An Experimental Musician-Based Study on Playability and Responsiveness of Violins

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Abstract

While playing an instrument, musicians usually seek both pleasant sound and perfect control. Focussing on the control part of string instruments, the mechanical response of the body translates into bow-string interaction and therefore into perceived responsiveness. How much do body resonances feed back through the bridge and thus influence playability? Investigations employ a specifically designed silent violin in which demountable bars under the bridge represent various admittance functions. In contrast to other research on violins, the method used here does not only rely on technical analyses but also on observations on musicians' subjective perceptions. This work is part of a research project on desirable violin sound properties in which the investigated interaction between musicians and a parametric electronic violin must not be hindered by unfamiliar responsiveness.

1 Introduction

There has been a lot of research on the quality of violins, mainly focussing on reliable objective criteria. Usually, quite technical approaches have been employed to investigate an instrument's physical or sound properties. The research context here requires musicians to be involved in analyses. Analysed sounds are therefore the outcome not of musical instruments alone, but also of musicians' conscious or intuitive action to compensate for an instrument's individual properties. Musicians are part of a feedback-loop and measured results vary according to individual skills and experience. To monitor the output of an instrument the musician does not only rely on his sense of hearing. Apart from the acoustical feedback an instrument also provides haptic feedback (Figure 1). Primarily, it is the bow-string interaction which offers important vibrotactile information. This information makes it easier for a player to adjust bow pressure or velocity, for example [1], [2].

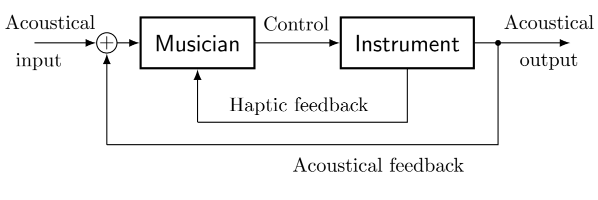

Figure 1: Feedback-loop between musician and instrument.

Musicians normally use terms such as playability and responsiveness to describe whether it is easy to play an instrument or not, i.e. whether an instrument facilitates technical skills and interpretative nuances or not. An important factor in the context of playability and thus of bow-string interaction, is the character of the violin body. For example, the minimum bow force that is required to produce steady string oscillation increases if the fundamental frequency is coupled with a distinctive body resonance [1], [2], [3]. Such a coupling often results in unstable oscillations. In extreme cases it will lead either to the well known wolf tone or to the flattening effect, which is a pitch decrease [4]. Anyway, a steady sawtooth motion, a so-called Helmholtz motion ([5], [6]), is replaced by a more indeterminate motion in which more noisy parts contribute to the sound. Musicians perceive a diminishing responsiveness when an increased bow pressure is required to produce a steady Helmholtz motion [7]. The opposite situation, where no body resonances influence the process is likewise problematic [2]. In case of silent violins, i.e. violins without a body, the string energy is not absorbed, so the playability is getting unfamiliarly easy. This again means less vibrotactile information about the contact between string and bow and thus little control for the musician.

This investigation is part of a research project, where musicians will explore desirable sound properties on violins. For this interactive investigation musicians will use a silent violin with a modifiable virtual body. During this development it became obvious that an unfamiliar haptic feedback is an enormous obstacle to such interactive sound evaluation. Two questions arise, (i) will this difficulty be likewise experienced by a majority of musicians, and if so (ii) to what extent will musicians sense even minor differences of resonance profiles behind the bow-string interaction.

2 Method

In order to investigate the relevance of an unfamiliar responsiveness, musicians were asked to compare the playability of a silent violin (SV) with the playability of their private violins. In addition, a specifically designed violin (VA) provides three different modes of body resonance profiles (Section 3). While the mechanical resonance profile can be changed within minutes, the outer appearance of this instrument is not changed. Experienced musicians were asked to play on different setups of resonances during one session. Afterwards they were asked to write down their impressions along a questionnaire. In order to compare the musicians' subjective findings with an objective technical analysis, the string oscillations were recorded.

3 Instrument Setup

Violin SV differs from commonly known silent violins and features a body, which is completely filled with polyurethane foam. The string oscillations can be recorded via piezo transducers in the bridge. This violin will be benchmarked against the private violins of musicians.

