Research article: The effect of early implantation on the acoustic features of vowels by cochlear implanted children

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Abstract
Cochlear implantation (CI) is a preferred treatment for severe-to-profound sensory neural hearing loss and has caused significant improvement in the language ability of cochlear implantees compared to the hearing aided patients. Although CI users have gained access to auditory feedback, there are still some gaps in their speech articulation compared to the normal hearings. One area in which the difference lies is their shortcomings in the accurate production of speech segments. They evidence difficulties in the production of vowels which are determinant factors in speech intelligibility and successful communication. As studying vowels from an articulatory perspective does not provide objective results, researchers have shown an inclination for acoustic studies to investigate the differentiating features, namely the first and second formants (F1 and F2) of the vowels articulated by CI speakers. The first formant (F1) correlates with the articulatory height of vowels (high/low dimension) and the second formant (F2) corresponds to the tongue position (the front/back dimension). F1/F2 ratio yields vowel space which provides both an objective representation of the vowel articulation accuracy and the main acoustic cue in auditory perception for listeners. The studies on the acoustic features of the vowels have demonstrated indefinite and contrasting results in the comparative investigations of CI users and normal hearing listeners. Some have reported a significantly reduced vowel space for CI users, while other studies have evidenced an increase in the vowel space of CI users due to the positive impact of CI. There are even studies that have claimed an improvement in the vowel spaces of CI users to the point of similarity with the normal hearing. Inconsistent findings seem to be due to methodological differences and considering different variables such as post- or pre-lingual deafness, CI adults or children, age at implantation and time elapsed

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after the surgery. Among these factors, age at implantation has wide-ranging consequences and requires more in-depth studies. This study aims at investigating the effect of early cochlear implantation on the first and second formants (F1 and F2) of the Persian vowels produced by CI children.
To this end, the vowel production of two groups of children, implanted before and after age three (CI<3, CI>3) with at least three years of device use length was studied. All CIs had been diagnosed with severe congenital hearing loss at both ears without any other disability and physical condition. There was a control group of five normal hearing age-matched children (NH group). After a speech therapist, each participant repeated CV syllables made up of one of the eight Persian plosives as onset and one of the six Persian vowels as nucleus. Using Praat software, the frequency of the first and the second formants of the vowels produced by children in three groups were extracted and then compared with each other. To find between-group variances, Kruskal-Wallis test was used with the significance level set at 0.05.
Findings of this study demonstrated that there were significant differences among the groups in the frequency of the first and second formants of all Persian vowels except for F1 and F2 of /a/ and F2 of /i/ and /e/ (eight cases). Mann–Whitney U test showed that CI<3 and normal hearing groups were significantly different from each other in F1 of the vowels /i/, /e/ and /u/, and F1 and F2 of the vowels /o/ and /ɑ/. The comparison between CI>3 and normal hearing groups demonstrated significant differences in the first mentioned eight cases (F1 of /i/ and /e/ and F1 and F2 of /u/, /o/ and /ɑ/). CI<3 and CI>3 groups were statistically different from each other in F1 of the vowels /i/ and /e/ and F2 of vowels /u/ and /o/.
Considering the first formant, we did not find any association between early implantation and F1 of the vowels by CIs. All CI users produced vowels with a more open mouth than the normal hearing which seems to be due to the exaggerated training method of therapists producing the vowels with more open mouth to give a visual cue to CIs about the articulation of vowels. In terms of F2, on the contrary, there is a clear relationship between age at implantation and vowel production. Although all CIs showed lower F2 than NHs and articulated back vowels more front than their normal place, the deviation was more observable in CI children who had undergone surgery after the age 3 (CI>3). This indicates that early implantation positively affects the cochlear implanted ones in articulating vowels with normal-like F2 as an important distinguishing acoustic feature of vowels.

Key Words: Persian Vowels, Vowel Space, Cochlear Implantation, Implantation Age, Formant