested.

5) In /u:/ the difference between F2 and F3 was comparitively low and F2 was high, the tongue placement is considered to be in mid palatal position. Even for /i:/ also, the tongue is considered to be in mid palatal position (Fant, 1968).

6) If Fl was low and the difference between Fl and F2 was - high, /a:/, then it is considered that the mouth opening is narrowed and there was tongue fronting according to Fant (1968). A similar finding was observed in the present study.

In general, it may be concluded that during the production of front vowels there was retraction of the tongue and during the production of back vowel fronting of the tongue was used by the hearing impaired.

DURATIONAL CHARACTERISTICS OF VOWELS

Table 1.9 and 1.10 and Graph-4 showed the durations of short and long vowels respectively. All hearing impaired children had mean vowel duration for both short and long vowels than that of the control group. This agrees well with the results reported by Rajanikanth (1986), Shukla (1987), Sheela (1988) and Jagadish (1989) but for the long vowel /u:/ the duration was less than the normals by 70msec. This was found to be statistically significant.

Table-1.9: The mean, S.D., Range and Mean differences values of vowels duration of short vowels in hearing impaired and normal groups (in msec).

Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a/*	165 (76)	54-303	111 (26)	69-164	54
/i/*	219 (100)	103-449	135 (48)	93-254	84
/u/*	208 (119)	91-533	137 (103)	69-485	71
/e/	249 (107)	90-412	197 (78)	124-433	52
/o/	249 (118)	76-530	147 (38)	93-251	102

* Significant difference between the means at 0.05 level

Table-1.10: The mean, S.D., Range and Mean differences values of vowels duration of long vowels in hearing impaired and normal groups (in msec).

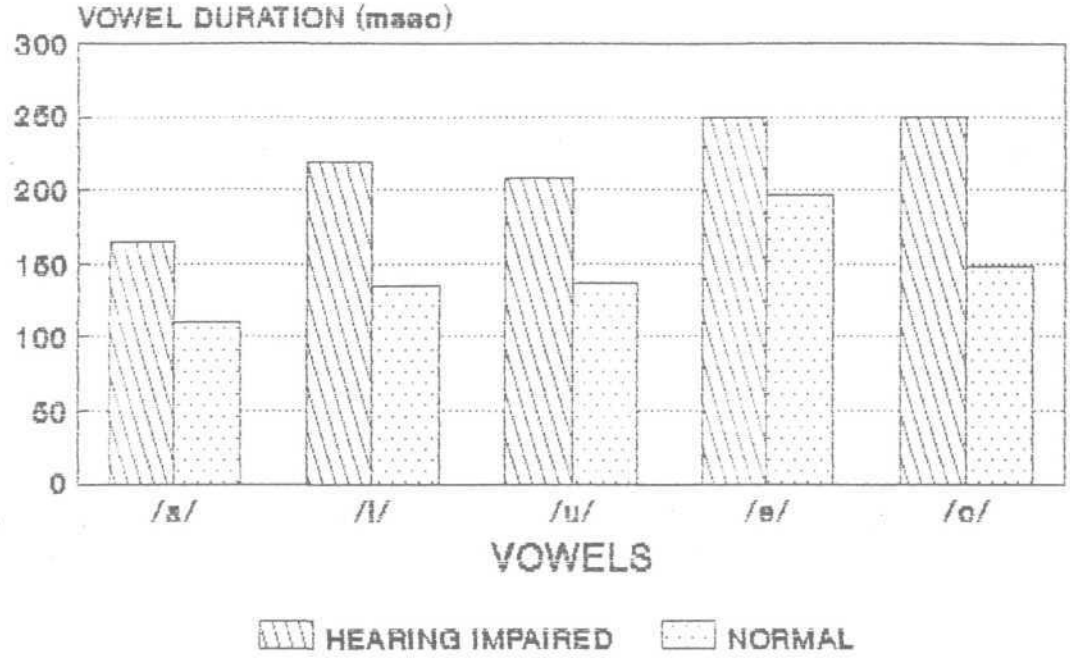
Vowels	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/a:/	334 (87)	204-479	285 (71)	202-405	49
/i:/	264 (66)	134-384	260 (79)	180-419	4
/u:/*	237 (99)	143-476	307 (83)	195-485	-70
/e:/*	333 (126)	0-602	291 (84)	205-458	42
/o:/	310 (80)	217-451	275 (89)	165-460	35

