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Relation between violin timbre and harmony overtone

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The timbre of violins has been studied by several researchers from various points of view including structure, acoustic characteristic, chemical composition of the varnish and acoustic radiation. Although many of them have mentioned that Stradivari's violin gives the most beautiful timbre, none of them clarified the reasons. In our previous study the timbre of about 30 violins from old ones to new ones had been studied and the relation between harmonic overtones and the expression words, which the audience receives from the sound of the violin, was analyzed. However, clarifying how the structure of overtone is related to the feeling of the listeners of sound such as "rich," "bright," and "soft." was not successful. In this paper, the changes in overtone structure relating to violinist's performance were analyzed. For instance, the power of non-harmonics frequency, which was assumed as noise, in "powerful" and "rich" expression was larger than that of the scale tone without expression.

1. INTRODUCTION

Several researchers have studied the timbre of violins from various points of view including structure, acoustic characteristic, chemical composition of the varnish, and acoustic radiation[1-7]. Although many of them have mentioned that Stradivari's violin gives the most beautiful timbre, none of them have clarified the reasons.

We have studied the timbre of about 30 violins from old ones to new ones and have attempted to analyze the relation between harmonic overtones and the expression words[8], which the audience receives from the sound of the violin. However, we have not been successful in clarifying how the structure of overtone is related to the feeling of the listeners of sound such as "rich," "bright," and "soft."

In this paper, we have analyzed how the changes in overtone structure are related to the difference in violinist's performance by Fast Fourier Transfer (FFT). For instance, the power (dB) of sound at the frequency area, the expression such as forte or piano and the bowing distance from a bridge were analyzed by spectrums. We also observed the SN ratio which was defined as the ratio of the power of harmonic overtone of the sound and that of non-harmonic overtone.

2. EXPRESSION WORD FOR TIMBRE

In table 1, we have showed the 11 expression words used in the experiment for investigating the effect of the difference in the musical expression on the acoustic spectrum. These words are commonly used for expressing the timbre of violin, which we selected for the experiment by considering the difference in acoustic characteristics and the easy imagination of the expression. For recording the player's performance, we selected 11 classical music that corresponded with each expression word. The tones were decided from the music such that the duration is long enough for calculating the spectrum and balance of tone height and volume.

In the present study, we expected the music character to influence the timbre naturally on recording the tone when performing the music. In other words, it may not be natural for a player to perform with expressional timbre by using only the open string tone or scale.

Table 1. Expression words and music at recording.

Expression word	Music
Warm	Brahms, Violin sonata No.1, theme from 1st mov.
Powerful	Beethoven, Symphony No.5, theme from 1st mov.
Weak	Schubert, Symphony No.8, theme from 2nd mov.
Rich	Brahms, Symphony No.1, theme from 4th mov.
Glitter	Ravel, Violin sonata, theme from 1st mov.
Passionate	Monti, Csárdás, introduction
Dark	Shostakovich, String quartet No.8, from 1st mov.
Bright	Beethoven, Violin sonata No.5, theme from 1st mov.
Calm	Franck, Violin sonata, theme from 1st mov.
Soft	Debussy, Violin sonata, from 1st mov.
Tense	Shostakovich, String quartet No.8, from 2nd mov.

3. RECORDING OF VIOLIN TONE

The recording was carried out in the semi-anechoic room of the university, and the music listed in Table 1 was recorded by correctly playing the notation of the music.

In addition, the chromatic scale without any expression was recorded once in order to compare it with musical expression tones. NV Gate OR30 series was used as FFT analyzer, and the frequency of sampling was 51.2 k/sec. The ICP 1/4 inch array microphone (type 130A23) was used. The frequency response was 20 – 20k Hz, and dynamic range was 30 – 143 dB. The microphone was set approximately 20 cm above the bridge of the violin. One of the concertmasters of a professional orchestra was considered as the test player, and the Lupo (in 1809; made in France) violin was used in the study.

4. ANALYSES AND RESULTS

i. Spectrum

The results obtained by comparing the spectrum of tone with musical expression with that without musical expression are shown in Figs.1 to 4.

Figure 1 shows the comparison of the spectrum with the expression word "powerful" and that without expression (written with "scale" in the figure). The player performed the lowest D4 tone on G string in fortissimo, and the bowing was near the bridge. The power of non-harmonics frequency, which was assumed as noise, in "powerful" expression was larger than that of the scale tone without expression. Near and over 4k Hz, there was a small difference between the shape of peak of harmonics and that of non-harmonics.

