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COMPARATIVE STUDY OF THE QUALITATIVE FEATURES OF THE LITHUANIAN AND LATVIAN MONOPHTHONGS

INTRODUCTION

Affinity of two surviving Baltic languages implies a preconcieved provision of two similar sound systems[1]. Both contemporary Baltic languages have many similarities, for example, phonological opposition of long and short vowels, a large number of diphthongs, and a pitch accent system; however, Lithuanian and Latvian sound systems have some significant differences, too (cf. Endzelin 1971; LG 1997, 24–39; Dini 2000; 2014; Balode, Holvoet 2001a, 10–12; 2001b, 46–48; Girdenis 2003 (= 2014); Kaukėnienė 2001; 2004a; 2004b; Kudirka 2005; Bacevičiūtė 2009; LVG 2013, 41–44, 75–79, etc.).

Until recently, mostly separate characteristics of the vowels of contemporary Standard Lithuanian and Standard Latvian employing more or less similar methodology have been examined. For example, the first extensive acoustic analysis (based on the results of experimental research) of unstressed vowels in Standard Baltic languages was presented by Lidija Kaukėnienė in her doctoral thesis (2004a): mainly various trisyllabic Lithuanian and Latvian words have been investigated to analyze the vowels in the pre-stressed and post-stressed position. Afterwards the spectra of pre-stressed and post-stressed vowels had been compared with the spectra of the corresponding stressed vowels, it was stated that in both languages unstressed vowels are reduced both qualitatively and quantitatively. The conclusions of that study suggest that the phonetic reduction is more distinct in Lithuanian than in the Latvian language. Both stress and the vowel's position with respect to stress make an impact on the quality and quantity of the vowels.

[1] The Baltic languages have retained the original sounds better than any other living Indo-European language (Endzelin 1971, 23).

Some prosodic features of stressed monophthongs both in Standard Lithuanian and Standard Latvian were analyzed by Robertas Kudirka (2005). The analysis of the spectrograms was based on investigation and description of the following attributes of the monophthongs: fundamental frequency, intensity, duration, and formant values. To carry out a comparison of the named features, mainly disyllabic Lithuanian and Latvian words accented on the first syllable were studied.

In the present article, some intermediate results of the research project "Acoustic characteristics of the sounds of the contemporary Baltic languages (experimental study)"[2] have been analyzed, i. e., the qualitative features of monophthongs of the contemporary Baltic languages pronounced in isolation are described. On the one hand such a production of vowels do not represent a pronunciation in everyday speech, while on the other hand their production is probably the closest to the acoustic and auditory monophthong targets determined by our mental prototypes.

The necessity to study and compare spectral structure of Lithuanian and corresponding Latvian isolated vowels using the same research methods could be explained as follows:

1) vowels produced in zero context[3] have not been studied and compared yet using the same methods and equipment that would permit a reliable comparison of phonetic inventories (quality similarities and differences) of both languages;
2) a comparison of the spectral characteristics of the isolated Lithuanian and the Latvian vowels will create a base for further corresponding

[2] The project *Acoustic characteristics of the sounds of the contemporary Baltic languages (experimental study)* (agreement No. MIP-081/2013) is funded by the Research Council of Lithuania and is carried out at the Institute of the Lithuanian Language.

[3] This type of production represents natural hyper-articulation and differs from production of the cardinal vowels (recordings of these vowels by Daniel Jones and others are available commercially) which have artificial articulation and are purposefully made by following a set of articulatory instructions, or isolated vowels of any language produced like cardinals (cf. Roca, Johnson 1999, 114–140; Kaukėnienė 2004b). Since cardinal vowels are idealized vowel sounds (cf. Jassem 1973, 190, table 13.1), they do not therefore necessarily correspond to the real vowels of any natural language or dialect (cf. Ladefoged 1975, 194–199; Murinienė 1998; Roca, Johnson 1999, 126; Bacevičiūtė 2000; Leskauskaitė 2000; Kaukėnienė 2004b; Urbanavičienė 2004; Jaroslavienė 2011, etc.).

comparative research of the sounds (allophonic variation of the phonemes) in both contemporary Baltic languages;

3) it would be a possibility to find out if analyzing isolated vowels may allow to define the acoustic targets, information of which might be important for the description of the sound system of any language.

The aim of the study

The aim of this paper is to describe and compare the main qualitative features (based on analysis of spectral characteristics and some of acoustic features) of the Lithuanian and the Latvian long and short monophthongs (i. e., vowels of uniform articulation[4]) pronounced in isolation by 12 male informants (20 to 50 years old).

Research material and the methods applied

The following sounds pronounced in zero context have been analyzed (IPA symbols are used in the present article):

Lithuanian vowels /ɩ[5], ɛ, a, ɔ, ω[6], iː, eː, æː, ɑː, oː, uː/ (corresponding traditional Lithuanian phonetic symbols would be */i, e, a, ɔ, u, i·, ę·, e·, a·, o·, u·/* accordingly) and

Latvian vowel /i, e, æ, ɑ, ɔ, u, iː, eː, æː, ɑː, ɔː, uː/ (corresponding traditional Latvian phonetic symbols would be */i, e, ę, a, o, u, ī, ē, ę̄, ā, ō, ū/* accordingly).

For this paper recordings (1944 items were selected and analyzed in total) of 6 native Lithuanian and 6 native Latvian male informants (having faultless articulation) were used. All informants are speakers of standard language. In this study the standard language is considered as a standardized language (generally the most formal version of the language) used for the needs of public life and culture (cf. LKE 1999, 87).

The material for research was recorded in closed premises using an Audio recorder (*Tascam HD-P2*) as well as a directional headset condenser microphone (*AKG C 520*). The given material was pronounced in a habitual speed and the most possible neutral way. All the Lithuanian and Latvian recordings were further transferred to computer memory and saved using the

[4] Sounds of changing articulation (/iɛ, uɔ/) will be compared and described separately in another upcoming article.

[5] This symbol was used in the "Lithuanian Grammar" edited by Vytautas Ambrazas (LG 1997). In the current IPA system [ɩ] corresponds to the symbol [ɪ].

[6] This symbol was used in the "Lithuanian Grammar" edited by Vytautas Ambrazas (LG 1997). In the current IPA system [ω] corresponds to the symbol [ʊ].

.wav file format. Segmentation of the analyzed elements was performed using the following sound processing and analysis software programs: an open source tool for sound analysis, visualization and manipulation *WaveSurfer* 1.8.8.p4 (developed by Kåre Sjölander and Jonas Beskow) as well as the program *Praat* 5.3.63 and its later versions (developed by Paul Boersma and David Weenink). The qualitative vocalic features were studied instrumentally on the basis of the purest excerpt of the Lithuanian and Latvian monophthongs: steady state was measured to determine the frequency values (in hertz (Hz)) of the first four formants (F1, F2, F3, and F4)[7]. *MS Excel* (for example, such functions as AVERAGE, SUM, MIN, MAX, STDEV, CONFIDENCE, T.TEST, etc.) was applied for further evaluation of the experimental data, i. e., there were statistical means (in Hz, z), standard deviation (SD, in Hz), coefficient of variation (cv, in %), the lowest and the highest values (in Hz), the coefficient of variation (in %), confidence intervals (in Hz; significance level = 0.001[8]) and the range of lowest and highest values (in Hz) calculated, also the values of F2' (in bark units (z)) were calculated using Anthony Bladon and Gunnar Fant's formula (Bladon, Fant 1978, 3):

$$F_2' = \frac{F_2 + c^2 \cdot (F_3 \cdot F_4)^{1/2}}{1 + c^2}$$

where c is calculated using values B_2=67 Hz un $K(f)$=12 · F2/1400 according to formula:

$$c = K(f) \cdot \frac{B_2 \cdot F_2 \cdot \left(1 - F_1^2 / F_2^2\right) \cdot \left(1 - F_2^2 / F_3^2\right) \cdot \left(1 - F_2^2 / F_4^2\right)}{(F_4 - F_3)^2 \cdot \left(\frac{F_3 \cdot F_4}{F_2^2} - 1\right)}$$

thus taking into account the influence of formants higher than F2 upon the perceptual quality of each monophthong.

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7 The phonological characteristics of the vowels are usually determined by the frequency values of the first two vowel formants (Girdenis 2003, 221–222; Bacevičiūtė 2008, 21; also compare Grigorjevs 2012, 166; DiCanio et al. 2015, 50, etc.).

8 A significance level of 0.001 equates to a confidence level of 99.9% (p=0.001, t=3.29).

For the graphical representations, both the traditional acoustic F2/F1 plane (in Hz) and the psycho-physical[9] F2'/F1 plane[10] (in z) were used in this paper (the mean value of the second formant of each vowel determins its coordinates on abscissae axis, while the mean value of the first formant – on ordinate axis). The transformation of the measured formant values (in Hz) into psycho-physical units (i. e. to bark (z) units) has been performed using Hartmut Traunmüller's formula[11] (see Traunmüller 1988, 97):

$$z = \left(26.81 \cdot \frac{f}{1960 + f}\right) - 0.53$$

The size of the monophthong symbols on the psycho-physical F2'/F1 plane is chosen so that they are represented by circles with the diameter 1 z, thus showing the zones of the equal perceptual quality (cf. Iivonen 1987).

The placement of monophthongs of each informant in planes has been based on mean values in hertz of each vowel (see Figures 1, 5), and the placement of monophthongs characterizing Lithuanian or Latvian male pronunciation has been based on the mean values calculated from the particular formant values (in Hz and z) obtained for 6 Lithuanian and accordingly 6 Latvian informants together (72 productions of each Lithuanian and 54 productions of each Latvian monophthong) (see Figures 3, 4, 7, 8, 9, Tables 1–4). Spectrogram examples are provided in Figures 2.1–2.12 and 6.1–6.12.

Reviewing interrelations between vowels of a single language (Lithuanian or Latvian), the mean data acquired in this study is compared with the data of some previous studies (see Figures 4 and 8).

To compare the general tendencies of the relations between Lithuanian and corresponding Latvian long and short monophthongs pronounced in

[9] The best representation of the vowel system is by using some scale that takes into account the peculiarities of human hearing. The Bark scale has been used in this article. This was done to achieve a more even spacing of vowels along the horizontal and vertical axis taking into account the logarithmic nature of perception (Grigorjevs 2013, 303).

[10] To account for the influence of the higher formants upon the perception of the vowel quality and to depict vowels on the two-dimensional vowel plane Gunnar Fant suggested using values of the first formant (F1) and the effective second formant (F2′) calculating F2′ from measured F1, F2, F3 and F4 (Fant 1983, 7; Bladon, Fant 1978, 3; also see Grigorjevs 2013, 304–308).

