



Research Paper:

Persian Vowel Production in Hearing-Impaired Children With Cochlear Implants: The Influence of the Implantation Age



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The authors declared no conflict of interest

ABSTRACT

Background and Objectives: Speech intelligibility is affected by vowel quality. Auditory feedback is an essential factor in vowel quality. The purpose of the current study was to compare vowel space and formant frequencies in Normal-Hearing (NH) and Cochlear-Implanted (CI) Persian-speaking children aged 4 to 6 years.

Methods: The participants were 10 CI children (5 girls and 5 boys) aged 4 to 6 years. All children had congenital hearing loss and received a multichannel CI before 2 years of age. The control group comprised 20 NH children (10 girls and 10 boys) aged 4 to 6 years. The two groups were matched by age. The participants were asked to produce six Persian vowels (/u/, /o/, /a/, /i/, /e/, /æ/) in /ChVCd/ context and then the average of formant frequencies (F1, F2,) was measured using Praat analysis software (Version: 5, 3, 27). The Independent samples t-test was conducted to assess the differences in F1 and F2 values between the two groups using SPSS 16.

Results: The mean values of F1 and F2 of all 6 Persian vowels were not significantly different between CI and NH children ($P > 0.05$).

Conclusion: Findings of the present study implied that children who were implanted CI under 2 years of age are likely to produce Persian vowels similar to normal-hearing children.

Keywords: Formant, Cochlear implant, Hearing, Articulation, Phonetics



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↑ *What is “already known” in this topic:*

The early age of cochlear implantation can improve the overall development of speech and language.

vowels are the core of words.

Correct vowel production is an essential ability for communion. Therefore, vowels can affect speech intelligibility in CI children

→ *What this article adds:*

Cochlear implantation under 2 years of age improves vowel production resulting in better access to speech signals and auditory feedback. The vowel space in children with CI who underwent surgery for CI before the age of 2 was very similar to that of the NH children. However, vowel space is slightly smaller in children with CI, which can be due to the reduction in F2 values in the anterior vowels.

C Introduction

Cochlear Implant (CI) prosthesis is an effective treatment for most Hearing-Impaired (HI) children [1]. This prosthesis affects the recognition of vowels and consonants and enhances the correct articulation of speech sounds and speech intelligibility in the CI population [2, 3]. Speech planning is based on the articulation of vowels in the speech chain [2]. Furthermore, vowels are the core of words, and misarticulating them results in misunderstanding the consonants in the context [4]. Therefore, correct vowel production is an essential ability for communication because vowels can affect speech intelligibility in CI children [2, 3].

Studies show formant structure is the most critical perceptual feature of vowels [5-7]. Johnson and Moulton argued that formants represent the shape and size of the vocal tract [8]. Vowels are speech sounds produced by tongue movement and lips rounding or stretching [9]. Tongue height is related to the first formant (F1) and tongue backing to the second formant (F2) [10]. In the HI population, the first two formants are centralization and vowel space decrease [11].

Some studies have examined the role of the child's age of cochlear implantation on the growth of the spoken language skills in children with CI [12]. Most of these studies have focused on language skills and speech perception [13, 14]. Research has shown that the overall development of speech and language is facilitated in children who undergo early cochlear implant surgery. Preliminary studies, such as those conducted by Ty-

Murray, Spencer, and Woodworth, showed that children who undergo surgery before the age of 5 have more accurate vowel production than the children who undergo cochlear implantation after the age of 5 [15]. Since the early 21st century, researchers have studied hearing-impaired children who have undergone cochlear implantation before 2. They concluded that speech development in HI children gets closer to that of normal-hearing children if cochlear implantation is performed at a lower age. Hammes et al. studied spoken language skills in 47 HI children who had undergone cochlear implantation before 48 months. They reported that children who had undergone cochlear implantation before 18 months had expressive language abilities similar to normal-hearing children of the same age [16].

