Differences of Sound Spectra in Violins by Stradivari and Guarneri del Gesú

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ABSTRACT

Thirty fine Cremonese violins made in the shops of Antonio Stradivari and Guarneri del Gesú are compared based on long-time average spectra. One-third octave band spectra were obtained from a commercially available recording where the same music pieces are played under similar conditions on each of the violins. Generally the spectra conform to a 10 dB band from 250 to 4,000 Hz. The average Stradivari is stronger in the 200 Hz and 250 Hz bands and above 1.6 kHz. Del Gesús are on average stronger from 315 Hz up to 1.25 Hz. These differences are perceived as a more brilliant sound and stronger fundamentals of the lowest notes of the Stradivari, versus a more dark sound in the del Gesú.

INTRODUCTION

Violins and other musical instruments are often studied based on admittance or radiation curves [1,2,3]. Such curves are rapidly recorded and are invaluable for judging and analyzing details in instrument characteristics and acoustical qualities [4]. However, few good instruments are available for such measurements. Makers and players prefer to play instruments to judge the quality rather than using analytical measurement methods, and musicians usually judge an instrument within seconds of playing. A trained listener should be able to do the same, even if the sounds come from a recording. Important information for judging the quality should be found in the sound spectra from the played violin. Thus it should be feasible to analyze recordings for the study of sound spectra from violins. This article investigates the sound spectra from fine Cremonese violins made by Antonio Stradivari and Giuseppe Guarneri del Gesú. A more general aim is to present a simple method that may be applied to available recordings, maybe right from your own CD archive.

METHOD

Signals from a commercially available recording (The Miracle Makers, by Bein and Fushi [4]) were plugged into a spectrum analyzer capable of performing one-third octave band measurements. Compact disks were played using a portable CD player (Sony SL-S320; bass boosting network turned off), and the signal was sent to a Norsonic N110 unit. One-third octave band analysis yielded equivalent sound pressure levels (time average sound pressure levels) from 63 Hz to 20 kHz. C- weighed equivalent sums of the spectra were calculated simultaneously. This standard acoustics instrumentation is commercially available for about US$5000. It may also be done using a personal computer with a CD-ROM, a sound card, and a spectrum analyzing program capable of performing one-third octave (or finer) band analysis. Matrices of data from the N110 analyzer were copied to a spreadsheet for further analysis.

This method is in principle the same used by Gabrielsson and Jansson [5]. They did their recordings in a reverberation chamber, thus reducing the effect of directivity from the instruments. Similarly, the recordings studied here were made in a recording studio with acoustical wall elements probably making the sound quite diffuse in the frequency region of interest for violin (above about 200 Hz). Gabrielsson and Jansson instructed the player to play each note in a complete scale as loudly as possible, whereas here the "excitation" is normal playing of musical pieces. It is important that the recording conditions of the Bein and Fushi CD are very similar, if not identical, for all instruments. One-third octave band analysis of recordings by soloists playing the same piece has also been done by W. Lottermoser [6].

SOME PHILOSOPHY ON THE METHOD

Researchers in acoustics use specific instruments and methods to simplify the complex spectra of music. For example, sound insulation and impact levels of building elements and reverberation times in auditoria are often measured in one-third octave bands. It gives good frequency resolution for the experienced sound field, and this octave band encompasses much of the "critical bands of hearing", the natural spectral bands of our ears. However, measuring time-average spectra has its limitations. Information on highly harmonic string sounds, temporal changes like string bow attack and decay, vibrato, and dynamic changes in the music are averaged out. Also, the changing timbre from playing different strings and positions is smeared out and thus buried in the average spectrum. All of these are attributes we would need to hear to recognize the sound as coming from a violin.

The strength of the method is, however, simplification reflecting the ear's sensitivity to loudness in different frequency bands. The bands are sufficiently detailed to give important gross scale information on the vibrating and radiating structure of the source. A trained acoustician will be able to tell much, but not all, from seeing time-averaged one-third octave band spectra and combining it with knowledge about the source. We may therefore expect to describe the *overall timbre* and *loudness* of the violin by measuring the played sound from the violin by using time-averaged one-third octave band sound spectrum levels. A calibration signal on the recordings (usually 94 dB @ 1 kHz), is however missing. The presented sound pressure levels are therefore some 15-20 dB lower than what is expected to be normal at the microphone position.

ON THE VIOLINS AND THE RECORDINGS

Thirty famous Cremonese instruments (Table 1) are played by Elmar Oliveira, a well known soloist. Oliveira plays two of the instruments (no. 5 and 26) on a regular basis.

