CAN WE HEAR THE GEOMETRICAL MEASURES OF A VIOLIN?

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ABSTRACT

A simplified version of Dünnwalds timbre parameters for Old Italian Violin Sound; L (bass), ACD-B (unnasality) and DE-F (clarity) are used to compare the sound of 15 Stradivarius and 15 Guarnerius del Gesú violins. The parameters was extracted from 1/12th octave band played long time average spectra obtained from a CD-recording with the same musical piece played on each of these fine violins.

A considerable spread in these parameters and the sound pressure levels were found in both groups of old violins. This spread is used for a direct correlation with the variation in thickness and other geometrical data of some 18 of these Golden age violins. In general, instruments with thinner plates and higher arc height have a statistical tendency of having higher values for L, ACD-B and DE-F and thus sound "more old Italian". But these have a tendency of sounding less loud. In particular the border and average thickness of the back plate is lower for violins with high L and ACD-B and the tops are generally thinner for violins with higher values of DE-F.

The development of timbre through Guarneri del Gesùs career is: towards less bass, more nasal, more clear and a stronger sound. Stradivari seems to have the opposite development through his longer career; Richer in bass, less nasal and slightly less loud with age. He seems to keep his brilliance through his career.

1. INTRODUCTION

This article deal with properties of the long time average spectra of recorded music played on violins by Stradivari and Guarneri del Gesù. I look at extracts from the violin spectra as used by Heinrich Dünnwald in his large study on several hundred violin timbre spectra [3, 4]. I briefly compare the two groups of old violins using Dünnwalds timbre parameters, look for any connection between each of these parameters, and between these parameters and the total sound level from the violins. I further look at how the timbre develop through Stradivarius and del Gesùs career, and finally correlate the timbre parameters and total sound levels with geometrical dimensions, arc height and thickness from some 18 of the studied violins.

A simple geometrical copy of a good old violin, including plate thickness, will probably only by accident sound similar to the original. But we know that if the wood of the copied violin is identical to the original, in addition to the exact copied geometry, the sound can be very close to similar [1,2].

Unfortunately there is not much information available on wood properties of old violins, and even less so coupled with the better known information, like plate thickness and overall geometry. Nevertheless we know that thicknesses of the vibrating plates are one of the important acoustical inputs. Makers know from experience that changing thickness of the top and back plates does influence the sound. A player will often be able to tell if the violin is thick, normal or thin, either from its sound or from its reaction to the bowing, or both.

The aim of this work has been:

- To gain experience on what the Dünnwald parameters, and thus Old Italian sound, means by listening to selected recordings with low and high values for each of the parameters as well as the equivalent sound pressure levels
- To look for any patterns in the spectrums and e.g. the production year of the makers as well as between the different timbre parameters and equivalent sound pressure levels.
- Investigate if any correlations between known physical measures from these violins and the parameters that describe Old Italian sound extracted from their long time average spectra can be found

1.1. Spectral commons to Old Italian violin sound

Dünnwald studied sound spectra from several hundred violins made by modern makers, amateurs, professionals, factory made, old Italian and other old masters [3, 4]. He apparently succeeded in finding parameters based on the measured violin spectra that separated the Old Italian, or other very good violins, from most of the modern violins. He claims that his parameters are independent of any preference for dark or brilliant sound [3].

Figure 1 show the frequency regions he used in his study calling them A, B, C, D, E and F. He also used a value, L, for the level of the first air resonance relative to the highest level (top) in the frequency region from 649 Hz to 1090 Hz. In more detail I interpret his parameters and timbre like this:

- **Bass:** $L\,[dB] = L_{max\,(244Hz\,-\,325Hz)} - L_{max\,(649Hz\,-\,1090Hz)}.$
- **Nasal:** $ACD\text{-}B\,[dB] = L_{eq(190\text{-}650Hz\,and\,1300Hz\text{-}2580Hz)} - L_{eq(650Hz\,-\,1300Hz)}.$
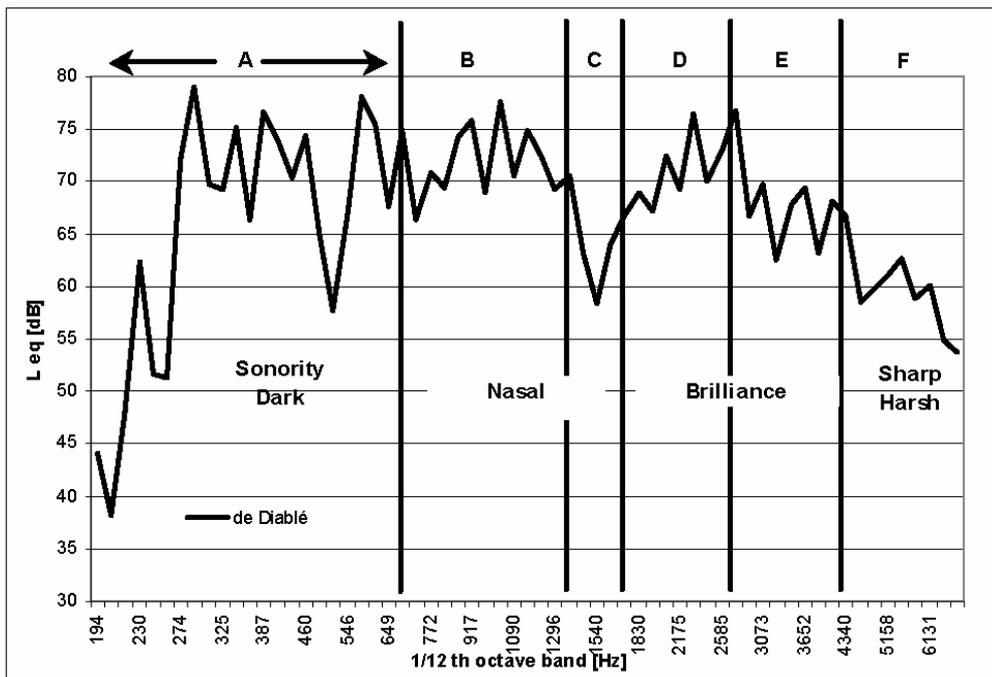- **Clarity:** $DE\text{-}F\,[dB] = L_{eq(1640Hz\,to\,4200Hz)} - L_{eq(4200Hz\,to\,6879Hz)}$

Figure 1. *Long time average spectrum of the Le Violon du Diablé, del Gesù violin. The frequency regions, A-E, for calculation of the Dünnwald parameters and common words describing violin timbre are shown.*

Dünnwald calculated the spectrum of every single played note from measured sine swept frequency responses of the violins (SPL vs. frequency). He calculated the parameters ACD-B and DE-F for every single tone and

used the Sone scale for his parameters [3, 4]. In this study the parameters are calculated directly from the time average sound pressure level spectra in $1/12^{th}$ octave bands using the dB scale. The spectra were obtained from CD recordings of played violins. This is an extension of earlier work on these recordings [5, 6]. Table 1 show his parameters and what they describe.

Table 1: *The Dünnwald parameters used in this study [4].*

Dünnwald	This study	Comment
L [dB]	Same	High values for good and bass rich violins.
ACD-B [Sone]	[dB]	High values for "not nasal" violins, low values in "nasal" violins.
DE-F [Sone]	[dB]	High values on "clear" violins, violins with low values are "harsh"

According to Dünnwald, Old Italian violins in general have high L, ACD-B and DE-F. Some 93 % of the tested Old Italian violins showed good values on all these parameters, but only 19 % of modern masters after 1800 met the criteria for a very good violin [3, 4].

2. METHOD

The long time average sound spectra were obtained from a CD recording. Elmar Oliveira plays an excerpt of a Sibelius concert on 15 violins made by Antonius Stradivari and 15 by Joseph Guerneri del Gesú on the Bein & Fushi recording "The Miracle Makers" [7]. These makers are generally regarded as the best violin makers. By very few exceptions, the best concert soloists play violins by either of these two makers. The spectra are analysed in $1/12^{th}$ octave bands each covering a single half note.

2.1. The used statistics

Correlations are investigated using tables and formulas in Excel. The correlation coefficient, R, is a measure for how close a set of data pairs follow a best fitted straight line through the data. If R is close to 0, then the xy-data points will look like a "cloud" or undefined "ball" of data with no patterns in it. If R is close to 1 or –1 the xy-data points will lie close to a line rising upwards toward right if R close to 1 or downward toward the right if R is close to –1.

Significance level, s-level or p-value, is a measure for how probable it is that I fail in my assumption that there is a correlation between x and y values in a data set. A significance level of 1% gives us a 99% chance of being right that there is a correlation between x and y. S significance level of 32 % gives us a 68% chance of being right.

A t-test is a statistical test used to compare two sets of y values (with the same x values) to determine if one set is larger or smaller than the other. If a t-test return a p-value (significance level) lower than 5% one may expect that there is a difference between the two data sets.

2.2. The instruments the data selection come from

Table 2 shows the violins and their makers as they are presented on the recording. The all have names after famous players that once has played them, well known owners or from the world of myths.