* Significant difference between the means at 0.05 level

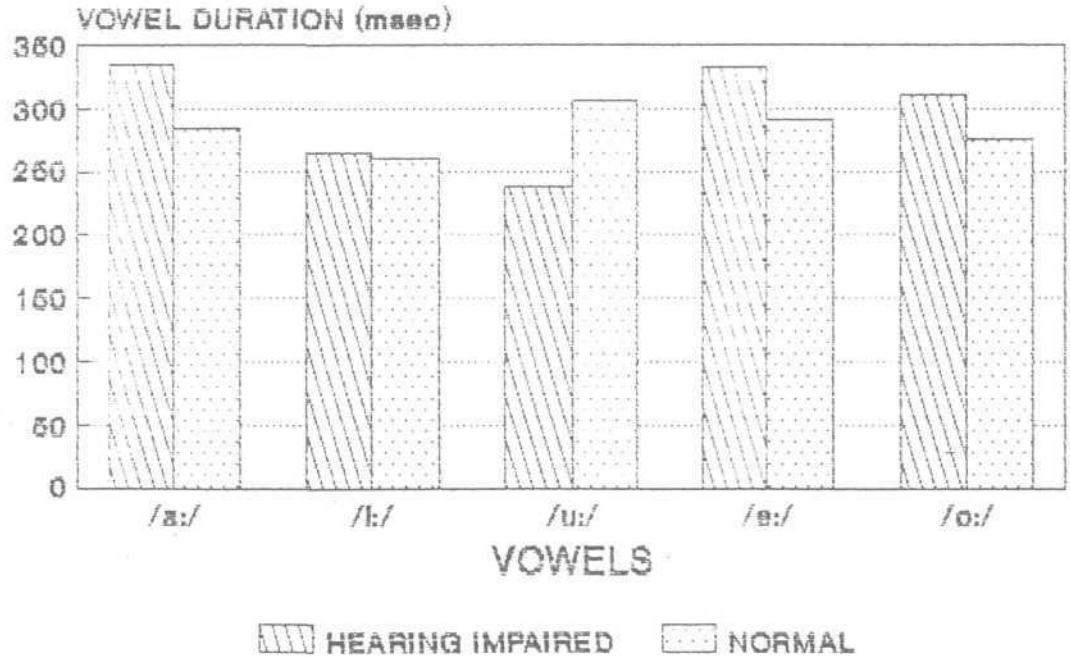
The short vowels produced by the hearing impaired children had longest duration of 249msec for mid vowels /e/ and /o/ followed by high vowels /i/ and /u/ (219 and 218msec resceptively) and finally by /a/ (165msec). Whereas the normals had the duration in the order: e>o>u>i>a (197>147>137>135>111). Thus the hearing impaired group followed more or less the same pattern as that of experimental group. Significant differences between normals and hearing impaired in the mean values of vowels duration /a/, /i/, /u/and /o/ with the difference in mean values being 54, 85, 71 and 102msec respectively for the control group.

In terms of range /a/ showed the lowest value and /u/ the highest value in both the groups whereas for long vowels no such pattern was observed. In terms of long vowels hearing impaired group showed /u:/ with 237msec as the lowest value and /a:/ with the highest value (334msec). Whereas the

GRAPH-4: SHOWING THE MEAN VOWEL DURATION OF HEARING IMPAIRED AND NORMAL GROUPS FOR SHORT VOWELS



GRAPH-4: SHOWING THE MEAN VOWEL DURATION OF HEARING IMPAIRED AND NORMAL GROUPS FOR LONG VOWELS



normals showed high vowels /i:/ and /u:/ as having lowest and highest (260 and 307 respectively) . However significant difference between their means was present for back high vowel /u:/ and front mid high vowel /e:/.

The hypothesis that there is no significant difference between the vowel duration values of the hearing impaired and normal children was accepted for /e/, /o/, /i:/ and /o:/ only and rejected for /a/, /i/, /u/, /u:/ and /e:/.

In terms of vowel duration in general vowels studied showed higher mean values in the hearing impaired than in normals.

The analysis of vowels produced by hearing impaired and normals showed the following:

1) The hypothesis that there is no significant difference between the means of Fl values of the hearing impaired and normal children was accepted for /a/, /e/, /o/, /a:/, /u:/, /e:/ and /o:/ and rejected for /i/, /u/ and /i:/.

2) The hypothesis that there is no significant difference between the means of F2 values of the hearing impaired and normal children was accepted for /a/, /u/, /o/ and rejected for /e/, /i/, /o/, /a:/, /i:/, /u:/, /e:/ and /o:/.

3) The hypothesis that there is no significant difference between the means of F3 values of the hearing impaired and normal children was accepted for both short and long vowels.

