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Acoustic aspects of segmental and suprasegmental productions of Greek hearing-impaired speech: A qualitative analysis

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Abstract
Hearing-impaired speech presents a number of characteristics deviating from normal, which concern both the segmental level, i.e. vowel and consonant errors, and the suprasegmental level, i.e. stress, intonation, resonance, voice quality etc. Errors on both levels can compromise speech intelligibility, that is, the ability of being understood. The current paper presents a qualitative analysis of the main segmental and suprasegmental errors observed in the speech of 10 Greek adult speakers with profound prelingual hearing impairment and of various intelligibility levels. Audio files and/or spectrographic displays, useful to clinicians, teachers and researchers, are provided to illustrate the above features and to help clarify acoustic measurement issues pertaining to the acoustic analysis of hearing-impaired speech.

Keywords: hearing impairment, intelligibility, acoustics, segmental and suprasegmental errors, qualitative analysis

1. Introduction

Speakers with hearing impairment (HI) demonstrate a variety of deficits in their speech on both the segmental and the suprasegmental level.

Regarding the segmental level, vowel errors including substitution of one vowel for another, neutralization, nasalization, diphthongization, as well as diphthong splitting (into its vowel components) or simplification (omission of the final part of the diphthong) are observed in HI speech. Different vowel error patterns have been observed by various researchers, i.e., low vowels are reported as more correctly produced than high and mid vowels (Nober 1967; Smith 1975; Geffner 1980), while others report the opposite (Angelloci, Kopp & Holbrook 1964; McGarr & Gelfer 1983). The variability of error patterns in the literature may be due to the recruitment of different subjects (degree of hearing loss, age, etc) and use of different materials (syllables, structured utterances, spontaneous speech), but also because of the lack of a “generic deaf speech pattern” (McGarr & Harris 1980: 309) which would indicate uniformity in production.

Vowel neutralization is very common in HI speech and leads to a more central and lax vowel. A great number of HI vowel production studies in English come to the conclusion that F1 and F2 formant values tend towards a neutral /ə/ which results in a reduced phonological space. Phonological space reduction has been attributed to a characteristic immobility of the second formant that has been described in the literature. The F2 contour represents tongue activity along the front-back dimension which the HI cannot track visually and therefore find more difficult to master. The first formant is also restricted in range, although it is considered, along with F0, to be one of the main factors contributing to HI vowel differentiation (Angelocci et al. 1964; Martony 1968; Monsen 1976; Rubin 1985; Stevens, Nickerson & Rollins 1983). The movement of the jaw is a visible cue that the HI can exploit to make the high-low distinction that relates to the F1 dimension (McGarr & Gelfer 1983). Moreover, residual hearing is most often located at the low frequencies, which promotes F0 and F1 audibility.

Consonant errors involve omission, especially word-finally (Geffner 1980), substitution and misarticulation. Front consonants are usually produced better than back due to their visibility (Huntington et al. 1968), while lingual consonants are more difficult to articulate due to tongue involvement in their production (Nober 1967; Oller, Jensen & Lafayette 1978). Sibilant productions (e.g., [s], [ʃ]) are exceptionally problematic due to aerodynamic and articulatory demands (McGarr et al. 2004), while voiced and voiceless sounds are frequently confused (Hudgins & Numbers 1942; Nober 1967; Smith 1975. Consonant clusters are often misarticulated or reduced. Finally, longer segmental duration has been observed which has been attributed to a need for vibrotactile maximization (McGarr & Campbell 1995).

On the suprasegmental level a variety of phenomena have been documented involving deviant temporal characteristics (Okalidou & Harris 1999; Vandam, Ide-Helvie & Moeller 2011), slower speech rate (Nickerson et al. 1974), faulty rhythm, improper placement of pauses (Boothroyd, Nickerson & Stevens 1974), reduced stressed-unstressed differentiation (Stevens, Nickerson & Rollins 1978; Osberger & Levitt 1979), flat or improper intonation (Osberger & McGarr 1982), phonation and voice quality problems (hoarseness, breathiness) and nasality (Fletcher & Daly 1976;

Whitehead 1983). In addition, less or more coarticulation than normal depending on context has been reported (Okalidou 1996; Okalidou & Harris 1999; Sfakianaki 2012b).

Few studies have been conducted on Greek HI speech. One acoustic study looking into mild-to-severe HI speech showed no significant differences in terms of vowel space area and dispersion (Vakalos 2009). Acoustic studies on Greek profound HI speech reported substantial vowel space reduction due to restricted F2 range, overlap among vowel categories, lower and more variable F3 frequencies, significantly longer segmental durations, smaller C-to-V effects (Nicolaidis & Sfakianaki 2007; Sfakianaki, 2012a; Nicolaidis & Sfakianaki 2016). EPG studies have shown more palatal contact for [t] and [s], less variability for [t], while [s], [c] and [ç] appear deviant from normal (Nicolaidis 2004; 2007).

In general, acoustic research in Greek HI speech is scant. A qualitative acoustic analysis with accompanying audio files could be useful for research, clinical and teaching purposes. The current paper features a categorization of the main segmental and suprasegmental issues encountered in Greek HI speech. In addition, drawing from a larger acoustic study (Sfakianaki, 2012b), it presents selected results on acoustic parameters including vowel space, mean vowel duration and stress effects on vowel space and vowel duration. Audio files and/or spectrogram displays illustrating the above features produced by speakers of different intelligibility levels are provided.

2. Methodology

Five speakers (control group), 2 male and 3 female undergraduate students with normal hearing (NH) , and ten speakers (experimental group), 5 male and 5 female, with hearing impairment (HI), 20-35 years of age, were recorded. Their hearing loss was prelingual, bilateral and sensorineural, ranging from 91 to 105 dB HL (PTA at 500, 1000 and 2000 Hz). They had been diagnosed and aided with conventional hearing aids before the age of 4, and they all had had oral education and many years of speech therapy, except for one speaker (HI_04) who had attended the primary school for the deaf and preferred using sign language.

The material consisted of /pV1CV2/ disyllables, half stressed on the first and half on the second syllable, where V=/i, ɐ, u/ and C=/p, t, s/, embedded in the carrier phrase ‘ ˈleʝe_____ˈpali ’ (Say _____ again.) and were repeated 10 times. The acoustic analysis was carried out with Praat (Boersma & Weenink 2013) and it involved F1 and F2 measurements at vowel onset, midpoint, offset as well as vowel duration measurements in both syllable positions. An LPC analysis with a Gaussian window of 25 ms for the midpoint & 15 ms for the onset & offset of the vowel was conducted. All measurements were checked manually and corrections were made where required. The data was normalized with the modified Watt & Fabricius method (Watt & Fabricius 2002) and treated statistically using univariate ANOVA (SPSS v.17) and Tukey post-hoc tests for within- and between-group differences (Minitab v.15).

The intelligibility level of the speakers with HI was rated by 60 naïve listeners, undergraduate students with normal hearing. The material used was 101 words adopted from the Greek Phonetic and Phonological Development Test (Panhellenic Association of Logopedists 1995) and 25 sentences of 8-14 syllables. Each intelligibility score was an average of 6 listeners. The scoring was based on the number of words understood correctly (Osberger, Maso & Sam 1993).

Two speakers were rated very highly intelligible, five speakers highly intelligible, two speakers moderately intelligible and one speaker almost unintelligible (see Table 1 below).

Speakers	**Intelligibility**			
	Words	**Sentences**	**Mean Total**	
HI_01, HI_02	>95%	>95%	>95%	*very high*
HI_06, HI_07, HI_08, HI_09, HI_10	80-89%,	85-97%	87-93%	*high*
HI_03, HI_05	60-69%,	81-84%	75%	*medium*
HI_04	<20%	<20%	15%	*very low*

Table 1. Speakers with HI divided into groups according to intelligibility level based on their word and sentence score (%).

3. Results & Discussion

In this section we present segmental and suprasegmental features of HI speech that showed deviation from normal. For each feature we provide example(s) with spectrographic display accompanied by the audio file. As mentioned above, the examples are either disyllabic words of the form /pV1CV2/ in the carrier phrase ‘ˈlej̥e_____ˈpali’ (Say _____ again.) or words and sentences from the intelligibility test. Bellow the spectrogram a broad transcription of the word *as it would have been normally produced* is provided, while the feature under study is highlighted.

3.1 Segmental Features

3.1.1 Vowel Errors

The main vowel errors observed in the data included centralization or neutralization, substitution, /u/-fronting, elongation, diphthongization and excessive variability.

Vowel Centralization or Neutralization

The acoustic analysis showed that in HI speech the three point vowels were centralized, that is, [u] was significantly fronted and raised, [i] was significantly backed and [ɐ] was slightly raised. Hence the HI vowel space displayed a 36% shrinkage compared with the NH one, mostly due to a restricted F2 range indicating limited front/back movement of the tongue, while the F1 range was more normal-like probably due to its audibility and visual accessibility (Monsen 1976; Shukla 1989). Two examples of vowel centralization are demonstrated bellow. The F2 frequency of /i/ in Figure 1 is lower than normal (1375 Hz), while the F2 of /u/ in Figure 2 is higher (1635 Hz). The first speaker is moderately intelligible and the second speaker is highly intelligible.

