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Positional Variations of Ukrainian Back Vowel Formants

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Abstract

The purpose of this paper is to study variations in the location of formants of Ukrainian back vowels caused by different phonetic features. To do so, the oscillograms and two-dimensional spectrograms of recorded sounds in speech flow were analyzed. The corresponding invariant acoustic parameters being the ratios between frequencies of the formants rising due to the tube resonance are determined. It is shown that different phonetic environments cause different formant configurations in vowels which is a case of sound assimilation. The following phonetic features were found to give rise to variations of Ukrainian back vowels: coda, distant assimilation by the next or preceding vowel, and progressive assimilation by the preceding hard or palatalized consonant. In particular, high vowels make the other vowels in the phonetic word move higher, and the front ones make the back ones move forward. Such formant shifts are more pronounced in unstressed positions and especially in a coda.

Keywords: Ukrainian back vowels, formant frequency ratio, invariant acoustic parameters, formant shift, sound assimilation

1. Introduction

Recently, interest in the Ukrainian language has been growing. This is due primarily to the important place that Ukraine currently occupies in the world as a result of Russian aggression, as well as Ukraine's close European prospects and, accordingly, the new future role of the Ukrainian language as a language of the European Union. All of this fully applies to the data from experimental phonetic studies of the Ukrainian language, which are necessary not only for purely phonetic studies but also for various natural language processing applications (Vakulenko, 2018; Vakulenko, 2023).

However, the Ukrainian phonetic data is far from being sufficient. The major experimental material on Ukrainian phonetics and orthoepy was collected decades ago (Bilodid, 1969; Tocjka 1981) and, apparently, appears to have been derived from a single informant for vowels and one for consonants. The next investigations (Vakulenko, 2011; Pompino-Marschall et al., 2017; Vakulenko, 2018) added some lacking data but did not resolve the problem completely.

So, we present in this paper some contemporary acoustic experimental data on assimilation effects on formant locations in the Ukrainian back vowels /α o u/. The research objective of this study is to clarify the formant shifts in the Ukrainian back vowels resulting from diverse phonetic environments and to collect supplementary experimental data to enhance vowel classification.

2. Method and Material

Even in pre-war times, the state of Ukrainian science, especially phonetics, caused considerable concern (see Vakulenko, 2018). Open Russian aggression practically made it impossible to carry out properly organized phonetic research. However, there is still room to conduct such research (though in a restricted mode), and some significant data can still be obtained. In particular, it was decided to use a smartphone to record phonetic material in place, i. e. in the place of the speaker's location.

The **informants** consisted of three male native Ukrainian speakers who spoke the basic (South-Eastern) Ukrainian dialect. The recording **device** was the Microphone for Xiaomi Redmi Note 10. The proposed **stimuli** comprised of the isolated sounds and distinct words. The isolated sounds were asked to be pronounced in the normal tone, in a whisper, and in ascending and descending tone. The individual word examples comprising diverse combinations of these were derived from the monograph (Bilodid, 1969) and augmented with additional author lexical units. For the wave **analysis**, we used SoundForge 4.0. The two-dimensional spectrograms were used to determine the formant frequencies, and the oscillograms were used for data segmentation and control of calculations of frequencies.

3. Results

/a/

The formant frequencies for a stressed Ukrainian phoneme /a/ are:

F1 = 670 Hz ("ğja") – 833 Hz (isolated), F2 = 994 Hz ("vsjake") – 1353 Hz ("tacja").

The formant frequencies for an unstressed /a/ are:

F1 = 520 Hz ("rjabá") – 819 Hz ("malá"), F2 = 994 Hz ("paljú") – 2054 Hz ("rjabí").

The formant ratio r_{21} = F2/F1 ranges from 1.34 to 1.82 for stressed allophones and from 1.34 to 3.69 for unstressed ones. The isolated /a/ has the value of r_{21} = 1.34: sound [α].

The Ukrainian texts are transliterated here according to system A of the national transliteration standard (DSTU, 2022), see also (Vakulenko, 2023).

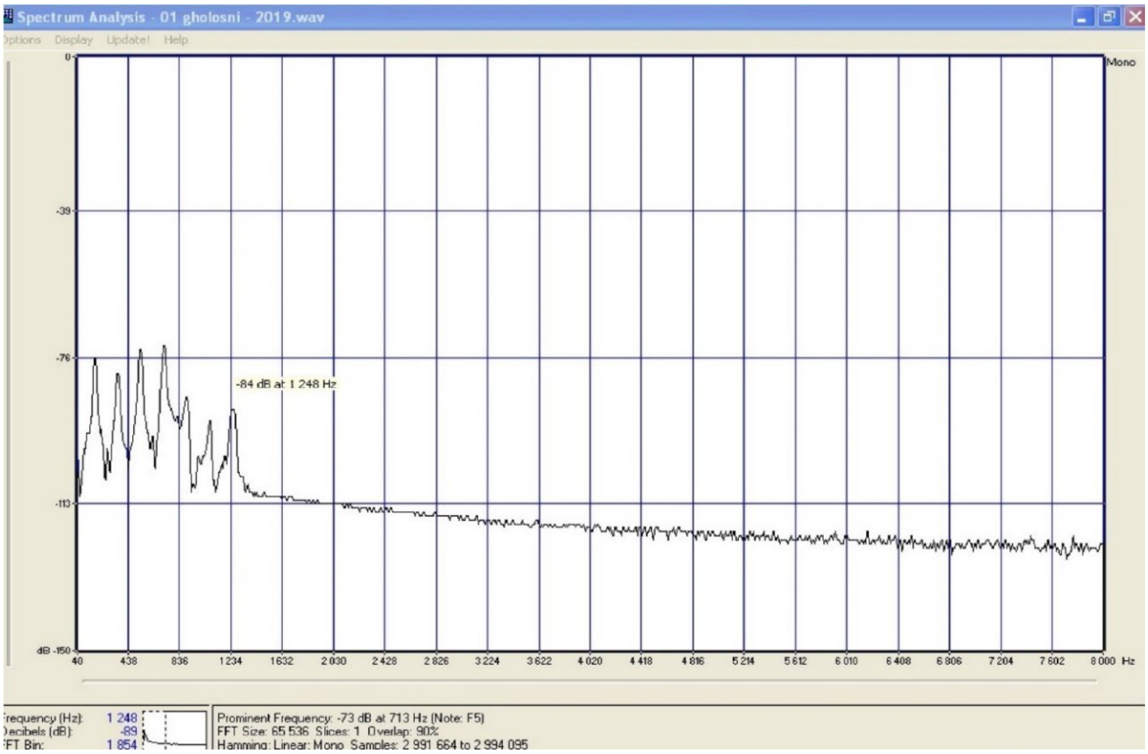
After a [j] and soft consonants, as well as in an unstressed position, the more central and elevated allophones appear.