4) The hypothesis that there is no significant difference between the vowel duration values of the hearing impaired and normal children was accepted for /e/, /o/, /i:/ and /o;/ only and rejected for /a/, /i/, /u/, /u:/ and /e:/.

CONSONANTS

The following tables-2.1-2.13 and Graphs-5-9 present details regarding formant frequencies, VOT as well as closure duration of the stop consonants of Kannada i.e.,the Mean, Standard Deviation and range of the parameters as presented byf the hearing impaired and the normal children. The two groups have been compared in terms of these parameters. The asterisk mark indicates the presence of a statistically significant difference between the means at 0.05 level.

FORMANT FREQUENCY CHARACTERISTICS OF STOP CONSONANTS

Table-2.1 and Graph-5 provide the mean Fl value for voiceless stop consonants /p/, /t/, /k/ produced by the hearing impaired and normals. Table-2.2 and Graph-5 show the Fl values for voiced stop consonants /b/, /d/ and /g/.

Table-2.1: The mean, S.D., Range and Mean difference, values of Fl of voiceless stop consonants in hearing impaired and normal groups (in Hz).

Conson-ants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/P/	569 (112)	376-784	594 (84)	423-740	-25
/t/	550 (125)	360-768	581, (145)	376-887	-31
/k/	633 (168)	394-941	556 (137)	387-925	77

Table-2.2: The mean, S.B., Range and Mean difference., values of Fl of voiced stop consonants in hearing impaired and normal groups (in Hz).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/b/	384 (151)	251-752	447 (147)	266-646	-63
/d/*	546 (171)	251-894	414 (108)	266-658	132
/g/	467 (190)	213-717	389 (180)	244-768	78

* Significant difference between means at 0.05 level

Voiceless consonants produced by the subjects of the hearing impaired group showed mean values lesser than that of the normals except for /k/. Difference between the mean values were: /p/ = -25Hz; /t/ = -31Hz; /k/ - 77Hz. Whereas among voiced consonants, hearing impaired group showed lesser mean value than normals in /b/ only.

For voiced consonants, the difference between the mean values of hearing impaired and normals was positive for /d/ and /g/ only. The values for /b/, /d/ and /g/ were -63Hz, 132Hz and 78Hz respectively. The difference was significant only for /d/ at 0.05 level. The higher Fl values in the consonants /d/and /g/ of the hearing impaired group may indicate velar or pharyngeal articulation in their production as suggested by Fant (1968).

Thus the hypothesis that there is no significant difference between the Fl values of normals and hearing impaired was accepted except for consonant /d/.

Table-2.3 The mean, S.D., Range and Mean difference values of F2 of voiceless stop consonants in hearing impaired and normal groups (in Hz).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/P/	1411 (225)	1010-1725	1289 (196)	934-1584	122
/t/	2222 (407)	1458-2854	2082 (303)	1537-2572	140
/k/*	1310 (258)	907-1788	1088 (186)	895-1694	222

* Significant difference between means at 0.05 level

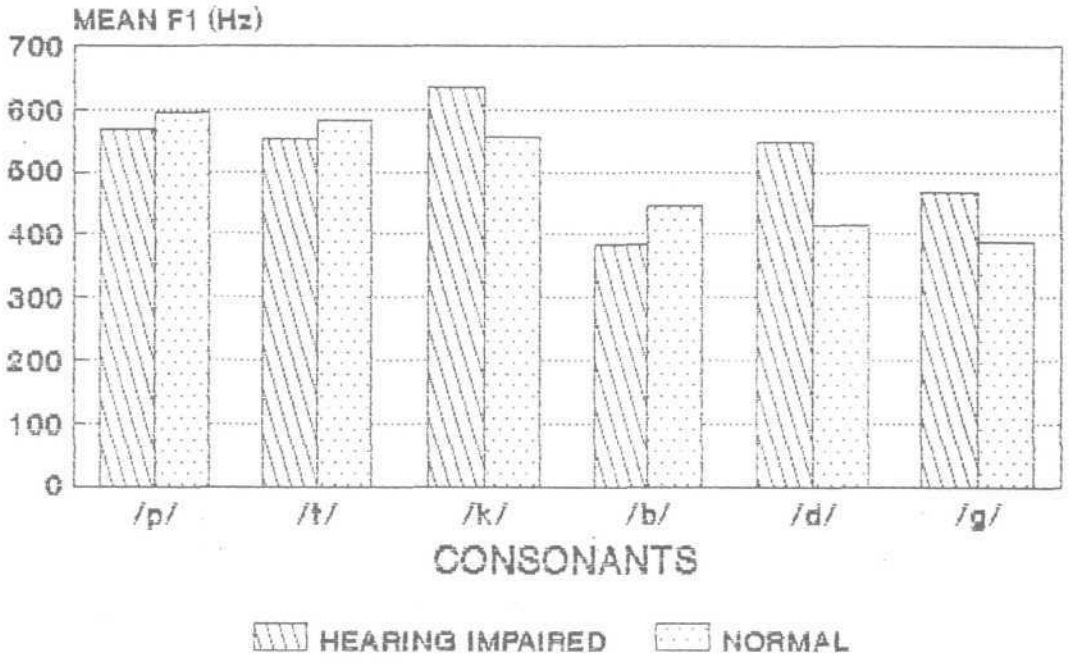
Table-2.4: The mean, S.D., Range and Mean difference values of F2 of voiced stop consonants in hearing impaired and normal groups (in Hz).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/b/	1345 (308)	800-1803	1295 (141)	1029-1430	50
/d/	2437 (455)	1568-3231	2709 (301)	2023-3341	-272
/g/	2595 (633)	1302-3601	2974 (325)	2447-3593	-379

