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ACTUALITIES AND METHODOLOGICAL CHALLENGES OF COMPARATIVE EXPERIMENTAL SOUND RESEARCH IN STANDARD BALTIC LANGUAGES

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Abstract: The present paper discusses the main topicalities and methodological challenges of comparative experimental research of the Lithuanian and Latvian sounds. There are still few studies on the sound systems of the contemporary standard Baltic languages that use modern experimental and statistical methods and are based on the same principles. Since the inventories of vowel and consonant phonemes in both languages have differences, it was important: a) to explore on the same principles and with the same methods the spectral characteristics of vowels and consonants in Standard Lithuanian and Standard Latvian at the beginning of the 21st century and to compare their main distinctive acoustic and other features; b) to discuss the choice of International Phonetic Alphabet equivalents for Lithuanian and Latvian phonemes showing variations of common vowel and consonant classifications of both languages. There are some other methodological issues to consider: peculiarities are important when selecting material for different languages, developing new terminology in national languages, preparing for further investigations, setting common goals, and so on.

Experimental acoustic investigations on Lithuanian and Latvian sound inventories should be continued in the future. The studies should address the influence of vowels of different quality on consonants; analysis should focus not only on phonologically significant differences but also on phonetic variants of phonemes.

Keywords: *Standard Lithuanian, Standard Latvian, sound, phoneme, vowel, consonant, experimental research.*

Lithuanian and Latvian languages belong to the Baltic branch of Indo-European language family, to the group of Eastern Baltic languages (cf. Figure 1). Both contemporary Baltic languages have opposition of long and short vowels, an abundance of diphthongs, a system of pitch accent. Naturally, however, throughout many years the languages have not evolved

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in the same manner, therefore besides the similarities they have also developed substantial differences that determine or can determine the

Figure 1. The European region: illustration of Language families by Minna Sundberg[1]

existence of different phonemic inventories. For example, Latvian has a fixed stress, a large subsystem of palatal consonants, while Lithuanian has a variable stress, secondary palatalization and phonological opposition of palatalized and non-palatalized consonants. An opposition between palatalized and non-palatalized consonants and a developed system of pitch accent in the same language, as it is in Lithuanian, nowadays is typologically rare. The Lithuanian language is considered the most archaic language that has the least changed structure of the living Indo-European languages.

The aim of the study

The aim of this paper is to discuss and review the main methodological challenges, goals and other peculiarities of comparative experimental studies of the sounds in the modern Baltic languages at the beginning of the 21st century. The inventories of vowel and consonant

[1]For more illustrations see https://mymodernmet.com/comic-artist-illustrated-linguistic-tree/.

phonemes in Standard Lithuanian and Standard Latvian have not only similarities but also differences, so one of the objective of such comparative sound studies was to describe on the same principles and with the same methods the spectral characteristics of Lithuanian and Latvian vowels and consonants and to compare their main distinctive features. Another important task was to explain the choice of International Phonetic Alphabet[2] equivalents for Lithuanian and Latvian phonemes showing similarities and differences of common vowel and consonant classifications of both standard languages. Also, some other peculiarities of experimental acoustic investigations are provided in this paper.

The first comparative experimental studies of Lithuanian and Latvian sounds: addressing different goals and objectives

Many researchers emphasize that the human hearing is extremely sensitive, surpassing experimental devices used in experimental phonetics which, as it is known, capture indicators of many additional factors and features besides the sound features related to the research object. Normally, the object of the experimental research is those sound elements that are not registered by the human ear and (or) those, in the case of which the analysis of acoustic features helps to increase the accuracy of their phonological interpretation. Experimental and auditory research is also used in description of sounds of various languages or dialects. Therefore, in the 20th century experimental research has become an inseparable part of studies aimed at analysing on the same principles vowels and (or) consonants in one or more different languages or dialects, as well as characteristics of the sounds and other topics. It is assumed that this type of research helps to highlight the differences and characteristics of the phonemic inventories of different languages or dialects, nuances of possible phonetic and phonological classifications, universal distinctive features of sounds, even the peculiarities of the empirical material and methods used in the studies, possible aims of the experimental analysis, and other matters.

Until 2015 there were still few studies on the sound systems of the contemporary standard Baltic languages that use modern experimental and statistical methods and are based on similar principles. The first researcher to present a comprehensive comparative synchronic analysis of acoustic features of unstressed Lithuanian and Latvian vowels was Lidija Kaukėnienė (Kaukėnienė 2004a, 2004b; also see 2005; 2010; 2012): using the aforementioned experimental and statistical methods, she investigated

[2]It is well known that International Phonetic Alphabetis a standardized international phonetic alphabet – an internationally recognized set of phonetic symbols designed to represent and analyse sounds of any languages of the World through the articulatory features of the sounds they represent (IPA 2015).

and described vowels in positions before and after the stressed syllables in various, mostly trisyllabic, Lithuanian and Latvian words. The researcher Kaukėnienė compared the investigated features of unstressed vowels with the corresponding features of the stressed vowels and concluded that in both languages unstressed vowels are reduced both qualitatively and quantitatively. She found that both stress and the position of the vowel in relation to the stressed syllable affect the quality and quantity of the vowel. Lithuanian data showed a more pronounced phonetic reduction that the corresponding Latvian data.

Robertas Kudirka (Kudirka 2004a; 2005; also see 2004b; 2009) analysed using experimental and statistical methods some prosodic features and formant structures of stressed vowels in Standard Lithuanian and Standard Latvian: he examined spectrograms and the values of the fundamental pitch, intensity, duration, formant values and other data and defined the acoustic features that differentiate circumflex and acute tones of Lithuanian and Latvian long vowels. The researcher mostly investigated initially stressed disyllabic Lithuanian and Latvian words. The data showed that Lithuanian and Latvian vowels (especially the circumflex vowels) differ in duration (Latvian long vowels are longer than the corresponding Lithuanian vowels) and in features of the fundamental pitch. Lithuanian circumflex vowels have a wider intensity range than the corresponding Latvian vowels.

