On the Prominence of the Violin Bridge Hill in Notes of Played Music

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Abstract

A qualitative relation was sought between the frequency region of the bridge hill of violins and perceived tonal qualities of violin notes. The prelude of Max Bruch’s Violin Concerto No. 1 was played twice on four violins in a large concert hall. A microphone recording of the music, outside the reverberation radius of the hall, represented a picture of the violin as experienced by a listener. The violins used for these tests included an 18th-century Italian violin of soloist quality, a French violin made in first decade of the 20th century, and two newly made fine violins. Four long notes covering the main range of the violin were copied into sound files and replayed via an equalizer where the levels could independently be adjusted in any octave band while listening. It was found that the 2- and 4-kHz octave bands caused the largest changes in note quality, i.e., the bands in which the bridge hill is to be found. In this frequency range the ear also has maximum sensitivity to weak sounds and maximum dynamic working range (difference in sound levels). Level shifts of the octave bands at 250 and 500 Hz showed surprisingly little influence on the notes. Increased levels in higher bands made the note shriller (harsher), and increased level in lower bands made the note rounder (more mellow). This indicates that fine frequency adjustment of the bridge hill is important.

As a physical measure of violin frequency response, the so-called bridge hill (BH) was recently suggested as a major quality parameter of the violin. Many acoustical measures of the violin have been introduced, but few have been tested. The experiments reported here—although somewhat informal and restricted—were conducted to obtain a qualitative evaluation of the importance of the bridge-hill frequency range.

PREVIOUS RESEARCH

Frederick Saunders, one of the founders of the Catgut Acoustical Society in 1963 [1], identified two prominent regions of strong response, which he labeled the air resonance and the main wood resonance. The two resonances were close in frequency to the middle open strings of the violin [2]. Later, Carleen Hutchins and John Schelleng developed a new violin family with the two resonances placed close to the open middle strings. Much of the fundamental acoustics for the violin is summarized in a compendium by the author [3]. Many references are given to this compendium and it is easily available on the Internet. The recorded material of this report was used in a previous paper in JVSA: VSA Papers [4].

Using the newly developed technique of hologram interferometry, Reinicke [5, 6] mapped the lowest two in-plane modes of the violin bridge on a rigid support. The lowest resonance falls at approximately 2.5 kHz. The resonances and a trace of the BH hump were found by Beldie [7, 8]. Later, Dünnwald [9-11] developed a new method to excite the violin. With this method he measured the radiation properties of violins in a special room and found that Old Italian violins show a hump at ~2.5 kHz. He also found that the main wood resonance is not one but two resonances. From measurements using soloist-quality violins, Jansson [12] found that the frequency responses of the bridge mobility had a bridge hill at approximately 2.5 kHz. He also found two resonances in the range of the main wood resonance. The measurements could be made in an ordinary room, and the responses were similar to the radiation responses measured by Dünnwald [13]. In his acoustical research on the violin bridge, Bissinger [14] found no correlation between violin quality and the BH driving
point or radiativity. In subsequent measurements, he found that the BH at 2.4 kHz is one of the dominating peaks in radiativity [15]. The two low-frequency peaks and the bridge hill were determined by Jansson and Niewczyk [16, 17] in their experiments using a modern violin (Stefan Niewczyk, 1992). By replacing the original standard bridge with a “plate bridge” with its first in-plane resonance well above 2.5 kHz, they observed that only a minor peak in the 2.5-kHz hump vanished. Thus, the bridge resonance was not the main physical phenomenon of the 2.5-kHz hump for this violin. In later experiments reported as “bridge or body hill,” these researchers [18] showed that the properties of the violin top plate play a major role in the 2.5-kHz hump, especially the cross-stiffness of the top plate in the bridge plane. A theory developed by Woodhouse [19] showed that both the top plate and bridge can be adjusted to set the properties of the 2.5-kHz hump. A model was developed applying the simplified bridge model developed by Reinicke [5] to a simplified model of the flexible soundbox. Experiments by Durup and Jansson [20] showed that the 2.5-kHz hump can be adjusted by the shape and placement of the f-holes, especially the distance between the upper parts.

**EXPERIMENTAL MATERIAL**

The experiments reported here utilized fine instruments and test apparatus that was readily available for simple but efficient listening tests. The playback levels in octave bands can be shifted directly while listening and their relative effects rated. It should be said that these relative effects were somewhat affected by the playback levels, but the discrepancies were small in relation to the broad trends sought. Some related psycho-acoustical experiments on violin sound have been presented by Fritz et al. [21], who developed a method for replaying a particular performance on different “virtual violins.”

The prelude of the Violin Concerto No. 1 by Max Bruch, a common musical excerpt for testing violins, was selected for the analysis [4]. It was performed for us by Bernt Lysell, concertmaster of the Swedish Radio Symphony Orchestra, in The Berwald Hall in Stockholm. The player stood in the usual soloist position, and the musical excerpt was recorded by an omni-directional microphone in the far field of the hall, i.e., at a position corresponding to a listening position. The recording was made by Rune Andreasson, sound engineer of the Swedish Radio. The prelude was played twice in succession on each of four violins.

