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A voice analysis comparison of children with cochlear implants, hearing aids, and normal hearing

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Abstract
Voice errors are one of the most common types of errors in children with hearing loss speech, and it is well known that deaf people's speech and voice characteristics differ significantly from those of normal hearing individuals. The study included 12 children (2 to 5 years). They are divided into 3 groups: children with a cochlear implant Group, children with hearing aids used, and normal hearing children. The voice was analyzed using the software program Dr. Speech Vocal Assessment. Values of voice parameters were analyzed using Statistical Methods. The result of this study shows that the mean value of habitual frequency was higher in children with the cochlear implant group and hearing aid users group as compared to the other groups and all voice parameters of 3 groups did not show statistically significant differences. A study done by Pickett in 1996 reported that the Fo was produced by children with hearing loss. Our study also evidence of increased F0 in children with hearing loss. However, all voice parameters did not show a significant difference between the children with cochlear implants, hearing aid users, and normal hearing; the result of cochlear implantation and hearing aid and voice and speech education is thus sufficient.

Keywords: Voice analysis, cochlear implant, Jitter, Shimmer, Dr. Speech

Introduction
Hearing plays an important role in the development and daily performance of children. Hearing Impairment (HI) occurs when there's a problem with or damage to one or more parts of the hearing mechanism. A cochlear implant is a sophisticated electronic device that stimulates the auditory nerve directly and thus provides a sense of sound to a person who is profoundly deaf or has a severe degree of hearing loss [1], There are types of hearing loss that involve damaged hair cells in the inner ear. The hair cells then cannot send sound to the auditory nerve. A cochlear implant bypasses the hair cells and sends sound to the auditory nerve. A cochlear implant can be fitted via surgery. A part of the implant is placed inside the inner ear, and another part is worn on the outside of the head which has a microphone to pick up sound. The Speech processor which looks like a hearing aid worn behind the ear (or attached to clothing) receives the sound sent to it. The speech processor turns the sound into a digital signal. This digital signal goes from the speech processor to the transmitter (on the outside of your head) and then to the receiver under your skin. The receiver sends the sound signal to electrodes placed in the inner ear or cochlea. The electrodes trigger the auditory nerve and let the brain notice incoming sounds. These parts work together to help the person notice the sound. Cochlear implants can be used in one or both ears [2]. A hearing aid has a microphone to pick up sound; a way to make sound louder called an amplifier; a receiver that sends the louder sounds to the ear; an on/off switch; and a battery compartment. Many people experience hearing loss. Hearing loss—whether mild, moderate, or severe—can cause communication problems at home, at work, and with friends. Hearing aids can be helpful for some types of hearing loss. Audiologists can test your hearing and help find the best hearing aid [2].
India has now crossed more than two decades since CI technology reached its shores. Today there are around 200 state-of-the-art cochlear implant centers across India, and more than 25,000 cochlear implantations have been done across India.

On 06 MAY 2018, Shri Krishan Pal Gurjar, Minister of State for Social Justice & Empowerment, said that 1149 Cochlear Implant Surgeries have been conducted successfully during the last 4 years (from 2014-15 to 2017-18). With the implementation of the Cochlear Implant program by the Ministry of SJ&E through Ali Yavar Jung National Institute of Speech and Hearing Disabilities (Divyangjan), Mumbai, around 1149 surgeries (916 under the ADIP Scheme and 233 under CSR) have been conducted across India. The Applicants have to apply based on advertisement/details on the website of AYJNISHD, Mumbai [3].

In children important functions of hearing: Are auditory system development, speech development, and personality development [4]. Hearing-impaired children develop without the necessary auditory stimulus. The lack of sound and the lack of positive environmental impact confuses a deaf child and inhibits him/her to develop speech [5]. It is well known that the speech and voice characteristics of deaf people differ significantly from those of normal-hearing people. The speech of the hearing impaired is characterized by the disorder of syntax, rhythm, resonance, and articulation [6]. According to Dale, deaf children are likely to have a restricted vocabulary. A normal-hearing 5-year-old child may have a vocabulary of approximately 2000 words, while the vocabulary of a profoundly deaf child may consist of only 250 words [7].

Children with hearing loss have voicing errors in their speech. Several studies have found that in children with hearing loss voicing errors were one of the most frequent types of errors in their speech [8]. Subsequent studies have also found that children with hearing loss have the presence of voicing errors in their speech [9-12]. Most frequently occurring vocal errors include resonance problems, unpleasant quality of voice, strain, high-pitched voice, altered breathing patterns, and utterance with excessive variation observed in children with hearing loss [13, 14]. Thus, in the speech of children with hearing loss voicing errors are strong evidence. It is thought to be due to the failure to coordinate the timing of respiration, phonation, and articulation in attempting to produce voicing contrasts [15].