Table 2: *The analysed old violins. From "The Miracle Makers" [7].*

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

2.3. Visualisation of timbre – a clue to understanding the violin sound

I have earlier investigated the played sound spectra from these 30 Old Italian violins showing direct characteristic differences between them [5, 6]. Here I wish to convert characteristics of the spectra to single numbers. Figure 1 show the LTAS for one of the old violins with the frequency regions for calculation of timbre parameters shown in Table 1. Indicated in the figure are words commonly used for description of violin timbre and which frequency regions they are assumed to be more influenced by. In general high levels in the frequency region A is connected to what may be called "sonority" or dark sound. High values in the regions B and C relate to what Dünnwald interpret as a "nasal sound", D and E regions may be attributed to "brilliance" [3]. Finally high levels in the region F is related to the more negative descriptions; "sharp" or "harsh" sound [3, 9].

3. RESULTS

3.1. How does Stradivari and Guarneri del Gesù violins compare?

Figure 2 show the average calculated levels in each of the bands given in Figure 1 comparing the averages over the 15 del Gesus and the 15 Strads. The average del Gesú has a higher level in the sonority/darkness and nasality band while the Strads are stronger in the brilliance region. This is in agreement with our earlier findings using 1/3rd octave bands [5].
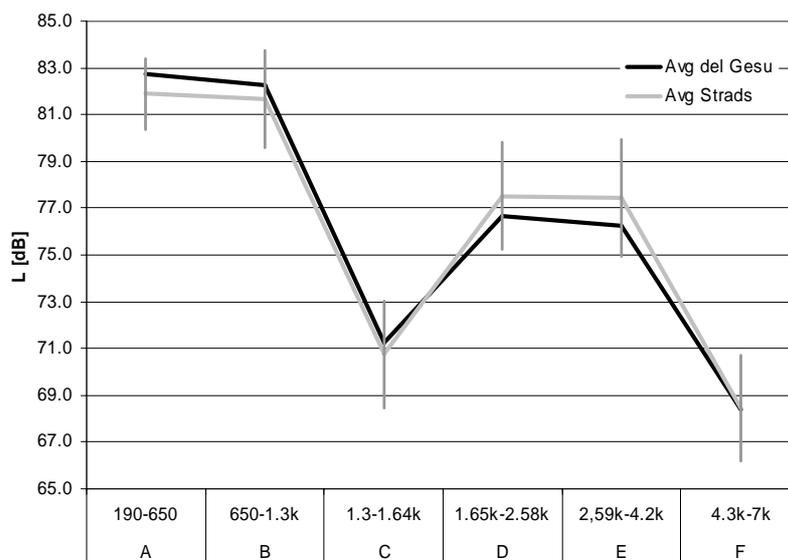

Figure 2. *Calculated levels of each Dünnwald frequency band for the average long time spectrum from 15 Strads and 15 del Gesús*

In Table 3 I show the calculated parameters given in Table 1 for each instrument group. In general the recordings of the del Gesus have slightly higher L and lower DE-F than the Strads.

Earlier studies of only the mechanical sound spectra, but also bowed spectra from violins, has shown that it is possible to predict the sound quality of violins solely from an analysis of $1/12^{th}$ octave bands (or bark bands) of the violin spectra [10,11].

Table 3: *Average timbre parameters for del Gesus, Strads and the modern violins.*

	del Gesùs (15)		Strads (15)		Difference
	Avg	**Stdev**	**Avg**	**Stdev**	**Strad – del Gesu**
L [dB]	-0.1	2.9	-0.9	2.9	-0.8
ACD-B [dB]	1.8	1.7	1.9	1.4	0.1
DE-F [dB]	11.2	2.3	*12.1*	1.2	*1.1*

3.2. Are there any connections between the timbre parameters and loudness?

First I would like to address if there are any connection between the timbre parameters and the total sound pressure level, SPL. Table 4 shows the correlation coefficients and calculated slope of the regression line between the parameters. The correlation may be interpreted as values coming from xy-plots of pairs of parameters as seen in Figure 4. The correlation coefficient, R, is the square root of the, R^2, that appears for the line examples in Figure 3 and 4. The average slope between the xy-pairs is given by the slope of the best fitted line through the data points. Please note that the data points may be quite well spread around the regression line, but still this best fitted line will give the trends (if any) in the data (with some caution for "outliers", single points that may destroy a signal (a regression) if it is positioned extreme compared to other points).
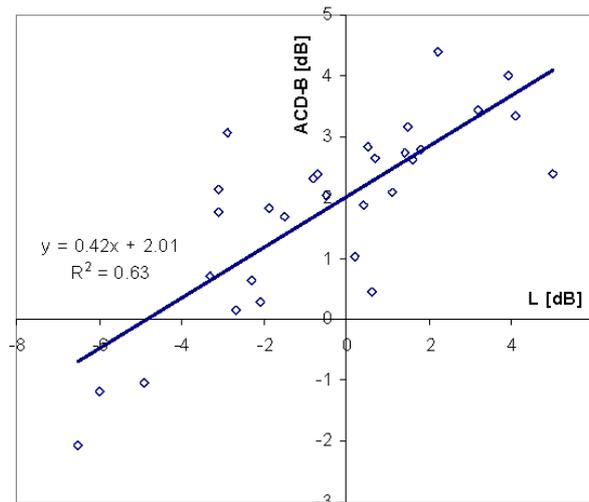

