PERCEPTUAL EFFECTS OF VIOLIN ACOUSTICAL MODIFICATIONS

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Abstract

This study is the first step in the psychoacoustic exploration of perceptual differences between the sounds of different violins. A method was used which enabled the same performance to be replayed on different ``virtual violins", so that the relationships between acoustical characteristics of violins and perceived qualities could be explored. Recordings of real performances were made using a bridge-mounted force transducer, giving an accurate representation of the signal from the violin string. These were then placed through filters corresponding to the admittance curves of different violins. Initially, limits of listener performance in detecting changes in acoustical characteristics were characterized. These consisted in increases in amplitude of single modes or frequency bands that have been proposed previously to be significant in the perception of violin sound quality. Then, the linearity of the perceptual effect of each modification was tested. Finally, a model for predicting thresholds was developed and used to predict the effect on the thresholds of parameters like vibrato.

INTRODUCTION

There is an extensive literature on the acoustics of the violin, and an even more extensive literature on human perception of sounds in general, and of musical sounds in particular. However, there is virtually no published research on the combined problem of the human capability for perception, discrimination and judgment of the sounds of violins with particular measurable acoustical properties. This is a very significant gap, since perceptual judgments must define what makes a violin different from other bowed-string instruments, and one violin different from another.

The ultimate aim underlying the research presented here is to answer the typical question that a violin maker will ask: “What will happen to the sound if I change such-and-such a constructional detail?” This paper starts the process of attacking that broad aim with a more modest target: to establish the just-noticeable difference (JND) for certain particular acoustical changes to the frequency response of a violin, to check the linearity of the perceptual effect with the amount of change and to predict the effect of parameters like vibrato on these JNDs. The acoustical changes all relate to quantities previously proposed as significant to the sound quality of a violin. This initial investigation is of admittedly limited scope but is already of interest to instrument makers, telling them for example how far they need to move an individual low body resonance to have an audible effect.

There are two stages necessary to such a study: to relate a constructional change to an acoustical change, and to evaluate the perceptual effect of that acoustical change. There is already a significant literature concerned with the first stage [e.g. Cremer, 1985; Durup and Jansson, 2005]. The experiments reported here concentrate on the second stage, that of establishing quantitative links between acoustical parameters of the instrument body and the perceptions of a listener.

The methodology of the study relies on the large impedance jump between the strings and the bridge of the instrument. The player manipulates the string to vibrate in certain ways, the vibrating string applies a force to the bridge and the body vibrates in response to this force, radiating sound to the listener. To a first approximation, the body motion has little backward influence on the string motion. Representative force waveforms can thus be recorded using normal playing on a violin whose bridge is equipped with a piezoelectric force sensor under each string. These predetermined force functions can then be applied to different violins, so that sound differences can be compared with no complications arising from variations in playing.

Such a test could be carried out using different physical violins, applying the force at the bridge with a vibration shaker of some kind. However, for this study a different approach was taken. The frequency response function of the violin was mimicked using a digital filter, and the output signal for listening tests was generated by applying this filter to the recorded bridge force signal. Once the violin response is represented in digital filter form, it becomes very easy to make controlled variations of a kind which would be virtually impossible to achieve by physical changes to a violin.

STIMULI

Generation principle

In order to create the stimuli, we first recorded input signals (i.e. the force applied by the bowed strings on the bridge) during a live performance on a violin whose bridge was instrumented with a piezoelectric force sensor under each string. Second, we measured a suitable frequency response function for the two chosen violins (a modern instrument of good quality made by David Rubio, and a student-quality instrument used for comparison in the final stage of the work).

The choice of frequency response function raises some important technical issues discussed in [Fritz *et al.*, submitted]. We have chosen to work with the input admittance function of the violin: this is defined as the velocity response at the string position on the bridge to a force applied at the same point. This particular frequency response function governs the energy transfer from string to body, and it is the most appropriate structural response for the present purpose. The approach used here can be considered as being comparable to listening to a stationary violin from a fixed position in an unchanging room.

The measurement procedure for input admittance was standard [e.g. Jansson, 1997]: the bridge was excited with a miniature force hammer (PCB 086D80) at the G-string corner, and at the E-string corner velocity was measured using a laser-Doppler vibrometer (Polytec OFV056/OFV3001). This calibrated input admittance was then processed by modal identification techniques [e.g. Ewins, 2000], and resynthesised from the fitted parameters in the frequency range up to 7000 Hz, to allow parametric modification. To cover this range, 54 modes were needed for the Rubio violin. The frequency response could be modified by manipulating the modal parameters (amplitude, frequency and Q factor), and then used to construct FIR digital filters to obtain the "sound" of modified virtual violins. The filtering (i.e. the convolution of the input signal with the inverse Fourier transform of the frequency response of the violin in the time domain) was carried out using Matlab.

