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Original Article

Frequency Characteristics in Children Using Cochlear Implant: A Comparison With Normal Hearing Peers

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BACKGROUND: To compare the frequency parameters of voice between children using cochlear implant (CI) and those with normal hearing and establishing a trend of development of voice characteristics across chronological and implant ages.

METHODS: The study included 87 children aged 12 to 72 months, with a mean age of 41 months. The subjects were divided into 2 groups: group 1 included 44 children using CIs, and group 2 included 43 children with normal hearing and age-appropriate speech and language characteristics. Both groups were categorized into 3 subgroups based on their chronological ages, group A (12-32 months), B (33-52 months), and C (53-72 months). The CI group (i.e., group 2) was further subdivided based on implant ages as group D (1-4 months), E (5-8 months), and F (9-12 months).

RESULTS: Comparison of vocal frequency parameters across chronological ages revealed a decline with increasing age in both groups; however, stability was not maintained in the CI group. There was a statistically significant difference in the vocal frequency parameters between normal hearing children and those with CI. Comparing across implant ages, there was a significant difference between groups D and F.

CONCLUSION: For better communication abilities of individuals with CI, along with early implantation and rehabilitation, there is a need to also focus therapy on providing training on speech modulations, especially on voice characteristics.

KEYWORDS: Auditory feedback, fundamental frequency, jitter, formant frequency, early intervention

INTRODUCTION

Voice is a crucial attribute as it, directly and indirectly, reflects on a person's age, gender, and emotional state. It is produced by the coordinated and interactive function of respiratory, laryngeal, and resonatory systems. The phonatory and articulatory subsystem matures and undergoes various developmental changes across age. Voice production involves both feedback and feedforward control, wherein immediate auditory feedback is crucial in controlling voice characteristics, such as fundamental frequency (F_0), formant frequency, and frequency perturbation (jitter).[1]

The F_0 is referred to as the number of glottis cycles per second.[2] It is an individual's natural frequency and an essential parameter in assessing the correctness of speech production. The normative range of F_0 for adult males is considered to be within 80-150 Hz, for adult females around 150 to 250 Hz, and above 250 Hz for children.[2] A study on acoustic features of vocalic utterance at 3 months, 6 months, and 9months of infants with normal hearing revealed an average F_0 value of 445 Hz at 3 months, 450 Hz at 6 months, and 415 Hz at 9 months of age.[3]

As a consequence of hearing impairment, speech and language skills tend to be either delayed or deviant depending upon several factors, such as type, degree, the onset of hearing loss, age at identification of deafness, and age at fitting appropriate

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amplification or implants.[4-6] Along with the deviancy, as mentioned earlier, due to lack of stimulation, the auditory feedback system loses the capability to regulate the voice characteristics. The vocal deviations that are prominently seen in individuals with hearing impairment include strain, breathiness, roughness, monotone, absence of rhythm, hoarseness, vocal fatigue, high pitch, reduced volume, and loudness with excessive variation; unbalanced resonance and imprecise articulation are essentially due to the lack of auditory monitoring of their own voice.[7-9] Hence, improving intelligible speech with an acceptable quality of voice is a challenge for speech therapists, even post-intervention due to the deprivation period.[10]

Formant frequency is the concentration of acoustic energy around a particular frequency in the speech wave.[11] The lowest frequency among formants is F_1, second is F_2. The F_1 reflects the tongue height and F_2 reflects the tongue advancement. The formants are essential in terms of perception and production to correctly identify the vowels. These formant frequencies depend on the shape and size of the vocal tract; hence the formants are found to be higher in young children than in adults and also found to be higher in girls than in boys of the same age.[12] The perturbation measure of the fundamental frequency is jitter, which is defined as the period to period variation in F_0.[13] There have been numerous studies that have documented the acoustic characteristics of voice in CI users, but limited documentation is available, especially in the Indian population that provides comprehensive information on frequency parameters, such as formants and jitter attributes in children using CIs, and not many works of literature have documented the change in these frequency parameters across implant age; hence this investigation aimed to study the same.

