AN ACOUSTIC ANALYSIS OF VOWELS PRODUCED BY GREEK SPEAKERS WITH HEARING IMPAIRMENT

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ABSTRACT

The study examines F1, F2 formant frequencies and duration of all five Greek vowels produced by six Greek speakers with profound hearing impairment and six speakers with normal hearing (three male and three female in each group). The speech material analysed was of the form /ˈpVCV/ where V=/ i, ɛ, ɐ, ɔ, u /, C=/p, t, k, s/. The study discusses differences in the above acoustic parameters as a function of hearing level, gender, stress and context. The results show longer vowel durations and a reduction of the vowel space for the speakers with hearing impairment. Significant variability due to stress and context was evident between the two groups. The paper discusses findings with reference to perceptual constraints affecting the speech of individuals with hearing impairment.

Keywords: hearing impairment, Greek, vowels, formant frequencies, duration, stress, context.

1. INTRODUCTION

Speech production by individuals with hearing impairment (HI) is commonly characterized by segmental errors, both vocalic and consonantal, and deviances in suprasegmental features including problems in controlling phonation, fundamental frequency, and timing.

With reference to vowel production, typical errors include substitution, neutralization, prolongation, diphthongisation, nasalisation (Markides [1]). Research on the acoustic characteristics of vowels has shown that speakers with HI produce less differentiated vowels and a more centralised vowel space. F1 and F2 formant frequencies show reduced ranges during the production of different vowel qualities, there can be extensive overlap of vowel areas and a tendency towards the neutral [ə] (Angelocci, Kopp & Holbrook [2]; Ryalls, Larouche & Giroux [3]). Such reduced differentiation of vowels has been attributed to limited auditory feedback and the relative invisibility of articulatory gestures needed for vowel production (Monsen [4]). Higher frequencies tend to be more affected as hearing sensitivity is greatly reduced above 1000 Hz for individuals with HI. As a result, generally, more errors have been reported for high and mid vowels compared to low ones and for front than back vowels. The high frequency, low intensity F2 formants of high vowels are more likely to be affected than the lower-frequency, more intense F2 formants of back vowels. In addition to the generally reduced perception of F2 formants, tongue placement along the front-back axis in the oral cavity is difficult to perceive visually. On the other hand, better residual hearing in the region of F1 frequencies and relatively better visibility of tongue height associated with jaw displacement, which can be accessible in speech reading, makes variation in F1 more prominent.

The temporal characteristics of the speech of individuals with HI are also affected. Typically longer vowel durations have been reported in several studies (e.g. Whitehead & Jones [5]).

It is worth pointing out that to date there has been limited research on the speech of individuals with HI in languages other than English. Such research is important both from a theoretical and a clinical perspective, as it can provide insights about those aspects that result from perceptual, physiological constraints and those that relate to the phonetic/phonological characteristics of particular languages.

The current study aims to compare selected acoustic parameters during vowel production by Greek speakers with HI and with normal hearing (NH). Greek has a simple five vowel system /i, ɛ, ɐ, ɔ, u/ (see Fourakis, Botinis & Kastaiti [6] for a description of their acoustic characteristics). F1, F2 formant frequencies and vowel duration will be examined for the two groups of speakers and differences as a function of hearing level, gender, stress and context will be discussed.

2. METHODOLOGY

2.1. Speech material

The speech material consisted of disyllabic words of the form /ˈpVCV/ with V=/i, ɛ, ɐ, ɔ, u/, and C=/p, t, k, s/. Only symmetrical sequences with stress on the first syllable were recorded. The words were embedded in carrier phrase /ˈleɣe __ ˈpali/, i.e. "say ___ again", and were repeated six times by all subjects. In total, 1440 words were recorded and analysed.

2.2. Speakers

Three male and three female young Greek adults with profound bilateral hearing impairment of early onset were recorded (three frequency pure tone average thresholds at 500, 1000 and 2000 Hz ≥ 100dB measured in the better ear). All had conventional behind-the-ear hearing aids; one speaker did not however use her hearing aid. All but one female speaker produced comfortably intelligible speech. They all had excellent lip reading skills and were educated in an oral communication setting. In addition, three male and three female young Greek adults with normal hearing were recorded for the control group. They were all speakers of standard Modern Greek.

