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Original Research Article

Acoustic Analysis of Voice in Subjects with Hearing Loss

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ABSTRACT

Background: Earlier research has documented voicing errors as one of the most common types of errors in the speech of subjects with hearing loss. Hearing loss, either congenital or prelingual, has marked effects on voice production. Even though many researchers in the past have used acoustic analysis of speech for studying the voice characteristics and errors in voice production of the children with hearing loss, most of these studies are hardly conclusive.

Aim of the study: The present study aimed at investigating the differences in fundamental frequency related, Intensity related, perturbation related and noise-related voice parameters between children with hearing loss and age-matched control subjects.

Method: Two groups of subjects participated in the study. Group A comprised of 30 children with hearing loss and group B comprised of 30 age-matched normal hearing children. Phonation samples of vowels /a/, /i/ and /u/ were recorded, and acoustic voice parameters were extracted and statistically analysed.

Results: The result of the present study showed that the results of the present study showed that the F0 related parameters, I0 related parameters, perturbation related parameters and noise related parameters were significantly different between the subjects with hearing loss and normal hearing subjects.

Conclusion: The study approves that the acoustic voice parameters area reliable and powerful marker of voice characteristics among the subjects with hearing loss.

Keywords: Voice, Acoustic analysis, Fundamental frequency, Jitter, Shimmer, Harmonic to noise ratio, Hearing impairment, Hearing loss.

INTRODUCTION

Hearing loss either at birth or soon after birth and during early childhood results in a concomitant deficiency in comprehension and usage of speech. Greater the hearing loss, the more deviant is the speech produced by the child. [1] There appears to be a reasonably good consensus in the literature regarding the nature of the voicing errors made by subjects with hearing loss. Studies have reported that voicing errors were one of the most frequent types of errors in the speech of subjects with hearing loss. [2] Subsequent studies have also reported the presence of voicing errors in the speech of children with hearing loss. [3-6] Most frequent vocal errors observed in children with hearing loss include resonance problems, strain, unpleasant quality of voice, high pitched voice, altered breathing pattern and utterance with excessive variation. [7,8] Thus, the voicing errors evidenced in the speech of subjects with hearing loss is thought to be due to the failure to coordinate the timing of respiration, phonation, and articulation in attempting to produce voicing contrasts. [9]

The poor phonatory controls in the individuals with hearing loss can be divided into two major parts. One part being inappropriate average fundamental frequency (F0) and the other 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. [10,11] Several investigators have noted that individuals with hearing loss have a relatively high average pitch or speak in falsetto voice. [12,13] Several Indian studies carried out on the children with hearing loss have reported that the fundamental frequency (F0) of the voice of children with hearing loss was higher than that of the normal hearing children. [14-19] It has also been reported that the speakers with hearing loss often tend to vary the pitch much lesser than the normal hearing speakers and their speech has been described as flat or monotone. [13,20]

Many researchers in the past have used acoustic analysis of speech for studying the voice characteristics and errors in voice production of the children with hearing loss. To develop more effective voice assessment and therapy for the children with hearing loss, it is necessary to know the deviation in their voice from that of the normal hearing children. Acoustic methods are valuable, quantitative and accurate tools that assist in describing the existence and severity of articulatory problems in the speech of children with hearing loss. Therefore, understanding the physiological processes involved in voice control in children with hearing loss is a major challenge for the specialists working in this area. Thus, the present study aimed to investigate the acoustic voice characteristics in the speech of children with hearing loss.

METHOD

Participants

Two groups of subjects participated in the presence study. Group A consisted of 30 children in the age range of 14- 16 years who had congenital bilateral hearing loss with a pure tone average greater than 70 dB in the better ear in the audiometric hearing testing. Subjects of Group 1 were chosen from the Polytechnic for the Differentially Abled, Mysore. All the subjects of group 1 had normal visual ability. Screening Checklist for Auditory Processing (SCAP) was used to rule out any auditory processing disorders, and Quick Neurological Screening Test (QNST) was carried out to rule out any neurological impairments. The speech was their primary means of communication and Kannada as their first language based on the investigator’s observation and the previous health-related records. The subjects having other associated problems such as mental retardation were excluded from the study. Group B consisted of 30 age-matched normal-hearing children. A convenience sampling strategy was used to recruit the subjects of group B. All the subjects of group B were screened for their speech, language, and hearing. Further, the subjects who passed the screening were taken as the participants for the present study. The first 30 participants under each group who agreed to participate constituted the pool of participants. Each parent signed the informed consent form agreeing their child’s participation in the study and to the dissemination of results.

