# AN ACOUSTIC AND ARTICULATORY DESCRIPTION OF THE ROMANIAN VOCALIC SYSTEM

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**Abstract**: This paper presents an acoustic and articulatory description of the seven standard Romanian vowels /i, ɨ, u, e, ə, o, a/. By revisiting previous instrumental studies (Avram 1963, Șuteu 1963, Teodorescu 1985, Renwick 2012), we offer a new interpretation of the material, a complementary statistical analysis, and a modern visualization of the data facilitated by R through the ggplot2 package (Wickham 2009). Another key point of this study is the ultrasound experiment conducted at ILPGA on the seven monophthongs. Finally, the acoustic data are correlated with the results obtained from the ultrasound study.

**Keywords**: phonetics, Romanian vowels, formant frequencies, ultrasound

## 1. Introduction

The aim of this study[1] is to provide an up-to-date analysis of Romanian vowels from an acoustic and articulatory perspective.

The paper is organized in 5 sections. Section 2 discusses the frequency of Romanian vowels, both in the UPSID database, and in an oral corpus of spontaneous speech. Section 3 offers an overview of different acoustic studies, compares the findings and provides a new interpretation and visualization of the data. The ultrasound experiment is discussed in section 4. Section 5 summarizes the findings, suggests mean frequencies hierarchies for F1 and F2, discusses their implication, and also presents various directions for future research.

## 2. Frequency of Romanian vowels

Romanian has seven phonemic monophthongs, /i, ɨ, u, e, ə, o, a/, and two unary diphthongs, /e̯a, o̯a/, (Chitoran 2002). In the UPSID database (Maddieson 1984, Maddieson and Precoda 1990), Romanian has an average frequency index of 0.381, comprising 32 segments (7 vowels, 2 approximants, 3 diphthongs and 20 consonants). At the outer extremes we find languages like Pirahã (0.618) or Rotokas (0.560), with the smallest inventory (only 11 segments), and !Xu (0.106), respectively, with the largest inventory (141 segments) found in the UCLA Phonological Segment Inventory Database (http://web.phonetik.uni-frankfurt.de/upsid_nr_seg.html).

The frequencies of Romanian vowels, glides and diphthongs /e̯o, o̯a, e̯a/ are given in Table 1.

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[1] Part of the results presented in this paper are an extension of Chapter 3 from our PhD dissertation (Niculescu 2018).

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**Table 1.** Frequency of Romanian vowels, glides and diphthongs in the UPSID database

| SEGMENT | % UPSID LANGUAGES | n | DESCRIPTION |
|---|---|---|---|
| /i/ | 87.14% | 393 | *high front unrounded vowel* |
| /a/ | 86.92% | 392 | *low central unrounded vowel* |
| /u/ | 81.82% | 369 | *high back rounded vowel* |
| /o/ | 29.05% | 131 | *higher mid back rounded vowel* |
| /e/ | 27.49% | 124 | *high mid front vowel* |
| /ə/ | 16.85% | 76 | *mid central unrounded ("@)vowel* |
| /ɨ/ | 13.53% | 61 | *high central unrounded (i_) vowel* |
| /j/ | 83.81% | 378 | *voiced palatal approximant* |
| /w/ | 73.61% | 332 | *voiced labial-velar approximant* |
| /e̯o/ | 0.67% | 3 | *mid front unrounded to mid back rounded diphthong* |
| /o̯a/ | 0.44% | 2 | *mid back unrounded to low central unrounded diphthong* |
| /e̯a/ | 0.22% | 1 | *mid front unrounded to low central unrounded diphthong* |

In terms of vowel inventory, Romanian is unique among Romance languages due to the two central vowels /ɨ, ə/, the former being less frequent, appearing in 61 out of the 451 languages under survey. In addition, Romanian is the only language in the database to possess the diphthong /e̯a/. Besides Romanian, the diphthong /o̯a/ appears in !Xu, while /e̯o/ is also found in Acoma and Lame.

As for the frequency of the seven monophthongs within contemporary standard Romanian, we will refer to a phonotactic study conducted by Niculescu (2018), Chapter 9. Based on 40 min of spontaneous speech (20.5k observations) forced aligned with an automatic speech transcription system described in Vasilescu et al. (2014), we concluded that /a/ is the most frequent vowel in the system, followed by /e/, /i/, /u/, /ə/, /o/, and /ɨ/. Our results slightly differ from those of Roceric Alexandrescu (1968)[2] due to various methodological settings with regard to differentiating or not between (semi)vowels. We preferred to have separate classes for vowels and glides.

Depending on vowel height, we observed that mid vowels occupy the first position in the hierarchy (38.9%), followed by high (32.3%) and low vowels (28.8%). Central vowels are first in terms of frequency (43.3%), followed by front (36.5%) and back vowels (20.2%).

### 3. Revisiting previous acoustic studies

We only took into account studies dealing with acoustic measurements of standard Romanian vowels in controlled speech, not spontaneous speech (Renwick et al. 2016a

[2] In the hierarchy proposed by Roceric Alexandrescu (1968), /e/ has the highest rate, followed by /a/, /i/, /u/, /ə/, /o/ and /ɨ/.

and 2016b, Vasilescu et al. 2016a and 2016b, Niculescu et al. 2017[3], a.o.). Also, we did not examine vowels generated by acoustic synthesis (Avram 1970, Şuteu 1971). We studied standard Romanian data (from a synchronic perspective), excluding dialectal variation.

Given these criteria, we selected the following papers: Avram (1963), Şuteu (1963), Teodorescu (1985) and Renwick (2012). When reviewing these studies, we gathered material strictly from the acoustic description of Romanian vowels and not from the comparison with other languages. All data were transcribed, reviewed, and processed in R and SPSS. Even though the authors have measured the frequencies for F1, F2 and F3, our analysis focuses on formant values from F1 and F2, as well as their variability, considered relevant and sufficient in mapping our data (Lindblom 1963, Ladefoged and Maddieson 1996, Johnson 1997, Ladefoged and Johnson 2011).

When computing the mean, we rounded the number up when the digit in the first decimal place was 5 or higher. Due to this approach, there are minor differences[4] from the original material. There are some errors in Şuteu (1963)[5] and Teodorescu (1985)[6] which have been corrected. We worked with non-normalized data.

[3] These are all studies dealing with large corpora of forced aligned oral speech.

[4] Modifications after rounding up to the first decimal place for total mean values (marked in italic are the results from the present study): F1 /ə/ *497 Hz* – 496 Hz (Avram 1963: 5), F2 /ɨ/ *1588 Hz* – 1587 (Avram 1963: 5), F1 /e/ *399 Hz* – 398 Hz (Şuteu 1963: 186), F2 /o/ *985 Hz* – 984 Hz (Şuteu 1963: 190), F2 /a/ *1193 Hz* – 1192 (Teodorescu 1985: 468), F1 /i/ *236 Hz* – 235 Hz (Teodorescu 1985: 468), F1 /ɨ/ *304 Hz* – 303 Hz (Teodorescu 1985: 468), F1 /o/ *467 Hz* – 466 Hz (Teodorescu 1985: 468), F2 /o/ *787 Hz* – 786 Hz (Teodorescu 1985: 468), F2 /u/ *703 Hz* – 702 Hz (Teodorescu 1985: 468). Also some minor differences are not due to rounding: F2 /e/ *1935* Hz – 1934 Hz and F1 /o/ *416 Hz* – 413 Hz (Şuteu 1963); F1 /ə/ *508* Hz – 506 Hz (Teodorescu 1985).

[5] First of all, F1 mean /a/ for all three groups is 703 Hz, not 730 Hz (Şuteu 1963: 188). This aspect is later corrected in the paper (Şuteu 1963: 194). When delivering the final results, the author states that F1 /i/ mean of all three groups is 317 Hz (Şuteu 1963: 194), even though this is the mean value of the first group (isolated vowels). Second of all, there is one value which we cannot account for, namely the mean value of F2 /a/ for all three groups (Şuteu 1963: 188). This value is 1278 Hz, but based on our revision of the data, the mean is in fact 1310 Hz. These results from Şuteu (1963) are also cited by Teodorescu (1985), with F1 mean /i/ 317 Hz, and F2 mean /a/ 1278 Hz (Teodorescu 1985: 470).

[6] The mean values presented in Table 4 (Teodorescu 1985: 466) have been revised as following: for group 1 (stressed vowels), subject 1 – F1 /a/ is 603 Hz, not 600 Hz; F1 /e/ is 443 Hz, not 440 Hz; F2 /i/ is 2046.6 Hz, rounded up to 2047 Hz, not 2050 Hz; F2 /ə/ is 1246.6 Hz, rounded up to 1247 Hz, not 1250 Hz; F1 /ɨ/ is 266.6 Hz, rounded up to 267 Hz, not 270 Hz; F2 /ɨ/ is 1366.6 Hz, rounded up to 1367 Hz, not 1370 Hz; F2 /u/ is 753 Hz, not 750 Hz. Similar discrepancies can be found also for group 1, subject 2 – F2 /a/, F1 /i/, F1 /ə/, F1 /ɨ/, F2 /o/, F1 and F2 /u/; group 1, subject 3 – F1 and F2 /a/, F1 /e/, F1 and F2 /i/, F2 /ə/, F1 and F2 /ɨ/, F1 /o/, F1 /u/; group 2 (unstressed vowels), subject 1 – F2 /a/, F2 /e/, F1 /i/, F1 and F2 /ə/, F1 and F2 /ɨ/, F1 /o/, F2 /u/; group 2, subject 2 – F1 /a/, F2 /e/, F2 /i/, F1 and F2 /ɨ/, F1 and F2 /o/, F1 and F2 /u/; group 2, subject 3 – F2 /a/, F1 and F2 /ə/, F1 /ɨ/, F1 and F2 /o/. These errors have an effect also on the means presented in the last three lines of Table 4 (Teodorescu 1985: 466). There are also some discrepancies with respect to ranges (Teodorescu 1985: 468): F1 /e/ varies between 370 Hz and 530 Hz, not 400 – 530 Hz, F1 /o/ varies between 400 Hz and 600 Hz, not 430 – 600 Hz, and F1 /u/ spans between 230 Hz and 370 Hz, not 230 – 330 Hz.