[11] In this formula *z* is the value of Critical Bands in barks, and *f* is frequency in hertz.

isolation more precisely, the program FORMANT2.PAS[12] was also used – according to the mean values of F1, F2, and F3 (Hz) the following acoustic parameters (numeric values) were calculated: flatness (Lith. *bemoliškumas*), compactness (Lith. *kompaktiškumas*), tenseness (Lith. *įtempimas*), and graveness or acuteness (Lith. *tonalumas*) (see Tables 2, 4).

The analysis of both languages has been based on the objective methods. The study embraces experimental, descriptive, and comparative approaches.

RESULTS AND DISCUSSION

The analysis of spectral characteristics and distinctive qualitative features of the Lithuanian monophthongs produced in zero context

The vowel system of Standard Lithuanian consists of long /iː, eː, æː, ɑː, oː, uː, iɛ, uɔ/ and short /ɪ, (<e>), ɛ, a, <ɔ>, ɷ/ (LG 1997, 28). Short phonemes /ɔ/ and optional /e/ are regarded as peripheral: /ɔ/ occurs in words of foreign origin only as well as in some Lithuanian proper names; while instead of optional close mid sound [e] a short [ɛ] is usually pronounced (cf. Girdenis 2003, 191; Pakerys 2003, 32–35, etc.). In the present paper, as it was mentioned above, Lithuanian /iː, eː, æː, ɑː, oː, uː, ɪ, ɛ, a, ɔ, ɷ/ were selected to be analyzed. The allophonic variation of the phonemes (influence of palatalized consonants, stress and syllabic tonemes) will be studied separately in further research.

To review the general tendencies of the Lithuanian long and short vowels, the individual data of all 6 Lithuanian male informants (speakers) should be shortly described first (see Figure 1 and examples of the spectrograms in Figures 2.1–2.12).

As can be seen in Figure 1 (also see Figures 2.1–2.12, Table 1), in all cases long monophthongs are located more peripherally on the acoustic F2/F1 (Hz) plane than their short counterparts respectively, although individual results of each informant vary to some extent. Despite the fact that the spectra of vowels depend on the individual speaker, it can be seen that there always remain certain quite constant relations (also compare Ladefoged 1967, 57; Sapir 1973, 104; Girdenis 2003, 222; Jaroslavienė 2014, 72, 82, etc.), for example:

[12] The program FORMANT2.PAS was created by Aleksas Girdenis on the basis of the method offered by Raymond Piotrovsky (Piotrovsky 1960, 24–38; also see Girdenis 2014, 238, footnote 144 and references).

- [iː], [eː], [ɪ] have a very high second formant (i. e. [iː] F2 = 2201 to 2492 Hz; [eː] F2 = 1922 to 2327 Hz; [ɪ] F2 = 1820 to 2205 Hz) and a very low first formant (i. e. [iː] F1 = 257 to 330 Hz; [eː] F1 = 396 to 496 Hz; [ɪ] F1= 323 to 425 Hz); analysis of the distance between the first and the second formant, as well as between the second and the third formant revealed that among all the Lithuanian vowels (both long and short ones) [iː], [eː], [ɪ] have the maximum distance between their F1 and F2 and the minimum distance between F2 and F3 (cf. Figures 2.1–2.4);
- both formants of [uː], [oː], [ɷ], [ɔ] are relatively low (arround 460 Hz and 830 Hz accordingly, i. e., [uː] F1 = 281 to 417 Hz, F2 = 576 to 705 Hz; [oː] F1 = 412 to 563 Hz, F2 = 655 to 872 Hz; [ɷ] F1 = 375 to 510 Hz, F2 = 810 to 979 Hz; [ɔ] F1 = 537 to 627 Hz, F2 = 897 to 1132 Hz); of all the long vowels [oː] and [uː] have the smallest distance between F1 and F2 and the largest – between F2 and F3; respectively, the same phenomenon is observed for short vowels [ɔ] and [ɷ] (cf. Figures 2.9–2.12);
- the first formant of [ɑː], [a] and [æː], [ɛ] is quite high (arround 730 Hz) while the second formant of [ɑː] and [a] is relatively low (arround 1250 Hz), i. e., close to the first formant, but the second formant of [æː] and [ɛ] is higher (F2 is arround 1710 Hz) – it is higher than that of [ɑː], [a] and lower than that of [iː], [eː], [ɪ] (e. g. [ɑː] F1 = 750 to 938 Hz, F2 = 1142 to 1268 Hz; [a] F1 = 610 to 782 Hz, F2 = 1120 to 1397 Hz; [æː] F1 = 680 to 795 Hz, F2 = 1616 to 1837 Hz; [ɛ] F1 = 535 to 714 Hz, F2 = 1608 to 1795 Hz). Among all the long and short vowels F3 of vowels [ɑː] and [a] is the closest to F1 (while F3 of [iː], [eː] and [ɪ] is the most distant from F1) (cf. Figures 2.5–2.8).

According to the mean values of the formants and statistical data summarized in the Table 1 (also compare Figures 1 and 3), the distance between the lowest (min) and the highest (max) values of the F1, F2 and F3 (in Hz), coefficient of variation (in percent) and the confidence intervals (in Hz) are going to be discussed to acquire a better understanding of the acoustic properties of vowels.

Comparing the distances from the lowest to the highest value for each formant of the Lithuanian vowels, the largest distances between values of $F1_{min}$ and $F1_{max}$ were observed for vowels [ɑː], [ɛ] and [a] (the distances could range from 172 to188 Hz), while [iː] had the smallest distance between values of $F1_{min}$ and $F1_{max}$ (73 Hz). Vowel [ɑː] had the smallest distance between values of $F2_{min}$ and $F2_{max}$ (126 Hz), at the same time having the largest distance between values of $F1_{min}$ and $F1_{max}$ (188 Hz). The distances between values of

$F2_{min}$ and $F2_{max}$ for vowels [iː], [ɪ] and [eː] are the largest (291 Hz, 385 Hz and 405 Hz respectively). For all the vowels the distance between values of $F3_{min}$ and $F3_{max}$ ranges from 211 to 497 Hz. The mean values of F3 for vowels [ɑː], [oː], [uː], [a], [ɔ], [ɷ] are usually lower than those for [iː], [eː], [æː], [ɪ], [ɛ].

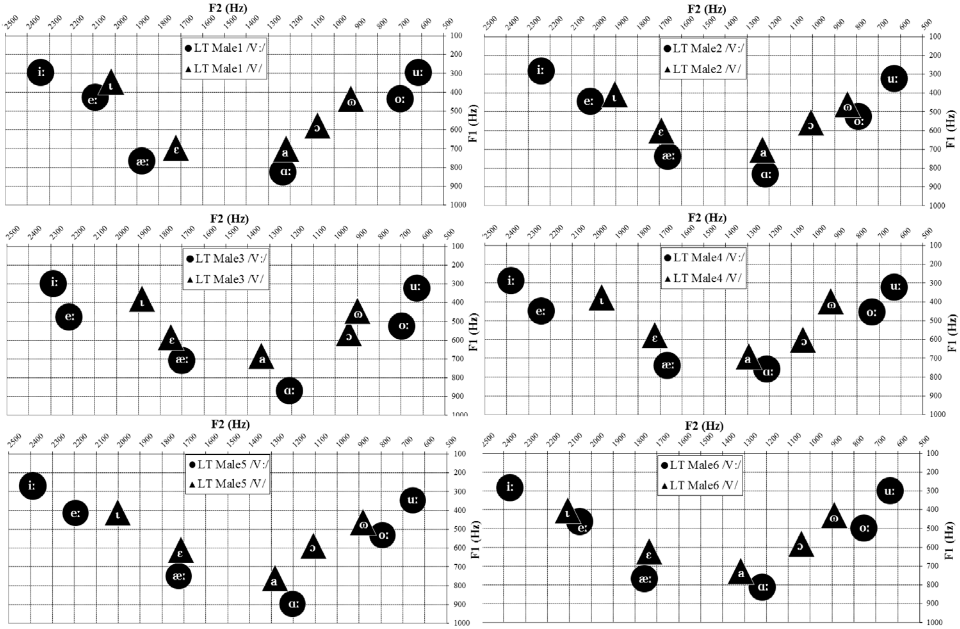


Figure 1. **Lithuanian monophthongs produced in zero context (isolation) by 6 male speakers in the acoustic F2/F1 (Hz) plane**. Filled circles represent long vowels, filled triangles – short vowels.