Figure 3. *A xy-plot between L and ACD-B for the violins. The correlation coefficient is R = 0.79 and the slope of the regression line is 0.42. This is an example of a highly significant correlation (s. level < 1%)*
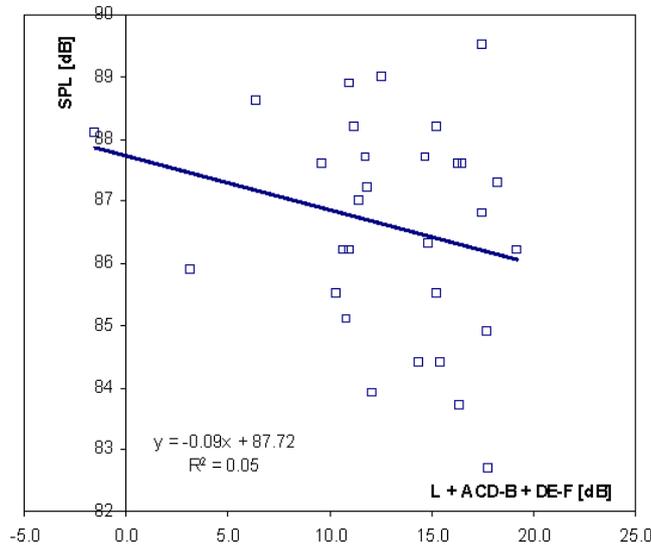

Figure 4. *A xy-plot between the timbre parameters summed (L + ACD-B + DE-F) and SPL. The correlation coefficient is R = 0.23 and the slope of the regression line is –0.09 dB/dB. This is an example of a not so significant, but interesting, correlation (s-level = 22%)*

I generally only present numbers for correlation coefficients and slopes for the convenience of the compressed information.

Table 4. *Correlation and slopes for the regression lines between timbre parameters and total sound pressure levels (SPL). Bold numbers are better than significant on the 5 % level, cursive are significant on the 22 % level, or better. The data are based on sound recordings from 30 old violins [7]*

Correlations between	L and			ACD-B and		DE-F and	Sum$_{L, ACD-B, DE-F}$ and
	ACD-B	**DE-F**	**SPL**	**DE-F**	**SPL**	**SPL**	**SPL**
Correlation coefficients	**0,79**	-0,05	*-0,33*	0,06	**-0,37**	*0,26*	*-0,23*
Slope of regression line dB/dB	**0,39**	-	*-0,20*	-	**-0,46**	*0,24*	*-0,12*

The low frequency parameter, L, and the un-nasality parameter ACD-B follow each other and are thus statistically dependent, see Figure 3. Violins with higher L (a strong Helmholz resonance in comparison to the frequency region 630Hz -1,1kHz) will also have a tendency of being "un-nasal". The slope for ACD-B/L is 0,4 dB/dB, ACD-B will in average increase about 0,4 dB for each dB increase in L. This agrees well with Dünnwalds original work where he found that the L parameter alone correlate highly with violin quality, only 34% of the violins he investigated passed this quality parameter [3].

The L and DE-F parameters seems to be independent, the same is true for the ACD-B (un-nasality) and the DE-F (clearness-harshness) parameter. This is promising, could it be that we can influence them independently?

However, there seem to be a dependency between the L and ACD-B timbre parameters and the total sound level (SPL) from the violins. Violins that have high L and ACD-B (a good timbre) have a weak, but significant, tendency of having a lower SPL (loudness). For each dB increase in L or ACD-B we will in average see a –0,2 or –0,46 dB decrease in SPL. Maximizing the sound output of a violin may be at the expense of a less good timbre. There is, however, a weak indication that the violins with higher DE-F have a tendency of sounding louder.

3.3. How does Stradivaris and del Gesùs timbre develop through their career?

The period after about 1700 is called "the Golden Period" of Stradivarius. There is also an idea among players that the later del Gesú violins are better than the earlier. The late del Gesú violins "the Ole Bull" and "the Cannon" are both rather heavily built violins. [12, 13]. Can we see a development in any of the timbre parameters with time?

Table 6 show the correlation between the timbre parameters and the production year of each of the two master makers, Guarnerius del Gesú and Stradivarius, see Table 2 for the violins and production year in this study [7].

Table 5. *Correlation coefficients and slopes between timbre parameters and production year.*
Bold numbers are significant on the 5 % level or better, the italic numbers are significant on the 25 %
level or better. The data is based on spectra obtained from [7].