There rises a nonlinearity in the position after a [ṯ]: the harmonics are not multiples of the fundamental frequency even in the stressed position.

The unstressed /a/ has the ability to acquire the properties of the preceding consonant, having a small amplitude of the fundamental frequency after the voiceless consonants and an additional Helmholtz formant (as in "sami", "xalva", etc.). The amplitude of this formant is smaller than the amplitude of the corresponding overtone of the harmonic signal corresponding to the configuration of a voiceless consonant. This is probably the effect of the progressive assimilation by the preceding consonant.

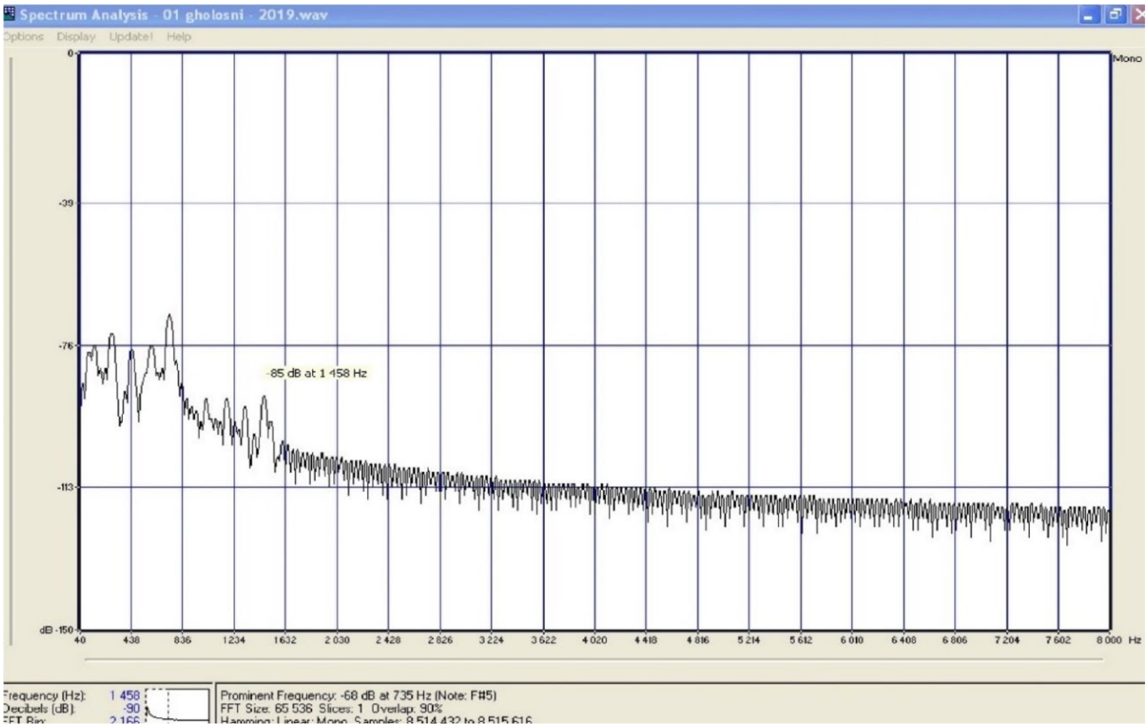
After consonants, when the Helmholtz formant is prominent, the second formant of an /a/ is replaced by a formant that is a multiple of the Helmholtz formant.

Figure 1. A 2d spectrogram of a final unstressed /a/ in "xata"



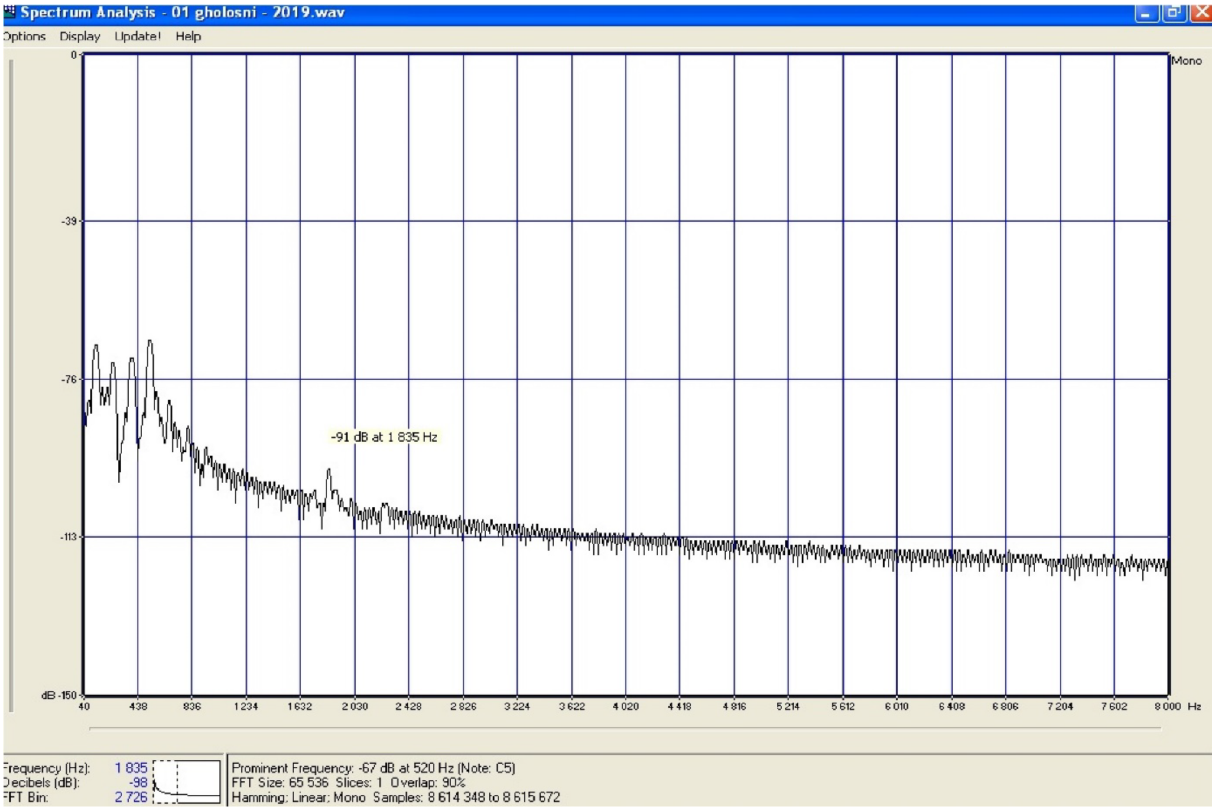
F1 = 4F0 = 713 Hz, F2 = 7F0 = 1248 Hz; r_{21} = F2/F1 = 1.75: sound [ɐ]. The probable cause is the coda.