### 3.1 Avram (1963) and Şuteu (1963)

Both studies (Avram 1963; Şuteu 1963) were conducted in the phonetic laboratory at the Linguistic Institute of the Romanian Academy using a Sona-graph Kay Electric Co.

Twelve subjects participated in the experiment (6 male, 6 female). The vowels were recorded in isolation (group 1)[7], in monosyllabic words (group 2), and in sentences (group 3). Avram (1963) examined /ə/ and /ɨ/, while the remaining vowels were measured by Şuteu (1963).

The revisited data are summarized in Table 2, while the vocalic spaces are illustrated in Figures 1 and 2:

**Table 2.** Mean frequencies in Hz of F1 and F2 based on the data gathered from Avram (1963) and Şuteu (1963), mean standard deviations (s.d.) in Hz and number of occurrences (n)

| AUTHOR | VOWEL | GROUP | F1 mean | F1 s.d. | F1 n | F2 mean | F2 s.d. | F2 n |
|---|---|---|---|---|---|---|---|---|
| Avram (1963) | /ə/ | 1 | **548** | 108 | 10 | **1400** | 215 | 10 |
| | | 2 | **499** | 162 | 18 | **1499** | 286 | 18 |
| | | 3 | **428** | 92 | 8 | **1534** | 261 | 8 |
| | /ɨ/ | 1 | **315** | 81 | 10 | **1584** | 308 | 8 |
| | | 2 | **345** | 84 | 15 | **1613** | 235 | 14 |
| | | 3 | **325** | 79 | 4 | **1506** | 307 | 4 |
| Şuteu (1963) | /a/ | 1 | **753** | 96 | 9 | **1147** | 95 | 9 |
| | | 2 | **724** | 106 | 40 | **1346** | 206 | 39 |
| | | 3 | **640** | 124 | 20 | **1313** | 327 | 17 |
| | /e/ | 1 | **383** | 51 | 10 | **2025** | 215 | 6 |
| | | 2 | **396** | 110 | 28 | **1937** | 307 | 27 |
| | | 3 | **442** | 169 | 6 | **1788** | 314 | 4 |
| | /i/ | 1 | **318** | 80 | 10 | **2225** | 242 | 6 |
| | | 2 | **300** | 78 | 15 | **2106** | 157 | 13 |
| | | 3 | **331** | 114 | 4 | **2158** | 52 | 3 |
| | /o/ | 1 | **360** | 49 | 10 | **700** | 111 | 10 |
| | | 2 | **435** | 121 | 27 | **1069** | 171 | 26 |
| | | 3 | **433** | 184 | 3 | **1200** | 180 | 3 |
| | /u/ | 1 | **348** | 79 | 10 | **675** | 71 | 10 |
| | | 2 | **333** | 78 | 15 | **985** | 181 | 13 |
| | | 3 | **325** | 79 | 5 | **1100** | 141 | 5 |
| | | 2 | **302** | 14 | 3 | **717** | 45 | 3 |

[7] The partition by groups in our own.

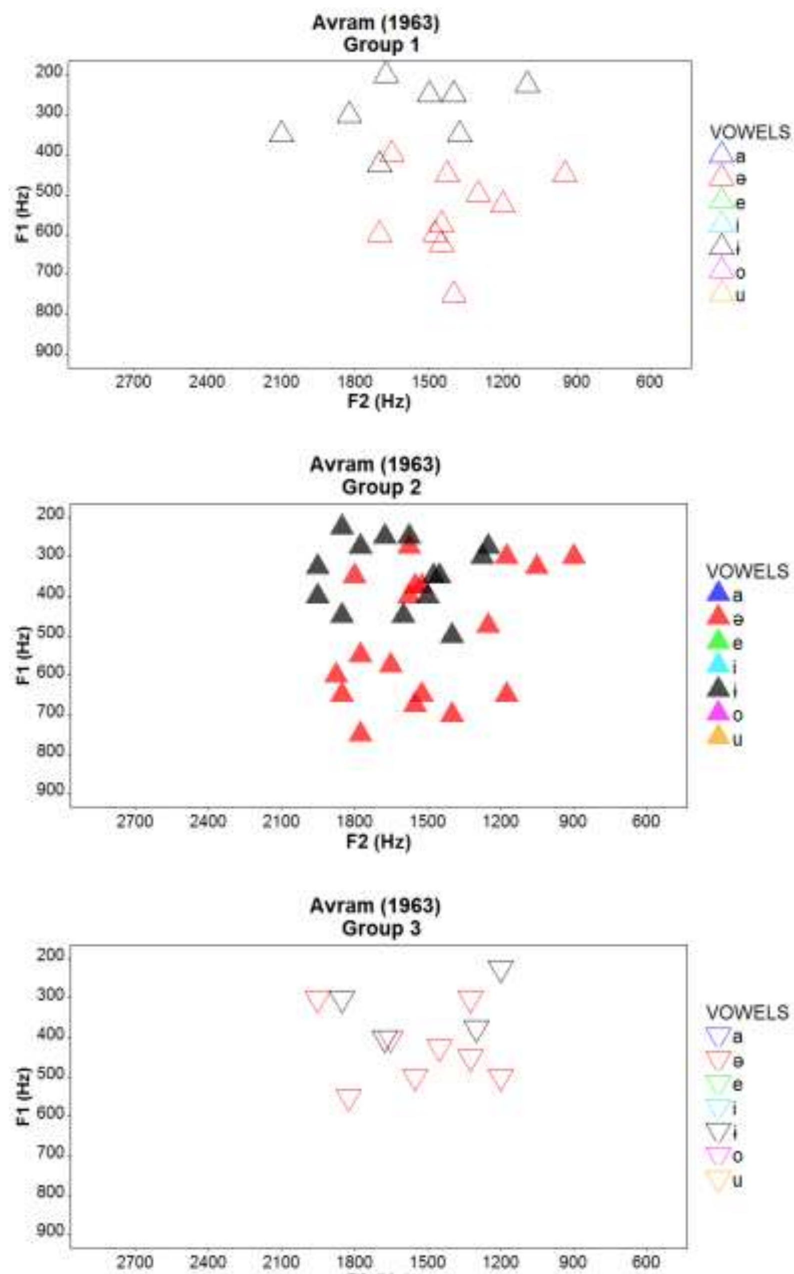



**Figure 1.** Vocalic spaces generated in R based on the data collected from Avram (1963)

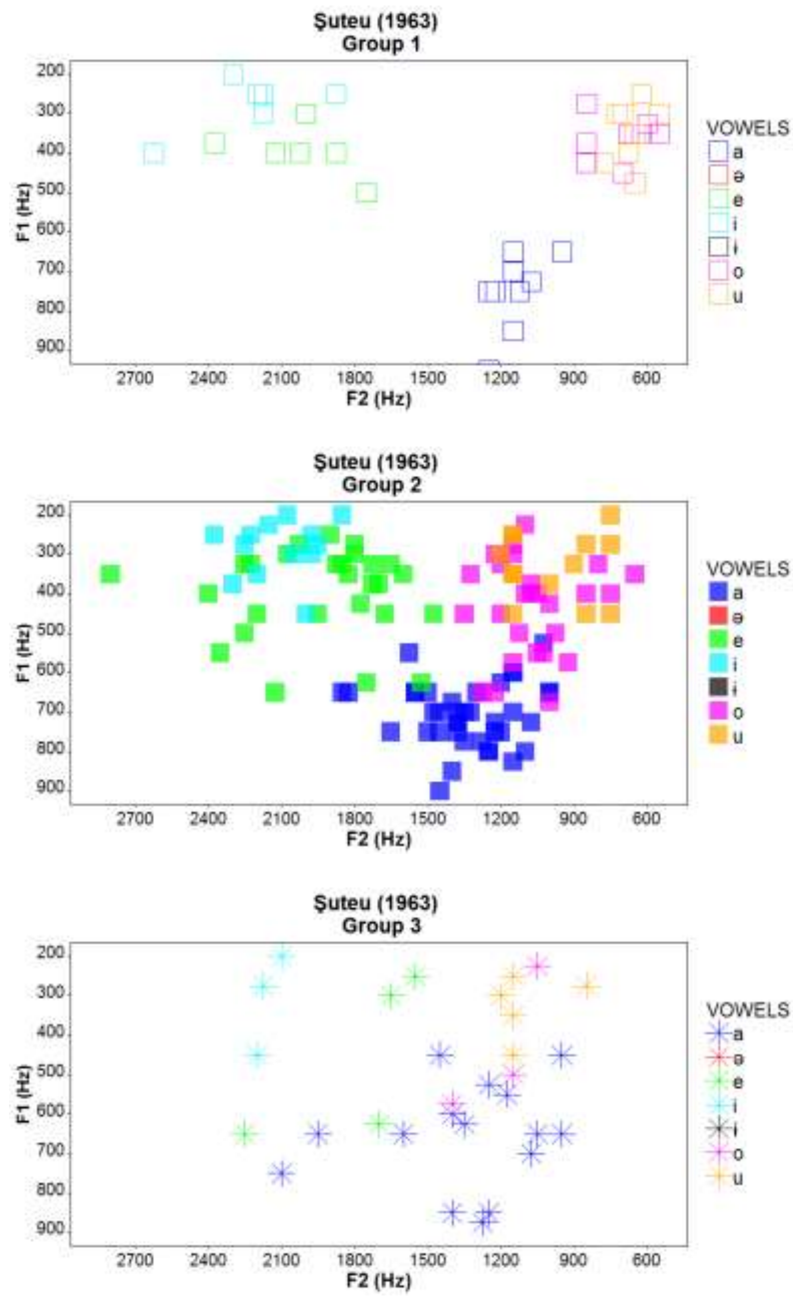



**Figure 2.** Vocalic spaces generated in R based on the data collected from Şuteu (1963)

The vowel /ə/ has a mean F1 of 497 Hz (s.d. = 137, n = 36), spanning from 275 Hz up to 750 Hz, while mean F2 is 1479 Hz (s.d. = 260, n = 36), with a high range of 1050 Hz (min. = 900 Hz, max. = 1950 Hz).

