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Psychoacoustical Issues of Dissonance in Lithuanian *Sutartinės*

Annotation

Sutartinės are a Lithuanian type of *Schwebungsdiaphonie* (Račiūnaitė-Vyčinienė 2002; Ambrazevičius, & Wiśniewska 2009; etc.). In contrast to Western art music, the dissonance-like sonorities in *Schwebungsdiaphonie*-cultures are at the core of the tonal structures. These cultures, although not abundant, are found in different locations all over the world.

It is a natural idea to predict that aesthetics and intervals of the sonorities in *sutartinės* are related strongly to certain psychoacoustical phenomena, namely to the perception of dissonance or roughness. On the one hand, studies of psychoacoustical roughness and sensory dissonance are really numerous. The notions of roughness and sensory dissonance are usually considered as synonyms. On the other hand, it was proposed that the ideal sounding of *Schwebungsdiaphonie* conforms to a maximum dissonance/roughness (Brandl 1989; the diaphony in the Balkans and elsewhere; Ambrazevičius 2008; etc.; the Lithuanian *sutartinės*). However, to be precise, the relations between roughness and sensory dissonance remain obscure. Therefore, in the current study, I aim to analyze the occurrences of the notions of roughness and sensory dissonance in the psychoacoustical studies and to define the case of *sutartinės* in this context.

The psychoacoustical studies were overviewed and discrepancies between the concepts of roughness and sensory dissonance were noted. The experimental findings on the intervals corresponding to the maximum values of roughness/sensory dissonance were collated and significant disparities were found. It seems that, at least for a substantial frequency range, roughness is associated with larger interval sizes. The collation of these results and the findings of acoustical measurements of *sutartinė* performances lead to the conclusion that the ideal vocal "clash" in *sutartinės* most probably corresponds to psychoacoustical roughness, but not to sensory dissonance.

Keywords: roughness, sensory dissonance, *sutartinės*, *Schwebungsdiaphonie.*

1. Introduction

The issue of consonance/dissonance is, probably, one of the "most ancient" issues in the history of music theory. The question whether sonorities should be considered as consonances or dissonances attracted the interest of scholars for many hundreds of years resulting in numerous theoretical treatises. And for many years, the answer seemed to be essentially simple: in one or another way, the issue was presumed to be tightly embedded in numerology. Briefly, consonance was equated to a "simple ratio" (of strings' lengths, frequencies, etc.) and dissonance meant "not a simple ratio".

However, really scholarly psychological studies appeared before some fifteen decades only (to mention Helmholtz 1863 as the seminal study). The later the more those studies revealed that the phenomenon of consonance/dissonance is quite multifaceted. Thus the rule of "simple ratios" appeared to be a crude oversimplification. For instance, consonance/dissonance depend on the exposure of an individual to a certain soundscape, i.e. on musical culture. This culturally dependent sense of consonance/dissonance is observed even in Western listeners. It results in the perception of just intervals by modern listeners as "lacking warmth" or "tasteless" and the preference is given to equal temperament (Roberts & Mathews 1984; Vos 1986).[1] Moreover, the sense of consonance/dissonance varies noticeably even in the frame of a single musical language (examples of the intervals in barbershop singing and violin music; Greene 1937; Sundberg 1982).

Quite a few musical cultures favour dissonances (in terms of physiological acoustics) rather than consonances in their polyphonies. This is described as various types of psychoacoustically based "diaphony of beats" (*Schwebungsdiaphonie*) in some places (although not abundant) throughout the world (Cazden 1945; Brandl 1989; Messner 1989; etc.). Moreover, dissonances are exploited in the music of idiophones. Beats between their partials occur due to inharmonicity of their spectra. This effect, as well as deliberate mistuning is used, for instance, to produce the distinctive "shimmering" quality of gamelan music.

To make things even more complicated, it is worth mentioning that there is prevalence of timbre over precise intervals in some cases. Thus, comparative study of consonance/dissonance and musical scales, in general, can be senseless if the determinant is timbre in the case under investigation.[2]

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1 The intervals in twelve-tone equal temperament could not be expressed by simple ratios of frequencies at all, except of octaves.