Rima Bakšienė (Bacevičiūtė 2009) has reviewed the development of the experimental studies on pitch accented monophthongs in Lithuanian and Latvian. She emphasized that experimental devices capture a multi-layered complex of sound features and the failure to consider this fact may lead to a totally inadequate assessment of prosodic and other phenomena.

Thus, as one can see, those studies address only some features of vowels of the contemporary Baltic languages and the development of their research; there were no comparative studies on the acoustic characteristics both of all Lithuanian and Latvian sounds – vowels and consonants – based on a similar methodology. In the very recent years there appeared new comparative experimental research on the sounds of the contemporary Baltic languages. Further, some main topicalities and challenges of such comparative studies of the Lithuanian and Latvian vowels and consonants will be discussed.

Recent innovative experimental research of Lithuanian and Latvian vowels and consonants: setting common goals and breaking stereotypes

In the international linguistics, Lithuanian and Latvian languages often are placed next to each other as particularly close languages. Their affinity also usually presupposes an assumption about the similarity of their

sound systems. Despite of the common Baltic origin, the inventories of vowel and consonant phonemes in standard Lithuanian and Latvian languages have differences, firstly, because of functional significance which is not universal. The most important goal and objective of innovative comparative experimental research was (and still is) to explore, compare and describe on the same principles and with the same methods such differences as well as similarities between Lithuanian and Latvian sound systems in various aspects.

In every language its native speakers are best capable of identifying with hearing and perception the functionally relevant elements of the language. So, first the task of investigating and comparing the sound systems of the contemporary Baltic languages was taken on by a group of Lithuanian and Latvian native speaking researchers, specializing in experimental phonetics[3]: Lithuanians Jolita Urbanavičienė and Jurgita Jaroslavienė, Latvians Juris Grigorjevs and Inese Indričāne. Extensive empirical material also consisted of recordings of native speaking informants with flawless pronunciation consistent with the norms of Standard Lithuanian or Standard Latvian. The acoustic characteristics of the Lithuanian and the Latvian sound systems were investigated simultaneously using the same methods and equipment that allowed a reliable comparison of phonetic inventories of both languages. Publications about vowels see Grigorjevs, Jaroslavienė 2015a; 2015b; Jaroslavienė 2017, etc.; publications about consonants see Urbanavičienė, Indričāne 2016a; 2016b; Indričāne, Urbanavičienė 2015a; 2015b; 2017; Urbanavičienė 2018, Jaroslavienė 2019, also cf. Grigorjevs, Jaroslavienė 2014, Jaroslavienė 2019 etc.

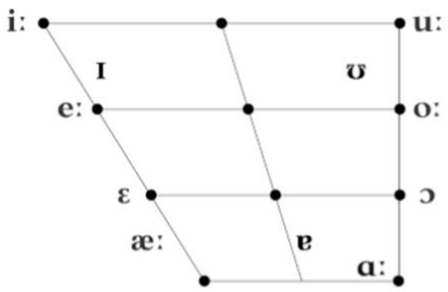

Figure 2. The IPA symbols used for the pure vowels of Standard Lithuanian

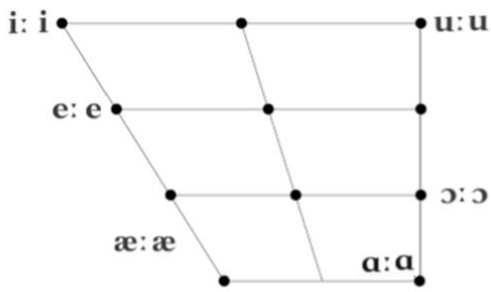

Figure 3. The IPA symbols used for the pure vowels of Standard Latvian

[3] In 2013–2015, Institute of the Lithuanian Language implemented a research project ‘Acoustic Characteristics of the Sounds of the Contemporary Baltic Languages (Experimental Study)’ (MIP-081/2013) funded by the Research Council of Lithuania.

As one can see from the Figures 4 and 5, Lithuanian and Latvian national transcriptions (written in black) are different[4]. Investigating sound systems in mentioned publications, it was important to check and discuss the choice of International Phonetic Alphabet (IPA) equivalents for Lithuanian and Latvian vowels and consonants and show the main differences of the IPA equivalents of both contemporary Baltic languages. International Phonetic Alphabet system is very useful in comparative linguistics. For example, what exactly IPA equivalents were chosen to use for Standard Lithuanian and Standard Latvian vowels produced in zero context (in isolation), see the following Figures 2 and 3 (also cf. Figures 15 and 16).

Comparative analysis shows that *different* IPA symbol equivalents for some similar pure vowels of the contemporary Baltic languages have been chosen not accidentally but because of closely related and quite different acoustic qualities as well as not identical production and auditory features of vowels: for example, especially Lithuanian [oː ɪ ɛ ɐ[5] ʊ] and corresponding Latvian [ɔː i æ ɑ u] are produced quite different (also compare the difference of Lithuanian and Latvian [eː] in Figures 10 and 11; 15 and 16). If produced in zero context the Latvian short monophthongs tend to have the same or very close acoustic quality as the corresponding long monophthongs, while the Lithuanian short monophthongs display the effect of the acoustic centralization if compared with the corresponding long ones.

One more challenge was to show similarities and differences of common vowel and consonant classifications of both Baltic languages. For example, in the phonological system of vowels, Lithuanian phonemes /iɛ uɔ/ function as independent long gliding phonemes (LG 2006; Girdenis 2009; 2014; Kazlauskienė 2018). Possible IPA equivalents might be [iɛ], [ɪɛ] and [uɔ], [ʊɔ]. This can depend on prosodic elements and other factors. In the Latvian grammatical tradition /iɛ uɔ/ are still classified as diphthongs, though there is no single approach to the phonological interpretation (Laua 1997: 12; LVG 2013: 46; Markus, Bonda 2014: 68–72; Grigorjevs 2016: 151). Compare Figures 4 and 5.

