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Investigating the Suppression of Mid-Range Harmonics in Violins

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ABSTRACT

The development of a way to alter an ordinary violin to improve its sound quality has implications in the music industry and the education sector. A simple way of improving a violin's sound will give more students the chance to play and own high-quality violins that they otherwise couldn't afford. Building on prior findings by a researcher named William F. Fry, this experiment investigates his claim that removing wood from the interior of a violin at certain locations (called Stradivari Holes #2, #3, and #4) will alter the vibrational characteristics of the violin, and suppress shrill, undesirable harmonics in the violin's sound. An original experimentation setup was designed to meet the needs of this project. A violin was bowed by an automated machine inside an anechoic chamber, and 1/24th octave band analysis was applied to the microphone data in order to determine the violin's frequency content. The peak amplitudes of the frequencies were computed, and the frequencies falling in the mid-range of 1500 Hz - 4000 Hz were compared before and after the alteration to the violin's structure. Only Stradivari Hole #4 was altered in this experiment in order to determine if merely thinning one hole was enough to improve the sound. The results were inconclusive; two possible explanations are that (1) more wood should be removed to produce a measurable difference, or that (2) all three holes must be thinned.

I. INTRODUCTION

A. Violin structure

The violin is one of the most famous instruments in Western music. Its design is essentially an air column which amplifies the vibrations of four strings. [1] The strings are excited by friction between a horsehair bow and the steel strings. This creates standing waves on the string. The string's vibrations are transmitted to the body of the violin via the **bridge**, a thin strip of wood that holds the strings up. The bridge's vibrations move the front plate of the violin, causing the air column inside the violin to amplify the sound. Two important structures that facilitate this process are the **bass bar** and the **sound post** (Fig 1). The bass bar is a long strip of spruce wood that is glued to the inside of the front plate. It passes directly under the left end of the bridge, and supports the downward movement of the bridge. [2] The sound post is a short dowel of wood that is placed under the right end of the bridge. It supports the front plate, preventing it from caving in.

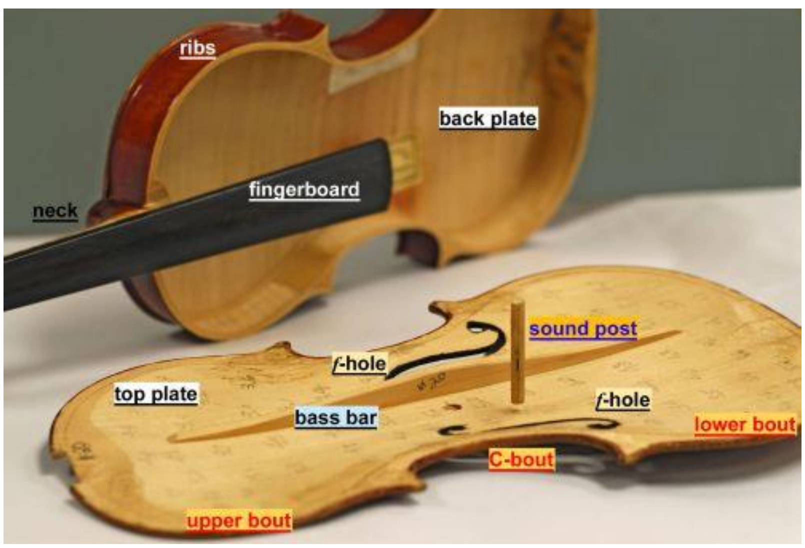


Fig 1. The interior of a violin. Structures to note are the sound post, bass bar, and f-holes. The top plate is referred to as the front plate in this paper.
Source: George Bissinger, 2007, "3-D Motion in Stradivari and Guarneri dG Violins", 153rd Acoustical Society of America Meeting

These features and precise dimensions of violins have been perfected and refined over centuries of trial and error. All modern mass-produced violins follow standard specifications, but the violins made by various Italian luthiers during the 17th and 18th centuries are widely regarded to be the finest of their kind. The famous luthiers (violin makers) of that time period, including Antonio Stradivari and Giuseppe Guarneri del Gesù, produced instruments that sell for millions of dollars today. Their instruments have also attracted significant interest. Scientists have attempted to provide explanations for the violins' superior and unique sound quality. One study by Joseph Nagyvary found that Stradivari instruments had brittle and fractured varnish with fine particles, in contrast with smoother modern varnishes. Nagyvary hypothesized that the vibrations of the instruments fractured and cracked open the varnish layers, changing the vibration modes of the violin and strengthening the fundamental tone and harmonics. [3] In any case, this project will not have been the first to study the harmonics present in a violin’s sound. Harmonics, which are called overtones in music, naturally occur in musical instruments and the human voice. Most instruments have harmonics with frequencies that are integer multiples of the fundamental frequency. In general, an abundance of harmonics is desired because it lends fullness and sophistication to the instrument's sound (compare a cello’s rich timbre to a tinny computer-generated pure tone). Harmonics also contribute to our perception of an instrument’s timbre, or tone quality. For example, an instrument with a timbre that is judged to be “bright” may produce notes with more high frequencies.

