SPECTRAL SOURCES OF SELECTED FEATURES OF VIOLIN TIMBRE

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SUMMARY: Selected features of the timbre of stationary violin tones are studied and their spectral sources are sought. The sound recordings of five different tones (B3, F#4, C5, G5 and D6) played on a set of violins are used. Spontaneous word description of timbre of individual sound obtained in listening test [1] was used for the selection of words, which describe specific feature of timbre (sharp, clear, dark and narrow). The same signals were sorted and assessed according to these verbal attributes in a second listening test [2]. Signals with extreme value of an attribute were modified in frequency bands with significant correlation between their levels and verbal attribute magnitude. Sorting and assessment of modified signals was used for the recognition of a potential spectral source of a studied timbre feature. The frequency position of the main source for sharpness and narrowness is established and its pitch dependence is discussed.

I. INTRODUCTION

Many authors have investigated sound timbre and tried to describe its main features and their spectral sources. The results of these studies are strongly dependent on the stimuli (listened context) [3] but also on the context of listeners: their experiences and quality of hearing.
The studies of many authors on different types of musical instruments led to two or three interpretable dimensions [4, 5]. We focused on only one instrument type – the violin, and on the stationary part of the tone. Thus only one dimension from [5] is potentially present in our contexts: sharpness, which was investigated in detail and described by von Bismarck [6].

II. PREVIOUS EXPERIMENTS

II.1. Basic experiment

The violin timbre was studied on recordings of 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) of eleven instruments of various qualities recorded in an anechoic room and played *détaché*, *naturale,* non-vibrato, and *mezzoforte* [7].
Recordings of tones were subsequently manipulated to disable an influence of transient parts on perception. Separate listening tests of all five tones resulted in timbre dissimilarity matrixes (used in the construction of perceptual spaces [7]) and words describing the timbre of the violin sound [1]. Comparison of five perceptual timbre spaces and use of the hypothesis of basic perceptual dimensions [8] provided four timbre dimensions for quasistationary violin sounds (Table 1).

Table 1. Timbre dimensions of stationary violin sounds

Dim.	Dimensional words: in English (in Czech)
I.	Soft (měkký) – Sharp (ostrý)
II.	Clear (jasný) – Damped (zastřený)
III.	Dark (tmavý) – Bright (světlý)
IV.	Narrow (úzký)

II.2. Second experiment

A further set of listening tests was carried out on five original tones [2] using the same eleven signals as in the basic experiment. Eleven listeners (violin players and sound designers) made a ranking (sorting) and rating (with values from 0 to 10) of signals on the magnitude of **Sharpness, Clearness, Darkness and Narrowness** separately for each of five tones. The test was prepared in a MATLAB (®The MathWorks) environment.
Factor analysis of group average ratings leads to a two-dimensional solution for all five tones, which are summarized in Figure 1.

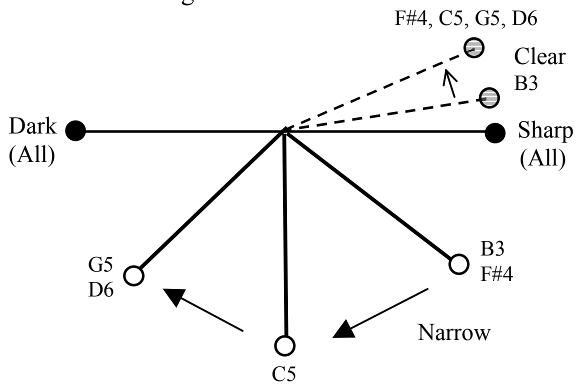

Figure 1. Two-Dimensional Factor Analysis solution

We conclude that there is a very stable, highly significant and negative correlation between Sharpness and Darkness, word attributes that form the first dimension as opposites. The position of Clear is stable and similar to Sharp (significant positive correlation). The position of Narrowness or its relation to Sharpness changes with increasing fundamental frequency. In tones B3 and F#4 the correlation is positive and nearly significant on 5%, in C5 the Sharpness and Narrowness are independent (orthogonal in factor space), in tones G5 and D6 they are again significantly correlated on 5% but the correlation is negative. This is the reason that only attributes **Sharp** and **Narrow** were chosen as representative enough for the subsequent investigation.

III. HYPOTHESIS ABOUT SPECTRAL SOURCES OF SHARPNESS AND NARROWNESS

The following spectral characteristics were calculated from recorded signals: levels in individual harmonics, levels in critical bands (Barks) and spectral center of gravity f_{cg} [5]. Individual rating and group average rating values were correlated with these spectral characteristics. Significant correlations of average rating values are summarized in Table 2. In tone C5, two groups of listeners emerge.

