A Comparison of Persian Vowel Production in Hearing-Impaired Children Using a Cochlear Implant and Normal-Hearing Children

*Narges Jafari, †Michael Drinnan, *Reyhane Mohamadi, *Fariba Yadegari, ‡Mandana Nourbakhsh, and §Farhad Torabinezhad, *,‡,§Tehran, Iran and †Newcastle upon Tyne, United Kingdom

Summary: Objective. Normal-hearing (NH) acuity and auditory feedback control are crucial for human voice production and articulation. The lack of auditory feedback in individuals with profound hearing impairment changes their vowel production. The purpose of this study was to compare Persian vowel production in deaf children with cochlear implants (CIs) and that in NH children.

Methods. The participants were 20 children (12 girls and 8 boys) with age range of 5 years; 1 month to 9 years. All patients had congenital hearing loss and received a multichannel CI at an average age of 3 years. They had at least 6 months experience of their current device (CI). The control group consisted of 20 NH children (12 girls and 8 boys) with age range of 5 to 9 years old. The two groups were matched by age. Participants were native Persian speakers who were asked to produce the vowels /i/, /e/, /æ/, /u/, /o/, and /a/. The averages for first formant frequency (F_1) and second formant frequency (F_2) of six vowels were measured using *Praat* software (Version 5.1.44, Boersma & Weenink, 2012). The independent samples *t* test was conducted to assess the differences in F_1 and F_2 values and the area of the vowel space between the two groups.

Results. Mean values of F_1 were increased in CI children; the mean values of F_1 for vowel /i/ and /a/, F_2 for vowel /a/ and /o/ were significantly different ($P < 0.05$). The changes in F_1 and F_2 showed a centralized vowel space for CI children.

Conclusions. F_1 is increased in CI children, probably because CI children tend to overarticulate. We hypothesis this is due to a lack of auditory feedback; there is an attempt by hearing-impaired children to compensate via proprioceptive feedback during articulatory process.

Key Words: Cochlear implant–Acoustic analysis–Formants–Vowel production.

INTRODUCTION

In prelingual deaf children, speech is characterized by a deficiency in consonant and vowel production. The learning of vowels is quite difficult for such children, and errors such as diphthongization and neutralization are seen in vowel investigations.[1–3]

Almost 30 years after the first cochlear implant (CI), this surgery has become a standard treatment for prelingual deaf children. Although these implants primarily improve speech perception, they can help to develop the production of vowels.[4] For example, Serry and Blamey[4] concluded that after CI surgery, the production of vowels, and especially of monophthongs, had improved.

One method to describe the quality of vowel production is acoustic analysis. A vowel may be described according to the up-down or posterior-anterior displacement of the tongue in the mouth; acoustically, these correspond to the first formant (F_1) frequency and the second formant (F_2) frequency.[5] The relationship between the first two formants is considered the most important acoustic cue of vowel auditory recognition by the listener,[6] and the auditory quality of a vowel is related to its formant frequencies.[7]

The importance of the formant is the relationship between formant pattern and articulation of vowel, which permits the conversion from acoustic to articulatory measures. This systematic relationship is best depicted by an F_1-F_2 formant plot in which the first formant is related to tongue height and the second formant pertains to tongue advancement.[8]

There is a specific space into the oral cavity called "vowel space" or "vowel limit," that production of vowels is limited within this space. So, theoretically speaking, tongue-position of any vowel in any language must be specific either on the vowel limit or into the Vowel Space.[9]

In some languages such as in English,[10] Slovenian,[11] and Dutch,[5] the corner vowels (/a/, /i/, /u/) represent extreme articulatory positions of the tongue. The formant frequencies of these corner vowels can be plotted in an F_1/F_2 diagram to form a vowel triangle which is a graphic representation to illustrate the articulation space.[12,13]

Patients with hearing impairment frequently have deviations regarding formant frequencies and vowel space. For example, the first two formants have been described as "centralized,"[14] or articulatory movements have been reported to be "small," which might reflect a diminution of articulatory space.[12]

Uchanski and Geers[15] compared second formant frequencies of English-speaking CI users with those of a normal-hearing (NH) group. They measured the anterior vowel /i/ and posterior vowel /ɔ/ which had respectively the highest and lowest F_2 values. They concluded that 87% of the formant values for /i/ and 88% of the formant values for /ɔ/ of the CI group were in the range

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From the *Speech Therapy Department, University of Social Welfare and Rehabilitation Science, Tehran, Iran; †Department of Medical Physics, Freeman Hospital, Newcastle upon Tyne, United Kingdom; ‡Linguistic Department, Al-zahra University, Tehran, Iran; and the §Speech Therapy Department, School of Rehabilitation Scinces, Iran University of Medical Sciences, Tehran, Iran.

Address correspondence and reprint requests to Narges Jafari, Speech Therapy Department, University of Social Welfare and Rehabilitation Science, Tehran, Iran. E-mail: soniajafary11@gmail.com

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of the formant values of the NH groups. They suggested that vowel space may be similar between CI users and NH listeners.