2 Here we stop at the consonance/dissonance of isolated sonorities. Further the temporal component of consonance/dissonance should be discussed.

Only several cases should be mentioned when the natural intervals really appear. For instance, these are so-called instrumental scales inbuilt in the design of certain musical instruments. The natural scale also inherently appears in overtone singing since it is based on the successive exaggeration of separate partials of the voice spectrum.

2. Dissonance and roughness

Beside of dissonance, another notion of roughness is used in psychoacoustical studies. Roughness is considered to be a specific "annoying" sense resulting from physiology of inner ear, from the action of the basilar membrane induced by beats. Similarly as other psychoacoustical quantities, roughness can be even evaluated from psychoacoustical experiments. The unit of roughness is asper (Fastl & Zwicker 2007: 257).

It was Herbert von Helmholtz who noticed the relationship of roughness and beats (Helmholtz 1863). He obtained that the strongest sense of roughness appears when the frequency of beats equals approximately 30–40 Hz. Starting from this seminal finding, the notions of dissonance and roughness (as psychoacoustical dimensions) usually tend to be equated, although sometimes they are distinguished. It is generally believed that the two notions are merely two manifestations of the same phenomenon; "roughness" belongs to a somewhat "technical" domain of psychoacoustics, whereas "sensory dissonance" stands for somewhat "music-colored" attribute.

The classical study of Plomp & Levelt (1965) could serve as a typical example of the presumed interchangeability of the two notions. While the authors asked the subjects to judge intervals on the scale "consonant-dissonant" (or, in the case of incomprehension, they substituted the "consonant" with "beautiful" or "euphonious" instead; p. 553), they exploited both notions of dissonance and roughness unambiguously in their discourse. Incidentally, in many other studies, the questions presented to the participants are not revealed and the procedures of the experiments are not (or only faintly) detailed. Therefore the subjective sonic qualities meant and evaluated in the experiments remain obscure.

However, it is also argued that, even though roughness is one of the main constituents of sensory dissonance, it is not the only one. Moreover, several types of roughness are distinguished or in some cases the multidimensionality of roughness is suggested.[3]

Now we will take a glance at the results of several studies on sensory dissonance/roughness. For instance, Ernst Terhardt (1968: 219) states that "the modulation frequency of maximum roughness increases with increasing carrier frequency initially and reaches a constant value f^*_{mod} = 75 Hz at carrier frequencies above approximately 2 kHz"[4] and presents the corresponding graph (see Figure 1). In his later study (1974), Terhardt claims the approximate identity of dissonance and roughness. However, there is some discrepancy between this claim and the factual results (Figure 2): it is clear that at least in the relevant spectral range the sense of roughness slightly differs from the sense of dissonance. Briefly, roughness is stronger for wider seconds and dissonance is stronger for narrower seconds.

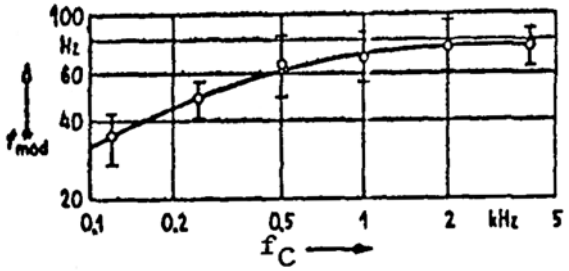

Fig. 1. Modulation frequency for maximum roughness f^*_{mod} as a function of carrier frequency f_c. Modulation factor is 1, *SPL* = 60 dB (Terhardt 1968: 219).

