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Acoustic Analysis of Persian Vowels in Cochlear Implant Users: A Comparison With Hearing-impaired Children Using Hearing Aid and Normal-hearing Children

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Simmary: Objective. Vowel production in essence is auditorily controlled; hence, the role of the auditory feedback in vowel production is very important. The purpose of this study was to compare formant frequencies and vowel space in Persian-speaking deaf children with cochlear implantation (CI), hearing-impaired children with hearing aid (HA), and their normal-hearing (NH) peers.

Methods. A total of 40 prelingually children with hearing impairment and 20 NH groups participated in this study. Participants were native Persian speakers. The average of first formant frequency (F_1) and second formant frequency (F_2) of the six vowels were measured using *Praat* software (version 5.1.44). One-way analysis of variance (ANOVA) was used to analyze the differences between the three3 groups.

Results. The mean value of F_1 for vowel /i/ was significantly different (between CI and NH children and also between HA and NH groups) ($F_{2,\ 57} = 9.229$, $P < 0.001$). For vowel /a/, the mean value of F_1 was significantly different (between HA and NH groups) ($F_{2,\ 57} = 3.707$, $P < 0.05$). Regarding the second formant frequency, a *post hoc* Tukey test revealed that the differences were between HA and NH children ($P < 0.05$). F_2 for vowel /o/ was significantly different ($F_{2,\ 57} = 4.572$, $P < 0.05$). Also, the mean value of F_2 for vowel /a/ was significantly different ($F_{2,\ 57} = 3.184$, $P < 0.05$).

Conclusion. About 1 year after implantation, the formants shift closer to those of the NH listeners who tend to have more expanded vowel spaces than hearing-impaired listeners with hearing aids. Probably, this condition is because CI has a subtly positive impact on the place of articulation of vowels.

Key Words: Cochlear implant–Hearing aid–Acoustic analysis–Formants–Vowel space.

INTRODUCTION

Since the first cochlear implantation (CI) in children in 1980, this surgery has become a standard treatment option for prelingual children with deafness in many countries.[1] As regards speech perception and language development, it is now well documented that children with severe-to-profound hearing loss get more benefits from cochlear implants than children who wear hearing aids.[2–5]

The inadequate auditory feedback in the individuals with hearing impairment would essentially change their vowel production. Prelingually, children with deafness have obvious problems in the production of consonants and vowels. There are segmental errors, both vocalic and consonantal, and deviances in suprasegmental features including vowel production, such as substitution, neutralization, prolongation, and diphthongization. Also, learning vowels may be quite difficult for children with hearing impairment.[6–8] Using an objective acoustic analysis of formant frequencies to describe the quality of vowel production would yield detailed information about the production of vowels in different populations with hearing impairment wearing hearing aids or having cochlear implants.

Formants—the resonances of the vocal tract—are considered as seminal parameters that characterize the qualities of sound waves in a language. These features of the air vibration depend on the altering size and shape of the mouth and throat known as the vocal tract. The relevant shape of a vowel is the tube formed in the vocal tract. Because the vocal tract has a complex shape, the air inside it vibrates in complex ways. In producing a vowel, the air behind the elevated tongue (ie at the throat side) vibrates in one way, and the air in front of it (ie at the mouth side) trembles in another manner. In producing the vowel in *heed*, for instance, the air behind the tongue will vibrate at 250 Hz and the air in front of it at about 2100 Hz. The resonance with a lower pitch (the former) is called the first formant (F_1), and the resonance with a higher pitch (the latter) is called the second formant (F_2).[9] The relationship between F_1 and F_2 is an important acoustic cue in auditory recognition of vowels.[10] This systematic relationship is best depicted by an F_1-F_2 formant plot in which F_1 is related to the tongue height and is described according to the up-down displacement of the tongue; and F_2 pertains to the tongue advancement or posterior-anterior displacement of the tongue in the mouth.[10–12]

There is a specific room in the oral cavity, vowel space area (VSA), in which the production of vowels is limited. The VSA is an acoustic index commonly used in clinical research to assess the normalcy of vowel articulation indirectly.[11] In some languages such as English,[13] Slovenian,[14] and Dutch,[12] VSA is typically formed by the Euclidean distances between the coordinates of F_1 and F_2 of the corner vowels /i/, /u/, and /a/ (triangular VSA), or the corner vowels /i/, /u/, /a/, and /æ/ (quadrilateral VSA or QVSA) in the F_1-F_2 plane.[11,15] Also, in the Persian language, the corner vowels /i/, /u/, /a/, and /æ/ represent extreme articulatory positions of the tongue.