MATERIALS AND METHODS

Before initiating this cross-sectional study, due approval was obtained from the MERF ethical committee and board for research. The data collection, analysis, and interpretation were made over 8 months. A total of 87 children participated in the study, with 44 children using CIs, and 43 children were normal hearing. The subjects were aged between 12 and 72 months, with a mean age of 41 months. They were divided into 2 groups: group 1 included children using unilateral CIs (MEDEL{Medical Electronics} – OPUS 2) [N = 44], and group 2 included age-matched children having normal hearing acuity with no apparent language delay [N = 43]. The 2 groups were divided into 3 groups, namely group A (12-32 months) [N = 18], group B (33-52 months) [N = 19], and group C (53-72 months) [N = 7]. Children using CIs were further subdivided based on their implant age as group D (1-4 months) [N = 16], E (5-8 months) [N = 14], and F (9-12 months) [N = 14]. All cochlear implanted children were fitted with the FS4 sound coding strategy. The presence of comorbid conditions, such as developmental disabilities, presence or history of any form of laryngeal pathology, and irregular attendance to habilitation sessions, were considered exclusion factors.

PROCEDURE

Phase I Collection of Demographic Details

Necessary demographic details and history concerning the child's hearing impairment, implant age, speech and language intervention, previous use of amplification devices, such as hearing aid, and history of laryngeal pathology if any were collected from the parents of children belonging to both groups (Table 1).

For those with normal hearing, apart from collecting necessary demographic details, the children's teachers and parents were asked about the child's hearing acuity and the child's speech and language status (Table 2).

Phase II Recording and Analysis

Test Environment

The recording was done in an environment with an acceptable ambient noise level ranging from 32.8 to 37.4 dBA (A-weighted decibels) measured using Sound Level Meter, Volcraft 322 data logger with electret condenser microphone using A-weighting network.

Equipment

Data collection and analysis were performed using PRAAT software version 4.4.33 installed in Acer laptop with Intel processor N3050, Windows 8.1, and recorded using Microphone Xpro-106 Clair.

Recording Procedure

Voice samples were mono recorded using PRAAT software at a sampling rate of 44.100 Hz. The device (CI) was activated and set into regular use settings during voicing tasks. The subjects were seated in an upright position, with a mouth-to-microphone distance fixed at 5 cm, 45° angle. Children were asked to phonate and sustain the neutral vowel at a comfortable pitch and loudness levels for 3-5 seconds, and recording was done for 3 trials. The mean values of sustained vowel production were considered for data analysis. All data were collected in real-time with the output screen in full view of the subjects. Sufficient practice trials were conducted before recording to ensure a proper understanding of the task by the client. However, retesting 20 children using CIs for a second time was required to obtain an appropriate response. All individuals with cochlear implantation underwent auditory-verbal therapy from switch on and speech therapy 6 months post switch on.

Statistical Analysis

The collected data were tabulated and statistically analyzed. A Shapiro–Wilk normality test was carried out to determine the normality of the data across chronological ages. A Kolmogorov–Smirnow (K-S) normality test was administered for the sample size distributed across implant ages. The mean, standard deviation (SD), and *P*-values were obtained using SPSS version 21.0. The presence of significance was checked for the frequency-related parameters, such as fundamental frequency (F_0), jitter (Jitt %), and formant frequencies (F_1 & F_2) between the 2 groups (group 1 & 2) as well as within the group (group 2). The *t*-test was used to obtain a significant difference between the groups. ANOVA and post-hoc analysis (least significance difference) were opted to find out significance across implant ages.

RESULTS

In the study, 261 voice samples were collected from a total of 87 participants; 132 voice samples from 44 children using CIs and 129 samples from 43 normal hearing children. CI group (group 1) comprised of 25 males and 19 females, normal hearing group (group 2) consisted of 18 males and 25 females (Table 3). A male to female ratio of 1.3 : 1 was maintained in both groups (Table 4). The data were normally distributed upon the normality test.