The vowel /ɨ/ has a mean value of 332 Hz (s.d. = 80, n = 29), spanning from 200 Hz to 500 Hz, and 1588 Hz (s.d. = 261, n = 26) for F2, also with a high range of 1000 Hz (min. = 1100 Hz, max. = 2100 Hz).

The mean value of F1 for /a/ is 703 Hz (s.d. = 116, n = 69), with a range of 650 Hz (min. = 450 Hz, max. = 1100 Hz). The mean value of F2 is 1310 Hz (s.d. = 240, n = 65), with a range of 1150 Hz (min = 950 Hz, max. = 2100 Hz).

For /e/, mean F1 is 399 Hz (s.d. = 108 Hz, n = 44) and mean F2 is 1935 Hz (s.d. = 294, n = 37), with a range spanning about 400 Hz (min. = 250 Hz, max. = 650 Hz) in the first formant, and 1325 Hz (min. = 1475 Hz, max. = 2800 Hz) in the second formant.

For /i/, F1 has a mean of 310 Hz (s.d. = 81, n = 29), with a range of 250 Hz (min. = 200, max. = 450 Hz), while F2 has a mean of 2145 Hz (s.d. = 176, n = 22), ranging from 1850 Hz up to 2625 Hz.

The vowel /o/ has a mean value of 416 Hz (s.d. = 115, N = 40) for F1, with a range of 450 Hz (min. = 225 Hz, max. = 675 Hz), and 985 Hz (s.d. = 232, n = 39) for F2, spanning from 550 Hz to 1400 Hz.

As for the vowel /u/, the first formant has a mean value of 339 Hz (s.d. = 77, n = 25), ranging from 200 Hz to 475 Hz, the second formant has a mean value of 850 Hz (s.d. = 211, n = 23), spanning from 550 Hz to 1200 Hz.

In what follows, we describe the results based on the measurements taken for the consonantal context. Both authors discuss the findings in terms of mean frequencies for F1 and F2, ranges and number of occurrences, for individual groups, as well as global statistics of the data (Avram 1963: 167-168, Şuteu 1963: 181-194). For monosyllabic words we wanted to examine the influence of the consonantal context over the values of the first two formants. Avram (1963) places each vowel in 3 different contexts, while the data from Şuteu (1963: 181-185) is unbalanced: 7 contexts for /a/, 5 for /e/, /i/ is placed in 4 contexts, /o/ in 5, and /u/ appears in 3 consonantal contexts. We regrouped the data and calculated the mean values, standard deviations and number of occurrences of each context. The results are presented in Table 3, while the mapping of the data is visible from Figure 3 to Figure 9.

**Table 3.** Mean frequencies in Hz of F1 and F2 based on the data gathered from Avram (1963) and Șuteu (1963), mean standard deviations (s.d.) in Hz and number of occurrences (n), grouped by consonantal context

| VOWEL | CONTEXT | F1 | | | F2 | | |
|---|---|---|---|---|---|---|---|
| | | mean | s.d. | n | mean | s.d. | n |
| /ə/ | p___r | **454** | 159 | 6 | **1342** | 345 | 6 |
| | ʦ___rʲ | **500** | 181 | 6 | **1679** | 136 | 6 |
| | m___r | **542** | 161 | 6 | **1475** | 266 | 6 |
| /ɨ/ | k___t | **345** | 106 | 5 | **1670** | 171 | 5 |
| | v___r | **370** | 89 | 5 | **1356** | 116 | 4 |
| | r___d | **320** | 59 | 5 | **1760** | 209 | 5 |
| /a/ | p___t | **725** | 191 | 6 | **1296** | 232 | 6 |
| | f___r | **705** | 69 | 5 | **1240** | 150 | 5 |
| | ʧ___s | **640** | 54 | 5 | **1650** | 177 | 5 |
| | h___m | **733** | 121 | 6 | **1217** | 161 | 6 |
| | m___k | **775** | 92 | 6 | **1245** | 108 | 5 |
| | ʦ___p | **729** | 51 | 6 | **1375** | 130 | 6 |
| | r___k | **741** | 86 | 6 | **1413** | 170 | 6 |
| /e/ | k'___l | **330** | 54 | 5 | **2165** | 422 | 5 |
| | s___k | **340** | 67 | 5 | **1705** | 91 | 5 |
| | ʤ___r | **379** | 82 | 6 | **2041** | 235 | 6 |
| | l___g | **371** | 58 | 6 | **1950** | 207 | 5 |
| | j___l | **538** | 127 | 6 | **1825** | 344 | 6 |
| /i/ | b___r | **258** | 52 | 3 | **2025** | 204 | 3 |
| | ʃ___r | **338** | 92 | 4 | **2056** | 163 | 4 |
| | m___k | **225** | 25 | 3 | **2200** | 156 | 3 |
| | ʦ___p | **340** | 65 | 5 | **2158** | 94 | 3 |
| /o/ | d___p | **340** | 84 | 5 | **1215** | 125 | 5 |
| | z___r | **495** | 153 | 5 | **1110** | 112 | 5 |
| | ʧ___k | **417** | 58 | 6 | **1083** | 97 | 6 |
| | h___p | **370** | 32 | 5 | **763** | 85 | 4 |
| | n___d | **538** | 134 | 6 | **1104** | 101 | 6 |
| /u/ | t___b | **320** | 92 | 5 | **860** | 174 | 5 |
| | ʒ___r | **355** | 73 | 5 | **1000** | 150 | 3 |
| | l___t | **325** | 79 | 5 | **1100** | 141 | 5 |