[4]Peculiarities of the national transcriptions of the Lithuanian and Latvian dialects and suitability of the International Phonetic Alphabet to represent sounds of the Lithuanian and Latvian dialects are not discussed in the present article (for the opportunities of the International Phonetics Alphabet application to the sounds of Lithuanian dialects, see Bakšienė, Čepaitienė 2017a; 2017b).

[5] Phonologically short Lithuanian /ɐ/ functions as a back vowel: non-palatalized consonants are used before it as before other back vowels. The latest textbooks on phonetics and phonology of Standard Lithuanian treat the short /ɐ/ as a back vowel (see Kazlauskienė 2018: 34–35; also see Pakerys 2003; Girdenis 2014; Grigorjevs, Jaroslavienė 2015b; Jaroslavienė 2017).

Besides, native speakers of Standard Lithuanian do not regard the short [e] (the variant of the 'Janus' phoneme /e/) as a separate sound and therefore cannot pronounce it in isolation (cf. Grigorjevs, Jaroslavienė 2015a; 2015b; Jaroslavienė 2015; 2017). Instead of the optional close mid-high vowel [e] used only in international words, usually the simple short [ɛ] is articulated. It must be agreed that the non-high (mid-high) vowel [e] fails to find a strong position in the system of the Standard Lithuanian because of its peculiar usage, its optional status, and the lack of distinctive function as well as the fact that in writing it is denoted by the same letter as the low short vowel [ɛ] (more about it see Pakerys 2003; Girdenis 2000; 2014). However, functionally these sounds are not identical: the accented international vowel does not become longer, whereas the accented Lithuanian one becomes longer. In dialects the international sound is diphthongised, whereas the Lithuanian one remains unchanged.

TONGUE HEIGHT			DURATION			
			LONG		SHORT	
			FRONT	NON-FRONT	FRONT	NON-FRONT
NON-LOW		HIGH	*i˙* [iː]	*u˙* [uː]	*i* [ɪ]	*u* [ʊ]
NON-LOW	NON-HIGH	GLIDING	*ie* [iɛ]	*uo* [uɔ]		
NON-LOW	NON-HIGH	NON-GLIDING	*ę˙* [eː]	*o˙* [oː]	*ę* [e]	*ɔ* [ɔ]
LOW			*e˙* [æː]	*a˙* [ɑː]	*e* [ɛ]	*a* [ɐ]

Figure 4. Phonological system of the Lithuanian vowels.
National symbols are in black, IPA equivalents are written in red

TONGUE HEIGHT	DURATION			
	LONG		SHORT	
	FRONT	NON-FRONT	FRONT	NON-FRONT
HIGH	ī [iː]	ū [uː]	i [i]	u [u]
MID	ē [eː]	ō [ɔː]	e [e]	o [ɔ]
LOW	ę̄ [æː]	ā [ɑː]	ę [æ]	a [ɑ]

Figure 5. Phonological system of the Latvian vowels.
National symbols are in black, IPA equivalents are written in red

A necessity to record, study and compare spectral structure and quantity of Lithuanian and the corresponding Latvian vowels produced in zero context using the same research methods might be explained as following: vowels produced in zero context (in isolation) have not yet been studied and compared using the same methods and equipment that would permit a reliable comparison of phonetic inventories (quality similarities and differences) of both languages. Besides, a comparison of the spectral characteristics of the isolated Lithuanian and Latvian vowels will create a base for further comparative research of the sounds (particularly allophonic variation of the phonemes because qualitative variations of vowels depend on the adjacent sounds and other factors) in both contemporary Baltic languages. It might give a possibility to find out if analysing isolated vowels may allow to define universal distinctive acoustic features, i.e. information, which might be important for the description of the sound system of any language.

One more significant challenge preparing material for comparative sound research was the fact that Standard Lithuanian and Standard Latvian have different number of consonants: Lithuanian language has 45 consonantal phonemes (because of palatalization), while Latvian language consists of 26 consonant phonemes.

The classification of Lithuanian and Latvian consonants according IPA in recent comparative papers is based upon the articulatory features of consonants that are grouped according to three main criteria: 1) voicing; 2) manner of articulation; 3) place of articulation. To describe the system of

consonants in Lithuanian, these three criteria are not sufficient and an additional criterion is needed: 4) palatalization, which distinguishes palatalized and non-palatalized consonant phonemes (palatalized Lithuanian consonants, following the conventions of the IPA, are represented by adding to the symbol of a consonant a modifying symbol, a superscript symbol for palatal approximant *j*, for example /bʲ/, /pʲ/). Problematic cases in the classification of Lithuanian and Latvian consonants and variation of terms are summarized andprovided in mentioned publications (see Urbanavičienė, Indričāne 2016a; 2016b; Indričāne, Urbanavičienė 2015a; 2015b; 2017; Urbanavičienė 2018). Providing joint articulatory classification of Lithuanian and Latvian consonants, according to the place of articulation, six groups of consonants are divided: labial, dental, alveolar, palatal, palatovelar and velar consonants. According to the manner of articulation, the consonants of both languages are divided into plosive, fricative consonants and affricates, and sonorants are divided into frictionless continuants (approximants), nasal, lateral consonants and trills. According to voicing the consonants of both languages can be voiced or voiceless. The feature of palatalization is used only in the classification of Lithuanian consonants (for this reason, the inventory of consonant phonemes of Lithuanian is almost twice as big as of Latvian); in Latvian this distinction does not serve as a criterion of differentiation and does not have a phonological status.