Acoustical modifications to be tested

Informal tests showed only a very slight perceptual influence of the Q factors of the major modes. Hence, it was decided to limit the study to measurements of thresholds for detecting increases in amplitude and of one or several modes of the original admittance function, as described below.

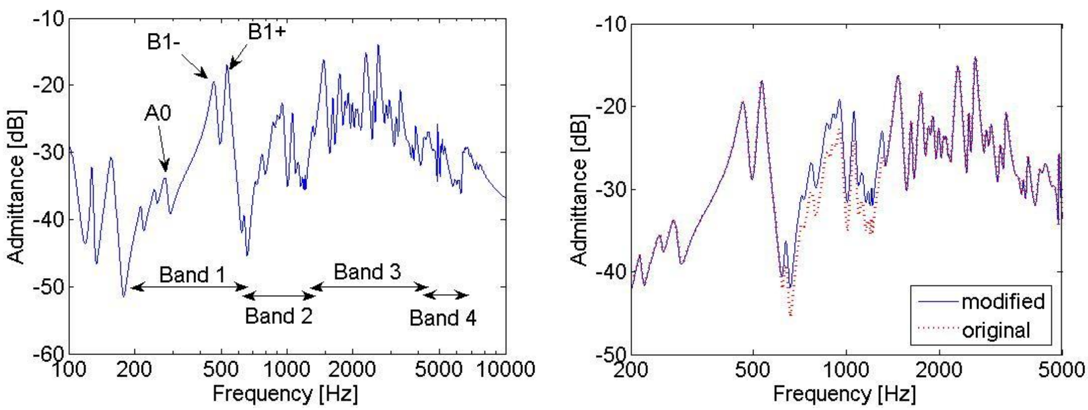

Figure 1: (a) The resynthesised admittance of the Rubio violin, indicating the modes and the Dünnwald bands which were modified;(b) An example of a shift in amplitude of all modes in Dünnwald band 2.

<u>Modes A0, B1- and B1+</u>

At low frequencies, the sound of a violin is dominated by three strongly radiating modes. Several authors have suggested that these modes are important for sound quality [e.g. Hutchins, 1962]. A0 is a modified Helmholtz resonance ("air mode"), which usually falls around 280 Hz. The two other modes are "plate modes" which arise primarily from the bending and stretching of the front and back plates: B1- is usually centered in the range 470-490 Hz and B1+ between 530-570 Hz. Collectively B1- and B1+ account for what early researchers on the violin called the "main body resonance".

In the admittance, the A0 mode has a very small amplitude compared to the other low modes, B1- and B1+. However, it plays a very significant role in the radiated sound. To represent this effect approximately, its amplitude was artificially increased by a factor of 5 (14 dB), so that its amplitude was similar to that of B1-, as observed in radiated sound measurement in far-field [e.g. Dünnwald, 1991].

The amplitude of each of these three modes was altered individually.

<u>All modes in each of the four Dünnwald bands</u>

Based on his measurement of the acoustical properties of a large range of violins that had previously been classified as of very good or moderate quality, Dünnwald [1991] proposed four frequency bands which he suggested were important for the judgment of sound quality: 190-650, 650-1300, 1300-4200 and 4200-6400 Hz. The first range includes the lower overtones and may be related to "richness", the second he associated with "nasality", the third with "brilliance" and the fourth with "clarity". We measured detection thresholds for a change in amplitude of all the modes within each of these bands. For a shift in amplitude, as a few modes were close to the boundary between two bands, it was decided, instead of using a rectangular passband, to apply a gain function with a flat top and sloping edges (half of a symmetric Hanning window, of total width equal to 100 Hz, outside the nominal range of the band).

Input signal

Since the purpose of the present tests was to establish the thresholds for discrimination of changes which are the lowest that can be achieved under optimal test conditions, it was decided to use two single notes for reasons explained in [Fritz *et al.*, 2006] and [Fritz *et al.*, submitted]. The choice of G3 at 196 Hz and E4 at 330 Hz results from the distribution of their harmonics. In particular, G4 has its second and third harmonics close to the centre frequencies of modes B1- and B1+, whereas E4 has no harmonics near these modes. We wished to assess whether this would lead to poorer discrimination of changes in B1- and B1+ when E4 was used.

Control of loudness

Large modifications of the modes, in particular of their amplitude, can lead to a change of loudness. To ensure that subjects would discriminate between the sounds on the basis of their spectral shape and not of their loudness, the overall level of each sound file was adjusted to keep the loudness level approximately constant at a value of 93 phons over the whole range of modifications (for more details, see [Fritz *et al.*, submitted]).