Figure 2. A 2d spectrogram of an unstressed /a/ in "davy"



F1 = 301 Hz, F2 = 609 Hz, F3 = 1519 Hz; r_{32} = F3/F2 = 2.49; r_{31} = F3/F1 = 5.05; r_{21} = F2/F1 = 2.02: sound [ɘ]. The probable cause is the distant assimilation by the next vowel.

Figure 3. A 2d spectrogram of an unstressed /a/ after a [rʲ] in “rjaba”



F1 = 520 Hz, F2 = 1835 Hz; r_{21} = F2/F1 = 3.53: sound [ə]. The probable cause is progressive assimilation by the preceding consonant.

/o/

The formant frequencies for a stressed /o/ are:

F1 = 241 Hz (“vikno”) – 504 (“oko”), F2 = 477 Hz (“djoğotj”) – 906 Hz (“dolju”).

The formant frequencies for an unstressed /o/ are:

F1 = 289 Hz (“kožux”) – 527 Hz (“otara”, “ğolubka”), F2 = 512 Hz (“ne tobi”) – 1082 Hz (“otoka”).

The formant ratio r_{21} ranges from 1.33 to 3.00 for stressed allophones and from 1.34 to 3.13 for unstressed. The isolated /o/ has the value of r_{21} = 1.50: sound [o].

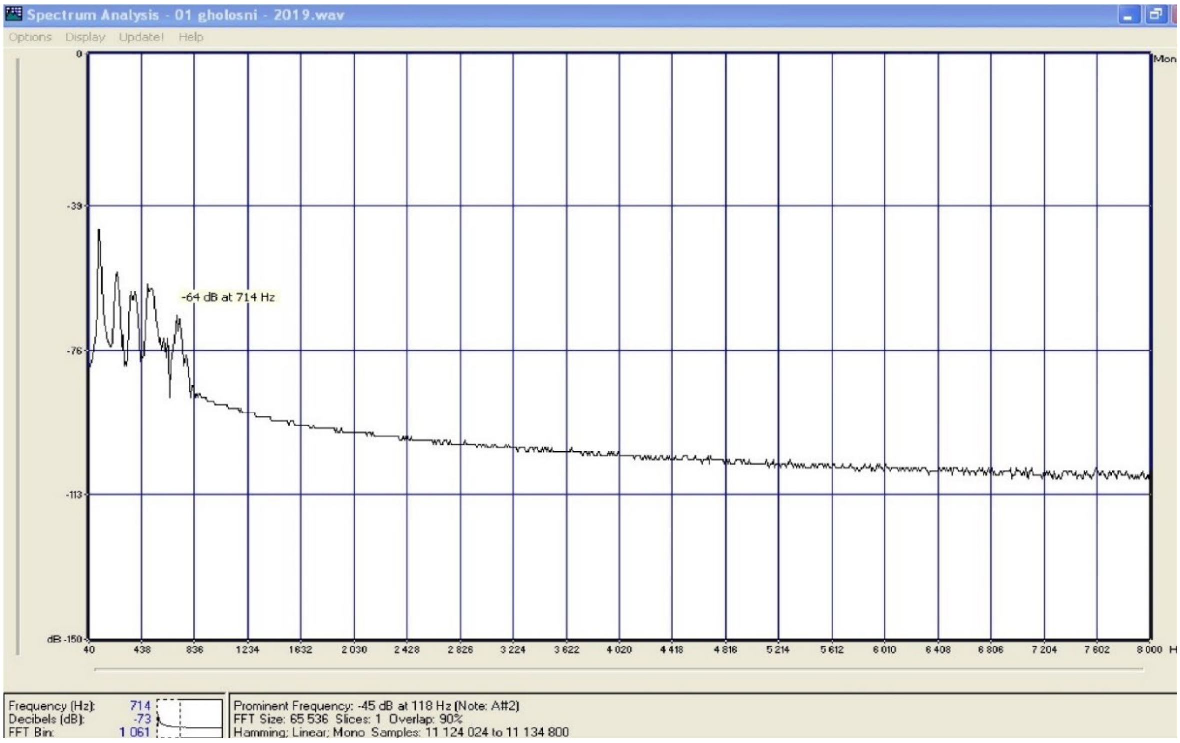
The stressed /o/ in the words “pole”, “volja”, “kolo”, “kola”, “vikno”, and “sjoğodni” is close to an [ʊ], whereas in the word “mova” it is realized as an [o].

The vowel assimilation effect is displayed in the pronunciation of “ne tobi”, “ta xodim”, and in some realizations of “kožux”, where the F1 decreases resulting in upward movement of the corresponding allophone. At the same time, the F1 does not noticeably decrease in “zozulja”, “ğolubka”, and in “na sobi”. Similarly, after a [j] and palatalized consonants, there appear allophones close to an [ʊ].

The unstressed allophones of an /o/ are not only more advanced but also lower than the stressed ones that supports the conclusion of (Vakulenko, 2018) about midheight character of this phoneme.