Two music sequences are used:

1. Jean Sibelius, excerpt from Movement 1, Violin Concerto in D Minor, Opus 47, is played on each of the 30 instruments (duration: 1 minute).
2. Fifteen different pieces are each played on a Stradivari and a del Gesù. Eight of the pieces are with accompanying piano (duration: 1-10 minutes). The composers are Bach, Kreisler, Bloch, Martinon, Paganini, Ysaye, Brahms, and Vitali.

RESULTS

Weighed Equivalent Sound Pressure Levels

The simplest filtering of the recorded data is the time-average weighed sound levels ($L_{C,eq}$) from each instrument (Figure 1). The values are weighted using a C-filter, which represents the ear's higher sensitivity for low-frequency sound when levels are higher than about 85 dB. Figure 1 shows the overall loudness of each instrument. Levels vary from about 62 to 68.7 dBC. Such a variation is experienced as a little under a doubling of the subjectively experienced sound level, which is a quite significant. However, both groups of instruments (Stradivari and del Gesú) give a mean sound level of 66 dBC. More detailed information of the sound spectra is required to analyze the timbre.

One-third Octave Band Spectra

Figure 2 shows spectra from the same musical piece on all 30 instruments. Only the bands that are expected to be interesting for a violin are shown; from 200 Hz to 10 kHz. We see that the width of the loudness is about 7 dB at the 250 and 315 Hz bands and about 10 dB over the rest of the spectrum. The curves also show some global similarities, which are difficult to attribute to either the music piece or the instruments.

Table 1. Violins studied using sound spectra analysis (from [4]).

No.	Maker	Date	Name
1	Antonio Stradivari	1679	*Hellier*
2	Guarneri del Gesú	1742	*Wieniawski*
3	Antonio Stradivari	1690	*Auer*
4	Guarneri del Gesú	1742	*Sloan*
5	Antonio Stradivari	1692	*Oliveira*
6	Guarneri del Gesú	1737	*King Joseph*
7	Antonio Stradivari	1701	*Dushkin*
8	Guarneri del Gesú	1735	*Sennhauser*
9	Antonio Stradivari	1707	*La Cathédralè*
10	Guarneri del Gesú	1720	*Kartman*
11	Antonio Stradivari	1708	*Ruby*
12	Guarneri del Gesú	1737	*Stern, Panette*
13	Antonio Stradivari	1710	*Vieuxtemps, Hauser*
14	Guarneri del Gesú	1740	*Ysaÿe*
15	Antonio Stradivari	1709	*King Maximilian*
16	Guarneri del Gesú	1734	*Le Violon du Diablè*
17	Antonio Stradivari	1715	*Baron Knoop*
18	Guarneri del Gesú	1735	*Plowden*
19	Antonio Stradivari	1722	*Jupiter*
20	Guarneri del Gesú	1744	*Ole Bull*
21	Antonio Stradivari	1723	*Kiesewetter*
22	Guarneri del Gesú	1734	*Haddock*
23	Antonio Stradivari	1727	*Dupont*
24	Guarneri del Gesú	1739	*Kortschak*
25	Antonio Stradivari	1734	*Willemotte*
26	Guarneri del Gesú	1726	*Stretton*
27	Antonio Stradivari	1736	*Muntz*
28	Guarneri del Gesú	1738	*Kemp*
29	Omobono Stradivari	1737	*Rawlings*
30	Guarneri del Gesú	1735	*D'Egville*

Figure 1. C-weighed 1 minute equivalent sound pressure levels from same music piece played on each of 30 Cremonese instruments [4]. C-weighing represent about the ear's loudness spectrum sensitivity at high sound pressure levels (> 85 dB).

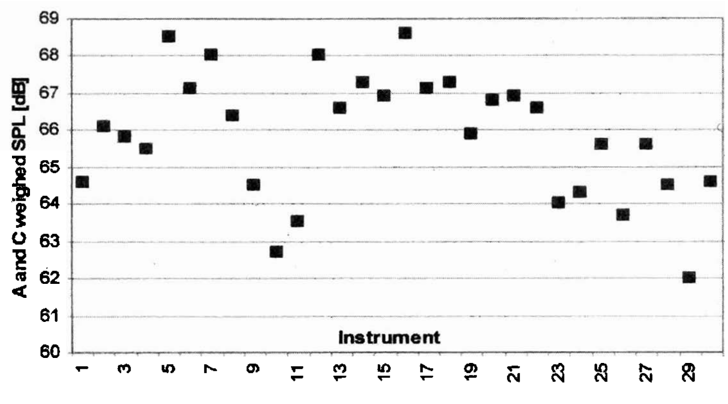


Figure 3 shows the spectrum from the 15 different pieces each played on a Stradivari and a del Gesú. We see a wider band at low frequencies, the 200 Hz and 250Hz bands. The higher levels here are from pieces with piano accompaniment. We also see similarities with the curves in Figure 2. The falloff starts at 4 kHz; there is a peak at 2.5 kHz, a valley at the 1.6 kHz band, a peak around 1 kHz, and finally a peak at 315 Hz.