B. Suppression of shrill harmonics

William F. Fry, a researcher who studied high-quality Italian violins and tried to emulate their sound in regular violins, reported that in the high-quality violins, there was a suppression of harmonics in the 1500 to 4000 Hz range. [4] The human ear is particularly sensitive to sound in this frequency range, so the harmonics in this range are deemed shrill and undesirable.

In the Stradivari violins that exhibited this suppression of shrill harmonics, Fry found three spots in the front plate that had been deliberately thinned by the luthier. He called them *Stradivari Holes #2, #4, and #5* (Fig. 2). In addition, he experimented with scraping away wood from those holes in ordinary violins, and claimed that it indeed suppressed the shrill region and made the violin sound brighter.

Fry also provided a mechanical explanation of this phenomenon. The mid-range 1500 – 4000 Hz sound is caused by low-frequency rotation of the bass bar. The bass bar is driven by (1) the bridge’s vibrations and (2) the rotation of the sound post fibers (SPF), which extend over a width approximately equal to the diameter of the sound post. According to Fry, removing mass at Stradivari Hole #4 decouples the low-frequency rotation of the bass bar and the sound post fibers by making the region between them less stiff. Stradivari Holes #2 and #3 regulate the high-frequency rotation of the middle part of the bass bar. To that end, this experiment attempted to verify Fry’s premise that removing mass at Stradivari Hole #4 suppresses the shrill region.