The efficiency of the method for the classification of the Latvian and Lithuanian plosives according to their place of articulation was tested and described by researchers Indričāne and Urbanavičienė (2015b). They concluded that by the spectral shape it is impossible to classify all the Latvian and Lithuanian plosives according to the place of their articulation. In Latvian it is possible to separate bilabials and dentals (diffuse flat or falling spectrum) from palatals and velars (compact spectrum). In Lithuanian it is possible to distinguish both palatalized and non-palatalized bilabials (diffuse flat spectrum) vs. non-palatalized dentals and the voiced palatalized dental [dʲ] (diffuse falling spectrum) vs. the voiceless palatalized dental [tʲ], palatovelars and velars (compact spectrum). The researchers provide that according to the mean value of spectral peak's frequency (in hertz, Hz) calculated for Latvian and Lithuanian plosives, it is possible to distinguish the following places of articulation: in Latvian – bilabial vs. dental, velar vs. palatal; in Lithuanian only the group of palatalized plosives shows more or less consistent tendencies – bilabial vs. palatovelar, dental. The Latvian plosive phonemes /g/ and /k/ have two contextual variants – palatovelar and velar. Both palatovelar and velar variants are characterized by a compact spectrum similar to the Lithuanian plosives having the same place of articulation. Further research is required to find out whether these

differences are objective or the result of some inaccuracy in measurements and/or of the application of measurement methods.

Lithuanian and Latvian consonants were analysed in prevocalic positions (compare spectrograms in Figures 6–9), in isolated sequences of CVC type, where C stands for a Lithuanian or Latvian consonant and V stands for a short or a long Lithuanian or Latvian vowel, e.g.: Lithuanian *mim* [mʲɪm], *mem* [mʲɛm], *mam* [mɐm], *mom* [mɔm], *mum* [mʊm], *mym* [mʲiːm], *mėm* [mʲeːm], *mem* [mʲæːm], *mam* [mɑːm], *mom* [moːm], *mūm* [muːm], *miom* [mʲɔm], *miom* [mʲoːm], *mium* [mʲʊm], *miūm* [mʲuːm]; *rir* [rʲɪr], *rer* [rʲɛr], *rar* [rɐr], etc.; Latvian *mim* [mim], *mem* [mem], *mem* [mæm], *mam* [mɑm], *mom* [mɔm], *mum* [mum], *mīm* [miːm], *mēm* [meːm], *mēm* [mæːm], *mām* [mɑːm], *mōm* [mɔːm], *mūm* [muːm]; *rir* [rir], *rer* [rer], *rer* [rær], *rar* [rɑr], etc.

For example, Lithuanian and Latvian obstruents are explored and described by Indričāne and Urbanavičienė (2015a). These consonants, like other consonants, have been studied in the phonetic context of all short and long monophthongs of Standard Lithuanian /ɪ, ɛ, ɐ, ɔ, ʊ, iː, eː, æː, ɑː, oː, uː/ and Standard Latvian /i, e, æ, ɑ, ɔ, u, iː, eː, æː, ɑː, ɔː, uː/ (the recorded material consisted of isolated CVC syllables). The researchers draw attention that obstruents of Lithuanian and Latvian can be divided into two groups: the first group contains more coarticulated obstruents – labials and velars; the second group includes less coarticulated obstruents – dentals, alveolars and palatals / palatovelars. Velars are the most coarticulated obstruents of both Baltic languages whereas Latvian palatals and Lithuanian palatovelars are the least affected by coarticulation. It can be concluded that locus equations are more useful as descriptors of coarticulation than as a method used for determining the place of articulation.