Violin VA differs from a common instrument in several aspects (Figure 2): (i) The bridge feet don't stand on the top plate but on two exchangeable aluminium bars with angle profile. These easily demountable 'resonance bars' are supported on the upper and lower blocks within the violin. For this investigation three different setups of resonances, VA1, VA2 and VA3 have been designed. (ii) The violin body is filled with polyurethane foam to dampen the violin's own body resonances. The bar area is kept clear from the polyurethane filling. (iii) The top of the bridge is instrumented with piezoelectric force sensors for recordings of string oscillations which are directly routed to an impedance converter inside the body.

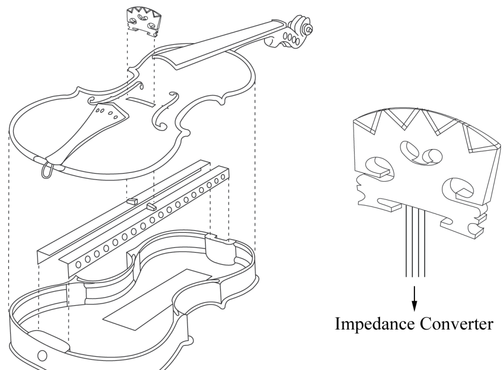

Figure 2: Schematic representation of the modified violin.

Figure 3 shows the frequency related admittance curves of Violin A, Violin SV and of two differently priced violins, serving as rough reference. The admittance functions were measured by exciting the instruments with an impulse and recording the bridge motion with an accelerometer fixed on the side of the bridge. Afterwards the transfer function was calculated.

The frequency range below 1 kHz significantly influences the attenuation factor of the fundamental frequencies and is therefore important for playability. In this range, the resonance behaviour of SV, VA1, VA2, and VA3 differs from the resonance behaviour of common violins in a few aspects: In Violin SV the prominent resonance valley which normally occurs around 700 Hz does not exist. Instead, there is a distinctive broad resonance which is related to the modified plate modes due to the filled body. Apart from this resonance the admittance function of SV does not show any distinctive peaks.

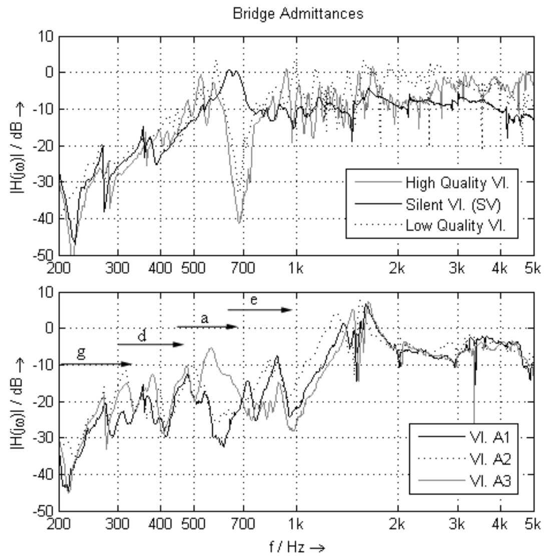

Figure 3: Bridge admittances of the Violin SV and two diffenrently priced violins (above) and bridge admittances of the Violins VA1, VA2, VA3 (below).

The admittance curves of VA1, VA2 and VA3 show a more varying run in the area of fundamental frequencies. In contrast to normal violins, the resonance curve of violin VA is roughly 10dB lower in the range of the first body resonances (about 440 - 580 Hz). The 'main wood resonance' of VA3 for example is shifted upwards by about one minor third. It replaces the prominent resonance valley which normally occurs in this area. Above 1 kHz all three setups show almost the same admittance behaviour.

4 Test Procedure

The ten musicians participating in this experiment had an average age of thirty years and an average playing experience of twenty-four years. They all pointed out to regularly play their violins and they all were remunerated for their effort.

The musicians were instructed to play a rising chromatic scale on all instruments without vibrato. The chromatic scale was played three times on each instrument, first with long continuous up- and down-strokes, afterwards staccato played in the middle of the bow and then tremolo played in the upper half of the bow. Finally the musicians were asked to play a piece of their own choice. After each scale they had to classify the playability on a scale from 1 (poor playability) to 6 (excellent playability) for each string separately. Furthermore they were encouraged to write down their individual impressions.

In order to draw the musicians' attention away from the acoustical feedback towards the haptic feedback they were given ear plugs with a damping of -30 dB. Nevertheless, the players obtained enough sound information for correct intonation. They were given the explicit instruction to concentrate on bow-string interaction.

5 Results and Analysis

Musician Questionnaire

Figure 4 shows how musicians rated playability, for each string and bowing technique separately. The grading of the private violins (PVs) is also shown. Entries represent medians and interquartile ranges.