Table 1. Demographic Details in Individuals with Cochlear Implants (CIs)

Subjects	Chronological Age (Years)	Implant Age	Duration of Deafness	Previous Intervention		Lingual	
				Yes	No	Pre	Post
Subject 1	1	6 m	6 m		✓	✓	
Subject 2	1.1	4 m	9 m		✓	✓	
Subject 3	1.1	7 m	6 m		✓	✓	
Subject 4	1.11	7 m	1 yr, 4 m		✓	✓	
Subject 5	1.2	2 m	1 yr		✓	✓	
Subject 6	1.4	1 yr	4 m		✓	✓	
Subject 7	1.8	7 m	1 yr, 1 m		✓	✓	
Subject 8	1.9	3 m	1 yr, 6 m		✓	✓	
Subject 9	2	1 yr	1 yr		✓	✓	
Subject 10	2.1	7 m	1 yr, 6 m		✓	✓	
Subject 11	2.2	1 yr	1 yr, 4 m		✓	✓	
Subject 12	2.3	4 m	1 yr, 11 m		✓	✓	
Subject 13	2.3	7 m	1 yr, 8 m		✓	✓	
Subject 14	2.4	1 m	1 yr, 3 m		✓	✓	
Subject 15	2.5	5 m	2 yrs		✓	✓	
Subject 16	2.5	1 yr	1 yr, 7 m		✓	✓	
Subject 17	2.8	4 m	2 yrs, 4 m		✓	✓	
Subject 18	2.8	9 m	1 yr, 11 m		✓	✓	
Subject 19	2.9	3 m	2 yrs, 6 m		✓	✓	
Subject 20	3	1 m	2 yrs, 11 m		✓	✓	
Subject 21	3	9 m	2 yrs, 3 m		✓	✓	
Subject 22	3.1	7 m	2 yrs, 6 m		✓	✓	
Subject 23	3.11	1 yr	3 yrs, 1 m		✓	✓	
Subject 24	3.3	1 m	3 yrs, 2 m		✓	✓	
Subject 25	3.3	8 m	2 yrs, 7 m		✓	✓	
Subject 26	3.5	5 m	3 yrs		✓	✓	
Subject 27	3.5	2 m	3 yrs, 3 m		✓	✓	
Subject 28	3.6	4 m	3 yrs, 2 m		✓	✓	
Subject 29	3.7	3 m	3 yrs, 5 m		✓	✓	
Subject 30	3.8	1 year	2 yrs, 10 m		✓	✓	
Subject 31	4	2 m	3 yrs, 10 m		✓	✓	
Subject 32	4	4 m	3 yrs,8 m		✓	✓	
Subject 33	4	4m	3yrs, 8m		✓	✓	
Subject 34	4	8 m	3 yrs, 4 m		✓	✓	
Subject 35	4	1 yr	3 yrs, 2 m		✓	✓	
Subject 36	4	1 m	3 yrs, 11 m		✓	✓	
Subject 37	4.1	5 m	3 yrs, 8 m		✓	✓	
Subject 38	4.6	1 m	4 yrs, 5 m		✓	✓	
Subject 39	5	1 yr	4 yrs	✓		✓	
Subject 40	5	6 m	4 yrs, 6 m		✓	✓	
Subject 41	5.1	8 m	4 yrs, 5 m	✓		✓	
Subject 42	5.1	1 m	5 yrs		✓	✓	
Subject 43	6	2 m	5 yrs, 10 m		✓	✓	
Subject 44	6	9 m	5 yrs, 3 m		✓	✓	

m, month; yr, year.

Table 2. Chronological Age in Individuals With Normal Hearing

Subjects	Chronological Age
Subject 1	2 yrs
Subject 2	2 yrs
Subject 3	2 yrs, 6 m
Subject 4	1 yr, 1 m
Subject 5	1 yr, 1 m
Subject 6	1 yr, 6 m
Subject 7	1 yr
Subject 8	1 yr, 3 m
Subject 9	1 yr, 4 m
Subject 10	1 yr, 3 m
Subject 11	1 yr, 1 m
Subject 12	1 yr, 3 m
Subject 13	1 yr, 2 m
Subject 14	1 yr, 1 m
Subject 15	2 yrs, 8 m
Subject 16	3 yrs
Subject 17	3 yrs
Subject 18	4 yrs, 2 m
Subject 19	4 yrs, 5 m
Subject 20	4 yrs, 6 m
Subject 21	4 yrs, 7 m
Subject 22	4 yrs, 7 m
Subject 23	4 yrs, 7 m
Subject 24	4 yrs, 8 m
Subject 25	4 yrs, 9 m
Subject 26	4 yrs, 9 m
Subject 27	4 yrs
Subject 28	5 yrs
Subject 29	5 yrs, 1 m
Subject 30	3 yrs, 1 m
Subject 31	3yrs, 9m
Subject 32	4 yrs, 1 m
Subject 33	4 yrs, 7 m
Subject 34	5 yrs, 8 m
Subject 35	6 yrs
Subject 36	6 yrs, 2 m
Subject 37	6 yrs, 3 m
Subject 38	6 yrs, 3 m
Subject 39	6 yrs, 3 m
Subject 40	6 yrs, 4 m
Subject 41	6 yrs, 4 m
Subject 42	6 yrs, 4 m
Subject 43	6 yrs, 5 m