	G del Gesú (n=15)		Stradivarius (n=15)		Change G. dG	Change Strads
	Correlation w prod year	Slope [dB/Year]	Correlation w prod year	Slope [dB/Year]	24 years [dB]	58 years [dB]
L	*-0.31*	*-0.15*	**0.52**	**0.09**	*-3.6*	**5.3**
ACD-B	*-0.28*	*-0.08*	**0.54**	**0.04**	*-1.9*	**2.3**
DE-F	*0.31*	*0.12*	0.09	-	*2.9*	-
SPL	**0.48**	**0.14**	*-0.41*	*-0.04*	**3.4**	*-2.3*

We see the most significant development for the Strads. They have a development towards less nasality (higher ACD-B) and more bass (higher L). The later Strads in the study also has a tendency of sounding less loud. This is basically the opposite development to the del Gesús witch has a tendency of sounding louder, more nasal and with less bass through the makers career. The later del Gesús also has a tendency of sounding more clear (higher DE-F) while the Strads seem to have no significant change of this parameter. The brilliance seem to be kept through Stradivaris long career.

The slopes are however rather small, from about – 0,04 to -0.15 dB/Year. The higher values are for the del Gesús. The production time span for Strads in the study are from 1679 to 1737, some 58 years. The del Gesús in the study span from 1720 to 1744, only 24 years. In Table 5 we see that the parameters in average change some 2-5 dB through the production years of the master makers. If we assume that a 1dB change in any parameter is just audible, we see that the changes over the careers are likely to be clearly audible, and in opposite directions for the two makers!

3.4. Detailed correlation analysis between timbre and geometrical measures

The geometrical data of some 18 of the instruments in Table 2 is known from the Biddulph book and some other sources [12, 13, 15]. I have been looking at thickness data of top and back plates, arc heights, body lengths, widths between- and lengths of f-holes and strings. Types of the strings (thickness) can be seen on pictures of the violins in the book following the Bein & Fushi recordings [7]. Normal string thickness are given the value 1 and "stark" the number 2. Table 7 and 8 show the maximum, average and minimum recorded values for the top and back plate parameters respectively.

Table 6. *Geometrical data from top plates of the violins [12, 14, 15].*

	Min h_t [mm]	Mh_t [mm]	$Maxh_t$ [mm]	MB_t [mm]	MIP_t [mm]	R-L h_t [mm]	Stdd. h_t [mm]	$Arch_t$ [mm]	BL_t [mm]	MUC_t [mm]	MC_t [mm]	MLC_t [mm]	ff-s [mm]	ff-l [mm]	ff-w [mm]
n	18	18	18	17	17	17	18	12	14	17	17	17	12	12	12
Max	2.4	2.9	4.4	3.0	2.8	0.23	0.7	17.4	358.8	2.8	2.9	2.8	42.5	82.6	75.0
Avg	**2.0**	**2.6**	**3.3**	**2.7**	**2.5**	**0.06**	**0.3**	**15.4**	**352.3**	**2.4**	**2.5**	**2.5**	**39.8**	**74.3**	**71.1**
Min	1.4	2.0	2.7	1.9	2.1	-0.19	0.1	12.5	349.0	2.0	2.2	2.1	38.0	71.0	67.3

Table 7. *Geometrical data from back plates of the violins and type of strings [12, 14, 15].*

	Min h_b [mm]	Mh_b [mm]	Max h_b [mm]	MB_b [mm]	MIP_b [mm]	R-L h_b [mm]	Stdd. h_b [mm]	$Arch_b$ [mm]	MUC_b [mm]	MC_b [mm]	MLC_b [mm]	$Mh_b - Mh_t$ [mm]	Arch-$Arch_b$ [mm]	G	D	A
N	17	17	17	17	17	17	17	12	17	17	17	17	12	27	27	27
Max	2.6	3.7	6.5	3.3	4.0	0.14	1.0	16.9	3.5	5.7	3.6	0.9	3.3	2	2	2
Avg	**2.2**	**3.1**	**4.9**	**2.8**	**3.3**	**-0.03**	**0.7**	**14.9**	**2.8**	**4.3**	**2.9**	**0.5**	**0.5**	**1.26**	**1.22**	**1.15**
Min	1.6	2.6	3.8	2.2	2.5	-0.24	0.4	13.5	2.1	3.2	2.5	0.0	-1.8	1	1	1