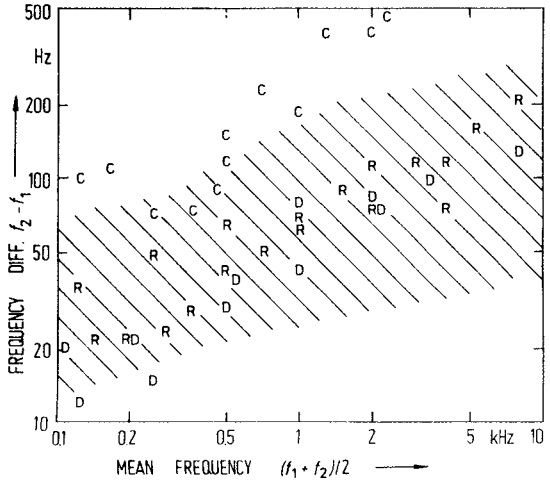

Fig. 2. Dissonance, consonance, and roughness; according to Terhardt, 1974: 1062. Hatching marks the area of pronounced roughness, "R", "D", and "C" mark, correspondingly, the maxima of roughness and dissonance, and the limit of appearance of consonance.

[3] See the forthcoming paper Ambrazevičius 2015, for details.

[4] A number of studies employ AM (amplitude modulated) sine tones, while others use sine tone pairs. However, it is stated that the results do not differ significantly for the two cases (e.g. Terhardt 1968: 219).

The findings of Andrzej Rakowski (1982) lead to the approximation for the frequency interval for maximum roughness as $2\sqrt{f}$. William Hutchinson and Leon Knopoff (1978) proposed noticeably different evaluation of dissonance. They designed their own approximation for the critical bandwidth as $1.72\,f^{0.65}$ and employed the Plomp's and Levelt's 1/4 CBW-criterion for the maximum dissonance.

The results of Marc Leman's model for roughness (2000) are presented in Figure 3. Pantelis N. Vassilakis (2001: 197–198) applied the model proposed earlier by William A. Sethares (1998; see the illustration from the second edition of his book on Figure 4). Finally, consider the evaluations by Fastl & Zwicker (Figure 5).

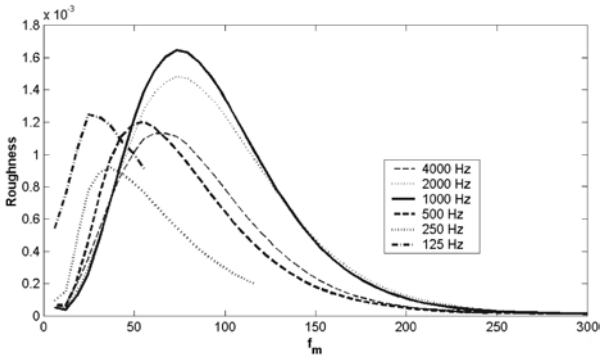

Fig. 3. Roughness in the function of modulation frequency of different carrier frequencies (modulation factor is 1; Leman 2000: DAFX-5).

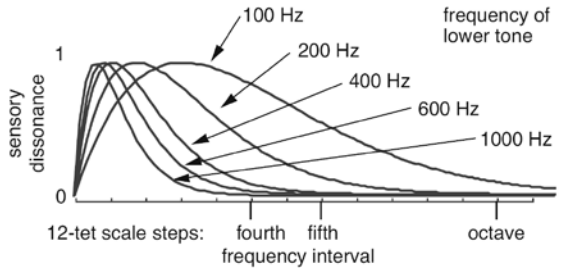

Fig. 4. Sensory dissonance in the function of frequency interval between two sine tones sounding simultaneously (Sethares 2005: 47). Curves for different frequencies of the lower tone are presented.

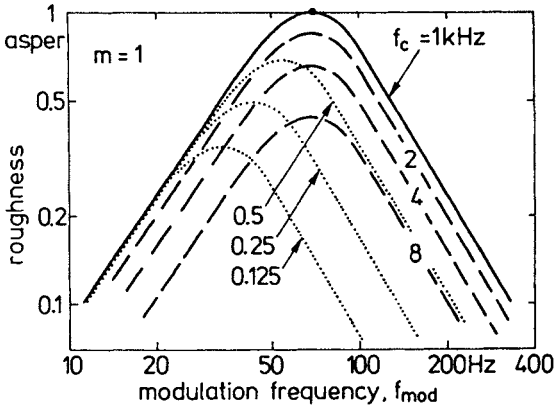

Fig. 5. Roughness of 100% amplitude-modulated tones; according Fastl & Zwicker 2007: 259. Curves for different centre frequencies are presented.