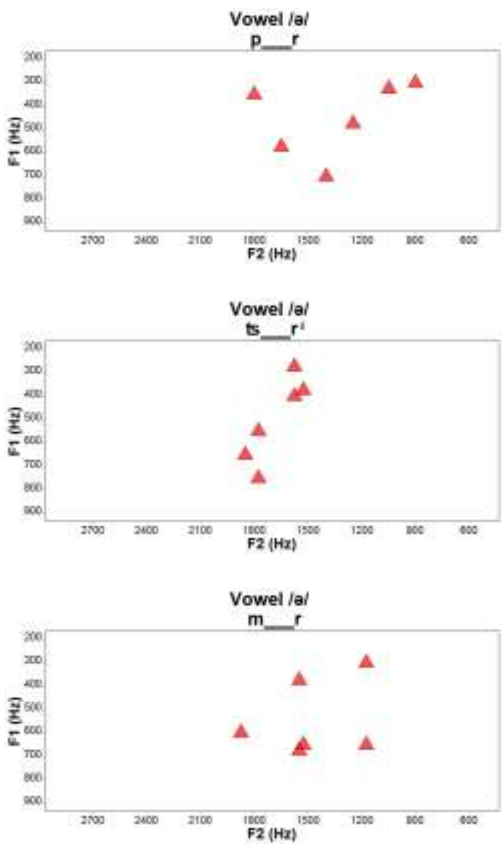



**Figure 3.** The vowel /ə/ in various consonantal contexts (based on data from Avram 1963)

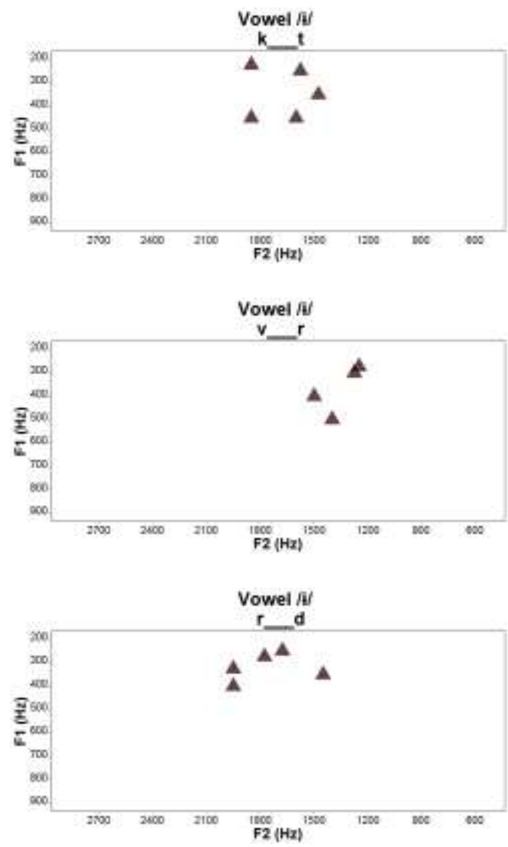



**Figure 4.** The vowel /ɨ/ in various consonantal contexts (based on data from Avram (1963)

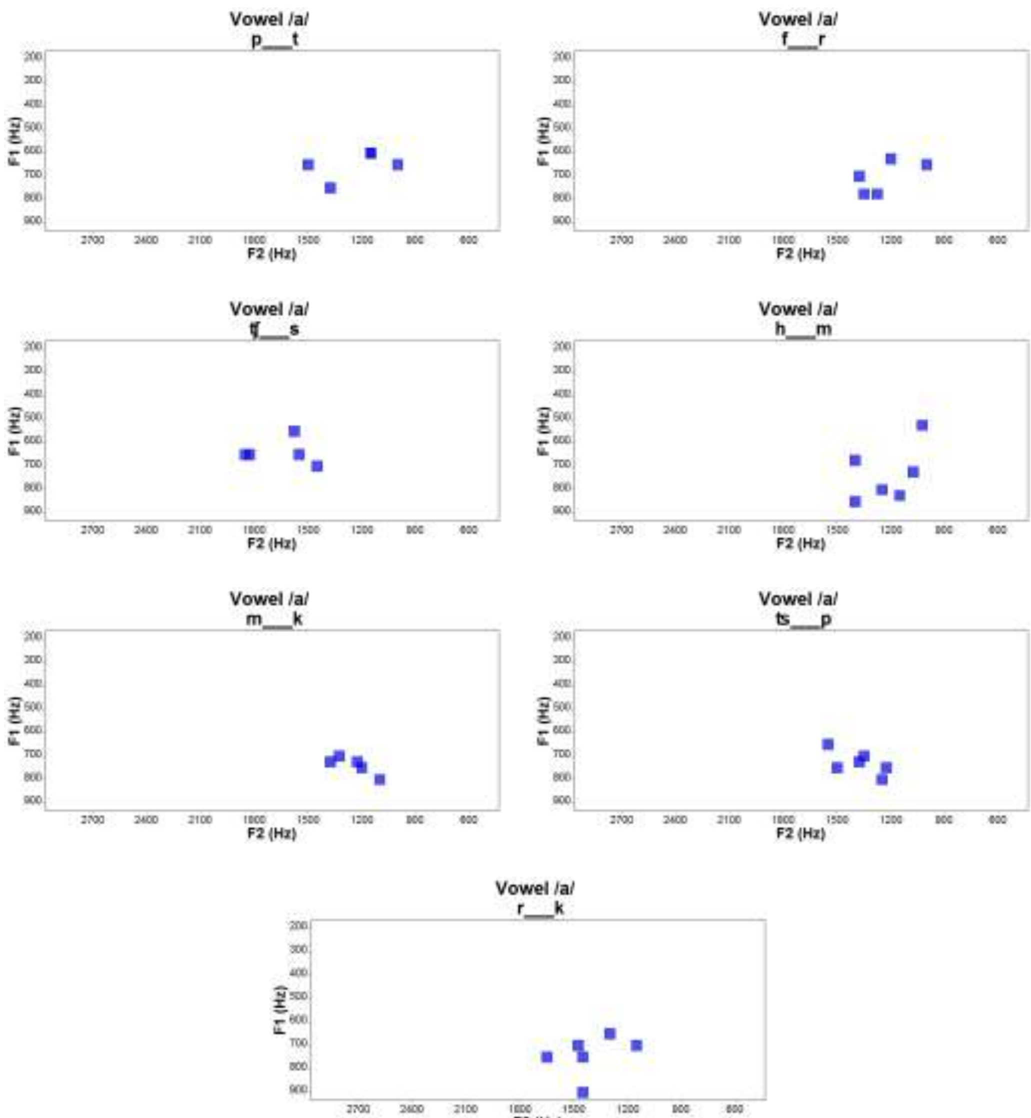



**Figure 5.** The vowel /a/ in various consonantal contexts (based on data from Şuteu (1963)

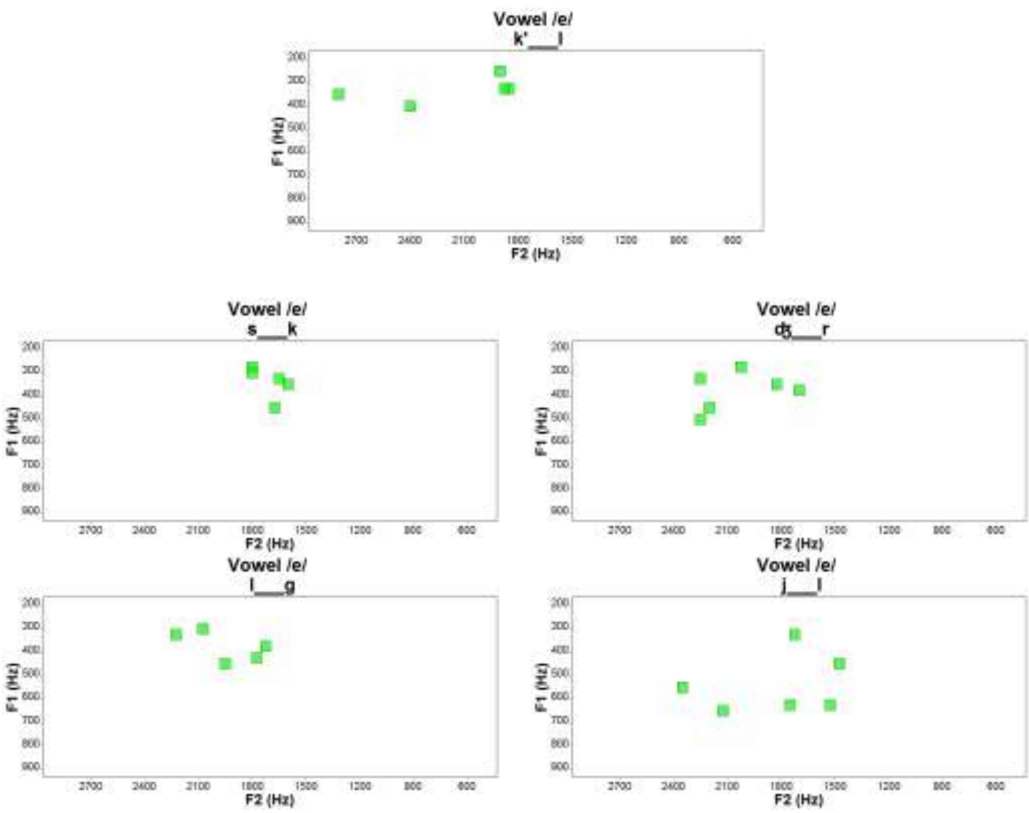



**Figure 6.** The vowel /e/ in various consonantal contexts (based on data from Şuteu (1963)

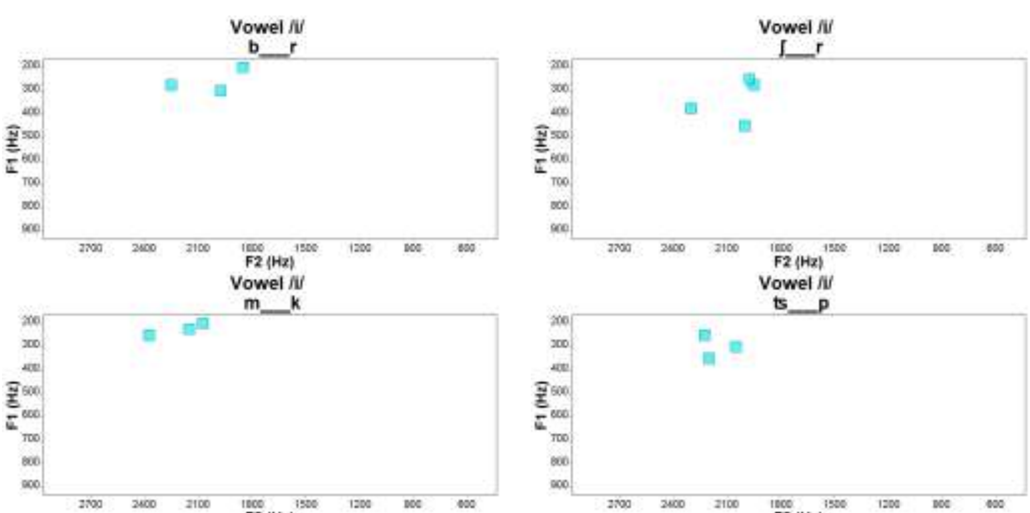



**Figure 7.** The vowel /i/ in various consonantal contexts (based on data from Şuteu 1963)

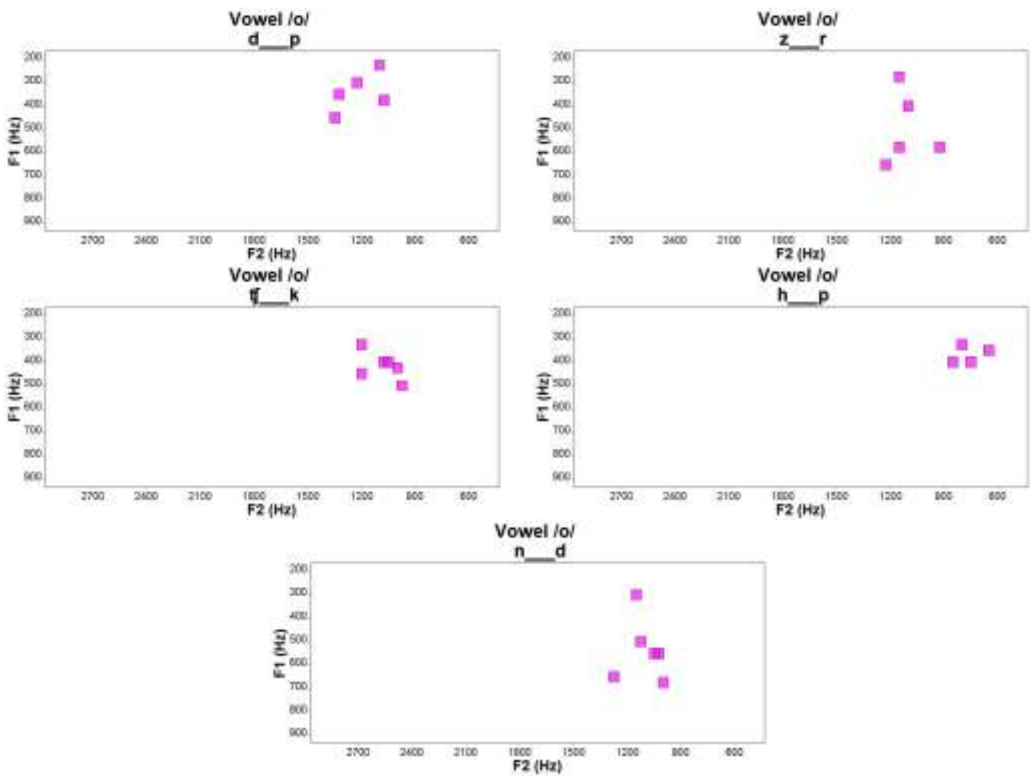



**Figure 8.** The vowel /o/ in various consonantal contexts (based on data from Șuteu 1963)

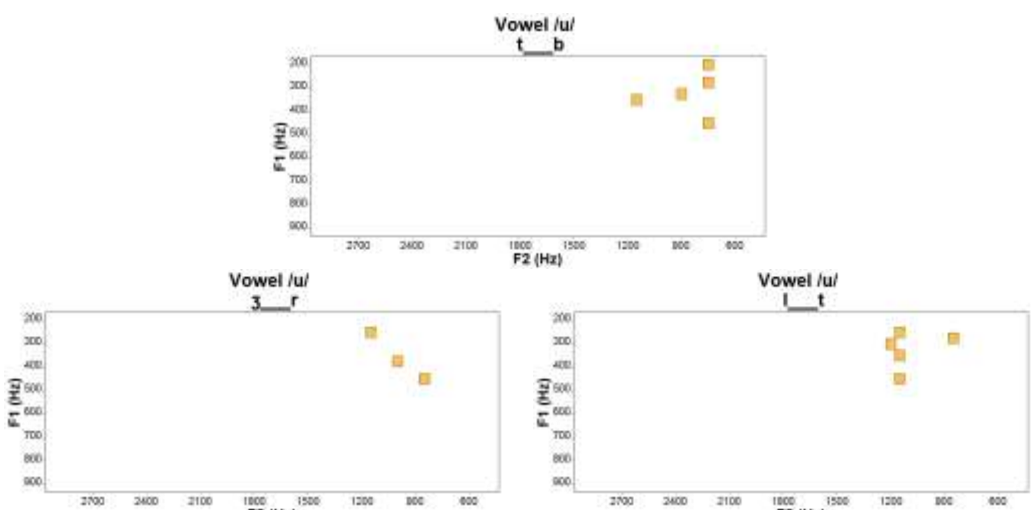



**Figure 9.** The vowel /u/ in various consonantal contexts (based on data from Șuteu 1963)

The vowel /ə/ is lower when preceded by a nasal (542 Hz), and higher when preceded by the bilabial /p/ (454 Hz). The second formant has the highest value in the "ʦ___r$^{i}$" context (1679 Hz), and the lowest value in the bilabial setting (1342 Hz). In short, this vowel is higher and further back when placed in the "p___r" context.

The vowel /ɨ/ is higher (320 Hz) and more toward the front of the acoustic space (1760 Hz) when preceded by a liquid ("r___d").

The vowel /a/ has the lowest F1 (640 Hz) correlated with the highest F2 (1650 Hz) in the "ʧ___s" context, meaning that the vowel is higher and more fronted in this particular setting.

With respect to the vowel /e/, the coarticulation with the preceding semiconsonant raises the first formant to the highest value in the series (538 Hz). The second formant has higher values when preceded by /ʤ/ (2041 Hz) and /k'/ (2165 Hz). The lowest values for F2 occur when the vowel is preceded by the alveolar fricative /s/ (1705 Hz).

The vowel /i/ has the lowest F1 when it follows after /m/ (225 Hz) and /b/ (258 Hz), and the highest F1 when if follows after /ʦ/ (340 Hz) and /ʃ/ (338 Hz). The second formant has a low frequency when preceded by /b/ (2025 Hz) and /ʃ/ (2056 Hz), and a higher frequency when preceded by /m/ (2200 Hz) and /ʦ/ (2158 HZ). Summing up, /i/ is higher and has a more fronted realization in the "m___k" context.

The vowel /o/ is lower when preceded by a nasal (538 Hz), and higher when preceded by a voiceless dental stop (340 Hz). In the "h___p" context, /o/ is more back (763 Hz), while in the "d___p" setting, /o/ undergoes fronting, having the highest F2 value from the series (1215 Hz).

The vowel /u/ is higher and placed more toward the back of the acoustic space when it follows after a voiced dental stop, namely in the "t___b" context (F1 320 Hz, F2 860 Hz).

### 3.2 Teodorescu (1985)

Three male subjects participated in the experiment conducted by Teodorescu (1985). The target vowels were embedded in logatoms followed and/or preceded by /p/. Both stressed (group 1) and unstressed vowels (group 2) were placed in initial, medial and word-final position.