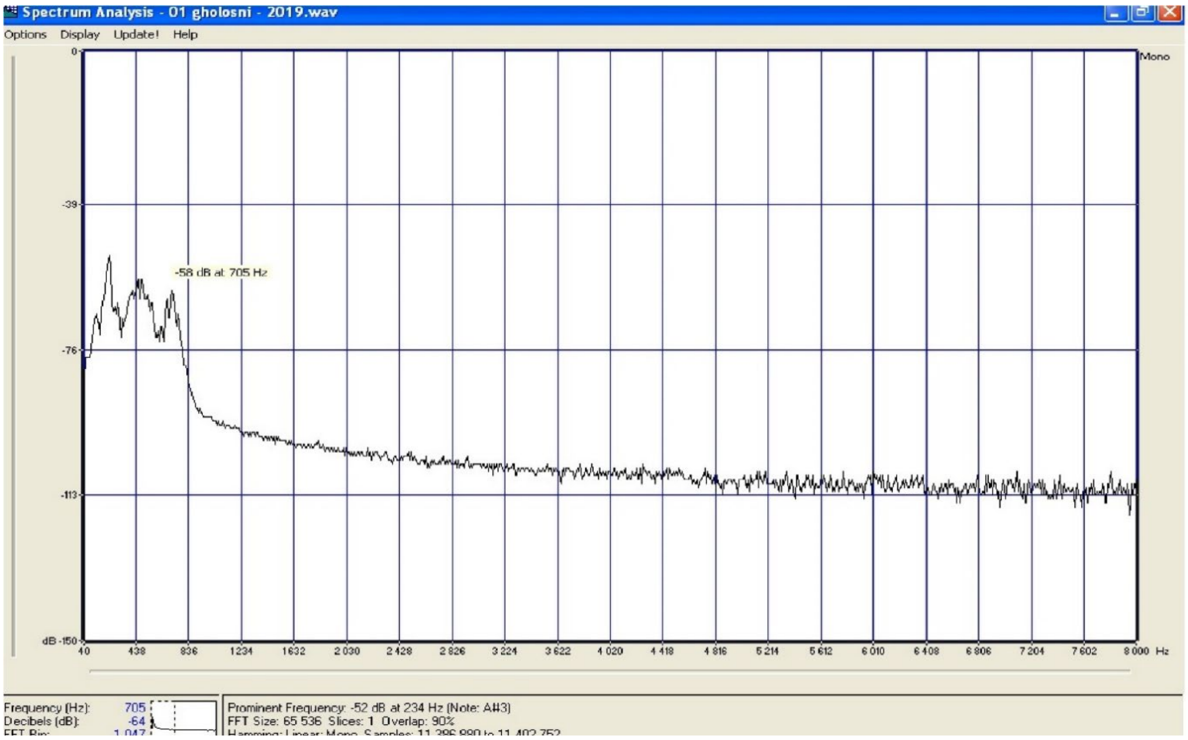
In the word “koxaty” and in some other words, the unstressed /o/ approaches an [ʊ] that may result from coarticulation with the preceding consonant.

Figure 4. A 2d spectrogram of an isolated /o/



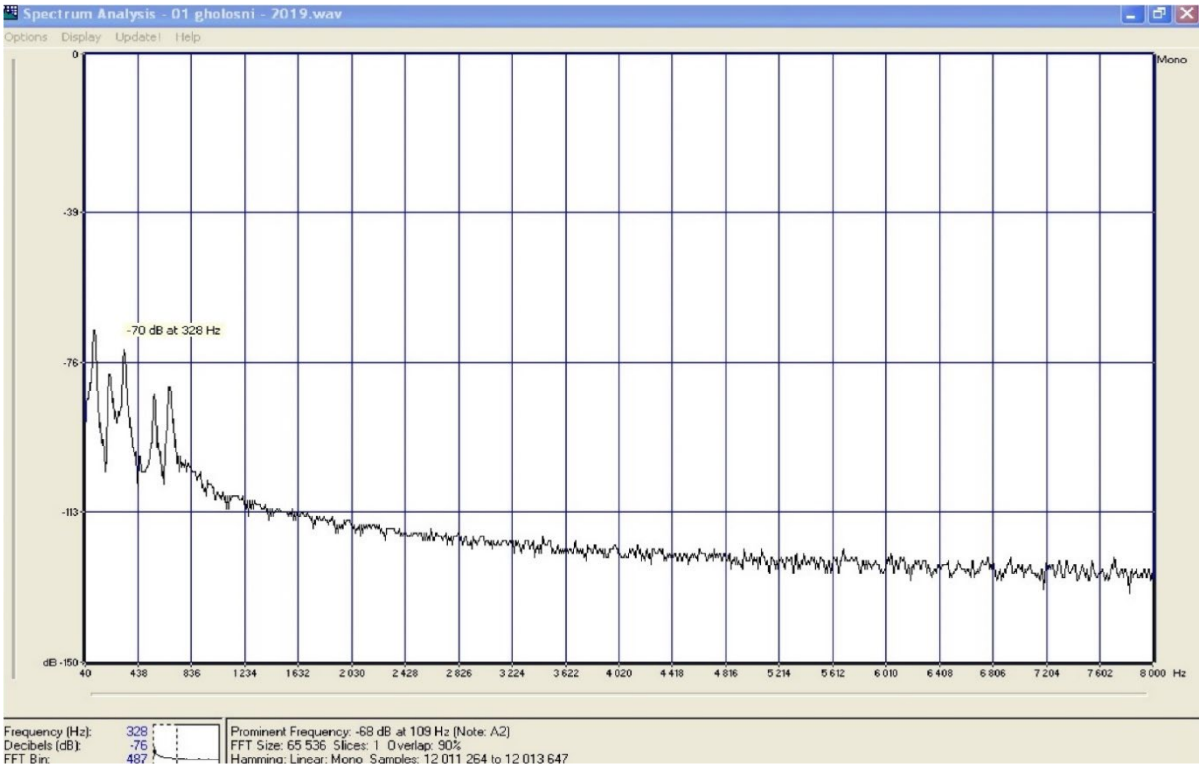
F1 = 499 Hz, F2 = 710 Hz; r_{21} = F2/F1 = 1.42: sound [o].