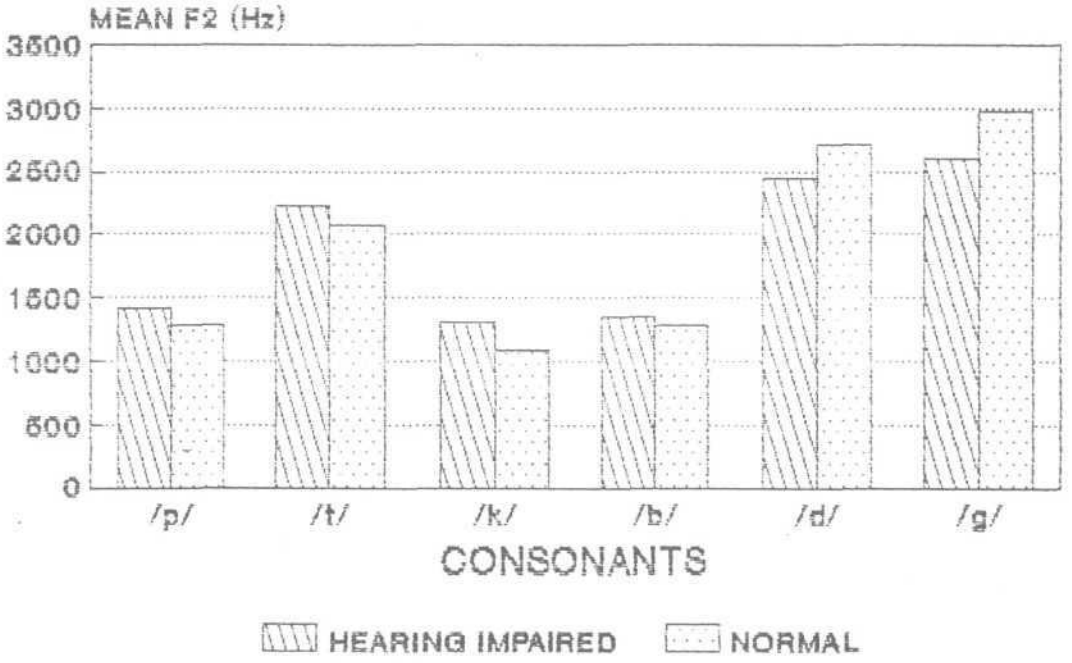
From the Table-2.3 & 2.4 and Graph-6, the difference between the mean values of /p/, /t/, /k/ of hearing impaired and the normals were 122Hz, 140Hz and 222Hz respectively. The difference in the mean values of /b/, /d/, /g/ were 50Hz, -272Hz and -379Hz between the hearing imapired group and the normal group.

The mean F2 values of all stop consonants were found to be higher except for /d/ and /g/ in hearing impaired group than in normal group as shown in Table-2.4. However, the significant difference between the two groups was found only for /k/. This higher F2 values of /p/, /t/, /k/ and /b/ in

GRAPH-5: SHOWING THE MEAN F1 OF HEARING IMPAIRED AND NORMAL GROUPS FOR CONSONANTS



GRAPH-6: SHOWING THE MEAN F2 OF HEARING IMPAIRED AND NORMAL GROUPS FOR CONSONANTS



the hearing impaired group suggest palatalization during the production of these consonants (Fant, 1968).

Thus the hypothesis there is no significant difference in F2 values of the hearing impaired and normals was accepted except for /k/.

The mean F3 values of hearing impaired and normals for voiceless stops are presented in Table 2.5 and Graph 7 for voiced stops in Table 2.6.and Graph - 7.