The general statistics are presented in Table 4, while the vocalic spaces are illustrated in Figure 10.

**Table 4.** Mean frequencies in Hz of F1 and F2 (based on data from Teodorescu 1985), mean standard deviations (s.d.) in Hz and number of occurrences (n)

| AUTHOR | VOWEL | GROUP | F1 | | | F2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | **mean** | **s.d.** | **n** | **mean** | **s.d.** | **n** |
| Teodorescu (1985) | /a/ | 1 | **646** | 92 | 9 | **1210** | 49 | 9 |
| | | 2 | **634** | 77 | 9 | **1176** | 69 | 9 |
| | /ə/ | 1 | **490** | 15 | 9 | **1343** | 157 | 9 |
| | | 2 | **527** | 37 | 9 | **1327** | 152 | 9 |
| | /e/ | 1 | **459** | 37 | 9 | **1790** | 177 | 9 |
| | | 2 | **463** | 53 | 9 | **1767** | 187 | 9 |
| | /i/ | 1 | **243** | 30 | 9 | **2134** | 155 | 9 |
| | | 2 | **228** | 20 | 9 | **2154** | 208 | 9 |
| | /ɨ/ | 1 | **289** | 55 | 9 | **1440** | 239 | 9 |
| | | 2 | **319** | 64 | 9 | **1404** | 165 | 8 |
| | /o/ | 1 | **466** | 38 | 9 | **811** | 69 | 9 |
| | | 2 | **468** | 56 | 9 | **762** | 109 | 9 |
| | /u/ | 1 | **270** | 32 | 9 | **686** | 95 | 9 |
| | | 2 | **305** | 32 | 8 | **723** | 69 | 8 |

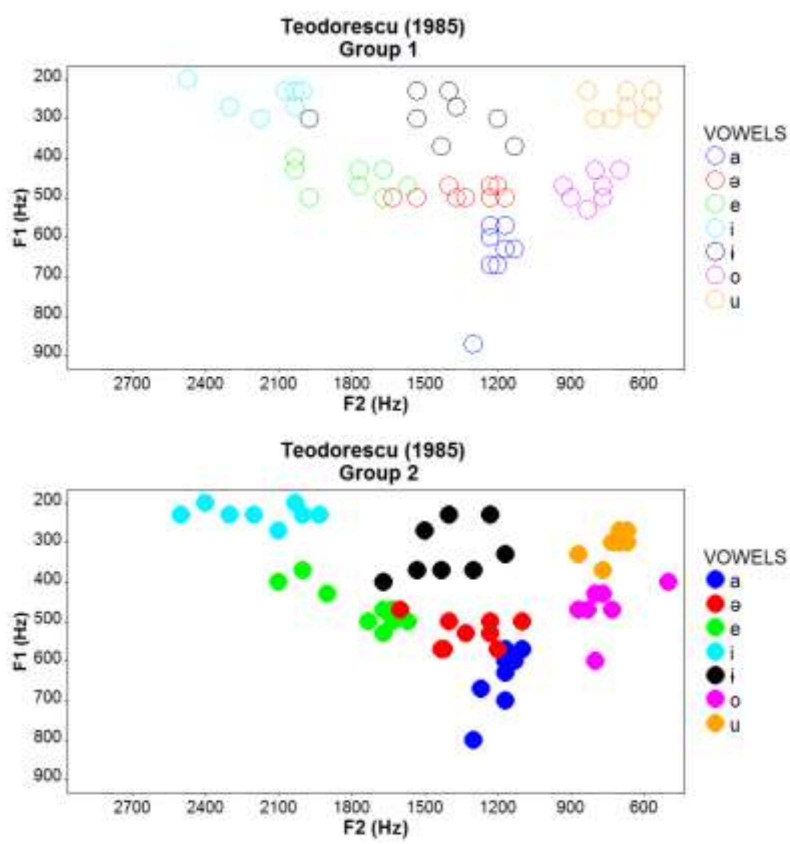



Figure 10. Vocalic spaces generated in R (based on data from Teodorescu 1985)

There are no high discrepancies between the two groups, meaning stress in not correlated to the frequency domain but more to the temporal one. That is why, in the future, the frequency measurements need to be compared with durational patterns.

The results from Teodorescu (1985) are as following. The mean value of F1 for /a/ is 640 Hz (s.d. = 82, n = 18), with a range of 300 Hz (min. = 570 Hz, max. = 870 Hz). For F2, the mean is 1193 Hz (s.d. = 61, n = 18), ranging from 1100 Hz to 1300 Hz.

The vowel /ə/ has a mean value of 508 Hz (s.d. = 33, n = 18) for F1, with a range of 100 Hz (min. = 470 Hz, max. = 570 Hz), and 1335 Hz (s.d. = 150, n = 18) for F2, ranging from 1100 Hz to1630 Hz.

As for /e/, the first formant has a range of 160 Hz (min. = 370 Hz, max. = 530 Hz), with a mean value of 461 Hz (s.d. = 44, n = 18), while the second formant varies between 1570 Hz and 2100 Hz, with a mean value of 1778 Hz (s.d. = 177, n = 18).

For the vowel /i/, mean F1 is 236 Hz (s.d. = 26, n = 18), and mean F2 is 2144 Hz (s.d. = 178, n = 18), with a range spanning about 100 Hz (min. = 200 Hz, max. = 300 Hz) in the first formant, and 570 Hz (min. = 1930 Hz, max. = 2500 Hz) in the second formant.

The mean value of F1 for /ɨ/ is 304 Hz (s.d. = 60, n = 18), with a range of 170 Hz (min. = 230 Hz, max. = 400 Hz). The mean value of F2 for /ɨ/ is 1423 Hz (s.d. = 202, n = 17), with a high range of approximately 840 Hz (min. = 1130 Hz, max. = 1970 Hz).

For the vowel /o/, the mean of F1 is 467 Hz (s.d. = 46, n = 18), and for F2 the mean is 787 Hz (s.d. = 92, n = 18). The first formant spans between 400 Hz and 600 Hz, while the second formant has a range of 430 Hz (min. = 500 Hz, max. = 930 Hz).