m, month; yr, year.

Table 3. Sample Size of Cochlear Implant (CI) Recipients and Normal Hearing Group

	CI (Group 1)				Normal Hearing (Group 2)
	IA				
CA	Group D (1-4 months)	Group E (4-8 months)	Group F (8-12 months)	Total	Total
Group A (12-32 months)	6	7	5	18	15
Group B (32-52 months)	7	6	6	19	12
Group C (52-72 months)	3	1	3	7	16

Table 4. Gender Distribution Across Chronological Ages

	CI (Group 1)		Normal (Group 2)	
	Mean (Years)	SD	Mean (Years)	SD
Group A				
Male	2.0	0.6	1.9	0.6
Female	1.8	0.6	2.1	0.4
Group B				
Male	3.5	0.4	3.7	0.3
Female	3.5	0.4	3.7	0.3
Group C				
Male	5.1	0.5	5.5	1.2
Female	5.0	0.2	5.5	0.8

Fundamental Frequency

As expected, due to laryngeal maturation effects, a lower mean F_0 value was observed for the older age children (group C) in both CI users and normal hearing (Table 5). The significant difference obtained in the older age group is not evident in the younger groups (group A and B) (Table 6) and no significant differences were obtained among implant ages (D, E, and F) in either younger or older age groups (Tables 7 and 8). Overall, F_0 values were higher in the CI group when compared to normal hearing, and the results were statistically significant (Table 5).

Table 5. Mean, SD, and *P*-Values of Acoustic Parameters Obtained for Both the Groups (Cochlear Implant (CI) and Normal Hearing)

Parameters	CI (Group 1)		Normal Hearing (Group 2)		*P*
	Mean	SD	Mean	SD	
F_0 (Hz)	310.36	58.6	293.21	50.67	.012*
Jitter (%)	1	0.87	0.66	0.49	<.01*
F_1 (Hz)	947.96	207.93	1147.07	145.27	<.01*
F_2 (Hz)	1582.51	264.4	1699.83	243.87	<.01*

*$P < .05$ to be significant.
SD, standard deviation.

Table 6. Mean, SD, and *P*-Values of Acoustic Parameters Obtained for Both the Groups (Cochlear Implant (CI) and Normal Hearing (NH)) Across Chronological Ages

Acoustics		F_0 (Hz)			Jitt (%)			F_1 (Hz)			F_2 (Hz)		
Group		Mean	SD	*P*	Mean	SD	*P*	Mean	SD	*P*	Mean	SD	*P*
A	CI	307.4	58.99	.23	1.2	1.21	.046*	919.68	163.5	<.01**	1557.21	280.9	<.01**
	NH	320.45	47.03		0.82	0.6		1198.89	158.7		1729.52	284.3	
B	CI	325.24	60.22	.16	0.82	0.13	<.01**	992.19	247.7	<.01**	1630.95	273.1	.06
	NH	307.93	50.82		0.58	0.42		1140.44	138.2		1726.2	209.5	
C	CI	277.84	37.05	<.01	0.71	0.46	<.01**	899.5	172.2	<.01**	1515.04	164.3	<.01**
	NH	256.69	27.57		0.59	0.39		1103.43	122.8		1652.3	223.4	

*Significant ($P < .05$), **highly significant ($P < .01$).
A, Chronological age 12 months-32 months; B, chronological age 32 months-52 months; C, chronological age 52 months-72 months.

