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RESEARCH ARTICLE

The role of age implantation on formants frequency changing in early and late cochlear implanted children: a study based on perceptual and acoustical assessments

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Abstract

Background and Aim: Age implantation is one of the effective factors on speech production outcomes in cochlear implanted (CI) children. The purpose of this study is to determine the role of age implantation on formant frequencies and production of three Persian vowels including /a/, /u/, /i/ in CI children.

Methods: Sixty nine congenitally deaf children who received CI were divided into three groups based on their age implantation. The first and second formant frequencies of vowels, as dependent variables, were measured by SFS software 1.2. The role of children's age implantation and their gender, as effective factors, were analyzed using a 3 (implantation groups)×2 (gender) two-way ANOVA with a post hoc Bonferroni honest significant difference test in SPSS 16.0.

Results: The mean values of F_1/a/, F_2/a/, F_2/u/, F_1/i/, F_2/i/ were significantly different among different groups ($p<0.05$). 100% of children who received CI before the age of 2 produced vowels correctly. Types of vowel production disorders were mostly nasalization and backing in children who received CI between the ages of 3 to 4 and after age 5. Analysis showed that the effect of age implantation on formant frequencies of vowels was significant ($p<0.05$).

Conclusion: Early age implantation (before 2) can cause an improvement of vowel production due to enhancement of F_1 and F_2 placement which is related to height and back-to-front movements of the tongue. Also, age implantation predicts the quality of vowel production.

Keywords: Cochlear implant; age implantation; formant frequency; vowel

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Introduction

The cochlear implant (CI), an electronic device which is used to provide a form of hearing for some completely deaf people, has been increasingly used since the early 1980s. Although French and Netherlands physicians, as in many other countries, have protested against this technology since the early 1990s [1], remarkable success have been reported during the past 35 years regarding this modern technological hearing device for speech and language development in children with hearing loss problem. Body of evidence emphasizes on the emergence of early-developing speech-language skills of cochlear implanted children including increased expressive vocabulary and comprehension skills [2], mean length of utterance [3], syntactic complexity [4], improved vowel space [5], and increased auditory perception [6].

Despite these progresses, children with cochlear implants (CIs) are known to have delay for speech production and language skills development. One of the problems of speech disorders in these children is inaccurate and incorrect vowel production [7]. Proper production of vowels is of great importance in speech as they are not only structural blocks of words, but also plosive consonants are formed near the vowels. The rhyme and prosody of speech are affected by the way vowels are formulated [8]. Some researchers believe that improving vowel production is 41-53% effective in speech intelligibility. Therefore, speech and language pathologists are interested in modification of vowel production in deaf children [9].

The vowel production process in vocal tract happens by the vibration of the vocal cords which provides sound source. This sound source consists of a fundamental frequency and its harmonics. Then this sound is changed by tongue, mandible and lips movements. In fact, the vocal tract acts like a filter and strengthen some harmonic frequencies and weaken others. Those frequencies that are strengthened are called ‘‘Formant’’. First and second formants (F_1, F_2) are generally important acoustic cues in auditory recognition of vowels which are calculated based on Hertz index. F_1 is related to the tongue height and is described according to the up-down displacement of the tongue in oral cavity, reversely. It means the more the height of the tongue is, the less is F_1. F_2 pertains to the tongue advancement or posterior-anterior displacement of the tongue in the mouth, directly. It means the more the anterior advancement of tongue is, the more is F_2. So, the relationship between F_1 and F_2 could determine the position of the tongue in oral cavity at vowel production [10]. Vowel production correctness was assessed in different ways. Acoustical analysis based on F_1 and F_2, and perceptual assessments based on auditory discrimination of experts are the most authentic approaches to evaluate it [11]. Vowels have an acoustic nature; hence, the important sense of its learning is auditory Therefore, learning how to produce vowels correctly is extremely hard for many of cochlear implanted children because these children had severe profound hearing loss and had been deprived of vowels’ auditory feedback. Factors such as age of implantation, diagnostic age of hearing loss, the remained amount of auditory sense, duration of cochlear implant usage, child’s communication mode with parents and caregivers, use of other hearing aids alongside CI, additional disabilities, being mono- or bilingual could be effective on speech and language skills development outcomes in cochlear implanted children [12].