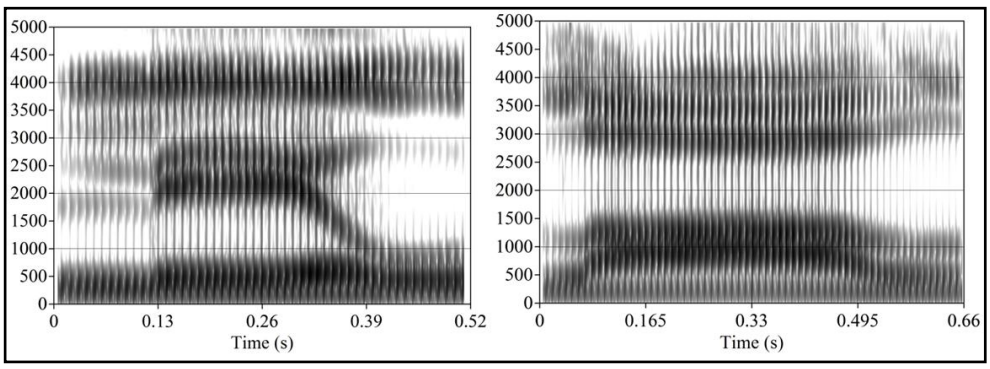

Figure 6. [lʲeːl] pronounced by Lithuanian

Figure 7. [lɑːl] pronounced by Lithuanian

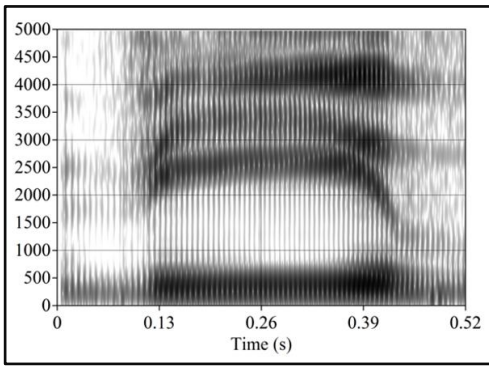

Figure 8. [ʊʲiːʊ] pronounced by Lithuanian

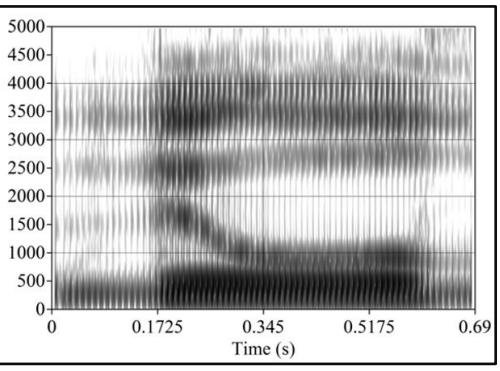

Figure 9. [ʊʲuːʊ] pronounced by Lithuanian

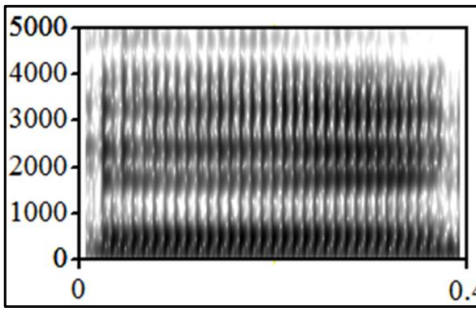

Figure 10. Latvian [eː]

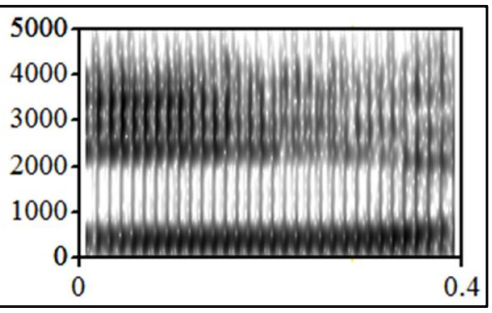

Figure 11. Lithuanian [eː]

It is important that analysis of the sounds of Standard Lithuanian and Standard Latvian was performed using the same free license sound processing and analysis software programs: *PRAAT* which is developed by Paul Boersma and David Weenink and *WaveSurfer* which is developed by Kåre Sjölander and Jonas Beskow (see Figures 12 and 13). And the material for research of sounds was recorded with a digital high-resolution audio recorder *Tascam DR-100MK II* and a head-set microphone *AKG C 520*.

Vowels produced in zero context #V#; (a)symmetric CVC, CVCV syllables, were read by 12 Lithuanian and 12 Latvian informants, 6 male and 6 female in each of the groups, aged 20–50 years. They all had faultless articulation; their pronunciation met the norms of standard Lithuanian or Latvian. The standard language was considered as a standardized variety of language used for the needs of public life and culture. It is also important, that almost all informants not only speak the standard language, but also one or more dialects and foreign languages.

Researchers provide that every segment (vowel or CVC, CVCV syllable) was repeated 3–5 times, with the same speed and the same intonation, as much as possible. Lithuanian long syllables were pronounced with circumflex (in Lithuanian ‘tvirtagalė’) pitch (because circumflex is the

non-marked variant in the final syllables of the words or one-syllable words). Latvian long syllables were pronounced with acute (in Latvian 'krītošā') or circumflex (in Latvian 'stieptā') intonation. During the investigation it was noticed that in pronunciation of plosives in isolated CVC type syllables stress is not crucial, since it mostly affects the end of the vocal segment and the postvocalic plosive.

For the spectral analysis of Lithuanian and Latvian sonorants, as in the case of vowels, the first step was to obtain greyscale spectrograms for the segments under study (with the maximum frequency of 5000 Hz, cf. Figures 6–9). For each sonorant the following were measured: the formants in the steady state (the middle part) (in Hz), *C→V* transition, i.e. the onset frequency and the middle frequency of the second formant of the consonant and its adjacent vowel as well as its dynamics, and other values (cf. Grigorjevs, Jaroslavienė 2014; Jaroslavienė 2019).

In total, approx. 50,000 segments (units) were analysed for studying vowels, consonants and phenomena of coarticulation. Mean value was calculated as the average of all realizations of the sound. To achieve statistical reliability, the data were obtained by summing up all realizations of the sound (from all informants); i.e., the quantity or qualitative features of each sound in each language were measured no less than 30 times.