The poor phonatory controls in individuals with hearing loss can be divided into two major parts. One part is the inappropriate average fundamental frequency (F0) and the other is improper intonation, i.e., little variation in F0 resulting in flat or monotonous speech or an erratic pitch variation. Thus, the auditory system is also capable of regulating certain parameters of voice, such as frequency and intensity [16, 17]. Several investigators have noted that individuals with hearing loss have a relatively high average pitch or speak in falsetto voice [18, 19]. Several Indian studies carried out on children with hearing loss have reported that the fundamental frequency (F0) of the voice of children with hearing loss was higher than that of normal hearing children [20-25]. It has also been reported that the speakers with hearing loss often tend to vary the pitch much less than the normal hearing speakers and their speech has been described as flat or monotone [19, 26].

Auditory feedback is considered important for the control of voice characteristics such as fundamental frequency (F0), intensity, and voice quality [27]. The Voice of the deaf can be too loud or too soft, or vary irregularly [28, 19]; it is usually described as tense, flat, breathy, and harsh, with differences in pitch and intonation [29]. Pre-lingually deaf people generally have a higher fundamental frequency of voice than normal-hearing people [30, 31]. They either vary pitch less than normal hearing speakers, producing a monotone voice [32] or show excessive pitch variation, resulting in abrupt changes [33]. CI child showed a lowering of voice intonation, better control of voice intensity, and a reduction of nasal quality. The use of CI significantly improved nasality. Striking features were a reduction of the f0 and better resonance. According to study children who received CI before their fourth birthday attain better acoustic control of speech, with normal F0 and improved vowel articulation.

Methods and Materials

This study aims to compare voice parameters among children with cochlear implant users, hearing aid users, and normal children who have normal speech and hearing development. This prospective study was conducted at Composite Regional Center Lucknow Utter Pradesh India (Speech and Hearing department). The study included 12 children of which 8 children were hearing impaired and 4 children were normal speech and language development.

The study comprised three groups and each group included 4 children:

Group 1: Children with a cochlear implant (CIG) (4).

Group 2: Children with hearing aid used (HAUG) (4).

Group 3: Normal hearing children (NHG) with normal speech and hearing development (4).

The mean age of children with cochlear implants is 3.5 years, hearing aid users is 4.25 years and normal hearing children is 4.00 years.

The mean age of children who received a cochlear implant at the age of 3.0 years and the children who used hearing aids the age of 3.125 years.

The mean age of children who attended auditory verbal therapy using a cochlear implant is 0.525 years and using a hearing aid is 1.125 years.

Inclusion Criteria

- Children with congenital hearing impairment.
- The mean age of children is 3.9 years
- Children with Moderate severe to profound hearing loss in both ears.

Exclusion Criteria

- Children who had used cochlear implants and hearing aids for < 5 months.
- Children with cognition and intellectual impairment were not considered.
- Children with voice disorders and any syndromic condition were also not participated in the study.

The voice of children was analyzed using the software program Dr. Speech Vocal Assessment. Long vowel /A/ was recorded using a microphone placed at a 90° angle and keeping a 5cm distance from the mouth.

Acoustic analysis of voice included 12 acoustic parameters: Habitual F0, mean F0, standard deviation (SD) of F0, maximal and minimal F0, jitter %, shimmer %, harmonic-to-noise ratio (HNR), signal-to-noise ratio (SNR), normalized noise energy (NNE), F0 tremor and amplitude tremor.

Written consent was taken from the parent to conduct the study and present the findings

The results of the analysis of the group of children with cochlear implants were compared with the results of children who used hearing aids and with the group of children with normal hearing. Descriptive analysis was performed i.e. mean, standard deviation, minima, and maxima, and the results are shown in table 2. To make a comparison between the 3 groups, the one-way analysis of variance (ANOVA), adopts a significance level of 5%.

Result

Table 1: Voice data of children with cochlear implants, children who used hearing aids, and children with normal hearing