Average Spectra of the One-third Octave Band Levels

To smooth out the picture we may look at the average responses of each instrument group (Figure 4). We see the similarities as mentioned above more clearly. We also see a difference between the two series around 500 Hz where the one-piece series show a valley while the 15-piece series show a peak. We expect the 500 Hz band, which has its –3 dB levels at 440 Hz and 565 Hz respectively, to contain the important C3 resonance, typically found around 550 Hz. This resonance is usually high in good instruments [1,2], but there is also typically a deep valley between the T1 (around 430-480 Hz) and the C3 resonance (around 520-560 Hz) often found around 500 Hz [1,2].

When we look closer at the musical tones that are played in the Sibelius violin concert excerpt, there are only a few fundamentals or harmonics played in that band (A#4, B4, C5 or C#5). The first harmonic in the string signal gives a 6 dB reduction in force level compared to the fundamental [1]. Also, the musical tones there are probably played quite weakly. This explains why there is a valley at the 500 Hz one-third octave band from the Sibelius excerpt in Figure 4.

The average curves for the Strads and del Gesús look quite similar, although there seems to be a systematic difference. The microphone is probably closer in the one-piece run, giving higher recorded levels for that series. Anyhow, black lines tend to lie at the same side of the gray line in each band as seen in Figure 4.

Differences Between the Average Spectra

Figure 5 shows the difference between the average curves shown in Figure 4. The curves show similarities indicating that there is a contribution from the frequency response of the instruments in spite of different played music pieces. The average Stradivari is likely to have higher sound levels in the bands 200 Hz, 250 Hz and above 1.6 kHz. The average del Gesú is likely to have higher sound levels in the bands from 315 Hz to 1.25 kHz. The likelihood of the bands 800 Hz, 2 kHz, 2.5 kHz and 4 kHz being different is somewhat less than the others as one of the curves are crossing the 0dB line in these bands. The differences are still quite small. Two imaginary instruments with the average responses as shown in figure 4 would sound very similar, and differences of about half a decibel should be barely audible.

Figures 2 and 3 show that the widths of levels are about 7-10 dB, indicating the level of differences between individual instruments.

Figure 2. One-third octave band spectra of 1 min excerpt of Sibelius D Minor concert played on 30 Cremonese instruments [4].

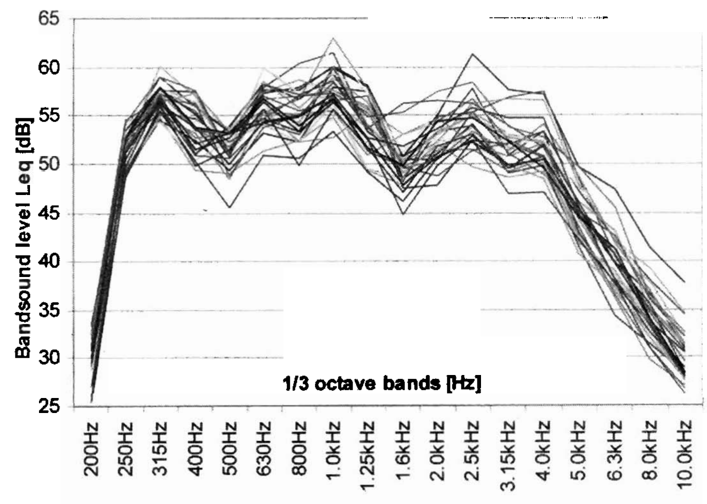
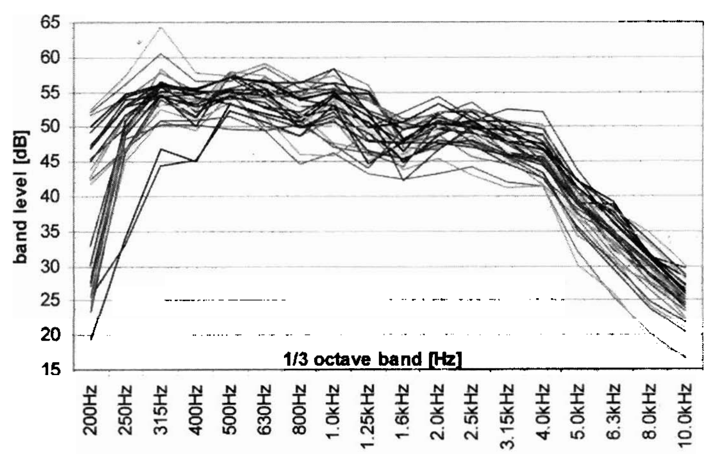


Figure 3. One-third octave band spectra of 15 musical pieces each played on a violin by Stradivari and Guarneri del Gesú [4].



