Objective Voice Analysis of Pediatric Cochlear Implant Recipients and Comparison With Hearing Aids Users and Hearing Controls

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Summary: Objectives. Phonation is influenced by hearing as a feedback mechanism. The purpose of the present study was to compare selected acoustic parameters in children using cochlear implants (CIs), those using hearing aids (HA), and their normal-hearing (NH) peers.

Methods. The participants were 15 children using CI (mean age: 72 months), 15 children using HA (mean age: 74 months), and 15 NH children (mean age: 77 months). The vowel /a/ was used to measure perturbation and mean fundamental frequency. The six Persian vowels in /CbVCd/ were obtained to extract vowel duration. Data were analyzed by one-way analysis of variance.

Results. Results revealed a statistically significant difference between the NH group and the HA group regarding fundamental frequency (F2a1 = 3.443, P < 0.05), jitter local (F2a1 = 1.629, P < 0.05), jitter local absolute (F2a1 = 6.519, P < 0.001), jitter rap (F2a1 = 7.151, P < 0.001), jitter ppq5 (F2a1 = 5.894, P < 0.001), shimmer local (%) (F2a1 = 8.070, P < 0.001), shimmer local (dB) (F2a1 = 3.884, P < 0.05), shimmer apq3 (F2a1 = 4.926, P < 0.05), shimmer apq5 (F2a1 = 8.442, P < 0.001), and harmonic-to-noise ratio (F2a1 = 4.117, P < 0.001). The mean values of the duration of all six vowels were significantly greater in children with CI and HA than in NH children (P < 0.001).

Conclusion. It seems that after 8 months of using CI, auditory control of voice production would be enabled. Furthermore, children with hearing impairment potentially regard vowel sound duration as a distinguishing feature, whereas in NH speakers, the duration has the least effect in vowel identification.

Key Words: Cochlear implant–Hearing aid–Jitter, shimmer, fundamental frequency–Harmonic-to-noise ratio–Vowel duration.

INTRODUCTION

Second-by-second and post-controlling of speech could be affected by auditory feedback, where the former plays a crucial role in suprasegmental features of voice and speech such as fundamental frequency (F0), quality, and voice intensity.1 Children with prelingual hearing impairment have clear-cut issues and malfunctioning in vocalization and speech production.2 Children in this group have problem controlling their vocal performance automatically, which results in lacking of voice quality and development of voice disorders, namely, breathy, rough, weak, unvoiced, and strident voice.3

Recently, the impacts of hearing loss on voice, with major focus on specific vocal features in diverse age groups, have been thoroughly investigated.3-5 According to a couple of literatures, the voice of children with hearing impairment has been mentioned to have a higher F0 than the voice of normal-hearing (NH) speakers.3,6 Furthermore, children with hearing impairment have a monotonous quality of voice as a result of lack in normal pitch variation, which can lead to disability of creating more than one tone, as well as voice adaptation with various frequencies and dynamic.5 Furthermore, they may reveal immoderate pitch variation, leading to pitch breaks.8 From another point of view, children with hearing impairment demonstrating the perturbation of glottal waveform. As a result, various papers have indicated that jitter and shimmer measurements were notably higher in the group with hearing loss than in the normal control group.8,10 In addition, children with hearing impairment produced noticeably higher spectral noise levels, which can be an indicator for using of more strain in vocalization.11