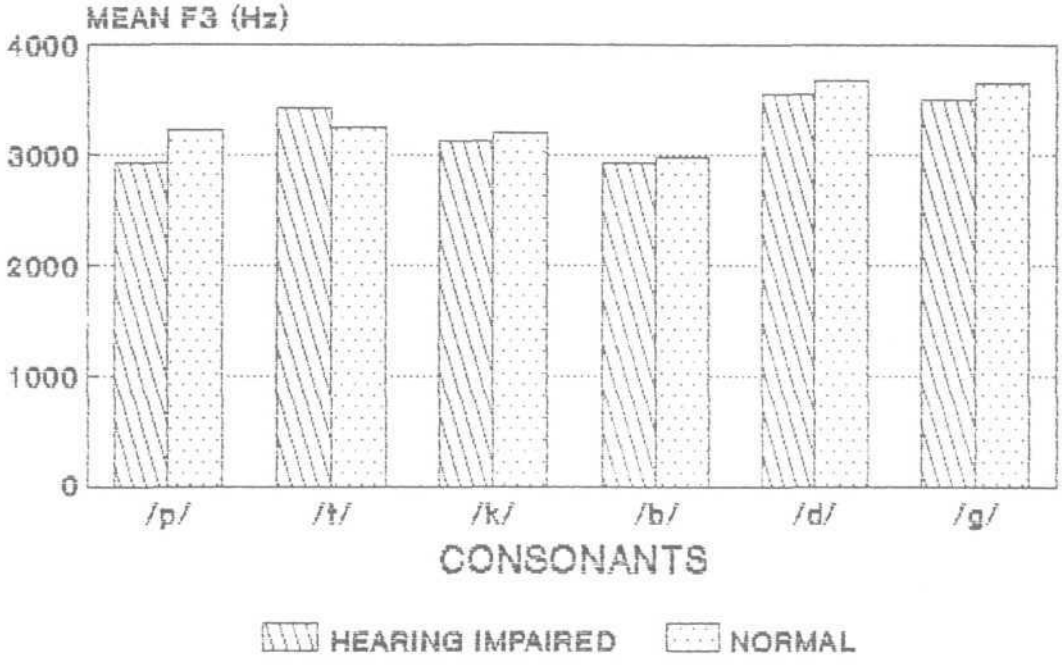
Table-2.5 : The mean, S.D., Range and Mean difference, values of F3 of voiceless stop consonants in hearing impaired and normal groups (in Hz).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/P/	2909 (368)	2321-3513	3221 (424)	2588-3858	-312
/t/	3415 (497)	2321-4000	3248 (366)	2480-3742	167
/k/	3109 (311)	2572-3629	3195 (544)	2113-3875	-86

Table-2.6: The mean, S.D., Range and Mean difference values of F3 of voiced stop consonants in hearing impaired and normal groups (in Hz).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff HI & Normals
/b/	2932 (465)	1662-3451	2973 (315)	2509-3759	-41
/d/	3542 (236)	3058-3858	3668 (264)	2980-3874	-126
/g/	3499 (362)	2980-3937	3647 (198)	3204-3907	-148

GRAPH-7: SHOWING THE MEAN F3 OF HEARING IMPAIRED AND NORMAL GROUPS FOR CONSONANTS



The difference between the mean values of /p/, /t/ and /k/ were -312Hz; 167Hz; -86Hz which implies that for /t/ the mean F3 value was higher in the hearing impaired group than in normal group.

The mean F3 values of hearing impaired group were lower than normals in all voiced consonants. The differences were /b/ - -41Hz; /d/ = -126Hz; /g/ = -148Hz.

However no significant difference between normals and hearing impaired was found for both voiced and voiceless consonants in terms of F3. Thus the hypothesis that there is no difference between F3 values of the hearing impaired and normals was accepted for all consonants studied.

Based on the analysis of consonants for the hearing impaired group, the following conclusion has been drawn:

The formant frequencies studied were not significantly different in hearing impaired group than in normal group.

FORMANT FREQUENCY RELATIONSHIPS OF STOP CONSONANTS

Table-2.7 present the mean difference between formant values of stop consonants produced by hearing impaired group and normals.

