Research Article

Acoustic Analysis of Fricatives /s/ and /ʃ/ and Affricate /ʧ/ in Persian-Speaking Cochlear-Implanted Children and Normal-Hearing Peers

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Highlights

- Distinction between fricatives /s/ and /ʃ/ is difficult for CI and NH children
- The Persian-speaking CI children produced the fricative /s/ as an allophone of /ʃ/

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ABSTRACT

Background and Aim: Hearing-impaired individuals have difficulty comprehending and producing speech sounds. Cochlear implantation is used to augment hearing. The present study aims to compare the production of fricatives /s/ and /ʃ/ and affricate /ʧ/ by Persian-speaking Cochlear-Implanted (CI) and Normal-Hearing (NH) children

Methods: Fifteen Persian-speaking NH children and 15 Persian-speaking CI children, matched for age, gender, and general health conditions, were included in the study. The stimuli included two voiceless Persian fricatives /s/ and /ʃ/ and one voiceless Persian affricate /ʧ/ along with the open front vowel /æ/ in three Consonant-Vowel (CV), Consonant-Vowel-Consonant (CVC), and Vowel-Consonant (VC) contexts (/sæ/, /æsæ/, /æs/, /ʃæ/, /æʃæ/, /æʃ/, /ʧæ/, /æʧæ/, /æʧ/). After recording all utterances, Praat software was used to measure the friction duration, rise time, and spectral peak of the consonants

Results: The CI children could not distinguish between /ʃ/ and /ʧ/ and produced affricate /ʧ/ as an allophone of /ʃ/ (p=0.01). Moreover, distinguishing between two fricatives /s/ and /ʃ/ was difficult for both groups. While NH children slightly treated these two sounds differently, the CI group produced fricative /s/ as an allophone of /ʃ/ (p=0.02). The rise time of /ʃ/ was longer in the NH children, except for /ʧæ/, where the CI children had a longer rise time.

Conclusion: The speech of CI children is different in producing /s/, /ʃ/, and /ʧ/ from their NH peers. The results can help speech therapists, clinical linguists, and application designers focus on speech sounds that are challenging for CI children to produce.

Keywords: Cochlear implant; speech production; fricatives; affricate

Introduction

Hearing Impairment (HI) is a complication that causes people to be deprived of hearing the whole or part of sentences uttered. It is the most frequent sensory deficit in humans, affecting nearly 20% of the global population, and the number is expected to double by 2050 [1, 2]. In Iran, almost 550,000 of the population suffers from hearing problems or deafness [3]. HI is considered to be the most prevalent congenital abnormality in newborns, and its prevalence is more than twice as much as the prevalence of other conditions diagnosed at the time of birth, such as hypothyroidism, phenylketonuria, and galactosemia [4]. It is caused by different factors, including aging, exposure to noise, illness, chemical or physical injury, and genetics. It can result in an inability to perceive speech sounds, decreased communication, and language delay [5]. Children with HI are at an increased risk of becoming struggling speakers. For children with HI, most of the auditory input may not be accessible, hindering speech development [6]. Thus, the speech of HI children is often less intelligible than that of Normal-Hearing (NH) children [2].

Studies have indicated that if children with HI receive services early, they may be able to develop language and speech on a par with their NH peers [7, 8]. One of these services is Cochlear Implantation (CI). A cochlear implant is a small, complex electronic device that can help provide a sense of sound to a profoundly or severely hard-of-hearing person [9]. The implant consists of an external portion that sits behind the ear and a second portion that is surgically placed under the skin. Hearing-impaired children with CI show increased gains in expressive language and speech perception compared to hearing-impaired children with no CI [7]. CI can augment hearing sufficiently to improve understanding of speech and environmental sounds, although the sound quality differs from that of normal hearing. Most studies of speech production by CI children have shown that progression after implantation is rapid and that intelligibility and fluency reach typical norms after a few months [8, 10]. In contrast, Boyce disclosed residual difficulties in speech production affecting some consonants and vowel contrasts [10].