With the arrival of cochlear implants (CIs), many studies desired to clarify which parameters would be changed after CI surgery or after using the other type of auditory prostheses (hearing aid [HA]).12-14 Among the different parameters, duration in vowel production, voice onset time, first formant frequency, second formant frequency, F0, jitter, shimmer, and harmonic-to-noise ratio (HNR) of the vowel /a:/1,5,15-17 have been investigated more than other parameters. Leder et al suggested that F0 is one of the earliest acoustic features that approximates normal values when adequate auditory feedback is provided after implantation.18 According to the literatures, jitter and shimmer are the two parameters that most immediately reach the values of normality after implantation.19,20 Van Lierde et al compared jitter values in subjects using HAs with jitter values in subjects using implants and observed that children with HAs demonstrated jitter values higher than normality standards. CI users presented decreased values for the same parameter.20 Garcia et al analyzed the voice of 62 children using different types of auditory prostheses (HAs or CIs), with a control group of NH children. Voice quality was evaluated from the production of a sustained vowel
/a/ by considering fo, jitter, shimmer, and noise to harmonic ratio (NHR) values. In hearing-impaired groups, there were statistically significant differences particularly in fo and shimmer values in comparison with the control group. It is worth saying that mentioned parameters were lower for the control group. De Souza et al compared acoustic parameters regarding the voice of cochlear-implanted children with acoustic parameters of the voice of NH children. Thirty-six cochlear-implanted children and 25 children with normal hearing participated in their study. The recordings and the acoustic analysis of the sustained vowel /a/ were performed using the Praat program. The parameters analyzed for the sustained vowel were the mean of the fo, jitter, shimmer, and HNR. De Souza et al found that the vocal parameter values in the children with CI were close to the values obtained in the group of children with normal hearing. Moreover, based on various studies, children with hearing impairment show reduced ability to discriminate differences in vowel duration, which consequently affect their speech intelligibility. The ability of individuals with hearing impairment using CI to discriminate durational differences has been studied by different researchers. Some studies could not find any differences between children with HAs and speakers with CI. Some others reported that children using HAs are better in speech production tasks than children using CIs. Furthermore, there is evidence that indicates both groups (CIs and HAs) perform similarly to NH children. Uchanski and Geers concluded that 8- and 9-year-old children using CI produced vowel duration up to 132 ms longer than their peers with normal hearing. VanDam et al studied the duration of point vowels in 4- and 5-year-old children with normal hearing compared with those with HAs and CIs. The authors realized that children with HAs and CIs produced greater vowel duration than did children in the NH group.

According to our knowledge, there are only two studies that have compared some acoustic properties of Persian vowels (first and second formant frequencies) between children using cochlear implants (CIs), those using hearing aids (HAs), and their normal-hearing (NH) peers. In other words, there were no investigations which simultaneously studied the several acoustic characteristics of implanted children and speakers using HAs with their NH peers in Persian language. As a result, the aim of this study was to compare fo, vocal perturbation values of vowel /a/ (it has been demonstrated that determination of jitter and shimmer in the vowel /a/ can be a good indicator of improvement in phonation control), and vowel duration of six different Persian vowels in children using CIs, children with hearing impairment using HAs, and their NH peers.

**SUBJECTS AND METHODS**

**Subjects**

Thirty children with prelingual hearing impairment were selected to participate in this study. The participants were 15 children with CI (six boys and nine girls), with an age range of 59–106 months (72 ± 1.22 months), and 15 children with severe-to-profound hearing loss using HA, with an age range of 54–101 months (74 ± 1.28 months). Children using CI received a multichannel CI at an average age of 3 years old. They had at least 8 months of experience with their current device (CI). They participated in speech and hearing rehabilitation programs before and after CI surgery, and had no other sensory problems. Children using HA had at least 1 year of experience with their HA device, which was fitted by audiologists. They also participated in speech and hearing rehabilitation programs before and after using their current device (HA). The control group included 15 NH children, ranging in age from 60 to 111 months (77 ± 1.18 months). This group was evaluated by an otolaryngologist for the sake of laryngeal and hearing health. Furthermore, children in the NH group were perceptually evaluated to ensure that they have normal voice quality. These three groups were matched by age.

**Voice samples**

The six Persian vowels /i/, /e/, /æ/, /u/, /o/, and /a/ were obtained from the six following words: bid, bed, bud, bod, bad, for extraction of vowel duration. Also, the vowel /a/ was produced separately for the purpose of perturbation data analysis.

**Recording procedure**

Voice samples were recorded in a quiet room at the children’s kindergarten and school or at the hospital of Tehran University. Room noise level was measured by a sound level meter (model: CEL-450; Keison Products, Chelmsford, Essex, England), with a minimum of 28.0 dB and a maximum of 40.8 dB.

Three voice samples of sustained vowel /a/, as well as the six previously mentioned words, were obtained by instructing the patients to repeat (owing to the inability of children to read samples) the samples they heard (which were produced in the same way and by the same examiner) at a comfortable pitch, habitual amplitude, and constant quality by using a microphone (AKG C410, A Harman International Company, Vienna, Austria; frequency response 50 Hz–20 kHz) placed on a stand 8 cm from and with an angle of 45° to the patient’s mouth to decrease aerodynamic noise from the mouth. Samples were collected by using a digital recorder (Kingston DVR-902, Shanghai, China). The acoustic parameters were evaluated by Praat software (Version 4.2.17, Paul Boersma and University of Amsterdam, The Netherlands) installed in a personal computer (Dell Inspiron 6400; Dell Inc, Round Rock, TX; sound card Sigmatel STAC 92XX C-Major HD Audio; Sigmatel Corp, Austin, TX) with a sampling rate of 22.050 Hz.

