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MEASURING THE PLAYING PROPERTIES OF VIOLINS

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1. INTRODUCTION

Obtaining reliable data on the auditory discrimination of violins has proved to be a very hard problem, following effort over several decades by many workers in the field. This difficulty makes it hard to investigate the physics of the instrument beyond a certain level, since it is not clear what questions one is trying to answer. Data which would be equally significant and which might prove easier to obtain relates to the playing properties of instruments, in other words to qualities perceived by the player rather than by a listener. Certainly, informal experience shows most players to be reasonably discriminating and consistent in making judgements while playing unfamiliar instruments. This paper discusses some physical measurements which can be made on an instrument and which stand a chance of correlating with such judgements by players.

The phrase "playing properties" covers a multitude of aspects of behaviour of the bow, string and instrument body. Some examples might be the variation from note to note, or from string to string, or in an overall sense from instrument to instrument, in the ease of playing with very light bow force or in the responsiveness to vibrato. These are the particular areas which will be addressed in this paper. There are many other possibilities, such as the variation between notes or between instruments in the maximum range of dynamic level or tone quality which can be obtained within the usual limits of acceptable violin performance. A player's perception of such attributes may vary considerably depending on the musical context, so care is necessary when collecting players' reactions.

One might first think of trying to measure physical parameters which determine playing properties by bowing the violin by machine in some controllable way, and then trying to duplicate the conditions in which the player was interested. Such approaches have indeed been tried, but have always been found to be fraught with difficulties. The present suggestion is to take advantage of existing knowledge of certain aspects of violin physics to suggest rather simple conventional vibration response measurements on the violin, which can be processed to produce predictions of the playing behaviour which can then be tested against player judgements.

2. MEASURING MINIMUM BOW FORCE

The first question which we address is that of the ease of playing a particular note with a light bow force. This turns out to be related to the question of the relative susceptibility of notes to undesirable "wolf" behaviour. We employ the well-known analysis of minimum bow force by

Schelleng [1]. He argued that the usual governing factor for minimum bow force is the breakdown of the desired "Helmholtz" motion of the string into a different regime of non-linear stick-slip oscillation in which there are two episodes of slipping rather than one in every fundamental period. The resulting sound is relatively weak in fundamental component, and is commonly described by players as "surface sound".

Schelleng produced an approximate formula describing how minimum bow force depends on the various parameters such as bow speed, bow position on the string, and behaviour of the string termination at the violin body. His analysis made some severe simplifying assumptions, so that it is not easy to apply it in a quantitative fashion to real instruments. However, if the steps of his argument are followed through, it emerges that the part of the calculation involving the most doubtful approximation can be replaced by a direct measurement on the instrument, after which the remainder of the calculation gives a plausible estimate of the note-to-note variation in the minimum bow force.

The argument begins by assuming that the string is executing an approximation to the idealised Helmholtz motion. For an ideal, lossless string this is a *free* motion of the string which is compatible with the presence of the bow — the bow does not need to do work since there are no losses to be compensated to sustain a steady motion. This changes when we allow for losses. Forces must be applied by the bow to the string so as to compensate for energy loss, and if the force demanded at any stage in the cycle exceeds limiting friction, the Helmholtz motion becomes impossible to sustain. This is the criterion which governs minimum bow force.

Energy in a real string is lost by coupling into the instrument body, in internal friction during wave travel along the string, on reflection from the player's finger at the other end of the string, and to a small extent by direct sound radiation by the string. The only one of these mechanisms which is likely to produce significant variation between instruments or from note to note on one instrument is the first, since the coupling between string and body will naturally depend on the material and constructional details of the body (including the bridge as part of the body for the purposes of this argument). We thus wish to calculate the extra force demanded at the bow due to the motion of the string termination in the bridge notch, since it is motion at this point which allows energy to be extracted from the string.