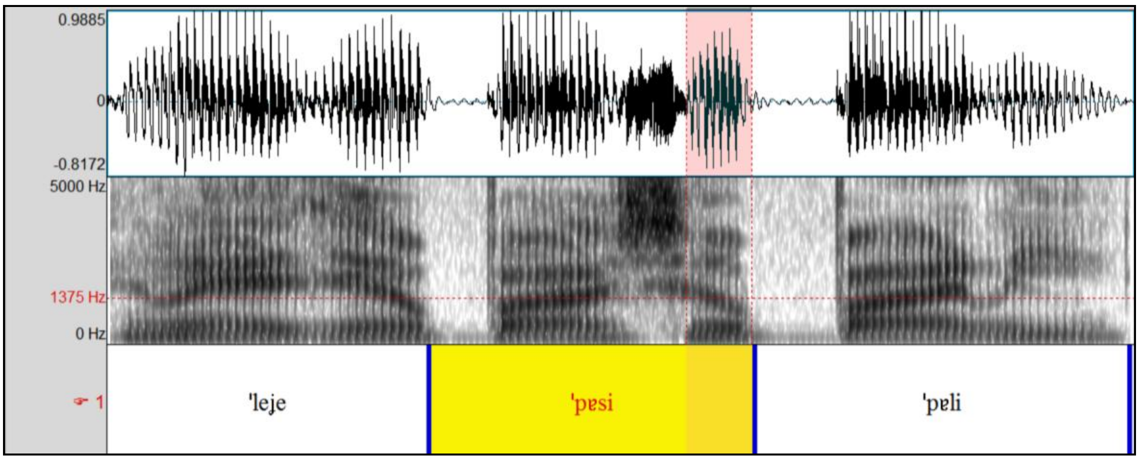


Figure 1. [ˈpɒsə] for /ˈpɒsi/: /i/ centralization by male speaker (PTA: 103.3 dB, intelligibility score: 75%)

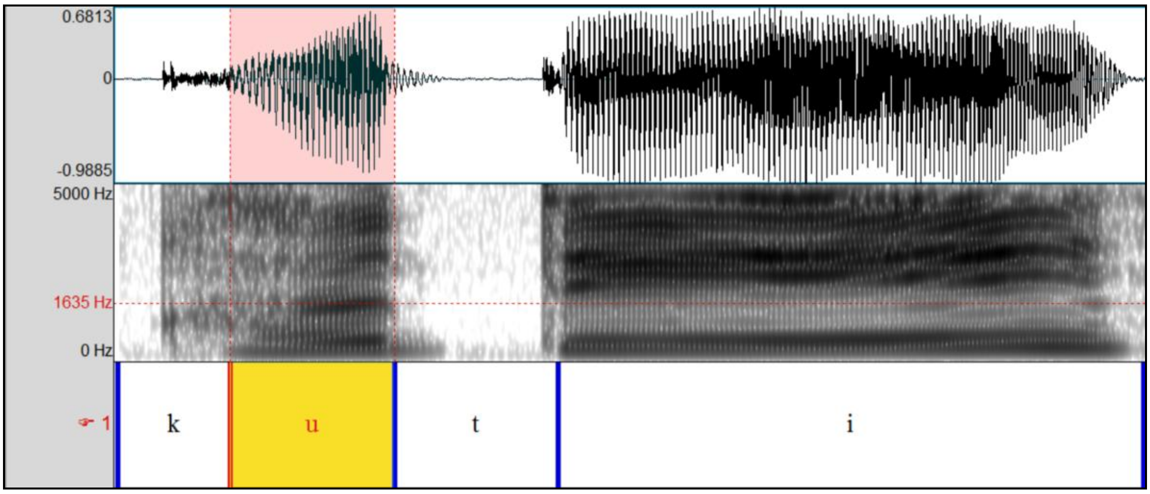


Figure 2. [kɵˈti] for /kuˈti/ (box): /u/ centralization by female speaker (PTA: 91.7 dB, intelligibility score: 87%)

Vowel Substitution

We observed substitution of one vowel for another. In the examples that follow, /e/ and /o/ are substituted for [ɐ]. In the first example there is diphthongization at the beginning of the vowel followed by an F2 drop, resulting in [ɐ] instead of /e/. In the second example it is evident that the formants in the two vowels, /o/ and /ɐ/, remain almost static. The speaker presented in Figure 3 is highly intelligible, while the speaker in Figure 4 is unintelligible.

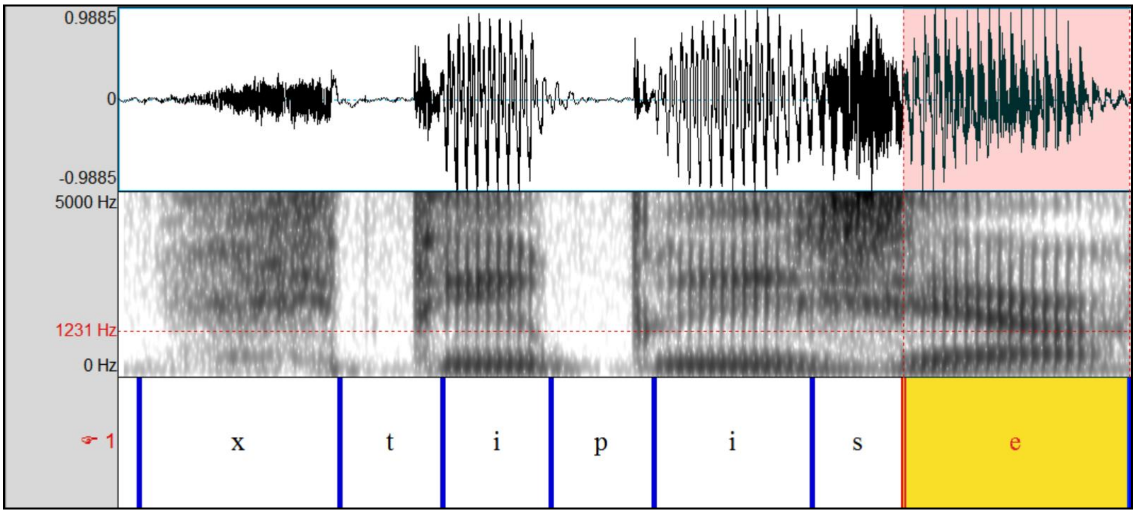


Figure 3. [ˈxtipis̬ʲɐ] for /ˈxtipise/ (hit-3rd person): /e/ substitution by male speaker (PTA: 103.3 dB, intelligibility score: 75%)

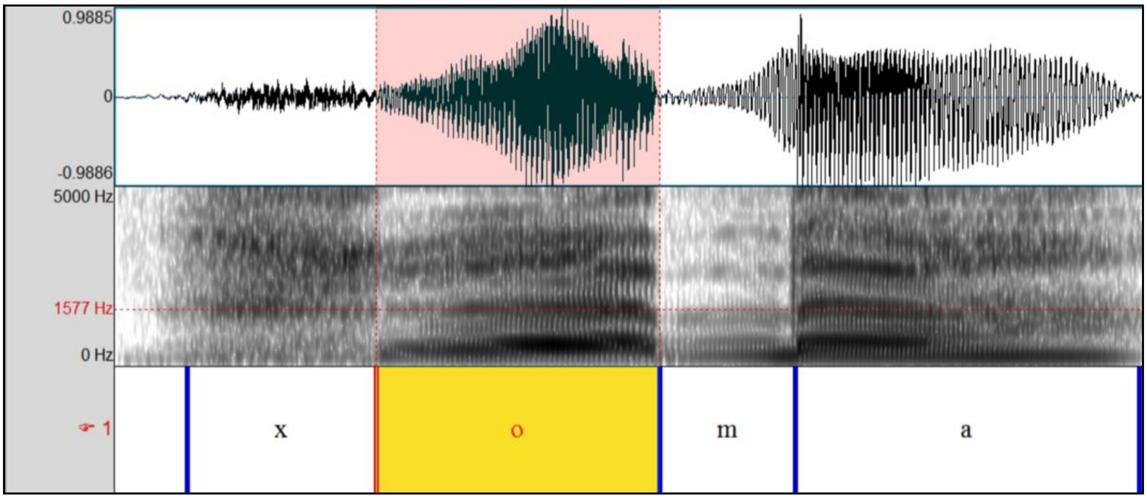


Figure 4. [ˈxɒmɒ] for /ˈxomɒ/ (soil, ground): /o/ substitution by female speaker (PTA: 105 dB, intelligibility score: 15%)

/u/-fronting

As mentioned above, /u/ was found significantly fronted in HI speech. An interesting observation was that as the intelligibility level dropped, the vowel sub-areas became more collapsed, /u/ became more fronted and the vowel space became smaller. An example of /u/-fronting by a highly intelligible male speaker, where /u/ is realized as [y] with an F2 higher than normal at about 1230 Hz, is illustrated in Figure 5 below.

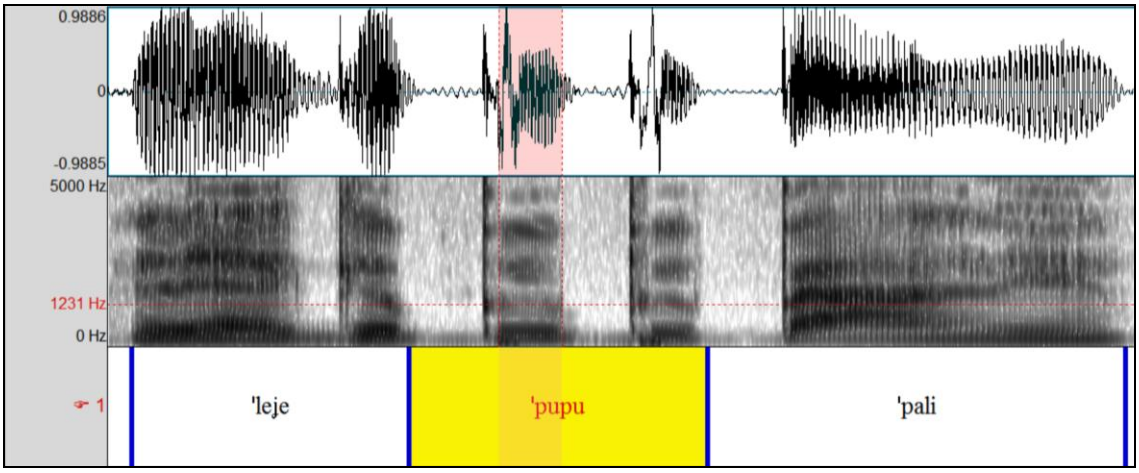
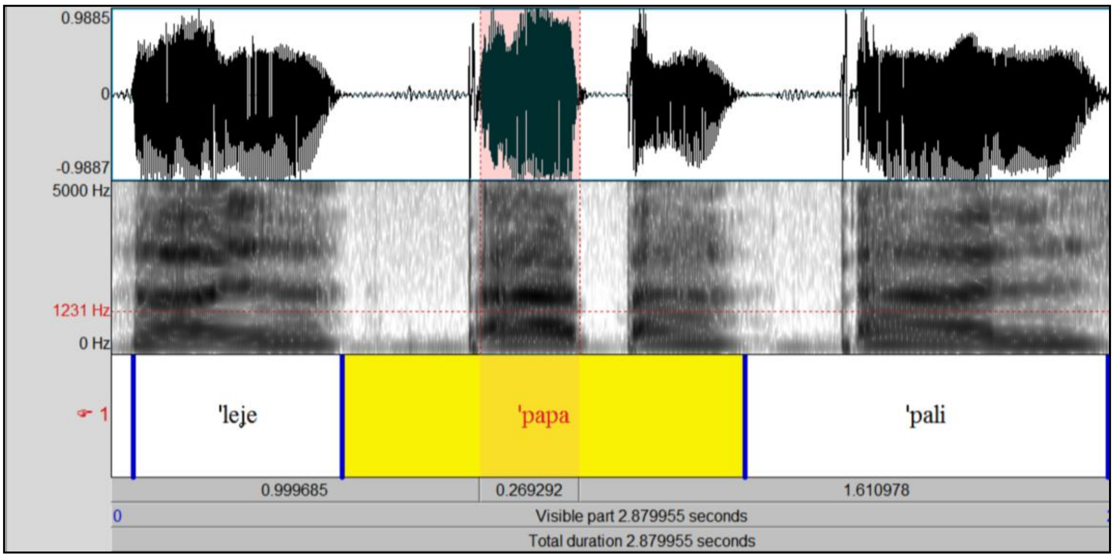