Horga and Liker[16] showed that vowel space is reduced in profoundly hearing-impaired groups without CI, by comparison with that in CI users and NH groups. Immediately after CI surgery, the vowel space of CI children was the same as that of hearing-impaired children. But, 1 year after the surgery, CI children's formants were close to NH ones, and they could produce all the vowels more intelligibly except for the vowel /a/.

Liker et al[17] compared formants of five Croatian language vowels of 18 profound hearing loss children with CI aged 9.5–15 years (three times during 20 months after the surgery) with those of an NH group. The first formant frequency of vowel /a/ was lower for the CI group than for the NH group. However, they reported higher F_2 frequencies in the CI children in comparison with those in the NH group that was related to a smaller and more fronted vowel space.

Similarly, Ibertsson et al[18] compared nine Swedish vowels in 21 CI children with a mean age of 15 years, 3 months, with those in NH children with a mean age of 8 years, 7 months. They evaluated F_1, F_2, and vowel space in both groups. Vowel space in CI children was significantly smaller than that in NH children.

Anjali R. Kant et al[19] compared 15 CI children suffering bilateral severe to profound hearing loss with 15 age-matched NH peers. Both groups produced /e/, /i/, and /u/ vowels, and the first three vowel formants were assessed by *Praat* software. Means of first and second formant frequencies for /e/ were lower in the CI children than those in NH peers. However, there was no significant difference between the groups for F_1 and F_2 frequencies of vowels /i/ and /u/.

In 2008, Hocevar-Boltezar et al[20] showed that after CI surgery, the vowel triangle area increased because of a change in F_1 for the /i/ and /u/ vowels.

Baudonck et al[21] compared three corner vowels /a/, /i/, and /u/ in CI children, severe hearing-impaired children using conventional hearing aids, and NH children. F_1 and F_2 were measured with *Praat* software. They found higher intrasubject variability in the CI group, although they did not show significantly different formant values compared with the NH children.

In Iran, CI surgery has been performed for children with profound hearing loss for 25 years. The standard Persian language has six oral vowels. Preliminary acoustic findings about the Persian language in Iranian children with hearing loss come from Dehgan and Scherer,[22] who investigated fundamental frequency in hearing-impaired children. However, there is not enough information about the formant features of CI children in Iran.

The aim of the present study was to compare Persian language vowel production and vowel space in 5- to 9-year-old CI children with their NH peers.

SUBJECTS AND METHODS

Subjects

The participants were 20 children (12 girls and 8 boys) having a CI for congenital hearing loss. They had age range from 5 years; 1 month to 9 years (mean age: 6 years; 3 months). They received a multichannel CI at an average age of 3 years and had at least 6 months experience of their current device. They participated in speech and hearing rehabilitation programs before and after CI surgery and had no other handicaps such as visual problems, other sensory deficits, or mental disability. Normal vocal tract structures and oral-motor skills of all the CI children were confirmed by examination.

The control group consisted of 20 children (12 girls and 8 boys) with NH. They were age-matched to the CI group, with age range of 5–9 years and a mean age of 6 years; 6 months.

Recording procedure

Recordings were made in a quiet room at the child's kindergarten or school or in the hospitals of the Tehran University. Room noise level was measured by a sound level meter (model: CEL-450; product of Casella CEL; Regent House, Kempston, Bedford, UK) with measured room noise that was minimum LA: 27.0 dB and minimum LC: 41.6 dB.

The subjects were instructed to produce the six Persian vowels /i/, /e/, /æ/, /u/, /o/, and /â/ with habitual vocal pitch and loudness and constant quality. The examiner made the vowel and asked the child to repeat it. Voice samples were recorded using the AKG Perception 220 Studio Condenser Microphone (AKG Acoustics GmbH, Vienna, Austria), placed on a stand at 10 cm from the front of the mouth and collected using a digital voice recorder (DVR-902; Kingston, China).

Acoustic analyses

Formant frequencies. Children were asked to produce each vowel three times, and the clearest one was chosen for analysis. We used *Praat* software (Version 5.1.44) to analyze the vowels, by cutting 0.1 second from the beginning and 0.1 second from the ending of each vowel; then the midvowel fragments with steady state formant patterns were selected using visual inspection of the waveform and the spectrogram. Formants F_1 and F_2 were measured.

Vowel spaces. F_1-F_2 planar area was computed with the following formula for the area of an irregular quadrilateral:

$$\begin{aligned}\text{Area} = 0.5\times\{&(/i/F_2\times/\text{æ}/F_1 + /\text{æ}/F_2\times/a/F_1 \\ &+ /a/F_2\times/u/F_1 + /u/F_2\times/i/F_1) - (/i/F_1\times/\text{æ}/F_2 \\ &+ /\text{æ}/F_1\times/a/F_2 + /a/F_1\times/u/F_2 + /u/F_1\times/i/F_2)\}\end{aligned}$$

where F_n = the formant number for the vowel symbol shown in the slashes, for example, /i/ F_2 is the second formant for vowel /i/.[23]

Statistical analyses

SPSS for Windows (Version 16.0, SPSS Inc., Chicago, IL) was used for the statistical analysis. For the variables F_1 and F_2 and for each of /i/, /e/, /æ/, /u/, /o/, and /a/, the results of the CI children were compared with those of the NH children. The statistical differences between the two groups were assessed using student's independent samples t test. Because we performed