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STATISTICAL STUDY ON SCALES OF LITHUANIAN VOCAL TRADITION: ACOUSTICAL AND COGNITIVE ASPECTS

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INTRODUCTION

Musical scale is one of the most important elements of the musical language, defining the usage of tones in the musical culture. It is a multidimensional phenomenon which is concerned with the intervals between the tones, the importance of these tones and the relationships between them, their usage in the musical form, intonation and other dynamic aspects. This study investigates two dimensions of a scale: intervallic structures and tonal hierarchies.

Scales of Lithuanian traditional music have been discussed in the works by Lithuanian and foreign scholars since the 19th century. However, many of them do not consider an important fact that intervals and tonal hierarchies in the scales of traditional music can differ significantly from those found in the tempered diatonic scales of the Western culture. This is due to, first of all, the apperception conditioned by the 12TET as well as to the orthography and templates typical of Western music, the uncritical following of acclaimed ethnomusicologists, the lack of knowledge in music psychology and the unwillingness to apply scientific research methods. To this date, there are some research projects conducted which managed to avoid these problems. These studies revealed new modal phenomena in Lithuanian traditional music. New research methods and possibilities for interpreting results were suggested as well. However, only a small portion of Lithuanian traditional music has been explored while applying quantitative methods; the main focus of the studies was the intervallic structures of scales. Little attention was paid to researching the differences and the similarities between the scales of different ethnomusical regions or to the diachronic changes of scales. Basically overlooked also were the modal phenomena found in the contemporary performances of secondary tradition and the subject of tonal hierarchies. At least Lithuanian ethnomusicologists have not used quantitative methods to explore the scales found in the traditional music of Lithuania's neighbouring countries; also unknown is their relationship to the scales of Lithuanian traditional music. These are the reasons for the **novelty** of this study. The **significance** of this research:

- it is a continuation of a recently established practice to analyse Lithuanian traditional music by applying quantitative methods borrowed from other fields of science;
- it demonstrates research methods created or adapted by the author and the others, and the application of these methods to solve specific problems.

The main **problem** of this research is the interpretation of scales based on quantitative research methods. Only vocal examples of the Lithuanian traditional music (mostly monophonic songs) are studied.

The **aim** of this paper is to determine what are the statistical regularities of the intervallic structures of scales and the tonal hierarchies in the Lithuanian traditional singing, to evaluate the similarities and differences between these elements as well as their changes – all to be considered in the theoretical, historical and geographical contexts. In order to achieve the aim, the following **objectives** were determined:

- to discuss the assumptions of the ontological formation of scales as well as the previous studies made on this subject;
- to summarize the existing methods of scale evaluation and data analysis and to create new ones;
- to assess the accuracy, the objectivity and the relevance of these methods for analysing the scales;
- to carry out a research of vocal traditions in Lithuania and in its neighbouring countries.

The **subject** of this research is the acoustic and the cognitive phenomena in scales of traditional singing. This study made use of the following research **methods**: the acoustic and statistical analysis, psychological testing, classification, comparative method, and mathematical modelling. In this study, folk songs recorded in Lithuania and in its neighbouring countries were analysed. Pitch and frequency measurements were performed in 349 examples of traditional singing. The measurements in 70 examples were made independently by the author, and in 214 examples together with Irena Višnevska. The measurements in another 64 examples were made by Dr. Rytis Ambrazevičius, and in one example jointly by all three scientists.[1] The pitch and frequency measurements were made using the software for acoustic analysis Praat[2] and the toolboxes of the computing environment MATLAB. Sound recordings for the psychological experiment were prepared using audio editing software Cool Edit Pro 2.1[3]. Numerical calculations, statistical analyses and generation of graphical representations of results were performed using Microsoft Office Excel, IBM SPSS Statistics and R.

The interdisciplinary of this research is revealed by its title as well as the research methods applied. In order to achieve the aim of this study, the knowledge of musicology, ethnomusicology, acoustics, music psychology, and statistics was employed, and information technologies were extensively used. These ought to ensure that the results were as objective as possible. It has been common practice in foreign musicology and ethnomusicology to apply such a variety of research methods for a few decades already, nevertheless, in Lithuania it is not yet common.

[1] The measurements with other scientists were made under the auspices of the "Lithuanian Traditional Musical Scales in a Cross-Cultural Context: Acoustical and Cognitive Aspects" project (Operational Programme for Human Resources Development for 2007–13. Priority 3 Strengthening Capacities of Researchers. VP1-3.1-ŠMM-07-V. Support to Research of Scientists and Other Researchers (Global Grant)).

[2] http://www.fon.hum.uva.nl/praat/

[3] The software was published in 2003 by Syntrillium Software corporation.

Thus this study is quite **original** because of the interdisciplinarity and methods applied.

The reviewed **literature** on research subjects contributed in designating the definition of the scale, identifying the approaches to the modal phenomena in the Lithuanian vocal tradition, understanding the main principles of the human memory and their manifestations in musical scales, and creating research methods. Published sound recordings of traditional music were also used. In total, over 400 publications were analysed.

This study is **composed** of the introduction, of three parts, of the conclusion, and of a bibliography. The first part presents the discussion of the modal phenomena from the viewpoint of music psychology as well as overview of studies on scales of Lithuanian vocal tradition. In the second part, research methods are presented, compared and assessed. The third part is concerned with the scales of Lithuanian vocal tradition examined in different aspects.

1. PSYCHOLOGICAL AND ETHNOMUSICOLOGICAL ASSUMPTIONS OF THE RESEARCH

There are two concepts, *mode* and *scale*, which signify similar phenomena. According to Powers and Wiering (2001, p. 775–777) the term of *mode* in the contemporary sense involves the phenomena of scale type, hierarchy of pitch relationships, class of melodies, certain kinds of norm or model for composition or improvisation etc. However, due to the broad and uncertain definition of *mode*, some authors avoid using the term in the works on ethnomusicology and music psychology and replace it by *scale* (see Burns, 1999; Dowling, 1978; Ellis, 1885; Krumhansl, 2000; Kunst, 1950; McAdams, 1996; Snyder, 2000; Thompson, 2013; Wallaschek, 1893). The latter term has a much narrower meaning and is defined as "collections of discrete pitch relationships" which "are used as a framework for composition and improvisation" (Burns, 1999, p. 215).

The musical phenomena examined in this study are better described by the concept of *scale*.[4] The conceptual scheme of scale perception (Dowling, 1978, 1982; see also Dowling & Harwood, 1986, p. 113–114) is proposed as a basis for separating these phenomena. Each level of the scheme is based on some universal (or, to be precise, on quasi-universal) principle of pitch perception. Three levels (out of four) are related to the pitch intervals between scale tones (intervallic structure) and to the hierarchies of tones. These levels are discussed in more detail bellow. Also, a short review is presented on the studies concerning the two phenomena in Lithuanian vocal tradition.

1.1. Memory: Structure and processes

The perception of a surrounding world and all the human activities relies in a large part on the architecture of the memory system. Some essentials of memory operation are discussed for easier comprehension of acoustic and cognitive aspects of musical scales.

The human memory is often represented as a system composed of three interconnected memory stores: sensory, short-term, and long-term memory (see Atkinson & Shiffrin, 1968, p. 92–94; Eysenck & Keane, 2000, p. 168; Pashler & Carrier, 1996; this model is highly oversimplified). The echoic memory is a kind of sensory storage for auditory stimulus. This memory holds raw (continuous) auditory information for 0.25 s (Massaro & Loftus, 1996, p. 73–80) to 2 s (Treisman, 1964; Crowder, 1970) or even 5 s (Glucksberg & Cowen, 1970). The contents of the short-term memory constitute selected and categorized (discrete) information units (Nairne, 1996). The duration limit of the short-term memory in the case of music perception is about 3–5 s (Snyder, 2000, p. 50). The capacity of

[4] There are two Lithuanian words, *darna* and *dermė*, which roughly correspond to *scale* and *mode*, but both their meaning and correspondence to English terms relay heavily on the context.

the long-term memory is nearly unlimited, and information can remain there for a lifetime. Two types of long-term memories – implicit and explicit – are distinguished (Eysenck & Keane, 2000, p. 205–211; Snyder, 2000, p. 72–79). Implicit memories take a lot of repetitive practice to be formed, but they are used quickly and unconsciously. Whereas explicit memories are formed quickly, but they require a conscious effort to be memorized and recalled.

The continuous flow of information passing through the sensory input is processed into discrete categories. Categorization drastically reduces the amount of information and helps to manage it. Discrimination between stimuli falling into different categories is very acute, while discrimination between stimuli of the same category is quite poor (Snyder, 2000, p. 81–82). Among the categories, certain categories are considered to be prototypes, called the cognitive reference points (Rosch, 1975), while other categories are coded, remembered, or verbalized based on a prototype (Rosch, 1978/2002, p. 259; Eysenck & Keane, 2000, p. 317–318).

Miller (1956) observed that subjects can assign the intensity of elementary (unidimensional) stimulus to one of 7 ± 2 categories. In the case of multidimensional stimulus (of a real world), all attributes are judged simultaneously, consequently their intensities are assigned to a smaller number of categories. The number of categories the short-term memory can handle at a time is also defined by the Miller's number 7 ± 2. The limits of the short-term memory can be stretched considerably by the process called chunking (Miller, 1956, p. 92–93). In the case of music perception, the short-term memory can retain a musical phrase containing up to 25 notes (five chunks of five notes each), but this capacity is only achieved if the phrase is no longer than 5 s (Fraisse, 1982, p. 157).

The aforementioned limitations of the memory system cause the stimuli to be perceived as grouped into larger units. Usually the only possible grouping of stimuli occurs unconsciously and in such a way that it is in the best correspondence with the structure of the real world. These regularities in perception are generalized as the Gestalt principles of grouping (Wertheimer, 1923/1938). Some of the most frequently discussed principles are proximity, similarity, common fate, good continuation (*Prägnanz*), and completion/closure. These principles operate in a similar fashion on both visual and auditory (musical) stimuli (Bregman, 1990; Deutsch, 2013).

1.2. The assumptions of scale development

Although (almost) every human-being has a memory system with the same architecture, people living in different places and in different historical periods could respond differently to the same environmental stimuli. This is explained by the fact that perception is dependent on innate (biological) and acquired (learned) properties of the human body (the brain, the nervous system, and the other organs). The variety of musical systems found all over the globe reveals how differently the pitch and other dimension of music are perceived by the users of those systems.

However, some regularities do exist in this variety, and the identification of them could lead to a better understanding of the essentials and the limitations of musical systems. Some psychoacoustic and cognitive mechanisms underlying the development and the structure of scales are discussed.

