

# Production of Greek vowels by hearing-impaired children

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<https://doi.org/10.36505/ExLing-2020/11/0036/000451>

## Abstract

The present study investigates the acoustic characteristics of Greek vowels produced by hearing-impaired children with profound prelingual hearing loss and cochlear implants. The results revealed a significant difference between vowels produced by hearing-impaired children and those produced by normal-hearing ones in terms of duration. Stressed vowels were significantly longer than non-stressed for both groups, while F0, F1 and F2 did not differ significantly between the two groups for any vowel, with the exception of /a/, which had significantly higher F1 when produced by hearing-impaired children. Acoustic vowel spaces were similar for the two groups but shifted towards higher frequencies in the low-high dimension and somehow reduced in the front-back dimension for the hearing-impaired group.

Keywords: hearing impairment, children, Greek vowels, duration, formants

## Introduction

Hearing-impaired speech is characterized by deviations both in segmental and suprasegmental level that often affect intelligibility and communication. As far as the segmental level is concerned, several deviations have been observed not only in the production of consonants, but also of vowels, despite the fact that their production is considered much easier. Among others, vowel substitutions and neutralization have been frequently reported in the speech of hearing-impaired individuals due to limited auditory feedback (e.g. Ryalls et al. 2003).

Acoustically, vowels produced by hearing-impaired speakers have been revealed to cover more restricted formant space, with more overlaps than the ones produced by normal-hearing speakers (e.g. Ryalls et al. 2003). Moreover, excessive duration is among the suprasegmental errors that have been reported in several studies (e.g. Hasanvand, et al. 2017) for both adults and children with hearing impairment. However, the results regarding the duration in hearing-impaired children's speech remain contradictory, as there are also studies reporting no difference in comparison to normal-hearing children's speech (Ghayedlou et al. 2020).

With regards to the production of Greek vowels, Nicolaidis & Sfakianaki (2007, 2016) have found significant differences between vowels produced by normal-hearing and hearing-impaired adults, such as prolonged duration and reduced vowel space for the latter group. To our knowledge there are no

studies on vowel acoustic parameters of Greek hearing-impaired children's speech in the literature.

Along this line of research, the present study aims at investigating the acoustic characteristics of Greek vowels, and particularly, duration, F0, F1 and F2, produced by hearing-impaired children by comparing them with those produced by normal-hearing children.

## Method

The speech material consisted of ten real CVCV words produced within the carrier phrase /'ipe \_\_ 'pali/ ("He/She said \_\_ again"). The first syllable was either stressed or non-stressed, containing the target vowel which varied among the five Greek vowels, while the preceding and following consonants were voiceless stops. Three hearing-impaired children aged 8-12 years old with profound prelingual hearing loss and cochlear implants and four normal-hearing peers produced the speech material three times at a normal tempo in a quiet room. A consent form was signed by the parents/carers. Duration, as well as F0, F1 and F2 (in the middle of each vowel) were measured in Praat software (Boersma & Weenink 2019). SPSS (v26) was used for data statistical analysis.

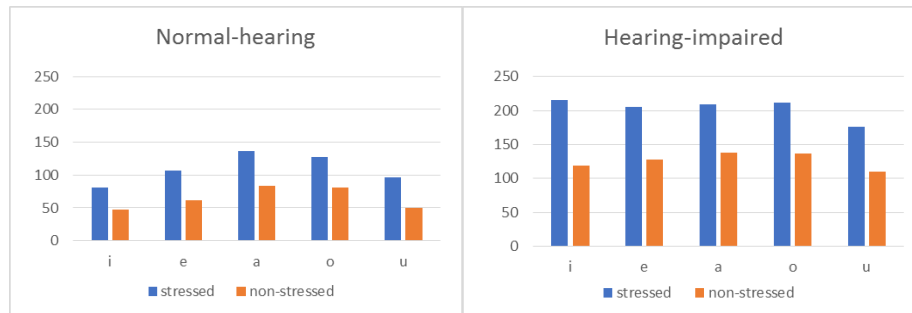
## Results

Table 1 shows the mean values of duration, F0, F1 and F2 per vowel, for normal-hearing and hearing-impaired children, averaged across stressed and non-stressed vowels as well as across boys and girls.