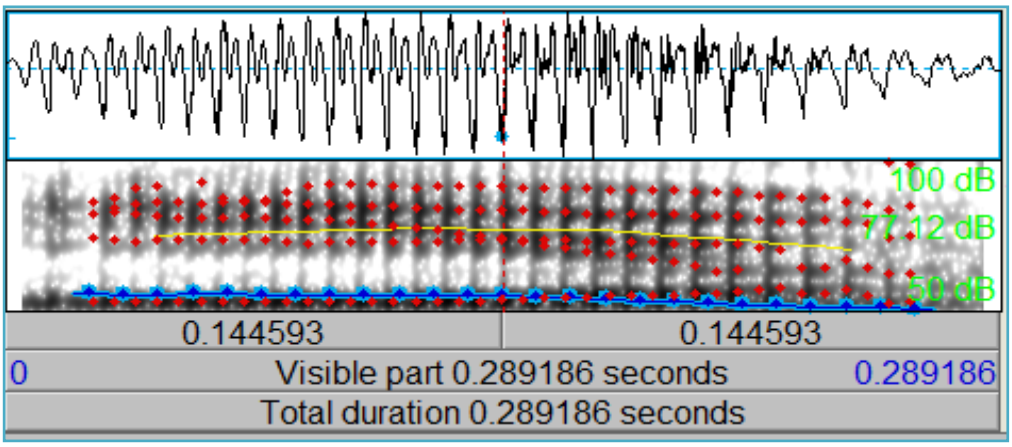

Figure 12. Screenshot of PRAAT

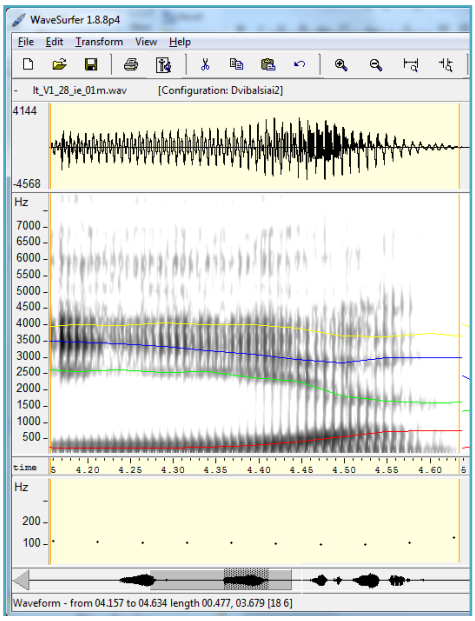

Figure 13. Screenshot of WaveSurfer

For examination of quantity and quality differences (and similarities) of short and long vowels, the results were analysed and compared on different aspects (see in Grigorjevs, Jaroslavienė 2015a; 2015b). For example, to study the qualitative vocalic features, the purest excerpt (steady state) of the Lithuanian and Latvian vowels was measured to determine the frequency values (in Hz) of the first four formants (F1, F2, F3, and F4), the fundamental frequency (in Hz) and the duration (in ms). *MS Excel* was used for further evaluation of the experimental data, i.e., there were statistical means (z, in Hz), standard deviation (SD, in Hz), coefficient of variation (cv, in %), confidence intervals (in Hz; significance level = 0.001), and the range of lowest and highest values (in Hz) were calculated. Also, the values of the effective second formant (F2', in bark units) were determined (see formula proposed by Bladon and Fant 1978). Its calculations include not only the frequencies of the first two formants, which generally determine the main acoustic characteristics of vowels, but also the frequencies of the third and the fourth formants and the fundamental frequency.

It is assumed that psycho-physical representation of the vowel system considers the peculiarities of human hearing better, since it considers the logarithmic nature of sound perception (Grigorjevs 2013: 303). The size of the monophthong symbols on the psycho-physical F2'/F1 plane circles with the diameter 1 z shows the zones of the equal perceptual quality (cf. Iivonen 1987).

In the comparative sound research (see Grigorjevs, Jaroslavienė 2015a; Jaroslavienė 2017), to characterise the vowel system of Lithuanian

and Latvian sound systems and to compare the female pronunciation data to the male data the procedure of interspeaker normalization has been performed, also tonotopic distances were calculated. After the transformation to psychophysical units and using values of tonotopic distances, the difference between the placement of the male and female data points has been reduced to a great extent. Also, obtained data was compared with the data of previous researchers (Figure 14). The mean data acquired by Grigorjevs and Jaroslavienė for Lithuanian and Latvian speakers show similar tendencies which in general correspond to those acquired in other studies, and vowel classifications follow the same pattern (Grigorjevs, Jaroslavienė 2015a: 72, 81).

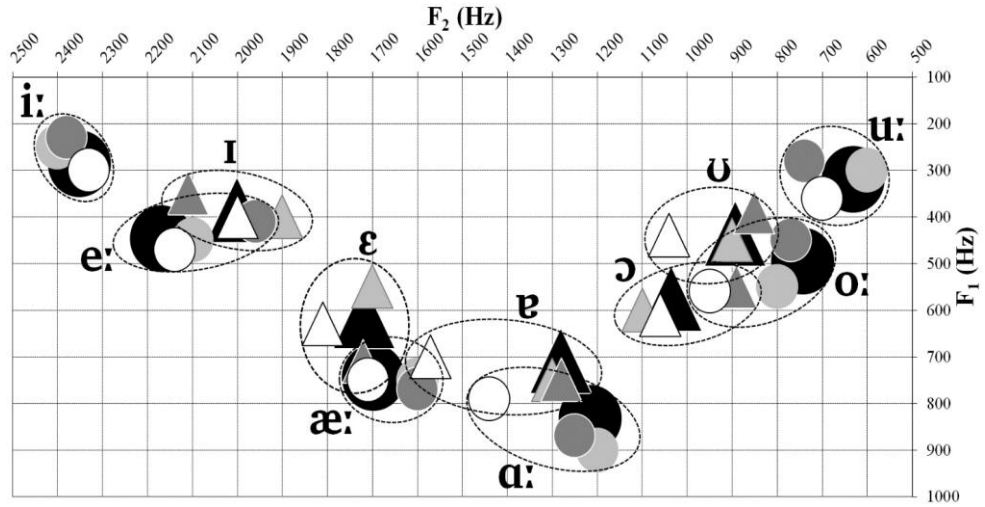

Figure 14. Example of mean data of the Lithuanian pure vowels in the acoustic F2/F1 (Hz) plane: compared data of different researchers. *Circles represent long vowels, triangles – short vowels.*

As it was already mentioned in this paper, the researchers concluded that the main differences in acoustic quality appear because of different production of the short and some long Lithuanian and corresponding Latvian vowels. To characterise the vowel systems of both contemporary Baltic languages in order to choose as accurate IPA symbol equivalents as possible, they calculated tonotopic distances between the fundamental frequency and the first formant ($F1-f_0$) and between the first and the second formant (F2–F1) (cf. Figures 15 and 16). It is well known that the first of these distances is closely related to the sound openness vs. closeness, and the second to its frontness vs. backness (Miller 1989: 2119; Ladefoged, Maddieson 2002: 284–286; Grigorjevs 2012: 163–165; Jaroslavienė 2017: 211–212). To compare more precisely the general tendencies of the relations

between Lithuanian and the corresponding Latvian long and short monophthongs pronounced in zero context, according to the mean values (i.e. the means of all realizations) of F1, F2, and F3 (Hz) acoustic parameters (their numeric values) were also calculated: flatness, compactness, tenseness, and graveness (see Grigorjevs, Jaroslavienė 2015a; 2015b).