Majority of the studies indicate that early cochlear implantation prevents inappropriate perceptual and expressive learning (especially vowels) [5,13]. However, some researches do not consider the effect of the age of implantation as a fundamental factor. For instance, Miyamoto et al. [14] believe that the age of implantation has some effect on speech intelligibility but this effect is not statistically significant. Geers et al. [15] and Vick et al. [11] confirm Miyamoto’s study expressing that early cochlear implantation cannot ensure reaching the natural levels of perception, speech and reading skills. In spite of improvements in prosthesis, novel surgical techniques and auditory-verbal rehabilitation strategies, cochlear implant users are not capable of receiving the whole acoustic spectrum of speech so it might have negative effects on the ability of proper vocalization ability particularly vowel production [16]. The reason for these paradoxical findings is maybe due to the types of vowel assessments. So, we tried to accomplish a comprehensive vowel assessment in this article. Therefore, considering the paradoxical literature and lack of information regarding Persian-speaking cochlear implanted children, we decided to determine the role of age implantation on formants frequency changing of three Persian vowels (/a/, /u/, /i/) in two acoustical and perceptual assessment ways.

Methods

This research was a cross-sectional descriptive analytic study. Based on inclusion and exclusion criteria and by the use of available sample methods, 69 hearing impaired children with cochlear implants were selected from the cochlear implant center of Amiralam Hospital, Tehran University Medical Sciences The inclusion criteria were having at least one year of hearing and speech rehabilitation after CI, using CI device at least for one year, using unilateral CI device, and structural health of speech articulators. Children with the history of an accompanying disease and intellectual disabilities, bilingual children or children with bilingual parents, children with neuromotor disorders like cerebral palsy and children with hearing impaired parents were excluded from the study. In fact, we selected children whose only problem was hearing loss. All the participants received advanced combinational encoder (ACE) strategies for speech processing alongside with conventional speech therapy programs (e.g. Audio-Verbal Therapy accompanying visual cues) for speech perception and production after CI surgery [17].

Children were divided age implantation into three groups according to the age of implantation: children who received CI before the age of 2 (n=21), children who received CI between the ages of 3 to 4 (n=29), and those who received CI after the age of 5 (n=19). All the children had congenital hearing loss and received rehabilitation services after CI. However, the groups were not homogenous based on the amount of using speech therapy and auditory training before CI surgery. All the participants received 24-channel Nucleus® model of cochlear implants in which all prosthesis electrodes were activated during speech sampling. Before and after implantation, auditory conditions of children have been assessed and followed up by the audiologist of cochlear implant clinic of Amir Alam Hospital. Thresholds of auditory responses in children who received CI before the age of 2 were assessed by neural response telemetry (NRT), and in children who received CI between the ages of 3 to 4, and those who received CI after the age of 5 were assessed by NRT and behavioral or streamline test.

The first and second formant frequencies values for vowels /a/, /u/, /i/, as dependent variables, were evaluated and calculated via perceptual and instrumental assessments. The Speech Filing System (SFS) software was used for instrumental assessment [18]. Standard phonetic contexts for acoustic analysis of the studied vowels are the non-words /had/, /hud/, and /hid/ [19]. Since these non-words are meaningless to cochlear implanted children and they probably could not comprehend these non-words semantically, we used three two-syllable Persian words including /færhad, færhud/, and /nahid/ which are boy and girl names in Iran. We showed three personal photos (photo of a girl for /nahid/ and photos of two boys for /færhad/ and /færhud/) to children, played the name of each shown photo by the audio player, and requested the children to repeat what they heard (verbal imitation task). Children's speech samples were recorded by the audio recorder option of the SFS software. In a quiet and noise-free room, the SHURE BG 1.1 /C15AHZ/ Pin 2 Hot model of microphone was connected to a Dell Inspiron 1300 laptop which was used to record the speech samples. The examiner, child, and one of his/her parents were present at the sampling room. The middle 30 ms of each vowel spectrum were selected by mouse on the SFS software for measuring F1 and F2. Before the study, to be assured of the reliability and validity of the SFS and microphone calibration, all the instruments were examined on 13 cochlear implanted children by doing the test-retest procedure three times in intervals of three days. Correlation coefficient was significantly high (r>0.89).

Performing auditory perceptual analysis for vowels is an important matter for two reasons: first, because it helps distinguishing vowels which may be pronounced differently according to a local dialect and second, it aids assessing the normality or abnormality of vowels based on listeners' judgments [7]. Children with CI imitated one examiner and produced 24 monosyllabic words containing the vowels /a/,

Table 1. Demographic Characteristics of the Participants

	Groups (age at implantation)		
	<2 years (G1)	3-4 years (G2)	>5 years (G3)
Number in groups	21	29	19
Gender	M:11, F:10	M:18, F:11	M:10, F:9
Chronological age in months [Mean (SD)]	60 (6)	78 (4)	89 (4)
Age at implantation in months [Mean (SD)]	20 (2)	43 (3)	65 (4)
Etiology of hearing loss	Congenital	Congenital	Congenital
Additional disabilities	-	-	-