Zamani et al. [17] examined the role of a child's age in the correct production of the Persian vowels. They showed that children who undergo cochlear implantation before the age of 2 have a better performance in the production of vowels than those who undergo cochlear implantation after 2.

Research conducted in different languages on formant frequencies in hearing-impaired children with CI has mainly examined children over 6. One of these studies is the study conducted by Liker et al. [18]. They compared the speech of 18 Croatian children with CI, who were at the age of 9.5 to 15 years, with the control group and found that the mean production of the first vowel /a/ was significantly lower in children with CI compared with the control group. They reported the declined movements of the jaw, which caused the vowel space to get smaller, as a reason for this finding. The children with

CI showed more anterior vowel space than the control group because of the higher frequency of the first structure. The frequency of the second structure in the posterior vowels was higher in people with CI, and it indicates the smaller vowel space in children with CI compared with children with normal hearing. Löfqvist et al. [19] showed that smaller vowel space in Swedish adolescents who had undergone surgery for CI. Neumeyer et al. [20] studied vowel production in two groups of German patients with CI: a group of 15-25 years old and a group of 55-70 years old. They compared them with two control groups of the same age. The results showed that the second structure in the group with the cochlear implant was lower than the control group, which caused their vowel space to get more compact. Jafari et al. [21] reported similar findings in 20 Persian-speaking children of 5 to 9 years old. They found that children with CI produce anterior vowels in a more posterior form and their vowel space is smaller than that in NH children. The present study aims to study vowel production and vowel space in 4-6 years old Persian-speaking children with hearing loss who had undergone CI before the age of 2 and compare them with the NH children of the same age.

Materials and Methods

Study subjects

The patients were 10 CI children (5 girls and 5 boys) with an age range of 4 -6 years (Mean±SD age: 5.2±0.68 years). They received multichannel CI before the age of 2. They participated in speech and hearing rehabilitation programs before and after CI surgery. They had no other history of neurological illness, muscular diseases, 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 NH group comprised 20 (10 girls, 10 boys) native Persian speakers. They were age-matched to the CI group (age range: 4-6 years, mean age: 5.5 years).

Voice sample

Six Persian vowels (/u/, /o/, /a/, /i/, /e/, /æ/) were investigated in six contexts, including /h/ and /d/ (/hud/, /hod/, /had/, /hæd/, /hed/, /hid/). Most studies have used standard context consist of monosyllabic (non)words each beginning with [h] and ending with [d] [22]. The contexts were recorded and played for children.

Recording procedure

All parents were given written informed consent before recruiting their children in the study. After the selection of subjects, the study tests were performed on children in a quiet room. The children were sitting on a chair with their necks fixed to avoid turning to the front, back, right, and left sides. After playing the voice sample for children, their voice was recorded with 44100 Hz sampling frequency in the stereo form to analyze formant frequencies. Furthermore, the microphone device (Shure-SM58 model) was used. The distance between the microphone and the mouth of the children was 10 cm.

Acoustic analysis

Praat analysis software (Version: 27, 3, 5) analyzed formants' frequency. For analysis of formants, 0.5 seconds of each vowel were selected. The middle part of the vowel is relatively stable. The mean values F1 and F2 for each vowel were used for vowel space. F1 is presented on the y-axis and F2 on the x-axis.

Statistical analysis

The data collected from Praat analysis were entered into SPSS version 16. The Kolmogorov-Smirnov test was performed to study normal distribution. The Independent sample t-test was used to compare different formant frequencies between NH and CI children. The significance level was set at $P < 0.05$.

Results

The results of the Kolmogorov-Smirnov test showed the normal distribution of formants ($P > 0.05$). Table 1 shows the demographic characteristics of the participants. The mean values and standard deviations of formant frequencies of six vowels are presented in Table 2 for CI and NH children. As presented in Table 1, the mean values of formant frequencies of vowels did not show significant differences ($P > 0.05$). These results are depicted in Figure 1 and Figure 2.