Table 7. Mean and SD Values of Acoustic Parameters Obtained for Children Using Cochlear Implant (CI) Across Implant Ages D (1-4 Months), E (5-8 Months), and F (9-12 Months)

CA	IA		F_0 (Hz)	Jitter (Jitt %)	F_1 (Hz)	F_2 (Hz)
Group A (12-32 months)	Group D	Mean	295.03	1.73	916.26	1621.55
		SD	77.57	1.91	149.56	258.30
	Group E	Mean	318.84	0.88	961.27	1557.82
		SD	51.63	0.47	132.87	199.09
	Group F	Mean	305.95	1.02	861.68	1473.59
		SD	39.05	0.41	209.95	392.66
Group B (32-52 months)	Group D	Mean	323.57	0.72	1001.72	1714.74
		SD	76.23	0.47	291.23	278.41
	Group E	Mean	329.77	0.85	1027.93	1671.00
		SD	41.74	0.43	267.46	251.82
	Group F	Mean	322.66	0.92	945.32	1493.13
		SD	57.74	0.36	164.31	246.49
Group C (52-72 months)	Group D	Mean	270.89	0.58	831.52	1433.57
		SD	50.46	0.26	195.23	159.77
	Group E	Mean	258.89	0.66	876.90	1662.18
		SD	14.02	0.20	101.86	94.15
	Group F	Mean	291.09	0.87	975.01	1547.46
		SD	21.18	0.64	147.07	151.75

Group D (1-4 months), group E (5-8 months), and group F (9-12 months).

Table 8. Description of *P* Value Across Implant Ages for Group D (1 to 4 Months), E (5 to 8 Months), and F (9 to 12 Months)

CA	IA	F_0 (Hz)	Jitter (Jitt %)	F_1 (Hz)	F_2 (Hz)
			P		
Group A (12-32 months)	D-E	.22	.03*	.39	.48
	E-F	.53	.75	.08	.39
	F-D	.61	.1	.35	.15
Group B (32-52 months)	D-E	.75	.34	.75	.6
	E-F	.73	.62	.33	.05*
	F-D	.96	.14	.49	.01*
Group C (52-72 months)	D-E	.63	.81	.69	.04*
	E-F	.21	.51	.39	.27
	F-D	.26	.21	.08	.13

*Significant ($P < .05$).
A, Chronological age 12 months-32 months; B, chronological age 32 months-52 months; C, chronological age 52 months-72 months; D, implant age 1-4 months; E, implant age 4-8 months; F, implant age 8-12 months.

Jitter%

Jitter percentages are higher for CI users when compared to children with normal hearing (Tables 5 and 6). Comparing across age groups (group A, B, and C), highly significant differences were obtained (Table 6) with slightly higher frequency percentage jitter values observed for the CI group when compared with the normal hearing group. However, on comparison among implant ages, a significant difference was obtained for the early implanted group (group D) when compared with later implanted groups (groups E and F), and this significance was restricted to the youngest CI recipient group (group A) (Tables 6, 7 and 8).

Formant Frequencies

F_1 and F_2 were the formants of interest in this study. CI recipients, in general, recorded lower formant frequencies when compared to the normal hearing group. Between groups, the analysis showed highly significant differences across all age groups for F_1. Whereas in the case of F_2, such differences were observed only for group A, the youngest and group C, the oldest (Table 6). On comparing among implant ages, significance was obtained for late implant groups in group B and, most importantly, the early (group C) implant group (Tables 6, 7 and 8). Nevertheless, good overall significance was obtained between CI users and normal hearing children for both F_1 and F_2 (Table 5).

DISCUSSION

This study aimed to compare the frequency parameters of voice in children using CI and those with normal hearing. The overall significance obtained in all parameters is in concurrence with findings of an earlier investigation by Srividhya et al.[9] and Wang et al.[14] They attributed these changes due to a lack of auditory feedback. The current study showed a significant difference between both groups in fundamental frequency values. The mean Fo values of the CI group remained higher than normal -earing children at all chronological and implant ages considered.[14-17] This is usually a result of tight glottal closure and higher vocal cord vibration.[18] This maladaptive change may be an effect of deficiency in the auditory feedback system.