The children with CI also seem to have difficulties producing fricatives. A study showed that CI children replace fricatives with other consonants [11]. Peng et al. ranked the accuracy of consonant production in CI children as follows: plosives, nasals, affricates, fricatives, and last, laterals; affricates were generally longer, and /s/ noise frequency was lower in CI children than in NH children [12]. These studies suggest that CI children struggle to produce fricatives, affricates, laterals, and formants in vowels [10]. To our knowledge, there is scant research on the speech production of Persian-speaking children with CI; only a few are based on objective acoustic measurements. Moreover, previous studies have contradictory results or insufficient evidence, barely allowing us to conclude the speech production of CI children [13, 14]. In this regard, the present study adopted a linguistic approach to the speech weaknesses of Persian-speaking CI children. We aimed to analyze the speech of these children acoustically in voiceless fricatives (/s/ and /ʃ/) and a voiceless affricate (/ʧ/) to find a systematic way to improve their language knowledge. The acoustic analyses that are used to distinguish fricatives from affricates are rise time, friction duration, and spectral peak. Rise time is the amplitude of friction noise that rises quickly to full amplitude in affricates and more slowly in fricatives. Duration indicates the friction amount; this amount is longer in fricatives. The spectral peak refers to the highest-amplitude peak of the Fast Fourier Transform (FFT) spectrum. This variable was used to distinguish the fricative /s/ from the fricative /ʃ/. The present study aimed to compare the production of fricatives and affricates in CI children and their NH counterparts.

Methods

In this study, participants were 30 children aged 4–6 years, 15 CI children (mean age: 55.83±1.78 months), and 15 NH children (mean age: 58.24±1.37 months). There were seven boys in each group. The CI children were under training in a center for hearing-impaired children in Kerman, Iran (Saba Center). The NH children were retained at a pre-elementary school in Kerman (Atiyeh Nursery School). The samples were selected using convenience and stratified random sampling techniques. Informed consent for participation was obtained from the children and their parents. The parents were completely informed about the objectives and procedures of the research and were assured that their participation was voluntary and anonymous. Both groups had undergone extensive screening by their respective institutions to ensure they were in good health, including assessments of vision, growth, age, cognitive abilities, and physical skills. As age was strictly controlled, the duration of hearing impairment and the received rehabilitation programs we're not expected to be significant intervening variables. In contrast to adults who vary in terms of hearing loss duration, children aged five or lower have relatively similar hearing loss duration [15]. Therefore, the only noticeable difference between the two groups in this study was their hearing status.

The participants' voices were recorded using a headphone (A4TECH HS-50, Motorola Inc., US) and an ASUS notebook. To have the best sound quality, the recording was done in a nearly quiet room, while sitting on a chair. A microphone was placed at approximately a 45-degree angle and 15 cm away from the mouth. After explaining and practicing the stimuli with the children, they were asked to repeat the words they heard. Subjects' utterances were recorded twice. The stimuli included two voiceless Persian fricatives /s/ and /ʃ/ and one voiceless Persian affricate /ʧ/ along with the open front vowel /æ/ in three contexts of Consonant-Vowel (CV), Consonant-Vowel-Consonant (CVC), and Vowel-Consonant (VC) (/sæ/, /æsæ/, /æs/, /ʃæ/, /æʃæ/, /æʃ/, /ʧæ/, /æʧæ/, /æʧ/). Since a relatively precise articulation process is required to produce a fricative sound, it is expected that hearing-impaired speakers exhibit errors for fricative consonants [16]. Voiceless fricatives were selected in this study, because voiced fricatives are not frequent in most languages (including Persian), need a variety of phonetically motivated alternations, and are challenging to produce [17]. Previous studies using fricatives concentrated on the alveolar fricative /s/ in normal and disturbed speech, because of its well-defined spectral pattern and its high occurrence rate in many languages [16, 17].