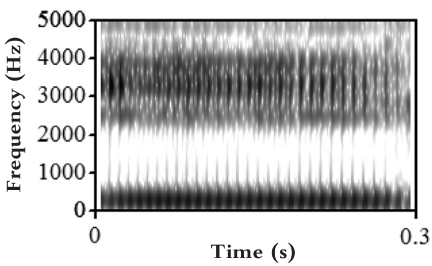


Figure 2.1. **Isolated [iː] produced by the first Lithuanian male speaker**

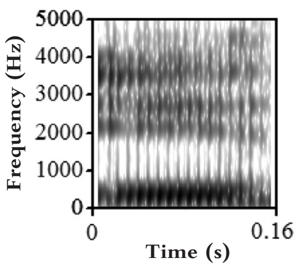


Figure 2.2. **Isolated [ɪ] produced by the first Lithuanian male speaker**

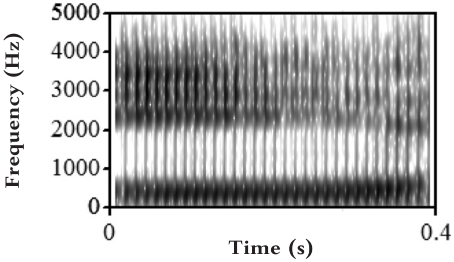


Figure 2.3. **Isolated [eː] produced by the first Lithuanian male speaker**

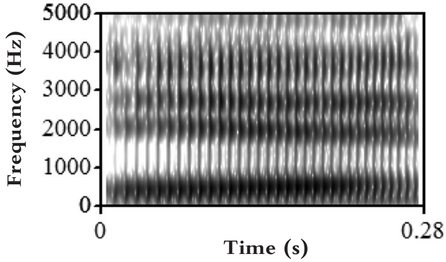


Figure 2.4. **Isolated [eː] produced by the second Lithuanian male speaker**

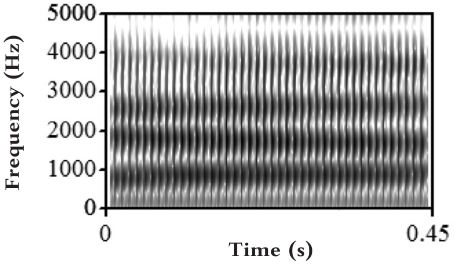


Figure 2.5. **Isolated [æː] produced by the first Lithuanian male speaker**

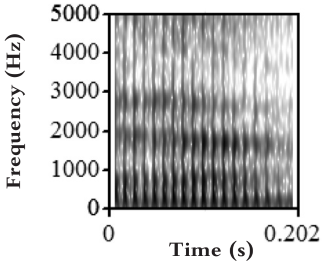


Figure 2.6. **Isolated [ɛ] produced by the third Lithuanian male speaker**

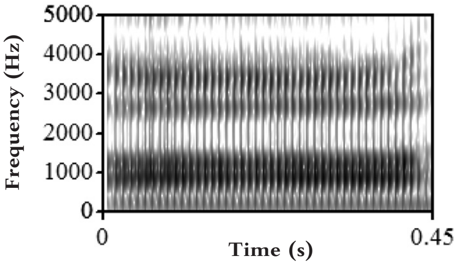


Figure 2.7. **Isolated [ɑː] produced by the fourth Lithuanian male speaker**

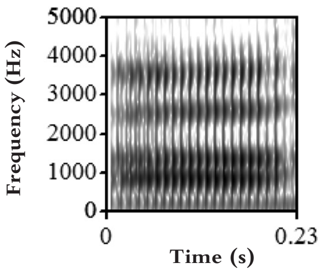


Figure 2.8. **Isolated [a] produced by the fourth Lithuanian male speaker**

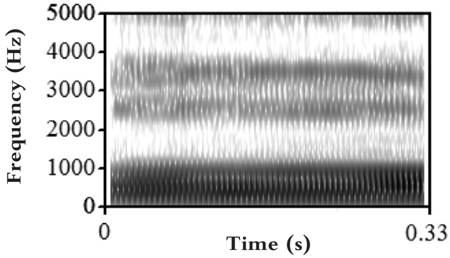


Figure 2.9. **Isolated [oː] produced by the sixth Lithuanian male speaker**

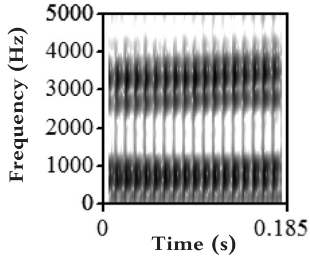


Figure 2.10. **Isolated [ɔ] produced by the third Lithuanian male speaker**

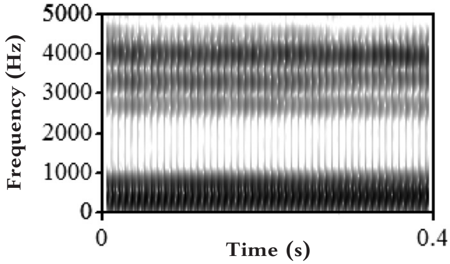


Figure 2.11. **Isolated [uː] produced by the fifth Lithuanian male speaker**

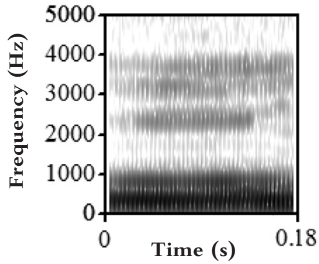


Figure 2.12. **Isolated [ɷ] produced by the second Lithuanian male speaker**

The estimated coefficient of variation proves that the mean values of the first formant of the Lithuanian vowels pronounced in isolation ranges from 4% to 9%, the mean values of the second formant ranges from 3% to 7% and the mean values of the third formant – merely from 2% to 6% (see Table 1).

The confidence intervals calculated for the formant (F1, as well as F2) values of the Lithuanian long and corresponding short vowels do not overlap (chosen significance level is 0.001), what leads to the conclusion that the quality of long and the corresponding short vowels pronounced in isolation varies statistically significantly. The Student's t-Test confirms[13] that there is a statistically significant difference (significance level 0.05) between the

[13] The T.Test analysis (two-tailed distribution; Type 'paired'; significance level 0.05) was performed to determine whether there is a statistically significant difference between the formant values (F1, as well as F2) of the long and corresponding short Lithuanian vowels produced in isolation by 6 native male speakers (the same analysis was perfomed on the Latvian data, too).

values of the F1 (as well as F2, except F2 of [ɛ] and [æː]) of the long and the corresponding short Lithuanian vowels. Graphical representation in the psycho-physical F2´/F1 (z) plane (see Figure 3b) also reveals significant differences between the long and the corresponding short monophthongs.

T a b l e 1. **Lithuanian vowels produced in zero context by 6 male speakers**: statistical means of the formants (Hz), the lowest (min) and the highest (max) values of the formants (Hz), standard deviation (SD, in Hz), coefficient of variation (cv, in %), and the confidence intervals (Hz)

Lithuanian vowels	F1			F2			F3		
	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)
[iː]	287±18 (257; 330)	6	284÷290	2351±74 (2201; 2492)	3	2346÷2356	3059±151 (2792; 3264)	5	3050÷3068
[ɪ]	385±27 (323; 425)	7	380÷390	2001±110 (1820; 2205)	6	1993÷2009	2609±83 (2461; 2717)	3	2604÷2614
[eː]	447±25 (396; 496)	6	443÷451	2169±107 (1922 ;2327)	5	2161÷2177	2833±120 (2667; 2994)	4	2826÷2840
[æː]	745±33 (680; 795)	4	741÷749	1697±57 (1616; 1837)	3	1692÷1702	2610±81 (2397; 2718)	3	2605÷2615
[ɛ]	613±46 (535; 714)	8	607÷619	1718±50 (1608; 1795)	3	1714÷1722	2616±54 (2523; 2737)	2	2613÷2619
[ɑː]	832±56 (750; 938)	7	826÷838	1216±30 (1142; 1268)	3	1213÷1219	2508±72 (2379; 2745)	3	2503÷2558
[a]	709±42 (610; 782)	6	704÷714	1280±62 (1120; 1397)	5	1274÷1286	2479±116 (2303; 2687)	5	2471÷2487
[oː]	496±42 (412; 563)	9	490÷502	743±52 (655; 872)	7	737÷749	2562±146 (2314; 2798)	6	2552÷2572
[ɔ]	576±26 (537; 627)	5	572÷580	1036±61 (897; 1132)	6	1030÷1042	2522±58 (2424; 2635)	2	2518÷2526
[uː]	320±28 (281; 417)	9	315÷325	631±30 (576; 705)	5	627÷635	2571±106 (2346; 2731)	4	2564÷2578
[ɷ]	436±29 (375; 510)	7	431÷441	893±37 (810; 979)	4	889÷897	2592±142 (2346; 2843)	6	2583÷2661

The mean values of the first three formants could be used to calculate the acoustic parameters associated with the features "acute"–"grave", "compact"– "diffuse", "flat"–"plain" and "tense"–"lax" (see Table 2, cf. with Table 1, Figures 1–3). According to the height of tonality (the timbre) [iː],

[eː], [æː] and [ɪ], [ɛ] pronounced in isolation are to be considered as acute vowels, they appear to be of a higher timbre (their second formant is higher than 1500 Hz, the numeric values of the graveness index are positive[14]) in comparison with corresponding grave or, more precisely, non-acute[15] vowels [ɑː], [oː], [uː] and [a], [ɔ], [ɷ] (the second formant of these vowels is below 1500 Hz, the graveness index of all the low-timbre sounds is negative).

Among the long vowels of Standard Lithuanian vowel [iː] is of the highest timbre (F2 = 2351 Hz, numeric value of graveness is 799), vowel [eː] is of the lower timbre (F2 = 2169 Hz, index of graveness is 570), while vowels [uː] (F2 = 631 Hz, numeric value of graveness is -315) and [oː] (F2 = 743 Hz, numeric value of graveness is -362) are of the lowest timbre. Among the short vowels [ɪ] is of the highest timbre (F2 = 2001 Hz, numeric value of graveness is 601), while [ɷ] (F2 = 893 Hz, index of graveness is -151) and [ɔ] (F2 = 1036 Hz, numeric value of graveness is -131) are of the lowest timbre. It can be noted that sounds of the lowest-timbre have the highest numeric value of flatness (Table 2); according to these values vowels [oː], [uː], [ɔ], [ɷ] are to be considered as the flat ones: numeric values of flatness are 115 for [uː], 111 for [oː] and [ɷ], and 109 for [ɔ]. According to this index, it might be suggested that the lips are the most active in pronouncing [uː].

Table 2. **Numeric values of the acoustic parameters of the Lithuanian vowels produced in zero context**

Lithuanian vowels	[iː]	[ɪ]	[eː]	[æː]	[ɛ]	[ɑː]	[a]	[oː]	[ɔ]	[uː]	[ɷ]
Compactness	719	773	784	874	846	932	900	920	895	869	871
Flatness	107	107	106	105	106	106	107	111	109	115	111
Graveness	799	601	570	171	265	-149	-31	-362	-131	-315	-151
Tenseness	1623	725	1055	552	447	623	450	823	562	1120	763

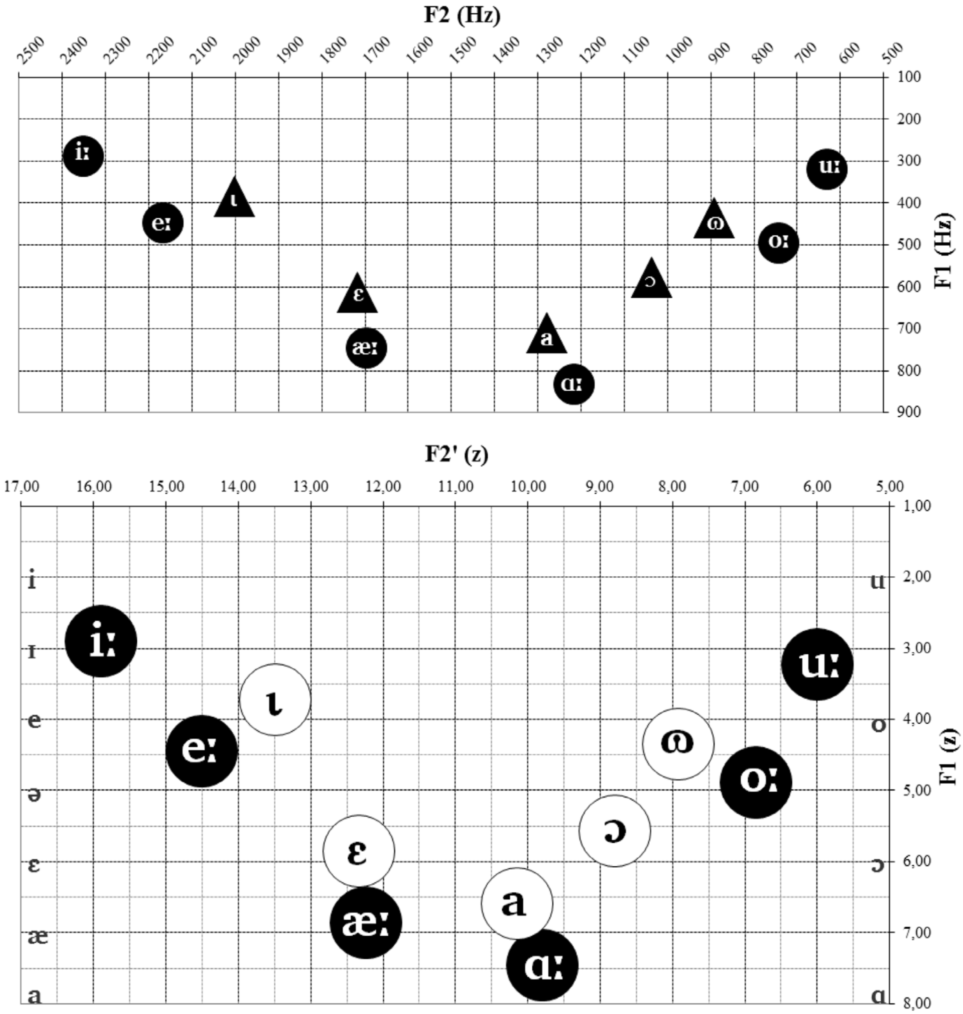
[14] The higher is the timbre the higher is the numeric value of the second formant and of the index (or coefficient) of graveness (showing acuteness of the sound).