Procedure

The recording took place in a room with relatively low ambient noise. Each subject was seated comfortably in a chair in front of the laptop computer screen during the recording. Participants were instructed to sustain the phonation of vowels /a/, /i/ and /u/ at their habitual pitch and comfortable loudness levels. Each individual was given several demonstrations of the task before the recordings. The voice recordings of participants were collected with a unidirectional microphone onto the

Praat software (version 5.3.23). The distance between the microphone and the participant's mouth was 15 cm. Recorded samples were digitized at a sampling frequency of 44.1 kHz and 16 bits/sample quantization. Three trials of the phonation of each vowel were obtained from each subject. Out of the three recordings, the most stable recording was chosen, and the 5-second segment from the middle of the recording was taken for further analysis. All the samples were analyzed in Praat software, and acoustic voice parameters were extracted from the samples for each vowel. The following voice parameters were extracted

I. Fundamental frequency (F0) related parameters
   1. Mean F0
   2. Maximum F0
   3. Minimum F0
   4. F0 Range
II. Intensity (I0) related parameters
   5. Mean I0
   6. Maximum I0
   7. Minimum I0
   8. I0 Range
III. Perturbation related parameters
   9. Jitter local
   10. Jitter ppq5
   11. Shimmer local
   12. Shimmer apq5
IV. Noise-related parameters
   13. Mean noise-to-harmonics ratio
   14. Mean harmonics-to-noise ratio

Statistical analysis

The tabulated data were subjected to both descriptive and inferential statistics using Statistical Package for the Social Sciences (SPSS 20; SPSS Inc, Chicago, IL). Mean and standard deviation values were obtained for all the fundamental frequency related, intensity related, perturbation related and noise-related parameters for all the three vowels for the subjects of group 1 and group 2. As a part of inferential statistics, Univariate analysis of variance (ANOVA) was carried out using an alpha level of 0.05 (95 % confidence interval), to see the effect of the independent variable (groups) on every dependent variable (each voice parameter).

RESULTS AND DISCUSSION

The present study intended to investigate the acoustic voice parameters between the speech of children with hearing loss and their age-matched controls. The results obtained from the acoustic analysis were treated with both the descriptive and inferential statistics. The results are discussed under the following subheadings.

Fundamental Frequency (F0) related Parameters

Table 1: Mean values of all F0 related parameters for subjects of Group A and Group B.

Parameters	Groups	/a/		/i/		/u/	
		Mean	SD	Mean	SD	Mean	SD
Mean F0	Group A	223.31	83.53	247.80	93.97	259.29	100.05
	Group B	188.40	59.53	194.09	62.00	191.39	63.50
Maximum F0	Group A	230.96	86.06	253.37	94.90	262.08	104.00
	Group B	214.09	70.33	228.30	73.07	237.42	76.70
Minimum F0	Group A	216.38	83.21	241.56	92.21	249.10	98.67
	Group B	202.79	61.56	219.52	78.98	227.35	72.32
F0 Range	Group A	41.59	16.33	11.80	8.22	12.97	11.30
	Group B	7.98	3.93	7.13	3.50	7.23	3.23

As it can be observed from the Table 1 showing the mean and standard deviation values obtained for all the frequency-related acoustic parameters of voice, subjects of group A showed lower Mean F0, Maximum F0 and Minimum F0 compared to the subjects of Group B. Further, the results of Univariate ANOVA carried out to see the significant effects of groups and vowels on each frequency-related parameters showed that there was a significant effect of group on Mean F0 ($F=88.2$, $p<0.05$), Maximum F0 ($F=55.1$, $p<0.05$), Minimum F0 ($F=45.3$, $p<0.05$) and the range of F0 ($F=35.0$, $p<0.05$). Thus, it was inferred from the results that Mean F0, Maximum F0 and Minimum F0 were significantly higher among the subjects of group A compared to subjects of group B. The results of Univariate ANOVA also showed that there was a significant effect of vowel on the values of Mean F0 (F=4.5, p<0.05), Maximum F0 (F=5.1, p<0.05), and Minimum F0 (F=6.5, p<0.05). It was noted that vowel /u/ had significantly higher Mean F0, Maximum F0 and Minimum F0 values compared to vowels /a/ and /i/. There were no significant differences seen in Mean F0, Maximum F0 and Minimum F0 values between vowel /a/ and /i/.