Figure 5. [ˈpypy] for /ˈpupu/: /u/-fronting by male speaker (PTA: 98.3 dB, intelligibility score: 92%)

Vowel Elongation

Although all speakers followed the vowel duration pattern [a] > [u] > [i], HI vowels were found significantly longer than NH vowels. The speaker with the lowest intelligibility level (HI_04) showed the greatest prolongation. In the spectrograms below, the duration of the utterance /ˈleʝe ˈpɐpɐ ˈpali/ (Say pope again) and that of the stressed /ɐ/ in /ˈpɐpɐ/ as produced by the unintelligible speaker (Figure 6a) and a speaker with NH (Figure 6b) are compared. In HI vs. NH speech, the utterance duration is more than double (2.88s vs. 1.27s) and the stressed /ɐ/ duration in /ˈpɐpɐ/ is three times longer (0.27s vs. 0.09s).

a



b

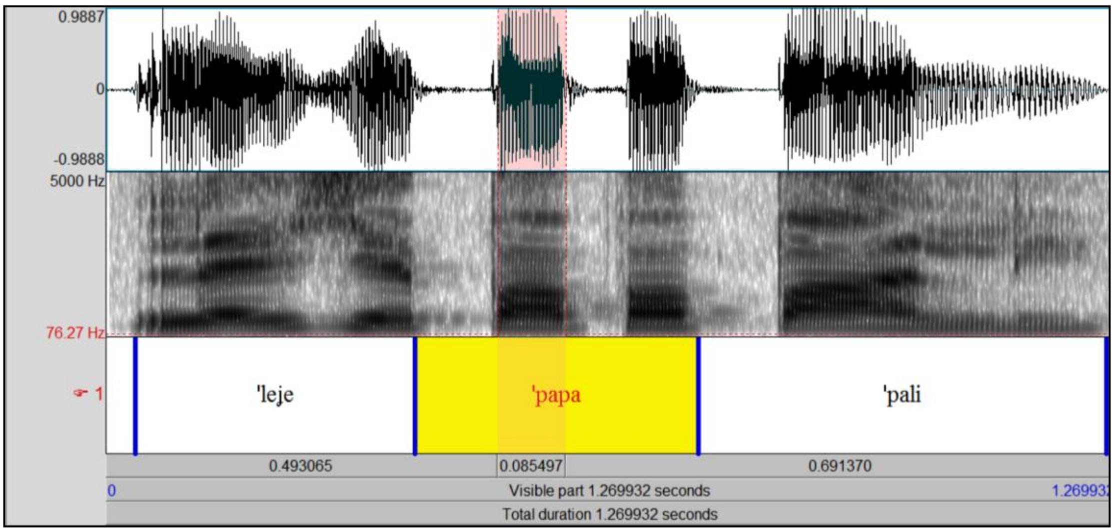


Figure 6. Duration of utterance and stressed /ɒ/ in /ˈpɒpɒ/ (a) by female speaker (PTA: 105 dB, intelligibility score: 15%) and (b) by female speaker with NH

Vowel Diphthongization

Many vowels were diphthongized, and diphthongization frequently also included vowel substitution. Figure 7 demonstrates an example of diphthongization of a stressed /u/ into [ɯʲ] produced by a moderately intelligible speaker, while Figure 8 illustrates both diphthongization and substitution of an unstressed /ɐ/ into [ʲə] produced by an unintelligible speaker.

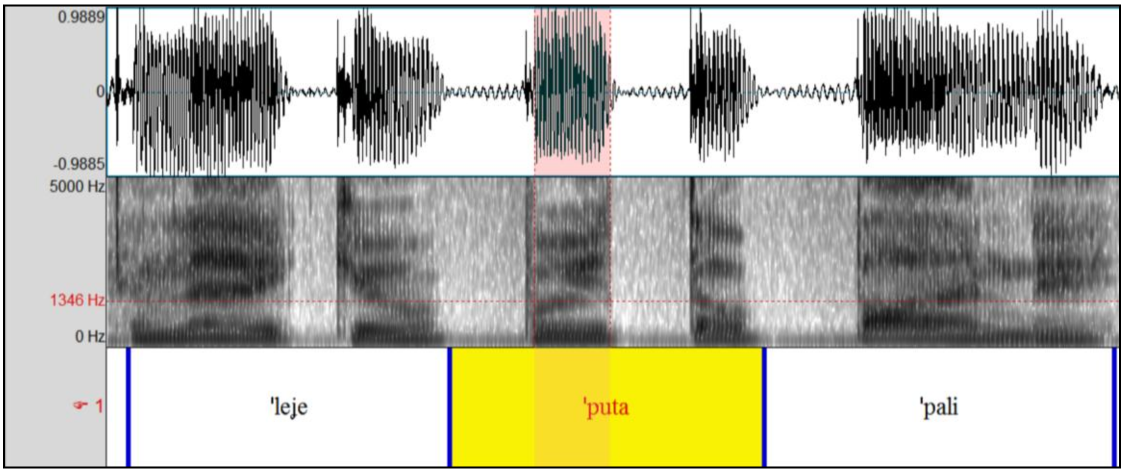


Figure 7. [ˈpuʲtɒ] for /ˈputɒ/: diphthongization of /u/ by male speaker (PTA: 101 dB, intelligibility score: 73%)

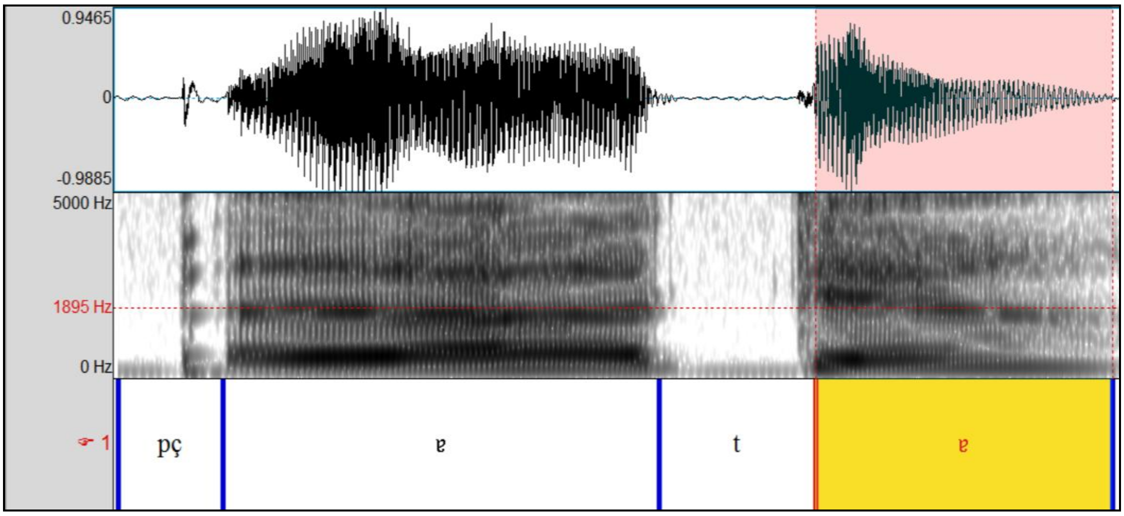


Figure 8. [piˈɒtʲə] for /ˈpçɒtɒ/ (dishes): diphthongization of unstressed /ɒ/ by female speaker (PTA: 105 dB, intelligibility score: 15%)

Production Variability

Most speakers showed excessive variability in their productions. Figure 9 shows the variability of /i/ in three repetitions of the disyllable /ˈpɐpi/ produced by an intelligible male speaker. His nasal formant was located around 1200-1500 Hz, hence in /ˈpapi/, F2 of [i] was usually the oral formant above the nasal formant and the vowel had an [ɨ]-like quality (Figure 9a). Nevertheless, in other repetitions of the same disyllable his [i] was a bit higher than a schwa, in which case, F2 of [i] was actually as low as the nasal formant found in other repetitions (Figure 9b). A production with no nasal formant is also given for comparison in Figure 9c.