When all utterances were recorded, Praat software (version 5.3.17) was used to measure the fricatives and affricate's friction duration, rise time, and spectral peak for all recorded utterances. The fricative onset and offset markers were used to measure the friction duration. The onset and offset of the fricatives were estimated using waveform display and spectrographic analysis. Fricative onset was located at the start of friction characterized by the presence of high-frequency energy in the spectrogram. The fricative offset was located at the point of cessation of friction or minimum intensity followed by the onset of vowel periodicity [18]. The time of friction onset to the highest amplitude of friction in waveform was measured to determine the rise time. The spectral peak was located at the highest amplitude on the spectrum that was derived from the FFT analysis in Praat software [18, 19]. Subsequently, the data were entered into SPSS software (version 17) and the significance level was set at 0.05. Wilcoxon and Mann-Whitney U tests were used to analyze the collected information. Since the sample size was small, nonparametric tests were used for all data.

Results

According to Figure 1, the mean and median of friction duration were higher in CI children than in

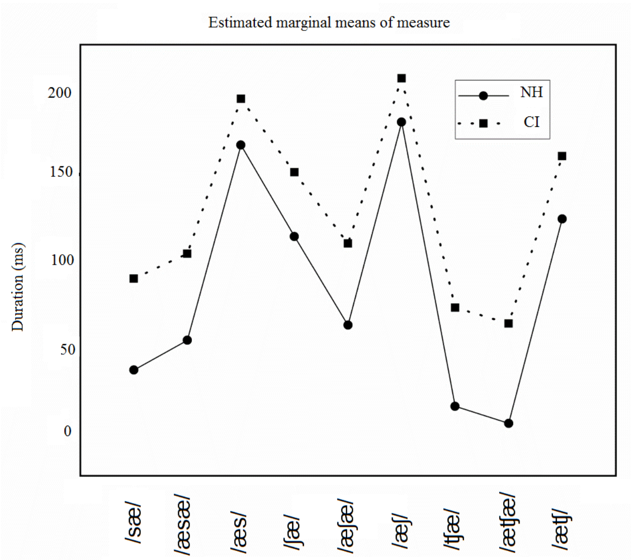

Figure 1. Duration of /s, ʃ, ʧ/ in cochlear implanted and normal hearing children. NH; normal hearing, CI; cochlear implanted

normal-hearing peers. The highest mean and median were related to the fricative /ʃ/ in /æʃ/ and the lowest were for the affricate /ʧ/ in /æʧæ/. Both groups had a similar pattern in friction duration. The differences in duration of /s/ in /sæ/ (p=0.03) and /ʃ/ in /æʃæ/ (p=0.01) were significant between the two groups. The spectral peak frequency for CI and NH children is shown in Figure 2. As can see, the pattern was different between the two groups. The highest amount of spectral peak in CI children was related to fricative /s/ in /sæ/. In NH children, the lowest peak was related to fricative /s/ in /sæ/. In both groups, fricative /ʃ/ had the highest peak. The highest peak in CI children was related to /ʃæ/ and highest peak in NH children was for /ʧæ/. The peak difference for /s/ in /sæ/ was significant between the two groups (p=0.02). According to Figure 3, the rise time of /ʃ/ in NH children was longer than in the CI children, but the CI children had longer time in /ʧ/, except for /ʧæ/. The CI children had longer rise time in affricate /ʧ/.

Friction duration of /s/, /ʃ/, and /ʧ/ in two study groups

In the CI children, fricative /ʃ/ in the VC context had the highest friction duration (249 ms). The results showed that friction duration of all three consonants of /s/, /ʃ/, /ʧ/ was longer at the end of syllables in CI children. Moreover, when these consonants were between vowels, their friction duration became shorter. Concerning the role of gender in friction duration, boys with CI had longer duration than girls but these differences were not statistically significant, except for /ʧæ/ ($p<0.05$).