Voice parameters	Children with Cochlear implants (CIG)				Children with hearing aid (HAG)				Normal hearing children (NHG)			
	1	2	3	4	1	2	3	4	1	2	3	4
Habitual Fo (Hz)	277.33	386.64	394.73	345.53	336.45	330.85	276.38	336.45	267.58	341.76	312.50	280.56
Jitter (%)	0.50	0.25	0.42	2.34	0.16	0.34	0.37	0.16	0.24	0.31	0.16	0.20
Shimmer (%)	2.86	2.31	2.23	10.80	1.08	2.28	2.40	1.08	2.30	3.26	1.07	1.82
Fo tremor (Hz)	1.61	2.38	1.35	12.60	3.68	1.00	1.00	3.68	1.11	3.55	3.15	7.34
NNE (dB)	-13.41	-17.35	-19.89	0.13	-16.11	-17.93	-16.32	-16.11	-15.27	-18.53	-14.79	-18.12
HNR (dB)	23.02	24.80	23.00	9.76	30.27	23.18	23.94	30.27	24.68	20.53	31.48	26.84
SNR (dB)	21.45	23.38	21.01	9.99	28.51	20.62	21.07	28.51	23.89	20.49	30.28	26.03
Amp Tremor (Hz)	2.45	2.38	1.22	12.60	1.35	1.00	1.40	1.35	2.01	3.77	5.62	2.66
Mean Fo (Hz)	291.57	373.51	395.51	352.72	335.28	329.91	290.59	335.28	259.21	373.13	309.02	278.84
SD Fo (Hz)	20.26	14.03	11.27	12.36	2.66	21.12	35.27	2.66	7.06	38.26	2.95	3.41
Max Fo (Hz)	347.24	390.27	412.15	386.84	339.23	373.73	370.59	339.23	275.63	464.21	312.77	282.69
Min Fo (Hz)	262.50	341.86	358.54	315.00	329.10	292.05	256.40	329.10	246.37	324.26	302.05	265.66

Table 1 presents the tabulated voice data and the results analyzed by comparing the values obtained in the three groups.

Table 2 presents the results of the descriptive analysis of the evaluated parameters of the three groups. The mean value of habitual frequency, jitter, shimmer, Fo tremor, amp tremor, mean Fo, max Fo, and min Fo was higher in children with the cochlear implant as compared to the other two groups.

Table 3 presents the results of the analysis of variance of the analyzed parameters among the three groups. All voice parameters do not show statistically significant differences among the 3 groups so, CIG = HAUG and NHG = HAUG

Table 2: Demonstrates the result of descriptive analysis of data objectives by the three groups

		N	Mean	SD	Min	Max	F(2,9) ratio	p-value
Habitual Fo(Hz)	CI	4	351.0575	53.6647	277.33	394.73	1.60484	0.25347
	HA	4	320.0325	29.22115	276.38	336.45		
	NH	4	300.6	33.30504	267.58	341.76		
Jitter (%)	CI	4	0.8775	0.980557	0.25	2.34	1.651253	0.244974
	HA	4	0.2575	0.113248	0.16	0.37		
	NH	4	0.2275	0.063966	0.16	0.31		
Shimmer (%)	CI	4	4.55	4.176067	2.23	10.8	1.506336	0.272718
	HA	4	1.71	0.729109	1.08	2.4		
	NH	4	2.1125	0.917292	1.07	3.26		
Fo tremor	CI	4	4.485	5.427648	1.35	12.6	0.372125	0.699397
	HA	4	2.34	1.547299	1.00	3.68		
	NH	4	3.7875	2.598209	1.11	7.34		
NNE (dB)	CI	4	-12.63	8.914632	-19.89	0.13	0.769342	0.491533
	HA	4	-16.6175	0.880582	-17.93	-16.11		
	NH	4	-16.6775	1.919746	-18.53	-14.79		
HNR (dB)	CI	4	20.145	6.97457	9.76	24.8	1.888503	0.206614
	HA	4	26.915	3.886425	23.18	30.27		
	NH	4	25.8825	4.558658	20.53	31.48		
SNR (dB)	CI	4	18.9575	6.066297	9.99	23.38	1.955593	0.197126
	HA	4	24.6775	4.429201	20.62	28.51		
	NH	4	25.1725	4.098474	20.49	30.28		
Amp tremor (Hz)	CI	4	4.6625	5.321644	1.22	12.6	1.154534	0.357825
	HA	4	1.275	0.184842	1.00	1.4		
	NH	4	3.515	1.580306	2.01	5.62		
Mean Fo	CI	4	353.3275	44.72529	291.57	395.51	1.446924	0.285194
	HA	4	322.765	21.59886	290.59	336.45		
	NH	4	305.05	49.79597	259.21	373.13		
SD Fo (Hz)	CI	4	14.48	4.017022	11.27	20.26	0.034624	0.966096
	HA	4	15.4275	15.83401	2.66	35.27		
	NH	4	12.92	16.9931	2.95	38.26		
Max Fo (Hz)	CI	4	384.125	27.0249	347.24	412.15	0.856861	0.456415
	HA	4	355.695	19.05531	339.23	373.73		
	NH	4	333.825	88.4025	275.63	464.21		
Min Fo (Hz)	CI	4	319.475	42.00531	262.5	358.54	0.86704	0.452532
	HA	4	301.6625	34.86511	256.4	329.1		
	NH	4	284.585	35.1078	246.37	324.26		