The researchers draw attention that according to the principles of IPA system and variable acoustic qualities and auditory features of the Lithuanian and Latvian pure vowels, national classifications (three-fold distinction by vowel height and two-fold distinction by vowels frontness or backness) differ from the articulatory international system (four-dimensional distinction by vowel height and three-dimensional distinction by vowels frontness or backness) (cf. Figures 2, 3; 4, 5, and 15, 16). Different graphical representations highlight peculiarities of vowels production of similar Lithuanian and Latvian pure vowels, especially the short ones (except [ɔ]), also Lithuanian [eː], [æː], [oː] and corresponding Latvian [eː], [æː], [ɔː] differ in their production vs. acoustic and auditory features, though relationship between the systems of long Lithuanian and corresponding long Latvian vowels as well as the systems of short Lithuanian and short Latvian vowels follow the similar pattern.

Registered values of relative duration support hypotheses that the distinction between long and short Latvian monophthongs is based on the relative duration mainly, but between long and short Lithuanian monophthongs – on combined cues of the formant structure and the relative duration. Duration ratio of short and long vowels both in Lithuanian and Latvian is about two. The differences in duration are reliable and statistically significant with the highest degree of statistical significance. High vowels tend be shortest among the long and short vowels (for more details see Grigorjevs, Jaroslavienė 2015a; 2015b; Jaroslavienė 2017).

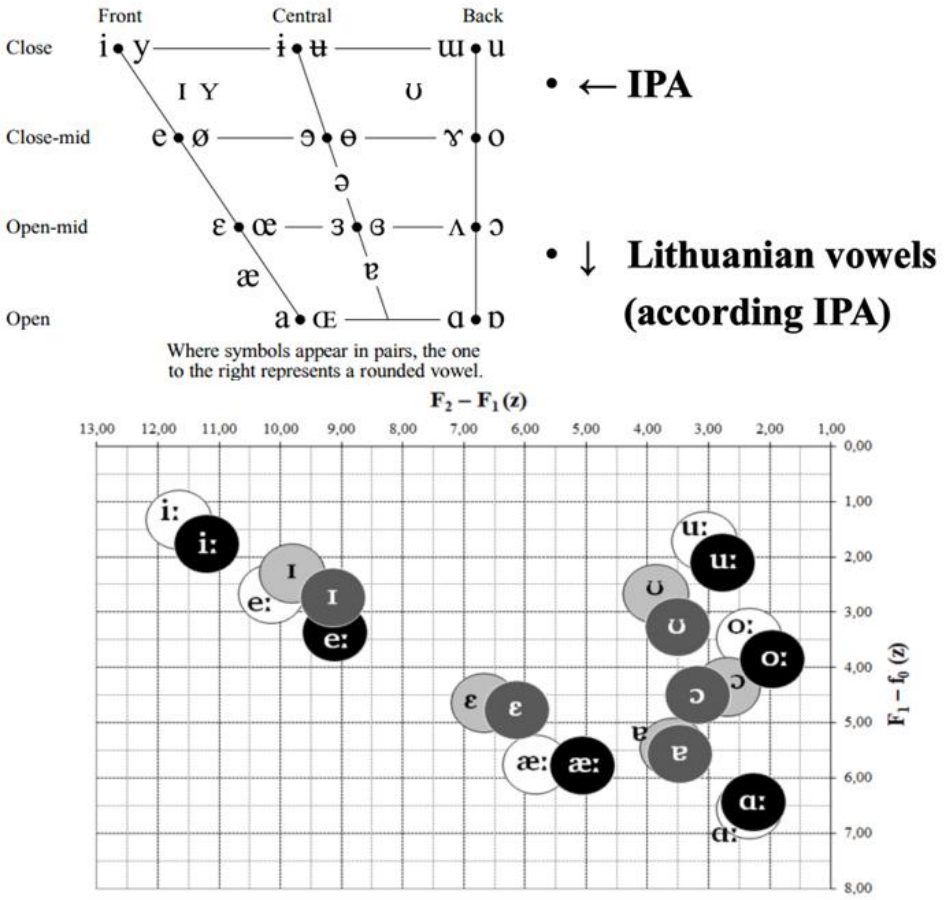

Figure 15. International Phonetic Alphabet chart (2015) and the mean data of the Lithuanian pure vowels plotted in the psycho-physical plane (in bark units, z) for normalization using tonotopic distances between F2 and F1 and between F1 and fundamental frequency f_0: *black circles represent long vowels produced by male speakers, white circles represent long vowels produced by female speakers, dark grey circles represent short vowels produced by male speakers, light grey circles represent short vowels produced by female speakers. Female data are normalized by k=17%.*