Figure 3 shows the vowel space of six Persian vowels. The y-axis presents the mean values of F1, and the x-axis shows the mean values of the second formant F2 for each vowel. The height and position of the tongue affect vowel space [23].

Discussion

The current study aimed to compare Persian language vowel production in children with CI who had undergone cochlear implants before the age of two with their NH peers.

Table 1. Demographic information of the study participants

Demographic Information	CI Children	NH Children
Number in group	10	20
Gender	5 girls and 5 boys	10 girls and 10 boys
Chronological age in y;mo	5;2 (4;1 to 6;0)	5;5

CI: Cochlear Implant; NH: Normal Hearing.

Values are presented as numbers or means with ranges inserted in brackets.

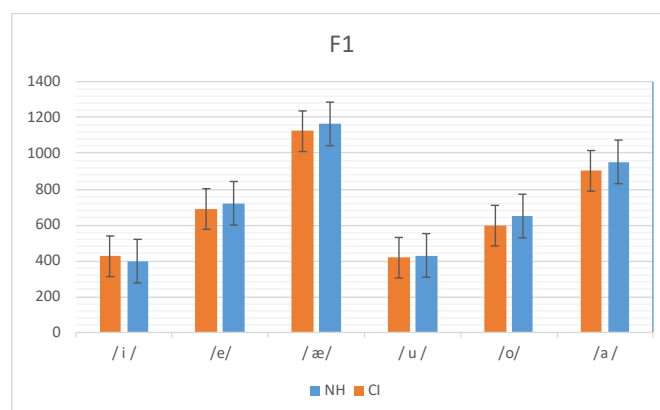
Formant 1

F1 is inversely related to the height of the tongue in the mouth. The lower the F1, the more closed each vowel is produced. In this study, the minimum and maximum values of F1 were related to vowels /u/ and /æ/ in children with CI and vowels /i/ and /æ/ in NH children.

In this study, F1 values obtained from children with CI are very close to F1 values of the NH children, and the F1 values do not show a statistically significant difference in any of the 6 vowels of the Persian language. This finding is consistent with the results of Zamani et al. [17]. In the studies that cochlear devices were implanted

Table 2. Comparison of Persian vowel production in CI and NH children

Vowel		Mean±SD		t	P
		CI Children	NH Children		
/a/	F1	902.37±171.54	952.46±90.27	-1.056	0.30
	F2	1512.64±185.83	1544.34±151.18	-0.502	0.62
/i/	F1	425.10±62.85	398.21±75.13	0.972	0.33
	F2	2586.05±216.72	2736.08±390.75	-1.045	0.30
/u/	F1	417.43±61.53	430.98±85.93	-0.443	0.66
	F2	1115.45±209.67	1132.07±279.70	-0.166	0.87
/æ/	F1	1123.01±157.77	1164.77±97.37	-0.898	0.37
	F2	1908.73±185.99	2066.77±227.39	-1.898	0.06
/e/	F1	689.03±138.82	721.66±96.97	-0.751	0.45
	F2	2365.97±454.29	2438.40±332.69	-0.497	0.62
/o/	F1	596.79±105.32	650.16±103.66	-1.322	0.19
	F2	1199.93±107.15	1242.24±125.92	-0.909	0.37