Furthermore, the centralization of formants and the compression of VSA in speakers who suffered from hearing loss were

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documented in numerous studies.[16] There are evidence of CI children for a relationship between natural recovery and effective treatment on the one hand and decentralization of formants and decompression of VSA on the other hand.[17–19] According to Uchanski and Geers,[17] who compared F_2 of vowel /i/ and vowel /ɔ/ in English-speaking CI users and that in normal-hearing (NH) group, 87% of the formant values for vowel /i/ and 88% of the formant values for vowel /ɔ/ of the CI group were in the normal limits. The authors proposed that the vowel space of CI users and NH listeners was similar.[17] Horga and Liker[18] in their acoustic analysis of vowels showed that vowel space in profoundly hearing-impaired groups without CI compared with those in CI users and NH group was reduced. They also found that at 1-year postsurgery, formants of CI children were close to NH group; and CI children were able to produce all of the vowels but /a/ more intelligibly.[18]

In a study of vowel production, Hocevar-Boltezar et al showed that after the CI surgery, the vowel triangle area increased due to a change in F_1 for the /i/ and /u/ vowels.[19] Baudonck et al compared F_1 and F2 of three corner vowels /a/, /i/, and /u/ in CI children, severe hearing-impaired children with conventional hearing aids, and NH children. They found higher intrasubject variability in CI group; although compared with NH children, they did not show a significant difference of the formant values.[20]

The results of the above-mentioned studies are not consistent with those reported in the study of Liker et al,[21] who compared CI children with profound hearing loss (3 times during 20 months after the surgery) with NH group for formants of 5 vowels in Croatian language. F_1 of vowel /a/ in CI group was lower than NH group. Yet, their results showed higher F_2 frequencies and smaller and more fronted vowel space in CI children.[21] Similarly, Ibertsson et al[22] compared nine Swedish vowels of CI children with those of a control NH group. They compared F_1, F2, and vowel space of the groups. Vowel space in CI children was significantly smaller than that in NH children.[22] Their results seemed to confirm the findings of Liker et al,[21] ie a smaller vowel space for CI group.

According to our knowledge, there is only one study that has compared the acoustic properties of Persian vowels between CI and NH children.[23] The aim of the present study was to compare the Persian language formant frequency and vowel space plot (based on the formant values) in Persian deaf children with CI, and HA children and their NH peer.

SUBJECTS AND METHODS

Subjects

Experimental groups

A total of 40 prelingually hearing-impaired children with congenital hearing losses participated in this study. They were Farsi native speakers and had no other sensory problems, neuromuscular disease, or mental disorder. HA children (n = 20, 10 girls and 10 boys) with the age range of 60–108 months (77 ± 1.35 months) and bilateral HA with a sever-to-profound hearing loss had received their first hearing aid before the age of 38 months. All HA children had at least 1-year experience with their HA device, and their device was fitted by audiologists. CI children (n = 20, 10 girls and 10 boys), with the age range of 62–112 months (78 ± 1.31 month) had received a multichannel CI at an average age of 42 months. They had at least 1-year experience of their current device. They had participated in speech and hearing rehabilitation programs before and after CI surgery.

Control group

The control group consisted of 20 NH children (10 girls and 10 boys) with the age range of 65–108 months (81 ± 1.14 months). Three groups were matched by age.

Subject demographics

Demographic data of the subjects including gender, chronological age, age of receiving hearing aid, and age of implantation are provided in Table 1.

Data acquisition

The recordings were carried out in a quiet room (the room noise level was measured by a sound level meter, model CEL-450) (product of Casella CEL; Regent House, Kempston, Bedford, UK); the measured room noise was Min LA (A-weighted, Sound Level): 27.0 dB and Min LC (C-weighted, Sound Level): 41.6 dB) in Tehran, either at the Hospital of “Amir Alam” affiliated to Tehran Medical Sciences University (for CI group), at the kindergarten and school (for NH children), and at the clinics of Iran Medical Sciences University (for HA peers).

Children were asked to repeat six Farsi vowels of /i/, /e/, /æ/, /u/, /o/, /a/ with their habitual vocal pitch, loudness, and constant quality. Vocal samples were recorded by a microphone (AKG C410, a Harman international company, Vienna, Austria, frequency response: 50 Hz–20 kHz), which was placed on a stand

TABLE 1.
Demographic Characteristic of the Participants

	CI Children	HA Children	NH Children
Number in groups	20	20	20
Gender	M: 10, F: 10	M: 10, F: 10	M: 10, F: 10
Chronological age in months	78 (62 to 112)	77 (60 to 108)	81 (65 to 108)
Age at onset of deafness in months	0 (0–0)	0 (0–0)	—
Age at implantation in, months	41	—	—
The lowest age of first hearing aid receiving in months	—	13	—

Abbreviations: F, female; M, male.