Figure 5. A 2d spectrogram of a rising-tone /o/



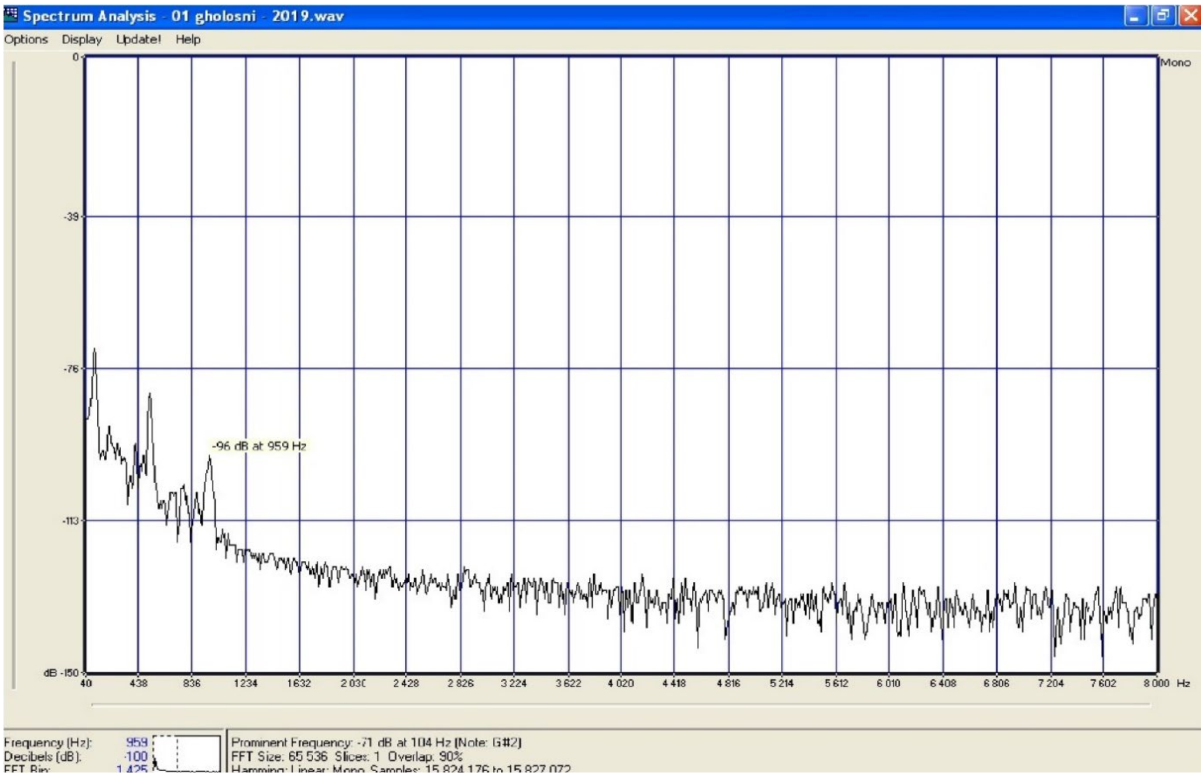
F1 = 469 Hz, F2 = 705 Hz; r_{21} = F2/F1 = 1.50: sound [o].

Figure 6. A 2d spectrogram of a stressed /o/ in "vikno"



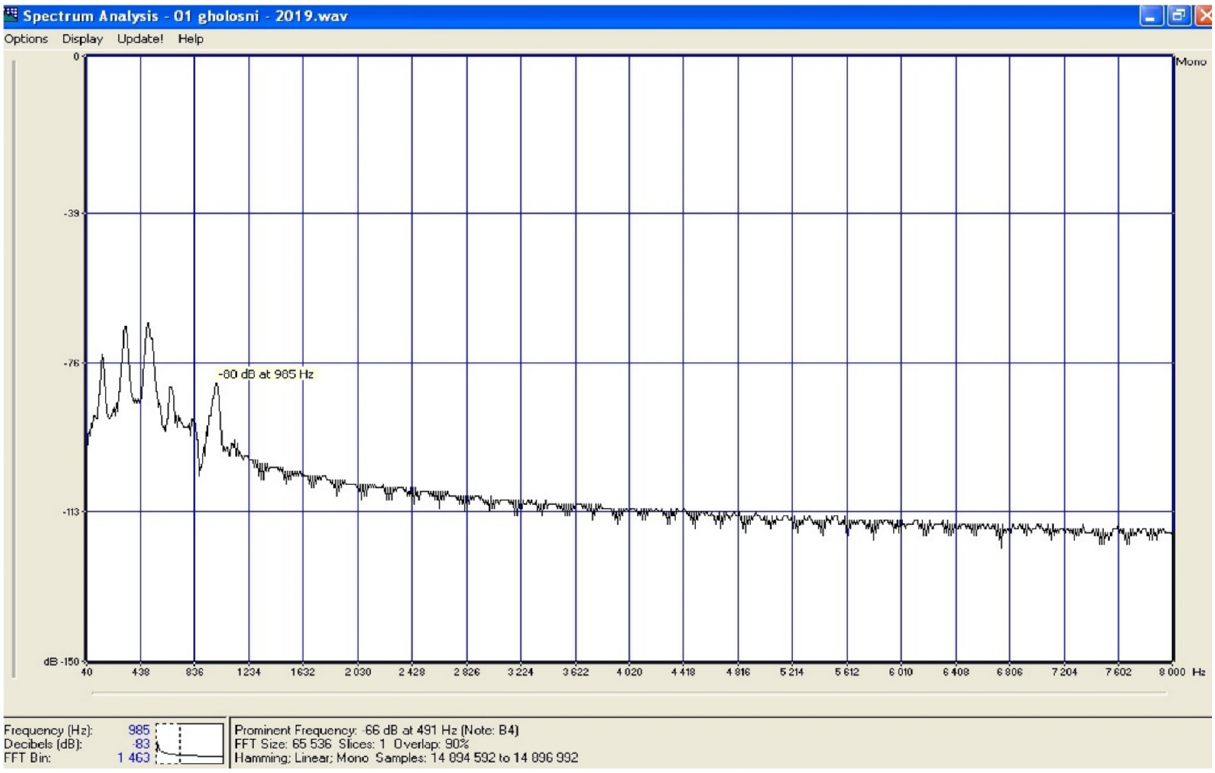
F1 = 3F0 = 328 Hz, F2 = 6F0 = 661 Hz; r_{21} = F2/F1 = 2.02: sound [ʊ]. The probable causes are distant assimilation by the preceding vowel and coda.

Figure 7. A 2d spectrogram of an unstressed /o/ in "djoğotj"