2.3. Data analysis

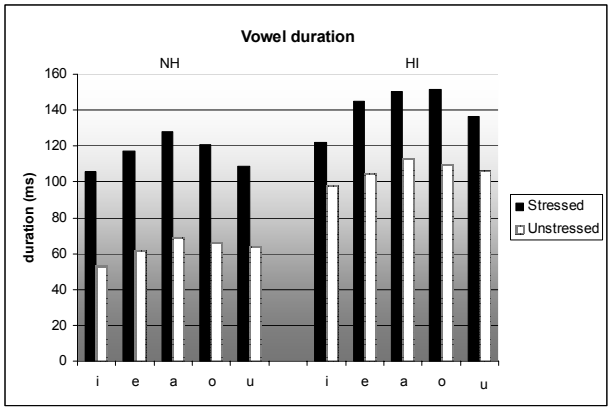
Acoustic data were recorded in the Phonetics laboratory of Aristotle University using an external Yamaha UW500 sound card and a Sennheiser e815S microphone. Data were sampled at 22.050 Hz. The duration of the stressed and unstressed vowels in the /ˈpVCV/ words and F1 and F2 frequencies at vowel midpoint for both vowels were measured. Formant frequency measurements were carried out using the automatic formant tracker of PRAAT and were all manually checked, and corrected when necessary, by the experimenters. The frequency difference between vowels having the highest and lowest F1 and the highest and lowest F2 was calculated for the male and female speakers with NH and HI in order to investigate differences in the vowel space of the two groups (see [4]).
Data were statistically processed using ANOVA with vowel, consonant, stress, group (HI, NH), and gender (male, female) as factors.

3. RESULTS

3.1. Duration

The vowel main effect ($F(4, 2867)=23,99$, $p<0.0001$) showed that there were significant inherent duration differences among vowels with /ɐ/ being the longest vowel and /i/ the shortest These findings are in agreement with previously reported data on Greek for speakers with NH, e.g. [6]. There was no significant interaction with group indicating that these durational differences occurred for speakers with NH and HI (Figure 1); the only exception appears to be the duration of the stressed /ɔ/ vowel which is of similar duration to /ɐ/ for the group of speakers with HI. In addition, the stress main effect was significant ($F(1, 2867)=930,193$, $p<0.0001$); unstressed vowels were shorter than stressed for both groups (cf. [6] for speakers with NH). Context effects on duration were also found with the stressed vowels being longest preceding /s/ and shortest preceding /p/ (consonant by stress interaction ($F(3, 2867)=16,877$, $p<0.0001$) (cf. [5]). Differences between groups were also evident with longer vowel durations produced by the speakers with HI (group main effect: ($F(1, 2867)=559,985$, $p<0.0001$). The group by sex interaction ($F(1, 2867)=497,121$, $p<0.0001$) showed that the female speakers with HI produced the longest vowels (Figure 2).

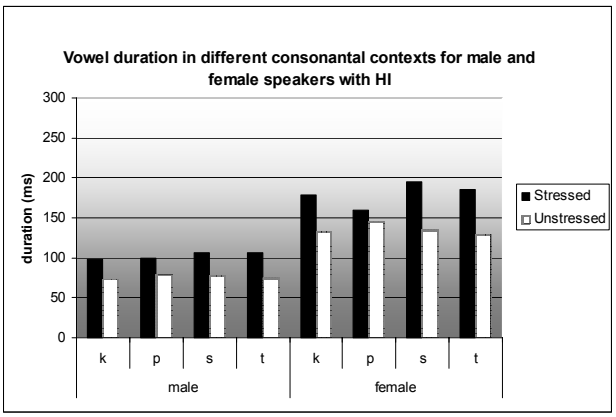
Figure 1: Duration of the stressed and unstressed vowels produced by the speakers with normal hearing (NH) and hearing impairment (HI).