Now let's compare the findings of the psychoacoustical studies. The curves in Figure 6 were composed based on the formulas and interpolations of graphically presented results from the discussed sources. Probably, the confusion between the dissonance, roughness, and its possible types explains why the results of the experiments show significant discrepancies. A closer examination of Figure 6 reveals that roughness is typically

associated with larger interval sizes, and that sensory dissonance is associated with narrower interval sizes. For instance, Terhardt in his experiment asked the subjects specifically to evaluate roughness (1968: 216), and the corresponding curve lies higher. On the contrary, as already mentioned, the well-known relating of the maximum dissonance to 1/4 of critical bandwidth (Plomp & Levelt 1965) refers specifically to dissonance but not to roughness.

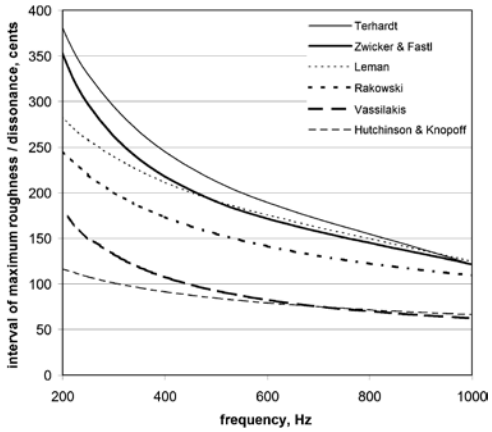

Fig. 6. Dependence of maximum roughness/dissonance on the central frequency. See the body text for details.

On the one hand, roughness is typically associated with the perceptual result of rapid fluctuation of envelope of sound pressure amplitude, i.e., with the subjective rate of amplitude change (expressed as product of the subjective modulation depth and f_{beats}; e.g. Fastl & Zwicker 2007: 262), or, briefly, with the "bumpiness of the [subjective] acoustic surface of a sound" (Parncutt 2006: 202). On the other hand, sensory dissonance could be probably connected to the features of critical bandwidth. Certain doubts remain whether the "bumpiness" and critical bandwidth are tightly related. From my purely subjective observations, the (sensory) "dissonance", "unpleasantness", or "annoyance" could be rather equalized to "harshness" and not so much to "roughness". One may therefore speculate that, for instance, a semitone in the middle of a piano keyboard sounds harsher, whereas the whole tone seems to be rougher. Incidentally, the terms such as "harsh" or "turbid" occur episodically when describing non-euphonious, unpleasant, or dissonant sonorities (e.g. Plomp & Levelt 1965: 554; Mashinter 2006: 65, 66).

3. *Sutartinės*: general remarks

Now from the "cosmopolitic" experiments on psychoacoustical roughness and sensory dissonance we move to the Lithuanian ethnic *sutartinės*. The most distinctive kind of Lithuanian *sutartinės* present a peculiar type of *Schwebungsdiaphonie*, i.e., the diaphony of the *sutartinės* is based mostly on intervals of the second occurring between the vocal parts which intertwine polyphonically and polyrhythmically.

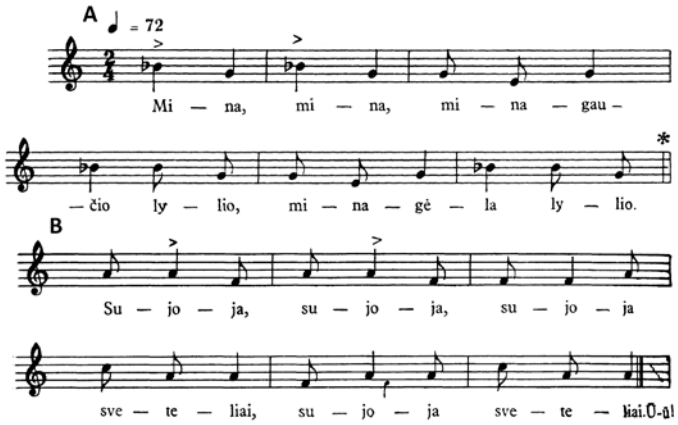

Fig. 7. *Sutartinė "Mina, mina, minagaučio lylio"*: original transcription of one part (Slaviūnas 1958: 657 [Nr. 428a]). The entrance of the canonically succeeding voice is asterisked.