Intensity (I0) related Parameters

Table 2: Mean values of all I0 related parameters for subjects of Group A and Group B.

Parameters	Groups	/a/		/i/		/u/	
		Mean	SD	Mean	SD	Mean	SD
Mean I0	Group A	72.27	7.88	72.40	8.20	72.36	8.10
	Group B	83.49	1.22	85.96	1.15	85.74	1.64
Maximum I0	Group A	75.36	8.01	74.91	8.53	74.91	8.12
	Group B	84.52	1.27	87.56	2.00	87.06	0.93
Minimum I0	Group A	54.78	25.90	54.53	25.75	55.46	25.72
	Group B	81.96	2.11	84.81	1.53	84.14	2.24
I0 Range	Group A	20.57	24.21	20.50	24.88	19.38	24.02
	Group B	2.56	1.82	2.71	2.27	2.85	2.07

Table 2 shows the mean and standard deviation values obtained for all the intensity related acoustic parameters of voice. It can be observed that the subjects of both the groups showed similar Mean I0, Maximum I0, Minimum I0 and I0 Range. Further, the results of Univariate ANOVA carried out to see the significant effects of groups and vowels on each intensity related parameters showed that there was a significant effect of group on Mean I0 (F=448.0, p<0.05), Maximum I0 (F=337.2, p<0.05), Minimum I0 (F=219.4, p<0.05) and I0 Range (F=90.0, p<0.05). The results of Univariate ANOVA also showed that there was no effect of vowel on any of the intensity related parameters. Thus, it was inferred from the results that Mean I0, Maximum I0, Minimum I0 and I0 Range were seen to be significantly lower in subjects of group A compared to the subjects of group B.

Perturbation related Parameters

Table 3: Mean values of all perturbation related parameters for subjects of both the groups.

Parameters	Groups	/a/		/i/		/u/	
		Mean	SD	Mean	SD	Mean	SD
Jitter Local	Group A	0.76	0.99	0.85	0.69	1.15	1.15
	Group B	0.22	0.44	0.26	0.70	0.29	0.52
Jitter PPQ5	Group A	0.38	0.22	0.52	0.42	0.70	0.73
	Group B	0.15	0.28	0.23	0.58	0.21	0.37
Shimmer Local	Group A	7.61	4.40	8.71	4.64	9.91	6.32
	Group B	3.55	5.93	3.26	5.50	3.70	6.06
Shimmer APQ5	Group A	5.14	4.21	6.02	4.06	6.59	4.32
	Group B	2.26	2.81	2.05	2.55	2.42	3.06

Jitter local, Jitter PPQ5, Shimmer local and Shimmer APQ5 were analysed as a part of perturbation related parameters. As it can be observed from the Table 3 showing the mean and standard deviation values obtained for all the perturbation related parameters of voice, subjects of group A showed higher mean values of all the perturbation parameters compared the subjects of group B. Results of Univariate ANOVA carried out to see the significant effects of groups and vowels on each perturbation parameter showed that there was a significant effect of group on Jitter local (F=62.0, p<0.05), Jitter PPQ5 (F=46.7, p<0.05), shimmer local (F=85.2, p<0.05) and Shimmer APQ5 (F=94.7, p<0.05). Thus, it was inferred from the results that Jitter local, Jitter PPQ5, Shimmer local and Shimmer APQ5 were significantly higher among the subjects of group A compared to subjects of group B. The results of Univariate ANOVA also showed that there was a significant effect of vowels only on Jitter PPQ5 (F=5.1, p<0.05). Jitter PPQ5 was seen to be significantly higher for vowel /u/ compared to vowels /a/ and /i/. There were no significant differences observed in Jitter PPQ5 values between vowel /a/ and /i/.

Noise related Parameters

Table 4: Mean values of all Noise related parameters for subjects of Group A and Group B.