In the NH children, fricative /ʃ/ in the VC context had the highest friction duration (213 ms). The friction duration of all three consonants (/s/, /ʃ/, /ʧ/) was longer at the end of syllables in NH children. Moreover, when these consonants were between vowels, their friction duration became shorter. The comparisons of friction duration in the NH group indicated significant differences between /ʃ/ and /ʧ/ (p=0.001 in CV; p=0.001 in VCV; p=0.003 in VC), which make them distinctive consonants in NH children's speech production. Fricative /s/ was completely different from /ʃ/ (p=0.02) and when it was between two vowels, it was distinctive from affricate /ʧ/.

Spectral peak of /s/, /ʃ/, and /ʧ/ in two study groups

In the initial position, /s, ʃ, ʧ/ had the highest spectral peak. In the CI children, no distinct /s/ was produced within the spectral peak; that is to say, the range of spectral peak for /s/ is 4000–8000 kHz while the highest peak for /s/ in this group was 3818 kHz. The /s/ was overlapped with /ʃ/, since the spectral peak of /ʃ/ varied from 3000 to 4000 kHz. In the CI group, fricative /ʃ/ was produced correctly in terms of spectral peak (3740 for /ʃæ/; 3571 for /æʃæ/; 3506 for /æʃ/). The differences in spectral peaks between the three consonants were not significant except for the peaks of fricative /s/ and affricate /ʧ/ in the CV context (p=0.04).

In the NH group, the final-position fricatives /s/ and /ʃ/ had the highest spectral peak among the three contexts. For the affricate /ʧ/, the spectral peak was

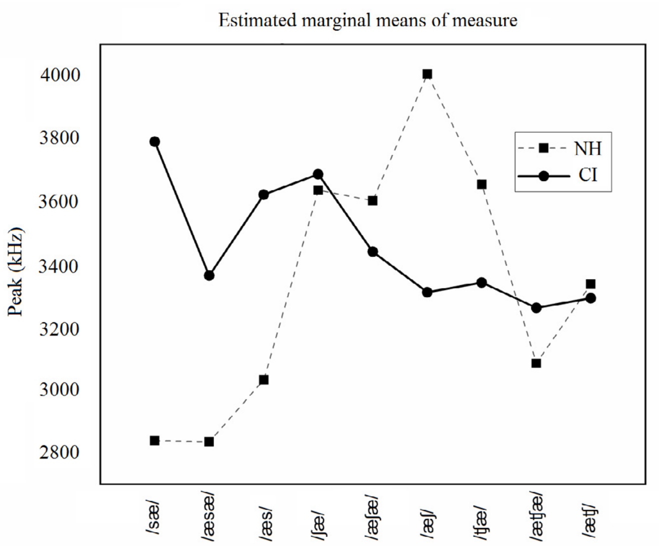

Figure 2. Peak of /s, ʃ, ʧ/ in cochlear implanted and normal hearing children. NH; normal hearing, CI; cochlear implanted

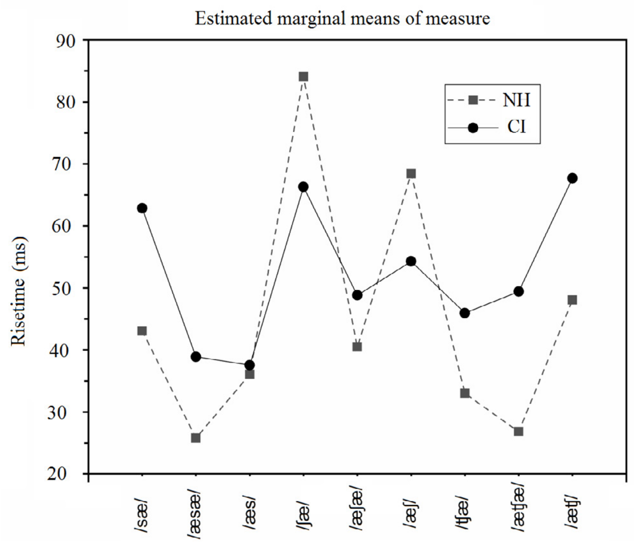

Figure 3. Rise time of /s, ʃ, ʧ/ in cochlear implanted and normal hearing children. NH; normal hearing, CI; cochlear implanted