As for /u/, the first formant has a range of 140 Hz (min. = 230 Hz, max. = 370 Hz), with a mean value of 286 Hz (s.d. = 36, n = 17), while the second formant has a range of 300 Hz (min. = 570 Hz, max. = 870 Hz), with a mean value of 703 Hz (s.d. = 83, n = 17).

When comparing the results from Avram (1963) and Şuteu (1963) to those from Teodorescu (1985), we notice the following patterns.

For /a/, Şuteu (1963) registers the highest values, both for F1 (703 Hz. vs 640 Hz) and F2 (1310 Hz vs. 1193 Hz), compared to Teodorescu (1985).

For /ə/, Teodorescu (1985) has a higher value for F1 (508 Hz vs. 497 Hz) and a lower value for F2 (1335 Hz vs. 1479 Hz) compared to the results from Avram (1963).

Teodorescu (1985) places /e/ much lower (461 Hz vs. 399 Hz) and more back (1778 Hz vs. 1935 Hz) than Şuteu (1963).

As for the vowel /i/, for the first formant (310 Hz vs. 236 Hz), Şuteu (1963) presents a higher mean than Teodorescu (1985). For the second formant, the two authors have almost identical results, Şuteu (1963) – 2145 Hz, Teodorescu (1985) – 2144 Hz.

For /ɨ/, Avram (1963) has the highest values, both for F1 (332 Hz vs. 304 Hz) and F2 (1588 Hz vs. 1423 Hz), compared to Teodorescu (1985), meaning that the vowel is lower in vowel height and more fronted in the data collected from the first author.

The vowel /o/ is lower in Teodorescu (1985) as opposed to Şuteu (1963) – 467 Hz vs. 416 Hz, and has a higher F2 mean in the data from the second author – 787 Hz vs. 985 Hz, thus denoting a vowel placed more toward the back of the acoustic space.

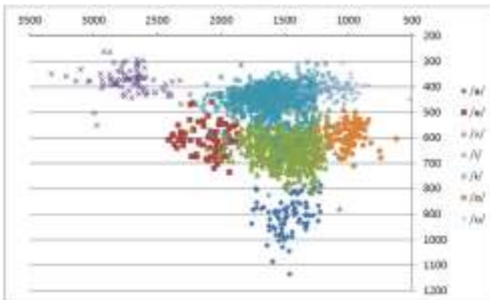
When comparing the means from Şuteu (1963) and Teodorescu (1985) for /u/, we observe that the former has higher values for F1 (339 Hz vs. 286 Hz) and F2 (850 Hz vs. 703 Hz) than the latter, meaning that the vowel /u/ is placed lower and more toward the front of the acoustic space in the experiment conducted by Şuteu (1963).

### 3.3 Renwick (2012)

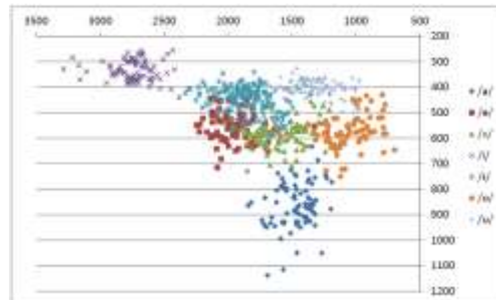
As part of her PhD dissertation, Renwick (2012) looked at acoustic characteristics of Romanian vowels. The data presented here comes from the forth chapter of her thesis (Renwick 2012: 127-180). Each vowel was tested in at least for words, embedded in the carrier-sentence *Spune X de trei ori* 'Say X three times', both stressed and unstressed contexts, with the number of syllables controlled for (Renwick 2012: 141-144). Six male and 15 female speakers took part at the experiment for Romanian monophthongs. The author also measured the duration of the vowels (Renwick 2012: 169-176). In the present paper, we focus on the results from the frequency domain summarized in Table 5.

**Table 5.** Mean frequencies in Hz of F1 and F2 (based on data d from Renwick 2012), mean standard deviations (s.d.) in Hz

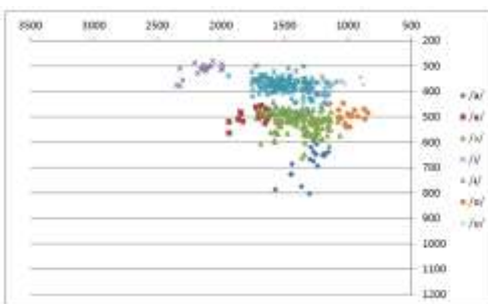
| **VOWEL** | **GROUP** | **F1** | | **F2** | |
|---|---|---|---|---|---|
| | | **mean** | **s.d.** | **mean** | **s.d.** |
| /a/ | 1 | **897** | 76 | **1463** | 133 |
| | 2 | **856** | 96 | **1473** | 142 |
| | 3 | **679** | 61 | **1302** | 111 |
| | 4 | **685** | 75 | **1239** | 66 |
| /ə/ | 1 | **636** | 61 | **1503** | 184 |
| | 2 | **583** | 54 | **1595** | 193 |
| | 3 | **519** | 39 | **1377** | 148 |
| | 4 | **490** | 30 | **1446** | 168 |
| /e/ | 1 | **603** | 59 | **2095** | 147 |
| | 2 | **552** | 57 | **1961** | 148 |
| | 3 | **495** | 27 | **1737** | 104 |
| | 4 | **438** | 26 | **1710** | 82 |
| /i/ | 1 | **377** | 48 | **2720** | 199 |
| | 2 | **333** | 38 | **2745** | 164 |
| | 3 | **317** | 28 | **2151** | 116 |
| | 4 | **294** | 22 | **2149** | 97 |
| /ɨ/ | 1 | **444** | 52 | **1600** | 199 |
| | 2 | **450** | 53 | **1850** | 197 |
| | 3 | **381** | 35 | **1482** | 162 |
| | 4 | **392** | 47 | **1683** | 165 |
| /o/ | 1 | **591** | 45 | **1003** | 109 |
| | 2 | **573** | 65 | **1073** | 185 |
| | 3 | **497** | 27 | **993** | 78 |
| | 4 | **494** | 28 | **986** | 124 |
| /u/ | 1 | **411** | 37 | **1106** | 146 |
| | 2 | **406** | 36 | **1324** | 192 |
| | 3 | **363** | 13 | **1116** | 111 |
| | 4 | **365** | 21 | **1232** | 149 |



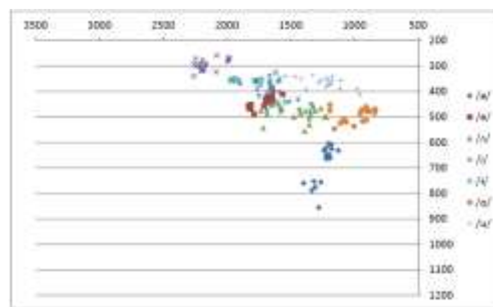
Group 1, stressed vowels – female speakers: Renwick (2012: 156)



Group 2, unstressed vowels – female speakers: Renwick (2012: 156)



Group 3, stressed vowels – male speakers: Renwick (2012: 157)



Group 4 unstressed vowels – male speakers: Renwick (2012: 157)

**Figure 11.** Vocalic spaces depicting stressed and unstressed vowels from male and female (Renwick (2012: 156-157)

As a result of sex-based anatomical differences, male and female speakers' vowels have different formant value (Renwick 2012: 160). When looking at the data, we observe that F1 is systematically higher for female speakers. Also, F2 tends to have lower values in the case of male speakers.

Unstressed vowels present a greater standard deviation in F2 compared to stress vowels (Renwick 2012: 159).

### 3.4 Discussion

In the final part of section 3, we corroborate the results from all the authors studied so far. Given the data, we propose the following visualizations:

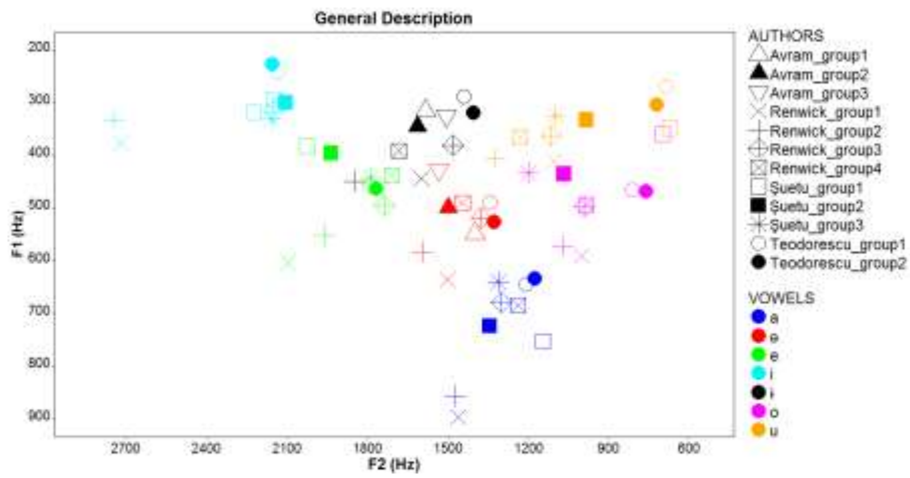



**Figure 12.** General vocalic space (based on data Avram 1963, Şuteu 1963, Teodorescu 1985, Renwick 2012)

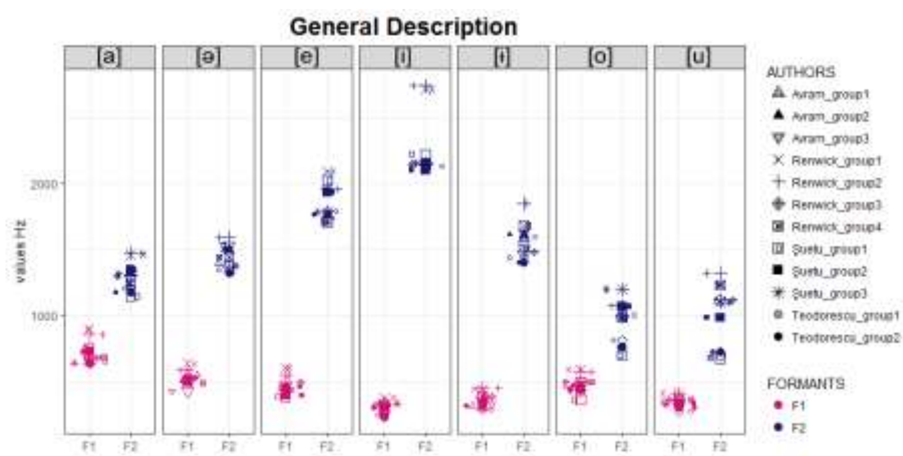



**Figure 13.** General vocalic space using the *facets()* function in R (based on data from Avram 1963, Şuteu 1963, Teodorescu 1985, Renwick 2012)

We now compare the mean values of F1 and F2 of all seven vowels, classified by group.