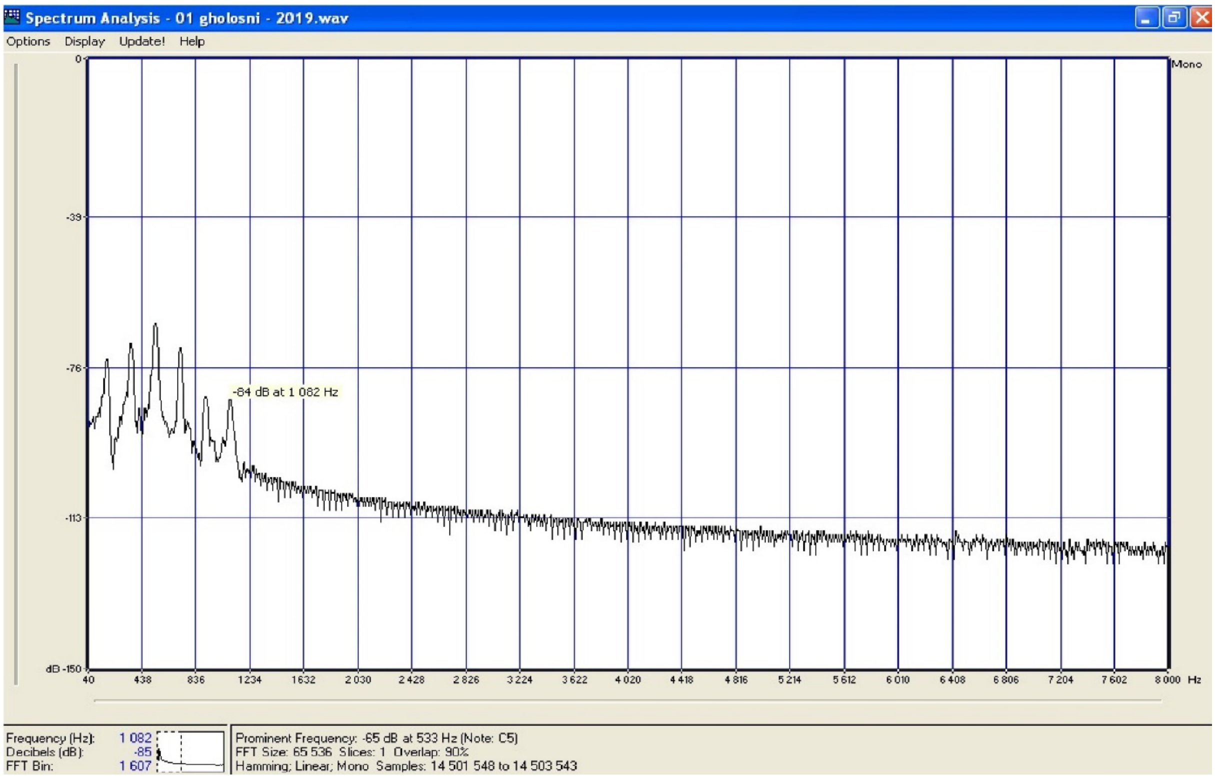
F1 = 5F0 = 521 Hz, F2 = 9F0 = 959 Hz; r_{21} = F2/F1 = 1.84: sound [o+].

Figure 8. A 2d spectrogram of an unstressed /o/ in "kožux"



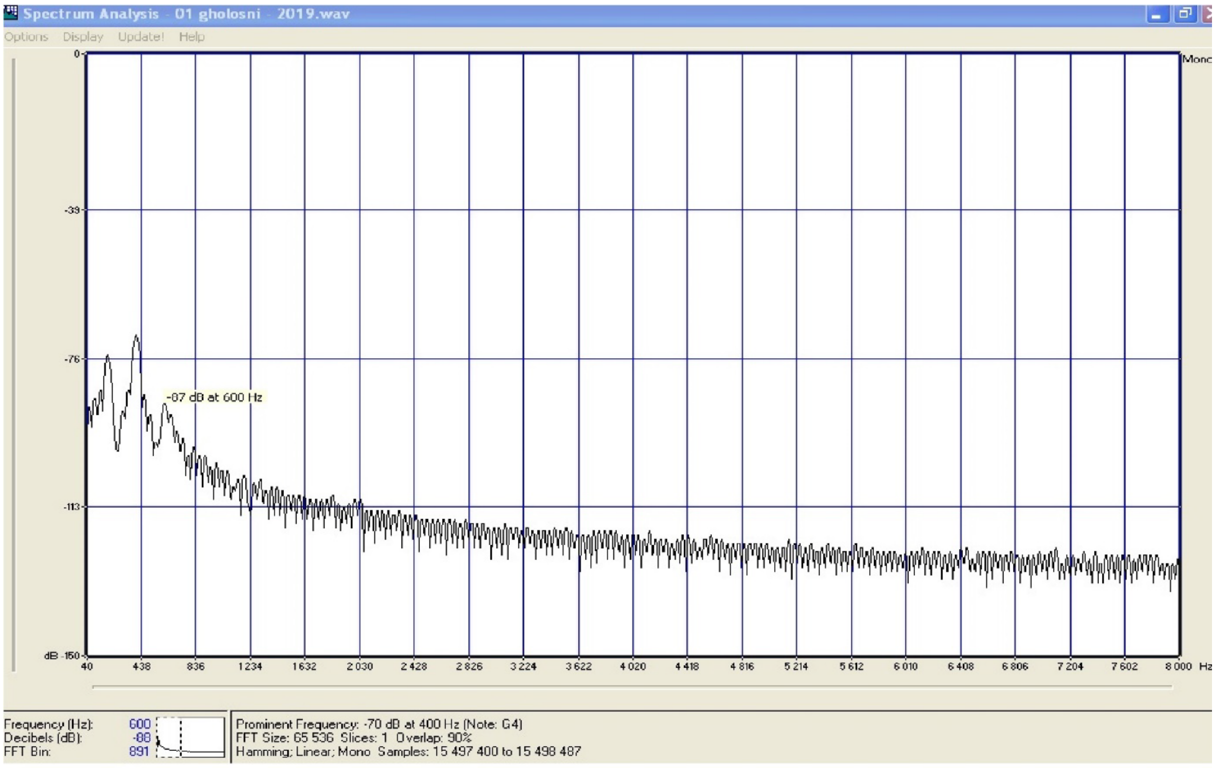
F1 = 3F0 = 491 Hz, F2 = 6F0 = 985 Hz; r_{21} = F2/F1 = 2.01: sound [o+].

Figure 9. A 2d spectrogram of an unstressed /o/ in "otoka"