Table-2.7: Shows the difference between formant frequencies in stop consonants of hearing impaired and normal groups (in Hz)

Vowels		Hearing Impaired group	Normal group	Mean difference hearing impaired and normal
/P/	Fl - F2	842	695	147
	F2 - F3	1498	1932	-434
	F3 - Fl	2340	2627	-287
/b/	Fl - F2	961	848	113
	F2 - F3	1587	1678	-91
	F3 - Fl	2548	2526	22
/t/	Fl - F2	1672	1501	171
	F2 - F3	1193	1166	27
	F3 - Fl	2865	2667	198
/d/	Fl - F2	1891	2295	-404
	F2 - F3	1105	959	146
	F3 - Fl	2906	3254	-348
/k/	Fl - F2	677	532	145
	F2 - F3	1799	2107	-308
	F3 - Fl	2476	2639	-163
/g/	Fl - F2	2128	2585	-457
	F2 - F3	904	663	241
	F3 - Fl	3032	3258	-226

Inspection of the table revealed that :

1) The difference between Fl and F2 values was higher in all voiceless consonants and only in /b/ among voiced consonants produced by hearing impaired than in the consonants produced by the normals..

2) The difference between F2 and F3 values was lower in /p/, /k/ and /b/ and higher in /t/, /d/ and /g/ in hearing impaired group than in normal group. The lower values in /p/; /b/, and /k/ may be considerd as indicating palatal retroflex articulation. Further a low F2 in /d/ and /g/ suggests velar and pharyngeal articulation (Fant,1968).

3) It is interesting to note Fl was lower in all voiceless consonants and higher in voiced consonants in hearing impaired group than in normals . This may be one of the many features leading to confusion of voice-voiceless distinction.

Hence the results of the analysis of stop consonants in terms of formant frequencies have been summarized in the following table.

Table-2.8: Shows the summary of comparison of formant frequencies (and their difference) of stop consonants interms of mean values (in Hz)

Stop Consonants	Fl	F2	F3	F1-F2	F2-F3	F3-F1
/P/	L	H	L	H	L	L
/t/	L	H	H	H	H	H
/k/	L	H	L	H	L	L
/b/	L	H	L	H	L	L
/d/	H	L	L	L	H	L
/g/	H	L	L	L	H	L

L - Mean value lower than normal;

H = Mean value higher than normal

DURATIONAL CHARACTERISTICS OF STOP CONSONANTS

Voice onset time

Table 2.9, 2.10 and Graph -8 present the mean VOT values of voiceless and voiced, stop consonants of the hearing impaired and normals respectively.

Table-2.9: The mean, S.D., Range and Mean difference, values of VOT of voiceless stop consonants in hearing impaired and normal groups (in msec.).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/p/	29 (70)	5-281	10 (4)	5-23	19
/t/	27 (41)	9-170	21 (12)	4-44	6
/k/	45 (35)	10-143	39 (13)	14-67	6

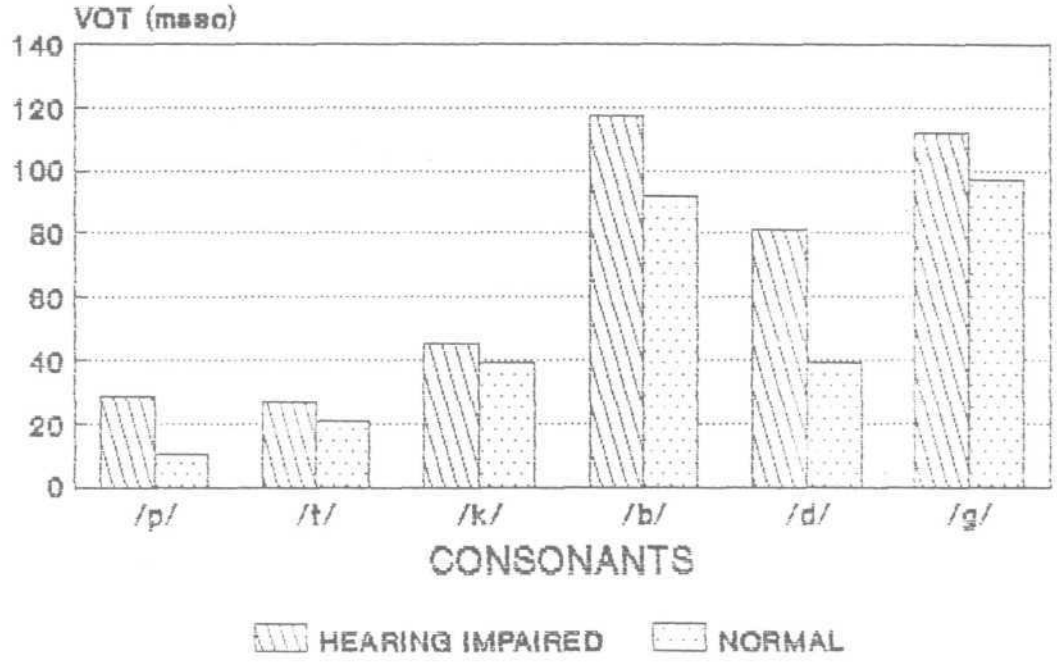
Table-2.10: The mean, S.D., Range and Mean difference values of VOT of voiced stop consonants in hearing impaired and normal groups (in msec).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/b/	117 (84)	3-311	92 (29)	13-136	25
/d/	81 (76)	4-214	39 (4)	34-45	42
/g/	112 (86)	14-270	97 (25)	53-151	15