Figure 7 shows a typical example of a *sutartinė*. This *sutartinė* was performed canonically by three singers in such a way that the two parts A and B (separated by an asterisk in the figure) sound simultaneously, except in the beginning when only one voice (part A) sounds. The lyrics change. Thus mostly intervals of the second occur continuously between the two voices.

When listening to the original recording of this *sutartinė* (Račiūnaitė-Vyčinienė 1998)[5], even unsophisticated ear could suggest the idea that the transcription in Figure 7 is actually crude or, at least, quite approximate: the real recording sounds "non-tempered" enough. To reveal the actual scale, the recording was analyzed acoustically: the pitches of dyads were measured and the intervals were calculated (Ambrazevičius 2005). The pitches were determined from the spectra of the dyads: certain partials were identified as belonging to one or the other of two voices, their frequencies were measured (see the example in Figure 8), and the pitches were calculated. Relatively stable portions of the dyads were considered in terms of spectrum (fortunately, the intrasonic intonation of *sutartinės* features quite stable segments).

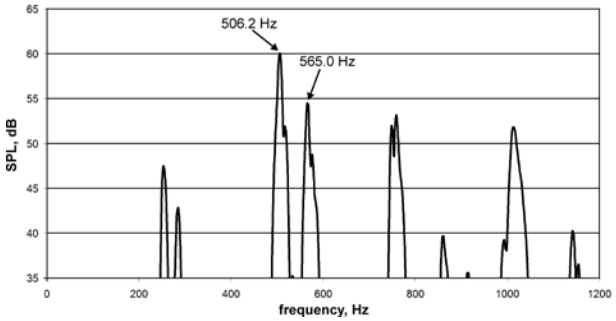

Fig. 8. Excerpt from typical spectrum of the *sutartinė "Mina, mina, minagaučio lylio"*

The statistical distribution of pitches is depicted in Figure 9. It shows approximately 1.8 of tempered semitone between the most frequent intonations. Thus the corresponding most frequent thirds in vocal parts (G3–B3 and A3–C4[6]) equal approximately 3.6 semitones, i.e. they are neutral. Fourth G3–C4 equals 5.4 semitones. D4 occurs very seldom, thus categorical conclusions about its position in the tuning system could not be drawn. Nevertheless C4–D4 equals 1.5–2.2 semitone, i.e. also roughly 1.8 semitones on the average. A3 and H3 are the most stable tones according to the corresponding sharp peaks in Figure 9. This bichord could be treated as certain bitonal nucleus and anchor of the tuning system. G3 and C4 are less stable, whereas F3 and D4 are the least stable. The zones of intonation are quite wide, even for the most stable anchors. Hence, to generalize, the two central steps are intoned relatively steadily in the course of the entire performance thus forming the nucleus of the scale. The marginal steps show greater freedom in intonation.

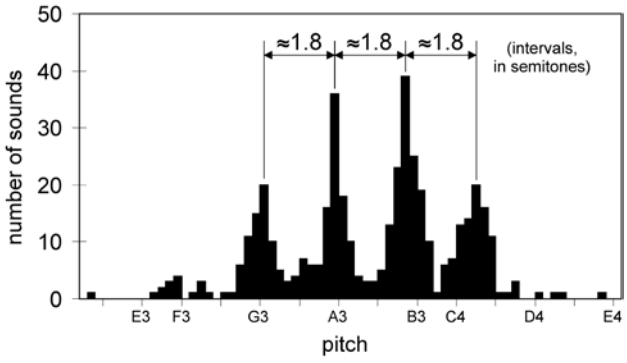

Fig. 9. Histogram of pitches in the *sutartinė* "Myna…" (Figure 1); all pitches in all parts.

The analysis leads to a conclusion that we have to be very cautious when treating and denominating the scale and tuning system aurally. The Western major-minor system and equal temperament work as elements of apperception, which results in "aural ghosts". They lead to misinterpretation that design of the scale is diatonic.

[5] The digitized version of the old recording (from the 1930s).