higher in the initial position. In the NH children, all /s/ productions were lower than their spectral peak range (i.e. 4000–8000 khz). The comparisons revealed that the fricative /ʃ/ was produced correctly according to the spectral peak (3682 for /ʃæ/; 3571 for /æʃæ/, 3691 for /æʃ/) in these children. The fricative /s/ was significantly different from the fricative /ʃ/ and the affricate /ʧ/.

For the fricative /s/, the mean spectral peak in CI children was higher, while it was higher for /ʃ/ and /ʧ/ in the NH children. Like CI children, the NH children could not produce fricative /s/ based on its peak range. Both groups had spectral peaks lower than the range in /s/, but the difference between was statistically significant in CV context, where CI children produced /s/ almost similar to the standard /s/. The other significant difference was related to the fricative /ʃ/ in /æʃ/, where the spectral peak of NH children was higher ($p<0.05$).

Rise time of /s/, /ʃ/, and /ʧ/ in two study groups

In this study, the rise time was used to distinguish between fricative /ʃ/ and affricate /ʧ/. In the CI children, fricative /ʃ/ was articulated in the initial position more frequently than /ʧ/; in the other positions, /ʧ/ had higher rise time. However, these differences between these two consonants were not significant.

In the NH children, fricative /ʃ/ in the initial position had the highest rise time. In all contexts, the rise time of /ʃ/ was longer than that of /ʧ/. These differences were statistically significant ($p<0.05$). The NH children tended to produce /ʃ/ and /ʧ/ perfectly. The rise time of /ʃ/ was longer than that of /ʧ/ in the NH children, while the rise time of /ʃ/ in CI children was longer than that of /ʧ/. The results demonstrate that the speech of CI children is different from NH children in producing /s/, /ʃ/ and /ʧ/.

Discussion

Children with CI and their NH peers were compared in this study regarding how they produce fricatives /s/ and /ʃ/ and affricate /ʧ/. According to the results, CI children could not distinguish between /ʃ/ and /ʧ/ and produced affricate /ʧ/ like the allophone of /ʃ/. The distinction between two fricatives /s/ and /ʃ/ was difficult for both groups. The CI group produced fricative /s/ like the allophone of /ʃ/. In CI children, fricative /s/ and affricate /ʧ/ lost their distinctive features and were produced like fricative /ʃ/.

Regarding the friction duration of /s/, /ʃ/, and /ʧ/ in CI and NH children, the findings are consistent with the results of Whitehead and Barefoot, where the HI speakers produced fricatives in VC context with more significant amount of duration than in VCV context [20]. Liker et al. and Mildner and Liker in the Croatian language reported that the average duration of the entire affricate position was significantly longer in the CI group than in the NH group [21, 22]. This is consistent with our results. In our study, the comparisons of friction duration in CI children indicated a little difference between two fricatives /s/ and /ʃ/ but these differences were not significant. Therefore, CI children could not distinguish between these two fricatives. Concerning fricative /s/ and affricate /ʧ/, the differences were not significant either, but the CI children produced fricative /ʃ/ and affricate /ʧ/ distinctively, except for the VC context. The male children with CI had longer friction duration than females, but the difference was not significant, except for /ʧæ/. These findings are against the results of Jongman et al. who showed the effect of gender on friction duration and reported that fricatives produced by English-speaking females were slightly longer than those produced by male speakers [18]. Despite the differences between the two CI and NH groups, the fricatives and affricate in the final position had longer friction duration in both groups, and the friction duration of fricative /ʃ/ in VC context was longer in both groups. Fricative and affricate consonants (/s/, /ʃ/, /ʧ/) are among obstruents, because they involve a severe obstruction in airflow. This characteristic can lead to the longer friction duration of these consonants in the word-final position [23, 24]. Not surprisingly, CI children produced these phonemes with longer friction duration. Unlike NH children, the speech of CI children is feedback-sensitive. When they learn how to produce sounds, they want to utter them as perfectly as their speech therapist, which causes them to intensify their production. Thus, this intensity makes their speech slightly different from their NH counterparts [25].