Table 2. Significant correlations of subjective rating values for Sharpness and Narrowness with f_{cg} and with levels of harmonics or of Bark bands (+ positive, – negative)

Tone	f_{cg}	bold is Bark band containing 1. harmonic										
D6		Bark:	3	4	5	6	7	8	**10**	20	22	23	24
	+	Sharp		+		+	+			+	+	+	+
		Narrow	–	–	–	–	–	–			–	–	–
G5		Bark:	2	4	6	7	**8**	20	22	23	24		
		Sharp	+		+				+	+	+		
		Narrow		–	–	–		–	–		–		
C5		Bark:	**6**	18	19	21	22	23	24				
	+	Sharp	–	+		+	+	+	+				
		N gr. 2		–		–	–	–	–				
		group 1	–		+		+	+					
F#4		Bark:	**4**	13	20	22	23	24					
	+	Sharp	–		+	+	+	+					
	+	Narrow	–	–		+	+	+					
B3		Bark:	**3**	16	17	18	19	20	21	22	23	24	
	+	Sharp	–			+	+	+	+	+	+	+	
	+	Narrow	–	+	+			+			+		

It is apparent from Table 2 that the correlations of Sharpness are stable namely in higher Bark bands in all five tones, but it is possible to recognize two behavioral models for Narrowness according to tone pitch:

a) it is similar to Sharpness for tones B3 and F#4, and group 1 of listeners in tone C5,
b) significant correlations have the opposite sign for group 2 in tone C5 and for tones G5, D6,

this is in good agreement with Figure 1. So only tones **B3, C5** and **D6** were used for further investigation.

The method used for the search of spectral sources for Sharpness and Narrowness was based on the selection of signals with extremely high or low value of rating of these verbal attributes and on manipulation of these signals by filtering. Levels of harmonics (harmonic spectra) of selected signals with x-coordinate in the Bark scale (calculated according formulas from [9]) are in Figure 2 and Figure 3.

Sharpness hypothesis:

a) higher level of the first harmonic decreases Sharpness only up to around 0.5 kHz (Bark 6),
b) high levels of higher harmonics increase Sharpness (in which frequency bands mainly?),
c) high levels of noise components below the fundamental (called Rustle in [10]) increase Sharpness in higher tones.

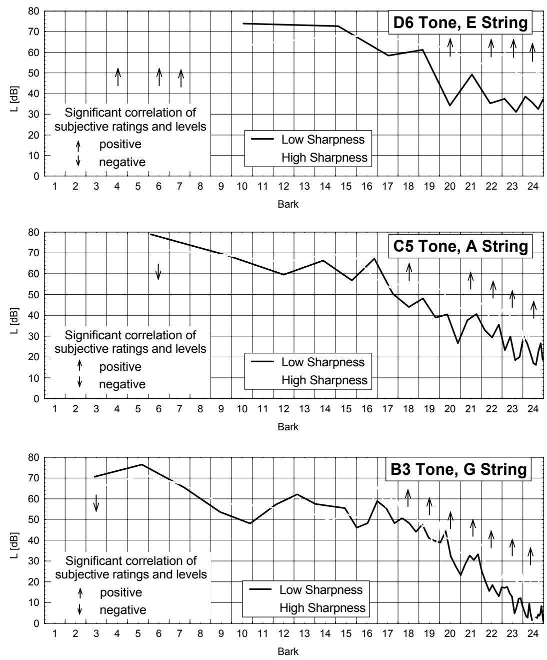

Figure 2. Harmonic spectra of tones with low and high degree of Sharpness for B3, C5, and D6 tones

Narrowness hypothesis:

a) the influence of the first harmonic level decreases with an increase in fundamental frequency (similarly as for Sharpness),
b) the 'length' of spectra influences Narrowness (in which sense?),
c) high levels of noise components below the fundamental (Rustle in [10]) decrease Narrowness in higher tones.