3.2. Formant frequencies

The vowel by group interaction was significant for both F1 and F2 indicating significant vowel formant frequency differences between the groups

Figure 2: Duration of the stressed and unstressed vowels in different consonantal contexts produced by male and female speakers with hearing impairment (HI).



with NH and HI (F1: F(4, 2867)=85,969, p<0.0001; F2: F(4, 2864)=644,454, p<0.0001). The vowel space was reduced along both the F1 and F2 axes for the speakers with HI. A reduction of 27.5% for male and 27% for female speakers with HI was evident for F1, and 39.9% for male and 48.2% for female speakers with HI for F2 (Figures 3 and 4).

Figure 3: The five Greek vowels produced by male speakers with NH and HI plotted in an F1 x F2 space.

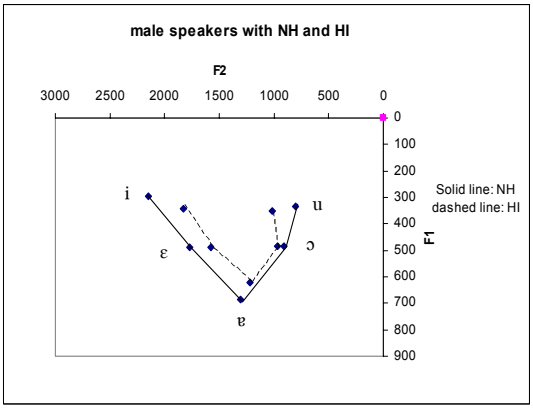
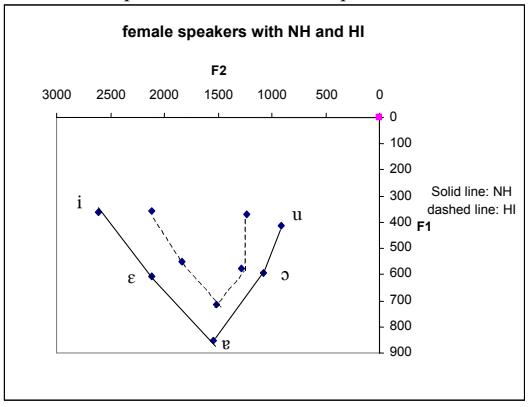


Figure 4: The five Greek vowels produced by female speakers with NH and HI plotted in an F1 x F2 space.



The vowel by stress interaction was also significant (F1: F(4, 2867)=72,338, p<0.0001; F2: F(4, 2864)=28,128, p<0.0001). Figures 5 and 6 show a reduction of the vowel space in the unstressed condition for both groups. A reduction of 13% in F2 and 29% in F1 was evident for speakers with NH and of 5% in F2 and 30% in F1 for the speakers with HI.

Figure 5: F1 x F2 space for the Greek vowels in stressed and unstressed position produced by speakers with NH.

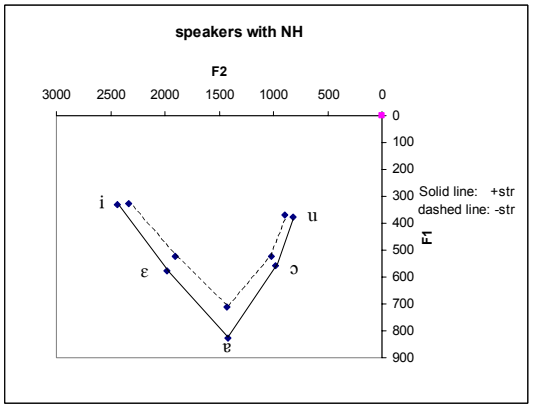
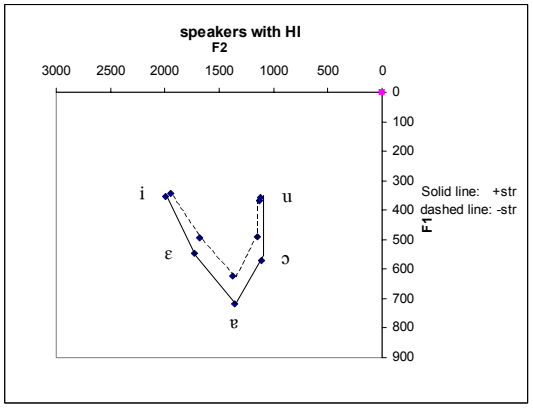


Figure 6: F1 x F2 space for the Greek vowels in stressed and unstressed position produced by speakers with HI.