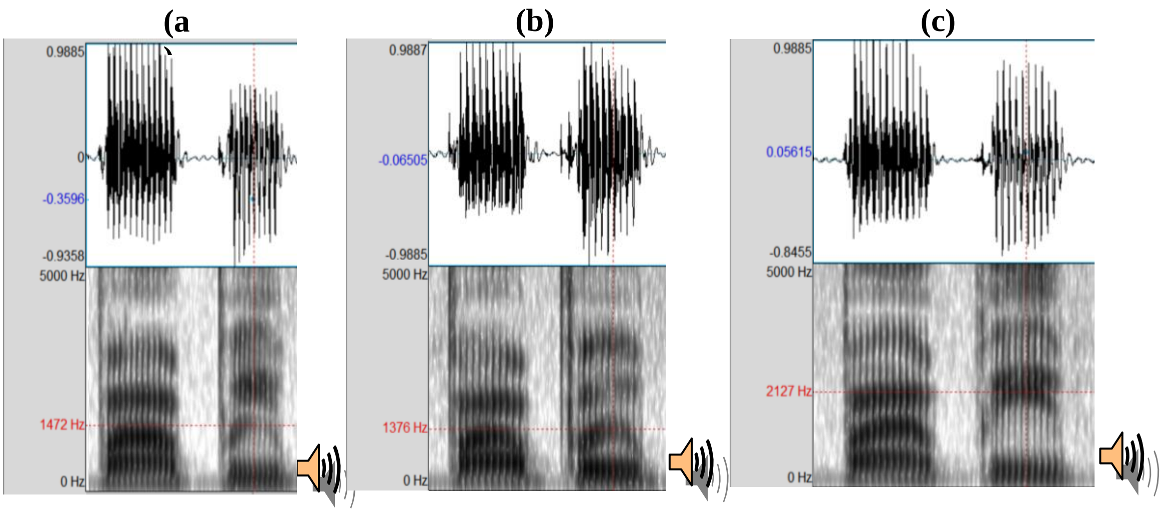


Figure 9. Variability in the F2 value of [i] in three repetitions of /ˈpapi/ produced by a male speaker (PTA: 103.3 dB, intelligibility score: 75%). In repetition (a) /i/ is produced as [ɨ], in repetition (b) /i/ is pronounced a bit higher than [ə] and, finally, in repetition (c) F2 of [i] appears to be within the normal range.

3.1.2 Consonant Errors

The most frequent consonant errors in the data involved omissions, substitutions and misarticulations. Misarticulation of consonants included distortions, incomplete stop closures, palatalizations, fronting and stopping.

Consonant Omission

This phenomenon most commonly involved omitting the word-final consonant, which for Greek is /s/ or /n/. The first example below demonstrates a final-/s/omission and the second example a final-/n/ omission by a highly and a moderately intelligible male speaker correspondingly. The highlighted sections show where the final consonants should be.

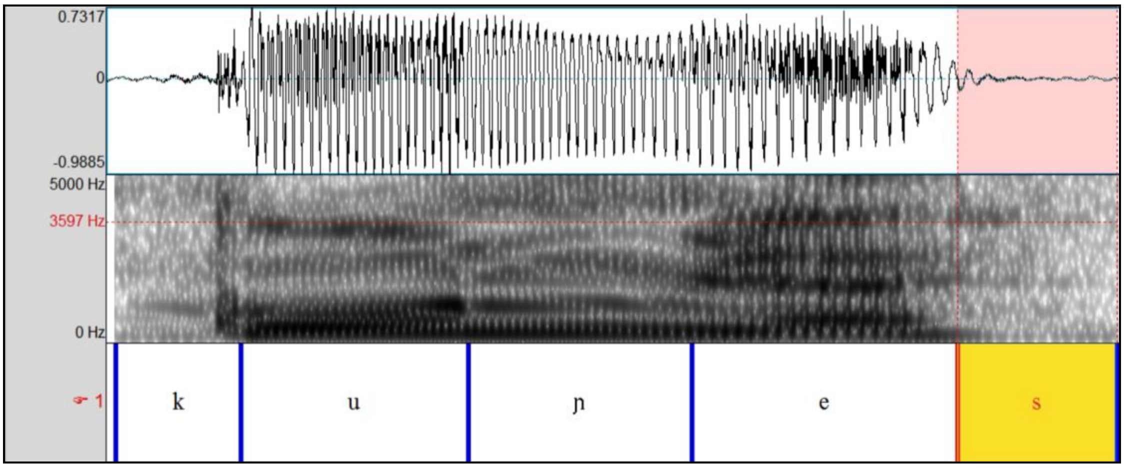


Figure 10. [ˈkunʲe̥] for /ˈkuɲes/ (swings): omission of final /s/ by male speaker (PTA: 99 dB, intelligibility score: 89%)

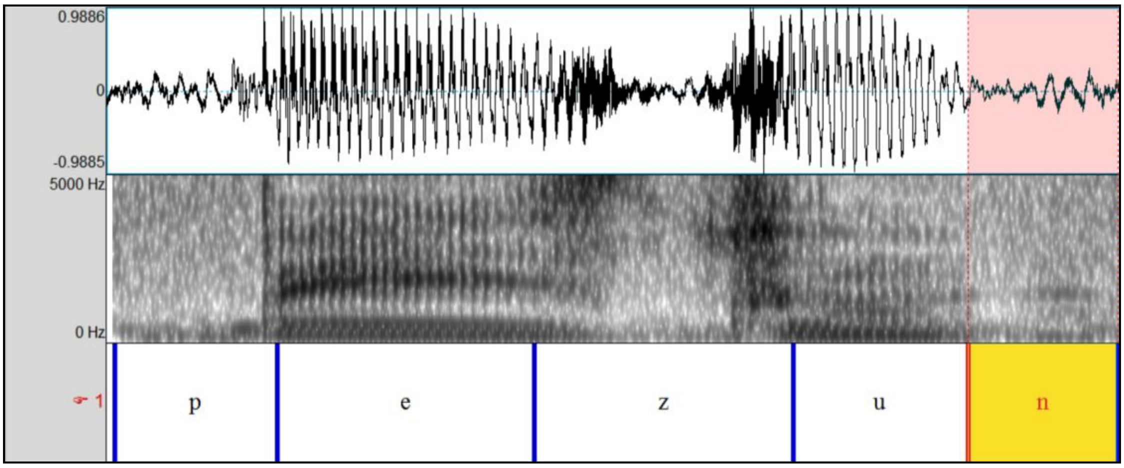


Figure 11. [ˈpezu] for /ˈpezun/ (they play): omission of final /n/ by male speaker (PTA: 101 dB, intelligibility score: 73%)

Consonant Substitution

A consonant was sometimes substituted for another, especially if it was challenging in terms of articulation such as the sibilant /s/. In the following Figure, word-final /s/ is substituted for the velar nasal [ŋ] by a highly intelligible female speaker.

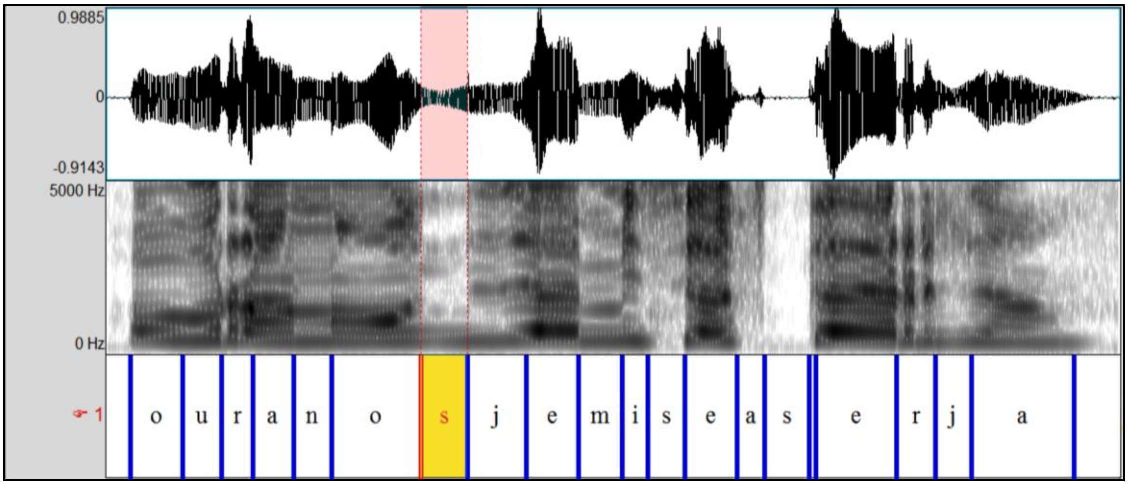


Figure 12. [urɒˈnoŋ] for /urɒˈnos/ (sky): substitution of final /s/ by female speaker (PTA: 103.3 dB, intelligibility score: 90%)

Consonant Misarticulation

As mentioned above (see Section 1.Introduction), consonants that are more visible are usually produced more easily as the speaker with HI can rely on visual feedback for input. Consonants articulated with the tongue and produced further back in the mouth, such as lingua-dentals, lingua-alveolars, lingua-palatals and lingua-velars, are harder to master (Nober 1967). Our data are in agreement with the above, as lingual consonants and especially /s/ were often misarticulated.

Regarding /s/, this fricative was very often produced with more palatalization than normal even by speakers who were over 90% intelligible. In Figure 13, /s/ in /ˈpisi/ produced by a very highly intelligible female speaker, is more palatalized than normal and its energy reaches lower than normal to about 2500 Hz. The same disyllable is also available in audio by two more speakers (audio files: 13_audio_pisi_02_HI_03.wav and 13_audio_pisi_07_HI_06.wav). Figure 14 shows another example of /s/ palatalization in the disyllable /pɐˈsɐ/ by a very highly intelligible speaker, with the energy of the fricative again reaching lower than normal to about 2900 Hz. In this case there is greater constriction in the middle of the fricative (vertical solid arrow) and an offglide is formed at the onset of the second vowel (horizontal dotted arrow). More examples of /s/ palatalization in the disyllable /pɐˈsɐ/ are provided in audio by three more speakers (audio files: 14_audio_pa_sa_06_HI_06.wav, 14_audio_pa_sa_02_HI_08.wav and 14_audio_pa_sa_03_HI_09.wav).