**Figure 1.** F1 of six Persian vowels in CI and NH children (error bars indicate standard errors)

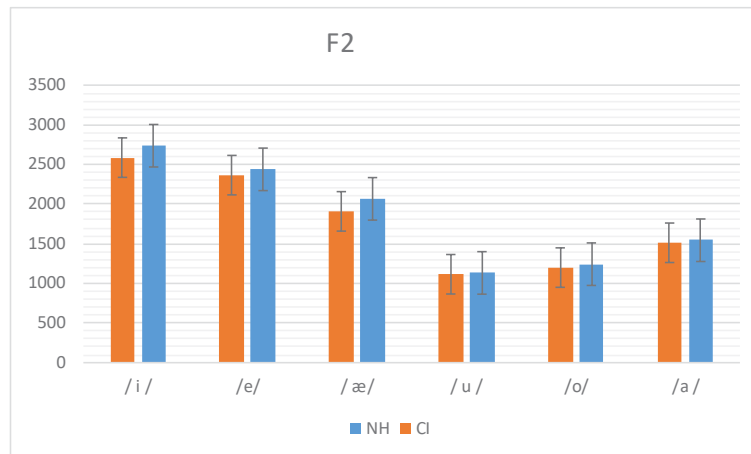


Figure 2. F2 of six Persian vowels in CI and NH children (error bars indicate standard errors)

in children under 2 years old, the results were similar to the results of the present study.

However, F1 values are slightly lower in all vowels produced by children with CI except for the vowel /i/. The lower value of F1 in 5 vowels of /a/, /u/, /æ/, /o/, /e/ may indicate that the Persian language vowels are produced in a more closed form in children with CI and jaw movements in these children are less than those in the NH children. Asghari et al. [24] and Jafari et al. [21] showed that F1 values for each of the 6 vowels in children with CI are higher than those for NH children. It should be emphasized that Jafari et al. studied CI children with an age range of 5 to 9 years [21]. All children with CI had received cochlear implantation at an average age of 3 years.

Liker et al. [18] reported that the average F1 for the vowel /a/ is significantly lower in children with CI than in NH children. The lower average F1 for the vowel /i/ in children with CI compared with the NH children was not observed in the present study. The slight increase in the F2 value in vowel /i/ may be attributed to their training before the surgery for CI. This means that speech therapists should teach vowel production based on providing visual feedback. This study confirms the results of Zamani et al. that examined the effect of the age of cochlear implant on speech [17].

Formant 2

F2 is directly related to the anterior-posterior movement of the tongue. The more posterior position of the tongue leads to the reduction in F2. F2 values of all vowels of the Persian language are less in children with CI

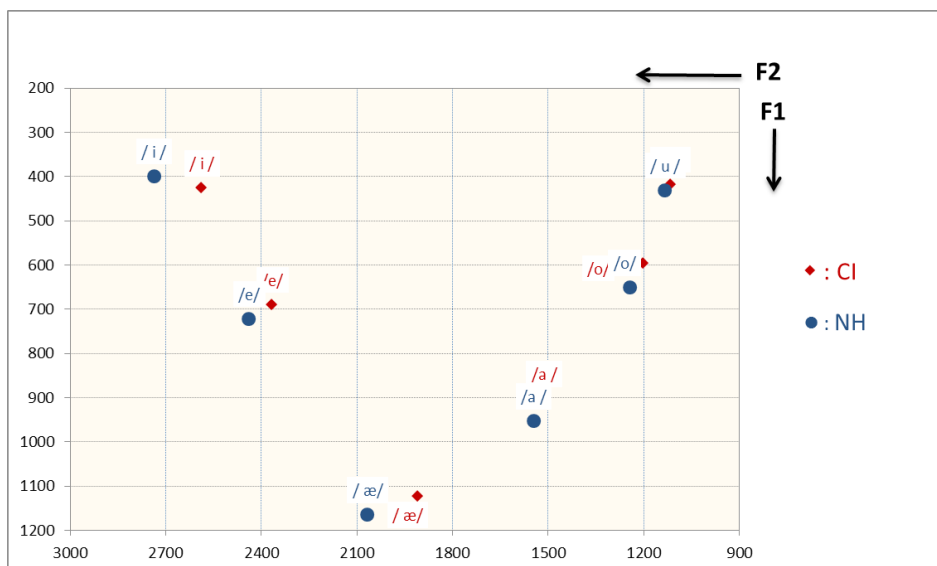


Figure 3. Vowel space of six Persian vowels in CI and NH children

than in the NH children. The minimum and maximum values of F2 in both groups of CI and NH children were related to the vowels /u/ and /i/, respectively.