Musical universals. Some musical phenomena found in most cultures of the world are considered musical universals, or, to use a more appropriate term, nearly universals (Huron, 2004), quasi-universals (Higgins, 2006; Nattiez, 2012), or statistical universals (Savage, Brown, Sakai, & Currie, 2015). Various researchers have presented very diverse ideas about the musical universals and the phenomena that are supposed to be universal (see Brown & Jordania, 2013; Burns, 1999; Dowling, 1978; Dowling & Harwood, 1986; Harwood, 1976; Higgins, 2006; Krumhansl, 1987; Parncutt, 1989; Savage et al., 2015; Snyder, 2000). The following is a selection of universals (quasi-universals) that are related with the development of musical scales:

1. categorical perception of musical pitch;
2. utilization of frameworks of pitch categories (scales);
3. five to seven pitches in a scale;
4. 12 steps per octave as an upper cognitive limitation;
5. principle of unequal intervals (intervallic asymmetry);
6. melodies of small successive intervals (no greater than 3–4 semitones);
7. octave equivalence;
8. preference of relative consonance (fourth, fifth, and octave);
9. influence of overtone structure on scale steps;
10. differentiation of scale pitches (tonal hierarchy);
11. pitch transposition (relative pitch);
12. stretching of octave and other intervals.

Pitch categorization. A musical pitch category is a pitch range of a certain size, and every pitch that falls into this range is perceived as belonging to the same category. Each category is determined by its ideal height (centre), its tolerance range for intonation fluctuations (size), and position of boundaries separating it from other categories (Parncutt, 1989, p. 29; Snyder, 2000, p. 136–143).

Usually, instead of fixed pitches, musicians (possessors of relative pitch) can identify differences between pitches (pitch intervals). Melodic and harmonic intervals are also perceived categorically (Burns & Ward, 1978; Siegel & Siegel, 1977a, b; see Burns, 1999), i.e. a small continuous range of differences between two pitches is assigned to the category of a certain interval. A set of intervals, employed in the single performance, in all the melodies of a certain style/genre, or in musical culture, constitute the musical scale. Most cultures of the world use discrete pitch categories (Dowling, 1978, p. 342)[5].

[5]There are some exceptions (see Roberts, 1926; Sachs, 1962; Malm, 1967).

The smallest perceptible distance between two pitches is defined as a just noticeable difference (JND) or differential limen / threshold. It is shown that pitch JND can be as low as 3–5 cents (Fastl & Hesse, 1984; Fastl & Zwicker, 2007, p. 186). On the one hand, these results are only valid under ideal listening conditions and only for tones in immediate succession. On the other hand, pitch JND facilitates in evaluating the perceptual significance of the difference between two tones close in pitch. Usually, the size of the smallest micro-intervals employed in the musical practice is 33–50 cents (Parncutt & Cohen, 1995).

Pitch categories used in most cultures are separated by semitones (100 cents) or wider intervals (Burns, 1999, p. 218; Roederer, 2008, p. 183), and the melodies of these cultures are generally made of intervals encompassing approximately 2–4 semitones (Dowling, 1968; Merriam, 1964). The limitations on the number of pitches and the interval sizes in scales are accounted for by two universal factors. One factor is Miller's number 7 ± 2. Scholars generally agree that most cultures in the world use five to seven pitches in their scales (Dowling & Harwood, 1986, p. 93). Due to octave equivalence, musical pitch has two dimensions (pitch class/chroma and height), i.e. it is at least two-dimensional stimulus. Thus development of most practical scales can be explained by an octave division into five or seven steps instead of a division of all possible pitch range. Another factor is the Gestalt principle of proximity. Perceptual grouping of tones due to the proximity in pitch and time is called melodic streaming (Parncutt, 1989, p. 40). If wider intervals (of 3–4 semitones) occur in the melody, it can break into separate streams (stream segregation; Bregman & Campbell, 1971; Harwood, 1976, p. 526).

Some cultures (e.g. the Indian and the Arab-Persian) make use of pitch nuances, i.e. pitch variations that take place inside of the boundaries of a musical category (Burns, 1999, 217). Nuances are represented at the level of echoic memory, but they are lost in the processes of categorization (Snyder, 2000, p. 86).

Being exposed to the "native" musical soundscape members of the musical culture acquire pitch categories and musical scales of the distinctive structure. When it became possible for members of one culture to explore the music of other cultures, a serious problem of pitch perception and interpretation emerged which is known in general form as the *emic vs. etic* problem (Ambrazevičius, 2008a, p. 73–77).

Intervallic structure of scales. In the discussions concerning musical universals, one can find frequent references to the unequal interval principle supposedly dominating the musical scales of most cultures (Sloboda, 1985, p. 254). According to this principle there is a preference for unevenly sized intervals separating adjacent scale pitches. Miscellaneous studies and experiments partly provided a cognitive basis for this principle (Ambrazevičius, 2008a, p. 167–172; Savage et al., 2015; Krumhansl & Schmuckler, 1986; Kessler, Hansen, & Shepard, 1984; Lynch, Eilers, Oller, & Urbano, 1990; Lynch & Eilers, 1991;

Trehub, Schellenberg, & Kamenetsky, 1999). However, there are lots of examples providing evidence on the opposite principle of equal intervals, especially in western and central Africa, southeast Asia, and Indonesia. These examples generally include equipentatonic and equiheptatonic scales that are based on the division of an octave (including imprecise versions) into five or seven approximately even steps (of 171 and 240 cents respectively; see Burns, 1999, p. 248–249). Several Western scholars have demonstrated the existence of equidistant or similar scales in European folk music. Grainger (1908, p. 158) noticed that singers from Lincolnshire (England) sang their songs in a "loosely-knit modal folksong scale". In the music of langeleik (Norway), Sevåg (1974, p. 210) identified "strange" scales of which "no two notes can be closer to each other than a somewhat short 3/4 tone". Some examples show that both principles of unequal intervals and of equitonics may co-exist in the same musical culture or even in the same musical style (e.g. *pelog* and *slendro* tunings of the gamelan). In summary, intervallic asymmetry is a possible but not obligatory result of scale development.

1.3. Overview of studies on tonal hierarchies

One of the most widespread structural principles, found in various musical cultures at various historical periods is tonal hierarchy (Krumhansl & Cuddy, 2010, p. 51). This principle manifests itself in the way that some tones occur more frequently, are performed with longer durations, are accented rhythmically or dynamically, and appear at structurally important moments in a musical flow, such as with cadences and phrase ends. Music psychologists describe tonal hierarchy as a pitch organization, within which different pitches (pitch-classes) are differently stable. Abundant literature on the theory of tonal music, as well as objections to psychoacoustic tradition of scale development, stimulated the first cognitive studies on tonal hierarchies.

Psychological experiments providing evidence of tonal hierarchies. Krumhansl and Shepard (1979) were the first to describe the probe tone method for psychological evaluation of tonal hierarchies. In this and subsequent experiments (see Krumhansl, 1990a), the participants had to rate, in the 7-point scale, how well each tone of the chromatic scale (12 tones, in total) fitted to the musical context (e.g. scale, chord, chord progression). The results obtained in Krumhansl and Kessler's (1982) experiment were summarized as standardized key profiles, i.e. 12-number vectors that represent psychological salience of each tone (tonal hierarchies) in the major and minor scales. The highest rating was given to the I scale degree (the tonic), slightly lower to the III and the V degrees (other tones of the tonic chord), still lower to other scale degrees, and the lowest ratings to non-scale (chromatic) tones.

The evidence revealed by probe tone technique and other methods showed that music theory was in close correspondence with psychological reality, even though the participants of the experiments had little or no knowledge of music theory and practice of music performance, or they behaved unconsciously during the experiments.

Cognition of tonal hierarchies. Krumhansl and Cuddy (2010, p. 53) suggested two psychological principles that govern the phenomenon of tonal hierarchies. The first is the principle of cognitive reference points (Rosch, 1975). Some tones acquire the role of reference points (e.g. the notes of the tonic chord) and other tones are perceived and memorized in regard to these points. Music differs from other forms of experience in that the most stable pitch depends on context and is not related to any absolute pitch (Bharucha, 1984; Laden, 1994; Bigand, 1997). The second principle is a sensitivity to statistical regularities. Listeners are exposed to the musical soundscape and thus they implicitly (unconsciously) learn the distribution of pitch classes in a particular musical style. Studies reported by Krumhansl (1985; 1990a, p. 66–76), Aarden (2003), and Temperley (2007) showed that there is a strong and statistically significant correlation between probe tone ratings (i.e. key profiles for major and minor) and pitch class distributions in the Western tonal music.

Krumhansl (1990a, p. 77) suggested that cognitive scheme of tonal hierarchies operates as a set of templates that are compared with tone distributions in the piece of music or its excerpt; the best fitted template induces the sense of tonality. Longuet-Higgins and Steedman (1971), Krumhansl and Schmuckler (Krumhansl, 1990a, p. 78–81), and Temperley (2007, p. 79–89) described different algorithms which simulate the induction of tonal hierarchy and estimate the most probable key of the musical excerpt. These algorithms identify the correct key for 8–9 excerpts out of 10, on average, but only in the case of very limited repertoire of tonal music.

The aforementioned algorithms only analyse the static properties of music (scales and pitch class distributions) and ignore the temporal order of tones. Browne (1981) and Brown and Butler (1981, 1989; Brown, 1988) criticized the theory of tonal hierarchies for its static approach to music and emphasized the dynamic aspect as well as the importance of context in establishing relationships between pitches. Unfortunately, Brown and Butler's experiments (Brown & Butler, 1981; Brown, 1988), due to the equivocal results and problematic interpretations, do not fully support their theoretical insights (see Krumhansl, 1990b).

Tonal hierarchies in non-western musical cultures. Studies on the cognition of tonal hierarchies typically concern themselves with Western music. Furthermore, participants in the experiments typically grew up in the Western tradition as well. Several studies on tonal hierarchies found in non-Western music showed both cross-cultural similarities and differences. The strategies of constructing tonal hierarchies seem to be similar, yet the listeners are nevertheless more sensitive to certain nuances in their native music (Castellano, Bharucha, &

Krumhansl, 1984; Kessler, Hansen, & Shepard, 1984; Nam, 1998; Krumhansl, Louhivuori, Toiviainen, Järvinen, & Eerola, 1999; Krumhansl et al., 2000; Aarden, 2003; Eerola, 2004).

1.4. Overview of studies on scales of Lithuanian vocal tradition

Lithuanian vocal tradition in a variety of theoretical aspects have been analysed since the 19th century by Lithuanian, Prussian (Lithuania Minor) and other international scientists. The main works on scales of Lithuanian vocal tradition are reviewed, as well as some methodological approaches to the scale phenomena used in this research are defined.

Traditional viewpoint to scales. Until now, the majority of ethnomusicologists (and other scientists) have a notion that diatonic heptatonic scales and related phenomena (tonicization, modulation, chromaticism etc.) prevail Lithuanian traditional music, i.e. they argue that the musical scales are based on 12TET.