**Fundamental frequency, perturbation analysis data, and HNR**

To derive irregularities belonging to phonation onset and offset, the stable 3 seconds of the midvowel segment of the voice sample /a/ was evaluated.

Mean fo, mean jitter (local), mean jitter (local, absolute), mean jitter (rap), mean jitter (ppq5), mean shimmer (local), mean shimmer (local, dB), mean shimmer (apq3), shimmer (apq5), mean shimmer (apq11), and mean HNR were obtained for each subject. Jitter is defined as the periodic variation from cycle to cycle, and shimmer is a cycle-to-cycle, short-term perturbation in amplitude of voice. Jitter (local) is the average absolute difference
between consecutive periods, divided by the average period shown as percentage. Jitter (local, absolute) is the cycle-to-cycle variation of fo, illustrated as microseconds. Jitter (rap), the relative average perturbation, is the average absolute difference between a period and the average of it and its two neighbor periods, divided by the average period, which is expressed as a percentage. Finally, jitter (ppq5) is a five-point period perturbation quotient, computed as the average absolute difference between a period and the average of it and four closest neighbor periods, divided by the average period and is shown as percentage. From the abovementioned categories for shimmer, shimmer (local) is the average absolute divergence between the amplitudes of consecutive periods, divided by the average amplitude depicted as percentage. Shimmer (local, dB) is expressed as the variability of the peak-to-peak amplitude in decibels. Shimmer (apq3) is the three-point amplitude perturbation quotient, the average absolute difference between the amplitude of a period and the average of the amplitudes of its neighbors, divided by the average amplitude. It is expressed as percentage. Finally, shimmer (apq5) is the five-point amplitude perturbation quotient, the average absolute difference between the amplitude of a period and the average of the amplitudes of it and its four closest neighbors, divided by the average amplitude shown as percentage.

On the condition of increased jitter and shimmer values, we can conclude that the laryngeal control has been decreased, consecutively.38

Another variable would be HNR, which is an indicator of the overall periodicity of the voice signal that quantifies the ratio between the periodic or harmonic part and the aperiodic or noise components.39

Vowel duration
Children were asked to produce each word three times, and the best one was registered for analysis.

To distinguish the vowel duration boundaries of the phonological segment, each child’s production was determined by visual investigation of the waveform and spectrogram, as well as using the audio playback. Henceforth, consonants and vowels were identified by using their features and transitions.

Statistical analyses
The results of the children with CI and HA were compared with the results of the NH children. A one-way analysis of variance with a post hoc Tukey test was used. SPSS Statistics 16.0 (SPSS Inc., Chicago, IL) was used for the statistical analysis.

RESULTS
Subject demographics
Demographic data of the subjects in the study, including number, gender, chronological age (months), age at deafness (months), age at first HA use, and age at implantation, are provided in Table 1.

Fundamental frequency, perturbation analysis data, and HNR
The mean values and the standard deviation of each parameter of the acoustic evaluation of the voice of the children using CIs, speakers using HAs, and their NH peers are demonstrated in Table 2.

Comparison of acoustic analysis results by using a post hoc Tukey test revealed statistically significant difference in fo (Hz) (F2, 51 = 3.443, P < 0.05), jitter local (%) (F2, 51 = 1.629, P < 0.05), jitter local absolute (ms) (F2, 51 = 6.519, P < 0.001), jitter rap (%) (F2, 51 = 7.151, P < 0.001), jitter ppq5 (%) (F2, 51 = 5.894, P < 0.001), shimmer local (%) (F2, 51 = 8.070, P < 0.001), shimmer local (dB) (F2, 51 = 3.884, P < 0.05), shimmer apq3 (%) (F2, 51 = 4.926, P < 0.05), shimmer apq5 (%) (F2, 51 = 8.442, P < 0.001), and HNR (Hz) (F2, 51 = 4.117, P < 0.001) values between children using HAs and their NH peers (Table 2).