[15] In Lithuanian [ɔː], [uː], [ɔ], [ɷ] (also [uɔ]) are realized by two types of allophones: before those vowels both hard and palatalized consonants (and /j/) can occur. After palatalized consonants (and /j/) fronted (i. e. "sharp") allophones are used: at the beginning of their pronunciation, the tongue is well advanced, but then generally pulls back to the position of the basic (i. e. "plain") allophones (cf. Girdenis 2003, 192 and the reference mentioned there, 229; Jaroslavienė 2014, 76–77, etc.). In the current article, the spectrum of basic ("pure" back) allophones is analyzed.

The analysis of the sound spectra shows that acoustic properties of the sound are related to the position of the tongue or mouth opening: the lower the tongue is positioned while pronouncing a vowel, the higher its first formant is. As examples of the spectrograms and Figures 1 and 3, as well as Tables 1 and 2 indicate, in the range of the low-frequency is the first [iː] and [uː] formant (F1 = 287 Hz, 320 Hz respectively), of the other monophthongs pronounced in isolation – [eː], [oː] and [ɪ], [ɔ], [ɷ] – the first formant ranges from 385 to 576 Hz. Among the long vowels Lithuanian [ɑː] and among the short vowels Lithuanian [a] has the highest first formants ([ɑː] F1 = 832 Hz, [a] F1 = 709 Hz respectively), meaning that the tongue is at the lowest position in pronouncing these sounds. The high F1 value (but lower than of vowel [ɑː]) is also characteristic to [æː] ([æː] F1 = 745 Hz; also compare [ɛ] F1 = 613 Hz).

In accordance with the position of both formants, isolated Lithuanian monophthongs can be divided by the degree of compactness (or diffuseness, which is inversely proportional to compactness). As it is provided in the Tables 1 and 2 (compare Figures 1 and 3), the most compact sound is [ɑː]: as it was already mentioned at the beginning of this section (review of the spectrum of vowels, according to the formants and their structure of individual speakers), in the acoustic space the first two formants of this vowel are little remote from each other and from the central part of the spectrum in general (numeric value of [ɑː] compactness is 932). In the margins of the spectrum [iː] and [uː] are located as non-compact and the most diffuse sounds (their spectral energy is dispersed in the margins of the spectrum, and compactness numeric values are from 719 to 869 respectively). Among the short vowels the most compact is the low-timbre [a] (index of compactness is 900), and in the marginal part of the spectrum, but not so peripherally as the long monophthongs [iː] and [uː], the F1 and F2 of short [ɪ] and [ɷ] are located.

The numeric values of tenseness for the Lithuanian long and short vowels show (Table 2) that the higher mean value of this parameter is characteristic to Lithuanian long vowels: tenseness values for [iː] and [ɪ] are 1623 and 725 respectively (i. e. for 898 less); for [uː] and [ɷ] are 1120 and 763 respectively (i. e. for 357 less); for [oː] and [ɔ] are 823 and 562 respectively (i. e. for 261 less). The difference in tension is probably less important distinguishing long isolated [æː], [ɑː] and their short counterparts [ɛ], [ɑ] respectively: tenseness values for [æː] and [ɛ] are 552 and 447 respectively (i. e. for 105 less); for [ɑː] and [a] are 623 and 450 respectively (i. e. for 173 less) (also compare LG 1997, 25; Girdenis 2003, 222, 226, etc.).



F i g u r e 3. **The mean data of the Lithuanian monophthongs produced in zero context (isolation) by 6 male speakers**: **3a** in the acoustic F2/F1 (Hz) plane, and **3b** in the psycho-physical F2´/F1 (z) plane. Filled circles represent long vowels, filled triangles and white circles – short vowels.

As it was already mentioned, spectral characteristics of vowels are closely associated with potential articulatory properties (see acoustic plane in Hz in Figure 3a and psycho-physical plane in z in Figure 3b; also compare Figure 1).

The second formant represents tongue advancement (the positions of the highest point of the tongue in the mouth in the front-back dimension, or more precisely, the resonating chamber formed between the place of tongue height and the lips) (Grigorjevs 2012, 166; also see Girdenis 2003, 223, etc.): accordingly the acute sounds [iː], [eː], [æː], [ɪ], [ɛ] should be regarded as front monophthongs, as the tongue is shifted into the front part of the mouth in pronunciation. The non-acute or grave sounds [ɑː], [ɔː], [uː] and [ɑ], [ɔ], [ɷ] shall be considered as non-front or back, as the tongue shifts to the back part of the mouth in pronunciation. However, even in pronouncing vowels of the same row, position of the tongue is different, as [iː] is the most front and [uː] is the backmost of all the vowels, while among the short vowels [ɪ] is the most front and [ɷ] is the backmost respectively.

The first formant reflects the aperture and height of vowel articulation, thus one can see that isolated monophthongs of Standard Lithuanian are split into low (compact), i. e. open vowels [ɑː], [æː], [ɑ], [ɛ] and non-low (non-compact) vowels: high (diffuse), i. e. close vowels [iː], [uː], [ɪ], [ɷ], and non-high or mid vowels [eː] and [ɔː], [ɔ] (neither diffuse nor compact). According to the mouth openness, the closest Lithuanian vowel is [iː], and [ɑː] is the most opened one. According to the position of the lips, flat short [ɔ], [ɷ] and long [oː], [uː] are rounded sounds. All the remaining (i. e. non-flat or plain vowels [iː], [ɪ], [eː], [æː], [ɛ], [ɑː], [a]) are unrounded.

Reviewing interrelations between Lithuanian vowels, the mean data of this study was compared with the data of some previous research by Aleksas Girdenis (see data in Girdenis 2003, 222, Table 25) and Lidija Kaukėnienė (see Kaukėnienė 2004b, 201, Table 1). The data (see Figure 4) shows that most vowels analyzed in this study more or less occupy in acoustic plane the similar position compared with the vowels of the previous studies. It can be observed that qualitative characteristics of the Lithuanian short and corresponding long vowels differ significantly: short vowels of different studies are centralized (shifted to the central part of the acoustic plane) in comparison to the placement of the corresponding long vowels.

Despite the fact that the mean values of F1 and F2 of Lithuanian vowels obtained in different studies vary (Figure 4), the general tendencies of vowel interrelation remain the same and vowel classification follows the same pattern.

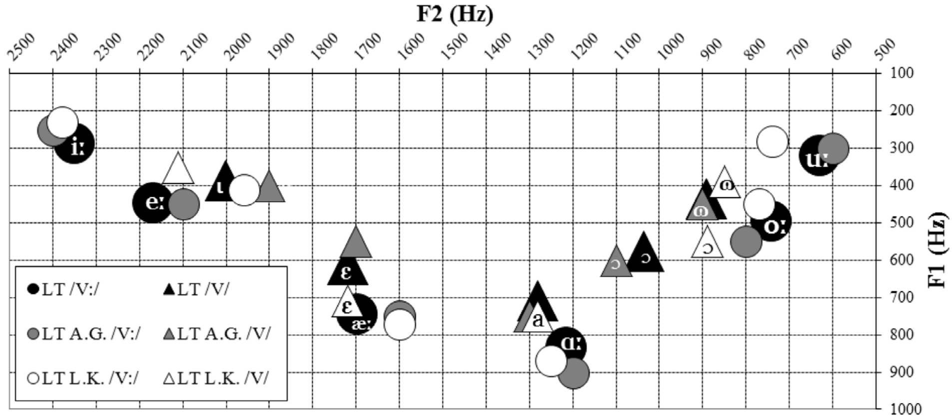


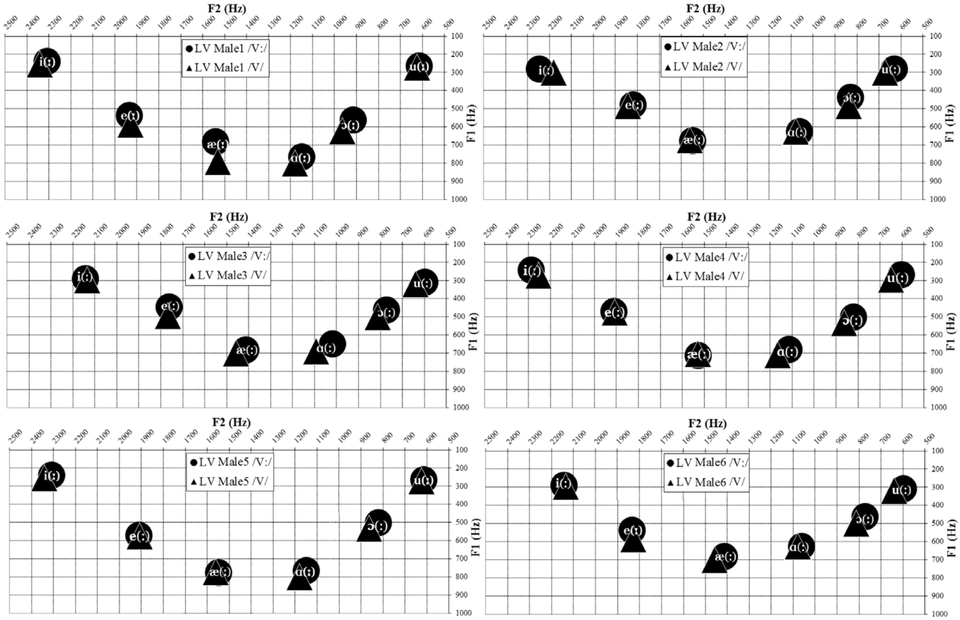
Figure 4. **The mean data of the Lithuanian monophthongs in the acoustic F2/F1 (Hz) plane**:
the mean data acquired in the present study is marked with large black symbols;
the data provided by Aleksas Girdenis (A.G.) (Girdenis 2003, 222) is marked with small grey symbols, and the data by Lidija Kaukėnienė (L.K.) (Kaukėnienė 2004b, 201) is marked with small white symbols.
Circles represent long vowels, triangles – short vowels.