Table 3: Demonstrates the result of the analysis of variance

Voice parameter	Analysis of variance		
	F(2, 9) Ratio	**P Value**	**Group comparison (p>0.05)**
Habitual Fo(Hz)	< F crit	> 0.05	CIG = HAUG = NHG
Jitter (%)	< F crit	> 0.05	CIG = HAUG = NHG
Shimmer (%)	< F crit	> 0.05	CIG = HAUG = NHG
Fo tremor	< F crit	> 0.05	CIG = HAUG = NHG
NNE (dB)	< F crit	> 0.05	CIG = HAUG = NHG
HNR (dB)	< F crit	> 0.05	CIG = HAUG = NHG
SNR (dB)	< F crit	> 0.05	CIG = HAUG = NHG
Amp tremor (Hz)	< F crit	> 0.05	CIG = HAUG = NHG
Mean Fo	< F crit	> 0.05	CIG = HAUG = NHG
SD Fo (Hz)	< F crit	> 0.05	CIG = HAUG = NHG
Max Fo (Hz)	< F crit	> 0.05	CIG = HAUG = NHG
Min Fo (Hz)	< F crit	> 0.05	CIG = HAUG = NHG

The F critical value is 4.26 at a 5% significant level and 8.02 at a 1% significant level.

Discussion

A study done by JM Pickett [34] reported that the high pitch or Fo produced by children with hearing loss (CI and HA) was due to the increased tension in the cricothyroid muscle and increased sub glottal airflow. The extra vocal effort that was needed to generate high-pitched sounds led to an increase in kinesthetic awareness of voicing beyond the possibly available awareness of voicing from residual hearing in children with hearing loss (CI and HA). Similarly our study also evidence of increased F0 in children with hearing loss (CI and HA), the current study results support the findings of the earlier studies.

A study by Yanagihara [35] and J Kreiman *et al.* [36], in which they observed that the Jitter and Shimmer were higher among the children with hearing loss (CI and HA) compared to the normal hearing children. Higher perturbation values indicate irregular vibration of the vocal folds and have been implicated as a physical correlate of rough or hoarse voice [35, 36]. Thus, it can be inferred from the results of our study that jitter and shimmer are higher and increased perturbation values noted in children with hearing loss (CI and HA) indicate the presence of rough or hoarse voice quality in children with hearing loss (CI and HA). Many earlier investigators have also documented similar results, and thus, the present study supports the results of all the previous researchers reporting an increase in perturbation values in children with hearing loss (CI and HA) [24, 25, 37].

Coelho *et al.* [29] found higher values of jitter and shimmer in children with cochlear implants, similarly, in our study value of jitter and shimmer in children with cochlear implants However, the literature data are contradictory to Baudonck's [13] study of the values of these parameters were higher in normal hearing children.

The mean value of SD Fo of children with cochlear implants and children using a hearing aid is higher as compared to normal hearing children which indicate insufficient control of voice frequency variation, probably due to insufficient auditory feedback. A study was done by Coelho *et al.* [29], in which they reported that higher values of SD F0 were found in children with hearing loss (CI and HA), which indicates insufficient control of voice frequency variation, probably due to insufficient auditory feedback. Baudonck [13] did not find a significant difference in SD F0 values between the children with cochlear implants and the normal hearing child. Similarly, in our study, there is no significant difference between children with cochlear implants, hearing aid users, and normal hearing children. Both studies support our study.

The HNR of children with normal hearing in our study was higher than the children with CI. This is consistent with the study by Hsu *et al.* where the children with CI demonstrate significantly lower HNR or higher NHR(noise to harmonic ratio) means the in-harmonic energy or the noise was stronger than the harmonic energy leading to poor voice quality.

Higher maximum and minimum values for MFo in children with cochlear implants are also observed by Coelho *et al.* [29], Similarly in the current study, children with cochlear implants have higher maximum and minimum values for MFo and there is no significant difference between the groups. Baudonck [13] did not find any significant differences considering parameter mean F0. Contrary to our findings, Seifert *et al.* [39] did a study in which they found lower mean F0 values in children with cochlear implants, and they also found that children implanted before the age of 4 showed no significant deviation regarding F0. This conclusion agrees with the results of many other studies [1, 40, 41] claiming that children who receive a cochlear implant at a younger age have better results in controlling voice pitch.

Conclusion

All voice parameters did not show a significant difference between the children with CI, HAU, and normal hearing children; the result of cochlear implantation and hearing aid and voice and speech education is thus sufficient.

As we have found from the given voice data the mean value of voice parameters of the hearing aid users group is much closer to the normal hearing group as compared to the cochlear implant group The reason behind that is the mean duration of auditory verbal therapy taken by hearing aid users group is more as compare to cochlear implant group and the second reason is that the mean duration of using amplification devices is more in hearing aid users group as compare to cochlear implant group.

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