The difference between our imaginary average Stradivari and average del Gesú is less than ± 2 dB. It is thus not unlikely that distinct Strads and del Gesús may have larger differences between them than the difference response curve in Figure 5.

A representation of the natural variation may be seen in Figure 6 where the standard deviation for each band is shown as error bars on the curve. All these variation bars cut the 0 dB level. Statistically, about 63% of the differences between these instruments will have their difference curve lying within the error bars. Using 2 standard deviations would include about 95% of all instruments. Then the width of the error bars would be from 4 dB at the 250 Hz band to about 12 dB at the 1.25 Hz band.

Figure 4. Average responses of the violins. Thin lines are from recordings of the same music piece, thick lines from 15 musical pieces each played on a violin by Stradivari and Guarneri del Gesú [4]. Black lines are mean values of Stradivari and grey lines are mean values of Guarneri del Gesús.

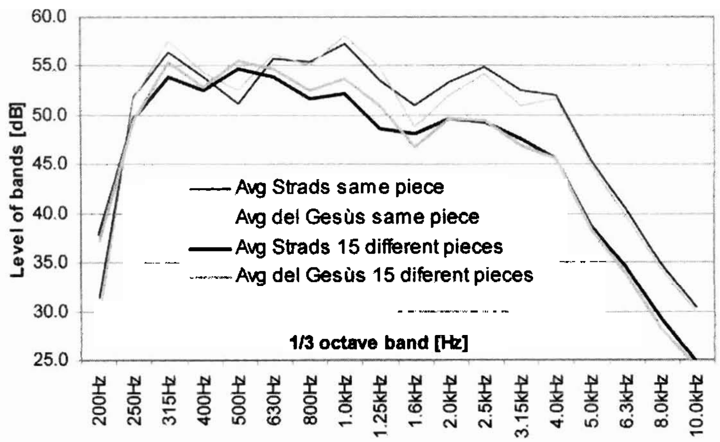
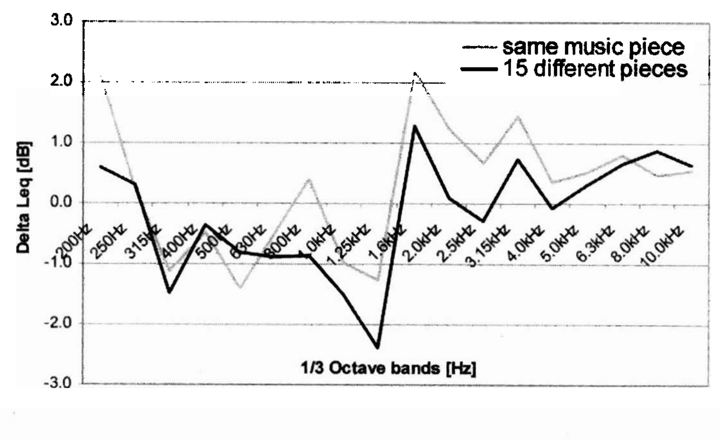


Figure 5. Difference between mean levels of violins by Stradivari and Guarneri del Gesú [4].



The error bars for the series with the same played piece is shown in Figure 7. They are a bit wider than those shown in figure 6, probably because the series with 15 different musical pieces are longer in time thus increasing the measurement precision. Figure 7 confirms the analysis as made for Figure 6. Comparing a Stradivari and a del Gesú may give a different result than comparing the average of all Stradivaris and del Gesús. But the average curve will still be the best guess for a difference between these instrument groups.

DISCUSSION

The variation between the 30 instruments is about 7-10 dB. Such a variation is clearly audible although the curves and, with few exceptions, look quite similar in shape, indicating similar timbre. On a recording the loudness of the instrument does not matter because we may turn up the volume if we like more sound. However, for a player and a listener in a concert hall, 7-10 dB represents a huge difference. If this variation is representative for such good old violins, we may ask, "what are the causes for such variations?" And is the result representative for the violin in general?

Figure 6. Difference between mean levels of violins by Stradivari and Guarneri del Gesú (error bars show ± 1 standard deviation for each band; 63% of spectra differences between instruments is likely to be found within these error bars. Increasing to ± 2 standard deviations for each band would include 95% of all instruments).