Schelleng modelled this energy loss by idealising the termination condition as a simple dashpot. By assuming also that the bowed point on the string is close to the bridge, he was then able to derive his criterion. A real violin body is, of course, far more complicated than a dashpot, and it is not obvious how one should even choose a value for an "equivalent dashpot" to use the criterion quantitatively. However, we can circumvent this. The final stages of Schelleng's argument are to calculate the *displacement* waveform at the string termination, and then to assume that the short portion of string between bridge and bow remains approximately straight, so that the force anomaly at the bow is simply proportional to the displacement waveform through a geometric effect of changing the angle of the string where it meets the bow. This last stage of argument seems quite robust — the bowed point really is usually very close to the bridge. Thus if we can determine the displacement waveform at the bridge by some more plausible means than assuming a dashpot there, we could readily estimate the influence of this effect on minimum bow force.

But it is reasonably straightforward to determine this displacement waveform by direct measurement. We could bow every note separately and measure all the waveforms, but there is an easier option available. Because we are always dealing with an approximate Helmholtz waveform, we know that the waveform of force exerted on the bridge by the string is approximately a sawtooth. Thus from a single measurement of admittance at the bridge notch, or more easily on one top corner of the bridge, we can calculate the required waveform for any desired note by using the known 1/n frequency spectrum of a sawtooth wave.

A sample of the results of this process appears in Figs. 1, 2 and 3. Figure 1 shows a measured admittance function on the corner of the bridge. Figure 2 shows a family of displacement waveforms, one for each semitone in the first octave on the D string. One cycle is shown of each waveform, with a time scale such that this cycle has constant width. The vertical scale is the same for each note. It is immediately apparent that both magnitude and waveform shape exhibit significant fluctuations between notes. Figure 3 shows the peak value of this waveform as a function of note, over a 3–octave range. One would expect the minimum bow force to exhibit fluctuations which mirror this curve, although with a scale and an offset which are not quite so easy to estimate because they depend on all the other loss mechanisms, which we are not determining.

It is worth pointing out immediately that the largest peak in Fig. 3, around G#, corresponds to a very well-known and gross fluctuation in minimum bow force — it is the "wolf note" frequency. Indeed, one can regard Fig. 3 as a plot of "wolf susceptibility". This alternative description lends some support to the hope that this measurement may indeed capture something of genuine significance to players.

3. SENSITIVITY TO VIBRATO

Before seeking to correlate player comments with the predictions of the measurements just outlined, it seems sensible to analyse another effect which is also likely to influence the perception of a player of the note-to-note variations in "ease of playing". This is the question of sensitivity of a given note to vibrato. As has been pointed out in the past [2], one of the most characteristic features of violin vibrato is that it involves not only fluctuations of pitch and overall amplitude, but also cyclic variation of the amplitudes of the different harmonics of the note, with markedly different amplitudes and phases.

When a player notices that one note is less responsive to vibrato that another, it is presumably the amplitude of these harmonic fluctuations which is varying, for a given imposed frequency variation. The player may well try to compensate by increasing the frequency variation. We would like to have some measure of this fluctuation in responsiveness, analogous to Figure 3. We do not have any model quite as definite as Schelleng's to go on in this case, but it is easy to sugest quantities which can be readily calculated and which might have roughly the right behaviour. For any given note, we require some sort of weighted sum of the *slopes* of the frequency response function at the fundamental and harmonics of the note in question, since the slope will govern, at least to a first approximation, the sensitivity of harmonic amplitude to imposed frequency variation. The right weighting for this sum needs to take account of (i) the frequency spectrum of the Helmholtz motion, (ii) the fact that absolute frequency fluctuations increase proportional to harmonic number, and (iii) the frequency sensitivity of the ear. Effects (i) and (ii) act in contrary directions, while the right function to use for (iii) is not immediately clear. Some experimentation is needed to try to define a suitable weighting, but then one might hope that a very similar measurement and subsequent computation to that seen in the previous section could be applied to this case.

4. REFERENCES

[1] J C SCHELLENG, 'The bowed string and the player', *J Acoust Soc Am* 54 p26 (1973)
[2] H FLETCHER & L C SANDERS, 'Quality of violin vibrato tones', *J Acoust Soc Am* 41 p1534 (1967).