G; group, M; male, F; female, SD; standard deviation

/u/, and /i/. As mentioned before, children's speech samples were audio recorded. The speech samples were played back for two examiners who were unfamiliar with children and they applied the percentage of vowels correctness (PVC) method to judge how correct the vowels were produced by children. The raters were educated in Master of Science (MSc) in speech therapy and are academic members of University of Medical Sciences. They are expert in language and speech disorders which are due to hearing impairments. Examiners were asked to only focus on the intended vowels and ignore the way children produced other phonemes of each word while scoring the correctness of studied vowels. Based on examiners' judgments, vowels produced correctly were scored by 1 and misarticulated ones were scored by 0. Any distortion, nasalization, backing, or diphthongization of vowels were considered as distorted vowel and scored by 0 [20]. The PVC was calculated using the following formula: (PVC=Vowels Correctness÷24×100).
The role of children's age implantation and their gender were analyzed using a 3 (implantation groups: under age 2, between 3 to 4, more than 5 years of age) × 2 (gender: male vs. female) two-way analysis of ANOVA with a post hoc Bonferroni honest significant difference test. SPSS 16.0 was used for the statistical analysis.

Results

Demographic characteristics of participating children are summarized in Table 1.
Based on the auditory perceptual analysis performed by the two raters, all the children who received CI before the age of 2 produced three vowels /a/, /u/, /i/ correctly in all 24 words. In other words, mean percent of correct production of vowels was 100% and this group of children had no vowel disarticulation. The mean percent of correct productions of three vowels /a/, /u/, /i/ were 95%, 83%, and 75%, respectively, in children who received CI between the ages of 3 to 4. Nasalization and backing were the main vowel disarticulations found in these children. The mean percent of correct productions of three vowels /a/, /u/, /i/ were 91%, 79%, and 66%, respectively, in children who received CI after the age of 5. Nasalization was the main vowel disarticulation in this group. The Cronbach's alpha coefficient of 0.96 and Pearson's correlation coefficient of 0.94 can reveal high levels of inter-rater agreement in auditory perceptual analysis.
Means and standard deviations of first and second formant frequencies (F_1, F_2) of the vowels /a/, /u/, /i/ which were calculated by SFS software for three groups of CI children are

Table 2. Between groups' comparison of formant frequencies value of three vowels /a/, /u/, /i/ among three groups of children

		Group1	Group2	Group3			Bonferroni test		
		Mean (SD)	Mean (SD)	Mean (SD)	F	p	G1-G2 post hoc	G1-G3 post hoc	G2-G3 post hoc
/a/	F_1 (Hz)	979.14 (99.95)	981.64 (120.40)	998.19 (121.16)	4.905	0.01*	0.12	0.03*	0.11
	F_2 (Hz)	1519.29 (168.53)	1491.19 (181.16)	1461.79 (188.11)	3.887	0.01*	0.02*	0.04*	0.01*
/u/	F_1 (Hz)	421.14 (49.95)	432.21 (39.91)	461.23 (33.01)	1.445	0.06	0.06	0.09	0.11
	F_2 (Hz)	2310.71 (101.22)	2212.73 (111.84)	2199.59 (120.33)	4.512	0.01*	0.01*	0.04*	0.11
/i/	F_1 (Hz)	415.98 (66.66)	433.10 (65.88)	441.10 (70.16)	3.111	0.04*	0.06	0.04*	0.07
	F_2 (Hz)	2808.55 (170.11)	2763.16 (169.02)	2700.11 (171.39)	4.918	0.01*	0.01*	0.01*	0.01*

* The difference is statistically significant; M; mean, SD; standard deviation, G; group

shown in Table 2. Seemingly, there were differences among formant frequency values of three groups of cochlear implanted children. For vowels /a/ and /i/, F_1 value was significantly different between first and third group ($p<0.5$); but, no significant differences were observed in formant frequency values of vowel /u/ among the three groups ($p>0.5$). Considering vowels /a/ and /i/, F_2 value was significantly different among three groups of cochlear implanted children. Also, for vowels /a/ and /i/, F_2 value was significantly different among three groups. Considering vowel /u/, a significant difference was found in F_2 value between first and second group and also between first and third group ($p<0.5$).

Results of complementary tests performed to determine the effect of age of implantation and gender factors on the first and second formant frequencies variations showed that regardless of all factors, age of implantation significantly influenced on F_1 value for vowel /a/ [$F_{(2,63)}=3.757$, $p=0.002$, $\eta^2=0.550$], and vowel /i/ [$F_{(2,63)}=6.665$, $p=0.010$, $\eta^2=0.344$]. Also, this analysis revealed significant effect of age of implantation on F_2 value of three vowels /a/ [$F_{(2,63)}=5.007$, $p=0.012$, $\eta^2=0.450$], /u/ [$F_{(2,63)}=5.112$, $p=0.011$, $\eta^2=0.434$], and /i/ [$F_{(2,63)}=7.864$, $p=0.001$, $\eta^2=0.569$]. However, the gender × age implantation interaction was not significant [$F_{(3,62)}=2.416$, $p=0.133$, $\eta^2=0.091$]. There were no other significant effects or interactions.