Vowel duration
The mean, standard deviation, maximum, and minimum for each vowel duration measurement are summarized in Table 3 for the CI, HA, and NH groups. The P value was calculated with one-way analysis of variance with a post hoc Tukey test. Findings revealed a statistically significant increase in the mean vowel duration values across the CI and HA groups in comparison with NH talkers (significant at P < 0.001) (Table 3).

Results showed that the order of the vowels based on the vowel length in NH children from maximum to minimum was /a/ = 170 milliseconds (ms), /æ/ = 165 ms, /æ/ = 154 ms, /a/ = 153 ms, /e/ = 152 ms, and /i/ = 150 ms. In children with CI, the order of the vowels based on the vowel length from maximum to minimum was as follows: /a/ = 342 ms, /æ/ = 296 ms, /æ/ = 279 ms, /a/ = 269, /e/ = 266 ms, and /i/ = 257 ms. In children with HA, the order

<p>| Table 1. Demographic Information of Participants in This Study |
|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Groups</th>
<th>Number in Groups</th>
<th>Gender</th>
<th>Chronological Age (mo)</th>
<th>Age at Onset of Deafness (mo)</th>
<th>Age at Implantation (mo)</th>
<th>Age at First HA Use (mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children with CI</td>
<td>15</td>
<td>M: 6 F: 9</td>
<td>Mean: 72 SD: 1.22</td>
<td>0 (0–0)</td>
<td>36</td>
<td>—</td>
</tr>
<tr>
<td>Children with HA</td>
<td>15</td>
<td>M: 6 F: 9</td>
<td>Mean: 74 SD: 1.28</td>
<td>0 (0–0)</td>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td>NH children</td>
<td>15</td>
<td>M: 6 F: 9</td>
<td>Mean: 77 SD: 1.18</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Abbreviations: F, female; M, male; SD, standard deviation.
**TABLE 2.**
Comparison of Fundamental Frequency, Perturbation Analysis Data, and HNR Between CI, HA, and NH Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cochlear Implant</th>
<th>Hearing Aid</th>
<th>Normal Hearing</th>
<th>Tukey Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>CI-NH Post Hoc (P)</td>
</tr>
<tr>
<td>Mean fo (Hz)</td>
<td>270.16 (32.03)</td>
<td>281.84 (40.91)</td>
<td>250.74 (34.22)</td>
<td>2.344 (0.4)</td>
</tr>
<tr>
<td>Jitter local (%)</td>
<td>0.779 (0.376)</td>
<td>1.026 (0.427)</td>
<td>0.662 (0.230)</td>
<td>2.1629 (0.01)</td>
</tr>
<tr>
<td>Jitter local absolute (ms)</td>
<td>6.961 (4.722)</td>
<td>8.539 (6.042)</td>
<td>2.952 (3.161)</td>
<td>2.6519 (0.003)</td>
</tr>
<tr>
<td>Jitter rap (%)</td>
<td>0.561 (0.083)</td>
<td>0.636 (0.126)</td>
<td>0.472 (0.166)</td>
<td>2.7151 (0.002)</td>
</tr>
<tr>
<td>Jitter ppq5 (%)</td>
<td>0.351 (0.083)</td>
<td>0.389 (0.051)</td>
<td>0.309 (0.071)</td>
<td>2.5894 (0.005)</td>
</tr>
<tr>
<td>Shimmer local (%)</td>
<td>6.104 (1.863)</td>
<td>6.998 (1.431)</td>
<td>5.063 (0.865)</td>
<td>2.8070 (0.001)</td>
</tr>
<tr>
<td>Shimmer local (dB)</td>
<td>0.795 (0.348)</td>
<td>0.888 (0.415)</td>
<td>0.573 (0.264)</td>
<td>2.3884 (0.02)</td>
</tr>
<tr>
<td>Shimmer apq3 (%)</td>
<td>3.502 (0.566)</td>
<td>3.711 (0.680)</td>
<td>3.103 (0.512)</td>
<td>2.4926 (0.01)</td>
</tr>
<tr>
<td>Shimmer apq5 (%)</td>
<td>3.705 (0.641)</td>
<td>4.194 (0.663)</td>
<td>3.261 (0.735)</td>
<td>2.8442 (0.001)</td>
</tr>
<tr>
<td>Mean HNR (Hz)</td>
<td>18.43 (3.011)</td>
<td>16.649 (4.027)</td>
<td>19.737 (2.498)</td>
<td>2.4117 (0.02)</td>
</tr>
</tbody>
</table>

*P* values on one-way ANOVA with a post hoc Tukey test, mean _ standard deviation _ df _ F ratio of acoustic parameters of the sustained vowel /a/ measures are reported.

