International Journal of Health Sciences and Research
www.ijhsr.org ISSN: 2249-9571

Original Research Article

Vowel Space Area in Speech of Children with Hearing Impairment

Narasimhan. S. V[1], Dr. Nataraja. N. P[2]

[1]Reader, Dept. of Speech & Language Pathology, JSS Institute of Speech & Hearing, Mysuru, Karnataka, India
[2]Director & Professor, Dept. of Speech & Language Pathology, JSS Institute of Speech and Hearing, Mysuru, Karnataka, India

Corresponding Author: Narasimhan. S. V

ABSTRACT

Background: Hearing impairment either congenital or prelingual has marked effects on the articulatory movements. Children with hearing impairment have problems in coordination of tongue and jaw movements and can be analysed acoustically by constructing vowel space area. Even though some studies on vowel space area in speech of children with hearing impairment have been carried out, most of these studies are hardly conclusive.
Aim of the study: The present study aimed at documenting the difference across formant frequencies and vowel working space area between children with hearing impairment and age-matched control subjects.
Method: Two groups of subjects participated in the study. Group 1 comprised of 30 children with hearing impairment and group 2 comprised of 30 age-matched normal hearing children. Phonation samples of vowels /a/, /i/ and /u/ was recorded and formant frequencies were extracted. Further, the vowel triangle area was also calculated.
Results: The results showed that there was a significant difference in formant frequency values between the subjects of group 1 and group 2. It was also noted that the vowel space area entailing vowels /a/, /i/ and /u/ of group 1 individuals was significantly reduced when compared to group 2. Thus, the results demonstrated more restricted tongue movements in subjects of group 1.
Conclusion: Further studies ought to focus on the correlation of the reduced vowel space area and the speech intelligibility measures to assist therapy outcomes to improve speech intelligibility in children with hearing impairment.

Key words: Vowel space area, Formant frequencies, Vowel triangle area, Hearing impairment

INTRODUCTION

Hearing impairment has a noticeable consequence on the children's capacity to acquire speech and language. [1] Speech and language are normally developed through the auditory modality [2] and normal functioning of auditory system is one of the important prerequisites for normal speech and language development as speech is acquired primarily through the sense of hearing. [3] Hearing impairment 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. [2]

Several authors have reported the impact of hearing loss on the acquisition and development of speech. [4-11] Presence of hearing loss disturbs the orderly and natural development of speech, language and communication. [12] Hearing-impaired child encounters double severe communication handicap. Normal speech is unintelligible to the hearing-impaired child and due to the lack of auditory feedback of his/ her own speech production; there is considerable difficulty in learning to speak correctly. [13] Hearing impairment results in communication problems, as it is not only difficult to perceive the environmental sounds, but also results in serious speech, language, voice and articulation deficits.

There appears to be a fairly good consensus in the literature regarding the nature of the speech errors made by hearing-impaired children. A normal hearing foetus has its auditory experience as early as second trimester of life. Normal hearing children are exposed to sounds from birth or even before birth, as early as second trimester. It was believed that the development of vocalization of children with hearing impairment and normal hearing children is the same, at least during the stage of babbling. It has frequently been noted that children with hearing impairment enter the babbling stage in the normal way and babbling of the child with hearing impairment fades over time. [14] This is usually, at about the time, when the child receives intensive stimulation from parents or the care givers. As the hearing impairment hampers the ability of the child to listen efficiently and hence start babbling, this motor activity ceases or gets delayed before the control mechanism in the brain has been established. [4-10]

Many earlier researchers have documented articulatory errors produced by children with hearing impairment. [15-17] Preliminary investigation on articulation errors in the speech of hearing impaired children was carried out on 192 subjects with moderate to profound degree of hearing loss in the age range between 8 to 20 years. Simple sentences were read by the hearing-impaired subjects and these reading samples were assessed by the teachers of the deaf children for rate of speech, articulatory precision and speech rhythm. Vowel errors, consonant errors and diphthong errors were documented, and these error patters were related to the intelligibility of speech. Voicing errors, substitution errors, nasality errors, omission of word initial and final consonants and misarticulation of consonants were the common types of errors reported in the speech of children with hearing impairment. [15]

Few researchers have also investigated the speech samples of hearing-impaired and normal hearing children to document the differences in formant frequencies in the speech these children. Sheela [18] studied four hearing-impaired children in the age range of 8-10 years and found that the hearing impaired had higher F1 and F2 and low F3 than those of the normal group. Studies have also noted that the F1 and F2 values in speech of children with hearing impairment were more than that of normal hearing children. [19,20] Nataraja et al [21] also investigated the formant frequencies in the speech of the children with hearing impairment and reported that there was significant difference between normal hearing and the hearing-impaired subjects in terms of the first three formant frequencies. Hearing impaired frequently misarticulated the vowels and thus F1 and F2 fall into areas normally associated with other vowels resulting in more extensive scattering of F1/F2 ratio.