[6] Here and hereafter a simplified marking for pitch class is used. For instance, C4 actually could be as high as C#4 or even higher.

Actually the tuning system has nothing in common with diatonics: there is no semitone/whole tone contrast in the sequence of intervals. The scale could be considered as "squeezed anhemitonics", since the intervals between the adjacent pitches are a bit narrower than the tempered whole tone.

One could try to visualize the revealed regularities of the scale in transcription (Figure 10) where a peculiar staff is intentionally applied to avoid associations with the diatonic scale.

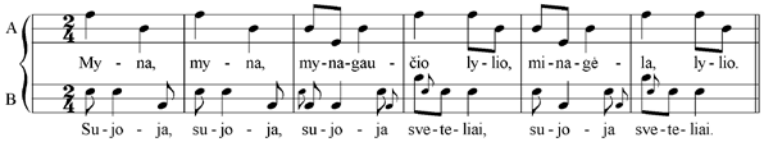

Fig. 10. Transcription of characteristic patterns of the *sutartinė "Myna, myna, mynagaučio lylio"* on an alternative staff. The petit notes show the most characteristic variants.

In the subsequent study (Ambrazevičius 2008), a total distribution of dyad-intervals in 25 *sutartinės* has been also composed. The distribution showed that the majority of the intervals are seconds. The category of the interval is quite wide and does not split into the individual categories of minor and major seconds. As in the case of the separate *sutartinė "Myna, myna, mynagaučio lylio"*, the seconds slightly narrower than the tempered whole tone (around 1.7 semitones) are most preferred.

So, again, we come to a simple conclusion: the intervals of second between the voices in the dyads of *sutartinės* comprise relatively wide category centred at, approximately, 170–180 cents. What accounts for such a peculiar interval? Let's return to the psychoacoustical studies on sensory dissonance / roughness and collate their results to the findings of the study on intervals in *sutartinės*.

4. Dissonance or roughness in *sutartinės*?

For female voices, frequency of the first formant ranges roughly from 400 to 1000 Hz. So this frequency range is expected to be the most intense range in the spectra of singing voices. This corresponds to the second or third (or sometimes fourth) harmonics. The application of these frequency values to the graphs in Figure 6 leads to an insight that the singers were aiming for maximum roughness: the most intense frequency range corresponds to the wide range of pitch intervals centered at slightly "squeezed" whole tone. Importantly, the aiming for maximum dissonance would lead to significantly narrower intervals, around 70–100 cents, what is not the case of *sutartinės*. It seems that specifically roughness was meant by the singers of *sutartinės* when describing the sonorities as "clashing" (clanging, warbling; but not "cutting" which would point to the sensory dissonance and narrower intervals). The "perfect clash" was considered by the singers as an essential quality and marker of a congenial performance. Earlier Brandl already concluded that the psychoacoustical correlate of the ideal ring in *Schwebungsdiaphonie* (found in the Balkans and elsewhere) is of maximum roughness (1989). It is actually dubious whether this statement really works for all traditions in Balkans, as there quite different intervals in the dyads could be registered for different cases (cf. Miljković 1998; Rihtman 1969). At any rate, the measurements in our studies support this statement when applied to Lithuanian *sutartinės*. Therefore it can be credibly stated that the scales of *sutartinės* are actually determined by psychoacoustical, i.e. by extramusical phenomenon.

Importantly, the noun *sutartinė* derives from the verb "sutarti" which means "to agree", "to be in concord" ("to live in concord", "to sing in concord", and so on); in other words, "to sing in consonance". Nowadays the word *sutartinė* is sometimes even applied to signify a perfect, harmonious performance in general, no matter the kind of the performance. Thus, in the case of the Lithuanian *Schwebungsdiaphonie*, roughness obtains a positive connotation: aesthetically and semantically, the sonorities in seconds are considered as consonances.

However, it should be pointed out that the requirement of maximum roughness is not categorical in the Lithuanian case for the following reasons: the intonational zone of a second is too wide, durations of the sounds are too short to produce exact intervals (initial glides are characteristic), and the partials are, on the average, too different in SPL.[7] All these factors diminish the role of maximum roughness. It could be stated that maximum roughness is a desirable quality, but the zone of the suitable roughness is quite wide; the factor of roughness is possibly reduced by other important factors of articulation.