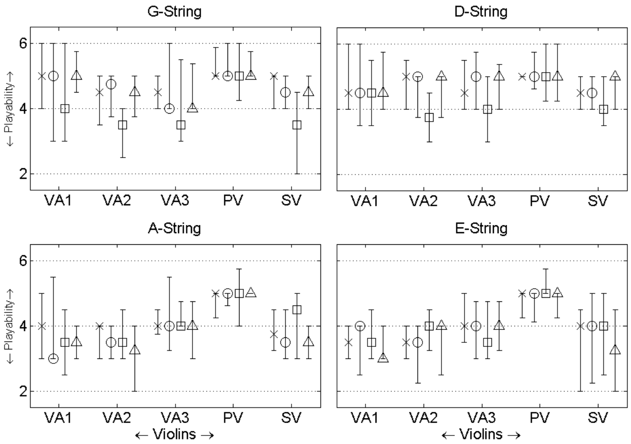

Figure 4: Medians and interquartile ranges of the rated playability of the violins A1, A2, A3, SV and the private violins PV, subdivided into strings and bowing techniques ($\times$ = long bowed, ○ = staccato, □ = tremolo, △ = free play).

It is obvious that the musicians' private violins were rated higher in most cases. Other ratings clearly relate to the specific variations of the violins used. The most obvious relations are:

As described above, the admittance curve of SV shows a boost at 700 Hz. This uncommon vibration characteristics was perceived by all musicians. Violin SV was rated lower on the e-string. This effect also touches the performance of the a-string.

In terms of noticeable differences between the three resonance profiles in violin VA musicians noted the prominent difference in the range of 500 to 600 Hz. VA3 differs from VA1 and VA2. This is reflected in the different perception of the a-string.

Musicians also strongly perceive the general difference between violin VA and their own violin. They seem to miss the familiar tactile feedback that usually comes along with the wood resonances. The resonance valleys of the violins VA1 and VA2 are shifted downwards. This untypical property has to result in a more or less unfamiliar and poor responsiveness, especially on the a- and e-strings. This fact is reflected in the musicians' subjective rankings, too.

In the range of the fundamentals of the lower strings, the playability of the instruments VA1, VA2 and VA3 was rated good to very good. This observation agrees with the fact that in the range of lower frequencies the admittance curves of these instruments are similar to that of normal violins.

The perceived playability also varies with bowing techniques. This can be observed for both violins on the g-string and the d-string. In case of tremolo-playing there are significant differences. This verifies the fact that a more difficult responsiveness in certain cases might be compensated by a higher bow pressure. In case of a faster bow change, played in the upper half of the bow, it is more difficult to control the bow pressure and therefore more difficult to produce a string oscillation with less undesirable noise components.

Technical Analysis

The recorded piezo and microphone signals were analysed in Matlab. For the purpose of detecting an unstable Helmholtz motion the spectral flux was calculated. The spectral flux is an indicator of how quickly the spectrum of a signal is changing. It is defined as the mean value of the correlation coefficients of spectral frames [8]:

$$SF = \frac{1}{M}\sum_{p=1}^{M} |r_{p,p-1}|, \tag{1}$$

where $M = \frac{Tf_s}{N}$, $T =$ is the total duration of the sound, $f_s =$ is the sampling frequency, $N =$ is the frame size in samples and $|r_{p,p-1}|$ is the absolute value of the Pearson product-moment correlation coefficient, which is defined as

$$|r_{p,p-1}| = \frac{Cov\,(X(\omega), Y(\omega))}{\sigma_X \sigma_Y}. \tag{2}$$

Here, $Cov(X(\omega), Y(\omega))$ is the covariance of the spectra of two successive windowed time frames with $N = 1024$, normalized by their standard deviations σ_X and σ_Y. The correlation coefficient is a measure of the linear relationship of the magnitude spectra of two frames at the times p and $p-1$. If the bow slides over the strings with little contact, i.e. in case of an unstable Helmholtz motion, the spectrum gets more disturbed and noisy. This again results in decreasing correlation coefficients and therefore in a lower SF. Figure 5 shows the time courses of the correlation coefficients of a steady and an unsteady Helmholtz motion of an f'' played on the e-string.