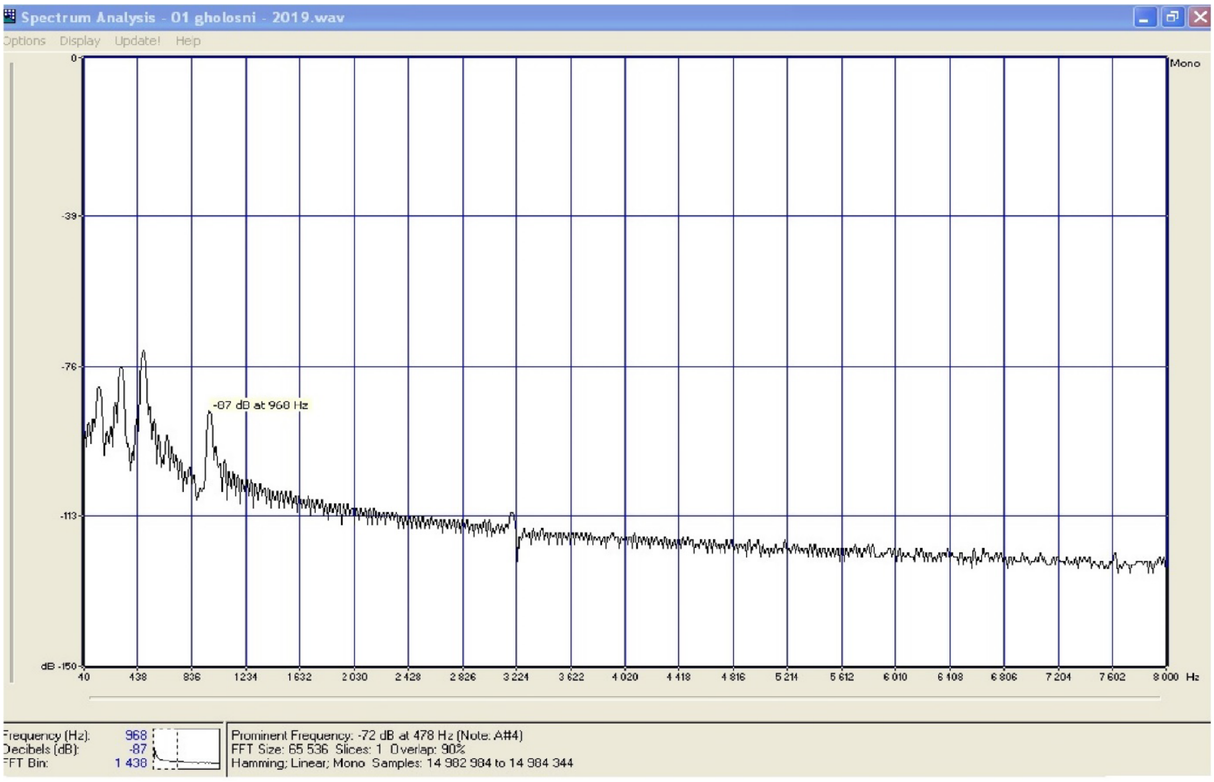
F1 = 3F0 = 533 Hz, F2 = 6F0 = 1082 Hz; r_{21} = F2/F1 = 2.03: sound [o+].

Figure 10. A 2d spectrogram of an unstressed /o/ in "ta_xodim"



F1 = 400 Hz, F2 = 3F0 = 600 Hz; r_{21} = F2/F1 = 1.50: sound [o].

Figure 11. A 2d spectrogram of an unstressed /o/ in "zozulja"



F1 = 3F0 = 478 Hz, F2 = 6F0 = 968 Hz; r_{21} = F2/F1 = 2.02: sound [o+].

/u/

The formant frequencies for a stressed /u/ are:

F1 = 206 Hz (“manjunja”) – 331 (“vudu”, “dumy”), F2 = 311 Hz (“manjunja”) – 556 Hz (isolated).

The formant frequencies for an unstressed /u/ are:

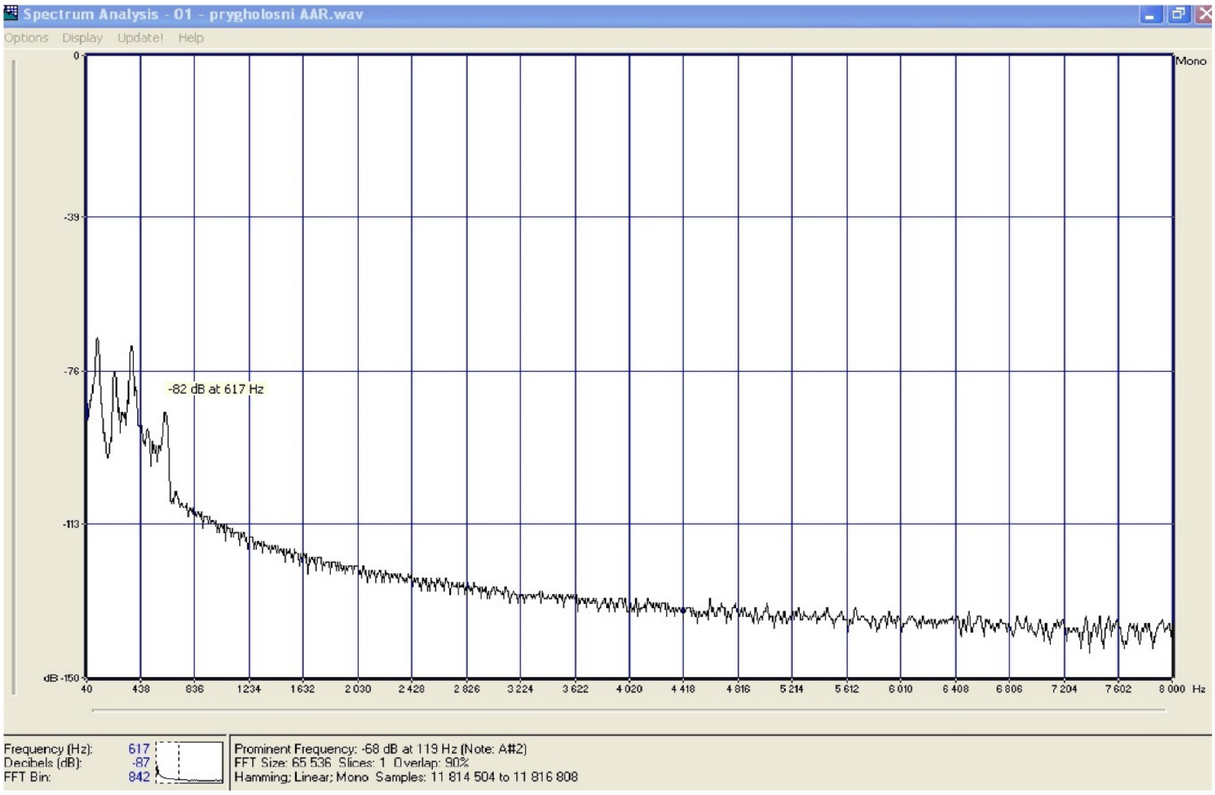
F1 = 241 Hz (“maljuvaty”) – 348 Hz (“maljuvaty”), F2 = 372 Hz (“maljuvaty”) – 766 Hz (“temu”).

The formant ratio r_{21} ranges from 1.48 to 2.00 for stressed allophones and from 1.47 to 2.53 for unstressed. The isolated /u/ has the value of r_{21} = 1.67: sound [u].

In the isolated sound, it was observed that F3 and F4 are not proportional to the fundamental frequency.