Figure 6 show where the border (B), upper centre (UC), centre (C), lower centre (LC) and inner part (IP = mean of UC,C and LC) of the plates are recorded. These are mean (M) values. Body length (BL), ff-width (ff-w), length (ff-l) and ff-spacing (ff-s) is also defined in Figure 6. Arc heights are recorded at the point of highest arching.
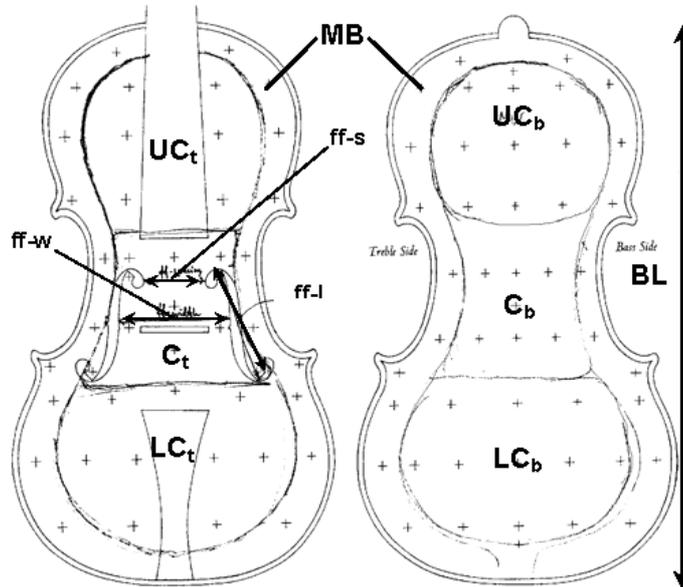

Figure 5. *The areas thicknesses are averaged over and geometrical dimensions selected for the correlation study.*

It is important to be aware that the different parts of violins are closely connected. If some part of a plate is thick, then the other parts of a plate is likely to be thick too (an example: 27 del Gesùs: Mean border thickness of top plates and centre of top plates correlation R=0.32 and p-value = 0.05). Thickness of top and back plates do correlate quite closely (27 del Geùs: R=0.62 p-value 0.001, 32 Strads: R=0.32, p-value 0.03). Thicker tops go with thicker backs, the slope is about 1mm thicker top per mm thicker back. The plates also tend to be thinner if they have higher archeight (27 del Gesùs R=-0.41, p-value = 0.03). These measures are thus not statistically independent. Interestingly these observations point to a sort of matching of the plates, also within each plate.

I will now present data from xy-plots between the raw data that Table 5 and 6 is based on, and the parameters: L, ACD-B, DE-F, and the total sound pressure level, SPL. Please be aware that I have included statistically

dependent measures in the study. This may lead to results showing greater, or smaller, influence from a geometrical measure than it really has. Nevertheless we may find important information using this simplified statistical method. The number of investigated measures are rather high (35) and I only present those that seem to give the highest influence.

Table 8. *Slope, correlation coefficients and significance levels for some geometrical measures that correlate with L.*

Influence on L (Bass) from:	Slope dB/mm	Correlation coeff.	Significance level
Mean h border back (MB_b)	- 7.3	**-0.75**	< 1 %
Mean h back – mean h top (Mh_b-Mh_t)	- 6.0	**-0.58**	1 %
"Strads harp"	-6.9	**-0.72**	2 %
Arc height top ($Arch_t$)	1.2	**0.48**	5 %
Right – left thickness top (L-R h_{top})	10.6	*0.37*	13 %

From Table 8 we see that the border thickness of the back and the archeight of the top seem to have a large influence on L. I also include an interesting observation that right – left thickness of the top also might influence L. (It seems to give a large influence when looking at the slope (10,6 dB/mm) but please be aware that the variation of the parameter L-R h_{top} is quite minute, only 0,4 mm). We find confirmation for the observation that thinning the back plate gives higher low frequency response in [16].
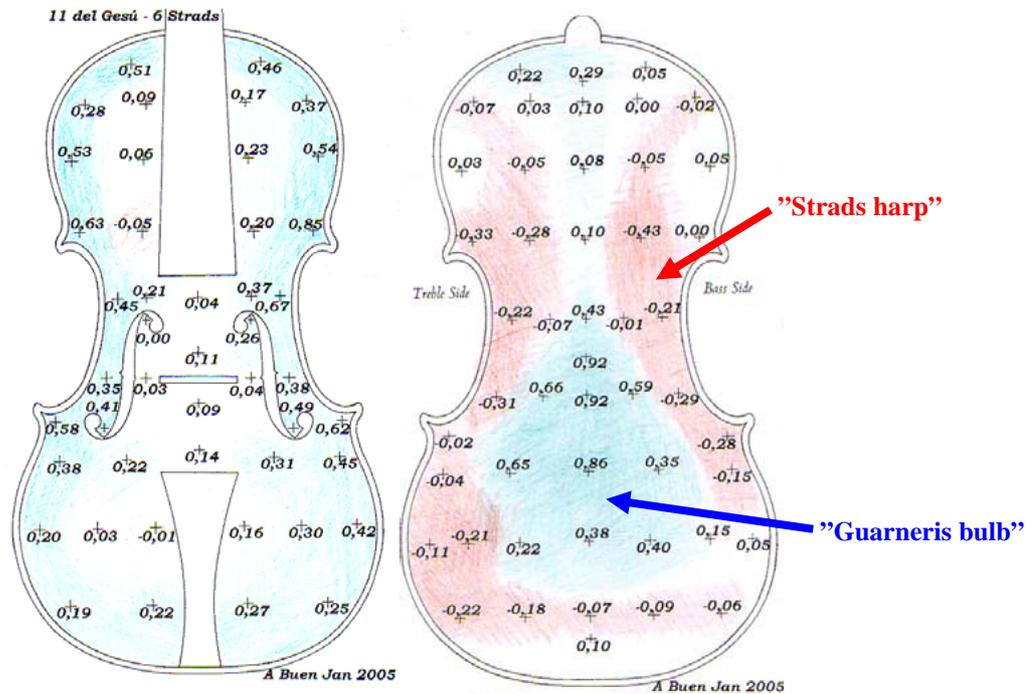