Some references of diatonic ("ancient Greek") scales in Lithuanian vocal monophony and homophony can be found in papers by Gisevius (1846?; not published), Gotthold (1847), Kurschat (1876), Bourgault-Ducoudray (1878), Bartsch (1886) etc. Brazys (1920, p. 5–7) offers to use music theory of the ancient Greeks when describing the scales and other features of the oldest Lithuanian folk songs. Čiurlionytė (1938, 1955, 1969) further develops the theory of diatonic scales; she even identifies the prevalence of different diatonic scales in different geographic regions and their rough "frequencies". In addition to theoretical considerations of diatonic scales, modal alternations and chromaticisms are registered in folk melodies (Čiurlionytė, 1955, p. 22–28; 1969, p. 233–238; Četkauskaitė, 1981, p. 26–35; 1998, p. 124–146).

Sutartinės are very distinctive Lithuanian polyphonic songs as a majority of their intervals formed by the voices are seconds (Burkšaitienė, 1990, p. 15). Probably this is the reason why many scholars, sort of purposely, avoid to discuss the scales of sutartinės. However, sparse claims of some scholars confirm that these scales are treated as of diatonic type (Juzeliūnas, 1972; Paliulis, 1984; Slaviūnas, 1969, p. 177–180).

There are at least two causes for diatonic scales and other phenomena related to 12TET to be found in Lithuanian vocal tradition. The first cause is related to national renaissance movements which occurred in Europe during the 19th century and in the beginning of the 20th century; the great interest was shown in national music, and its origins were linked to ancient Greek civilization (Ambrazevičius, 2006, p. 1820; 2008a, p. 87). The second cause is the music orthography of Lithuanian folk music transcriptions which is based on the Western system of music notation (the latter is designed for transcribing pitches of 12TET; Ambrazevičius, 1997, p. 38).

Alternative viewpoint to scales. Already the first folk song collectors noticed that it is quite complicated to write down Lithuanian folk melodies according to the laws of Western professional music and using the western notation system (Rhesa, 1825, p. 347–348, Bartschas, 1886–1889/2000, p. 34). And in more recent times, Lithuanian ethnomusicologists faced with a similar problem (e.g. Čiurlionytė, 1940, p. 94). Lithuanian musicologists and ethnomusicologists of the 20th and 21st centuries propose some notes on folk song scales that do not fit to the 12TET framework (Burkšaitienė, 1990, p. 21–22; Četkauskaitė, 1981, p. 31; Čiurlionytė, 1969, p. 206; Račiūnaitė-Vyčinienė, 2000, 2003; Sabaliauskas, 1904, 1911, 1916).

The important factor in the perception of the music from foreign cultures is the so-called "aural ghosts" which occur due to differences between the cultural insider's (performer's) modal thinking and outsider's (ethnomusicologist's) one (Ambrazevičius, 2008a, p. 73–77). Ambrazevičius (2006, p. 1821; 2008a, p. 170–171; 2008b) observed that 12TET apperception and well-established templates of Western music can influence the analysis of Lithuanian traditional music, and misleading conclusions about "ancient Greek" scales, modal alternations, and chromaticisms can be drawn.

Ambrazevičius (2006, 2009) analysed almost 100 sound recordings using acoustic and statistical methods and validated the assumption that traces of equidistant scale can be found in Lithuanian folk songs. Ambrazevičius and Wiśniewska (2008) showed that some "chromaticisms" in Lithuanian folk songs can be explained simply by performance rules. In addition, Ambrazevičius studied the phenomena of interval evolution and unfolding scales (Ambrazevičius, 2008a, p. 226–228; Ambrazevičius, Budrys, & Višnevska, 2015, p. 172–191), he proposed some techniques for eliminating gradual transposition of pitch (Ambrazevičius, 2001, 2004a, 2005–2006).

Diatonic and equitonic models. Diverse viewpoints to scales of Lithuanian vocal tradition show different methodological approaches to the subject of the research and many possible ways to interpret the results. The scales in this research are discussed with regard to two theoretical frameworks (models). To generalize, the theories behind those scales in Lithuanian traditional music are based on the framework of 12TET diatonics (i.e. structural intervals constituting all the scales are tempered whole tones and semitones), the *diatonic model* is introduced. To generalize the theories of alternative viewpoint contradicting diatonic model, the *equitonic model* is introduced. The two models are considered as possible reference points that could assist in the better understanding of the results of the research.

Tonal anchors and tonal hierarchies. In addition to the intervallic structure of scales, Lithuanian musicologists and ethnomusicologists studied differentiation of the scale degrees in traditional music. Usually their research is focused to analyses of individual melodies; rhythmically, metrically, functionally, and by other means emphasized melodic pitches are identified, and the role of tonal anchors is assigned to them (tonal anchors constitute the framework of the scale; Čiurlionytė, 1969, p. 208–214; Juzeliūnas, 1972, p. 32–67; Venckus, 1969). For the reasons already mentioned, most scientists consider tonal anchors as an immanent property of the music, ignoring the psychological aspect of the phenomenon. However, some of their proposed theories of tonal anchors, based on empirical evaluations, had a great importance in the development of the classification systems of Lithuanian folk tunes (Četkauskaitė, 1965, 1969, 1981, 1998).

Psychological aspect of the differentiation of the scale degrees, so-called tonal hierarchies, in Lithuanian vocal tradition was studied occasionally by Ambrazevičius (2008a, p. 164–174; 2011; Ambrazevičius & Wiśniewska, 2009). A probe-tone experiment was conducted by Ambrazevičius and Wiśniewska (2009) in which subjects had to judge the tonal hierarchy in the sutartinė (the recording of the authentic performance). The tonal profile of the sutartinė substantially differs from the major and minor key profiles; the highest ratings are given to the nucleus of the two adjacent tones (separated by the interval of the second and belonging to two different voices) in the centre of the scale, and the stability of the other scale degrees decreases moving towards the margins of the scale. It was also observed that the more stable pitches are in the tonal hierarchy the more stable their intonation is in the authentic performances (sound recordings) of sutartinės (Ambrazevičius, 2008c; Ambrazevičius & Wiśniewska, 2009).

Notation of scale degrees. In this research, scale degrees are denoted by Roman and Arabic numbers in the unified way. In the case of monophonic songs, the scale degree corresponding to the tonal centre (the tonic) is denoted with I and scale degrees above it are denoted by other Roman numerals, while degrees below the tonic are denoted by Arabic numerals starting from 7 (…5, 6, 7, I, II, III…). In the case of sutartinės, the upper pitch in the "scale nucleus" is denoted as the upper case letter I and the lower pitch is denoted as the lower case letter i. The scale degrees above I are denoted as upper case Roman numerals in ascending order, and the degrees below i are denoted as lower case Roman numerals in reverse order (…iii, ii, i, I, II, III…). If higher (sharp) and lower (flat) versions of the same degree occur, they are differentiated by adding an upward and downward arrows next to the numbers (e.g. III↑ and III↓).

2. METHODS OF INQUIRY

Objectification of different aspects of musical scales (quantitative evaluation) is possible only with employing methods from different sciences. Acoustic analysis is applied when identifying intervallic structure of musical scales. Weights of scale tones – tonal hierarchy – are estimated by techniques of psychological testing. The obtained data is further analysed by mathematical-statistical techniques and only then they are interpreted based on the knowledge of psychoacoustics and cognitive music psychology. Various techniques of acoustic and statistical analysis, and psychological testing are discussed and compared and the ones best suitable for the research on scales are chosen.

2.1. Methods of acoustic analysis

Acoustical measurements of musical pitch are of great importance for various fields including ethnomusicological studies among others. One of the purposes of acoustical measurements is to identify the intervals in scales of traditional music.

Evaluation of the musical scale logically splits into separate tasks: (1) extraction of fundamental frequency (and other sound properties) from the recording; (2) chunking of continuous pitch track into separate tones and the estimation of their pitches (and other properties); (3) calculation of the intervallic structure of scale based on the collected data.

If one presumes that some errors and issues related to the process of scale evaluation can occur (due to imperfections of computer software or methods of inquiry etc.), the question arises about how precise the final result should be and what is the tolerable limit of error. This question is closely related with pitch JND (see Chapter 1.2). The difference of 10 cents between actual pitch and its estimate is considered as the limit of tolerance.

Pitch detection algorithms. The fundamental frequency ($f0$) of musical performance can be extracted using computer software called pitch[6] detection algorithm (PDA). Many free and commercial PDAs are available, so the natural question arises: if all of them solve the same task, are their outputs similar and equally reliable?

Three popular PDAs are discussed: auto-correlation (AC; Boersma, 1993), YIN (de Cheveigné & Kawahara, 2002) and SWIPE' (Camacho & Harris, 2008). Their performance was tested on synthesized sine tones and typical examples of a natural voice. 22 sine tone examples of constant and changing $f0$s were synthesized. The examples include steady tones, tones with regular vibrato, tones with "slow vibrato" (the undulation rate of which is 1 Hz), and glides. The examples of the same type differ in one or more parameters (pitch, vibrato amplitude, duration etc.). Four examples of a natural voice were prepared from the

[6] Here pitch is equated to $\log f0$.

recordings of monophonic Lithuanian folk songs (performed by four female singers). These examples contain short segments (approximately 0.5–0.7 s) of a typical performance situation, with steady tone, vibrato tone, convex tone, and tone with embellishments.

The intonograms[7] of all of the sound examples were generated using all three PDAs (the default settings of the algorithms were used). An intonogram consists of a set of samples corresponding to the fundamental pitch (log*f*0) of a sound example at every 10 ms. The generated intonograms of the sine tone examples were aligned with the actual ones in time so that the difference between the two intonograms was the smallest possible. The actual intonograms were known in advance, as they were determined in the synthesis of the sound examples. In contrast, it is impossible to obtain the actual intonogram of the natural voice performance, so the outputs of different PDAs generated for the same example were compared only between each other.

The specific method chosen for evaluating the deviation between the two intonograms depends on the type of sound example (steady tone, glide, etc.). The overall discrepancies between the two intonograms are evaluated by finding the absolute differences between aligned samples of both intonograms and then calculating the mean. However, these discrepancies may have only a negligible influence on the final results in certain situations. For example, the integral (perceived) pitch of a quasi-stationary segment or vibrato tone can be approximated to the averaged value of its intonogram. The comparison of two means calculated from intonograms helps to identify the difference between integral pitches. This method was applied for steady and vibrato tones only. Many research projects on vocal or instrumental performances investigate the phenomena of vibrato. Thus it is important for the PDA to detected the minima and maxima of each vibrato cycle as accurately as possible. In this case the extreme points of vibrato cycles in the two aligned intonograms are compared. This method was applied for examples of regular vibrato and "slow vibrato". A visual comparison of aligned graphs of intonograms was also used in this investigation.

In the case of sine tone examples, the deviations between the output of the algorithm and the actual pitch were evaluated by different methods. AC and YIN algorithms performed well enough: the deviations between generated and actual intonograms were mostly considerably less than 1 cent. But the performance of SWIPE' algorithm was low. The averaged discrepancies were from 2 to 19 cents. The means of the generated intonograms were sharp or flat from 2 to 6 cents. The generated pitches of extreme points of regular vibrato and "slow vibrato" were too high or too low up to 21 cents. Though the fundamental tone of glides rose evenly, SWIPE' detected strange bumps differing from the actual pitch up to about 29 cents.