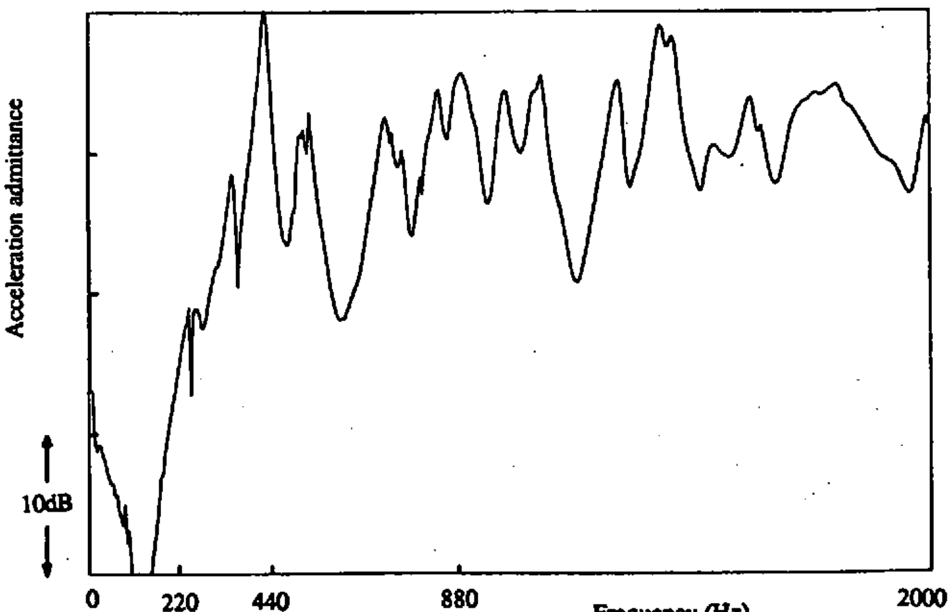

Figure 1. Admittance measured on the side of a violin bridge

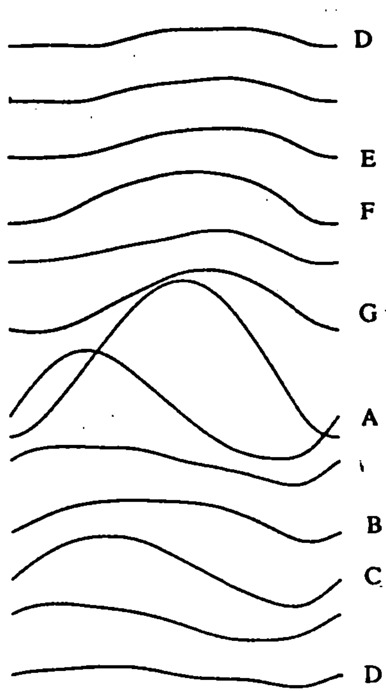

Figure 2. Bridge displacement waveforms for each semitone on the D string of a violin, deduced from Fig. 1. One cycle is shown in each case. The vertical scale remains constant throughout.

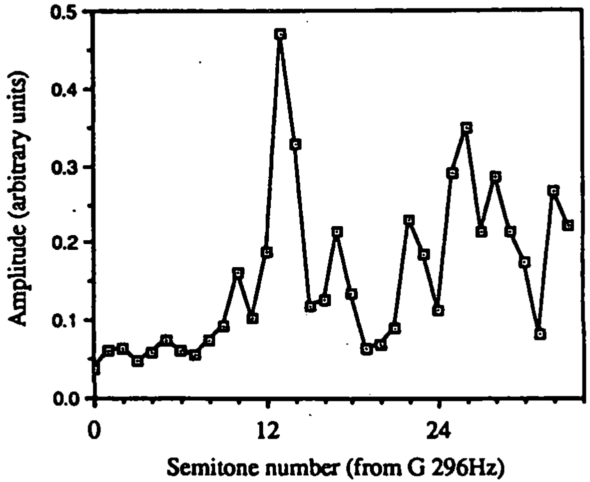

Figure 3. The amplitude of the bridge displacement waveform for each semitone from G (196Hz) up to E (1320Hz)