Finally, the consonant main effect was also significant suggesting contextual effects on the vowel (F1: F(3, 2867)=40,010, p<0.0001; F2: F(3, 2864)=61,972, p<0.0001); effects were present in both groups although there were significant differences between them (consonant by group interaction: F1: F(3, 2867)=14,126, p<0.0001; F2: F(3, 2864)=9,479, p<0.0001). Greater variability in F1 and F2 displacement due to context was evident for the female speakers with HI (consonant by gender interaction: (F1: F(3, 2867)=19,679, p<0.0001; F2: F(3, 2864)=5,104, p<0.002) .

4. DISCUSSION

This study has shown that both temporal and spatial features (as reflected in formant frequency variation) are affected during vowel production by speakers with HI. Regarding temporal variation, vowel duration was longer for the group of speakers with HI compared to the speakers with NH. Lengthening of vowels in the speech of individuals with HI has been reported before (e.g. Whitehead & Jones [5]). Duration deviances may be reflected both in prolongation of steady states or in the transitions/movements from one articulatory position to the next.

Three further interesting findings concern, first, the presence of inherent vowel durational differences in both groups. These correlate relatively well to the degree of openness of the oral cavity for the group with HI; the open vowel /ɐ/ generally showed the longest duration and the close /i/ the shortest. Second, context effects on vowel duration were evident for both groups with stressed vowels being longer in the environment of a fricative compared to a plosive. Whitehead & Jones [5] also showed longer vowel duration in a sibilant compared to a plosive environment for speakers with moderate to severe HI and smaller, but non-significant, effects for profoundly deaf speakers. For the former group, presence of such timing effects was interpreted to suggest learning through the auditory channel. The small effects found for the deaf speakers indicated, however, that some small durational differences can also be language universal. Third, unstressed vowels were found to be shorter than stressed for both groups indicating that durational shortening is a feature that is controlled in the unstressed condition by the group of speakers with profound HI of this study.

Regarding the formant frequencies of vowels, this study has shown that vowel categories appear to be clearly defined but the vowel space is considerably reduced for speakers with HI. There was greater reduction in the F2 dimension (cf. Monsen [4] for English adolescents with HI) which may be interpreted to relate to reduced hearing sensitivity at higher frequencies and the reduced visibility of articulatory gestures forming the vowel constriction along the front-back axis of the vocal tract.

Absence of stress caused a reduction of the vowel space for both groups. A shift of the vowel space toward a higher location in the F1 by F2 space was also evident. Similar findings have been reported for normative Greek data by Fourakis et al. [6]. F1 values were generally lower in the unstressed condition especially so for the open and mid vowels. For the speakers with HI, this finding indicates that there is target undershoot in the unstressed condition. This was especially evident for F1 which shifted by the same percentage as for speakers with NH while reduction of F2 was less than half in percentage. This finding suggests that absence of stress is indicated more by changes in F1 in the speech of individuals with HI. This change can be learned and achieved due to better hearing sensitivity at lower frequencies and better visibility of gestures relating to mouth opening.

Our data has also shown evidence of contextual effects in both groups. Due to limitations in space it is not possible to discuss coarticulatory effects from the four consonants on all five vowels. What is worth pointing out, however, is that coarticulatory effects were present in the group of speakers with HI providing evidence of coproduction of gestures. Differences in the degree of effects and further variability between the two groups will be reported in a future study.

Finally, differences between male and female speakers were evident in our data. Longer vowel durations were found for the female speakers with HI which may relate to, among others, preferences in speaking style and carefulness in articulation. In addition, greater variability in formant displacement due to context was found for the female speakers with HI. Both of these findings need to be investigated further in future research.

5. REFERENCES

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