Figure 6: *The difference in thickness between the 11 del Gesús and 6 Strads in the study. Blue areas are in average thicker in the del Gesús, the red areas are in average thicker in the Strads. I call the red area for "Strads harp" and the thicker blue area in the back plate for "Guarneris bulb" Data from [12, 14 and 15]*

Table 9: *Slope, correlation coefficients and significance levels for some geometrical measures that correlate with ACD-B.*

Influence on ACD-B (un-nasality) from:	Slope dB/mm	Correlation coeff.	Significance level
Mean h border back (MB_b)	- 3.5	**-0.65**	< 1 %
"Strads harp"	- 3.2	**-0.62**	< 1 %
Mean h back (Mh_b)	- 3.3	**-0.60**	1 %
Arc height top ($Arch_t$)	0.8	**0.58**	2 %
Mean h lower centre top (MLC_t)	- 4.7	*-0.44*	6 %
Mean centre top (MC_t)	-3.9	*-0.41*	9 %

From table 9 we see the same influence from mean border thickness and archeight on ACD-B as on L, but there is a more general influence from the back plate. The thinner back the less nasal the instrument will sound. There is also an interesting correlation with the centre and lower centre thickness of the top. Thinner plates here also seem to appear in violins with a less nasal sound. Meinel found increase in the frequency response around 450 Hz after thinning the back plate in the left side of the C-bout area [17].

Table 10: *Slope, correlation coefficients and significance levels for some geometrical measures that correlate with DE-F.*

Influence on DE-F (clarity) from:	Slope dB/mm	Correlation coeff.	Significance level
ff-length (ff-l)	0.4	**0.48**	5 %
Mean h back – mean h top (Mh_b-Mh_t)	3.4	*0.46*	6 %
Arc height top ($Arch_t$)	0.8	*0.45*	7 %
Mean h top (Mh_t)	-4.0	*-0.42*	8 %
Mean h border top (MB_t)	-2.9	*-0.42*	8 %
Mean h inner part top (MIP_t)	-4.5	*-0.39*	11 %

Table 10 shows that the correlations are weaker than for the other paramers, but we may say that DE-F mainly seems to be influenced by the top plate thickness and arc height. The ff-length statistics is influenced by the long ff-holes on the "Ole Bull" del Gesú which has a high DE-F level. If I remove this instrument, the correlation disappears (signal is lost in "noise" from other parameters with higher influence). I still present the result as Saunders found that longer f holes are a little better, and does give a bit more high frequency sound [18].

The results here indicate that thinner borders of the top plates appear in somewhat clearer violins. An influence from the border thickness on the violin spectrum is also in agreement with the findings of Saunders [18]. Jansson, Niewczyk and Frydén also found a large influence from the cutting of the upper part of the ff-holes and from off centre thinning of the top plate [19].

In general thinner top plates appear in more clear violins. Thinner tops, especially along the border, might be an explanation why the Strads in average have higher DE-F values than the average del Gesú. But there might be other reasons like e.g. a harder type of wood in the Strads. Further investigation is needed here.

In general I can say that violins with high values for L, ACD-B and DE-F have a tendency of having thinner plates.

Table 11: *Slope, correlation coefficients and significance levels for some geometrical measures that correlate with SPL.*

Influence on SPL (loudness) from:	Slope dB/mm	Correlation coeff.	Significance level
Mean lower centre top (MLC_t)	7.3	**0.70**	< 1 %
Mean h top (MH_t)	3.9	**0.46**	5 %
"Guarneris bulb" in back	1.4	*0.46*	6 %
Mean centre back (MC_b)	1.3	*0.45*	7 %
Mean h inner part top (MIP_t)	4.6	*0.46*	7 %
Mean h centre top (MC_t)	3.9	*0.42*	8 %

In table 11 we see that the influence generally is opposite to the timbre parameters. Thicker top and centre- and lower centre of the back plate appear in the louder of the violins. The opposite behaviour (thinner plates - better timbre, but lower SPL) confirms our findings in Table 5 that higher values of the good timbre parameters is more likely to appear in violins with lower SPL.