EXPERIMENTS

Experiment 1: perceptual thresholds

<u>Procedure</u>

Thresholds were estimated using a three-alternative forced-choice procedure. A three-down one-up adaptive tracking rule was used which estimated the 79 % correct point on the psychometric function [Levitt, 1971]. Three sounds — two the same (the reference violin sound), one different (the modified violin sound) — were played in a sequence, and the subject was asked to choose which one was different. In order to allow echoic memory to operate effectively [Darwin, 1972], the sounds and the inter-stimulus intervals were each 300 ms in duration. Subjects were given visual feedback during the experiment but did not get any practice or any training beforehand. The sounds were presented diotically via Sennheiser HD580 headphones, chosen because of their diffuse field response, in a relatively quiet environment. The sampling rate was 44100 Hz and the number of bits was 16.

Subjects

Three groups each of 18 subjects were selected according to their musical background. The first group had relatively little musical training (less than 6 years of formal training) and did not practice regularly: this group will be termed "non-musicians" in the following. The two other groups both had considerable musical training (more than 8 years of formal training) and practiced at least weekly. These last two groups were differentiated according to the instrument played: the violinists, viola players and cellists were in one group, and the remaining musicians in the other. Fifty subjects were between 18 and 40 years old, and the four others were between 50 and 60 years old. All subjects reported having normal hearing, although this was not checked. No systematic effect of age was observed in the results. Subjects were paid for their participation.

Experiment 2: linearity of the perceptual effect of a modification in amplitude

Procedure

We restricted the experiment to a modification in amplitude of all modes in each Dünnwald band. Knowing the thresholds for each band from Experiment 1, we designed 8 tests (2 notes, 4 bands) in which pairs of sounds were presented twice. Pairs were selected from a corpus of five sounds: a reference sound and four modified sounds, with an amount of modification equal to 1, 2, 3 or 4 times the respective threshold, where the threshold is expressed as the change in amplitude relative to the original amplitude.

Subjects

The subjects were 15 musicians, with more than 8 years of formal musical training and at least weekly music practice.

RESULTS

Thresholds

The threshold results for the two single notes G and E are summarized in Fig. 3. The x-axis represents the various conditions: amplitude modification of all modes of the *i*th Dünnwald band "Bd i" or of one single mode A0, B1- or B1+. The mean thresholds range from about 3 dB (musicians, band 3, note E) to over 10 dB (non-musicians, modification of A0, both notes).

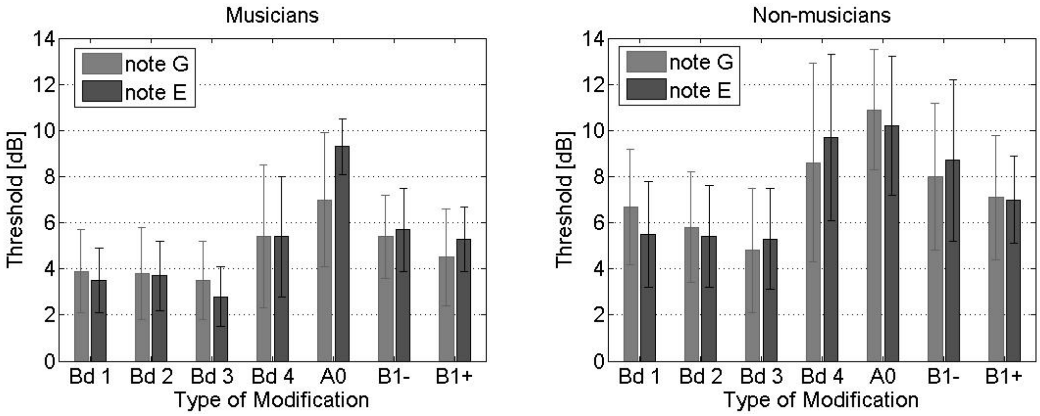

Figure 3. Mean thresholds for detecting a modification in amplitude, expressed in dB. The upper and lower panels show results for musicians and non-musicians, respectively. The type of modification is indicated by the label under each pair of bars. Light and dark bars show results for the notes G and E, respectively. Error bars represent ± one standard deviation across subjects for each category of subject.

Results are presented only for two categories of subjects, as initial analyses of variance (ANOVAs) did not show any significant difference between string players and other musicians, so the results for these two groups were combined. The average thresholds were calculated as the geometric mean since the standard deviation of the thresholds across subjects tended to increase with the mean value of the threshold.