Three of the violins were of good professional quality and the fourth was a soloist’s instrument. The first violin was made by Peter Westerlund in 1995 (PW95), the second by Leon Bernardel in 1909, and the third by Westerlund in 2004 (PW04). The fourth violin was made by Giovanni Battista Guadagnini in 1778, the violin played professionally by Bernt Lysell. Frequency responses in the form of bridge mobility had previously been measured for the first two violins and the Guadagnini violin [12, 13].

Four prolonged quarter-notes were selected for the analyses: the starting note on the open G-string (196 Hz), the fifth note A4# (466 Hz), the 12th note A5# (932 Hz), and the final note G6 (1568 Hz), i.e., notes at approximately 200, 500, 1000, and 1500 Hz fundamental frequency, respectively. The notes were cut out and stored in a sound file by the sound-editing program Soundswell™ [22]. Each note was then played back via an equalizer in octave bands included with the PC-soundcard (SoundMaxADI1988). The octave bands were 125, 250, 500, 1k, 2k, 4 k, 8 k, and 16 kHz. Each of the four notes (played on the four violins twice, so 32 notes in total) was replayed continuously in an endless loop joined as smoothly as possible.

These sounds were listened to by the author first via a loudspeaker coming with the PC and then via Sony in-ear phones designed for use with personal audio systems. Sweep note tests with listening indicated that the author’s ears and PC loudspeaker almost covered the LF range analyzed, and earphones covered it fully. The sliders of the equalizer were in turn shifted from normal to maximum repeatedly until a judgment could be made. The 50-Hz hum was a little irritating, but it did not mask the partials of the played notes.

The levels were cycled over the range 0 to +20 dB by the sliders in each octave band of the equalizer while listening. The result of listening should give a first, admittedly coarse, measure of the importance of different frequency regions.
The magnitude of influence for each octave band was classified as (1) small, (2) noticeable, (3) large, or (4) maximum.

EXPERIMENTAL RESULTS

The bridge mobility in the form of a frequency response function (FRF) is presented in Fig. 1 for the Guadagnini violin [3]. The bridge mobility shows a weak peak slightly below 300 Hz, which comes from the air resonance, i.e., the air volume acting as a spring for the air plug masses in the f-holes. At just below and above 500 Hz two prominent peaks and clear phase shifts are shown for the two resonances in the “main wood” resonance range. A rounded hump, the BH, occurs at ~2 kHz with local fine details superimposed on the underlying smooth hump. The phase shift also shows a smooth trend with superimposed fine details.

The PW95 violin has a rather pronounced BH peak at 2 kHz and a rapid phase shift. The level above 2 kHz remains fairly high. The bridge mobility of the Bernardel violin has a clear peak in the BH hump at 2 kHz. The level is fairly high above the BH hump. The phase drops steadily in the range of the BH hump. No bridge mobility FRF has been made of the PW04 violin, but it is likely to have a BH hump at approximately 2 kHz.

The tonal spectra of notes played on the Guadagnini violin (from the second performance) are shown in Fig. 2 [22, SWELL, tools, spectrum sections]. The first note (196 Hz fundamental frequency) shows a weak first-partial peak at -75 dB, a strong second partial at -48 dB, and a second maximum just above 2 kHz at -55 dB. This peak level at 2 kHz is -10 dB higher than neighboring peaks. The visible spectrum (within a 40 dB range) ends at ~5 kHz. The second note (466 Hz fundamental frequency) shows a strong fundamental at -40 dB and a strong fourth partial at ~2 kHz at -50 dB. neighboring partials are 10 dB weaker. The visible spectrum (within a 40-dB range) ends at ~5 kHz, i.e., the spectrum has a similar envelope to the previous spectrum. The third note (932 Hz) has a strong fundamental and a monotonically decreasing peak level. Partial end at 6 kHz (within the 40-dB range). There is a tendency for split partial peaks. The fourth note (1568 Hz) is dominated by the first two partials at -50 dB, followed by steadily decreasing peak levels up to 8 kHz (at -80 dB). The higher frequency range for this note is probably associated with the fact that it is played on the E-string and the Helmholtz “corner” on the

Figure 1. Frequency response (amplitude and phase) of the bridge mobility of a violin made by G.B. Guadagnini in 1778. Measured over the frequency range 100 Hz to 5.1 KHz.
Figure 2. Spectra of the sound produced by the 1778 G.B. Guadagnini violin at four notes: a. G3 (196 Hz), b. A4# (466 Hz), c. A5# (932 Hz), and d. G6 (1568 Hz). The relative sound amplitude ranged from -80 to -40 dB over the frequency range from 0 to 8 kHz.
E-string is sharper.

In broad terms, the other three violins showed the same tonal spectra, although differences could be found for some individual spectra. The spectra of the same notes played the first time showed the same features.