Thus, it can be inferred that the formant frequencies and formant transition in the speech of children with hearing-impairment reflects the restriction in their articulatory movements from one phoneme to the subsequent phoneme. [17,22,23] It is reported that the changes in the duration, extent and direction of the formant frequencies, especially those of the second formant, functions as an important acoustic cue for the place of articulation. [24,25] As the children with hearing impairment typically produce many articulatory errors, distortions in the formant transition can be commonly expected. [26]

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 impairment. Further, acoustic measures can also be helpful in monitoring the progress in speech and articulation among the hearing-impaired children. Thus, as pointed out by Honda & Kusakawa [27] the basis for utilizing acoustic measure to evaluate speech motor function is straightforward as the speech signal includes quantifiable acoustic measures those reflect on the characteristics of speech production and perception. Thus, the precision of the articulatory movement and the coordination of tongue and jaw movements in hearing impaired children may be analysed through acoustic analysis and one of the acoustic methods that could be utilized for this purpose is the construction of the vowel space area using vowel formant frequencies.

Vowel space measures have been extensively employed in the area of research that investigates the aspects of articulation among various disorders to examine the intelligibility of speech. [28,29] The hypothesis underlying the use of this measure is that greater vowel working space reflects the better movement of the articulators with respect to tongue height (dimension of first formant frequency) or tongue advancement (dimension of second formant frequency). Thus, it can be inferred that the children with hearing impairment have imprecise articulation and the intelligibility of speech is significantly distorted.

Thus, from the literature review, it is clear that the formant frequencies vary in a reasonably predictable manner depending upon the articulatory movements and the vocal tract configuration and these changes could be predicted by constructing the vowel space area. Further, it is documented fact that children with hearing impairment have affected articulation due to which vowel space area can greatly vary. Thus, considering vowel space area as a measure of the accurate articulation that indicate gross motor ability of the tongue and jaw coordination, the existing studies on vowel space area and formant frequencies in the speech of children with hearing impairment are scanty. Even though some studies on vowel space area among individuals with hearing impairment have been carried out, most of these studies are hardly conclusive. Thus, the present study aimed at investigating difference across formant frequencies and vowel working space area between children with hearing impairment and age-matched control subjects.

METHOD

Participants

Two groups of subjects participated in the present study. Group 1 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. 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 2 consisted of 30 age-matched normal hearing children. A convenience sampling strategy was used to recruit the subjects of group 2. All the subjects of group 2 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 formant frequencies were extracted from the samples for each vowel. Further, the Vowel Space Area was also constructed based on the mean values of the first two formant frequencies for each group.

Statistical Analysis

The tabulated data were subjected to both descriptive and inferential statistics using Statistical Package for the Social Sciences (SPSS 11.5; SPSS Inc, Chicago, IL). Mean and standard deviation values were obtained for the F1 and F2 of 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 independent variable (groups) on every dependent variable (F1 and F2 of vowels /a/, /i/ and /u/ and vowel space area).

RESULTS AND DISCUSSION

The present study intended to document the formant frequencies and to differentiate the vowel space area between the speech of children with hearing impairment and their age-matched controls. The results obtained from the acoustic analysis were treated with both the descriptive and inferential statistics.

Table 1: Mean values and standard deviation (SD) of F1 and F2 values for subjects of group 1 and group 2 across all three vowels

Vowels		Vowel /a/		Vowel /i/		Vowel /u/	
Groups		Mean	SD	Mean	SD	Mean	SD
F1	Group 1	630.77	98.08	489.68	74.35	490.04	90.12
	Group 2	760.27	86.72	384.51	69.07	388.11	83.20
F2	Group 1	1154.61	271.09	1686.37	334.14	1131.51	266.63
	Group 2	1345.47	104.77	2551.30	269.67	1318.03	153.48

As it is evident from the table 1, across vowel /a/, group 1 subjects exhibited significantly lower F1 ($F=29.35$, $p<0.05$) compared to that of group 2. On the other hand, the average F1 value of /i/ in group 1 was significantly higher ($F=32.21$, $p<0.05$) than that of group 2 and this difference was also significant. Similarly, the F1 of vowel /u/ in group 1 was also significantly higher ($F=20.71$, $p<0.05$) than that of group 2.