Linearity

There was no statistically significant effect of band, the order of presentation of the sounds in a pair, or the note, so results were averaged across all four bands and across both notes. A one-dimensional scaling analysis based on the symmetric matrix of dissimilarity thus obtained gave the results shown in Fig. 4. The magnitude of the modification is expressed as the change in relative level in dB.

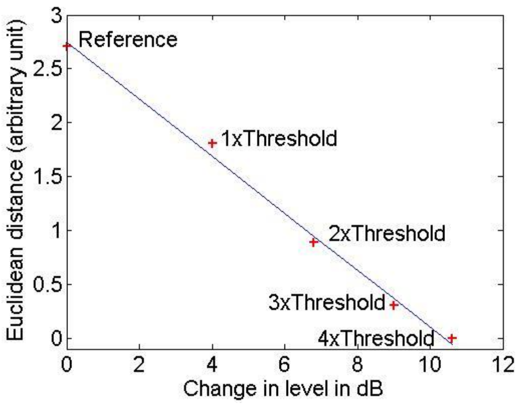

Figure 4. Euclidean distance between the five sounds of the corpus: the crosses result from the one-dimensional scaling; the solid line is a linear fit, with a coefficient of correlation r = –0.997.

So if the amount of modification is expressed as the change in level in dB, the perceptual effect of the modification is linear.

PREDICTIONS

In [Fritz *et al.*, submitted], predictions of threshold were made using three different models based on excitation patterns. The best performance was obtained using a multichannel model based on optimal combination of information across channels. As experiments like the one described above to obtain thresholds are long and tedious, and thresholds are "best" when short notes are used, perhaps because of limitations of echoic memory, it is interesting to use such a model to study the effect on the predicted thresholds of parameters like the choice of the note or the amount of vibrato in the input.

Purely synthesized inputs (sawtooths) were used instead of the two pre-recorded single notes G3 and E4. A diatonic scale from G3 to A4 was synthesized, with and without vibrato.

First, vibrato seems not to affect the predicted thresholds. It is necessary to check whether this is true in practice, as echoic memory may not work effectively for long notes, which are needed to hear the vibrato.

Secondly, as we are interested in obtaining thresholds for discrimination of changes which are the lowest that can be achieved under optimal test conditions, these predictions allowed us to find the optimal note for each modification, and these results are summarised in Table 1.

Modification	Optimal note	Predicted threshold in dB
Band 1	A3 (220 Hz)	1.9
Band 2	C4 (261 Hz)	2.9
Band 3	any	1.9
Band 4	B3 (247 Hz)	3.2
Mode A0	D4 (294 Hz)	3
Mode B1-	A3 or A4 (440 Hz)	3.8
Mode B1+	D4	3.6

Table 1. Notes which give the lowest predicted threshold for each modification.

CONCLUSIONS

The work described in this paper represents the first stage of a project to provide quantitative information about the discriminability of and perceptual preferences between violins. The eventual aim of the project is to make direct links between the perceptual results and parameters relevant to instrument makers: materials choices, constructional geometry and set-up details. The results will also inform efforts to improve the quality of computer-synthesized string sounds.

This initial study explored two aspects of violin acoustics which have received great prominence in the earlier literature as possible indicators of aspects of "quality": the three individual low-frequency modes of vibration (below 700 Hz), which dominate the sound of a violin and are usually labelled A0 (a modified Helmholtz resonance), B1- and B1+ (two strong "wood modes"); and a set of four frequency bands proposed by Dünnwald (190-650 Hz, 650-1300 Hz, 1300-4200 Hz and 4200-6400 Hz) on the basis of measurements of a large number of violins of varying quality. Tests were conducted to establish thresholds for the perception of a change in amplitude of each of the three modes separately and for blocks of modes lying in the four Dünnwald bands. Finally, a test was conducted to determine the linearity of the perceptual effect of such modifications.

Results were presented for two groups of listeners: with and without extensive musical training. As might have been anticipated, the musically trained listeners had consistently lower thresholds. For modifications of amplitude, the best thresholds were in the range 3-5 dB for individual modes and 1-3 dB for the Dünnwald bands. However, these thresholds could probably have been lowered by using different notes for each modification, as predicted by the model based on excitation patterns. The perceptual effect of such modifications is linear when the size of the modification is expressed as the change of level in dB.

There is strong anecdotal evidence that certain subtle differences between violins can be perceived by violinists, and have great importance to them. It is sufficient to note that the market values of superficially similar violins range over some four orders of magnitude: in round numbers, from about \$100 to \$1000000. The authors are conscious of the fact that the tests described here are based on sounds which are very unmusical — our short single notes are barely recognizable as violin sounds — and so the thresholds obtained here only tell part of the story of violin discrimination.

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