Effects significant at *P* < 0.05 (*) and *P* < 0.001 (†) are noted.

**Abbreviations:** fo, fundamental frequency; M, mean; SD, standard deviation.

**TABLE 3.**
Comparison of Vowel Duration Between CI, HA, and NH Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cochlear Implant</th>
<th>Hearing Aid</th>
<th>Normal Hearing</th>
<th>Tukey Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (Med)</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>/bId/</td>
<td>257</td>
<td>250</td>
<td>84</td>
<td>415</td>
</tr>
<tr>
<td>/bed/</td>
<td>266</td>
<td>239</td>
<td>108</td>
<td>571</td>
</tr>
<tr>
<td>/bId/</td>
<td>279</td>
<td>269</td>
<td>96</td>
<td>496</td>
</tr>
<tr>
<td>/bud/</td>
<td>269</td>
<td>210</td>
<td>136</td>
<td>672</td>
</tr>
<tr>
<td>/bod/</td>
<td>296</td>
<td>287</td>
<td>111</td>
<td>511</td>
</tr>
<tr>
<td>/bad/</td>
<td>342</td>
<td>319</td>
<td>125</td>
<td>613</td>
</tr>
</tbody>
</table>

Effects significant at *P* < 0.001 (*) are noted.

**Abbreviations:** M, mean; max, maximum; Med, median; min, minimum; SD, standard deviation.
was /æ/ = 388 ms, /a/ = 369 ms, /o/ = 335 ms, /e/ = 297 ms, /a/ = 289 ms, and /u/ = 277 ms.

**DISCUSSION**

The purpose of the present study was to compare, using *Praat* software, the fo, four frequency perturbation parameters (jitter local, jitter local absolute, jitter rap, and jitter [ppq5]), four amplitude perturbation parameters (shimmer local, shimmer local dB, shimmer [aq3], and shimmer [aq5]), and HNR values of the vowel /a/, as well as to compare vowel duration of six different Persian vowels in word level between children using CIs, children with hearing impairment using HAs, and their NH peers. Notably, *Praat* is a free and user-friendly software that helps the clinician to place reliance on objective scientific data.

The major tenet of our current study is sustained vowel, which is practical because of less articulatory variations among speakers. Particularly, performing voice assessment by the aid of sustained vowel phonation, that is, the vowel /a/ (among the other vocal tasks), possesses beneficial elements owing to being a point vowel. It is worth saying that the production of the abovementioned vowel would be easy and consistent for children. Also, it has been demonstrated that determination of jitter and shimmer in the vowel /a/ can be a good indicator of improvement in phonation control.

**Fundamental frequency, perturbation analysis data, and HNR**

In the present study, the results obtained from the children with hearing impairment are compared with the ones obtained from a control group of NH children. Findings revealed statistically significant difference in fo, in all four frequency perturbation parameters (jitter [local], jitter [local absolute], jitter [rap], jitter [ppq5]), in all four amplitude perturbation parameters (shimmer [local], shimmer [local dB], shimmer [aq3], shimmer [aq5]), and HNR between children with hearing impairment using HAs and their NH peers. Although the mean values of all analyzed acoustic parameters were higher in children using CI than in children in the control group, there was no statistically significant difference between these two groups of participants.

Based on our obtained results, the values of fo were higher for the children with hearing impairment using CI and speakers using HA than in children with normal hearing. According to prior studies, auditory feedback would be regarded as a primary sensory channel, which easily paves the way for the observation and control of the fo. As far as the literature is concerned, children with hearing impairment have high fo, which is derived from auditory feedback shortages. It would be apparent that children with hearing impairment tend to increase the fo value to elevate the auditory sensation besides monitoring and controlling their voice. It is more to say that an increase in fo value, could be derived from a couple of items as follows: less ability to control the vertical position of the larynx (revealed by high position of the larynx), increase in phonation attempt, incapability to control subglottic pressure, tension elevation during glottis cycle, and laryngeal musculature controlling deficits. Regarding the laryngeal musculature and vocal tract posture regulation, sufficient phonation would be done by the aid of auditory feedback (AF). Henceforth, grasping audiometric thresholds can be regarded as an indicator of vocal production control for CI users compared with the normal group.