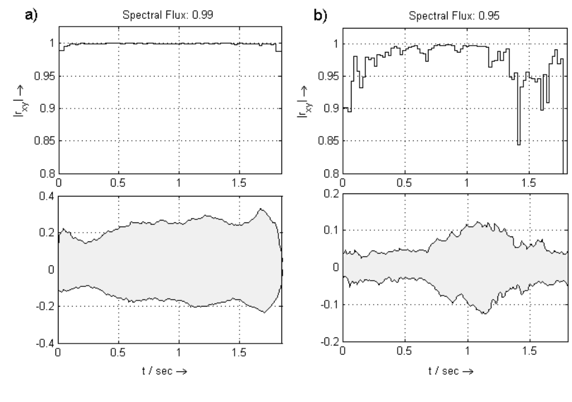

Figure 5: Time courses of the correlation coefficients (of spectra of successive time frames) and corresponding time signal envelopes of a) a steady string oscillation and b) an unsteady string oscillation.

The SF of each played tone has been calculated. Figure 6 and Figure 7 show the medians and interquartile ranges (long-bow played, displayed in whole steps). The locations of the open strings are labelled on the x-axis. In order to compare the musicians' play in a more reliable way, the SF values of each musician are normalized to the particular minimum and maximum value corresponding to the whole scale. So what is displayed is the relative distance between the most stable and the most unstable Helmholtz oscillation. A median close to unity indicates a constant sawtooth motion and a median closer to zero indicates a more chaotic or disturbed string oscillation. The clear decline of the SF values on the e-strings verifies the result that the musicians hardly managed to produce a steady oscillation.

The technical analysis confirms the ratings discussed above in most cases. The most obvious agreement is the poor performance of the e-string.

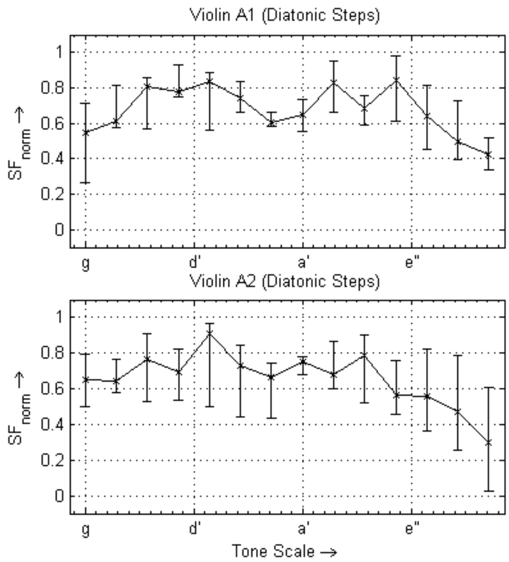

Figure 6: Violin A1 and A2: Medians and interquartile ranges of normalized spectral flux.

6 Conclusion

In this paper a method has been developed to investigate the relationship between musicians' subjective statements on playability and objective technical observations. The study has emphasized that it is possible to measure playability by directing the musicians' attention to the haptic feedback of an instrument. In most cases the technical analysis correlates well with the subjective statements of the musicians. A major finding is that all musicians clearly perceived the difference between the silent violin and their own violin. On some strings the playability is unacceptable. Perceived responsiveness also varies with bowing technique. In terms of sensitivity, all musicians noted even minor differences as presented with the built-in resonance profiles. Another finding is that perceived playability also relates to what musicians

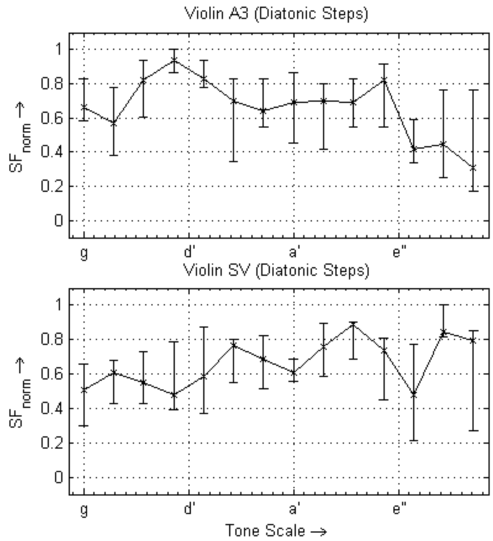

Figure 7: Violin A3 and SV: Medians and interquartile ranges of normalized spectral flux.

are used to traditional instruments. We also confirm that the playability of an instrument closely relates to its bridge admittance function. The more the latter correlates with a typical string-body impedance ratio the easier an instrument can be played.

Acknowledgement

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