On the other hand, Fig.2 is a result of pianissimo tone with less vibrato, where the expression word was "weak." The overall power is less in higher frequency than without the expression "scale." In this "weak" tone, the bow was moved near the finger board.

The result of C4 (261.6 Hz) in Fig.3 was a note in the famous melody of Brahms Symphony No.1 4th movement, and this tone was recorded with the expression "rich." The difference in the spectrum is seen over 6th overtone and near 2k Hz. The power of non-harmonics is larger than that of tone without expression, and the peak of integer harmonics are low and blurred. This tendency was also seen in the other tones, which were played with the expression "warm" in a sonata of Brahms, "soft" in Debussy, and "calm" in Franck.

The spectrum of C6 from a Shostakovich's string quartet played with musical expression "tense" is shown in Fig.4. In this case, the power is still high in the higher-order overtones over 10^{th} overtone, and the peak of overtone over 10k Hz is sharp; therefore, the timbre is clear, and its metal factor is dominant. This is caused by the position and pressure of bowing and the fingering when a player pushes the string with finger standing or laying.

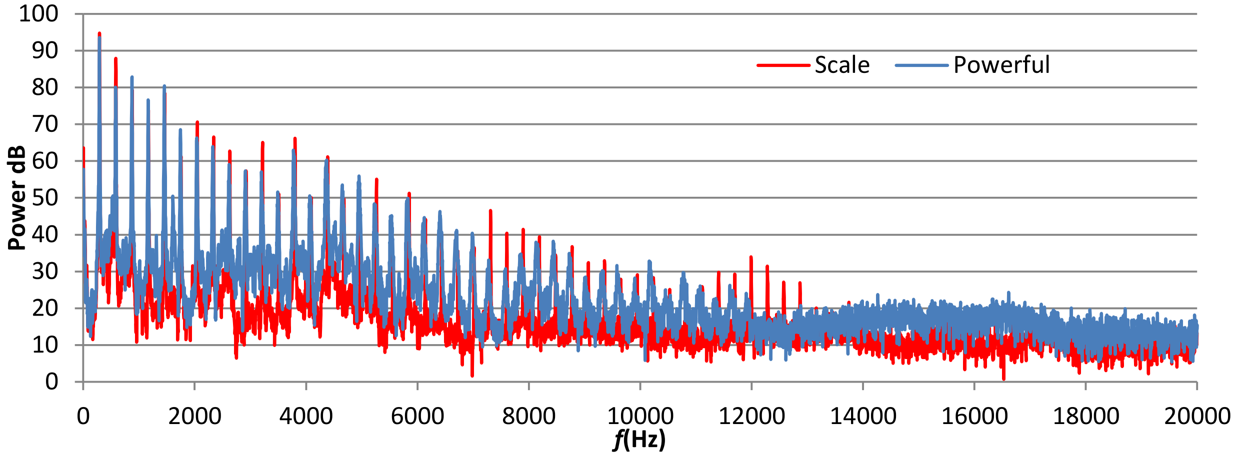

Fig.1 Spectrum of violin tone played with expression "powerful" and scale tone without expression, D4(293.7Hz), from Beethoven Sym. No.5 1st mov. Introduction.