However, this deficiency may be persisting for a variable period post-implantation in which most young children learn to make proper use of auditory stimulus. The change may be because, just like auditory afferent pathways, the feedback system also sets into ongoing maturation, reinforcing the laryngeal maturation.[6,14] This can be seen in our study with the older age group children (group C of both normal hearing and CI) where they have recorded lower mean Fo values than the other younger groups, this is well-supported in the literature as well.[19] Regardless of this reduction in Fo in CI users overall, a downward sloping trend nor stability could be seen across implant ages (mean Fo), which we attribute to the ongoing but delayed development of the auditory feedback system.

However, those with greater implant ages, that is, early implantees had frequency parameters closely comparable to normal hearing individuals, which is yet again a strong finding advocating early intervention that is extensively reported.[20]

The number of studies focusing on allied frequency parameters, such as jitter and formant frequencies, is meager, and the present paper sought to add to the existing literature on the subject.[6,8,21] This was again a driving factor to investigate those. The significance of comparing the parameters mentioned previously in normal hearing children and CI users endorses our claim. It is in concurrence with one such investigation by Coelho[7] where children using CI obtained higher jitter values as well. An evident decline in mean jitter (%) could be seen with an increase in chronological age. Unfortunately, significant effects could not be documented in comparison within implant ages except for the early implanted children belonging to group A. The considerable development seen in group A could be influenced by their age at implantation.[14] For the other 2 groups, the lack of significance could be due to the variability among subjects and insufficiency to visualize progress within the first year of implantation.

The auditory feedback system's role is known to extend even in control of motor adjustments, as well as the neuromuscular skills involved in speech and maturity.[20] Hence a compromised auditory feedback system tends to contribute to deviancies in speech production due to variation in tongue placements. In our study, both F_1 and F_2 were found to be significantly different, which simply suggests abnormality in tongue height and anterior-posterior displacement. The lower value of F_2 obtained is indicative of a probable abnormal posterior pharyngeal constriction. This could be improved with a combined auditory-verbal therapy approach and speech therapy post-implantation, especially if the intervention provided is as early as 6 months. It can help normalize the formant frequencies.[22]

Thus, the present study's findings highlight the need for early identification of hearing loss, appropriate provision of personal amplification, including implantation, early comprehensive habilitation, including various aspects of speech and language skills inclusive of speech modulations/intonations, and voice characteristics.

Limitation

A longitudinal study design rather than the utilized cross-sectional design would have yielded more reliable results. We believe so because a longitudinal study design involving repeated measures in the same individual would have resolved the irregularities seen across the mean scores of the considered parameters across implant ages and improved the validity of the study.[14]

CONCLUSION

Results from the present study have thrown light on the less spoken auditory feedback system and its persisting deviancies despite intervention.[4] Most times, jitter and formant frequency characteristics are overlooked. We believe that monitoring just the Fo changes/characteristics does not stand for drawing a conclusion on frequency characteristics as a whole, hence urge professionals to monitor jitter and formant frequency characteristics too. This would give a holistic picture and may facilitate the use of targeted rehabilitation techniques directed to improving or normalizing voice in these individuals. This attempt would, in turn, reinforce the auditory feedback system. An equal focus on voice characteristics in the habilitation of children using CIs may pave a way to alleviate these differences seen when compared to normal hearing children. We believe that these parameters, if considered as routine outcome measures, would aid in drawing valuable information not only about the development of the vocal tract but also the maturation of the auditory feedback system.

Ethics Committee Approval: Due approval has been obtained from ethical committee of Madras ENT Research Foundation (P) Ltd and MERF -Institute of Speech and Hearing after thorough review.

Informed Consent: Due consent was obtained from the parent of children included in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – J.L.S., S.D.; Design/ Supervision – J.L.S., S.D.; Literature Search / Data Collection and/or Processing – S.R., A.U.; Analysis and/or Interpretation/ Writing – S.R., A.U., J.L.S., S.D.

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REFERENCES

1. Akil F, Yollu U, Ozturk O, Yener M. Differences of the voice parameters between the population of different hearing tresholds: findings by using the multi-dimensional voice program. *Clin Exp Orl*. 2017;10(3):278-282. [CrossRef]
2. Tavares EL, de Labio RB, Martins RH. Normative study of vocal acoustic parameters from children from 4 to 12 years of age without vocal symptoms. A pilot study. *Braz J Orl*. 2010;176(4):485-490.
3. Kent RD, Murray AD. Acoustic features of infant vocalic utterances at 3, 6, and 9 months. *J Acoust Soc Am*. 1982;72(2):353-365. [CrossRef]
4. Coelho AC, Medved DM, Brasolotto AG. Hearing loss and the voice. *An Update Hear Loss*;2015;2:103-128.