The analysis of spectral characteristics and distinctive qualitative features of the Latvian monophthongs produced in zero context

The monophthong system of Standard Latvian consists of 12 phonemes[16]: /i, e, æ, ɑ, ɔ, u, iː, eː, æː, ɑː, ɔː, uː/ (Laua 1997, 12–25; LVG 2013, 37–44), where /ɔː/ and /ɔ/ occur in recent loan words only (Laua 1997, 20) without stable phonological function of the length. The main qualitative features of the Latvian monophthongs produced in isolation are going to be described in the present section.

It can be seen on the acoustic F2/F1 (Hz) planes (see Figure 5) that although the placement of vowels varies for each speaker, the vowel systems follow the same pattern, and in all cases markers of long and short monophthongs overlap demonstrating very little difference in their acoustic quality. The similarity of the acoustic quality of long and short monophthongs can be also observed in the dynamic spectrograms (Figures 6.1–6.12) and in the numeric values of formants (Table 3).

[16] The vocalic inventory of Standard Latvian consists of 22 phonemes – 12 monophthongs and 10 diphthongs (Laua 1997, 12).



F i g u r e 5. **Latvian monophthongs produced in zero context (isolation) by 6 male speakers in the acoustic F2/F1 (Hz) plane**. Filled circles represent long monophthongs, filled triangles – short monophthongs.

Inspecting the numeric values of the first three formants (Table 3, Figure 5) it can be observed that:

- [iː], [eː], [i], [e] have the highest values of the second formant ([iː] F2 = 2107 to 2339 Hz; [eː] F2 = 1723 to 1967 Hz; [i] F2 = 2072 to 2431 Hz; [e] F2= 1740 to 1974 Hz) and low values of the first formant ([iː] F1= 225 to 312 Hz; [eː] F1 = 421 to 553 Hz; [i] F1 = 280 to 318 Hz; [e] F1 = 430 to 603 Hz); analysis of the distance between the first and the second formant, as well as between the second and the third formant reveals that among all the Latvian vowels [i(ː)] and [e(ː)] (both long and short ones, similarly to the case of the Lithuanian [iː], [eː], [ɪ]) have the maximum distance between their F1 and F2 and the minimum distance between F2 and F3 (cf. Figures 6.1–6.4);
- both the first and the second formant of [uː], [ɔː] and [u], [ɔ] are relatively low ([uː] F1 = 237 to 319 Hz, F2 = 513 to 700 Hz; [ɔː] F1 = 422 to

593 Hz, F2 = 755 to 943 Hz; [u] F1 = 251 to 340 Hz, F2 = 581 to 704 Hz; [ɔ] F1 = 460 to 653 Hz, F2 = 784 to 997 Hz); vowel spectrum analysis proves that [u(:)] and [ɔ(:)] have the smallest distance between F1 and F2 and the largest – between F2 and F3 (cf. Figures 6.9–6.12);

- the first formant of [ɑː], [æː], [ɑ], [æ] is quite high ([ɑː] F1 = 614 to 793 Hz; [ɑ] F1 = 617 to 822 Hz; [æː] F1 = 617 to 787 Hz; [æ] F1 = 640 to 814 Hz), at the same time the second formant of [ɑː] and [ɑ] is relatively low ([ɑː] F2 = 985 to 1194 Hz; [ɑ] F2 = 1031 to 1249 Hz), i. e., close to the first formant, and F3 of vowels [ɑː] and [a] is the closest to F1 (but F3 of [i(:)] is the most distant from F1), while the second formant of [æː], [æ] ([æː] F2 = 1367 to 1575 Hz; [æ] F2 = 1443 to 1577 Hz) is higher than that of [ɑ(:)], but lower than that of [i(:)], [e(:)] (cf. Figures 6.5–6.8).

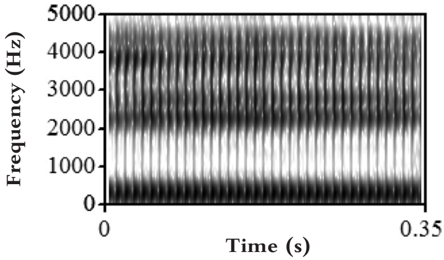


Figure 6.1. **Isolated [iː] produced by the third Latvian male speaker**

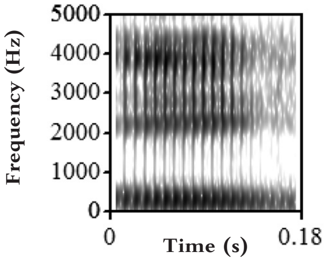


Figure 6.2. **Isolated [i] produced by the third Latvian male speaker**

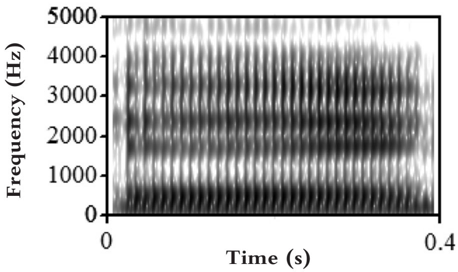


Figure 6.3. **Isolated [eː] produced by the third Latvian male speaker**

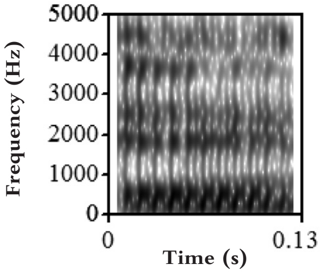


Figure 6.4. **Isolated [e] produced by the third Latvian male speaker**

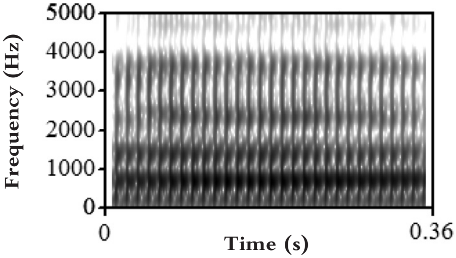


Figure 6.5. **Isolated [æː] produced by the fourth Latvian male speaker**

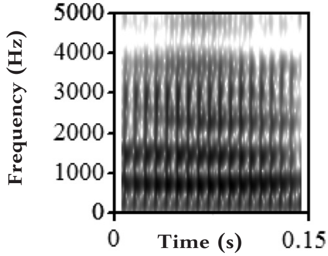


Figure 6.6. **Isolated [æ] produced by the fourth Latvian male speaker**

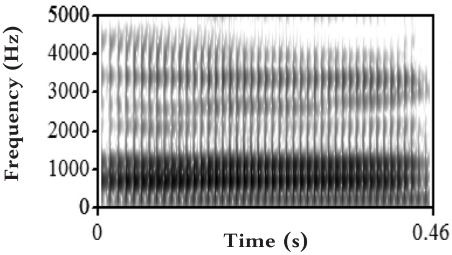


Figure 6.7. **Isolated [ɑː] produced by the sixth Latvian male speaker**

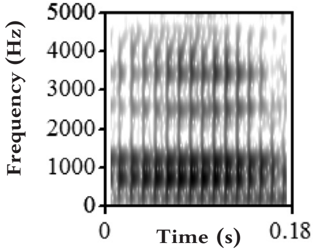


Figure 6.8. **Isolated [ɑ] produced by the sixth Latvian male speaker**

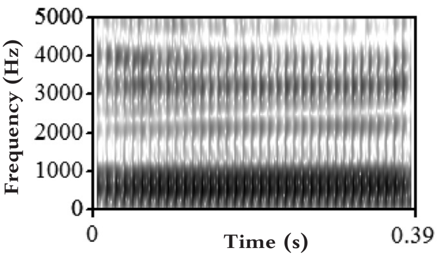


Figure 6.9. **Isolated [ɔː] produced by the first Latvian male speaker**

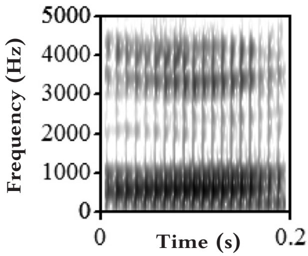


Figure 6.10. **Isolated [ɔ] produced by the first Latvian male speaker**

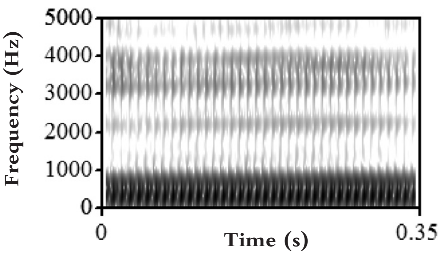


Figure 6.11. **Isolated [uː] produced by the second Latvian male speaker**

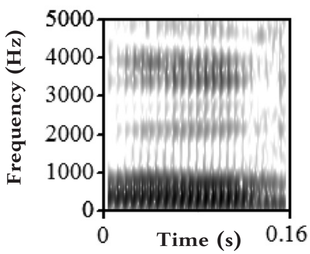


Figure 6.12. **Isolated [u] produced by the second Latvian male speaker**

According to the mean values of the formants and statistical data summarized in the Table 3 (also compare Figures 5 and 7), the distance between the lowest (min) and the highest (max) values of the F1, F2 and F3 (in Hz), coefficient of variation (in percent) and the confidence intervals (in Hz) are going to be discussed to acquire a better understanding of the acoustic properties of vowels.

Comparing the distances from the lowest to the highest value for each formant of the Latvian vowels, the largest distances between values of $F1_{min}$ and $F1_{max}$ were observed for short monophthongs[17] (the distances range from 89 Hz to 205 Hz), while the corresponding long monophthongs had smaller distance between values of $F1_{min}$ and $F1_{max}$ (from 82 Hz to 179 Hz). Vowel [u] has the smallest distance between values of $F2_{min}$ and $F2_{max}$ (123 Hz). Vowels [i], [eː], [e] and [iː] have the largest distances between values of $F2_{min}$ and $F2_{max}$ (they are 359 Hz, 244 Hz, 234 Hz and 232 Hz respectively). For all the vowels the distance between values of $F3_{min}$ and $F3_{max}$ ranges from 165 Hz ([e]) to 694 Hz ([æː]), while the mean values of F3 for vowels [æ(ː)], [ɑ(ː)], [ɔ(ː)], [u(ː)] are usually lower than those for [iː] and [eː] (Table 3).