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[7] Here and hereafter the notion of intonogram actually means log*f*0 track, as traditionally accepted by the PDA authors.

In the case of the natural voice examples, the three PDAs were compared in all possible pairs and the differences between outputs were evaluated. Visual comparison showed that the intonograms generated by AC and YIN were more similar to each other than to those generated by SWIPE’. However, YIN and SWIPE’ gave generally smoother intonograms than AC. The averaged absolute deviations between outputs of different algorithms were quite large; up to 15 cents. Nevertheless, the outputs of AC and YIN differed the least. The averaged intonograms of quasi-steady and vibrato tones given by the PDAs were also compared. The difference between results of AC and YIN were as small as 0.4 cents, while the difference between results of any of these algorithms and SWIPE’ varied from 1.8 to 3.1 cents.

Testing PDAs showed that, even with sine tone examples, no algorithm can perform without small errors which, probably, manifest even more clearly when estimating the pitch of natural sounds. Fortunately, in many cases two of three algorithms make errors that are smaller than 10 cents. Some software packages make use of the PDAs discussed here.[8] It is worth mentioning that when considering results obtained employing certain software, the accuracy and reliability of the algorithm used should be taken into account before making scientific conclusions. The author chose AC algorithm (realized in the software for acoustic analysis “Praat”) for the pitch measurements.

Semi-manual evaluation of a musical scale. Vocal music, especially performed by folk singers, is characteristic of unstable intonation. Additionally, in such performances, not only separate sounds are intoned unsteadily, but also the realizations of the same scale degree occur with somewhat different pitches, over the course of performance. These issues and the related evaluation of a musical scale are discussed.

The subjective pitch is not precisely equal to the “objective” pitch (log*f*0). Consequently, fast undulations of the “objective” pitch are not necessarily perceived as the changes of subjective pitch (see Sundberg, 2013, p. 92–98). This is because changes in frequency and intensity that take place in approximately 100–200 ms tend to be integrated in the echoic memory, so the result of the sensation is a single, steady, averaged sound (integral pitch; Ambrazevičius, 2008a, p. 117).

The semi-manual technique tested already in the earlier studies of similar kind (Ambrazevičius, 2005–2006; 2008a; Ambrazevičius & Budrys, 2012; Ambrazevičius, Budrys, & Višnevska, 2015) is presented. The technique enables the pitches of monophonic performance to be measured precisely enough. Computer software for acoustical analysis “Praat” (AC algorithm) is applied. The

[8] AC is implemented in “Praat” software, YIN and SWIPE’ – in “Tarsos” software (http://tarsos.0110.be/), AC and SWIPE’ – in “PsySound3” software (http://psysound.wikidot.com/start), SWIPE’ – in “NoteView” software (http://sam.arts.unsw.edu.au/research-and-creative-practice/research-projects/empirical-musicology/), etc.

user analyses the continuous intonogram and measures perceived (integral) pitches of tones by selecting appropriate portions of intonogram.

Pitch estimations of separate tones make up the primary array, and its subsequent analysis enables recognition of the essential features of scales. Static and dynamic scale aspects can be demarcated. The current study examines only the static aspect of scales. The static scale is calculated based on the pitch estimates of tones (not necessarily of all tones) in a single performance. A certain scale degree is assigned to each estimate. The arithmetic mean method is applied on all the occurrences of the same scale degree and the averaged pitch of that scale degree is calculated.

If pitch extraction software is considered reliable, two questions still arise. How precise can the manual pitch measurements be? How precise can the evaluation of static scale based on these measurements be?

To examine these issues, a semi-manual technique was tested with the monophonic recording of Lithuanian folk song “Vaikščiojo tėvulis”. The recording contained 14 melostrophes featuring complicated semi-free rhythm and abundant ornamentations. Three subjects (the author, Dr. Rytis Ambrazevičius and Irena Višnevska) measured the pitches and onsets of each tone in the first six melostrophes. The sound onsets were used for estimating the inter-onset-intervals (IOIs), i.e. the sound durations.

The subjects made measurements in melostrophes 1–3 independently. After the results were collated, typical shortcomings were revealed and discussed. Then the procedure was repeated with melostrophes 4–6. The measurements in the melostrophes 4–6 were more precise compared with measurements in melostrophes 1–3. Therefore, only the results obtained from melostrophes 4–6 are considered.

Pitch estimates made by the three subjects for the same tone differed (in terms of standard deviation) by 6.5 cents, on average, for melostrophes 4–6. The differences between the estimates diminished in the case of pitches with longer durations. For example, in the case of tones shorter than 0.2 s the averaged difference is 18 cents, and in the case of tones with durations of 0.2–0.5 s the averaged difference drops to 6 cents. Consequently, pitch measurements of individual tones are acceptably precise only if quite long sounds are analysed.

To verify the hypothesis that there is a relationship between measurement precision and pitch duration, a linear regression analysis was performed on the data. The regression model is successful enough for predicting the measurement precision (the standard deviation of the pitch estimates given by the three subjects), yet it also has some shortcomings. At any rate, the regression analysis has shown that pitch duration is not the only determinant in measurement precision.

The discussed examination shows that the manual measurements of separate pitches are not very precise. Yet this study considers static scales, therefore it is more interesting to know how precise the evaluations of scale pitches could be based on the manual (limitedly precise) measurements of separate pitch occurrences.

For each subject, pitches of scale degrees were calculated from pitch estimates of individual tones in melostrophes 4–6 using the method of arithmetic mean. The comparison of data showed that pitches of the same scale degree differed by 2–4 cents between the subjects. This level of precision was obtained even when all pitch estimates of short sounds were included in the scale evaluation. The scale evaluation becomes even more precise when only longer pitches were considered.

To summarize, it can be concluded that the evaluations of musical scales as arithmetic means of manual pitch estimations are sufficiently precise, and the error is less than ±10 cents.

Automatic techniques of scale evaluations. Semi-manual evaluation of musical scale is a tedious and time-consuming process thus it is not very attractive. Two possibilities to automatize this process are discussed. First, the computer software for acoustic analysis "NoteView" could be employed, second, the process of scale evaluation could be simplified with the aid of different techniques of statistical analysis.

"NoteView" is a software tool that performs essentially the same procedure as a researcher that evaluates separate pitches from intonograms (Gunawan & Schubert, 2010). The software was tested on melostrophes 4–6 from the recording of "Vaikščiojo tėvulis". It extracted averaged pitch, temporal position, and some other parameters for every sound event. Scale degrees were assigned to each event manually.

"NoteView" missed a total of 19 notes in melostrophes 4–6, compared with semi-manual evaluations. The pitches of the mutual notes occurring both in the semi-manual evaluations and in the "NoteView" readings were collated. The individual pitches differed by approximately 9 cents on average, but some cases differed up to 28 cents and even more. The pitches of scale degrees were calculated from the "NoteView" readings and compared with pitches obtained from semi-manual evaluations. The pitch deviations for different scale degrees equal roughly 3–8 cents (6 cents, on the average).

Some authors (Ambrazevičius, 2004b, p. 135–136; Ambrazevičius & Budrys, 2012; Askenfelt, 1979, p. 110, 115; Biró, Ness, Schloss, Tzanetakis, & Wright, 2008; Will & Ellis, 1996, p. 194) propose techniques of scale evaluations that are based on the notion that quasi-stationary pitch segments corresponding to pitch categories are significantly longer than transitions, glissandos, glides and non-structural sounds. Various techniques of statistical analysis (histogram, kernel density estimate, LTAS[9]) are applied on the data (samples) of intonogram or spectrogram, and the structure of pitch categories and consequently the scale properties are determined.

[9] Long-term average spectrum.

Kernel density estimation (KDE)[10] was applied on intonogram of melostrophes 4–6 from the recording of “Vaikščiojo tėvulis” (it was generated with AC algorithm). Discriminate peaks of the KDE correspond to the pitches of scale degrees and valleys show positions of boundaries between the pitch categories. These results were compared with pitches of scale degrees obtained from semi-manual evaluations. The absolute deviations of scale pitches determined by the two techniques range roughly from 4 to 14 cents (8 cents, on the average).

The idea of automated scale evaluation is attractive because of a significant saving of time resources. If imprecision of some 10 cents does not matter, the considered automated methods can be applied. Nevertheless, the semi-manual method of pitch evaluation, though time-consuming, is preferable if more precise evaluation comparable to the lower values of JND is required. It can be concluded that the automatic techniques are insufficiently precise and therefore they are not suitable for the current research. The author made all pitch measurements semi-manually.

2.2. Methods of statistical analysis

An acoustic analysis alone does not provide strong conclusions on intervallic structures of scales and prevalent principles of modal thinking. Quantitative interpretation of measurement results is forwarded by various techniques of statistical analysis.

Graphical representation of data. Sufficiently comprehensive conclusions about pitch categories can be drawn from various graphs. The simplest way to visualize the data is by representing pitches as points on a line. In the case of a sufficiently large sample, pitches can be grouped into bins of equal width and represented in a histogram. The properties of the probability distribution are roughly estimated from the shape of the histogram and some conclusions concerning pitch categories are drawn. In the case of a small sample, data visualization by histogram becomes ineffective. A better solution is to use the more sophisticated method of kernel density estimation. This method produces a kernel density estimate (KDE), or a smooth continuous curve, which approximately corresponds to a probability density function of the variable in the population (see Wand & Jones, 1995). KDE can substitute for the histogram, i.e. conclusions about pitch categories can be drawn from KDE graph.

Assessment of modality in pitch distributions. Estimating the number of modes in the pitch distribution helps to identify whether tones of similar pitch constitute either one or more pitch categories. Usually, modality assessment is made from a graphical representation of the data. However, some problems

[10] KDE values were calculated using software *Kernel Density Estimation (v1.0.11) in Free Statistics Software (v1.1.23-r7)* (Wessa, 2012).

leading to erroneous conclusions might arise. For example, in case of a small sample, the shape of the graph may result simply by chance. Similarly, even though it is impossible to distinguish two clear peaks in the graph, the distribution might still be bimodal.

Many statistical methods for modality assessment exist (see Hartigan & Hartigan, 1985, p. 70–71; Frankland & Zumbo, 2002, 2009; Knapp, 2007, p. 8–10). Four methods, including the normality (Shapiro–Wilk) test, kurtosis (Muratov & Gnedin, 2010, p. 1286), bimodality coefficient (SAS Institute Inc., 2012, p. 1934), and the dip test (Hartigan & Hartigan, 1985) were tested on small samples (10–24 observations). Each sample contained realizations of the same scale degree in a particular repertoire. Some pitch distributions were unimodal and others were bimodal. The normality test, bimodality coefficient, and the dip test almost always identified a unimodal distribution, while the kurtosis almost always showed bimodality.