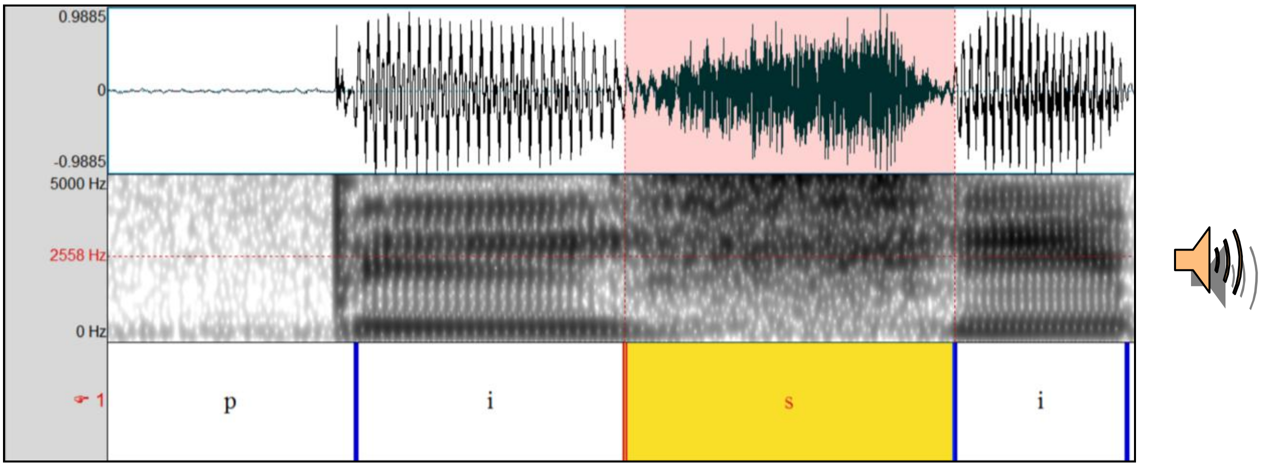


Figure 13. /ˈpisi/: palatalization of /s/ by female speaker (PTA: 101.6 dB, intelligibility score: 98%).

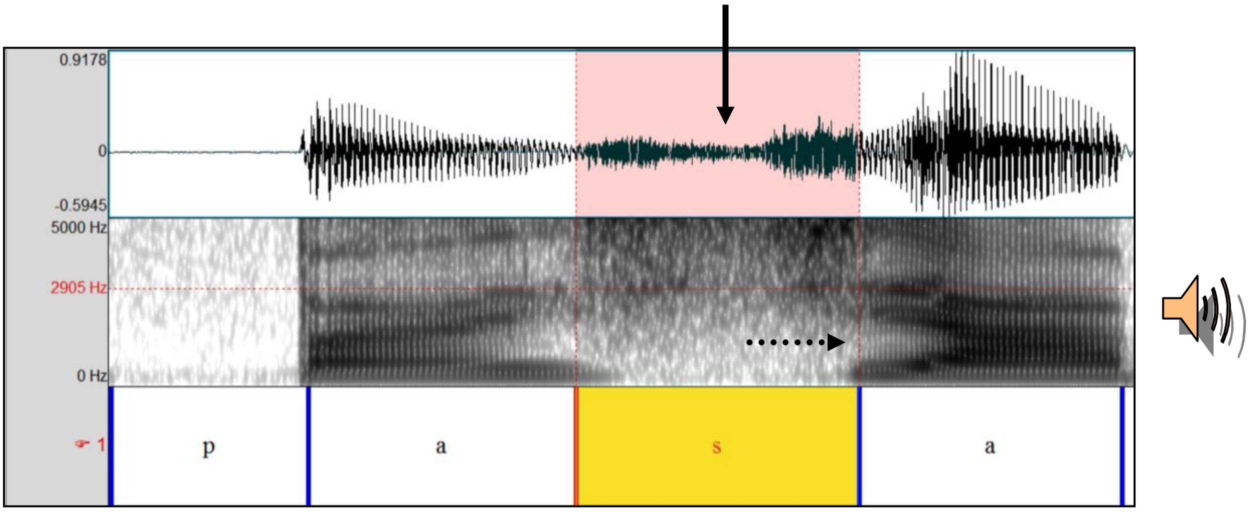


Figure 14. /pɒˈsɒ/ (pasha): palatalization of /s/ by female speaker (PTA: 101.7 dB, intelligibility score: 96%)

More examples of /s/ misarticulation are provided below. Figure 15 illustrates a /s/ produced with a lateral escape of air, while Figure 16 shows a final /s/ which is misarticulated and produced with less friction.

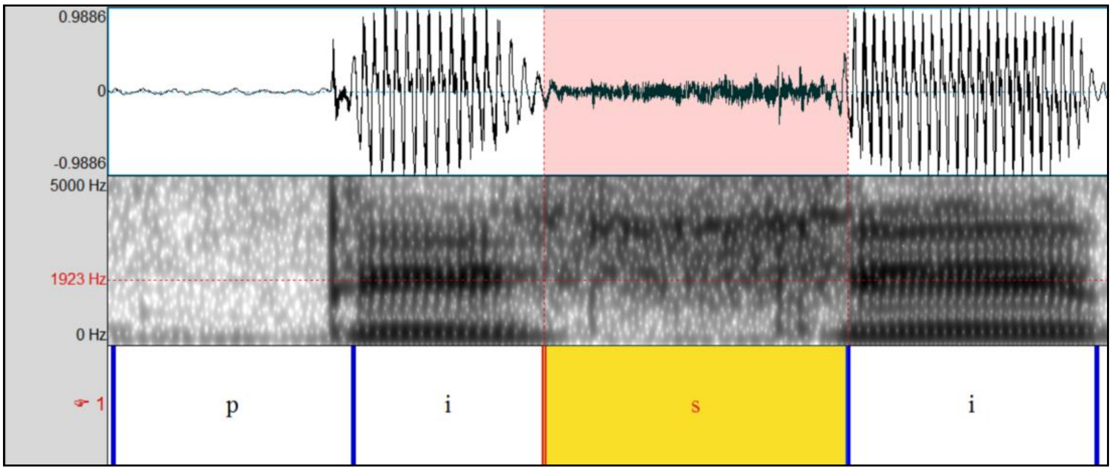


Figure 15. /piˈsi/: misarticulation of /s/ by male speaker (PTA: 101 dB, intelligibility score: 73%)

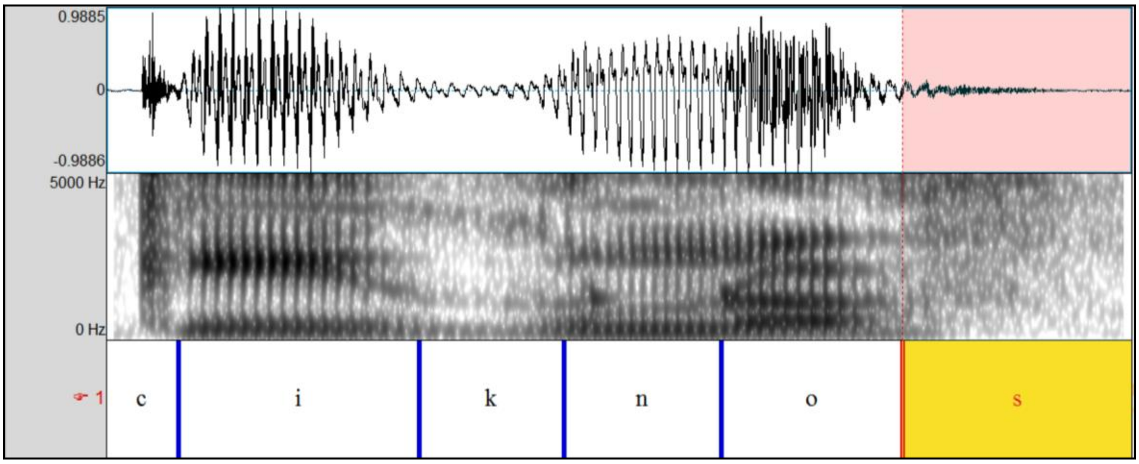


Figure 16. /ˈciknos/ (swan): misarticulation of /s/ by male speaker (PTA: 103.3 dB, intelligibility score: 75%)

Another lingual consonant which was often misarticulated was the dento-alveolar /t/. In Figure 17, the production of target /t/ in /ˈpiti/ is distorted in terms of placement, and it is also articulated with increased acoustic energy during the closure interval, suggesting possible escape of air, by a highly intelligible male speaker. In Figure 18, /t/ in the word /miˈterɐ/ (mother) is articulated either as a dental click or as an ejective by a highly intelligible male speaker.

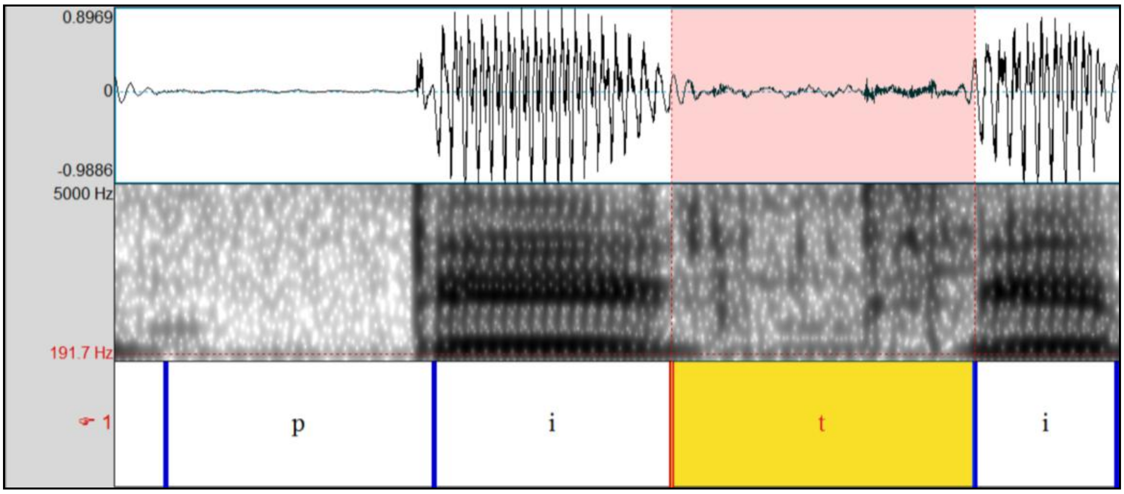


Figure 17. /ˈpiti/: misarticulation of /t/ by male speaker (PTA: 99 dB, intelligibility score: 89%)