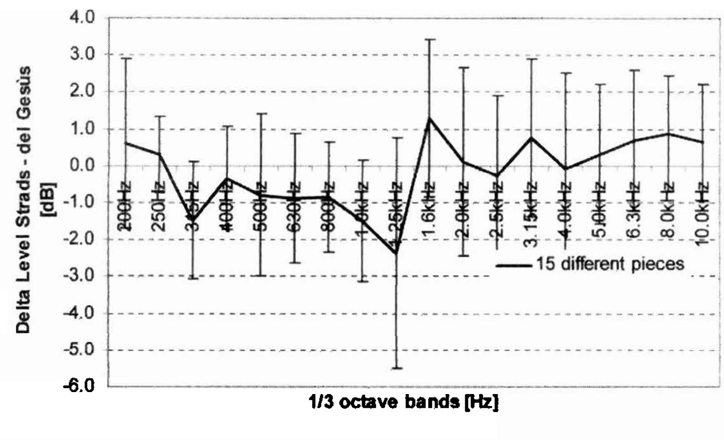
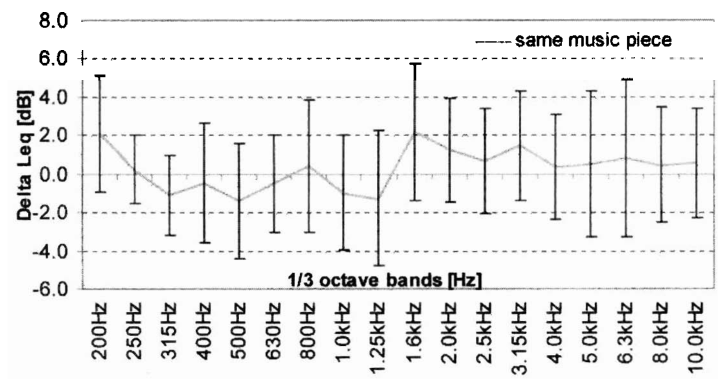


Figure 7. Difference between mean levels of violins by Stradivari and Guarneri del Gesú (error bars show ± 1 standard deviation for each band; 63% of spectra differences between instruments is likely to be found within these error bars. From series with same piece on all instruments).



It is puzzling to see that the curves are not higher in the so called "body hill region" around 2.5-3.15 kHz than for the other more resonant regions [1]. These instruments may sound more pleasant to the musician's ears than the more typical modern violin, which often has higher levels in the 2.5-3.15 kHz range.

The difference between the average Stradivari and del Gesú in the experimental set seem to be independent of the played music. One may again ask for the reasons for the systematic dissimilarities? What construction details contribute to such characteristics? Possible candidates for the causes of the variances and differences include string composition and weight, bridge weight and resonant characteristics, wood density, elastic parameters and damping characteristics of the wood, plate thickness, arching, sound post and bridge position, varnish, moisture content in the air and wood, size and shape of the radiating structure, the vibrating shape and phase of the resonances in the instrument, room configuration, measurement equipment, the player, and the method of holding for playing.

"There seem to be systematic differences between the average Stradivari and del Gesú"

The difference in timbre does not seem to be explained by variability in strings. In photos of each of the recorded violins [4], 28 of them are mounted with Dominant strings (based on winding colors; green is "stark", violet is "medium" and yellow is "weich"). Four Strads are mounted with stark, 10 with medium, and none with weich G, D and A strings (or only G and D). For Guarneris, three are mounted with stark, 10 with medium, and none with weich. The King Joseph has a stark G-string, and the Ole Bull has a stark G and D. Of course, it is questionable that the photos were taken at the same time that the recordings were made. Comparing the violins with stark strings to those without, we cannot see a similar trend to Figure 5. On the contrary two of the weaker sounding instruments in the recordings (the Kartman and the Ruby) have stark strings and two of the strongest violins, the Oliveira and Violon du Diable, have medium strings.

The player-violin system and its feedback loops are highly complex. General conclusions are the best we can hope for based on such limited data.

CONCLUSION

The one-third octave band spectra from Stradivari and del Gesú violins looks similar even when different music pieces are played on the instruments. However, there seem to be systematic differences between the average Stradivari and del Gesú responses varying from close to 0 dB in the 4 kHz band to 2 dB in the 200 Hz and 1.25 Hz bands and -2 dB in the 1.6 kHz band. Such differences are heard as a more dark sound in the del Gesús and a more brilliant sound and strong fundamentals of the lowest notes in the Strads. More work is needed to understand the causes of such variances and differences.

ACKNOWLEDGEMENTS

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