An alternative method of modality assessment is presented. For a pitch distribution, the KDE is calculated and plotted. When the graphical representation shows some departures from unimodal distribution, such as a strong asymmetry or more than one peak, an additional test is performed. The assumption is that a bimodal distribution consists of a mixture of two normal distributions (Eisenberger, 1964). The probability density function of a mixture distribution is fitted to the KDE by applying the method of least squares (minimization), and five parameters (including two means and two standard deviations) are estimated. Some mathematical manipulations with these parameters help to distinguish between unimodal and bimodal cases (see Schilling, Watkins, & Watkins, 2002, p. 225). Also these parameters reveal the structure of pitch categories.

If neither the KDE graph has features of bimodality nor do other means prove the bimodality of the data, then it is assumed that the pitches are drawn from a normal distribution. The method of least squares is applied to determine the best fitting probability density function of a normal distribution to the KDE, and two parameters (mean and standard deviation) are estimated.

Diatonic contrast. An index of diatonic contrast (DC) was introduced by Ambrazevičius (2006, p. 1818; 2008a, p. 139, 285–288). DC measures intervallic asymmetry of the scale, i.e. it shows whether the scale is “more diatonic” or “more equi-tonic”. In the case of perfect diatonic scale, DC equals to one. In the case of perfect equidistant scale, DC equals to zero.

Cluster analysis. Cluster analysis identifies “groups of individuals or objects that are similar to each other but different from individuals in other groups” (Norušis, 2011, p. 375). Agglomerative hierarchical clustering is used for classification of musical scales according to their intervallic structure. Cluster analysis is performed by statistical software packages such as SPSS from IBM.

The intervallic structures of scales are the data for evaluating similarity. The intervallic structure can be represented in several ways. The basic representation is a set of relative pitches with regard to the I scale degree (which is thus normalized to 0; *Representation of relative pitches*). Another way to represent the intervallic structure is to calculate the intervals between adjacent scale degrees (*Representation of succeeding intervals*). A composite of these two representations is a set of intervals between scale degrees for all possible pairs (*Representation of all intervals*). Initial tests on various scales showed that, in most cases, this representation gives results which best approximate the subjective similarity evaluations. However, clustering will be performed not only with this kind of scale representation, but also with other representations depending on the analysis goals. Other optimal parameters of cluster analysis were defined experimentally (squared Euclidian distance and averaged linkage between groups[11]).

The disadvantage of cluster analysis is the requirement of classifying objects that have an equal number of attributes. Musical scales vary in the number of scale degrees, so one should select only examples comprising the same scale degrees; if some examples possess additional degrees above or below, then these degrees are excluded from the analysis.

There is no strict criterion for finding the best cluster solution, and the optimal number of clusters depends on the goal of the investigation (e.g. Norušis, 2011, p. 377). After applying some cluster solution, each group is examined and common intervallic patterns among scales are revealed.

The scales with similar relative intervallic structures (and with only reasonable differences in absolute numbers) tend to be perceived as similar (for example, two major scales, one based on 12TET and the other slightly stretched). If only the relative intervallic structures are considered, then the range of each scale must be normalized. This eliminates the effect of "contracting" or "stretching" of otherwise similar scales from the cluster analysis.

2.3. Methods for research of tonal hierarchies

Methods for research of tonal hierarchies differ essentially from the already discussed techniques applied in studying intervallic structures of scales. Huron (2006, p. 41–52) and Auhagen and Vos (2000) describes some methods developed to register perceived tonal hierarchies. A few of them are discussed here.

The probe-tone method has already been discussed (see Chapter 1.3). Several modifications to this method have been implemented. For example, a pair of tones or a chord instead of a single probe tone have been used. Investigating the phenomenon of modulation, a progressive probe-tone method is employed (Huron, 2006, p. 46). The obvious shortcoming of the probe-tone method is the tiring process of data gathering. As a result, various side effects can appear

[11] For details on hierarchical clustering, see, Tan, Steinbach, & Kumar (2006, p. 515–526), Norušis (2011, p. 377–388).

(Auhagen & Vos, 2000, p. 431–432). Another shortcoming is that the musical context is stopped, and the "fit" ratings for the probe tone may depend on whether the listener perceives the tone as a continuation of the melody or its completion (Huron, 2006, p. 47).

The final-tone method[12] is similar to the probe-tone method. The subjects, after hearing a short melody or fragment of a real musical work, judge how well the final tone *continued* or *completed* the melody (see Palmer & Krumhansl, 1987a, b; Boltz, 1989a, b; Schmuckler, 1989; Bigand, 1993, 1997). Compared to the probe-tone method, the final-tone method is more effective in terms of data collection speed, but it is less effective in terms of how much data is collected. When analysing perceived tonal hierarchy, the results of both methods show statistical correlation (Palmer & Krumhansl, 1987a, b; Bigand, 1993, 1997), so priority should be given to the method the results of which are easier to analyse and interpret.

Huron assigns various experimental designs to the method of production where participants have to sing, play, or notate an improvised, yet expected continuation for a musical fragment (Carlsen, Divenyi, & Taylor, 1970; Carlsen, 1981; Lake, 1987; Schmuckler, 1988, 1989; Povel, 1995; Larson, 1997, 2002). The method has many shortcomings, e.g. necessary ability to sing or play, expertize in music theory, and so on (Huron, 2006, p. 43–45). Besides Huron's noted experiments, there exist some other experimental designs where listeners have to hum the tonic (Brown & Butler, 1981; Brown, 1988), the first scale that came to their mind (Cohen, 1991) or the most fitting tone as the musical example plays (Heylen, Moelants, & Leman, 2006). Despite the benefits of the latter methods (requiring less musical competence and conscious effort from the subjects), the information gathered is rather small.

The reaction time method is based on the idea that more stable tones in a context are more quickly and more reliably recognized. Janata and Reisberg (1988) unified the reaction time and probe-tone methods. After hearing a probe tone preceded by a context, the listeners had to determine if the tone belongs to the induced key or not as quickly as possible by pressing one of two buttons. Aarden (2003) applied another modification of the reaction time method. In his experiments, while listening to an ongoing melody, listeners had to indicate the direction taken by each tone (ascended, descended, or remained the same) by pressing one of three buttons as quickly as possible. The largest benefit of the reaction time method is the ability to accurately measure the listener's expectations. Furthermore, because of its specific nature and speed, this method is not susceptible to conscious influence, and it is very time efficient, too.

[12] In many studies (Cuddy & Lunney, 1995; Krumhansl et al., 1999; Krumhansl et al., 2000), this tone is called the "continuation tone", but "final tone" better captures the principles of the method and covers more modifications of the method.

There are some highly specific experimental designs intended to register unconscious responses of participants. These designs include bradycardic response and ERP[13] (Huron, 2006, p. 51–52). Both methods are especially useful for investigating the response of animals and prelingual children to musical stimulus.

Although some modifications of the reaction time method probably seem the most attractive, they need specific equipment and skills. Therefore, for the current research, the probe tone technique is chosen, which is simpler but gives similar results.

[13] Event-related potential.

3. SCALES IN LITHUANIAN VOCAL TRADITION AND THEIR CONTEXTS

The analysis of traditional music usually begins with Western transcription, which represents the cultural outsider's modal thinking rather than the insider's. As a result, misleading conclusions regarding the musical scales can be drawn. The present research is based not on transcriptions but on acoustic and psychological data. Various statistical methods are applied for the quantitative analyses of scales.

3.1. Scales of Lithuanian folk songs: General tendencies

The main goal of this investigation is to reveal general patterns of the intervallic structures found in scales of Lithuanian monophonic songs. The results are discussed with regard to two theoretical frameworks, diatonic and equitonic.

Inquiry. Sample of 73 monophonic songs recorded in various places of Lithuania and performed by various singers was analysed. Most recordings were made in the 1960s, and some are from later decades (from 1956 to 1998). A representative repertoire of vocal tradition was formed, i.e. songs of diverse genres and places of origin were included into sample.

The pitches of all of the structurally important sounds in the songs were measured[14]. The recordings of songs were relatively long. Therefore, only one or a few melostrophes (from the beginning) of every song were chosen for the investigation. The static scale was obtained for every performance. Relative pitches in each scale were calculated (in regard to the I scale degree).

For each scale degree (except the I degree the pitch of which is equal to zero), a histogram of relative pitches found in all the scales of the sample was constructed. The mean and the standard deviation of each pitch distribution were calculated. If a histogram shows a bimodal distribution, then it is assumed that there are two pitch categories, therefore two means and the two standard deviations are estimated. The diatonic contrast (DC) values were calculated for 72 scales[15]. Three cluster analyses were performed on a selection of 51 scales. Each analysis was applied on different combination of scale degrees and on different scale representations.

Results. The realizations of II, IV, and V scale degrees make up homogeneous pitch categories. That is, comparing the scales, there is no reason to conclude about different versions (e.g., higher or lower) of these degrees. The realizations of 7 and III scale degrees fall into two different pitch categories. As a result, we can talk about high and low versions of these degrees in different scales. However, in the

[14] Pitches of individual sounds in 70 recordings were measured by the author, in two recordings by Dr. Rytis Ambrazevičius, and in one recording by the author, Dr. Rytis Ambrazevičius and Irena Višnevska.
[15] Because of the peculiarity of the DC methodology, one scale was not analyzed.

case of the III degree, the pitch categories are not absolute; the boundary between the categories is unclear and the distance between the centres is narrower than a tempered semitone. The realizations of the VI scale degree make up one, though wide and unstable, pitch category. As a result, a Western listener could hear two versions of the VI degree (either eight or nine semitones above the I degree) in different scales.

DC values showed that the manifestation of the equitonic model is slightly more pronounced than the diatonic one in the scales under investigation (the median DC value is 0.45).

The first cluster analysis was intended to ascertain how the II, IV and V scale degrees are intoned in regard to the I degree. Two large groups of scales were identified. In the first group, the II, IV, and V scale degrees do not deviate very much from their tempered equivalents; the average pitches of these degrees in the group are, respectively, 1.97, 5.11, and 7.03 semitones above the I degree. In the second group, the II, IV, and V scale degrees are somewhat sharper, with average pitches of 2.09, 5.36, and 7.49 semitones above the I degree. A general tendency for the fourth and fifth to be wider compared to those of 12TET can be seen in both groups.

The second analysis was intended to identify possible groupings of scales according to the within-scale intervallic patterns among the I to V degrees. This analysis proposed six groups of scales. Each group can be matched into one of three intervallic patterns: equitonics-like, major-like, and minor-like. However, only two groups contain scales which resemble “real diatonics” with more or less similarly sized “whole tones” and much narrower “semitones.” A mixture of intervals varying in size with the properties of both equitonics and diatonics dominate the other groups.

