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Interpretation of Violin Spectrum Using Psychoacoustic Experiments

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Abstract

Couple of psychoacoustic experiments with violin tones of several pitches led to the extraction of timbral attributes such as Sharpness, Darkness, Narrowness, Rustleness, Glossiness and Buzzing. The hypotheses about their spectral sources were formulated and verified in subsequent listening tests. The frequency position, level and pitch dependence and mutual connections of these spectral sources are discussed.

1. Introduction

In many psychoacoustic experiments dealing with timbre of (musical) sounds, the sound context is prepared arising from the definition of timbre [1]: all sounds listened to by judges have the same pitch, loudness and duration. Based on pioneering work of von Bismarck [2], one of the recognized (and mostly the most prominent) timbre dimension in nearly all studies is sharpness, which is strongly influenced by the energy distribution in stationary spectrum. Bismarck also proposed a formula for sharpness calculation [3], it is based on the calculation of loudness in critical bands and its value can be successfully approximated by the center of gravity of the spectrum. Because of time-consuming listening tests, only one pitch is commonly used and rarely further stationary dimension than sharpness is spectrally interpreted.

During several past years, our laboratory had prepared couple of experiments with violin tones of different contexts (pitches) and using various listening test methods. The results of individual experiments were published on couple of acoustic conferences. The presented paper summarizes essential results of these experiments and tries to contribute to the discussion of possible generalization of the conclusions to other sound contexts.

All realized research tasks had similar outline: stimuli preparation (recording of violin tones played détaché, naturale, non-vibrato, and mezzoforte in anechoic room) – listening test execution (monophonic signals in headphones) – statistic evaluation of test results – interpretation of test results (hypotheses about stationary spectral sources of timbral events: levels of individual harmonics, critical bands or third and twelfth octaves, center of gravity) – manipulation of stimuli (signals) according to hypotheses – specific additional listening tests – decision about hypotheses.

2. Essay I: 5 pitches, 11 violins, 1 direction

The tones **B3** (fundamental frequency 247 Hz, played on G string), **F#4** (370 Hz, D), **C5** (523 Hz, A), **G5** (784 Hz, E), and **D6** (1175 Hz, E), were played on 24 violins of various qualities and recorded in the standard listening position. The duration and shape of the recording transients were unified to highlight the quasistationary part of the sound [4].

Based on the results of listening tests [5] (17 signals selected for each pitch, 20 judges, pair dissimilarity in timbre) 11 signals best representing perceptual space of timbre were selected for each pitch. In the following **Spontaneous Verbal Description (SVD)** listening test judges described perceived differences in timbre in all pairs of sounds spontaneously in words [6, 7] (11 signals, 10 judges).

The SVD results for five pitches were compared [8] and four verbal attributes (sharp, dark, clear, narrow) were selected and used in the **Verbal Attribute Ranking and Rating (VARR)** test [9] (the same 11 signals as used in SVD, another 10 judges, ranking of signals according to the specified verbal attribute followed by rating of sorted signals).

For a certain verbal attribute and pitch it revealed, that the correlation between frequencies of SVD occurrences and averaged rates of VARR was not significant [7]. Further investigation of words correlated in SVD occurrences showed add-on character of these words according to spectral characteristics (see example in Figure 1). That is why the VARR results will be considered better pertinent to spectral properties.

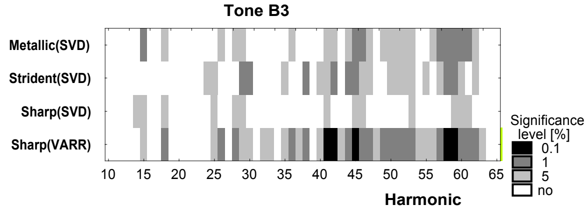

Figure 1: Correlation of Sharp (VARR, SVD) and Sharp add-on words with level of harmonics.

2.1. Sharpness and Darkness

Sharpness and Darkness were found as opposite attributes of timbre, the Pearson correlation coefficient in VARR was highly significant in all five pitches (it varied from –0.96 to –0.98). The correlation of the Sharp and Dark attributes in SVD (frequencies of occurrences) or in VARR (averaged rates) with levels of the first harmonic is summarized in Figure 2.