The mean VOT values of hearing impaired were found to be higher than that of normals, though there was no significant difference between the two groups. The difference between the mean values of hearing impaired to that of the normals were as follows:

For /p/ = 19msec, /t/ and /k/ = 6msec, for /b/ - 25msec; /d/ - 42msec; /g/ - 15msec.

GRAPH-8: SHOWING THE MEAN VOT OF HEARING IMPAIRED AND NORMAL GROUPS FOR CONSONANTS



In the hearing impaired group, the mean VOT value was shortest for /t/ and /d/ whereas in normals /p/ and /d/ showed lowest values. But in both the groups, voiced consonants had more VOT values than that of the voiceless consonants. Similar report has been made by Shukla (1987)

The mean VOT values produced by both the groups increased as the place of articulation moved backward in the oral cavity. The results of the normal group agree with the results reported by Savithri (1990).

Thus the hypothesis that there is no significant difference in VOT values of hearing impaired and normal children was accepted.

Consonants Closure Duration

Tables-2.12, 2.13 and Graph - 9 present the closure duration of voiceless and voiced consonants respectively. The consonants closure duration of /p/, /b/ and /t/ and /d/ /t/ and /d/ on analysis showed that the mean values of all the consonants produced by hearing impaired were higher than that of normals ranging from 36msec to 103msec.

Table-2.12: The mean, S.D., Range and Mean difference values of Closure duration of voiceless stop consonants in hearing impaired and normal groups (in msec).

Conson-ants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/p/*	164 (61)	89-266	120 (19)	79-150	44
/t/	185 (82)	85-332	142 (22)	96-184	43
/ʈ/	135 (81)	63-109	97 (19)	65-132	38

* Significant difference between means at 0.05 level

GRAPH-9: SHOWING THE MEAN CLOSURE DURATION OF HEARING IMPAIRED AND NORMAL GROUPS FOR CONSONANTS

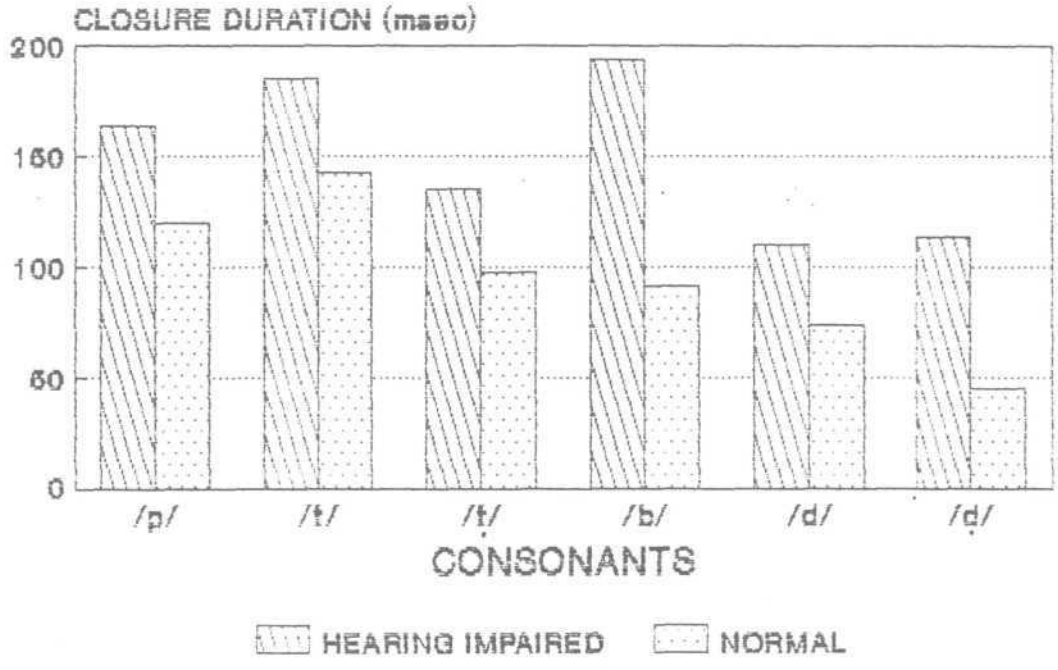


Table-2.13: The mean, S.D., Range and Mean difference values of Closure duration of voiced stop consonants in hearing impaired and normal groups (in msec).