The third analysis was similar to the second one, except it was sensitive to the fact that scales having a similar relative intervallic structure are perceived as similar (scales with normalized ranges were considered). Four groups of scales were identified. One group has an intervallic pattern similar to equidistant scale, two groups to the major scale, and one group to the minor scale. The averaged DC values for each group were calculated. The groups appearing to be equitonic-like have DC values well below 0.5, and those featuring properties of diatonics have DC values either just under 0.5 or above it. It was concluded that the minor-like scales are most affected by the diatonization, while the major-like scales take an intermediate position between equitonics and diatonics.

Discussion. The results show various phenomena of intonation and modal thinking including the framework of a stable fourth/fifth (Četkauskaitė, 1981, 1998), interval stretching, intermediate cases between equitonics and diatonics, wide intonation zones etc. In general, significant deviations of data from the theoretical models indicate that, at least in this sample, the principles of both equitonics and diatonics coexist.

The results of this investigation match the results obtained by Ambrazevičius (2009), even though there are some discrepancies. These are the more pronounced diatonization of scales and especially the partial splitting of the III degree into two pitch categories. This is not difficult to explain; the samples of Ambrazevičius' investigation consisted mostly of recordings from the 1930s, so the modal thinking of performers in that era retained more archaic features.

3.2. Scales of Lithuanian folk songs: Geographical, stylistic, and diachronic aspects

In this investigation, two objectives are considered. First, the similarities and differences among the scales of vocal tradition involving three ethnomusical dialects (regions) of Lithuania and two musical styles are revealed. Second, the scales of the contemporary secondary Lithuanian vocal tradition are discussed in the context of the primary tradition developing over the course of the 20th century.

Scales in different dialects and styles. Geographic borders of the Lithuanian ethnomusical dialects correspond approximately to the borders of ethnographic regions, Aukštaitija, Dzūkija, Suvalkija, and Žemaitija (see Čiurlionytė, 1969, p. 290). Stylistically the vocal tradition splits into monophonic songs and polyphonic sutartinės as well as other styles not considered in the current research. Geographic and stylistic aspects are partially related, for instance, sutartinės are located in north-eastern Aukštaitija only (Čiurlionytė, 1938, p. 272; Slaviūnas, 1969, 1974). Therefore, the two aspects are further considered together.

Three samples containing 62 recordings of songs representing the regions of Suvalkija (sample S; 25 examples), Žemaitija (sample Z; 10 examples), and Aukštaitija (sample A; 27 examples), were composed. The first two samples consist of monophonic songs while the third sample consists of polyphonic sutartinės. Some of the oldest recordings made in the 1930s were analysed with the expectation that the dialects would be least influenced by foreign musical traditions and/or musical education. For evaluating the scales of monophonic songs, the same procedure as in previous investigations was applied (see Chapter 3.1). In the case of sutartinės, the spectra of the vocal dyads were considered, i.e. pitches of individual tones were estimated from the spectrogram and static scale was obtained for every sutartinė[16].

For determining the general tendency towards either the diatonic or equitonic model in each dialect or style, the diatonic contrast (DC) was calculated for all scales. The evaluation of the DC showed that the scales in all three samples are statistically more similar to the equitonics; 71% of the examples have DC values less than 0.5. The traces of the equidistant scale are not equally strong for the different dialects under investigation; the polyphonic sutartinės from Aukštaitija show the strongest equitonic impact, while the element of diatonics is relatively more pronounced in the monophonic songs from Suvalkija.

[16] Pitches of individual sounds in all recordings were measured by Dr. Rytis Ambrazevičius.

For each sample, separate cluster analysis was performed on the selected and modified data[17]. 11 scales were analysed from sample S, 10 scales from sample Z, 14 scales from sample A; only relative intervallic structures were considered. These analyses showed the examined sets of scales splitting into more or less distinct groups with characteristic intervallic structures. Quasi-equitonic scale groups were identified in all three dialects. However, each dialect is characteristic of scales with specific intervallic patterns. For instance, Žemaitian songs are distinguished by the most "chaotic" or diverse scales, and their intervals are significantly stretched compared to the conventional cases (12TET). In contrast, the scales of many Aukštaitian sutartinės are quite symmetric and even strikingly similar.

The cluster analysis was also performed on the composite set of 29 scales selected from the three samples to ascertain if there is any relationship between the intervallic structure and particular dialect or style (monophonic vs. polyphonic). The results do not provide solid evidence regarding scales as being specific to particular dialects/styles.

Changes in the scales of the secondary vocal tradition. Over the course of the last century, the lifestyle of Lithuanians has changed drastically, from rural to mostly urban. This process affected many areas of daily life, including musical traditions. On the one hand, the ancient, unbroken oral tradition has almost vanished by now. On the other hand, the current, so-called secondary tradition is very active; many singers and groups perform "reconstructions" of traditional songs. As a result, the musical scales in the vocal tradition have also experienced considerable transformation.

Three sample sets of monophonic songs representing a different historical period were compiled, 177 items in total. The sample of 35 songs from the interwar period features recordings from the 1930s of the Suvalkian and Žemaitian primary (unbroken) vocal tradition (already discussed samples S and Z). The sample from the middle period contains 73 recordings of the Lithuanian primary vocal tradition from the second half of the 20th century (sample from Chapter 3.1). Finally, 69 vocal performances of urban folklore groups (the secondary tradition), recorded from 1986 to 2009, constitute the sample from the current period (the scales of songs were evaluated by applying the same procedure as in previous investigations; see Chapter 3.1)[18].

The differences between vocal tradition examples recorded in three different time periods were examined. The main hypothesis was that the scales in Lithuanian traditional vocal music noticeably shifted from Grainger's (1908) "loosely-knit" modes to the 12TET versions of diatonics over the course of the

[17] Because of the peculiarity of the cluster analysis, only scales comprising a specific set of scale degrees were analyzed (additional degrees above or below were excluded from the analysis; see Chapter 2.2).

[18] Pitches of individual sounds in all recordings were measured by the author and Irena Višnevska.

20th century. The scales were discussed in regard to two theoretical models, equitonic and diatonic. The DC values of the scales were calculated in order to quantify the ratio between the equitonic and diatonic manifestations in each sample.

The comparison of the scales found in recordings from different historical periods confirmed the hypothesis regarding changes in modal thinking in Lithuanian vocal tradition. Equitonics is found to be typical for the samples both from the 1930s and the second half of the 20th century (with slightly more diatonic-like examples in the latter sample). Diatonics is more typical for the sample of contemporary recordings of urban folklore groups. The quartiles of the DC values (successively, Q_1, *Me*, and Q_3) are the following: for the sample of the interwar period – 0.28, 0.45, 0.55, for the sample of the middle period – 0.34, 0.45, 0.62, for the sample of the current period – 0.54, 0.74, 1.11.

The results for the interwar and middle periods are somewhat unexpected: these periods have very similar average DC values. Therefore, it can be concluded that the changes in modal thinking in the unbroken tradition were minor during the period from the 1930s to the 1990s, but the modal thinking of the contemporary urban folklore groups shows significant change. The era and drastic soundscape alterations (radio, TV, new types of musical activities, etc.) had less influence on the scale structure than the extinction of the unbroken oral tradition did.

The DC values for the sample of the current period songs deviate much further from the median (the interquartile range is wider) compared to other samples. To explain the phenomenon, the distribution of DC values and the intervallic structures of scales were examined in more detail. The distribution of DC values is found to be heterogeneous. Therefore, based on the intervallic structures of the scales, the performances of the secondary tradition can be divided into two groups. In the recordings of the first group, the contrast between whole tones and semitones is relatively small (the DC median value is 0.6). The scales found in the recordings of the second group either roughly match 12TET or have a sharpened contrast between whole tones and semitones (the DC median value is 1.2). Probably those performers whose recordings are included in the first group imitate an authentic performance style, either consciously or not, but the influence of the "native" equal temperament prevents their reproducing actual scales. Performers in the second group make use of exclusively diatonic scales in their performances, possibly because of the extensive prevalence of Western transcriptions.

Two cluster analyses were performed on selected scales from the current period songs. The first analysis was intended to identify any possible group of scales that feature a neutral third[19]. The second analysis was performed to verify whether there are any "hidden" manifestations of equitonics — contracted or stretched equidistant scales — in the sample. In general, almost all of the

[19] A neutral third can often indirectly indicate equitonics (Ambrazevičius, 2006, p. 1821).

performances in the sample from the current period were found to be based on diatonic scales. Some sporadic occurrences of scales resembling equitonics do not form a homogeneous group, so they can be treated as outliers.

3.3. Scales in the neighbouring vocal traditions

As is well known, the boundaries of European countries have frequently moved. Thus, the area of a traditional music is sometimes not confined to the borders of modern states. Lithuanians and neighbouring nations have a common historical background as well as related languages, customs, religions, and rituals. The aim of this investigation is to explore the musical scales in Belarusian, Polish and Latvian monophonic folk songs, while also comparing these scales with scales of Lithuanian folk songs. The majority of scholars consider the diatonic system of scales prevailing in these regions/dialects (see Encyklopedia PWN, 2015; Kšanienė, 2005, p. 151; Дожына, 2014). It was shown in previous investigations (see Chapters 3.1 and 3.2) that some phenomena inconsistent with 12TET diatonics can be detected in Lithuanian traditional music. Two possible principles, equitonics and diatonics, were traced in recordings of monophonic songs and polyphonic sutartinės. The attempt is made to detect these two principles and/or their modifications in the scales of neighbouring vocal traditions.

Inquiry. 145 recordings of traditional monophonic songs performed by Belarusians, Latvians, and Poles were selected from publications prepared by professional ethnomusicologists and from archives of traditional music. Songs were arranged into groups according to the nationality of the performer and his/her residence. Songs from Belarus and Polish songs from the Vilnius region were additionally grouped into rye/oat harvesting songs and songs of other genres. Songs were arranged into seven groups: various Belarusian songs (20), Belarusian rye harvesting songs (22), Kurpie region (Poland) songs (19), Suvałki region (Poland) songs (20), Latvian songs (18), various songs of the Vilnius region (Lithuania) Poles (24), and rye/oat harvesting songs of Vilnius region Poles (22). For evaluating the scales of songs, the same procedure as in previous investigations was applied (see Chapter 3.1)[20].

Realizations of a particular scale degree across a group of songs (in static scales of these songs) constitute a sample. Such samples were considered in this investigation by examining the properties of their pitch distributions, calculating generalized scale for each song group[21], and making comparisons among samples as well as among song groups. The correct interpretation of data is possible only

[20] Pitches of individual sounds in all recordings were measured by the author and Irena Višnevska.

[21] The set of pitches available for all melodies in a musical culture, particular dialect or genre constitutes the tonal material (Dowling, 1978, 1982; see also Dowling & Harwood, 1986, p. 113–115) or tuning system (Snyder, 2000, p. 136–39), and is referred here as a generalized scale. A generalized scale consists of a set of pitch categories defined by two parameters, the position of the category centre in relation to the I scale degree and its size.

after determining the structure of the pitch categories that constitute the scales in a particular musical dialect or genre. For this task, various methods of statistical analysis including graphical representation (especially histogram and kernel density estimate), modality assessment (for small samples), and diatonic contrast (DC) were applied on the data.