According to Peterson and Barney [30] & Hillenbrand et al, [31] variation in F1 is principally related to tongue height during vowel production. In the present study, it was noted that the F1 of the two high vowels /i/ and /u/ among group 1 speakers was significantly higher as compared to group 2 speakers. Thus, the range of F1 values for the high-low vowel contrast reduces among group1 subjects as compared to subjects of group 2. This constricted range of F1 values for the high-low vowel contrast implies that group 1 subjects have more restricted jaw and tongue vertical movements.

Across F2, as it can be observed from the table 1, it was noted that F2 values across all the three vowels, i.e., /a/ ($F=12.93$, $p<0.05$), /i/ ($F=121.72$, $p<0.05$) and /u/ ($F=11.02$, $p<0.05$) was significantly reduced in group 1 subjects as compared to group 2 subjects indicating the restriction in tongue advancement. F2 –F1 differences were also calculated for all the three vowels for the subjects of both the groups. In group 1 subjects, the high front vowel /i/ showed F2-F1 difference of 1196.69 Hz and for high back vowel /u/ F2-F1 difference of 641.47 Hz was noted. When compared to group 2, group 1 illustrated a significantly limited range of F2- F1 values for the front-back vowel contrast (/i/-/u/). It is a known fact that F2 or F2- F1 difference mostly varies with tongue advancement, i.e., the more anterior the tongue position, F2 and F2-F1 difference tends to be higher. Further, the limited range of F2-F1 reflects the reduced front-back movement of the tongue. Thus, the present study demonstrated more restricted tongue advancement in group 1 subjects.

Further, the vowel triangle area was also calculated using the formula given by Liu, Tsao & Kuhl, [32] for the subjects of both the groups. It was noted that the vowel triangle area was reduced in speech of group 1 (Vowel triangle area =186,310. 28) subjects compared to that of group 2 subjects (Vowel triangle area = 769,537.03). The limited vowel triangle space area reflects the restricted movement of the tongue with respect to elevation and anterior-posterior movement for the group 1 individuals. Even though the present study only considered children with hearing-impairment in the age range of 14 to 16 years, limited vowel working space area and centralized articulation were evidenced. Thus, the results reflected more restricted vertical and horizontal tongue movements in the speech of children with hearing impairment compared to their age-matched controls.

CONCLUSION

The present study aimed at documenting the differences among vowel space area between hearing-impaired children and normal hearing children. A total of 30 subjects with hearing impairment 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 analyzed using PRAAT software. The result of the present study showed that vowel space area in subjects with hearing impairment was much reduced than normal hearing subjects indicating the restricted and narrowed range of tongue and jaw movements. However, the present study failed to comment on the gender-linked differences across the measures of vowel space area. Nevertheless, from a clinical point of view, the study approves that the measure is a reliable and powerful marker of tongue movement and articulatory coordination among the subjects with hearing impairment. Further studies ought to focus on the correlation of the reduced vowel space area and the speech intelligibility measures to assist in the therapy outcomes aimed at improving speech intelligibility in individuals with hearing impairment.

REFERENCES

1. Whernall E, Fry DB. The deaf child. First Edit. William Heinemann Medical Books Limited; 1964.
2. Ross M, Giolas TG. Auditory management of Hearing impaired children. University Park Press; 1978.
3. Vanriper C, Erickson RL. Speech Correction: An Introduction to Speech Pathology and Audiology. Ninth Edit. Allyn and Bacon; 1996.
4. Moeller MP, Hoover B, Putman C, Arbataitis K, Bohnenkamp G, Peterson B, et al. Vocalizations of infants with hearing loss compared with infants with normal hearing: Part II - Transition to words. Ear Hear. 2007;
5. Rvachew S, Slawinski EB, Williams M, Green CL. The impact of early onset otitis media on babbling and early language development. J Acoust Soc Am. 2002;
6. Stoel-Gammon C, Otomo K. Babbling Development of Hearing-Impaired and Normally Hearing Subjects. J Speech Hear Disord. 1986;
7. Eilers RE, Oller DK. Infant vocalizations and the early diagnosis of severe hearing impairment. J Pediatr. 1994;
8. Ertmer D, Mellon J. Beginning to talk at 20 months: early vocal development in a young

