POSSIBILITY OF APPLICATION OF OBJECTIVE PSYCHOACOUSTIC METRICS ON MUSICAL SIGNALS

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Abstract: Objective psychoacoustic metrics (loudness, sharpness, and roughness) were calculated for sets of violin tones B3, F#4, C5, G5, and D6. The results were compared with verbal attributes subjective evaluations obtained during listening tests performed on the same signals. The relations among objective and subjective evaluations are studied and possibilities of objective metrics application on musical signals are discussed.

1. Introduction

The sound as a physical phenomenon can be described by acoustics quantities such as sound preassure level, fundamental frequency or frequency spectrum. These physical properties are reflected in human consciousness as a sensations which man can describe using subjective psychoacoustic quantities such as loudness, pitch or timbre. Timbre is commonly considered as a multidimensional subjective psychoacoustic quantity. The main features (categories, dimensions) of sound timbre can be searched from the results of listening tests.

As the listening tests are time consuming and expensive to carry out, the relations among physical properties of the sound and it's subjective perception has been described by mathematical models of human perception. Those models defines number of objective psychoacoustics metrices (eg. loudness, sharpness, roughness, tone-to noise ratio, prominence ratio) which can be computed directly from the measured signal without performing any listening test. Metrices are defined usualy for band noise signals, so their application on musical signals with discrete spectrum is a matter of interest.

2. Method

In prior experiments performed by Štěpánek [1, 2] violin tones of 5 different piches (see Table 1) played on 24 violins of various quality were studied. The same loudness, pitch and tone duration was maintained during the recording or later equalized. Attack and decay transients were subsequently manipulated to weaken their influence on perception. Stimuli (sounds) in tests were listened to using headphones. At first the pair dissimilarity listening test was performed on the stimuli. Based on it's results the 17 most appropriate sounds for each pitch were used for construction of perceptual spaces.

Table 1. Description of analyzed violin tones

Tone	String	Nominal frequency [Hz]
B3	G	247
F#4	D	370
C5	A	523
G5	E	784
D6	E	1 175

Eleven sounds best representing each perceptual space were used in the next listening test. The test included both verbal descriptions of timbre differences and judgements of preference of the perceived sound quality in pairs of recordings. Listeners have described perceived differences spontaneously in words (spontaneous verbal description). Results of both experiments were compared. In the study described in this paper the signals were analyzed and objective psychoacoustic metrices were computed using PULSE Sound Quality ver. 3.0 software by Brüel & Kjær. The results were compared with the results of previous experiments.

The algorithm for computing of loudness has been standardised in ISO 532B standard (method is described also in [3]). It is based on graphical integration of partial loudness distribution function, which is computed from signal levels in individual critical bands approximated by third-octave bands. Sharpness is defined as a weighted sum of specific loudness over 24 critical bands. There are several algorithms of sharpness computation. They differe mainly in definition of weighing functions. Zwicker sharpness used in PULSE Sound Quality is defined as [4, 5]

$$S = 0.11 * \frac{\int_1^{24} N'(z) * g(z) * z * dz}{\int_1^{24} N'(z) * dz} \qquad (1)$$

where
S = Zwicker sharpness
N' = specific loudness
$g(z)$ = weighing function

Implemented weighing function is

$$g(z) = \begin{Bmatrix} 1 & \text{for } z \le 16 \\ 0.066 * e^{0.171*z} & \text{for } z > 16 \end{Bmatrix} \qquad (2)$$

The software have also implemented algorthm according to Aures which encompases slight influence of loudness on sharpness:

$$S = 0.11 * \frac{\int_1^{24} N'(z) * g(z) * dz}{\ln(0.05N + 1)} \qquad (3)$$

where N = overall loudness,

$$N = \int_1^{24} N'(z) * dz \qquad (4)$$

Both algorithms were used in this study.

Roughness is a measure of the amount of low- and middle-frequency variations in the signal amplitude. It is calculated on the basis of time varying loudness. The formula for roughness calculation was first given by Zwicker. The implementation in PULSE Sound Quality uses slightly modified algorithm using envelope analysis to find the modulation frequency and the percentile loudness values to find variations of the amplitude.

Specific roughness for Bark z is

$$R'(z) = 0.0003 * f_{\text{mod}}(z) * \Delta L_E(z) * \Delta z \qquad (5)$$

$$\Delta L_E(z) = 20 * \log(N'_Z(1) / N'_Z(99)$$

where
$f_{mod}(z)$ = modulation frequency
$N'_z(1)$, $N'_z(1)$ = percentile loudness value

The roughness is a sum of all specific roughnesses

$$R = \int_1^{24} R'(z) * dz \qquad (7)$$

3. Results

Software analysis was performed on signals of all 24 instruments. Comparison with listening tests was performed only on subsets of 11 signals relevant for each pitch. The values of Zwicker sharpness, Aures sharpness and roughness were corelated with ratings of verbal attributes “sharp”,”dark”, “clear” and “narrow” on stimuli during listening test.

Table2 presents Spearman coefitients of corelation among attribute ratings and psychoacoustics metrices for individual pitches. Figure 1 shows relations among computed values of Zwicker sharpness and rating of perceived sharpness of signals in listening test for tone pitch E5, G5, and D6.