Results. Among the examined examples, double (lower and higher) versions of scale degrees are not found only in the group of various Belarusian songs. The objective evidence from statistical data analysis shows that these scales are based on principle of equitonics; the similarly sized (163–194 cents) intervals between the adjacent scale pitches, the pitch of the III scale degree that is close to the neutral third, and the loose intonation compared to other groups support this. The Kurpie region songs are the most affected by diatonization. The scales of these songs became assimilated with major, minor and other diatonic scales due to the double versions of the 7, III, and VI scale degrees. Furthermore, the generalized scale shows that centres of pitch categories are located closest to the corresponding tempered diatonic pitches and category sizes, on average, are narrower, compared to the other groups. The scales of all the other groups are more or less affected by diatonization, nevertheless, some distinct discrepancies between them and the diatonic model are observed.

In order to compare different groups of songs (including the group of Lithuanian songs from previous investigation; see Chapter 3.1), two properties of the generalized scales were considered, the intervallic structure and the intonation stability. The intervallic structure was evaluated by calculating DC for a generalized scale. The intonation stability of a particular pitch category roughly corresponds to its size. Therefore, the overall intonation stability for a generalized scale was evaluated by averaging all category sizes of that scale (the smaller the value, the more stable the intonation).

There are some clear parallels between the songs sung by Belarusians and Vilnius Region Poles. Rye/oat harvest songs of both groups are distinguished by higher diatonization (the generalized scales have higher DC values) compared to the songs of other genres, suggesting that this property depends on the genre. On the contrary, the intonation stability depends more on the region; the intonation is less stable in the Belarusian songs compared to Vilnius region Poles' songs.

The Lithuanian songs geographically close to the Vilnius Region occupies the middle position (in regard to DC values of generalized scales) between the various songs and rye/oat harvest songs sung by Vilnius Region Poles. This can be explained by the fact that these songs were not differentiated by genre in previous investigation. The additional examination of the Lithuanian song group revealed similar tendencies between the songs of rye/oat harvest and of other genres as in the cases of Belarusians and Vilnius Region Poles.

Even though Latvian songs have distinctive features (e.g. they have a unique musical form; Butkus, 1995, p. 128–131), the principles of scale construction seem to be nearly identical between Latvians and Lithuanians (in terms of intervallic structure and intonation stability).

The songs from the Suvałki and Kurpie regions were unexpectedly different (especially in the DC values of generalized scales). The generalized scale of the Suvałki region was more similar to Lithuanian, Vilnius region Poles', Belarusian, and even Latvian scales. These facts are consistent with the ethnomusicologists' insights about the similarity of traditional music for both Poles and Lithuanians in the Suvałki region (Sokołowski, 1994) and about the distinctiveness of the Kurpie region (Stęszewski, 1965; Przerembski, 1993).

Discussion. The analysis of the intervallic structure of scales has additionally revealed that the same musical universals like the principle of equidistant scales, the stable framework of the perfect fourth and fifth, and the phenomenon of interval stretching are found in the neighbouring vocal traditions. The equitonic and diatonic models supplemented with these and other phenomena become flexible systems that can explain the diversity of the scales in the dialects/genres discussed.

3.4. Tonal hierarchies in Lithuanian folk songs

In the last investigation, the question of tonal hierarchies in Lithuanian vocal tradition is discussed. Tonal hierarchies in the performances of six monophonic songs are extensively studied. The cognitive mechanisms that could account for the induction and perception of tonal hierarchies in the monophonic songs and sutartinės are modelled.

Experiment. A psychological experiment was designated, in which the probe-tone method by Krumhansl and Kessler (1982) was applied, yet it was adapted for the specific musical contexts. The recordings of authentic performances of six Lithuanian folk songs were chosen as contexts. When choosing the song, the main aim was to find contexts that would possess as diverse scale structures as possible and that they would diverge from 12TET by various degrees. Only tones of actual scale (those that sounded in the context) and of clear pitch (with the octave dimension) were selected as probe tones.

57 listeners participated in the experiment. 56 subjects indicated having experience in musical practice, i.e. having some kind of musical training and/or present/past experience in performing it. 12 subjects indicated having experience in performing folk music. The subjects heard each of six excerpts from Lithuanian folk songs repeated a few times and followed by a certain probe tone. The subjects were asked to judge how these tones fitted the excerpts in a musical sense. The rating was made on a seven-point scale, where 1 meant that the tone did not fit the excerpt at all and 7 meant that the tone fitted the excerpt perfectly. The subjects indicated their responses by circling the appropriate number on the response sheet. The data from every subject's response sheet included 36 ratings and personal data. The ratings revealed the perceived probe tone stability in the excerpts from

the different folk songs. The ratings of all 57 subjects were entered into the computer and different types of data analysis were performed.

Results. Correlation analysis of all the ratings revealed that similar judgment tendencies could be observed in the majority of subjects. Nevertheless, the scores given by seven of them significantly differed from the general tendencies. Having compared the seven subjects among themselves, one can state that they did not form a homogeneous group. It is likely that these discrepancies appeared as a result of misunderstanding the experimental task or because of an inattentive way of performing it, thus the ratings by these subjects were not included in further analysis.

The aim of further analyses was to find out whether experience in performing folk music as well as other factors impacted the probe-tone ratings. The three-way mixed analysis of variance (ANOVA), the agglomerative hierarchical cluster analysis, and Chi-square test showed that all the subjects of the experiment (except the 7 subjects excluded earlier) formed one homogeneous group and that their division into smaller groups, based on their experience in performing folk music or on any other criteria, is invalid.

The ratings given to each probe tone were averaged across 50 subjects and the tonal profiles were derived for each context. All excerpts from the folk songs have modal structures that are distinct and different from one another. In nearly all the contexts the probe tones, subjectively defined in advance as tonics (the I scale degrees), were given the highest ratings. In the majority of songs, one or two stable tonal anchors (the ones that received highest ratings) above the I scale degree can be observed. Additionally, the probe tones which received the highest ratings also have the lowest standard deviations of ratings, i.e. the subjects responded in a similar way when judging the most stable scale tones.

For every excerpt, one-way ANOVA with repeated measures was performed on probe-tone ratings. The results showed that at least some of the differences among the average ratings in all the cases are statistically significant, i.e. the tonal profiles are not random and they reflect real differences in ratings. Based on the multiple comparisons with Bonferroni correction, the relative hierarchical levels of tones in each scale were identified. Second-tonal, quart-tonal, quint-tonal, and triadic structures of tonal anchors were found in four songs, whereas two remaining songs have only one distinct tonal anchor (the I scale degree).

Modelling. As it was revealed above, having been exposed to the excerpts from the folk songs, the listeners were able to rate the stability of probe tones quite similarly and systematically. Thus it is important to determine the objective properties (and their combinations) of the songs that could have possibly influenced the subjects' response. Before performing further analyses, some studies directly or indirectly concerning the phenomenon of tonal hierarchies are discussed. The majority of the factors influencing the perception of the tonal hierarchies are reasonably objective and can be measured quantitatively. Thus one can ascertain how an average listener would rate a specific probe tone, if he or she based his or her rating on a particular property of the musical text or the probe tone. 30 possible factors were discerned and grouped into 8 categories: the distribution of tones, the metric accents, the structural accents, the recency effect, the echoic memory, the internalized tonal hierarchies, the probe tone pitch, and the probe tone deviation from 12TET.

By employing correlation analysis, one factor (independent variable), that best predicts the average ratings given to the probe tones by the listeners, was found. This factor is the total duration of scale degree or, more precisely, the normalized value[22] of the power function of total duration ($(\sqrt{T})'$). Strong correlation ($r = 0.862$) between the average ratings and $(\sqrt{T})'$ was found, i.e. the longer the scale degree is sounding in the context, the higher rating it receives.

Multiple linear regression revealed that the average ratings are best predicted by the three-predictor model including the $(\sqrt{T})'$, the internalized major tonal hierarchy, and the probe tone deviation from 12TET in regard to the I scale degree. In other words, beside of the longest sounding pitches, the highest ratings are given to the I, III, and V scale degrees, and the pitches deviating least from 12TET. This regression model explains approximately 82% of the variance of the average ratings given by the listeners ($r^2_{adj} = 0.816$).

This regression model was tested with an excerpt from a sutartinė used in the probe tone experiment by Ambrazevičius and Wiśniewska (2009). The output of the model was compared with the average ratings given to the probe tones by two groups of subjects (the experts and non-experts). The predicted values quite accurately reproduce the ratings given by the non-expert group ($r = 0.964$, $p < 0.001$), but slightly less accurately those given by the expert group ($r = 0.909$, $p < 0.005$).

The attempt to apply the regression model to the excerpt of a sutartinė revealed that the same factors affect the probe-tone ratings both in the case of monophonic songs as well as in the essentially different polyphonic style of sutartinės. The model predicts better the ratings of average listeners that are accustomed to the templates of western common practice or similar music (preferentially with major tonal hierarchy), but not the ratings of experts familiar with the genre. Yet some inconsistencies between the predictions and actual probe-tone ratings show that it is extremely difficult (if at all possible) to find a universal model fitting different listeners and different styles.

[22] The scale degree with the largest value ($\max(\sqrt{T})$) is established, and then the values of all the degrees are divided by this value.

CONCLUSIONS

1. Traces of equitonic modal thinking were found in all the samples of the primary Lithuanian vocal tradition. The scales in 71% of the oldest interwar recordings and in 58% of the recordings from the second half of the 20th century had structures of approximately evenly sized intervals, not even roughly similar to the 12TET scales. Thus the prevailing and, quite possibly, the historically older principle of scale construction in Lithuanian traditional music is equitonics.
2. However, some examples of the Lithuanian vocal tradition are distinctive of higher diatonization which leads the scales to assimilate with the major, the minor, and the other diatonic scales. A fairly large number of such examples shows that the diatonic structures noticeable in scales are not coincidental or a result of inaccurate measurements, but a tendency of a more recent type of modal thinking. In order to identify, what the influences were that conditioned the rise of the diatonic thinking, a separate study is required.
3. Differences between the scales in the vocal styles of different Lithuanian ethnomusical regions can be observed. The polyphonic style of *sutartinės* in the Aukštaitija region tends to have modal structures that can be related to the aesthetics of the maximum roughness (voice clash), i.e. to psychoacoustic principles. Whereas the scales of monophonic performances representing Suvalkian and Žemaitian traditions, which can be characterized by quite diverse or even unsystematic intervallic structures, are regulated by less rigid melodic-linear principles of modal thinking.
4. Recordings of the secondary Lithuanian vocal tradition (of urban folk singers) can be characterized exclusively by the diatonic scales. This can be related to the extinction of the natural unbroken oral tradition. Contemporary performers living in the 12TET environment, thinking in Western music categories, and using (subjective) folk song transcriptions cannot reproduce the authentic modal structures, even though a slight tendency to deviate from the diatonic scales can be observed in some of the performances.
5. Both equitonic and diatonic principles of scale construction are found in the vocal traditions of Lithuania's neighbouring counties – Belorussia, Poland, Latvia – and of the Polish ethnic minority of Lithuania. Equally found are other scale-related phenomena (universals) that are observed in musical cultures around the globe. The comparative analysis of generalized scales (which summarize the usage of pitch categories in a particular repertoire) has shown that intervallic structures of scales found in Lithuanian vocal tradition (generalized across the all ethnomusical regions of Lithuania) are most similar to those of the Latvian tradition and fairly different from those of the Vilnius Region Poles' tradition.