Consonants	Hearing Impaired Mean (SD)	Range	Normals Mean (SD)	Range	Mean diff. HI & Normals
/b/*	194 (98)	66-360	91 (36)	44-194	103
/d/*	110 (38)	68-213	74 (28)	26-122	36
/ḍ/*	113 (88)	45-390	45 (19)	17-281	68

* Significant difference between means at 0.05 level

The hearing impaired group showed higher mean values than normals. This is in agreement with the findings of Whitehead (1991). The closure duration values of normals agree well with results reported by Savithri (1990) also. Significant difference between the mean values was present for the closure duration of /p/, /b/, /d/ and /d/ when the two groups were compared. According to Whitehead (1991) the increased build up of intra oral air pressure behind the constriction with a subsequent greater peak flow rate upon release leads to increased closure duration.

Thus that there is no significant difference in the closure duration of the hearing impaired to that of normal was not accepted totally as there was significant difference for the consonants /p/, /b/, /d/ and /d/ at 0.05 level. The analysis of stop consonants produced by hearing impaired and normals shows the following:

1) Thus the hypothesis that there is no significant difference between the Fl values of normals and hearing impaired was accepted except for consonant /d/.

2) Thus the hypothesis that there is no significant difference in F2 values of the hearing impaired and normals is accepted except for /k/.

3) Thus the hypothesis that there is no difference between F3 values of the hearing impaired and normals was accepted for all consonants studied.

4) Thus the hypothesis that there is no significant difference in VOT values of hearing impaired and normal children was accepted.

5) Thus the hypothesis that there is no significant difference in the closure duration of the hearing impaired to that of normal was not accepted totally as there was significant difference for the consonants /p/, /b/, /d/ and /d/ at 0.05 level.

Thus the results of the present study show that

1) All the vowels of hearing impaired showed a higher F2 values than that of normals. Fl & F3 value of hearing impaired were found to be similar than that of normals.

2) All hearing impaired children had higher mean vowel duration than that of normals indicating prolongation of the vowels.

3) The formant frequencies Fl, F2 and F3 of stop consonants were similar in both groups.

4) The mean VOT of voiced consonants were more than that of voiceless consonants in both the groups.

5) There was no significant difference in the mean VOT values of both the groups at 0.05 level though the hearing impaired group showed longer VOT values.

6) The closure duration of the hearing impaired group was more than that of the normals which was statistically significant.

SUMMARY AND CONCLUSION

"Great strides have been made in understanding the speech of the hearing impaired, but our knowledge in this area is far from complete" (Osberger and Mc Garr 1986).

In the present study the speech of five severe/or profoundly congenital hearing impaired and five normal hearing Kannada speaking subjects has been analyzed spectrographically. Spectrographic analysis was done with the help of the computer and the following conclusions were drawn.

A list of ten nouns were used as stimuli. The carrier phrase 'idu' was elicited used along with the stimulus words.

Vowels of Kannada such as /a/, /a:/, /i/, /i:/, /u/, /u:/, /e/, /e:/, /o/, /o:/ and stop consonants /p/, /b/, /t/, /d/, /k/, /g/, /ṭ/ & /ḍ/ were analyzed .

From the analyses the following parameters from the vowels and consonants were obtained:

- Formant frequencies of the vowels (Fl, F2 and F3)
- Vowel duration
- Formant frequencies of stop consonants (Fl, F2 and F3).
- Voice onset time of stop consonants
- Closure duration of stop consonants

All the vowels of hearing impaired showed a higher F2 values than that of normals. Fl & F3 value of hearing impaired were found to be similar than that of normals.

All hearing impaired children had higher mean vowel duration than that of normals indicating prolongation of the vowels.

The formant frequencies Fl, F2 and F3 of stop consonants were similar in both groups.

The mean VOT of voiced consonants were more than that of voiceless consonants in both the groups.

There was no significant difference in the mean VOT values of both the groups at 0.05 level though the hearing impaired group showed longer VOT values.

The closure duration of hearing impaired group was more than that of the normals which was statistically significant.

RECOMMENDATIONS

The study may be done with large number of subjects including both the sexes to delineate the developmental stages of speech acquisition in the hearing impaired.

Various spectral parameters and their relations to the factors affecting the speech intelligibility in the hearing impaired children may be studied.

Such information will be useful in planning therapy with hearing impaired children.

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