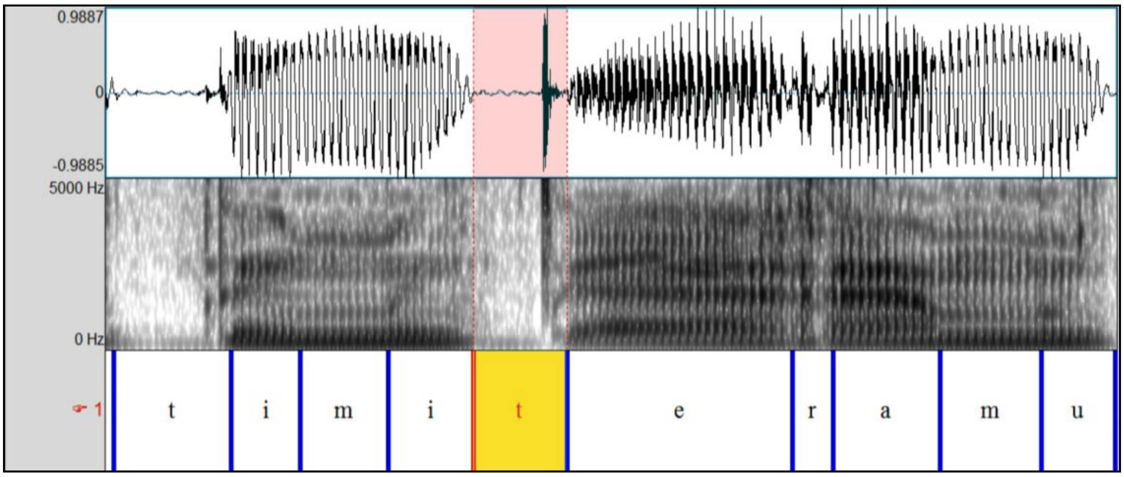


Figure 18. /ti miˈterɒ mu/ (my mother-acc.): misarticulation of /t/ (highlighted) by male speaker (PTA: 98.3 dB, intelligibility score: 92%)

Among the consonants that were often misarticulated are /r/, [ç], /g/ and /θ/. Audio files with examples are available. The rhotic /r/, which is typically realized as an alveolar tap in Greek (Baltazani & Nicolaidis 2012), was misarticulated as a uvular trill in the word /moˈɾo/ (baby) by a highly intelligible male speaker (audio file: 18_audio_009_word_HI_07_intel test.wav). The palatal fricative [ç] in the word /ˈtreçi/ (run -3rd sing.) was realized as a [s] by a highly intelligible female speaker (audio file: 18_audio_003_word_HI_06_intel test.wav). The velar plosive /g/ in the word /feˈgɐɾi/ (moon) was articulated as its homorganic fricative [ɣ] by a very highly intelligible female speaker (audio file: 18_audio_074_word_HI_02_intel test.wav). The dental fricative /θ/ was produced as the dento-alveolar stop [t] in the word /tsuˈliθrɐ/ (slide-noun) by a highly intelligible male speaker (audio file: 18_audio_001_word_HI_08_intel test.wav).

Finally, the affricate /dz/ seemed to be articulatorily demanding and was often misarticulated word-initially and word-medially. In Figure 19, /dz/ in the word /ˈdzɐmi/ (window glass) is produced as [s] by a moderately intelligible male speaker. It is interesting that, although this speaker usually produces /s/ as [ʃ], in this case he seemed to be able to make the appropriate constriction for a /s/. In Figure 20, /dz/ in the word /fliˈdzɐni/ (cup) is realized as [ɟ] by a highly intelligible male speaker.

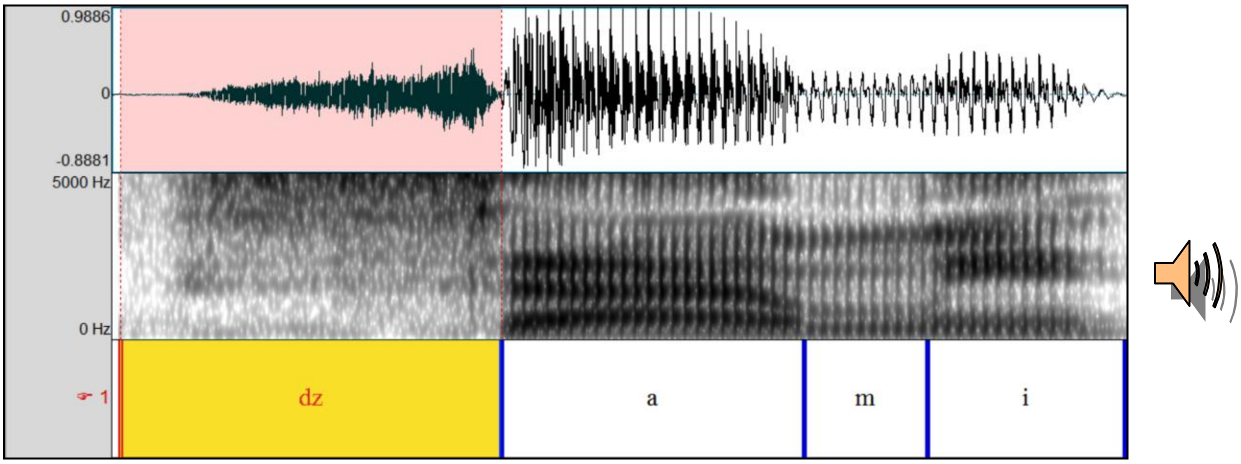


Figure 19. [s] for /dz/ in /ˈdzɒmi/ (window glass) by male speaker (PTA: 103.3 dB, intelligibility score: 75%)

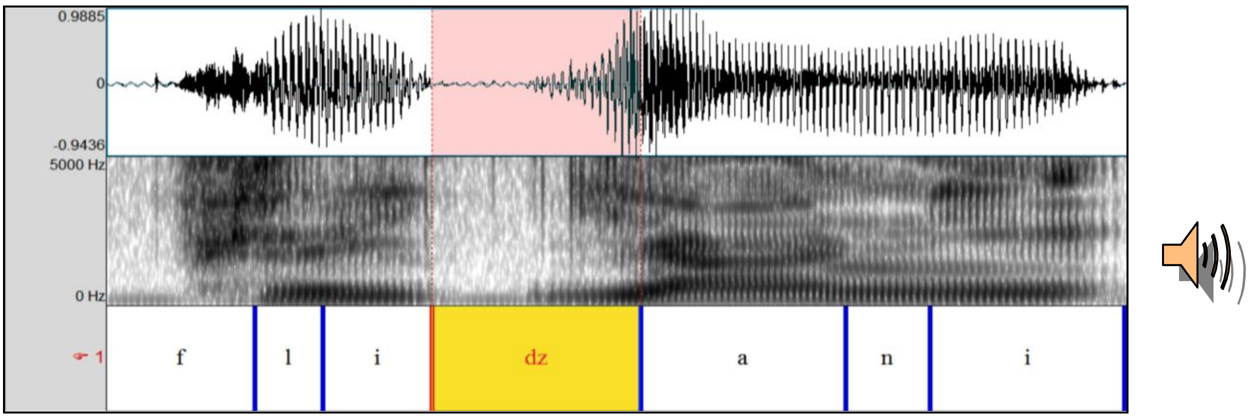


Figure 20. [ɟ] for /dz/ in /fliˈdzɒni/ (cup) by male speaker (PTA: 98.3 dB, intelligibility score: 93%)

3.1.3 Consonant Cluster Errors

Consonant cluster reduction was observed frequently in the data. Two examples of word-medial cluster reduction are given below. In Figure 21, /str/ in the word /ˈkɐstro/ (castle) is reduced by a highly intelligible male, as the /s/ is completely omitted (CCCV to CCV syllable). Also the /r/ sounds more like the alveolar approximant [ɹ] and has a non-native quality. In Figure 22, the cluster /kl/ in the word /kɐˈɾeklɐ/ (chair) is reduced to [k] by a highly intelligible female speaker (CCV to CV syllable).

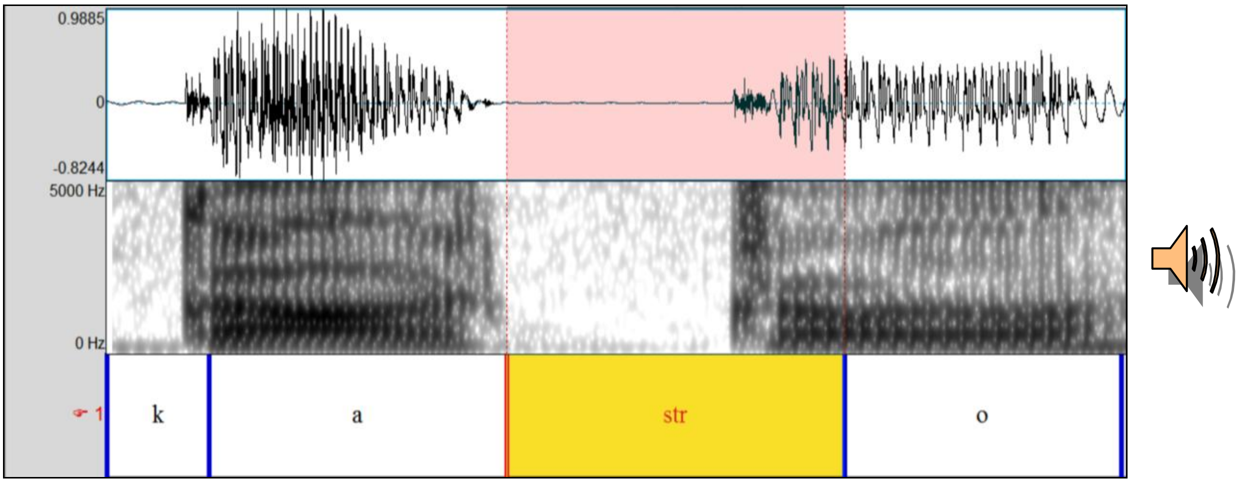


Figure 21. [tɹ] for /str/ in /ˈkɒstɾo/ (castle) by male speaker (PTA: 99 dB, intelligibility score: 89%)