Teodorescu (1985), group 2, registers the lowest mean value of F1 for /a/ (634 Hz) among the authors under survey, followed by Şuteu (1963), group 3 (640 Hz). Mean F2 has a lower value in Şuteu (1963), group 1 (1147 Hz), as well as in groups 2 (1176 Hz) and 1 (1210 Hz) from Teodorescu (1985). Based on the data collected from female speakers (stressed and unstressed), Renwick (2012) presents the highest values for F1 (856 Hz, 897 Hz) and F2 (1463 Hz, 1473 Hz), meaning that, in her data, /a/ is lowest and most fronted.

Avram (1963), group 3, has the lowest F1 for /ə/ (428 Hz), and one of the highest F2 means (1534 Hz). This vowel is more posterior in Teodorescu (1985), group 2 (1327 Hz) and 1 (1343 Hz), and more anterior in Renwick (2012), group 2 (1595 Hz).

F1 /e/ spans between 383 Hz (Şuteu 1963 – group 1) and 603 Hz (Renwick 2012 – group 1). F2 /e/ has a range between 1710 Hz (Renwick 2012 – group 4) and 2095 Hz (Renwick 2012 – group 1).

The vowel /i/ is as low as 228 Hz, 243 Hz (Teodorescu 1985 – groups 2 and 1, respectively), and as high as 333 Hz, 337 Hz (Renwick 2012 – groups 2 and 1, respectively) in the first formant. For F2, /i/ is more posterior in the data collected by Şuteu (1963), group 2 (2106 Hz), Teodorescu (1985), group 1 (2134 Hz), and more anterior in the female recordings gathered by Renwick (2012), both stressed (2720 Hz) and unstressed (2745 Hz).

Teodorescu (1985), group 1, registers the lowest mean value of F1 for /ɨ/ (289 Hz), followed by Avram (1963), group 1 (315 Hz). The highest mean values for F1 are found in Renwick (2012), group 1 (444 Hz) and group 2 (450 Hz). Both vowel groups studied by Teodorescu (1985) have the lowest F2 mean (group 2 – 1404 Hz, group 1 – 1440 Hz). Again, Renwick (2012) presents the highest mean for F2 (1850 Hz). In short, /ɨ/ is lower in vowel height and presents a more fronted actualization in the data collected from female speakers (unstressed vowels) in Renwick (2012).

Şuteu (1963) displays the lowest F1 values (group 1 – 360 Hz, group 3 – 433 Hz, group 2 – 435 HZ), meaning that /o/ is higher in this case. The vowel is lower in group 2 (573 Hz) and group 1 (591 Hz) from Renwick (2012). The extreme values for F2 are recorded by Şuteu (1963), group 1 (700 Hz) and group 3 (1200 Hz).

The first (270 Hz) and second group (305 Hz) from Teodorescu (1985) present the minimum values of F1 for /u/, then Şuteu (1963), group 3 (325 Hz), group 2 (333 Hz) and group 1 (348 HZ). The third group (363 Hz), the fourth group (365 Hz), the second group (406 Hz) and the first group (411 Hz) from the study conducted by Renwick (2012) score the maximum values for F1. The second formant spans between 675 Hz (Şuteu 1963 – group 1) and 1324 Hz (Renwick 2012 – group 2).

## 4. Ultrasound experiment on Romanian vowels

This section highlights the preliminary results obtained from an ultrasound experiment carried out at ILPGA, (Paris 3, France), during a LabEx EFL mobility grant (Oct. 2016 – Jan. 2017).

From the beginning, we would like to state that the productions are our own. A general clinical ultrasound was used, with the probe placed at the median plane of the mandible. The vowels were recorded in one session[8] (sustained vocalization), without altering the position of the probe. The results are presented in Figure 14. The tip of the tongue is portrayed on the right part of the image. From these preliminary results we can deduce various aspects as following. Among front vowels, /i/ appears to be articulated with the tongue tip placed more anterior than /e/. As for the central vowels, we observe that /a/ is the furthest back central vowel, followed by /ə/ and /ɨ/. When comparing /o/ with /u/, we observe that /o/ is more posterior than /u/.

[8] During the recording, we were assisted by PhD student Yaru Wu, under the supervision of Martine Adda-Decker.

Given this description, along the front – back axis, we would place the vowels in the following order: /i/ – /e/ – /ɨ/ – /ə/ – /a/ – /u/ – /o/. This hierarchy should be treated with caution, since no additional measurements were taken.

The results are portrayed in Figure 14:

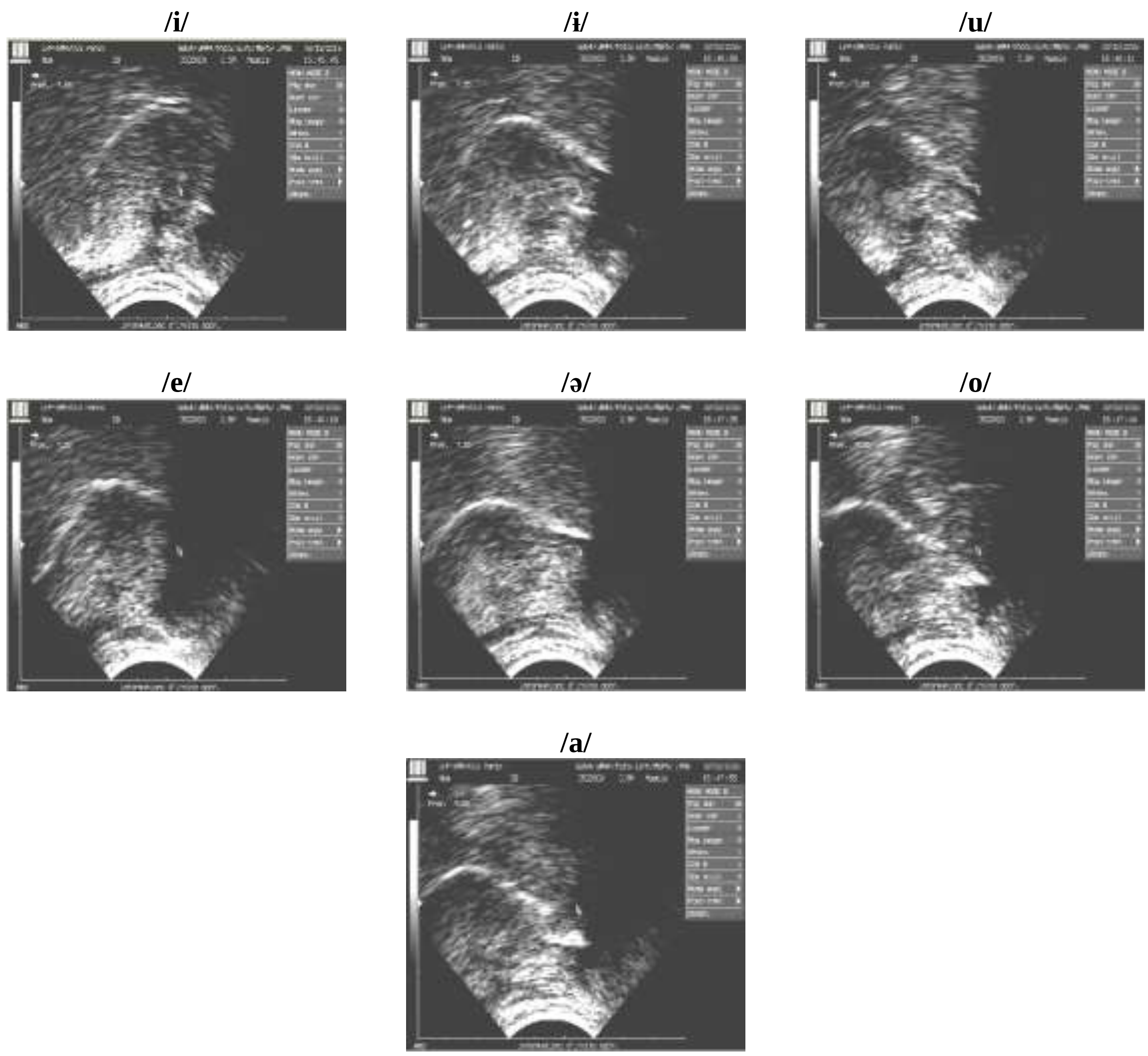



**Figure 14.** Ultrasound images of the vowels /i/, /ɨ/, /u/, /e/, /ə/, /o/, /a/

## 5. Conclusions

This study aimed to describe the Romanian vocalic system at the interface between acoustic and articulatory phonetics.

By mapping the data onto acoustic spaces, we gain a better understanding of how the vowels cluster together, what is the acoustic distance between the seven monophthongs and how they vary along the F1 and F2 axis. In turn, these observations can provide new insights into the phonological changes concerning the vocalic system.

### 5.1 F1 frequency hierarchies

In conclusion, the hierarchies of the mean frequencies for the first formant gathered from the reviewed studies are as following.