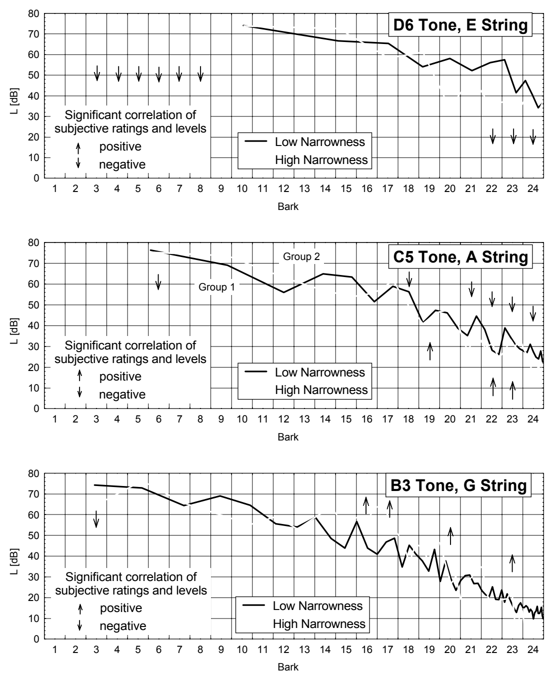

Figure 3. Harmonic spectra of tones with low and high degree of Narrowness for B3, C5, and D6 tones

IV. METHOD

IV.1. Stimuli

Stimuli for listening tests were prepared with the aid of manipulation of selected original signals in specific frequency regions according to hypothesis. The following forms of manipulation were used: suppression of all higher frequencies (harmonics), attenuation or amplification of a specific part of the spectrum (containing one harmonic or group of harmonics or Rustle components) the amount of change was defined according to appropriate level differences of extreme signals (see Figure 2, 3) and is described later in the discussion. The spectrum changes were carried out by filtering in similar way as described in [10], and by weighted summation of filtered signal complements. Big changes in loudness due to manipulation were corrected. Suppression of higher frequencies cannot be done in an arbitrary region, signals with 'too short' spectrum sound unnatural and cannot be evaluated properly, so the suppression of harmonics under frequency 4.5 kHz in tones B3 and C5 or under 7 kHz in D6 is not possible.

IV.2. Listening tests

The following sets of signals were prepared:

a) for Sharpness, about ten signals for each of tones B3, C5 and D6 containing signals from Figure 2 and their appropriate clones,

b) for Narrowness, about ten signals for each of tones B3, C5 and D6 and one separate set for very Narrow and not Narrow signal (and its clones).

A ranking and rating test described in paragraph II.2. was carried out with one part of the listeners group.

V. RESULTS

V.1. Sharpness

Only one case of suppression of higher harmonics (later specified in each tone) was used for each tone.

B3 tone: listeners in signals described the main changes in Sharpness with filtered higher harmonics above 5.4 kHz (harmonic number 22) and in signals with the change of the first harmonic (±6 dB). Influence of the change of harmonics from 13 to 15 (±12 dB) was markedly lower.

C5 tone: the main changes were revealed in filtering of harmonics above 6.2 kHz (H12), lower changes due to manipulation with H1 (±6 dB) and negligible changes due to manipulation of H5 (-12 dB), H6 (-6 dB) and H8 (-18 dB) it is in frequencies 2.6, 3.1 and 4.2 kHz.

D6 tone: filtering of harmonics above 11.7 kHz (H10 and higher) and level change in H1 had no influence on Sharpness. There was no concordance among listeners in influence of Rustle components. The main influence was specified by changes in level of one 'preferred' harmonic, H5 (5.9 kHz), H6 (7.1 kHz) or H8 (9.4 kHz) in different listeners.

These results are summarized in Figure 4.

V.2. Narrowness

Gradual suppression of higher harmonics was applied in all three tones in Narrow and not Narrow signals to detect the influence of 'shortening' the spectrum separately in both types of the signal.

B3 tone: maximal increase of Narrowness was achieved by increasing the level in frequency band 2.7 – 5.4 kHz (H11 to H22) about 12 or 18 dB, lower increase by decreasing in the same band and comparable increase by lowering the level of H1. 'Shortening' had smaller influence and was concentrated on frequency 6.5 kHz in the 'not Narrow' signal and on frequency 5 kHz in Narrow signal.

C5 tone: the 'shortening' of the spectrum caused maximal increase of Narrowness and was concentrated on frequency 8.4 kHz and about 6 kHz in both signals. Changes in frequency band 2.6 – 4.2 kHz in both directions had a smaller influence (but caused an increase in Narrowness) and was comparable to the influence of H1 changes (which was lower in 'not Narrow' signal).

D6 tone: the greatest increase of Narrowness was in the 'shortening' of 'not Narrow' signal above 7 kHz. Suppression of Rustle increased the Narrowness. Any change in the level of H1 increased Narrowness but more in the Narrow signal. Reducing the levels in the band 8 – 14 kHz increased Narrowness; increasing levels had no influence.