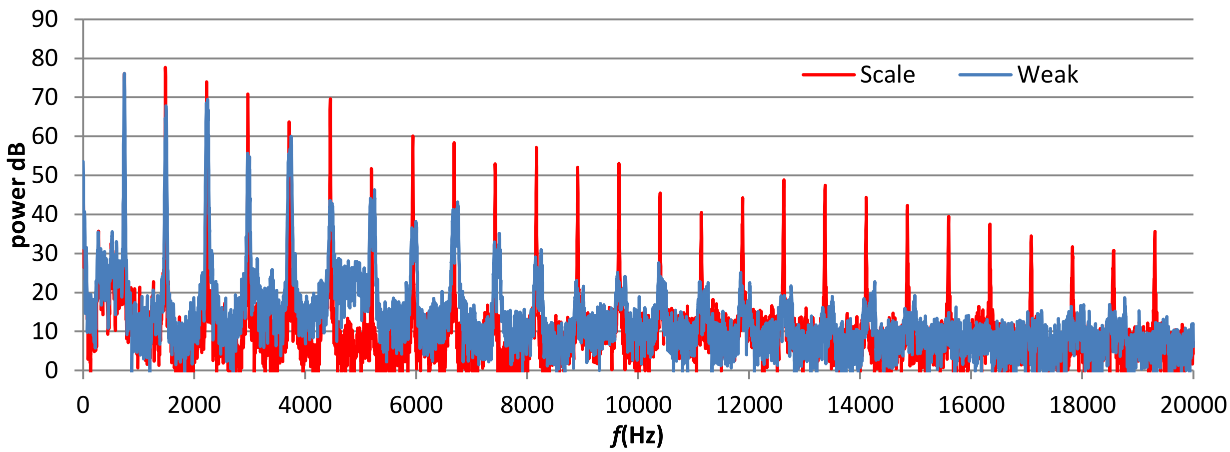

Fig.2 Spectrum of violin tone played with expression "weak" and scale tone without expression, F#5(739.9Hz), from Schubert Symphony No. 7 2nd mov.

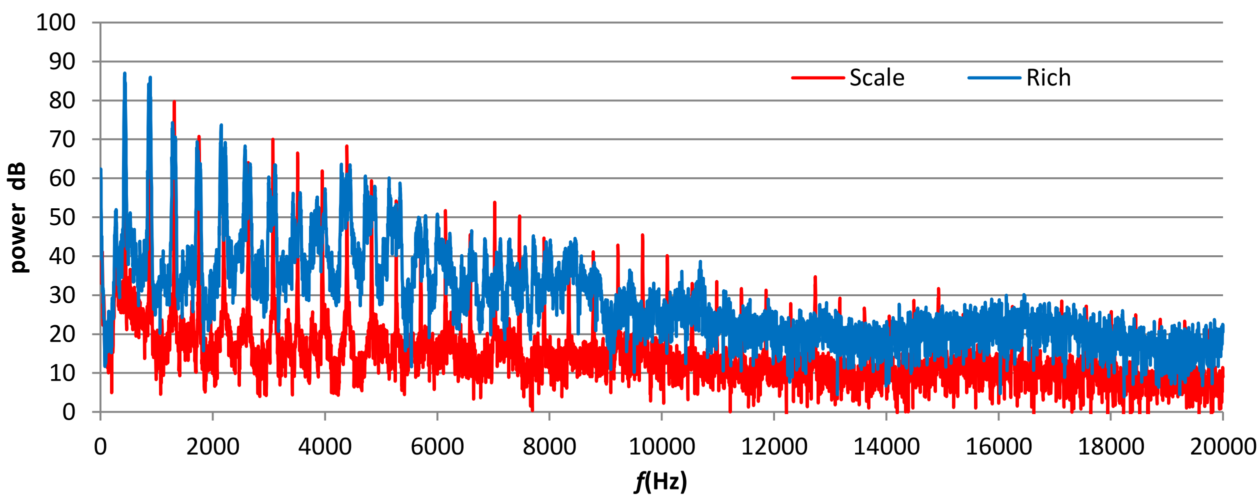

Fig.3 Spectrum of violin low tone played with expression "rich" and scale tone without expression, C4(261.6Hz), from Brahms Sym.No.1, theme of 4 mov.