By taking the fo into account, appropriate fo after cochlear surgery, which is in harmony with our current study findings, was reported by Hocevar-Boltezar et al. On the contrary, findings illustrated in the current study were not parallel with the ones obtained in Garcia and Vila Rovira’s piece of work. The major findings of their study were statistically noticeable between the children using CI and the control group. Likewise, based on Campisi et al’s findings, fo did not undergo any change after CI surgery in a group of 21 children with hearing impairment.

As a result, the prominent disparity between the mean values of the parameters revealing the phonation quality (jitter and shimmer) has been observed in two groups: children with hearing impairment and their NH peers. Although the mean values of jitter (%) and shimmer were higher in children with CI than in children in the control group, there was no statistically significant difference between these two groups.

Jitter and shimmer values, which are short-term markers, indicate the level of vocal perturbation so as to determine the phonatory system consistency that could be applied to check phonation quality. Thus, the increased values would be linked by phonation and neuromuscular control deficits for children with hearing impairment.

Regarding to the post CI’s functions, jitter and shimmer are going to be regarded as the major parameters which can rapidly access the values in NH speakers. In other words, the abovementioned parameters indicate developed phonation control in speakers with CI. Based on our findings, cochlear-implanted children possess a better detailed control over phonation than speakers with HAs; our findings are supported by prior studies. In a previous study done by Hocevar-Boltezar et al, children using CI obtain more hearing control, which paves the way for the improvement of the quality of their phonation. More importantly, Hocevar-Boltezar et al were on this belief that this trend is largely owing to their neuromuscular control of phonation plasticity.

A study performed by Horga and Liker reported that regarding jitter and shimmer, children with CI showed better results than did children who use conventional HAs. Their results seemed to confirm the findings of the present study. Notably, Garcia and Vila Rovira reported that children with HAs do not exhibit statistically significant disparities in jitter and shimmer compared with the control group, which was not in the same line with the abovementioned study.

The HNR measures for the children with hearing impairment were lower than for their NH peers. These differences were merely statistically significant between the HA group and the NH group. Moreover, this finding is consistent with that of a previous study in the literature. Hocevar-Boltezar et al reported in their study that HNR improved after CI surgery.

The HNR could be taken as an indicator of the overall periodicity of the voice signal that quantifies the ratio between the periodic or harmonic part and the aperiodic or noise components (coming from turbulent airflow produced at the glottis during phonation) and it can be considered as an indicator to ascertain the vocal function. It sounds that children with hearing impairment have atypical
voice quality, which is linked with overaspiration and spectral noise.\textsuperscript{47}

Based on our results, it seems those parameters (fundamental frequency, perturbation analysis data, and HNR) would be considered as acceptable pointers to assess voice control after cochlear implantation. The analyzed acoustic parameters in our study suggested that children who received implants can obtain faster improvement of voice production control. Children with HA revealed more voice changes in comparison with cochlear-implant users. To be more exact, the compensated auditory feedback is more prominent in children using CI than in children with HA. In other words, cochlear implantation enables auditory control of voice production and helps in better control of phonation after 8 months of use of this kind of prosthesis. Therefore, we consider that the auditory control of voice was possible after 8 months’ implantation and result in voice improvement.

**Vowel duration**

Place and height of the tongue are the foundation of Persian vowel classification. Precisely, six of them can be categorized into two groups based on their place of articulation: front vowel group, including /i, e, æ/; and back vowel group, including /u, o, a/. Persian vowels are divided into three groups on the basis of tongue height: close (high) vowels: /u, i/; mid (half close) vowels: /e, o/; and open (low) vowels: /a, æ/\textsuperscript{48}. In standard Persian language, the major distinction among individual vowels in /i,e,æ/ /u,o,a/ and /a,æ/ pairs is of a qualitative nature. Traditionally, /e,o,æ/ and /i,u,a/ are ordered as short and long, respectively, because they are remnants of short /i,u,a/ and long /i,u,æ/ vowels of Middle Persian. These two classifications of vowels still act in a different fashion in the phonological system of Modern Persian. Acoustic analyses of long and short vowels have indicated the two groups as different in duration.\textsuperscript{49}

According to the findings of the present study, children with hearing impairment had greater vowel durations than did their NH peers; also, results revealed more variable vowel duration in the HA group. Children did not vary as a function of device type. To be more exact, they don’t behave differently through using the various types of auditory prosthesis (CIs or HAs). However, the present work shows that vowel length in children using CI was closer to the values in the NH group. In addition, considering the order of the vowels based on the vowel length from maximum to minimum, we found that children with CI and NH speakers showed a similar pattern.