Table 2. Corelations among verbal attribute ratings and psychoacoustics metrices, values significant on level p=0.01 are in bold. S = sharpness, R= roughness

	S		R
	Zwicker	Aures	
Attribute	Tone B3		
sharp	**0.826**	**0.952**	-0.228
dark	**-0.838**	**-0.955**	0.173
clear	**0.761**	**0.827**	-0.391
narrow	**0.665**	**0.573**	0.027
	Tone F#4		
sharp	**0.883**	0.685	-0.436
dark	**-0.952**	-0.708	0.455
clear	0.705	0.411	-0.482
narrow	0.618	0.096	-0.045
	Tone C5		
sharp	**0.966**	0.685	0.601
dark	**-0.938**	**-0.753**	-0.606
clear	**0.934**	**0.767**	0.574
narrow	-0.260	-0.516	-0.273
	Tone G5		
sharp	0.137	0.642	0.227
dark	-0.100	-0.615	-0.118
clear	-0.282	0.303	0.345
narrow	0.287	-0.312	-0.545
	Tone D6		
sharp	**0.864**	**0.877**	0.682
dark	**-0.864**	**-0.922**	-0.673
clear	0.573	0.690	0.618
narrow	-0.164	-0.306	-0.618

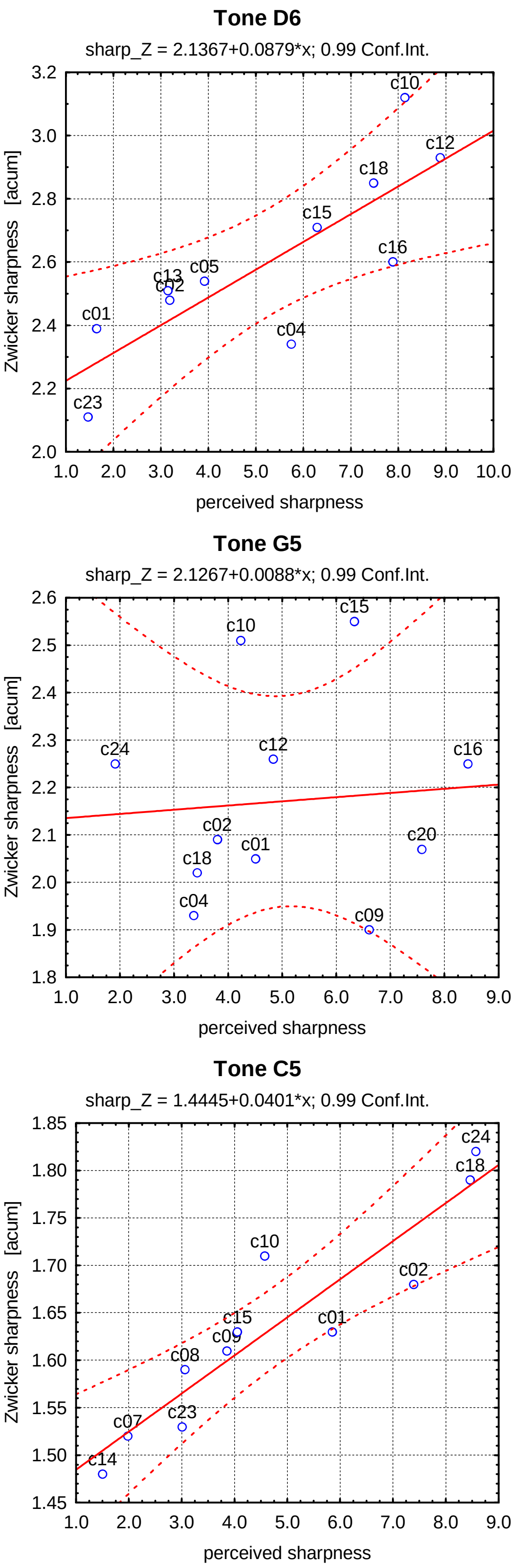

Figure 1. Scatterplots presenting the relation among perceived sharpnes rating and Zwicker sharpness for tone C5 ($r_s = 0.966$), G5 ($r_s = 0.137$), C5 ($r_s =\ 0.864$).

presented in Table 2 shows that relations among results of listening tests and computed psychoacoustic metrices may be inconsistent in some cases. Note that respondents rates attribute under question independently for each pitch, so their rating scales may be different for each pitch.

Strong positive correlations of Zwicker sharpness and rating of attribute “sharpness” for tone pitches B3, F#4, C5 and D6 are in agreement with presumption of which sound property the Zwicker sharpness should represent. Correlation of Aures sharpness is wery strong and significant for pitches B3 and D6, for other pitches is significantly weaker. There is low correlation of both sharpness types for pitch G5. As Figure 2 shows, sharpness ratingsin listening test were scattered and divited into several groups.

Negative correlation among computed sharpness and rating of “dark” is in accordance with opposite meaning of attributes “sharp” and “dark” (see [1]).

Zwicker roughness shows no significant correlation with rating of any studied attribute.

5. Conclusion

Comparison of set of objective psychoacoustic metrices and verbal attribute ratings in listening test was performed on set of violin sounds of five tone pitches. It shows that relations among computed metrices and corresponding verbal attribute ratings are dependent on algorithm used for metric computation and may be inconsistent in some cases.

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References

[1] Štěpánek, J. (2002): The Study of Violin Timbre Using Spontaneous Verbal Description and Verbal Attribute Rating. Forum Acusticum Sevilla 2002 (ISBN 84-87985-06-8), MUS-06-008.

[2] Štěpánek, J. (2002): Evaluation of timbre of violin tones according to selected verbal attributes, Acoustics Banská Štiavnica 2002, EAA symposium, (ISBN 80-228-1159-9), 129 - 132

[3] Zwicker, E., Fastl, H. (1990): Psychoacoustics - Facts and Models, Springer - Verlag, Berlin, (ISBN 3-540-52600)

[4] Bismarck, G. von (1974): Sharpness as an Attribute of the Timbre of Steady Sounds, *Acustica*, 30, 159-172.

[5] --- (1999): PULSE Sound Quality user manual, Brüel & Kjær