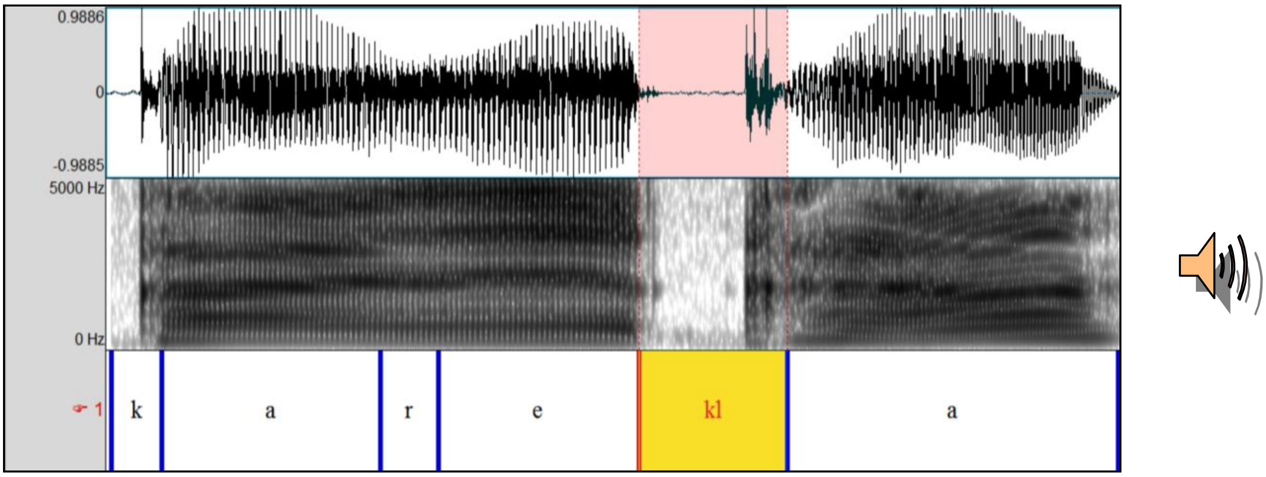


Figure 22. [k] for /kl/ in /kɒˈɾeklɒ/ (chair) by female speaker (PTA: 91.7 dB, intelligibility score: 87%)

3.2 Suprasegmental Features

The main suprasegmental issues observed in the data involved stress, intonation, rhythm, voice and resonance.

Stress

Our data showed that stressed-unstressed differentiation was different than normal for speakers with HI in terms of frequency, amplitude and duration, as also reported in the literature (Ando & Canter 1969; O'Halpin 1997; Most 1999). Firstly, lack of stress seemed to cause slightly more vowel space reduction for the HI group due to a more pronounced shift along the F1 (24.8% reduction for the NH group and 28.4% for the HI) (also Barzaghi & Mendes 2008, for Brazilian Portuguese HI speech).

Secondly, although unstressed vowels were found statistically significantly shorter than stressed vowels for both groups, this difference was more pronounced for the speakers with NH. In the literature, some studies report restricted durational shortening in HI unstressed vs. stressed syllables (Stevens et al. 1978; Osberger & Levitt 1979; McGarr & Harris 1980), while other studies document excessive duration differences due to stress in HI speech (Reilly 1979, for American English; Barzaghi & Mendes 2008, for Brazilian Portuguese). According to our data, concerning vowel [i], the durational shortening occurring due to the absence of stress was 50% for the NH while 39% for the HI. Vowel [u] was shorter by 46% for the NH whereas for the HI by 36%. Unstressed vowel [a] was shorter than its stressed counterpart by 43% for the NH and by 35% for the HI. Hence, for both groups, the pattern of vowel duration sensitivity to stress was [i] > [u] > [a], although the speakers with HI presented less vowel duration compression due to lack of stress relative to the speakers with NH. Besides duration shortening, another parameter signifying stressed-unstressed differentiation that was less pronounced for the speakers with HI was intensity reduction, that is, the difference in intensity between the stressed and the unstressed vowel of a disyllable.

For example, the disyllable /piˈtu/ produced by a moderately intelligible male speaker with HI is shown in Figure 23a and the same disyllable produced by a speaker with NH is demonstrated in Figure 23b. Regarding duration shortening, the difference in duration between the stressed /u/ and the unstressed /i/ is 12 ms for the speaker with HI (/u/ is 127 ms and /i/ is 115 ms), whereas the difference is 67 ms for the speaker with NH (/u/ is 110 ms and /i/ is 43 ms). Regarding intensity reduction, the difference in intensity between the stressed /u/ and the unstressed /i/ measured at the point of maximum intensity of the vowel is 3 dB for the speaker with HI (max. intensity for /u/ is 53 dB and for /i/ is 50 dB), whereas the difference is 6 dB for the speaker with NH (max. intensity for /u/ is 57 dB and for /i/ is 51 dB). Hence both duration and intensity differences between the stressed and the unstressed vowel of the disyllable are more pronounced for the speaker with NH.

a

b

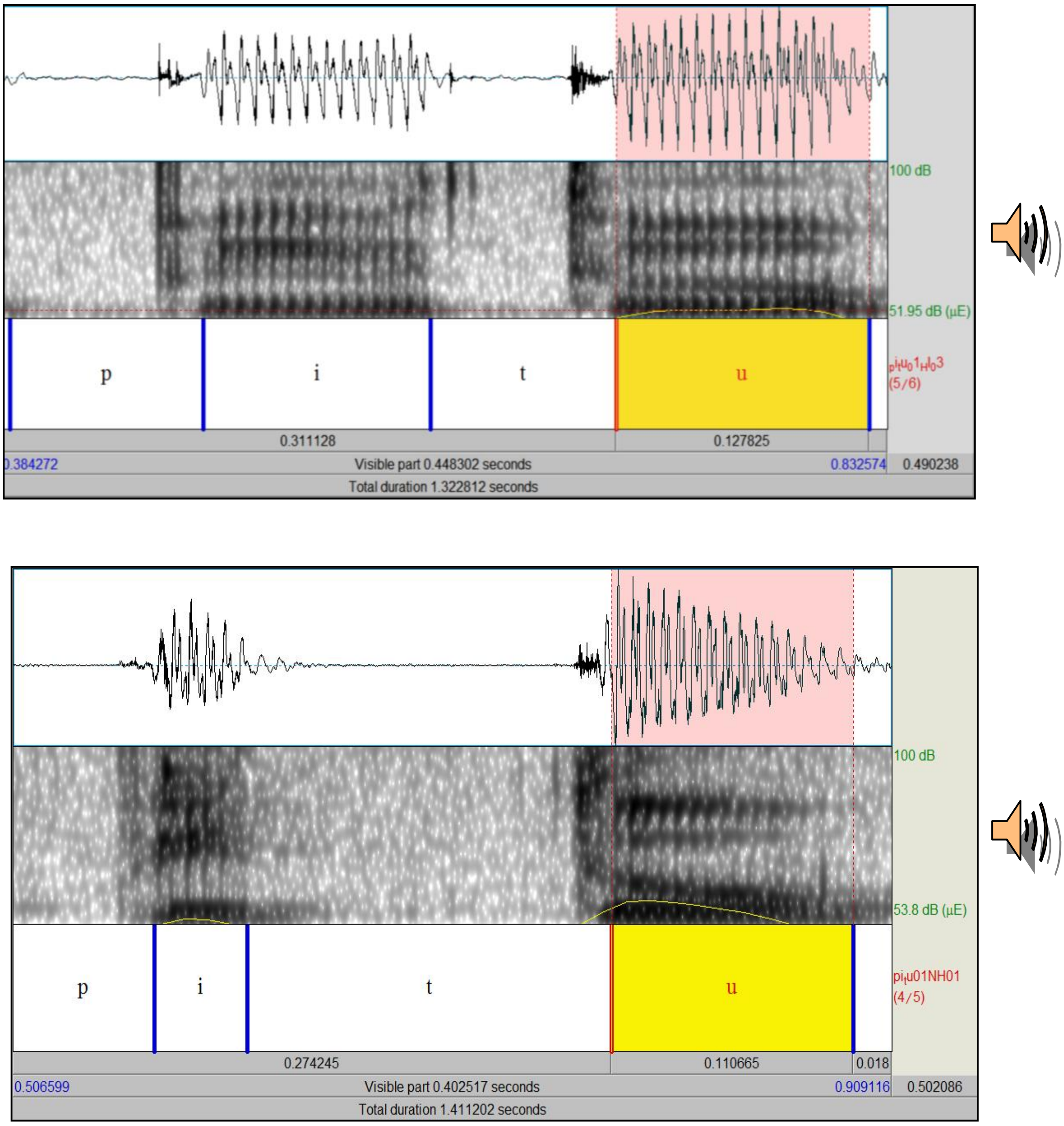


Figure 23. /piˈtu/ (a) by male speaker (PTA: 103.3 dB, intelligibility score: 75%) and (b) by male speaker with NH. The yellow line illustrates the intensity contour.

Incorrect stress placement was another issue encountered in HI speech, although this phenomenon was more frequent when intelligibility was low or moderate. Highly intelligible speakers seemed to master this feature. For example, the word /ˈespɐse/ (it broke) as produced by an unintelligible female speaker is demonstrated in Figure 24a and as produced by a very highly intelligible female speaker in Figure 24b. As stress should be on the first vowel, this vowel is expected to be longer and louder than the other two. However, for the unintelligible speaker the longest and loudest vowel is /ɐ/, therefore stress is perceived on the second rather than on the first vowel. The highly intelligible speaker, though, places stress correctly on the first vowel, which is longer and louder than the other two.