The results of the present study were consistent with previous reports in the literature. Initially, Calvert objectively measured the phonemic duration in the speech of children with hearing impairment by using the spectrographic analysis of words. The author reported that children with hearing impairment had an extended vowel duration compared with their peers with normal hearing.\textsuperscript{50} Similarly, Osberger and Levitt found that the prolongation of vowels in the speech of children with hearing impairment leads to syllable prolongation.\textsuperscript{51}

In addition, Monsen and Shaughnessy reported longer vowel duration in CI talker by acoustic analysis of duration in children with hearing impairment, which was parallel with the findings of the present study.\textsuperscript{52} In another study by Neumeyer et al, results showed that vowel duration of the CI group was greater than that of the controls.\textsuperscript{53} The authors were unsure of the source of these differences in vowel duration, but they mentioned that the Lombard effect induced by NH listeners through binaural masking also produces an increase in vowel duration.\textsuperscript{54} Furthermore, the results of the study done by VanDam et al were in agreement with the findings of the present study. VanDam et al studied developmental aspects of the duration of point vowels in children with normal hearing compared with those with HAs and CIs at 4 and 5 years of age. Accordingly, they found that children with HAs and CIs produce greater vowel duration than do children in the NH group.\textsuperscript{30} Also, they reported that children with HAs and CIs did not perform differently from each other.

Besides, it should be noted that recognition of intonation correlates with three acoustic parameters: fo, intensity, and duration, particularly in conversational speech. Inappropriate intonation can be the cause of low intelligibility in children with CI,\textsuperscript{55} which has been reported in the study by Kord et al, who compared the acoustic correlation of intonation (such as duration) in 25 children with CI and 25 NH speakers.\textsuperscript{56} They found that the performance of children with CI in using acoustic correlation of intonation is lower than that of their NH peers, which results in inappropriate intonation. As a result, the authors have suggested that intervention of intonation should be regarded in treatment program for children with CI. Additionally, control of articulatory timing is a vital aspect during spoken language learning, and it is a very major element in skilled motor performance.\textsuperscript{55}

Furthermore, durational control improvement indicates more matured productions. In other words, reduction in vowel duration is evident for improvement of intelligibility in speakers with hearing impairment.\textsuperscript{30} In addition, it has been shown that control of duration improves the intelligibility of speakers with hearing impairment.\textsuperscript{57} Therefore, authors propose that future studies should consider and examine the duration as an intonational element which it would be valuable further research investigate vowel duration in the sentence level and conversational speech tasks.

The participants of this study had their CI surgery and the rehabilitation programs about 8 months before the study measurements were made. It seems that they are at the outset of their hearing feedback training. Presumably, had more time passed following their CI surgery and had they received more than 1 year of speech therapy and auditory training, the duration values of their Persian language vowels would have been close to their NH peers.

**CONCLUSION**

According to the findings, the values of the parameters related to the phonation quality were higher for the children with hearing impairment using CI and speakers using HA than for the NH children; these differences were statistically significant between children with hearing impairment using HA and NH speakers. It seems that after cochlear implantation, the children with hearing impairment improved their phonation control. However, this improvement was not statistically significant in comparison with HA users. We suppose that the significant improvement in the
children using CI would be the consequence of the acquired hearing control, and more than 8 months is needed.

In addition, based on the acoustic measures, we conclude that children with prelingual hearing impairment have some deviations in vowel duration. In other words, the values of vowel duration were greater in the children using CI and the HA group than in NH speakers. Duration serves as a secondary feature to modify expression of contrasts in vowels and other segments. Authors have suggested that children with hearing impairment, by producing extended vowels, are trying to prognosticate the identity of different vowels. From another point of view, children with hearing impairment probably consider vowel duration as a distinctive feature, whereas in NH speakers, duration has the least role in vowel identification.

It is apparent that increased motor practice, along with development of linguistic skills, can potentially lead to shorter vowel duration production in children with hearing impairment. Likewise, 8 months after surgery, children using CI have auditory feedback improvement that has led to vowel duration values closer to the ones obtained by NH children.

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