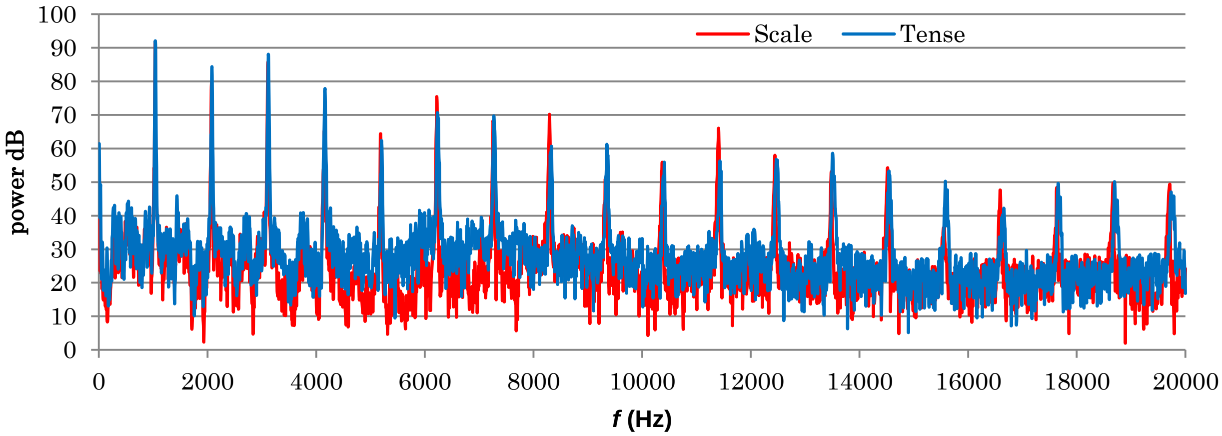

Fig.4 Spectrum of violin high tone played with expression "tense" and scale tone without expression, C6(1046.5Hz), from Shostakovich String Quartet No.8, theme of 2 mov.

ii. SN ratio

From the above discussion, it seems that the power balance of integer overtone and around frequency, which determines the timbre, is affected by pitch and volume. In the present paper, we defined SN ratio and R_n, which is the ratio of the power of n-th integer overtone to the power around the overtone (Eq (1), Fig. 5).

$$R_n = S_n - N_n \qquad (1)$$

Here, S_n is the power of n-th overtone (dB), and N_n is RMS of power around n-th overtone (dB), i.e. RMS (P_i, n-1 < i < n + 1).

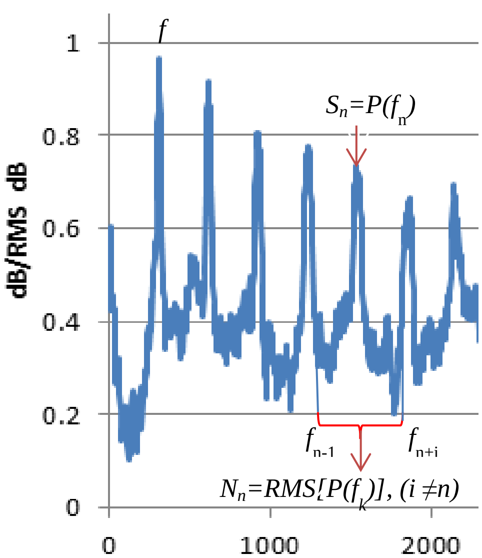

Fig.5 Definition of SN ratio on n_{th} overtone.

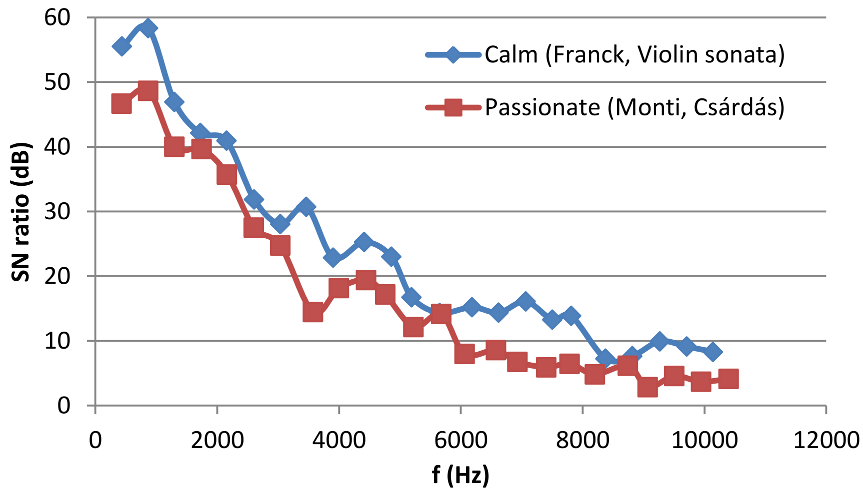

Fig.6 Comparison of SN ratio between Passionate(Csárdás) and Calm(Franck).

Fig.6 shows a sample of the result of SN ratio obtained from the recording. SN ratio mostly has a peak at the frequency of fundamental wave or at 2nd overtone to 5-th overtone, and then the power of peaks descends. The *piano* tone in Franck's sonata, which was played above near finger board of violin to produce much harmonics, tended to have high SN ratio in overall overtones, compared with the fortissimo tone of Csárdás, which was played near a bridge of violin with expression "passionate." From this result, it can be derived that the SN ratio is affected by a volume notation in a score and bowing position from bridge related to volume notation.