5. Ryalls J, Larouche A, Giroux F. Acoustic comparison of CV syllables in french-speaking children with normal hearing, moderate-to-severe and profound hearing impairment. *J Multilingual Commun Disord*. 2003;1(2):99-114. [CrossRef]
6. Ching TY, Dillon H, Marnane V, et al. Outcomes of early- and late-identified children at 3 years of age: findings from a prospective population-based study. *Ear Hear*. 2013;34(5):535-552. [CrossRef]
7. Clement CJ. *Development of Vocalizations in Deaf and Normally Hearing Infants*. Utrecht: LOT; 2004.
8. Coelho AC, Brasolotto AG, Bevilacqua MC. An initial study of voice characteristics of children using two different sound coding strategies in comparison to normal hearing children. *Int J Audiol*. 2015;54(6):417-423. [CrossRef]
9. Srividya A, Premalatha BS, Gore M. Comparison of acoustic analysis of voice parameters in children with cochlear implants and normal hearing. *J Laryngol Voice*. 2016;6(2):6(2):31. [CrossRef]
10. Gautam A, Naples JG, Eliades SJ. Control of speech and voice in cochlear implant patients. *Laryngoscope*. 2019;129(9):2158-2163. [CrossRef]
11. Lapteva O. *Speaker Perception and Recognition: an Integrative Framework for Computational Speech Processing*. Kassel: Kassel University Press GmbH; 2011.
12. Huber JE, Stathopoulos ET, Curione GM, Ash TA, Johnson K. Formants of children, women, and men: the effects of vocal intensity variation. *J Acoust Soc Am*. 1999;106(3 Pt 1):1532-1542. [CrossRef]
13. Lieberman P. Perturbations in vocal pitch. *J Acoust Soc Am*. 1961;33(5):597-603. [CrossRef]
14. Wang Y, Liang F, Yang J, et al. The acoustic characteristics of the voice in cochlear-implanted children: a longitudinal study. *J Voice*. 2017;31(6):773.e21-773.e26. [CrossRef]
15. Higgins MB, McCleary EA, Schulte L. Articulatory changes with short-term deactivation of the cochlear implants of two prelingually deafened children. *Ear Hear*. 2001;22(1):29-45. [CrossRef]
16. Van Lierde KM, Vinck BM, Baudonck N, De Vel E, Dhooge I. Comparison of the overall intelligibility, articulation, resonance, and voice characteristics between children using cochlear implants and those using bilateral hearing aids: a pilot study [Comparación de la inteligibilidad global, la articulación, la resonancia y las características de la voz entre niños con implante coclear y niños con auxiliar auditivo bilateral: un estudio piloto]. *Int J Audiol*. 2005;144(8):452-465.
17. Lenden JM, Flipsen Jr P. Prosody and voice characteristics of children with cochlear implants. *J Commun Disord*. 2007;40(1):66-81. [CrossRef]
18. Higgins MB, McCleary EA, Ide-Helvie DL, Carney AE. Speech and voice physiology of children who are hard of hearing. *Ear Hear*. 2005;26(6):546-558. [CrossRef]
19. Cappellari VM, Cielo CA. Característicasvocaisacústicas de criançaspré-escolares. *Rev Bras Otorrinolaringol*. 2008;74(2):265-272. [CrossRef]
20. Garcia JV, Rovira JM, Sanvicens LG. The influence of the auditory prosthesis type on deaf children's voice quality. *Int J Pediatr Orl*. 2010;1(74(8)):843-848.
21. Coelho AC, Brasolotto AG, Bevilacqua MC. Systematic analysis of the benefits of cochlear implants on voice production. *J Soc Bras Fonoaudiol*. 2012;24(4):395-402. [CrossRef]
22. Seifert E, Oswald M, Bruns U, et al. Changes of voice and articulation in children with cochlear implants. *Int J Pediatr Orl*. 2002;66(2):115-123. [CrossRef]