The estimated coefficient of variation (in percent) indicates that the mean values of the first formant vary from 6% to 11%, which suggests the largest variation, while coefficients for the second and the third formant (similarly to the Lithuanian monophthongs) vary less, i. e. F2 – from 3% to 7%, and F3 – from 2% to 6% (Table 3).

The confidence intervals (significance level is 0.001) calculated for the formant values (of F1, as well as of F2) of the Latvian long and corresponding short monophthongs do not overlap (except confidence intervals for F1 of [æː] and [æ], and for F2 of [eː] and [e][18]), what leads to the conclusion that the quality of long and the corresponding short Latvian vowels (except [æː], [æ] and [eː], [e]) pronounced in isolation varies statistically significantly[19].

[17] Except for [i(ː)] – the distance between values of $F1_{min}$ and $F1_{max}$ was 70 Hz for [i] and 87 Hz for [iː].

[18] The 95% confidence level (significance level is 0.05) also shows the confidence intervals of the following vowels do intersect: [æː] F1 = 709÷715 Hz, [æ] F1 = 714÷720 Hz; [eː] F2 = 1853÷1859 Hz, [e] F2 = 1859÷1865 Hz.

[19] Although, as in the case of the Lithuanian language, confidence intervals of the third formant of the long and corresponding short vowels tend to be contiguous or overlap.

T a b l e 3. **Latvian vowels produced in zero context by 6 male speakers**: statistical means of the formants (Hz), the lowest (min) and the highest (max) values of the formants (Hz), standard deviation (SD, in Hz), coefficient of variation (cv, in %), and the confidence intervals (Hz)

Latvian vowels	F1			F2			F3		
	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)	x̄±SD (Hz) & (min value; max value in Hz)	cv (%)	Confidence interval (Hz) (99.9%)
[iː]	265±24 (225; 312)	10	260÷270	2246±66 (2107; 2339)	3	2241÷2251	2842±154 (2600; 3149)	5	2832÷2852
[i]	280±20 (248; 318)	7	276÷284	2228±85 (2072; 2431)	4	2222÷2234	2831±130 (2629; 3065)	5	2823÷2839
[eː]	483±36 (421; 553)	7	478÷488	1856±70 (1723; 1967)	4	1851÷1861	2515±70 (2392; 2614)	3	2510÷2520
[e]	509±47 (430; 603)	9	502÷516	1862±69 (1740; 1974)	4	1857÷1867	2506±50 (2418; 2583)	2	2503÷2509
[æː]	712±44 (617; 787)	6	707÷717	1494±58 (1367; 1575)	4	1489÷1501	2463±158 (2208; 2902)	6	2453÷2473
[æ]	717±45 (640; 814)	6	711÷723	1520±41 (1443; 1577)	3	1516÷1524	2451±112 (2317; 2720)	5	2444÷2458
[ɑː]	681±50 (614; 793)	7	675÷687	1085±52 (985; 1194)	5	1080÷1090	2477±84 (2342; 2629)	3	2471÷2483
[ɑ]	706±59 (617; 822)	8	699÷713	1129±51 (1031; 1249)	5	1124÷1134	2469±79 (2299; 2613)	3	2464÷2474
[ɔː]	492±50 (422; 593)	10	485÷499	833±57 (755; 943)	7	826÷840	2362±124 (2122; 2607)	5	2354÷2370
[ɔ]	535±60 (460; 653)	11	526÷544	870±63 (784; 997)	7	863÷877	2350±127 (2104; 2571)	5	2341÷2359
[uː]	281±22 (237; 319)	8	277÷285	611±40 (513; 700)	7	606÷616	2331±132 (2103; 2543)	6	2322÷2340
[u]	295±24 (251; 340)	8	290÷300	647±30 (581; 704)	5	643÷651	2346±138 (2108; 2564)	6	2337÷2355

However, the Student's t-Test analysis as well as the graphical representation of monophthongs in the psychophysical plane (Figure 7b) shows contradictory results. For example, using T.Test function the differences between F1 values of [æː] and [æ], [uː] and [u], as well as between F2 values of [iː] and [i], [eː] and [e] were proved to be statistically insignificant. Graphical representation in the psycho-physical F2′/F1 (z) plane (Figure 7b) reveals that the Latvian long and corresponding short monophthongs differ less than 1 z, which also indicates that the long and corresponding short vowels pronounced in isolation have very close perceptual quality (cf. Iivonen 1987). The fact that the long and the corresponding short Latvian vowels are qualitatively similar (although not completely identical) to a great extent is supported by the acoustic parameters (Table 4), computed from the first three formants of every vowel, too.

Table 4. **Numeric values of the acoustic parameters of the Latvian vowels produced in zero context**

Latvian vowels	[iː]	[i]	[eː]	[e]	[æː]	[æ]	[ɑː]	[ɑ]	[ɔː]	[ɔ]	[uː]	[u]
Compactness	714	722	809	816	882	881	916	916	901	909	852	852
Flatness	108	108	107	107	106	106	108	108	111	111	116	116
Graveness	826	797	453	434	105	119	–156	–136	–224	–220	–244	–218
Tenseness	1323	1279	388	377	255	286	619	608	813	815	1277	1212

According to the height of timbre, it is possible to set apart acute and grave sounds. Latvian monophthongs [ɑ(:)], [ɔ(:)] and [u(:)] can be characterized as low-timbre, i.e. grave sounds, because they are separated from the others by their second formant located below 1500 Hz and their negative numeric values of graveness (Table 4). It should be noted that long vowels (the same as in Lithuanian language) are characterized by larger amount of graveness (and lower value of F2)[20] than the corresponding short ones: index of graveness for [ɑː] is –156 (cf. F2 = 1085 Hz), but for [ɑ] it is –136 (cf. F2 = 1129 Hz); for [ɔː] it is –224 (cf. F2 = 833 Hz), but for [ɔ] it is –220 (cf. F2 = 870 Hz); for [uː] it is –244 (cf. F2 = 611 Hz), but for [u] it is –218 (cf. F2 = 647 Hz). The largest difference between the numeric values of graveness (26) is observed for [uː] and [u].

Latvian acute monophthongs [i(:)], [e(:)], [æ(:)] can be characterized as high-timbre, because of their second formant located above 1500 Hz and their positive numeric values of graveness or acuteness (tonality feature). Most of the long high-timbre monophthongs are more acute (higher value of the index of graveness and of F2) than their short counerparts: for [iː] the index of graveness is 826 (F2 = 2246 Hz), for [i] it is 797 (F2 = 2228 Hz); for [eː] it is 453 (F2 = 1856 Hz), for [e] it is 434 (F2 = 1862 Hz), but for [æː] the index 105 (F2 = 1494 Hz) is lower than for [æ] which is 119 (F2 = 1520 Hz). The second formant's values of [æ(:)] are very close to the marginal value

[20] The amount of graveness is inversely proportional to the numeric value of graveness.

1500 Hz distinguishing low-timbre/grave vowels from high-timbre/acute ones and could suggest interpreting these monophthongs as being neither low- nor high-timbre, whereas the positive values of graveness suggest that they belong to the group of high-timbre, i.e. acute vowels.

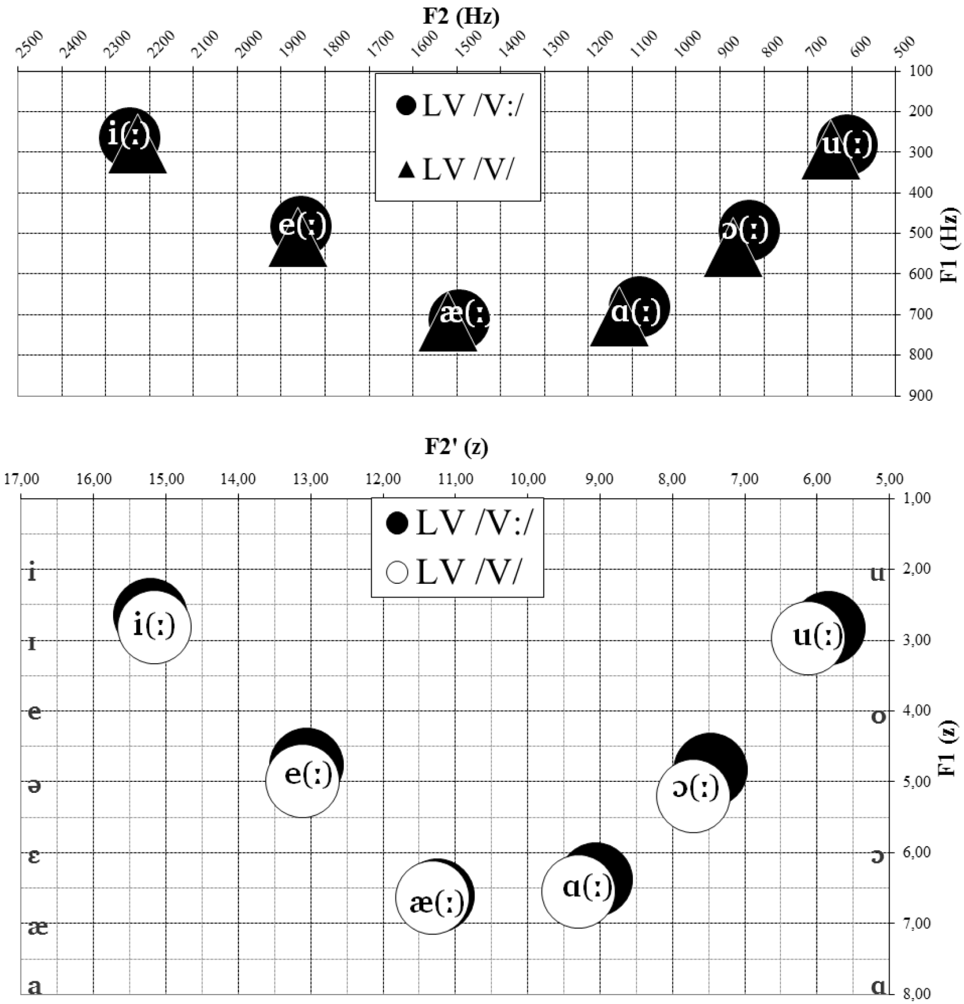


Figure 7. **The mean data of the Latvian monophthongs produced in zero context (isolation) by 6 male speakers**: **7a** in the acoustic F2/F1 (Hz) plane, and **7b** in the psycho-physical F2´/F1 (z) plane.
Filled circles represent long vowels, filled triangles and white circles – short vowels.