These results are again summarized in Figure 4.

VI. DISCUSSION

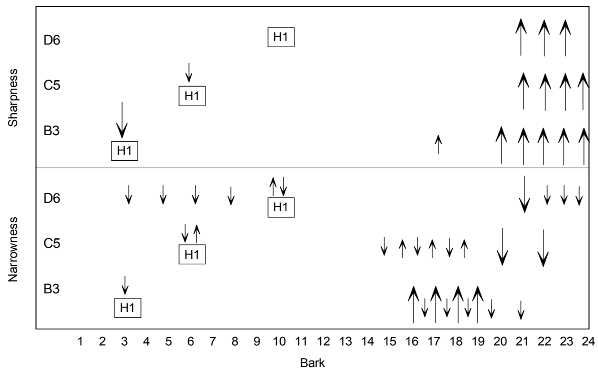

Figure 4. An outline of hypothesis events proved by listening tests (level change in the spectrum in the direction of the arrow causes increase of attribute, the length of the arrow corresponds to the size of attribute change), positions of the first harmonic are denoted H1

The main changes recognized in listening tests are marked in Figure 4.

Additional listening tests verified part a) and b) of Sharpness hypothesis. Decreasing influence of the first harmonic with increasing pitch is in good agreement with results in [11]. Components above 5 kHz make the main contribution to Sharpness in all three tones. The influence of noise components was not proved.

The situation regarding Narrowness is rather complicated. Additional listening tests verified positively only part c) of the hypothesis. The influence of the first harmonic is less important then in Sharpness. In higher tones the change in level in both directions can increase Narrowness, so the balance of the fundamental frequency level is important, and ever more crucial in Narrow signals.

Concerning the 'length' of the spectra, this has an importance but the mechanism is dependent on pitch or, more precisely, on the shape of the spectral envelope. To explain this phenomenon it is useful to look at the spectral envelope of mean spectra in Figure 5. In tone B3 an increase of levels in Barks 16 and 17 (frequency band 2.7 – 3.7 kHz) masks substantially higher components (see high slope of the envelope above this region), but the decrease of levels in the same band lowers its contribution to 'non Narrowness'. The lower slope of the envelope in higher tones weakens masking effects of levels in this frequency band on higher frequency components. The influence is more critical in the sense of proper balance of levels in the context of the whole spectrum. The frequency band above 5 kHz has a greater influence on Narrowness in higher tones. Furthermore, the content (number of audible components) of the spectrum can also play a certain role. To recognize the proper relation between the influence of spectrum 'length' and the richness of the content will need further investigation.

Concerning the change of correlation of Sharpness and Narrowness with dependence on pitch, this can be explained again from the changing slope of the spectral envelope. Higher levels in the 5 – 6.5 kHz band in lower tones increase both Sharpness (high levels) and Narrowness (masking effects on higher frequency components). In higher tones the situation in Sharpness remains the same, but the lower slope of the spectral envelope weakens masking effects and higher levels alone lower Narrowness.

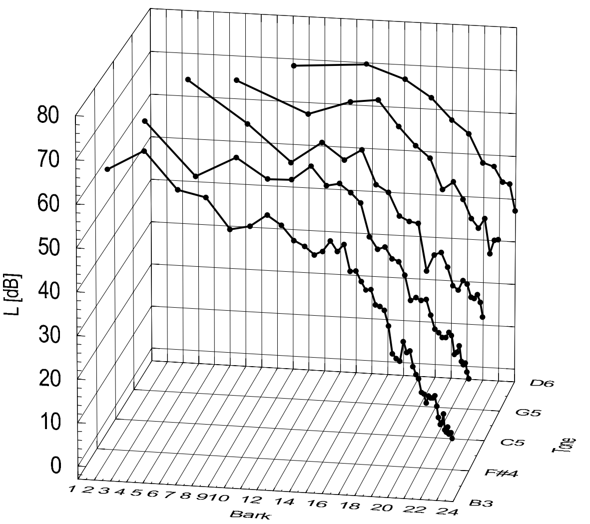

Figure 5. Mean spectrum of eleven signals for each studied tone

VII. CONCLUSION

The presented study detected some behavioral rules for Sharpness and Narrowness and relations between them in violin tones. Presented conclusions are strictly dependent on the slope of spectral envelope and cannot be simply generalized for other types of harmonic spectra. Listener experience and hearing also influenced the results.

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