The Sharp attribute correlated with spectral center of gravity significantly and positively in all pitches except of G5 [10], but significant positive correlation was found in all five pitches with levels of high critical bands [10], see also Table 1.

Table 1: Significant and positive correlation of Sharp (VARR) with levels in critical bands

Tone	18	19	20	21	22	23	24	Critical band
D6			+		+	+	+	
G5					+	+	+	
C5	+			+	+	+	+	
F#4			+		+	+	+	
B3	+	+	+	+	+	+	+	

Additional listening tests were made with the manipulated signals of low and high degree of the attribute Sharp for pitches B3, C5, and D6 to verify the influence of levels of the first and of higher harmonics [10], results are presented in Figure 3.

2.2. Narrowness

The correlation of the Narrow attribute (SVD and VARR) with levels of the first harmonic are marked in Figure 2. Manipulation of signals with low and high degree of the Narrow attribute [10] verified the influence of levels of spectral components and is summarized in Figure 3.

2.3. Rustleness

The Rustle attribute and its add-on words (Sandy, Hissy, Scrubs, Dusty, Horsehair) were extremely often pronounced in the tone D6 in SVD [11, 12]. Significantly correlated levels of harmonics and third-octaves are marked in Figure 4.

Additional listening tests with manipulated signals revealed that the main source for the perception of the attribute Rustle are spectral components below the fundamental in the band from 200 to 900 Hz (violin modes A0, T1, C3) [11, 12] with time varying levels above 25 dB [13].

In other pitches, a significant correlation below fundamental occurred only in G5 and was found in the band from 200 to 600 Hz; in B3, F#4, and C5 correlated bands were found in the neighborhood of 15 kHz.

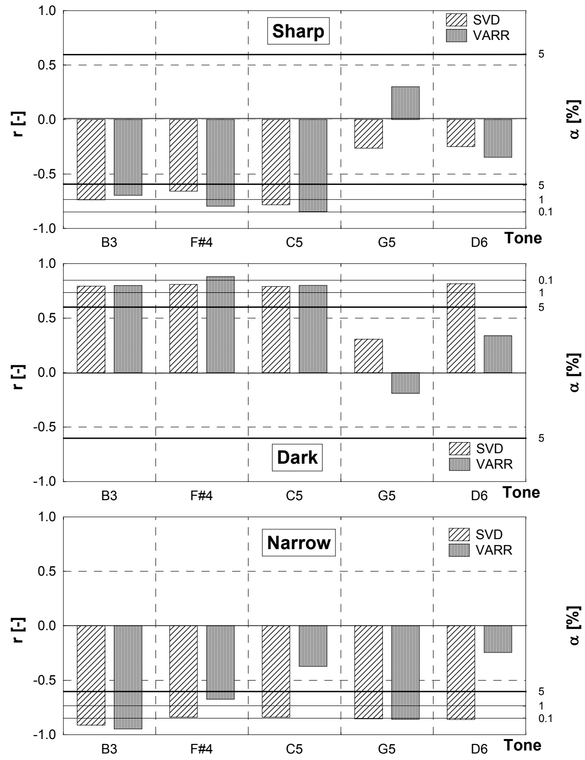

Figure 2: Correlation of Sharp, Dark, and Narrow with level of the first harmonic, r is the Pearson correlation coefficient, α is the significance level.