According to the position of both first formants, isolated Latvian monophthongs could be divided by the level of compactness (vs. diffuseness). As it is provided in the Table 4, among grave vowels, the most compact vowels are the low-timbre [ɑː] and [ɑ] (numeric value of compactness is 916 for both [ɑː] and [ɑ]) while among acute vowels the most compact vowels are [æː] and [æ] (numeric value of compactness is 882 for [æː] and 881 for [æ]) (also cf. LVG 2013, 43, Table 6). In the margins of spectrum acute [i(ː)] and grave [u(ː)] are located as the most diffuse vowels, their numeric values of compactness are the lowest ones (ranges from 714 to 852).

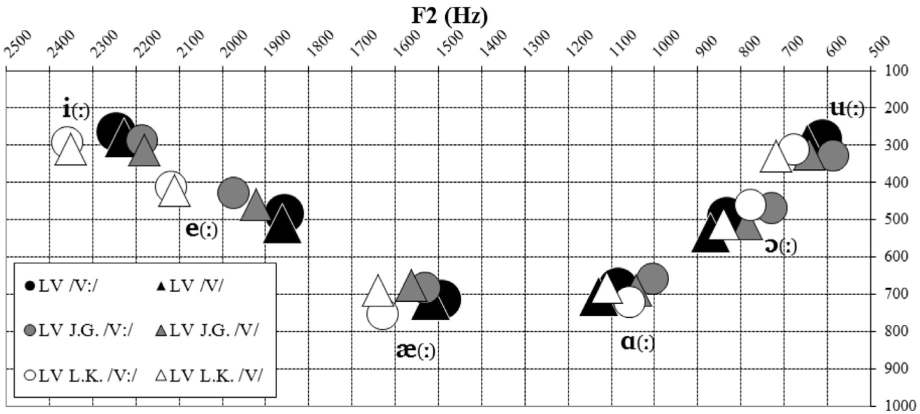
It can be observed (Figures 5–7, Table 3) that in Latvian (like in Lithuanian) diffuse monophthongs have the lowest values of the first formant ([iː] F1 = 265 Hz, [i] F1 = 280 Hz, [uː] F1 = 281 Hz and [u] F1 = 295 Hz); while compact monophthongs have the highest values of the first formant ([ɑː] F1 = 681 Hz, [ɑ] F1 = 706 Hz, [æː] F1 = 712 Hz and [æ] F1 = 717 Hz). Among the acute sounds Latvian [eː] and [e], while among the grave sounds Latvian [ɔː] and [ɔ] are considered to be mid (neither diffuse nor compact) monophthongs (cf. [eː] F1 = 483 Hz, [ɔː] F1 = 492 Hz, [e] F1 = 509 Hz and [ɔ] F1 = 535 Hz). Hence, it can be concluded that the jaw opens most and the body of the tongue descends to the lowest position pronouncing [ɑː], [ɑ] and especially [æː], [æ].

It can be noted that (as in the Lithuanian) the highest numeric value of flatness is characteristic to flat (rounded) low-timbre/grave sounds: it is 116 for [u(ː)] and 111 for [ɔ(ː)]. According to these values, it may be assumed that lips are the most protruded during pronunciation of the Latvian [u(ː)]. For all the other (unrounded) monophthongs the coefficient of flatness is below 110 (it ranges from 106 for [æ(ː)] to 108 for [i(ː)] and [ɑ(ː)]).

The numeric values of tenseness in Table 4 show that Latvian [eː], [ɑː] and especially [iː] and [uː] have a higher index of this acoustic feature than the corresponding short ones while for [æ(ː)] and [ɔ(ː)] the numeric value of this index is similar or higher in case of short monophthongs. All this indicates that tenseness is not a feature essential for classification of the Latvian monophthongs.

As it can be observed in Figure 7b, the variation between long and corresponding short vowels is very small being the largest (and statistically significant) for back monophthongs [ɑ] and [ɑː], [uː] and [u], and especially [ɔ] and [ɔː], though even the differences in the perceptual quality of [ɔ] and [ɔː] do not exceed ½ z[21].

In acoustic (in Hz, Figure 7a) and psycho-physical (in z, Figure 7b) planes the second formant represents a position of the highest point of the tongue in the mouth in the front-back dimension, accordingly the high-timbre (acute) monophthongs [iː], [i], [eː], [e], [æː] and [æ] should be regarded as front sounds as the tongue is shifted into the front part of the mouth in pronunciation, while Latvian low-timbre (grave) vowels [ɑː], [ɑ], [ɔː], [ɔ], [uː] and [u] should be regarded as back monophthongs as the tongue shifts to the back part of the mouth in pronunciation.



F i g u r e 8. **The mean data of the Latvian monophthongs in the acoustic F2/F1 (Hz) plane**:
the mean data acquired in the present study is marked with large black symbols;
the data provided by Juris Grigorjevs (J.G.) (G r i g o r j e v s 2008, 34) is marked with small grey symbols, and the data by Lidija Kaukėnienė (L.K.) (K a u k ė n i e n ė 2004b, 201) is marked with small white symbols.
Circles represent long vowels, triangles – short vowels.

[21] Although grave monophthongs [ɔ] and [ɔː] are relatively new phonemes in the Latvian sound system, and there are rather few minimal pairs where the length difference distinguishes word meaning, they gradually acquire all the features characteristic to other Latvian phonemes, and there is no point to exclude them from the system or move them to its periphery. The differences in the perceptual quality of [ɔ] and [ɔː] do not exceed ½ z (Figure 7b), what indicates that they are probably perceived as variants of the same sound.

The height of the first formant and its proximity to the upper formants defines the amount of spectral energy between peaks and the relative predominance of one centrally located formant region (Jakobson et al. 1963, 27). Accordingly this formant reflects compactess of the sound – the higher is value of F1 the more compact (and more open) is the sound: isolated monophthongs of Standard Latvian are split into high (diffuse), i. e. close vowels [i(ː)], [u(ː)], and low (compact), i. e. open vowels [æː], [æ], [ɑː], [ɑ]. Acute [e(ː)] and grave [ɔ(ː)] should be considered as mid vowels (neither diffuse nor compact).

The tendencies discussed above correspond to a great extent to the observations made in other studies of the isolated monophthongs of Standard Latvian (e. g. Grigorjevs 2008, 34–37, 100; 2012, 157, 180). If the data acquired during the present study and studies by Juris Grigorjevs (see Grigorjevs 2008, 34, Table 1) and Lidija Kaukėnienė (see Kaukėnienė 2004b, 201, Table 2) are plotted in the same acoustic F2/F1 (Hz) plane (see Figure 8), it can be easily noticed that despite some inter-speaker differences vowel systems of all studies follow the same pattern. The main difference in the results of the earlier studies is that monophthongs [e] and [eː] are shifted from intermediate position between [i(ː)] and [æ(ː)] (as observed in the present study) towards position of [i(ː)]. This phenomenon can be caused by different factors, but the extent of it does not affect the phonological classification of monophthongs [e] and [eː], and therefore it can be left without further exploration.

GENERAL CONCLUSION

Comparing spectral features as well as inspecting the numeric values of the formants and acoustic parameters (cf. Figures 1–3, 5–7, Tables 1–2, 3–4), the following qualitative similarities and differences among Lithuanian and corresponding Latvian monophthongs can be observed.

- Lithuanian [iː], [ɪ], [eː] and Latvian [iː], [i], [eː], [e] are acute vowels: they are characterized by a high second formant, considerably approaching the third formant, and have a low first formant; these vowels have the maximum distance between their F1 and F2 and the minimum distance between F2 and F3 among all the vowels.

However, Lithuanian [iː] and [eː] produced in zero context have a higher F2 than corresponding Latvian [iː] and especially [eː], and F2 of the Latvian short [i] is much higher than that of the Lithuanian [ɪ]. Latvian [iː] and [i] produced in zero context have lower F1 values than the corresponding Lithuanian [iː] and especially [ɪ].

The analysis of the distance between the first and the second formant, as well as between the second and the third formant revealed that Lithuanian long [iː] and [eː] have larger distance between their F1 and F2 as well as the larger distance between their F2 and F3 than corresponding Latvian [iː] and [eː]. The distance between F1 and F2 of the Lithuanian [ɪ] is much smaller than that of Latvian [i].

A comparison of acoustic parameters shows (Tables 2, 4) that Lithuanian [eː] is a sound of a higher timbre and a higher acuteness and especially tenseness when compared with the Latvian [eː], while Latvian [i] is a sound of a higher timbre and a higher acuteness and tenseness when compared with the corresponding Lithuanian [ɪ].

- Lithuanian [uː], [ɷ], [oː], [ɔ] and Latvian [uː], [u], [ɔː], [ɔ] are grave (non-acute) flat vowels: they have relatively low values of the first and the second formant, and analysis of their spectra indicates that these vowels have the smallest distance between F1 and F2 and the largest – between F2 and F3.

However, Latvian [uː] and [u] have lower F1 and F2 frequencies if compared with Lithuanian [uː] and especially [ɷ]. Latvian [ɔː] and [ɔ] are produced close to Lithuanian [oː] while Lithuanian [ɔ] is more open and centralized. The F2 frequencies of Latvian [ɔː], [ɔ] are higher than of Lithuanian [oː], but lower than of Lithuanian [ɔ]. Latvian [ɔː] has the same F1 value as Lithuanian [oː], but the F1 frequency of Lavian [ɔ] is higher at the same time being lower than of Lithuanian [ɔ].

Among Lithuanian [uː], [ɷ], [oː], [ɔ] and Latvian [uː], [u], [ɔː], [ɔ], the smallest distance between F1 and F2 but the largest between F2 and F3 is characteristic for Lithuanian long vowel [uː] and especially [oː], while the largest distance between F1 and F2 is characteristic to Lithuanian [ɷ] and [ɔ].

Among all the monophthongs (Tables 2, 4) Lithuanian [uː] and epsecially [oː] have larger negative values of graveness when compared to the corresponding Latvian [uː] and [ɔː] while tenseness is higher for Latvian [uː] and [u] (also [ɔ]) than for Lithuanian [uː] and especially [ɷ] (and [ɔ]). Besides, Latvian [ɔ] and especially [uː], [u] (also some other Latvian vowels) have a higher numeric value of flatness (and lower formant values) than corresponding Lithuanian counterparts. This indicates that these Latvian sounds are of lower timbre than corresponding Lithuanian vowels (cf. Girdenis 2003, 228).