The average values of F2 in all six vowels of the Persian language were lower in children with CI than in the NH children, although there was no significant difference in the values of F2 between the two groups. The present study results confirm those findings of Jafari et al. [21], which showed that F2 values are lower in the anterior vowels.

Vowel space

In the present study, the vowel space in children with CI who underwent surgery for CI before the age of 2 was very similar to that of the NH children. However, vowel space is slightly smaller in children with CI, which can be due to the reduction in F2 values in the anterior vowels. Jafari et al. and Liker et al. [18] referred to shrinkage and centralization of the vowel space in their study. Thus, the study results showed that the formant frequencies of Persian vowels were not significantly different between the two groups.

It seems that When HI children receive cochlear implants before the age of 2, they experience a shorter duration of auditory deprivation. Therefore, it is possible to receive relatively high-quality acoustic signals provided by a cochlear implant.

Hocevar-Boltezar et al. [25] and Wang et al. [26] argued that enlargement of the vowel space in children with CI could indicate the acceptable effect of hearing of vowels due to cochlear implantation at the suitable time. Jafari et al. showed that one year after cochlear implantation surgery, F1 and F2 of Persian vowel /w/ approached the frequency of structures of NH children [23].

Conclusions

The formant frequencies of six Persian vowels in CI and NH children were not different significantly. Cochlear implantation under 2 years of age improves vowel production resulting in better access to speech signals and auditory feedback. The current investigation was limited by confounding variables, including impairment, quality of training programs, and motivations in children and their families. We did not examine children who had CI after the age of 2 and did not compare formant frequency of the Persian language vowels in children with CI before the age of 2 with children who had CI after 2. In this study, we did not compare vowel production in

children with CI and HI children using hearing aids. This topic should be investigated in future studies.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by Student Research Committee of University of Social Welfare and Rehabilitation Sciences (Code: USWR.REC.1391.380)

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Authors' contributions

All authors equally contributed to preparing this article.

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تولید واژه‌های زبان فارسی در کودکان کاشت حلزون شده: تاثیر سن کودک در زمان کاشت حلزون

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چکیده

مقدمه: کیفیت تولید واژه‌ها می‌تواند وضوح گفتار را تحت تأثیر قرار دهد. بازخورد شنیداری عامل مهمی در کیفیت واژه‌هاست. هدف از این مطالعه مقایسه فضای واژه‌ای و بسامد فرمونت‌ها در کودکان شنوا و کاشت حلزون شده چهار تا شش ساله بود.

مواد و روش‌ها: شرکت‌کنندگان، ۱۰ کودک کاشت حلزون (۵ دختر و ۵ پسر) و ۲۰ کودک (۱۰ دختر و ۱۰ پسر) چهار تا شش سال بودند. همه کودکان کاشت حلزون شده دچار کم‌شنوایی مادرزادی بودند و قبل از دوسالگی کاشت حلزون شده بودند. از شرکت‌کنندگان خواسته شد تا شش واژه فارسی (a/æ/ɛ/ɪ/i/ə/o/ɔ/) را تولید کنند و سپس میانگین فرکانس‌های فرمونت‌های اول و دوم (F1، F2) با استفاده از نرم‌افزار Praat نسخه ۵.۳.۲۷ اندازه‌گیری و یافته‌ها بین دو گروه مقایسه شده و فضای واژه‌ای ترسیم شد.

یافته‌ها: میانگین فرمونت اول و دوم بین دو گروه شنوا و کاشت حلزون شده تفاوت آماری معنی‌داری نداشت.

نتیجه‌گیری: بر اساس یافته‌های مطالعه حاضر کودکان مبتلا به CI زیر دو سال احتمالاً واژه‌های زبان فارسی را مشابه کودکان شنوا تولید می‌کنند.

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