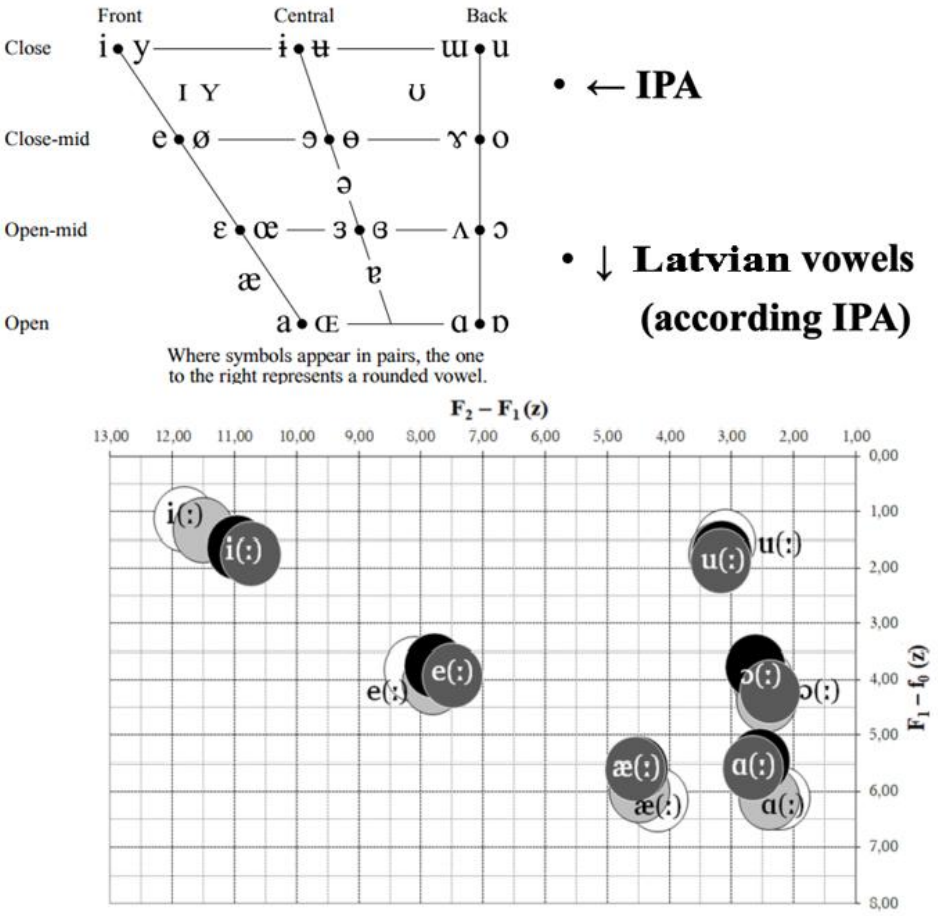

Figure 16. International Phonetic Alphabet chart (2015) and the mean data of the Latvian pure vowels plotted in the psycho-physical plane (in bark units, z) for normalization using tonotopic distances between F2 and F1 and between F1 and fundamental frequency f_0: *black circles represent long vowels produced by male speakers, white circles represent long vowels produced by female speakers, dark grey circles represent short vowels produced by male speakers, light grey circles represent short vowels produced by female speakers. Female data are normalized by k=21%.*

The researchers conclude that according to the position of tongue elevation and on the basis of the concise analysis of dynamic spectrograms, acoustic, articulatory and auditory characteristics as well as functional features of the Lithuanian and Latvian pure vowels produced in isolation, long and short Lithuanian [iː eː æː ɪ ɛ] and Latvian [iː eː æː i e æ] are regarded as *front* and Lithuanian [ɑː oː uː ɐ ɔ ʊ] as well as corresponding Latvian [ɑː ɔː uː ɑ ɔ u] are regarded as *back* vowels. By the tongue height

and varying degrees of mouth openness (the distance between the tongue and the palate) and functionally long and short Lithuanian and Latvian have *high* ([iː uː ɪ ʊ] and [iː uː i u]), *mid* ([eː oː ɔ] and [eː ɔː e ɔ]), and *low* ([ɑː æː ɐ ɛ] and [æː æ ɑː ɑ]) vowels accordingly. By the position of the lips, the Lithuanian [oː], [uː], [ɔ], [ʊ] and Latvian [ɔː], [uː], [ɔ], [u] are *labial* (rounded) sounds, and all the remaining vowels are *non-labial* (unrounded).

It should be noted that in the Lithuanian language the back vowels [uː uɔ oː ʊ ɔ] that follow palatalized consonants become advanced a little, and [ɑː ɐ] become completely front. When Lithuanian [uː uɔ oː ʊ ɔ] become advanced, they are not mid-vowels: in articulating them the tongue first moves forward and later withdraws to the back of the mouth (Kazlauskienė 2018; Girdenis 2014). And, as has already been mentioned, in Lithuanian Language /iɛ uɔ/ are regarded as vowels of gliding articulation.

Conclusion

In the paper the main methodological and other peculiarities and challenges of modern comparative experimental studies of the Lithuanian and Latvian sounds (vowels and consonants) were reviewed. There are still few studies on the sounds of both standard languages that use modern experimental and statistical methods and are based on the same principles. Analysis of spectral characteristics and comparison of acoustic parameters of sounds show that Lithuanian short and long pure vowels pronounced in isolation differ in quality much more than the correspondent Latvian short and long sounds. The largest difference in quality was observed between Lithuanian and Latvian short vowels (Latvian short vowels are similar in quality to their long counterparts); also, the Lithuanian [æː], [ɛ] and [eː], [oː] are much more close and high than the corresponding Latvian [æː], [æ] and [eː], [ɔː]. Nevertheless, the relationship between vowel phonemes in both languages remains similar: vowels are categorized according to the same or similar distinctive features. Vowel duration must be considered as one of the main features of the opposition between Latvian short and long vowels. In Lithuanian, vowels differ not only in quantity, but particularly in quality.

The symbols of International Phonetic Alphabet for the Lithuanian and Latvian sounds were chosen not randomly but with consideration of the acoustic and articulatory features of sounds and their functional significance (relevance), also attitudes toward their use, prevalent in the traditional Lithuanian and Latvian grammars as well as discussed in the most recent works.

The researchers observed that most sensitive to coarticulatory effects are Lithuanian and Latvian velar and labial consonants, while almost not affected by coarticulation are dental consonants of both languages, as well as Latvian alveolar, palatal and Lithuanian palatalized consonants.

Lithuanian voiceless alveolar consonants are more sensitive to the influence of the vowels in their phonetic environment, while the voiced alveolar consonants themselves affect the quality of the adjacent vowels.

Experimental acoustic investigations on Lithuanian and Latvian sound inventories should be continued to address the influence of vowels of different quality on consonants and focus on phonetic variants of phonemes. The research should be broadened by including some more acoustic features, different positions of vowels and consonants (not only in syllables, but also in real words and phrases), consideration of informants' place of birth, age, and so on.

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