Table 1. Mean duration (ms), F0, F1 and F2 (Hz) values per vowel for normal-hearing (NH) and hearing-impaired (HI) children.

Vowels	Duration		F0		F1		F2	
	NH	HI	NH	HI	NH	HI	NH	HI
i	64	167	257	262	401	408	2748	2618
e	84	166	243	247	667	615	2023	2035
a	110	173	255	244	832	931	1512	1551
o	104	174	241	260	621	591	1265	1400
u	73	143	235	255	438	393	930	951

A 4-way Anova (group x gender x stress x vowel) for each one of the dependent variables revealed a significant difference between vowels produced by hearing-impaired children and those produced by normal-hearing ones in terms of duration [ $F(1,30)=44.207$ ,  $p<0,0001$ ]. Subsequent t-tests per vowel revealed significant differences for all vowels (marginally for /a/). Stressed vowels were significantly longer than non-stressed for both normal-hearing [ $t(38)=-5.061$ ,  $p<0.0001$ ] and hearing-impaired children [ $t(28)=-4.055$ ,  $p<0.0001$ ] (see Figures 1, 2).



Figures 1, 2. The duration of Greek vowels for normal-hearing and hearing-impaired children in stressed and non-stressed condition, respectively.

F0, F1 and F2 did not differ significantly between the two groups for any vowel, except for /a/, which exhibited significantly higher F1 when produced by hearing-impaired children ( $t(12)=-2.680$ ,  $p<0.05$ ).

The main effect of vowel on F1 [ $F(4,30)=41,737$ ,  $p<0.0001$ ] and F2 [ $F(4,30)=136,949$ ,  $p<0.0001$ ], as well as subsequent post-hoc tests, indicated significantly distinguished vowel categories for the two groups in terms of both the low-high and the front-back dimension, respectively. In total, the acoustic space of hearing-impaired children is similar with the one of normal-hearing children but shifted towards higher frequencies in the low-high dimension and somehow reduced in the front-back dimension (Figure 3).

A main effect of gender was observed on F0 [ $F(1,27)=8,808$ ,  $p<0.05$ ], with boys having significantly higher mean F0 than girls (256 vs. 224 Hz).

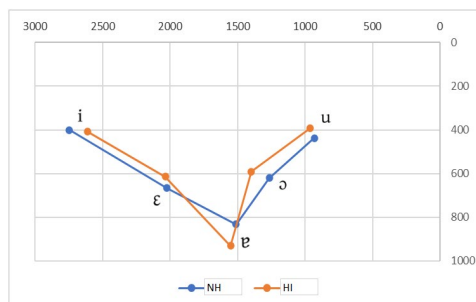


Figure 3. The acoustic spaces of Greek vowels as produced by normal-hearing (NH) and hearing-impaired (HI) children.

## Discussion and conclusions

Overall, the results indicate significant temporal differences in vowel production between normal-hearing and hearing-impaired children and few differences in vowel acoustic spaces.

In terms of duration, vowels produced by hearing-impaired children were significantly prolonged, as previously reported for the English language too (Vandam et al. 2011). Vowels produced by normal-hearing children exhibited identical temporal hierarchical structure with those produced by both normal-hearing (Fourakis et al. 1999) and hearing-impaired adults (Nicolaidis & Sfakianaki, 2007), i.e.  $i < u < e < o < a$ ; while, for hearing-impaired children the order was  $u < e, i < a, o$ , with all vowels having almost the same duration except for the shortest /u/. Stressed vowels were significantly longer than non-stressed for both groups, indicating that they both use the temporal parameters similarly to normal-hearing and hearing-impaired adults (Nicolaidis & Sfakianaki, 2007), in order to denote the effect of stress.

Regarding formant frequencies, vowel categories are clearly distinguished for all children. Compared to normal-hearing, hearing-impaired children show: (1) higher F1 for the low vowel, and (2) somehow reduced space in the front-back dimension; which may be related to the increased and reduced visibility of articulatory gestures forming the vowel constriction along the low-high and front-back axes of the vocal tract, respectively.

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