The acoustics behind this observation could be that thicker plates give more efficient sound radiation, and that the gain in radiation more than outweighs the loss in admittance a greater surface mass and stiffness will give. However, results by Bissinger indicate that this may only be true at higher frequencies, around the critical frequency (3 – 4 kHz) [20]. Another, rather speculative, explanation may be that a violinist will tend to play louder on a thicker violin as it will withstand a harder bowing technique. Thin violins tend to be played more softly to sound good. A third explanation is that thicker instruments tend to get relatively high sound levels in the B region. In Figure 1 we see that this region tend to have the highest SPL, and even more so when the plates are thick and the L becomes lower. The tones around the first air resonance will then no longer be the loudest. Meinels results also indicate that bad violins may sound loud especially in the nasal region [17]. This should be studied further.

It is interesting to note that the regions of higher influence for loudness in the plates are those that influence the mode 2 frequencies of the top and back plates [21]. We may expect higher loudness for a higher mode 2 frequency, but it might be at the expense of a less good timbre.

4. DISCUSSION

It is important to be aware of that our data are rather limited in amount. I have data for only 17 (18) of the 30 violins given in table 2. It would have been very interesting to look at a larger data set where geometrical data, e.g. thickness, for all the 30 old violins were present. Will the found correlation between timbre parameters and plate thickness, arc height and ff-hole length survive an extension of the data set? Any information on the wood parameters would also be of high importance. The best way to find out is by trying.

However, our results give some preliminary answers to the stated questions. These may be given the status of being hypotheses that should be tested further.

5. CONCLUSIONS

Louder violins seem to sound less Italian. In general thinner violins tend to sound more like Old Italian violins, but the thinner violins in this study has a tendency of sounding less loud. There are however violins that both have high values of L, ACD-B and DE-F and also a high SPL. An example is "*the Violon du Diablé*" a violin with rather high score on any of these parameters.

The thicknesses of the back plate seem to influence the low frequency parameter, L and the nasality ACD-B more. In particular it seems as the border thickness of the back plate is very influential on the nasality and bass response. The thicknesses of the top plate seem to influence the high frequency parameter, DE-F more. The length of the ff-holes also seem to influence the DE-F, longer holes give higher values.

Higher arc height of the top plate (17,4 mm highest in study) appear with violins with high values on any of L, ACD-B and DE-F. Arc height does however not seem to influence the SPL of the violins. Jansson and Niewczyk studied violins with high arc height and found that they in general had equally good high frequency response, but not the strong C3 resonance (around 550Hz), as found in 25 other good instruments they studied [22, 23]. They did not report the archeights from the violins though, and most of the violins were German or Swedish, only one were Italian. Of the good violins were 17 Old Italian and one Old German.
I assume the archeights were higher than any in the present study.

A later extension of the statistical analysis using multiple regression indicate that the archeight might play a more significant role than only through the tendency of appearing with thinner plates. This should be studied further.

The above given results give a preliminary clue to the understanding of the sound difference between the average Strad and del Gesu. The thinner top plates of the 6 Strads in the correlation study seem to give the typical higher DE-F values. The thicker "strads harp" region (border thickness of the back plate) in the 6 Strads seem to give a lower L (bass) parameter, asymmetry of the top plates of the del Gesús may also contribute to this. The thicker lower centre of the top and back plate ("Guarneris bulb"), appear in violins with higher sound levels for the 11 del Gesús in the correlation study.

Stradivarius and del Gesú seem to have exactly the opposite development in the timbre through their career. The Strads grew less nasal, more bass, but keeps the brilliance through the 58 years (at least for the 15 violins in this study). Del Gesús violins grow more nasal, less bass, more brilliant and louder through the 24 production years in this study.

6. SUGGESTIONS FOR FURTER WORK

A way to test the hypotheses I have stated here is by doing tests during the making of new instruments. As we know that the data here come from a statistical number of violins, we would probably be best off by copying the geometry of the average Strad or del Gesú and start off the changes from the average thickness. We should of course use a wood assumed to be closest possible to the average old wood (low density and high stiffness?). A particularly promising hypothesis is that thinning along the border of the back plate will give more bass and less nasal sound. This could be done from the outside of the violin with strings on and moreover it does not seem to influence the SPL.

Any experiences from makers testing or that may already have tried anything of this, would be greatly appreciated if they shared their results. The author is also very interested in any geometry data, (or wood data, weights, sound speeds or anything), on any of the given instruments in Table 2 for a possible extension of the data set.

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