[7] Roughness shows substantial dependence on the ratio of amplitudes of the "clashing" harmonics. The strongest roughness occurs for equal amplitudes. The more different in SPL are the harmonics, the weaker is the sense of roughness (Terhardt 1968; Vogel 1975; Guirao and Garavilla 1976).

5. Conclusions

The close inspection of psychoacoustical studies on roughness / sensory dissonance show significant divergences in their findings. Most probably, this results from different experimental conditions and confusion of notions of roughness and sensory dissonance. Attempts to separate these two notions reveal that, at least for a substantial frequency range, maximum roughness tends to be associated with larger interval sizes, compared to the case of maximum sensory dissonance.

Brandl's insight on aiming for maximum psychoacoustical roughness in performance of *Schwebungsdiaphonie* (exemplified mostly by the examples of Balkan music traditions), most probably, is valid for the case of Lithuanian *sutartinės* as well. Here specifically roughness and not sensory dissonance is meant; this results from the collation of the findings of psychoacoustical studies on roughness / sensory dissonance and the findings of acoustical measurements of *sutartinė* performances. The rough quality of the sonorities in *sutartinės* obtains positive connotations, i.e., in a broad sense, these sonorities are considered as "consonances". The maximum roughness is obtained for the intervals slightly narrower than the tempered whole tone, for the characteristic spectra of the female voices of *sutartinės* singers. This results in the peculiar scale structures deviating considerably from the twelve-tone equal temperament. As a side product, the problem of transcription occurs, making the conventional five-lined staff unsatisfactory for adequate presentation of the scale structures in the roughness-based *sutartinės*.

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Psichoakustiniai disonanso aspektai sutartinėse

Santrauka

Reikšminga sutartinių dalis priskirtina samplaikų diafonijai (*Schwebungsdiaphonie*; Račiūnaitė-Vyčinienė 2002; Ambrazevičius & Wiśniewska 2009 ir kt.). Kitaip negu vakarietiškoje akademinėje muzikoje, samplaikų diafonijos kultūrose disonansų tipo sąskambiai formuoja garsų sistemos branduolį. Šios kultūros, nors ir negausios, randamos įvairiose pasaulio vietose.

Tikėtina, kad sutartinių sąskambių intervalams didelės reikšmės turi tam tikri psichoakustikos reiškiniai, būtent disonanso arba šiurkštumo suvokimas. Viena vertus, psichoakustinio šiurkštumo ir sensorinio disonanso tyrimų išties daug. Šiurkštumo ir sensorinio disonanso sąvokos paprastai tapatinamos. Kita vertus, manoma, kad samplaikų diafonijos skambesio siekinys – stipriausias disonansas / šiurkštumas (Brandl 1989; diafonija Balkanuose ir kitur; Ambrazevičius 2008 ir kt.; sutartinės). Tačiau, tiksliai kalbant, šiurkštumo ir sensorinio disonanso sąryšis lieka miglotas. Todėl šiuo tyrimu apžvelgiamos šiurkštumo ir sensorinio disonanso sąvokos įvairiuose psichoakustikos darbuose ir apibrėžiamas sutartinių fenomenas psichoakustikos kontekste.

Atidžiau panagrinėjus įvairių mokslininkų pateikiamus eksperimentinių šiurkštumo / sensorinio disonanso tyrimų rezultatus (dažniausiai neskiriant šių sąvokų), išryškėja reikšmingi jų skirtumai ir prieštaravimai. Stipriausias šiurkštumas, atrodo, atitinka platesnius intervalus negu stipriausias sensorinis disonansas. Sugretinus šiuos rezultatus su sutartinių intervalų akustinių matavimų rezultatais, prieinama prie išvados, kad idealus balsų „sumušimas" sutartinėse tikriausiai atitinka stipriausią psichoakustinį šiurkštumą, o ne sensorinį disonansą.

Reikšminiai žodžiai: šiurkštumas, sensorinis disonansas, sutartinės, samplaikų diafonija.