Discussion

The main purpose of the present study was to determine the role of age implantation and it's interactions with other factors on formants frequency changing of Persian vowels in three groups of cochlear implanted children. Acoustical and perceptual analysis of the three Persian vowels /a/, /u/, /i/ was conducted by SFS software and inter-rater assessment.

Different shapes and sizes of the vocal tract lead to different vocal qualities, which are partly reflected in our vowel production. Mandible, lips, and tongue alter the size of the vocal tract. Mandible makes these changes through vertical movements. Nevertheless, tongue is the most important organ for vowel production in the Persian language because it is the main organ for creating the following features to create vowel discrimination, including: front-to-back positions and openness-closeness. Lips are also considered as important body parts in vocal quality changes because their shape causes some changes in the vocal tract; however, lips are not assumed to be the origin of phonological distinction in the Persian language because the shape of the lips in back vowels (/a/, /o/, /u/) is often round, whereas in front vowels (/i/, /e/, /æ/) is usually spread. Place and height of the tongue are the basis of Persian vowels classification. Six vowels of the Persian language are divided into two groups according to their place of articulation [21]. Since tongue's shape and movements are invisible when vowels are produced, judging the tongue status and its degree of uprising is difficult. So, it could be calculated using F_1 and F_2 values which are related to height and back-to-front advancement of the tongue using acoustic software, and estimated placement and movements of the tongue [10].

Having in mind that F_1 is reversely related to height of tongue in oral cavity, results showed that age of implantation could be effective on F_1 in this manner that increased F_1 value for two vowels /a/, /i/ was as a result of increased age of implantation. It means the more the age implantation increases (implantation happens later in life), the less normal uprising movement of the tongue during two vowels /a/, /i/ production becomes. The second rule in vowel production is F_2 which has a direct relationship with the back-to-front movements of the tongue. It means the more forward the position of the tongue is during vowel production, the more F_2 value increases. These results showed if the age of age implantation increases, F_2 value will decrease. As a result, position of the tongue during vowel production was more back posterior in children who have late-cochlear implantation (after 3 years of age). By analyzing these acoustical findings alongside with auditory perceptual assessments outcomes, it is revealed that those deaf children with cochlear implantation before the age of 2 have total correctness of vowel production, but other two groups of children that have their implantation after the age of 3 have vowel production disorder such as backing and nasalization of vowels. Backing and nasalization are determined by the more posterior position of the tongue during vowel production. Researchers mentioned that speakers with hearing impairment tend to keep their tongue retracted in a back position [22].

These findings are interpretable from different aspects. First, children are strongly relied on audition sensation for vowel perception and production in language developmental periods. This matter was confirmed in blind children because these children do not have vowel production disorders though they have congenital blindness [23]. Consequently, it could be expected that early cochlear implantation (before age of 2) with decreased auditory deprivation stage allow children to have the right and comprehensive experience of the environment [11,24], which significantly affects the quality of simple Persian vowels articulation and facilitates near to normal-sounding production. Second, some researchers believe that children who have hearing loss tend to have an articulatory overcompensation in their speech resulting from imitating therapists and family's incorrect exaggerated trainings of articulation movements which is done in order to facilitate lip-reading and speech-reading. It might cause some faulty learning before implantation speech therapy stages of deaf children who have late cochlear implantation [7,25]. Our findings demonstrated that deaf children with late cochlear implantation (especially those who received CI after the age of 5) had changes in F_1 and F_2 values which were indicators of vowel backing and nasalization as a result of over withdrawing of the tongue. Findings of this study are in agreement with previous researches which hypothesized that "early cochlear implantation could decrease audition deprivation stage and therefore will prevent error speech perception and production learning" [9,26]. It has been found that early cochlear implantation leads to a greater differentiation of the vowel inventory [27]. Recently, research findings regarding the acoustic characteristics are equivocal. The vowel space of children with an early cochlear implantation has been described as significantly similar to peer normal-hearing children [25,28].

The present research has one main limitation that warrants discussion. This study has involved only children who have CI and we suggest granting comparisons between CI children and normal hearing peers in future studies.

Conclusion

Generally it could be stated that early age implantation is a predictive factor to improve first and second formant frequencies condition which causes normal vowel production due to correct height and advancement of the tongue. Also, no other significant main effect or interaction have been observed (e.g. main effect of gender or interaction between gender×age implantation) on outcomes. It could be suggested to speech and language pathologists that they must use factor of age of implantation in clinical decision makings for cochlear implant candidacy to enhance chances of speech intelligibility based on improvement of vowel production.

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