a

b

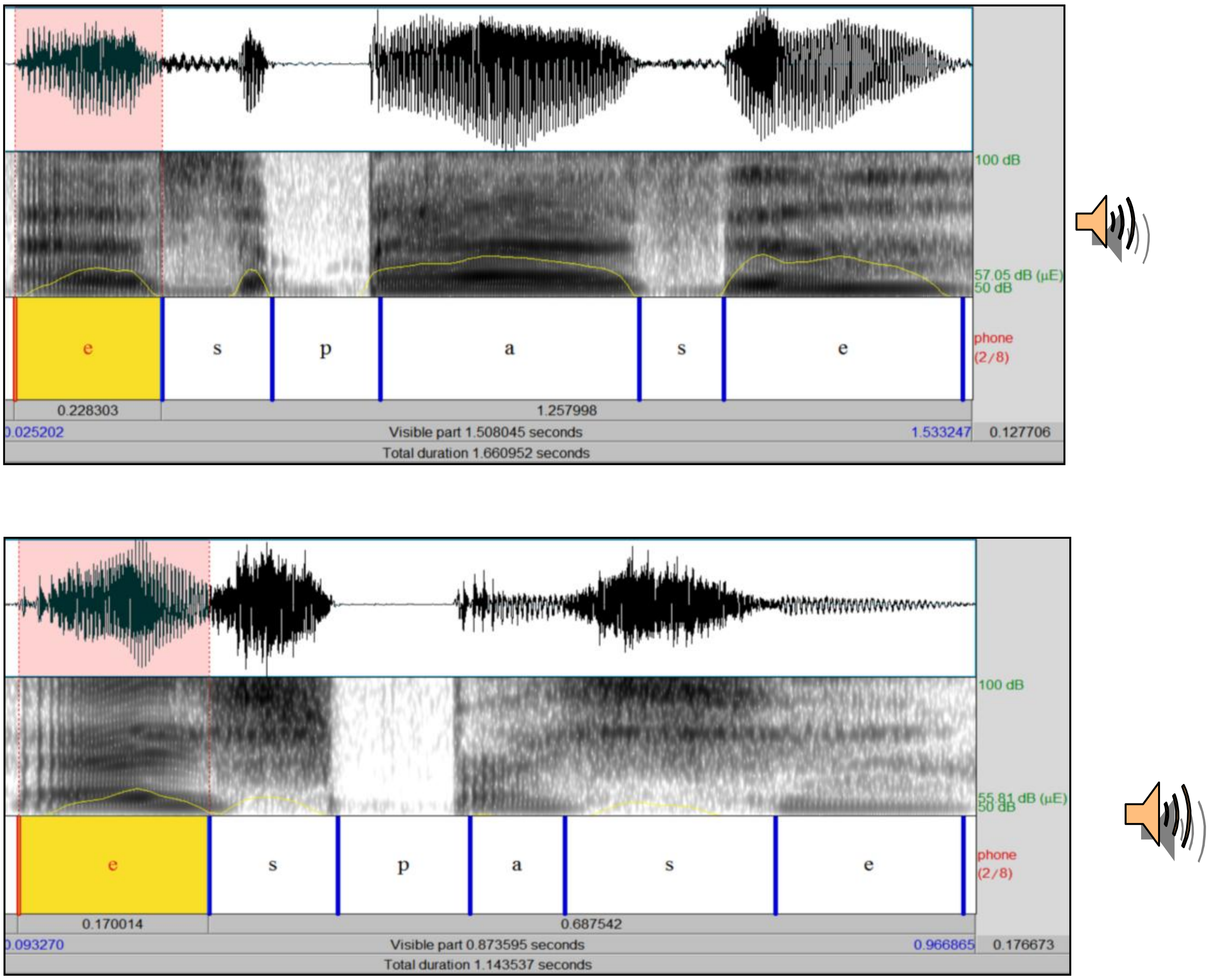


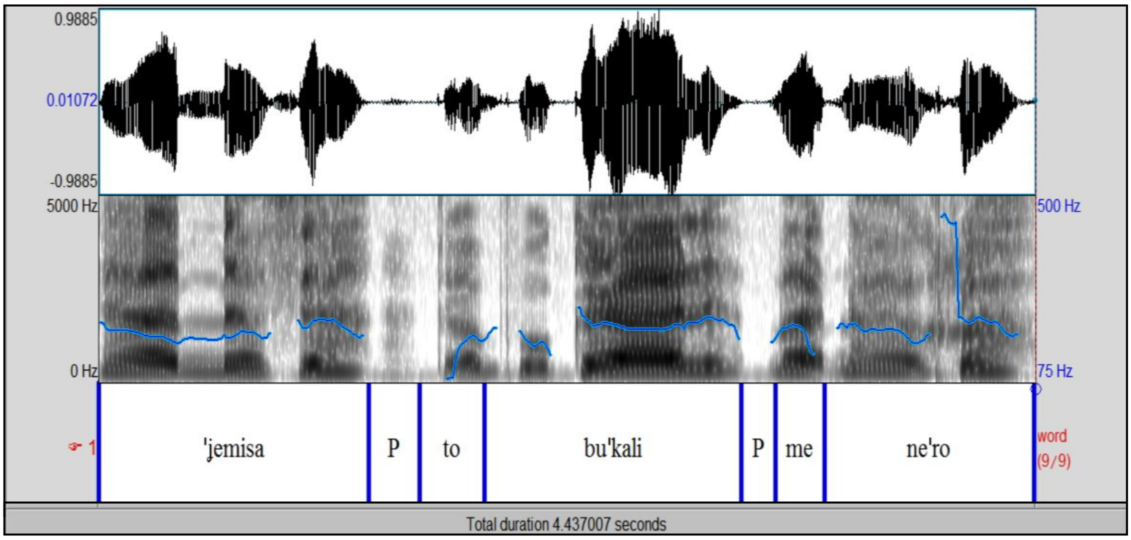
Figure 24 /ˈespɒse/ (a) by unintelligible female speaker (PTA: 105 dB, intelligibility score: 15%) and (b) by highly intelligible female speaker (PTA: 101.7 dB, intelligibility score: 96%). The yellow line illustrates the intensity contour.

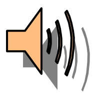
Intonation & Rhythm

Prosodic aspects of speech, such as intonation and rhythm were different than normal, especially when intelligibility was low. Highly intelligible speakers seemed to produce more natural intonation patterns.

Figure 25 below presents the intonation contour of the phrase /ˈɟemisa to buˈkɐli me neˈɾo/ (I filled up the bottle with water) as produced by an unintelligible female speaker (Figure 25a) and a highly intelligible speaker (Figure 25b). It is evident that for the unintelligible speaker the pitch range is much more restricted resulting in a monotonous intonation pattern, as reported in the literature (Angelocci et al 1964; Sussman & Hernandez 1979; Osberger & MacGarr 1982). In addition, the duration of the phrase is double for the unintelligible speaker, and within the phrase there are two pauses. Frequent or incorrect pausing was observed in our data by speakers with less than high intelligibility which, according to the literature, has been attributed to poor respiratory control affecting speech rate, stress and rhythm (Calvert 1964).

a





b

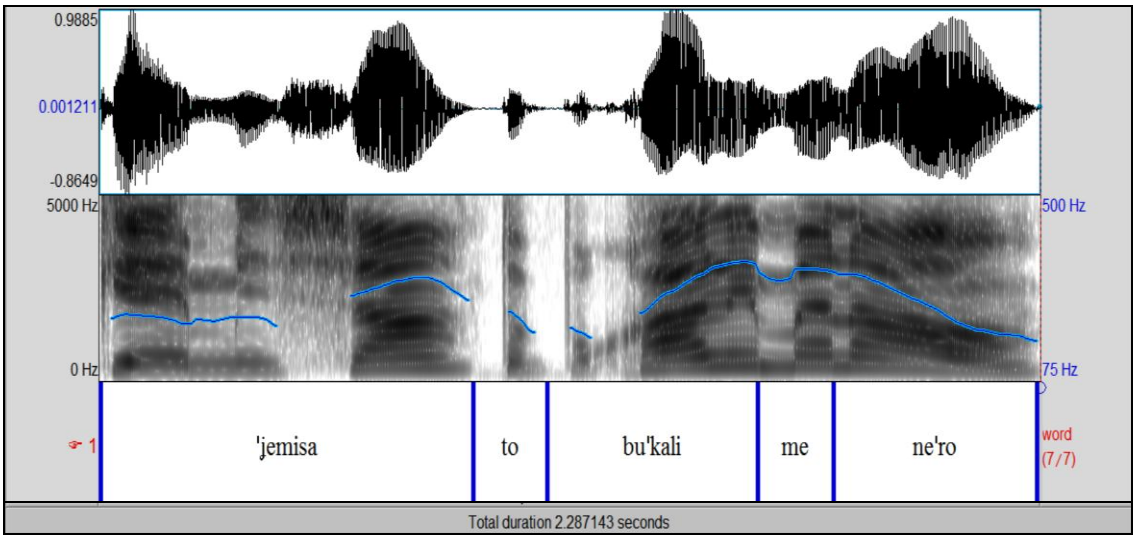


Figure 25 /ˈɣemisa to buˈkɒli me neˈɾo/ (I filled up the bottle with water) (a) by unintelligible female speaker (PTA: 105 dB, intelligibility score: 15%) and (b) by highly intelligible female speaker (PTA: 91.7 dB, intelligibility score: 87%). The blue line illustrates the pitch contour.

Voice and Resonance

Voice quality has been described as unpleasant or deviant in speakers with HI. Some main characteristics observed in our data that contributed to voice problems were *breathiness* (audio file: 26a_audio_20_phrase_HI_04_intel_test.wav) which can be caused by excessive or insufficient airflow rate during speech (McGarr & Löfqvist 1982), excessive *nasality* (audio file: 26b_audio_20_phrase_HI_03_intel_test.wav) which could be attributed to improper velopharyngeal timing (Pratt & Tye-Murray 2009), *laborious speech* or *'overfortis' voice quality* (audio file: 26c_audio_22_phrase_HI_04_intel_test.wav) due to over-expenditure of energy during speech, and *laryngealization* or *harshness* (audio file: 26d_audio_07_phrase_HI_10_intel_test.wav) because of excessive laryngeal muscle activity (Markides 1983).

Voice and resonance problems can be quite detrimental to speech intelligibility. Indeed, our data has shown that speakers with low or medium intelligibility presented more voice problems in comparison with very highly intelligible speakers who had better voice quality and showed less suprasegmental errors (audio file: 26e_audio_19_phrase_HI_01_intel test.wav).

4. Conclusions

The present study provided a categorization of segmental and suprasegmental errors in Greek HI speech, an area yet to be explored. Examples illustrated by spectrographic displays and accompanying audio files, which can be useful to clinicians, teachers and researchers, were provided. Our acoustic analysis showed that decision-making on formant location is highly problematic when analyzing HI speech, as both automatic and manual measurements are often inaccurate or in error due to excessive variability in production and other problems, such as nasal formants, laryngealization, etc. (Sfakianaki, 2012b). Qualitative analysis can contribute to the clarification of segmentation and formant measurement issues and to a more comprehensive interpretation of acoustic characteristics in HI speech.

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