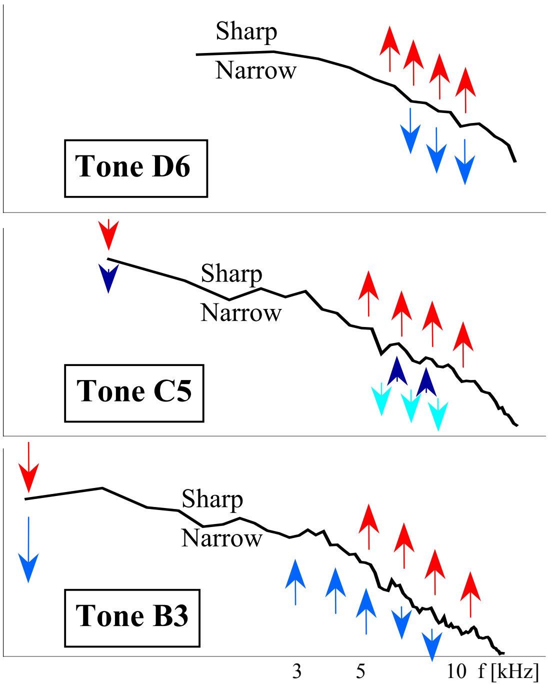

Figure 3: Increase of the Sharp and Narrow attributes caused by spectrum level change in the arrow direction (length corresponds to the size of increase); there are two different strategies for C5 and Narrow.

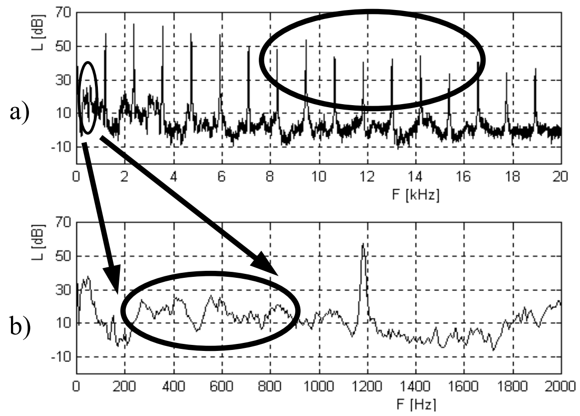

Figure 4: The tone D6 potential sources of Rustle (marked with ellipses); a) the power spectrum, b) its lower part (from ref. [12]).

3. Essay II: 4 pitches, 1 violin, 98 directions

Free string tones were played on the Carl Ludwig Bachmann's violin (1766). Since it was not possible to pre-determine timbre profile of the instrument surrounding sound, the enormous number of recording positions was used, the **98-microphone method** [14, 15] (Figure 5).

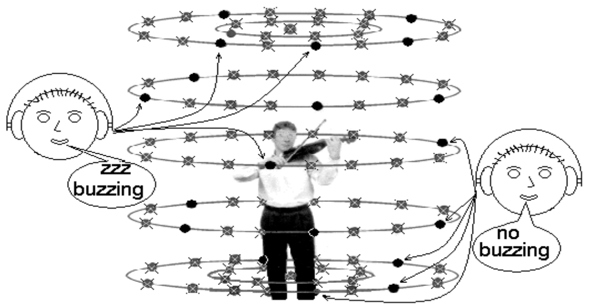

Figure 5: Representative sounds from 98-microphone method with and without Buzzing.

Consecutively the **Context-Reduced Rating method (CRR)** [15, 16] allowed to locate the space segments with minimal timbre changes and to select adequate number of its representative sounds (Figure 5). The next listening test led to the timbral properties characterization in spontaneous answers and than to quantification of the property levels.

3.1. Buzzing and Glossiness

From the results, except other, properties Buzzing and Glossiness, joined together in one timbre factor [17], were studied. Respondents felt Buzzing as something like *zzz* in sound, and Glossy like *sss*. This was the case only with G3 tone (196 Hz), Buzzing did not occur in higher tones. A correlation analysis revealed the association of the spectral harmonic levels in frequency region from 5.3 to 7 kHz (harmonics from 27 to 36) with perception of Buzzing and 7.3 to 8.5 kHz (harmonic 37 and higher) with Glossy [17].

An additional listening test with the bandpass filtered signals (see Figure 6) showed that one harmonic is not enough to evoke this effect. If several neighboring harmonics are present at a similar level, than the level of harmonic components in the aforementioned frequency band for this pitch is directly proportional to the levels of Buzzing and Glossy.