**Table 6.** F1 frequency hierarchy based on the data collected from Avram (1963)

| Avram (1963) | | |
|---|---|---|
| | **$F1_{max}$** (low) ⟵ | ⟶ **$F1_{min}$** (high) |
| | **/ə/** | **/ɨ/** |
| Group 1 | 548 | 315 |
| Group 2 | 499 | 345 |
| Group 3 | 428 | 325 |
| **General** | **497** | **332** |

**Table 7.** F1 frequency hierarchy based on the data collected from Șuteu (1963)

**Șuteu (1963) – Group 1**

| **$F1_{max}$** (low) ⟵ | | | | ⟶ **$F1_{min}$** (high) |
|---|---|---|---|---|
| **/a/** | **/e/** | **/o/** | **/u/** | **/i/** |
| 753 | 383 | 360 | 348 | 318 |

**Șuteu (1963) – Group 2**

| **$F1_{max}$** (low) ⟵ | | | | ⟶ **$F1_{min}$** (high) |
|---|---|---|---|---|
| **/a/** | **/o/** | **/e/** | **/u/** | **/i/** |
| 724 | 435 | 396 | 333 | 300 |

**Șuteu (1963) – Group 3**

| **$F1_{max}$** (low) ⟵ | | | | ⟶ **$F1_{min}$** (high) |
|---|---|---|---|---|
| **/a/** | **/e/** | **/o/** | **/i/** | **/u/** |
| 640 | 442 | 433 | 331 | 325 |

**Șuteu (1963) – General**

| **$F1_{max}$** (low) ⟵ | | | | ⟶ **$F1_{min}$** (high) |
|---|---|---|---|---|
| **/a/** | **/o/** | **/e/** | **/u/** | **/i/** |
| **703** | **416** | **399** | **339** | **310** |

**Table 8.** F1 frequency hierarchy based on the data collected from Teodorescu (1985)

| | Teodorescu (1985) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **F1max** (low) | | | | | **F1min** (high) | |
| | **/a/** | **/ə/** | **/o/** | **/e/** | **/ɨ/** | **/u/** | **/i/** |
| Group 1 | 646 | 490 | 466 | 459 | 289 | 270 | 243 |
| Group 2 | 634 | 527 | 468 | 463 | 319 | 305 | 228 |
| **General** | **640** | **508** | **467** | **461** | **304** | **286** | **236** |

**Table 9.** F1 frequency hierarchy based on the data collected from Renwick (2012)

| Renwick (2012) – Group 1 | | | | | | |
|---|---|---|---|---|---|---|
| **F1max** (low) | | | | | **F1min** (high) | |
| **/a/** | **/ə/** | **/e/** | **/o/** | **/ɨ/** | **/u/** | **/i/** |
| 897 | 636 | 603 | 591 | 444 | 411 | 377 |

| Renwick (2012) – Group 2 | | | | | | |
|---|---|---|---|---|---|---|
| **F1max** (low) | | | | | **F1min** (high) | |
| **/a/** | **/ə/** | **/o/** | **/e/** | **/ɨ/** | **/u/** | **/i/** |
| 856 | 583 | 573 | 552 | 450 | 406 | 333 |

| Renwick (2012) – Group 3 | | | | | | |
|---|---|---|---|---|---|---|
| **F1max** (low) | | | | | **F1min** (high) | |
| **/a/** | **/ə/** | **/o/** | **/e/** | **/ɨ/** | **/u/** | **/i/** |
| 679 | 519 | 497 | 495 | 381 | 363 | 317 |

| Renwick (2012) – Group 4 | | | | | | |
|---|---|---|---|---|---|---|
| **F1max** (low) | | | | | **F1min** (high) | |
| **/a/** | **/o/** | **/ə/** | **/e/** | **/ɨ/** | **/u/** | **/i/** |
| 685 | 494 | 490 | 438 | 392 | 365 | 294 |

In terms of F1 frequency hierarchies, we present the following observations.

The high vowels /i, ɨ, u/. From Şuteu (1963), we learn that /i/ is higher than /u/. Based on the data collected by Teodorescu (1985) and Renwick (2012), we conclude that /i/ is higher than /u/, which in turn is higher than /ɨ/. In addition, these observations align Romanian with the results obtained by de Boer (2011), his study demonstrating that for the 29 out of the 30 languages under investigation, F1 is higher for high back vowels than for high front vowels.

The mid vowels /e, ə, o/. The vowel /o/ is lower than /e/ in the study conducted by Şuteu (1963). Teodorescu (1985) alongside Renwick (2012), groups 2 and 3, place /e/ as the highest mid vowel, followed by /o/ and /ə/. For stressed vowels produced by female speakers, Renwick (2012) proposes the order /o/ – /e/ – /ə/, where /ə/ is the lowest mid vowel. As for unstressed vowels recorded by male speakers, the hierarchy is /e/ – /ə/ – /o/, the back vowel presenting the highest F1 mean value.

### 5.2 F2 frequency hierarchies

To sum up, the hierarchies of the mean frequencies for the second formant gathered from the reviewed studies are as follows.

**Table 10.** F2 frequency hierarchy (based on data collected from Avram 1963)

**Avram (1963) – Group 1**

| $F2_{max}$ (front) ← | | → $F2_{min}$ (back) |
|---|---|---|
| | **/ɨ/** | **/ə/** |
| | 1584 | 1400 |

**Avram (1963) – Group 2**

| $F2_{max}$ (front) ← | | → $F2_{min}$ (back) |
|---|---|---|
| | **/ɨ/** | **/ə/** |
| | 1613 | 1499 |

**Avram (1963) – Group 3**

| $F2_{max}$ (front) ← | | → $F2_{min}$ (back) |
|---|---|---|
| | **/ə/** | **/ɨ/** |
| | 1534 | 1506 |

**Avram (1963) – General**

| $F2_{max}$ (front) ← | | → $F2_{min}$ (back) |
|---|---|---|
| | **/ɨ/** | **/ə/** |
| | **1588** | **1479** |

**Table 11.** F2 frequency hierarchy (based on data from Şuteu 1963)

**Şuteu (1963)**

$F2_{max}$ (front) ← → $F2_{min}$ (back)

| | **/i/** | **/e/** | **/a/** | **/o/** | **/u/** |
|---|---|---|---|---|---|
| Group 1 | 2225 | 2025 | 1147 | 700 | 675 |
| Group 2 | 2106 | 1937 | 1346 | 1069 | 985 |
| Group 3 | 2158 | 1788 | 1313 | 1200 | 1100 |
| **General** | **2145** | **1935** | **1310** | **985** | **850** |

**Table 12.** F2 frequency hierarchy (based on data from Teodorescu 1985)

| | **Teodorescu (1985)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **F2$_{max}$** (front) | | | | | **F2$_{min}$** (back) | |
| | **/i/** | **/e/** | **/ɨ/** | **/ə/** | **/a/** | **/o/** | **/u/** |
| Group 1 | 2134 | 1790 | 1440 | 1343 | 1210 | 811 | 686 |
| Group 2 | 2154 | 1767 | 1404 | 1327 | 1176 | 762 | 723 |
| **General** | **2144** | **1778** | **1423** | **1335** | **1193** | **787** | **703** |

**Table 13.** F2 frequency hierarchy (based on data from Renwick 2012)

| | **Renwick (2012)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **F2$_{max}$** (front) | | | | | **F2$_{min}$** (back) | |
| | **/i/** | **/e/** | **/ɨ/** | **/ə/** | **/a/** | **/u/** | **/o/** |
| Group 1 | 2720 | 2095 | 1600 | 1503 | 1463 | 1106 | 1003 |
| Group 2 | 2745 | 1961 | 1850 | 1595 | 1473 | 1324 | 1073 |
| Group 3 | 2151 | 1737 | 1482 | 1377 | 1302 | 1116 | 993 |
| Group 4 | 2149 | 1710 | 1683 | 1446 | 1239 | 1232 | 986 |

In terms of F2 frequency hierarchies, we present the following observations.

The front vowels /i, e/. In this case, the results unanimously attest that /i/ has a more fronted realization compared to /e/. These results are also confirmed by ultrasound.

The central vowels /ɨ, ə, a/. From Avram (1963), we learn that /ɨ/ has a more fronted actualization than /ə/. Teodorescu (1985) and Renwick (2012), all four groups, show that /a/ is the most back central vowel, followed by /ə/ and /ɨ/, where /ɨ/ registers the highest F2 mean value. These observations are also confirmed by the ultrasound experiment.

The back vowels /u, o/. Similar to the case of mid vowels, the F2 hierarchies for back vowels also vary among the authors. On the one hand, for Şuteu (1963) and Teodorescu (1985), /u/ is the farthest-back vowel. On the other hand, the measurements taken by Renwick (2012) state that /o/ is more back than /u/. At the present moment, from the preliminary results obtained with the ultrasound, we can confirm Renwick's account.

### 5.3 Future research

The acoustic and articulatory study of Romanian vowels can continue in various directions.

First, we suggest elaborating new experiments which take into consideration the effects of consonantal context over the frequencies of F1 an F2 (see Stevens and House 1963, Hillenbrand et al. 1995, 2001, to name just a few).

Second, there is the matter of where the measurements of formant frequencies are actually taken. We propose a departure from the central, "steady-state" extraction, and test various points in the vowels so as to map F1 and F2 trajectories (Hillenbrand 201). In turn, this approach can lead to an integrated description of monophthongs and diphthongs.

Third, we argue for correlating the frequency domain with the temporal domain in the future studies.

Fourth, we recommend looking at large corpora of forced aligned spontaneous speech (Vasilescu et al. 2016b, Niculescu et al. 2017), which have proven to be of high relevance in acoustic analysis, testing various linguistic hypothesis and exploring sound change and variation (Ohala 1996, Adda-Decker 2006, Vasilescu et al. 2015).

Fifth, we would like to continue and reduplicate the ultrasound experiment, also taking into account different measurements.

The last recommendation deals with perceptual studies, since there is little information concerning Romanian data from this perspective.

Last but not least, we hope that acoustic and articulatory studies will have a better representation within the field of Romanian linguistics.

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