LISTENING TESTS WITH THE GUADAGNINI VIOLIN

The second playing of the Guadagnini violin was selected for the first and the most detailed analysis. As the concert instrument of the player, it is reasonable to suppose that he had adapted well to it after the first playing. The lowest note G3 (196 Hz) was little influenced by the level in the 250-Hz band, as indicated in Table 1. The fundamental partial is rather weak, but still it is often presumed that the fundamentals of all notes are important. The weak fundamental in the 250-Hz octave band and its insensitivity to level changes support the conclusion that it is not so important. By contrast, level changes in the octave band at 2 kHz shift the judgment of the tonal influence to maximum. The note became more prominent and sharper with increased level in the 2-kHz octave band, i.e., the band in which the BH hump is found.

The second lowest note, A4# (466 Hz), was only slightly influenced by the level in the band of the fundamental frequency, 500 Hz. The level of the 2-kHz octave band gave maximum influence. The influence of the octave band levels is roughly the same as for G3.

The third note, A5# (932 Hz), was maximally influenced by the 2-kHz octave band levels, the BH band. The note is again affected by the higher octave levels roughly the same as G3.

The highest note, G6 (1568 Hz), is maximally influenced by the 4-kHz octave band. The influence on the note is somewhat shifted towards higher octave bands.

Higher levels in the lowest octave bands make the note quality more mellow—a small effect—and higher levels in the higher octave bands make the note harsher—a large effect and a maximal influence in the 2-kHz band except from the fourth note, a note of rather high fundamental frequency. Note that the BH hump is in the 2-kHz octave band.

The results from listening to the notes from the first performance were essentially the same: no more than a one-place change in a few instances.

LISTENING EVALUATIONS OF ALL FOUR VIOLINS

A summation of the perceived tonal quality changes for all four violins, each played twice on the four notes, is given in Table 2. Maximum changes were found in the 2- and 4-kHz octave bands. This includes the range of the BH hump at ~2.5 kHz. The second playing on the Guadagnini violin, the best of the four violins (belonging to the player and with the best adaptation), showed all maxima at the 2-kHz band except at the 4 kHz for the highest note played. Thus, there is support for the importance of the BH hump.

Again, the tonal timbre was more mellow (a small effect) with increased levels in the lower octave bands, and more brilliant (harsher and

Table 1. Perceptual change of tonal quality as a function of octave band for fundamental frequency and octave band.*

<table>
<thead>
<tr>
<th>Played note</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1 kHz</th>
<th>2 kHz</th>
<th>4 kHz</th>
<th>8 kHz</th>
<th>16 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3 (196 Hz)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>A4# (466 Hz)</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A5# (932 Hz)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>G6 (1568 Hz)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

*Ratings: 1-small, 2-noticeable, 3-large, and 4-maximum; second playing test with the G.B. Guadagnini violin.
a large effect) with increased levels in higher octave bands.

These results should be taken with caution, however. The player is likely to produce the note he is seeking with all means at his disposal, i.e., not necessarily playing all violins in the same manner. It should be mentioned that the increase in bandwidth of octave bands with center frequency produces a slight but definite level increase for higher frequencies (+3 dB per band if spectra were flat). This should not affect the result.

**SUMMARY AND CONCLUSIONS**

The results found in this somewhat informal analysis are rather interesting. Still, it must be remembered that these tests cannot be considered as having proved a general truth. The author has served as the single evaluator (without a previous hearing test), and the sound-reproducing systems were not of the highest quality.

The first violin entry passage of Max Bruch’s Violin Concerto No. 1 was played in the concert hall of the Swedish Radio Symphony Orchestra by concertmaster Bernt Lysell on three good violins and his own soloist-quality violin. The performances were recorded by an omni-directional microphone in the far field.

First, selected notes of the Guadagnini violin were tested. Levels were shifted in octave bands, from 250 to 16,000 Hz, of the four played notes, at approximately 200, 500, 1000, and 1500 Hz fundamental frequencies during listening. It was found that shifts in the 2-kHz octave band were the most sensitive for the lowest three notes, i.e., the range of the BH hump, and thus support the importance of this hill. For the highest note the 4-kHz octave band was most sensitive, probably set by the method of playing and/or string properties. The notes, also the lowest, were less sensitive to the levels of the lowest octave bands, i.e., the bands including the main resonances of the violin. An increased level at the lower octave band made the note “more mellow,” while a higher level at high frequencies made it “harsher.” This indicates the importance of a well-positioned BH hump. Listening experiments with the other three violins supported the findings obtained with the Guadagnini violin.

It should also be noted that the ear is most sensitive to weak sounds and has maximum dynamic working range (difference in sound levels) in the 3-kHz frequency range. The 3-kHz frequency range falls in the range of the 2- and 4-kHz octave bands.

The simplicity of the testing and the retesting encourages the author to conclude that the results are representative for him at least.

**ACKNOWLEDGMENTS**

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**REFERENCES**


[8] L. Cremer, op. cit., Fig. 16.2, p. 430.


[13] E. Jansson, *Acoustics for Violin and Guitar Makers*, op. cit., Fig. 7.27.


[17] E. Jansson, *Acoustics for Violin and Guitar Makers*, op. cit., Fig. 7.24.