Concerning the spectral peak of /s/, /ʃ, and /ʧ/ in two groups of children, the results showed that the spectral peak in the CI children had a different pattern than the NH children. This is against the findings of Yang et al., who found that, in Chinese-speaking NH children, /s/ had the highest spectral peak and /ʧ/ had the lowest peak [26]. Regarding the rise time of /s/, /ʃ/, and /ʧ/ in the two groups, our results indicated that /ʧ/ lost its obstruent features in CI children and was produced like a fricative; however, /ʧ/ in the word-initial position had shorter rise time than /ʃ/. Therefore, the CI children produced /ʃ/ and /ʧ/ similarly. As mentioned in Yang et al.'s study, affricates are undoubtedly the most difficult consonants for CI children, which explains why /ʧ/ was substituted by stops, fricatives, or fricative-like noise most of the time [26]. These findings are consistent with the results of Sohrabi and Jalilevand for Persian speakers and Yang and Xu for Mandarin speakers, who showed that CI and NH children have different abilities in producing the sibilants and affricates [14, 27]. Our results are also consistent with the findings of Reidy et al. and Todd et al. who reported significant differences between the speech sounds produced by English-speaking children with CIs and their NH peers, even for sounds perceived to be correct by adults [13, 28].

Finally, our results showed a significant difference between the two groups regarding the affricate /ʧ/. The NH children produced this affricate distinctively from fricatives /s/ and /ʃ/, while CI children produced this affricate as an allophone of /ʃ/. Moreover, distinguishing between two fricatives /s/ and /ʃ/ was difficult for both groups. These results are consistent with the findings of Reidy et al., who concluded that English-speaking CI children produced /s/ with less contrast with /ʃ/ and produced /ʃ/-initial words more intelligibly than /s/-initial words [13].

Conclusion

The speech of CI children is different from NH peers in producing /s/, /ʃ/, and /ʧ/. The CI children cannot distinguish between /ʃ/ and /ʧ/ and produced affricate /ʧ/ as an allophone of /ʃ/. The distinction between two fricatives /s/ and /ʃ/ is difficult for both groups. The CI children produce fricative /s/ as an allophone of /ʃ/. The results of this study can help speech therapists, clinical linguists, and application designers focus on speech sounds that are challenging for CI children to produce. Further studies are recommended to analyze other factors of fricatives, such as the center of gravity, linguistic features of voiced fricatives, and other phonetic, phonological, morphological, semantic, and pragmatic features in CI and NH children with larger sample sizes and in different contexts. The effect of various devices and the duration of received rehabilitation programs can be another intriguing research avenue. One of the challenges of the study was the selection and inclusion of the NH group. In future studies, stricter inclusion criteria are recommended to accurately reflect the between-group differences.

Ethical Considerations

Compliance with ethical guidelines

The sample selection was on a voluntary basis. Informed consent was obtained from all the participating individuals and their parents. Moreover, they were ensured that their anonymity would be strongly protected and that the results would be used for research purposes only. The ethical code of the article is as follows: E.A. 95.03.12.01

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Authors' contributions

RR: Study design, interpretation of the results, and drafting the manuscript; MK: Acquisition of data, interpretation of the results, and drafting the manuscript; SG: Interpretation of the results and drafting the manuscript; MM: Statistical analysis.

Conflict of interest

The authors declare no conflicts of interest with respect to the content, authorship, and/or publication of this article.

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