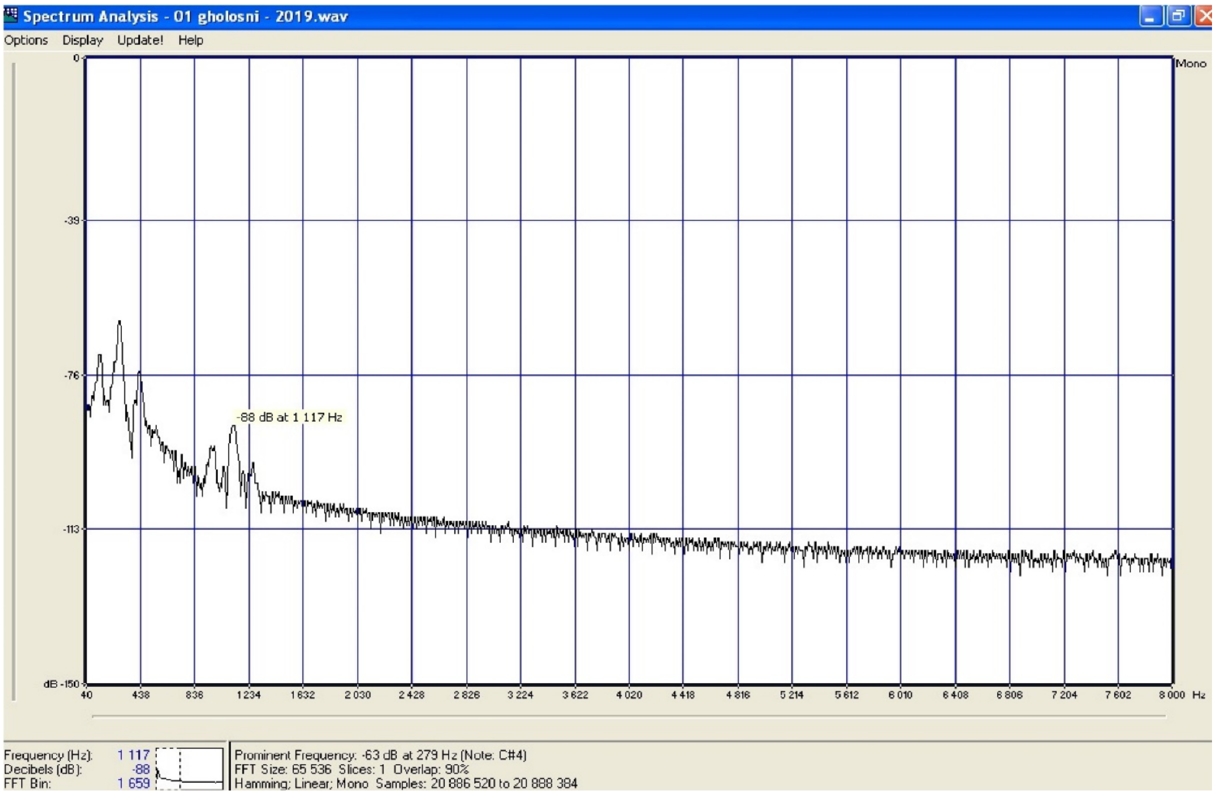
After palatalized consonants, combined formants were observed with similar formant ratios.

Figure 12. A 2d spectrogram of a stressed /u/ in “buv”



F1 = 372 Hz, F2 = 617 Hz; $r_{21} = F2/F1 = 1.66$: sound [u].

Figure 13. A 2d spectrogram of a stressed /u/ in "ljuba"



F1 = 2F0 = 279 Hz, F2 = 3F0 = 425 Hz, F3 = 7F0 = 959 Hz, F4 = 8F0 = 1117 Hz, F5 = 1257 Hz; r_{54} = F5/F4 = 1.25; r_{53} = F5/F3 = 1.31; r_{52} = F5/F2 = 2.96; r_{43} = F4/F3 = 1.16; r_{41} = F4/F1 = 4.00; r_{21} = F2/F1 = 1.52: sound [u] mixed with an [ʊ]. The probable cause is progressive assimilation by the preceding palatalized consonant having combined formants.

The results are systematized in Table 1.

Table 1. Formant frequencies and ratios of the Ukrainian back vowels

Vowel	F1, Hz	F2, Hz	Formant ratio
a (stressed)	670 – 833	994 – 1353	1.34 – 1.82 (4/3)
a (unstressed)	520 – 819	994 – 2054	1.34 – 3.69
o (stressed)	241 – 504	477 – 906	1.33 – 3.00 (3/2)
o (unstressed)	289 – 527	512 – 1082	1.34 – 3.13
u (stressed)	206 – 331	311 – 556	1.48 – 2.00 (5/3)
u (unstressed)	241 – 348	372 – 766	1.47 – 2.53

4. Discussion

The obtained results agree with the earlier classification of Ukrainian back vowels proposed in (Vakulenko, 2018), supplementing and amending the data on their formant location presented in (Bilodid, 1969; Tocjka 1981). In particular, the observed formant shifts in unaccented allophones of an /o/ challenge the assumptions of Pompino-Marschall, Steriopolo, and Żygis (2017) who classified this phoneme as /ɔ/ and support our earlier conclusion about its midheight character (cf. Vakulenko, 2018). The results obtained in (Vakulenko, 2011) are generalized by the variations in acoustic invariants for different allophones.

Due to the consonantal character of the Ukrainian language, the contrast between tense and lax sounds and phonemes as described in (Crystal, 2008, 271, 480), reduces to the contrast between stressed and unstressed allophones of the same phoneme.

The task to determining the ranges of fundamental frequency and formant frequencies for the group of speakers should be carried out accurately and carefully because each speaker has their own frequency range, and the same sounds produced by different informants usually have different frequency spectra. One way to avoid possible inconsistencies is to build vowel diagrams for each individual speaker and then generalize them.

The obtained results suggest that the phonetic features giving rise to allophony of Ukrainian back vowels, are the following: coda, distant assimilation by the next or preceding vowel, and progressive assimilation by the preceding hard or palatalized consonant. Thus, we have established a broader class of features resulting in vowel variations than found earlier for Russian vowels where it was concluded that "the feature responsible for the variation in Russian vowels is the same feature that differentiates between soft and hard consonants in Russian" (Cavar & Lulich, 2021, 31).

5. Conclusion

So, in this paper, we presented acoustic experimental data on the Ukrainian back vowel formant shifts caused by assimilation effects in various environments. This made it possible to specify more precisely how and to what extent the assimilation of these sounds occurs in different circumstances. The obtained results add important information about Ukrainian vowel behavior needed for both phonetic studies and natural language processing. Particularly, this data facilitates the classification of the Ukrainian back vowels and enhances comprehension of the extent and significance of sound assimilation in Ukrainian and cognate languages.

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