6. In the vocal traditions of Lithuania and of some of its neighbouring countries, one can observe cases of partial diatonization as well as the fact that both diatonic and equitonic principles coexist. In the Lithuanian samples, quasi-major type scales with soft differences between narrower and wider scale intervals (DC $\leq$ 0.5) as well as quasi-minor type scales with sharper differences between both types of intervals (DC > 0.5) were found. In the two Belarusian repertoires representing different genres, opposite scalar structures were found; the ones were more similar to equitonics with wide intonation zones, and the others were more similar to diatonics with narrower intonation zones. In one repertoire of Vilnius Region Poles, the two versions of the III scale degree were found, each roughly coinciding with the neutral (equitonic) third and the major (diatonic) third.
7. Lithuanian monophonic songs have clear tonal hierarchies that the contemporary listeners are able to comprehend and recognize. Tones identified during the psychological experiment in the six examples as hierarchically the most important ones nearly coincided with the tonal anchors determined empirically. The quasi-diatonic scales contain modal structures of tonal anchors that are similar to major or minor triads. Whereas the quasi-equitonic scales have either two tonal anchors separated by an interval of the second or fourth, or only one clear tonal anchor (the I scale degree).
8. The multiple linear regression showed that the most important factors affecting the listeners' evaluations in the probe tone experiment are: (1) the total duration of the scale degree in the context, (2) pitch deviation from the 12TET of the degree, and (3) internalized tonal hierarchy of the Western major scale. Assuming that the probe tone ratings reflect the perceived tonal hierarchy, it can be argued that the cognitive mechanism at work when listening to monophonic Lithuanian folk songs and sutartinės is quite accurately described by the regression model.

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LIST OF RESEARCH PUBLICATIONS ON THE TOPIC OF DISSERTATION

Publications in international databases (articles in periodicals, collections of articles and conference proceedings)

1. Ambrazevičius, Rytis; Budrys, Robertas. Lietuvių tradicinio dainavimo dermių kitimas ekvitonikos ir diatonikos santykio aspektu // Res humanitariae. Klaipėda: Klaipėdos universiteto leidykla. ISSN 1822-7708. 2013 T. 1(13), p. 7–22. [IndexCopernicus; Central & Eastern European Academic Source]
2. Budrys, Robertas. Tonų hierarchijos muzikos psichologijos tyrinėjimuose // Lietuvos muzikologija = Lithuanian musicology. Vilnius: Lietuvos muzikos ir teatro akademija. ISSN 1392-9313. 2014, t. 15, p. 72–87. [Humanities International Complete; Humanities International Index; Music Index; Répertoire International de Littérature Musicale (RILM)]
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REZIUMĖ

Muzikinė dermė – vienas svarbiausių muzikos kalbos elementų, nusakančių garsų vartoseną muzikinėje kultūroje. Tai – daugiamatis reiškinys, aprėpiantis intervalus tarp dermės garsų, tų garsų svarbą ir santykius, jų naudojimą muzikinėje formoje, intonavimo ir kitus dinaminius aspektus. Šiame darbe yra paliestos dvi dermės dimensijos – intervalika ir tonų hierarchija.

Ankstesniuose tradicinės lietuvių muzikos dermių tyrimuose neatsižvelgta į svarbų faktą – tradicinės muzikos dermės gali gerokai skirtis nuo Vakarų kultūroje įsitvirtinusių diatoninių dermių. To priežastys yra lygiosios dvylikalaipsnės temperacijos nulemta apercepcija, vakarietiškos muzikos ortografija ir šablonai, nekritiškas sekimas etnomuzikologijos autoritetais, muzikos psichologijos žinių stoka, vengimas taikyti tiksliųjų mokslų metodus. Šiuo metu jau yra atlikta tyrimų, kuriuose išvengta minėtų problemų. Jie atskleidė naujų derminių reiškinių tradicinėje lietuvių muzikoje. Tačiau objektyviai patyrinėta tik nedidelė jos dalis. Tuo grindžiamas šio darbo naujumas. Tyrimas aktualus tuo, kad: (1) tęsiama pradėta praktika tradicinę lietuvių muziką ir jos dermes analizuoti objektyviais kitų mokslo sričių metodais; (2) parodomi kitų ir šio darbo autoriaus sukurti ar pritaikyti tyrimo metodai bei jų taikymas konkrečioms užduotims spręsti. Darbo tikslas – nustatyti statistinius tradicinio lietuvių dainavimo dermių intervalikos ir tonų hierarchijų dėsningumus, įvertinti šių elementų panašumus, skirtumus bei kaitą teoriniame, istoriniame ir geografiniame kontekstuose. Darbo tikslui pasiekti iškelti šie uždaviniai: (1) aptarti ontologinio dermių formavimosi prielaidas ir ankstesnius tyrimus; (2) apibendrinti esamus ir sukurti naujų dermių matavimo bei duomenų analizavimo metodų; (3) įvertinti metodų tikslumą, objektyvumą ir tinkamumą muzikinėms dermėms tirti; (4) atlikti vokalinių lietuvių ir kaimyninių tautų tradicijų tyrimą. Darbo objektas – akustiniai ir kognityvūs tradicinio dainavimo dermių fenomenai. Darbe tirti lietuvių ir kaimyninių tautų liaudies dainų įrašai. Taikytos akustinės, matematinės ir statistinės analizės, psichologinio testavimo, klasifikavimo, lyginamasis ir matematinio modeliavimo metodai. Atlikti garso aukščio arba dažnio matavimai 349 garso įrašuose.

Darbą sudaro trys dalys. Pirmoje aptariami derminiai reiškiniai iš muzikos psichologijos pozicijų, taip pat apžvelgiama literatūra apie vokalinės lietuvių tradicijos dermes. Dėl biologinių priežasčių (atminties struktūros ir procesų) kai kurie muzikiniai reiškiniai – vadinamosios kvaziuniversalijos – randami daugumoje pasaulio kultūrų. Jie gali paaiškinti muzikos ir vieno jos esminio elemento – dermės – formavimosi bei sandaros ypatumus. Pavyzdžiui, daugumoje kultūrų dermę sudaro penki septyni garsai, juos skiria maždaug vieno trijų pustonių dydžio intervalai, o tarp garsų stebima diferencijacija (kai kurie garsai yra svarbesni už kitus). Tradicinio lietuvių dainavimo dermių tyrimuose įžvelgiamos dvi tendencijos. Vieni mokslininkai tiria subjektyvias dainų transkripcijas, jas interpretuoja remdamiesi vakarietiškosios (diatoninės) muzikos

teorija. Kiti mokslininkai (daugiausiai dr. Rytis Ambrazevičius) analizuoja garso įrašus, taiko matematinius ir statistinius metodus, o gautus rezultatus interpretuoja pagal muzikos psichologijos žinias. Šio pobūdžio tyrimai atskleidė, kad lietuvių liaudies dainų dermės gerokai skiriasi nuo vakarietiškų diatoninių, jose aptinkama ekvitonikos (vienodų intervalų struktūros) pėdsakų.

Antrojoje dalyje pristatomi, lyginami ir vertinami tyrimo metodai. Lyginamoji garso aukščio nustatymo algoritmų analizė padėjo išrinkti geriausią algoritmą akustiniams garso aukščio matavimams (autokoreliacija). Pristatyti rankinis ir du automatiniai būdai atlikimo (garso įrašo) dermei įvertinti, nustatyta, kad rankiniu gauti rezultatai yra tiksliausi. Išbandyti ir dermių tyrimams pritaikyti įvairūs matematiniai ir statistiniai metodai: dalis jų jau taikyta kitų mokslininkų tyrimuose, dalis „pasiskolinta“ iš įvairių mokslo sričių. Taip pat trumpai apžvelgti metodai tonų hierarchijų suvokimui tirti, pasirinktas bandomojo tono metodas.

Trečiojoje dalyje tyrinėjamos lietuvių liaudies dainų dermės įvairiais aspektais: (1) nustatyti bendrieji dermių intervalikos bruožai vienbalsėse lietuvių liaudies dainose; (2) įvertinti dermių intervalikos panašumai ir skirtumai Lietuvos etnomuzikiniuose regionuose (geografinis aspektas); (3) nustatyti esminiai dermių intervalikos skirtumai pirminėje ir antrinėje vokalinėje tradicijoje (diachroninis aspektas); (4) lygintos etninių grupių (baltarusių, lenkų, latvių) dermės, vertintas lietuvių liaudies dainų santykis su muzikinėmis kaimyninių tautų tradicijomis dermių aspektu; (5) analizuotos tonų hierarchijos šešiose lietuvių liaudies dainose.

Padarytos šios išvados: (1) visose pirminės vokalinės lietuvių tradicijos įrašų imtyse aptinkama ekvitoninio derminio mąstymo pėdsakų; (2) vis dėlto daliai tradicinio lietuvių dainavimo pavyzdžių būdinga ryškesnė diatonizacija, lemianti dermių supanašėjimą su mažoru, minoru ir kitomis diatoninėmis dermėmis; (3) pastebimi vokalinių stilių, būdingų skirtingiems Lietuvos etnomuzikiniams regionams, dermių skirtumai; (3) antrinės vokalinės lietuvių tradicijos (miesto folkloro atlikėjų) įrašai pasižymi išskirtinai diatoninėmis dermėmis; (4) tradicinėje kaimyninių tautų – baltarusių, lenkų, latvių – ir Lietuvos tautinių mažumų (lenkų) muzikoje aptinkami ir diatoninis, ir ekvitoninis darnų sudarymo principai, taip pat įvairūs kiti derminiai reiškiniai (universalijos), randami muzikinėse pasaulio kultūrose; (4) ir lietuvių, ir kai kurių kaimyninių tautų vokalinėse tradicijose pasitaiko iš dalies diatonizuotų pavyzdžių ir atvejų, kai kartu egzistuoja abu – ekvitonikos bei diatonikos – principai; (5) vienbalsės lietuvių liaudies dainos turi aiškias tonų hierarchijas, kurias geba suvokti ir atpažinti šiuolaikiniai klausytojai; (6) svarbiausi faktoriai, veikiantys tonų hierarchijų suvokimą, yra dermės laipsnių, skambėjusių kontekste, trukmės, jų aukščio nuokrypiai nuo tolygiosios dvylikalaipsnės temperacijos ir išmokta mažoro dermės tonų hierarchija.

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