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 produced to measure perturbation and mean fundamental frequency. The six Persian vowels in /C_bVC_d/ 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 ($F_{2,51} = 3.443$, $P < 0.05$), jitter local ($F_{2,51} = 1.629$, $P < 0.05$), jitter local absolute ($F_{2,51} = 6.519$, $P < 0.001$), jitter rap ($F_{2,51} = 7.151$, $P < 0.001$), jitter ppq5 ($F_{2,51} = 5.894$, $P < 0.001$), shimmer local (%) ($F_{2,51} = 8.070$, $P < 0.001$), shimmer local (dB) ($F_{2,51} = 3.884$, $P < 0.05$), shimmer apq3 ($F_{2,51} = 4.926$, $P < 0.05$), shimmer apq5 ($F_{2,51} = 8.442$, $P < 0.001$), and harmonic-to-noise ratio ($F_{2,51} = 4.117$, $P < 0.001$). 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 (fo), 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 fo than the voice of normal-hearing (NH) speakers.[3,6] Furthermore, children with hearing impairment have a monotonous quality of voice[7] 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.[9,10] 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 prosthesis (hearing aid [HA]).[12–14] Among the different parameters, duration in vowel production, voice onset time, first formant frequency, second formant frequency, fo, jitter, shimmer, and harmonic-to-noise ratio (HNR) of the vowel /a:/[3,15–17] have been investigated more than other parameters. Leder et al suggested that fo 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

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/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.[21] 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.[22]

Moreover, based on various studies, children with hearing impairment show reduced ability to discriminate differences in vowel duration, which consequently affect their speech intelligibility.[23] 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.[24] Some others reported that children using HAs are better in speech production tasks than children using CIs.[25,26] Furthermore, there is evidence that indicates both groups (CIs and HAs) perform similarly to NH children.[27,28] 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.[29] 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.[30]

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 (HA), 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.[31,32] 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[13]), 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, bæd, 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.[33]

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.[34,35]

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.[36,37] *Jitter (local)* is the average absolute difference