Fig.7 shows the relation of SN ratio and fundamental wave's frequency (f_0) of violin tone with each expression. Here, the vertical axis indicates a frequency when the SN ratio falls below 40 dB as a representative. Therefore, the high value of vertical axis refers to the high overall SN ratio. This confirmed the tendency of SN ratio of the whole integer overtone to rise with the higher pitch of the fundamental wave (correlation coefficient is 0.78).

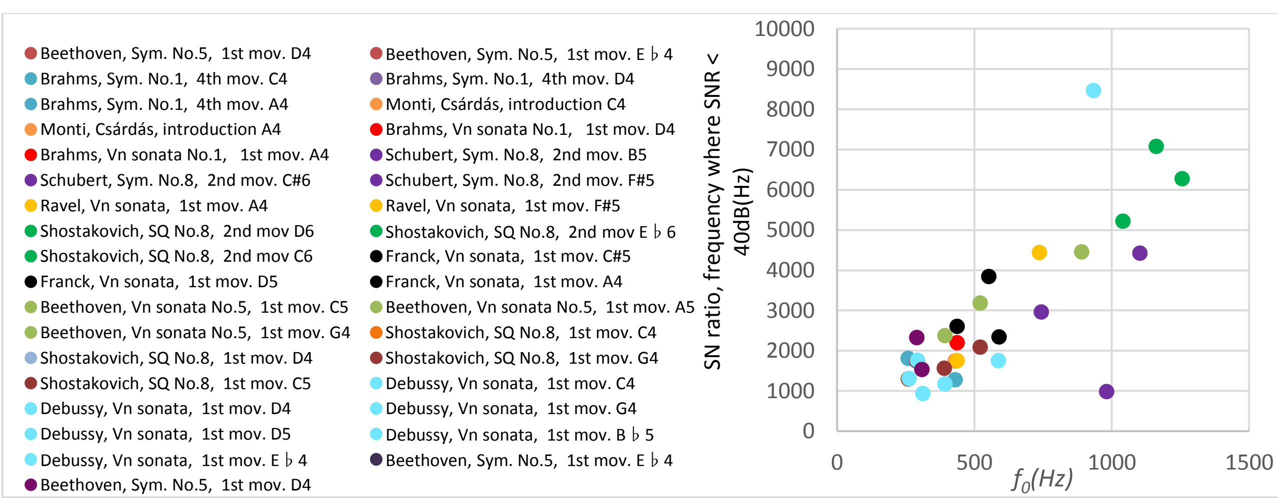

Fig.7 Relationship between f_0 and SN ratio （frequency where SNR < 40dB）, Correlation coefficient = 0.78.

5. DISCUSSION AND CONCLUSION

Recorded violin tone was analyzed using a spectrum, and we confirmed that the higher pitch has a higher SN ratio up to the high-level overtone and that the sound contains a lot of integer overtone. On the other hand, the lower pitch has low SN ratio and contains much non-harmonic tone, which seems to give a delicate or rich impression of timbre. Increasing the power of other non-harmonic frequencies refers to the reduction of clearance of overtones, noise of timbre, and blurred timbre.

This difference of overtone that determines timbre may come from the methods of bowing related to musical expression[9,10]. In other words, it depends on the pressure, position, and velocity of bowing. In the above analysis, we mentioned the factor of bowing, but the fingering of the left hand also affects the timbre[11]. The test player performed with laying left fingers and wide vibrato when he expressed soft sound. This effect by the difference between fingering with standing or laying left fingers is now under investigation.

We obtained the following results,

- Volume
  - Fortessiomo (bowing : near bridge, high pressure, slow velocity) :
    Non-integer overtones increase
  - Pianissimo (bowing : near finger board, low pressure, fast velocity) :
    Integer overtones increase
- Pitch
  - Higher : Integer overtones increase
  - Lower : Non-integer overtones increase
- Vibrato
  - Peaks of integer overtone become blurred
  - Non-integer overtones increase

As the future work, we need to record the other violins and players and analyze the phase of overtone for better effectiveness.

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