Parameters	Groups	/a/		/i/		/u/	
		Mean	SD	Mean	SD	Mean	SD
HNR	Group A	0.13	0.17	0.13	0.17	0.09	0.13
	Group B	1.08	3.62	0.98	3.31	1.27	4.08
NHR	Group A	13.36	6.49	15.62	11.26	15.31	7.01
	Group B	12.08	6.99	11.52	6.27	11.52	7.97

As it can be observed from Table 4, showing the mean and standard deviation values obtained for HNR and NHR, subjects of group A showed higher NHR and lower HNR compared to the subjects of Group B. Further, the results of Univariate ANOVA carried out to see the significant effects of groups and vowels on HNR and NHR showed that there were significant differences in NHR (F=14.9, p<0.05) and HNR (F=14.1, p<0.05) between the subjects of both the groups. Further, it was also noted from the results of the Univariate ANOVA that there were no effects of vowels on the NHR and HNR values. Thus, it was evidenced that the subjects of Group A showed significantly higher values of NHR and significantly lower values of HNR compared to the subjects of Group B.

The results of the present study showed that the Mean F0, Maximum F0 and Minimum F0 were significantly higher among the subjects with hearing loss compared to that of normal hearing subjects. Many earlier investigators have also reported similar findings in children with hearing loss [14,18,19,21,22] Pickett [23] also studies mean pitch or F0 in children with hearing loss and reported that the high pitch produced by subjects with hearing loss was due to the increased tension in the cricothyroid muscle and by increased subglottal 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 subjects with hearing loss. As the present study also evidence increased F0 in subjects with hearing loss, the current study results support the findings of the earlier studies, and the results of the present study are completely in consonance with the results of all the research above.

It was also evident from the results that the Mean I0, Maximum I0 and Minimum I0 were significantly lower in the speech of the subjects with hearing loss compared to that of normal-hearing subjects. Many earlier investigators have also reported similar results in children with hearing loss. [18,19] Thus, the results of the present study are completely in agreement with the results reported by Fazil [18] and Rajinikanth. [19]

It was also observed that the Jitter local, Jitter PPQ5, Shimmer local and Shimmer APQ5 were significantly higher among the subjects with hearing loss compared to the normal hearing subjects. Higher perturbation values indicate irregular vibration of the vocal folds and have been implicated as a physical correlate of rough or hoarse voice. [24,25] Thus, it can be inferred from the results of the present study that increased perturbation values noted in subjects with hearing loss imply the presence of rough or hoarse voice quality in subjects of hearing loss. 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 the speech of subjects with hearing loss. [18,19,22]

Harmonic to Noise (H/N) ratio is defined as the mean amplitude of the average wave divided by the mean amplitude of the isolated noise components for the train of waves (expressed in dB). Therefore, the decrease in HNR and increase in NHR values indicate higher noise levels in the voice signal due to imperfect closure of the vocal folds. Researchers have also shown that a characteristic feature of hoarseness is the replacement of harmonics by noise energy, and thus, the best measure of hoarseness would be the ratio of one to the other. [26] Several investigators have found high correlations between listeners evaluations of roughness and the acoustic feature of spectral noise for simulated, rough vowels produced by normal speakers. [27-30] As the results of the present study revealed that the subjects with hearing loss showed significantly higher values of NHR and significantly lower values of HNR compared to the normal hearing subjects, it can be inferred that the subjects with hearing loss have poor harmonic organisation and higher glottal noise energy during the production of voice. Hence, the present study strongly supports the results of the earlier studies documenting the significant differences in HNR and NHR values between the subjects with hearing loss and normal hearing subjects.

CONCLUSION

The present study aimed at investigating the differences in voice parameters between subjects hearing loss and normal hearing children. A total of 30 subjects with hearing loss and 30 normal hearing subjects in the age range of 14 to 16 years participated in the study. Phonation samples of three vowels were recorded and analysed using Praat software. The result of the present study showed the F0 related parameters, I0 related parameters, perturbation related parameters and related noise parameters were significantly different between the subjects of hearing loss and normal hearing subjects. However, the present study failed to comment on the gender-linked differences across the acoustic measures of voice. Nevertheless, from a clinical point of view, the study approves that the acoustic voice parameters area reliable and powerful marker of voice characteristics among the subjects with hearing loss.

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