cochlear implant recipient. J Speech, Lang Hear Res. 2001;
9. Kent, Osberger, Netsell, Hustedde. Phonetic Development in Identical Twins Differing in Auditory Function. J Speech Hear Disord. 1987;
10. Oller, Eilers. The role of audition in infant babbling. Child Dev. 1988;
11. Oller, Eilers, Bull, Carney. Prespeech Vocalizations of a Deaf Infant: A Comparison with Normal Metaphonological Development. J Speech Hear Res. 1985;
12. Chermak GD. Handbook of audiological rehabilitation. Thomas CC, editor. Illinois; 1981.
13. Levitt H. Errors of Articulation in the Speech of Profoundly Hearing-Impaired Children. Vol. 51, Journal of the Acoustical Society of America. 1972.
14. Mavilya. Spontaneous vocalization and babbling in hearing impaired infants. In G. Fant (Ed.). In: International symposium on seeech communication abilities and profound deafness. Washington, D.C.: A. G. Bell Association.; 1968.
15. Hudgins, Numbers. An investigation of the intelligibility of the speech of the deaf. Genet Psychol Monogr. 1942;25:289–392.
16. Markides. The speech of deaf and partially hearing children with special reference to factors affecting intelligibility. Br J Disord Commun. 1970;2:126–40.
17. Smith CR. Residual hearing and speech production in deaf children. J Speech Hear Res. 1975;
18. Sheela. Analysis and Synthesis of hearing impaired speech. Unpublished Master's Degree Dissertation submitted to University of Mysore; 1988.
19. Kanaka. Acoustic Analysis of Speech of Tamil speaking Hearing Impaired Children. Unpublished Master's Degree Dissertation submitted to University of Mysore; 1998.
20. Poonam. Acoustic Analysis of Speech of Punjabi speaking Hearing Impaired Children. Unpublished Master's Degree Dissertation submitted to University of Mysore; 1998.
21. Nataraja NP, Savithri SR, Venkatesh CS. Speech Oriented Learning System for the Hearing Handicapped, SOLSH. Mysore; 1993.
22. Calvert DR. Some acoustic characteristics of the speech of profoundly deaf individuals. Unpublished doctoral dissertation, Stanford University; 1961.
23. John, Howarth. The effect of time distortions on the intelligibility of deaf children's speech. Lang Speech. 1965;8:127–34.
24. Delattre PC, Liberman AM, Cooper FS. Acoustic Loci and Transitional Cues for Consonants. J Acoust Soc Am. 1955;
25. Liberman, Delattre, Gerstman, Cooper. Tempo of frequency change as a cue for distinguishing classes of speech sounds. J Exp Psychol. 1956;52:127–37.
26. Osberger, Mc Garr. Speech Production Characteristics of the Hearing Impaired. Speech Lang [Internet]. 1982 Jan 1 [cited 2019 Jun 25];8:221–83.
27. Honda K, Kusakawa N. Compatibility Between Auditory and Articulatory Representations of Vowels. Acta Otolaryngol [Suppl]. 1997;532:103–5.
28. Bradlow AR, Torretta GM, Pisoni DB. Intelligibility of normal speech I: Global and fine-grained acoustic-phonetic talker characteristics. Speech Commun [Internet]. 1996;20(3):255–72. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3066472&tool=pmcentrez&rendertype=abstract
29. Narasimhan SV, Nikitha M, Nikita Francis. Articulatory Working Space Area in Children with Cerebral Palsy. Int J Heal Sci Res [Internet]. 2016;6(2):335.
30. Peterson GE, Barney HL. Control methods used in a study of the vowels. J Acoust Soc Am. 1952;24:175–84.
31. Hillenbrand J, Getty LA, Clark MJ, Wheeler K. Acoustic characteristics of American English vowels. J Acoust Soc Am. 1995;97(5 Pt 1):3099–111.
32. Liu H-M, Tsao F-M, Kuhl PK. The effect of reduced vowel working space on speech intelligibility in Mandarin-speaking young adults with cerebral palsy. J Acoust Soc Am. 2005;117(June):3879–89.

How to cite this article: Narasimhan. SV, Nataraja. NP. Vowel space area in speech of children with hearing impairment. Int J Health Sci Res. 2019; 9(8):97-102.

******