- Lithuanian [ɑː], [a], [æː], [ɛ] and Latvian [ɑː], [ɑ], [æː], [æ] are compact vowels: they have relatively high frequency values of the first and relatively low values of the second formant (i. e. close to the first formant). The third formant of Lithuanian [ɑː], [a] and Latvian [ɑː], [ɑ] is the closest to the first formant while the second formant of Lithuanian [æː], [ɛ] and Latvian [æː], [æ] is higher than that of Lithuanian and Latvian [ɑː], [a], [ɑ], but lower than that of Lithuanian and Latvian [iː], [eː], [ɪ], [i], [e]. However F2 frequencies of Latvian [ɑː] and [æː] is lower than F2 of the corresponding Lithuanian sounds [ɑː] and [æː]. Among these vowels the most compact sound is Lithuanian [ɑː].

- The mean values of the third formant for Lithuanian [ɑː], [oː], [uː], [a], [ɔ], [ʊ] and Latvian [æː], [ɑː], [ɔː], [uː], [æ], [ɑ], [ɔ], [u] are usually lower than those for the Lithuanian [iː], [eː], [æː], [ɪ], [ɛ] and Latvian [iː], [eː], [i], [e] respectively.
- In both Baltic languages [ɪ]/[i], [eː], [e] and [iː] have the largest distances between values of $F2_{min}$ and $F2_{max}$, though the estimated coefficient of variation (in percent) indicates that the second, as well as the third formant (mean values) vary less than the first.

To summarize the comparison of spectral characteristics and registered acoustic parameters (their calculated mean values) it can be seen that the long and especially corresponding short Lithuanian and Latvian vowels vary, though in general vowel interrelations in both language systems are similar. To compare the quality relations of long and short monophthongs in the Lithuanian and the Latvian languages more precisely the mean values for all male informants (speakers) of each language were used to create vowel plots in psycho-physical F2′/F1 (in z) plane (see Figure 9).

It can be clearly seen that the symbols for short (dark grey) and long (black) Latvian monophthongs overlap to a great extent (while not completely), the largest difference is observed in quality of [ɔ] and [ɔː], but even it does not exceed 1 z between the centers of their zones. The symbols for short Lithuanian monophthongs (white symbols) demonstrate a considerable amount of acoustic centralization in comparison to their long counterparts (light grey symbols). The distances between the centers of the long and the short Lithuanian monophthongs exceed 1 z, thus signalizing about the difference of their perceptual quality, and these distances increase in direction from the open to the close monophthongs. Actually the results of the present study confirm the general tendency that qualitative characteristics of the Lithuanian long and corresponding short vowels differ to a great extent.

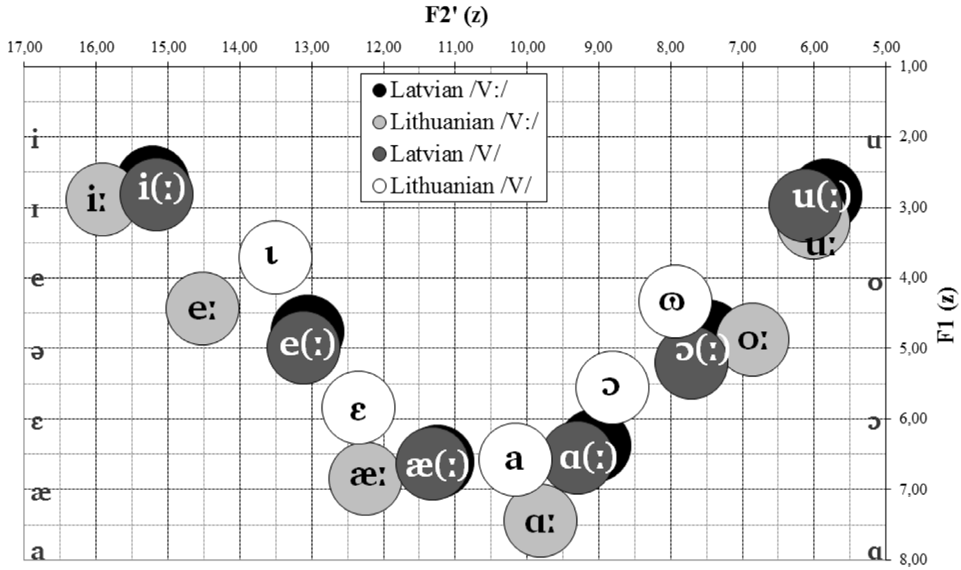


Figure 9. **The mean data of the Lithuanian and the Latvian monophthongs acquired in the present study in the psycho-physical F2´/F1 (z) plane**: Lithuanian long vowels – light grey symbols, short vowels – white symbols; Latvian long vowels – black symbols, Latvian short vowels – dark grey symbols.

Despite the fact the quality of Latvian monophthongs produced in isolation varies very little (Figure 9, Tables 3–4) and statistical analysis of the spectral characteristics shows contradictory results, spectral structure of long and corresponding short counterparts can be perceived differently: all the long vowels have lower F1 mean, $F1_{min}$, $F1_{max}$ as well as F2 mean, $F2_{min}$ (except [i] and [iː]), and $F2_{max}$ values than their corresponding short correlates; the mean values of both the first and the second formants differ statistically significantly for the long and corresponding short vowels [ɑ] and [ɑː], [ɔ] and [ɔː] while the confidence intervals (confidence level is 99.9% and 95%) of F1 and F2 values do not overlap of all the long and corresponding short vowels (except F1 of [æː] and [æ], and F2 of [e] and [eː]). Such qualitative feature as graveness for all the Latvian long and corresponding short monophthongs also differs to some extent; and tenseness for [i] and [iː], [u] and [uː], as well as diffuseness for [i] and [iː], [e] and [eː] do not coincide.

The mean data acquired in this study for Lithuanian and Latvian speakers show similar tendencies which in general correspond to those acquired in other studies (Figures 4 and 8), and vowel classifications follow the same pattern: Lithuanian [iː], [eː], [æː], [ɪ], [ɛ] and Latvian [iː], [eː], [æː], [i], [e], [æ] should be regarded as acute (front) vowels while Lithuanian [ɑː], [oː], [uː], [a], [ɔ], [ɷ] and corresponding Latvian [ɑː], [ɔː], [uː], [ɑ], [ɔ], [u] should be regarded as grave (back) (or non-acute (non-front)) vowels. In relation to frequency of the first formant and its proximity to higher formants Lithuanian [iː], [uː], [ɪ], [ɷ] and Latvian [iː], [uː], [i], [u] are diffuse (high, close) while Lithuanian [æː], [ɑː], [ɛ], [a] and Latvian [æː], [ɑː], [æ], [ɑ] are compact (low, open) vowels. In Standard Latvian, [eː], [ɔː], [e], [ɔ] the same as corresponding sounds [eː], [oː], [ɔ] in Standard Lithuanian are mid sounds on the basis that they are treated as neither diffuse nor compact.

LIETUVIŲ IR LATVIŲ KALBŲ MONOFTONGAI: LYGINAMOJI KOKYBINIŲ POŽYMIŲ ANALIZĖ

Santrauka

Straipsnyje analizuojami izoliuotai ištarti dabartinių baltų bendrinių kalbų pastovios artikuliacijos balsiai: atsižvelgiant į spektrines jų charakteristikas ir kai kurias akustines ypatybes (pagal pirmąsias tris formantes apskaičiuotą tonalumą, kompaktiškumą, bemoliškumą ir įtempimą), lyginami kokybiniai garsų požymiai.

Dabartinių baltų kalbų tiriamiesiems balsiams žymėti straipsnyje naudojami tarptautinės fonetinės transkripcijos rašmenys (an. IPA): lietuvių kalbos balsinės fonemos /i, e, a, ɔ, u, iˑ, ẹ̈ˑ, eˑ, aˑ, oˑ, uˑ/ žymimos atitinkamai /ɪ, ɛ, a, ɔ, ɷ, iː, eː, æː, ɑː, oː, uː/, latvių kalbos /i, e, ę, a, o, u, ī, ē, ę̄, ā, ō, ū/ – atitinkamai /i, e, æ, ɑ, ɔ, u, iː, eː, æː, ɑː, ɔː, uː/. Medžiagą lyginamajam instrumentiniam tyrimui pagal vienodą metodiką įskaitė kalbos defektų neturintys šeši lietuvių ir šeši latvių kalbos gimtakalbiai atstovai vyrai. Rūpimi segmentai analizuoti kompiuterinėmis garsų analizės programomis *WaveSurfer* (kūrėjai Kåre Sjölander ir Jonas Beskow) ir *Praat* (kūrėjai Paul Boersma ir David Weenink). Svarbiausi lyginamojo tyrimo rezultatai pateikiami šio straipsnio lentelėse ir paveiksluose (juose formančių reikšmės išreikštos hercais ir barkais).

Gautų rezultatų analizė rodo, kad izoliuotai ištartų lietuvių bendrinės kalbos ilgųjų ir atitinkamų trumpųjų balsių kokybė išties skiriasi, o latvių bendrinės kalbos izoliuotai ištarti ilgieji ir atitinkami trumpieji monoftongai kokybiškai panašūs, tačiau nėra visiškai sutapę. Tai iš dalies patvirtina ir statistinio duomenų vertinimo rezultatai.

Palyginus abiejų tirtųjų kalbų balsių kokybę (ir santykius akustinėje ir psichofizinėje erdvėje), matyti, kad labiausiai skirtingų kalbų skiriasi trumpieji garsai, tačiau atskirų

kalbų santykiai tarp balsių išlieka panašūs: lietuvių [iː], [eː], [æː], [ɪ], [ɛ] ir latvių [iː], [eː], [æː], [i], [e], [æ] laikytini aukšto tembro (priešakiniais) balsiais, o lietuvių [ɑː], [oː], [uː], [a], [ɔ], [ɷ] ir atitinkamai latvių [ɑː], [ɔː], [uː], [ɑ], [u], [ɔ] – žemo tembro (užpakalinės eilės) garsais. Pagal pirmosios formantės reikšmę ir spektro sklaidą lietuvių [iː], [uː], [ɪ], [ɷ] ir latvių [iː], [uː], [i] ir [u] atsiskiria kaip difuziniai (aukštutinio pakilimo) balsiai, o lietuvių [æː], [ɑː], [ɛ], [a] ir latvių [æː], [ɑː], [æ], [ɑ] laikytini kompaktiniais (žemutinio pakilimo) garsais. Latvių kalbos balsiai [eː], [ɔː], [e], [ɔ] yra tarpiniai (vidutinio pakilimo) garsai, kaip ir atitinkami lietuvių bendrinės kalbos balsiai [eː], [oː], [ɔ].

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