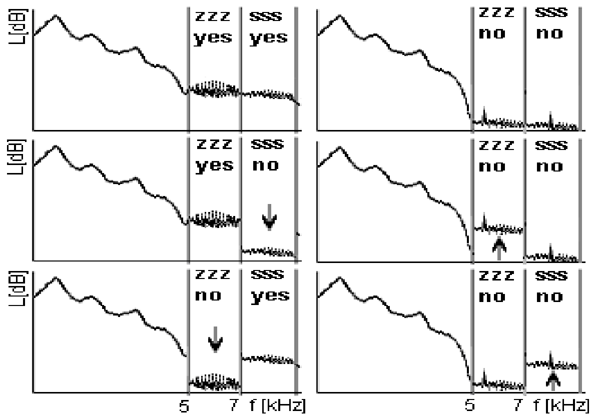

Figure 6: Scheme of the manipulation of signals with and without Buzzing and Glossy occurrence.

4. Discussion

For this study the first task was the selection of basic or interesting timbral attributes from the results of listening tests. Some of them constituted the first dimension of the perceptual spaces of different pitches (Sharp, Dark [6, 8]), changed the position inside the perceptual spaces (Narrow [8]), raised its frequency of occurrence (Rustle, tone D6 in SVD, [11, 12]) or originated the same perceptual factor but were perceived as different features (Glossy, Buzzing [17]).

It occurred fairly often that the values of significant correlation offered two very distinct frequency bands (Rustle in Figure 4) or too broad band (Sharp in Figure 1). Decision about hypotheses required additional listening tests with selected signals (with or without inquired perceptual event) and/or their clones obtained through manipulation.

Sharp: The main source for the perception of Sharpness are high levels of harmonics in the band from 5 to 10 kHz in all studied pitches B3, F#4, C5, G5, D6 (Table 1, [10]). It revealed that increasing first harmonic level decreases perception of Sharpness, but this influence weakens with increasing pitch and there is no influence above 1 kHz.

Narrow: The influence of the first harmonic level on the perception of Narrowness decreases with the increase of pitch. In tone C5 this decreasing divided the judges into two groups, the first one used strategy similar to that used in tone B3, the second one similar to D6. Significant positive correlation of the Narrow attribute with the level of the first harmonic in tone G5 (Figure 2) is probably caused by the two times greater variability of its values then in other tones. Concerning higher harmonics, we suppose the connection of the Narrowness perception with such spectral component, which has the highest audibly pronounced frequency. Its position is dependent on the shape of the spectral envelope (masking) and on absolute harmonic levels and can be the same for all judges (tone B3, Figure 3) or not (different strategies in tone C5).

Rustle: This attribute is induced mainly by time varying spectral components with mean levels above 25 dB in the band from 200 to 900 Hz, they are not masked through harmonics in tone D6, partially G5. The higher harmonics have lesser influence, the relevance of the band about 15 kHz in lower pitches was up to now not asked.

Buzzing and Glossy: Both attributes have the same conditions to come on: sufficient number of neighboring harmonics must have sufficient levels (but they must occur in different frequency band, Buzzing: 5.3 – 7 kHz, Glossy: 7.3 – 8.5 kHz). Their decreasing number with increasing pitch is the reason for vanishing these attributes (Buzzing sooner, Glossy afterwards). Time variability of these harmonics contributes to the nature of their perception.

5. Conclusions

It is possible to separate described attributes of violin timbre into two categories:

- Sharpness and Narrowness are the attributes connected with the spectral energy distribution. Both frequency boundaries of the spectrum affect their perception. The influence of the lower bound level (first harmonic) decreases with pitch, influence of the upper bound is dependent on the levels of individual harmonics (audibly pronounced) and on the shape of the spectral envelope (masking). Upper bound form of the spectrum induces the detachment of Sharpness and Narrowness in higher pitches.
- Rustleness, Buzzing and Glossiness perception is qualified by the sufficient levels of the group of time varying spectral components in specific frequency band.

The way of fulfillment of the above mentioned principles of violin timbre is connected with spectral component frequencies, thus primarily with pitch.

Acknowledgments

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