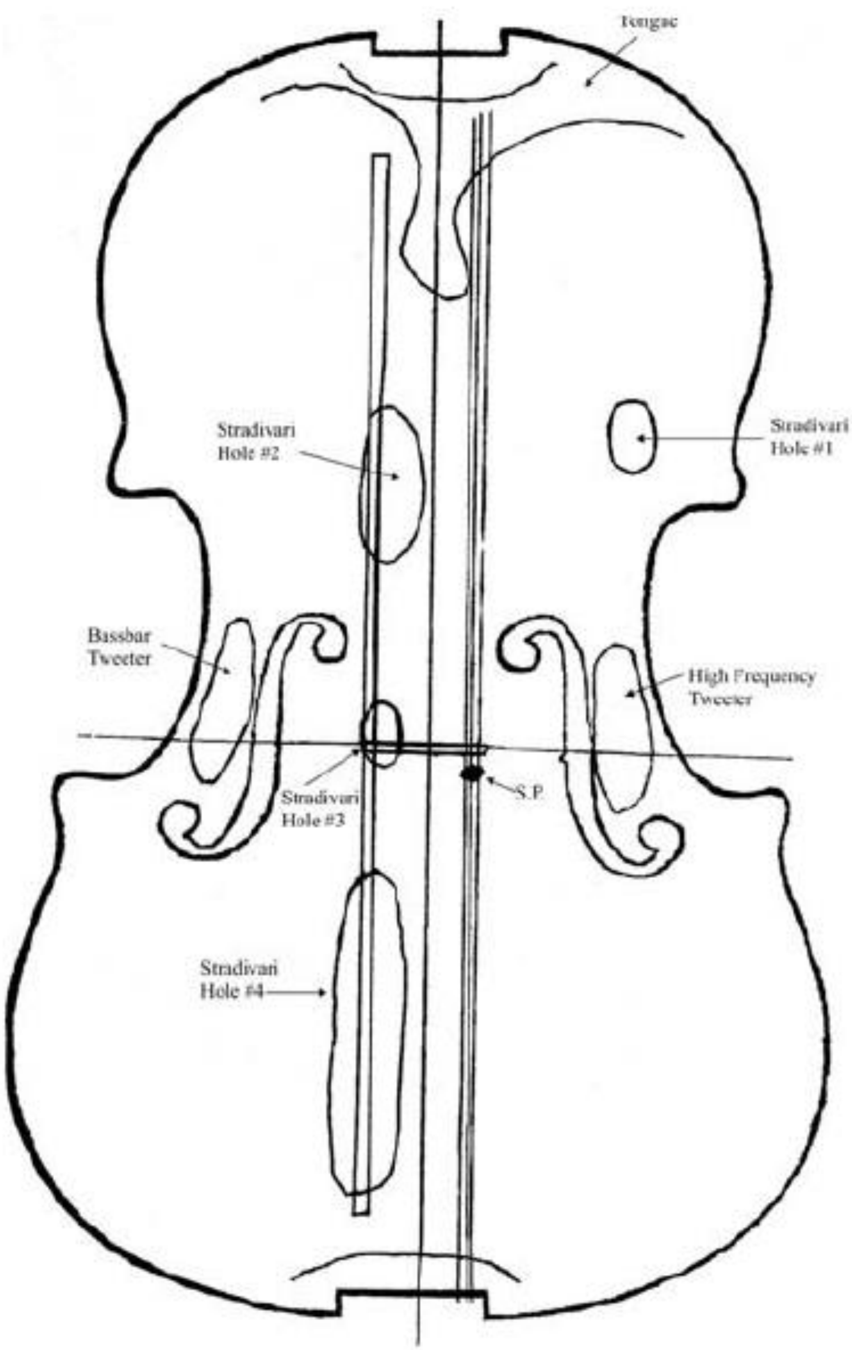


Fig 2. Schematic representation of the Stradivari Holes and other thinned locations in the front plate of a violin (top view). Stradivari Holes #2, #3, and #4 play a role in suppression of the shrill harmonics. Note that the sound post fibers pass under the sound post, labeled as S.P.
Source: Cremona Violins: A Physicist's Quest for the Secrets of Stradivari by Kameshwar C. Wali, Chapter 6

The experiment used a novel automated bowing machine (Fig. 3 and 4) that was significantly different from existing (also unique) bowing machines; a machine used in another study hung the violin and used a horsehair-sewn belt to bow the violin. [5] This experiment's machine was an acrylic frame that supported the violin and held in position a motorized belt, to which the actual bow was attached. The violin was clamped at the location of the shoulder rest, where a violin player would clamp the violin between the chin and the shoulder. The neck of the violin was unclamped. The bow was attached to a motorized belt, parallel to the ground. A weight was added to its tip to simulate the force that a violinist would apply on the strings. The bow played at the midway point between the fingerboard and the bridge. A directional microphone was mounted near the violin to collect sound data. The entire setup was housed in an anechoic chamber, which is a foam-lined room designed to silence and absorb all echoes. An anechoic chamber simulates free field conditions; it is the acoustical equivalent of standing on top of an infinitely tall flag pole. [6] The motorized belt was controlled from outside the chamber. To ensure that sound data was being taken at the same points every time, a camera was mounted in the chamber. The bow started playing at the same location every time, and sound data was collected at the same instant every time.

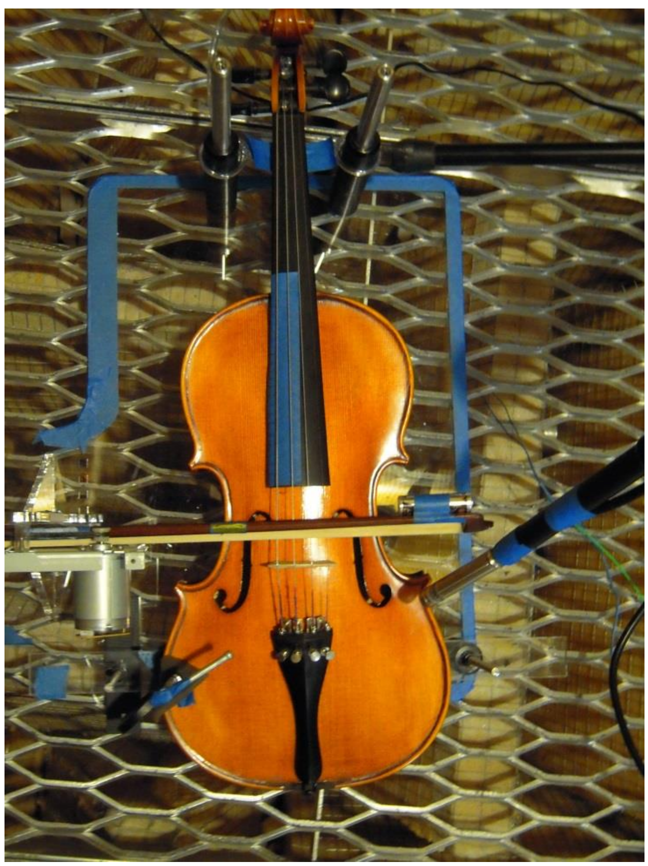


Fig 3. Close-up view of the violin on the bowing machine. The acrylic frame supports the violin at its base and neck, and the corner of the violin is clamped. The bow moves perpendicular to the strings and plays the open-string A note (second string from the left).

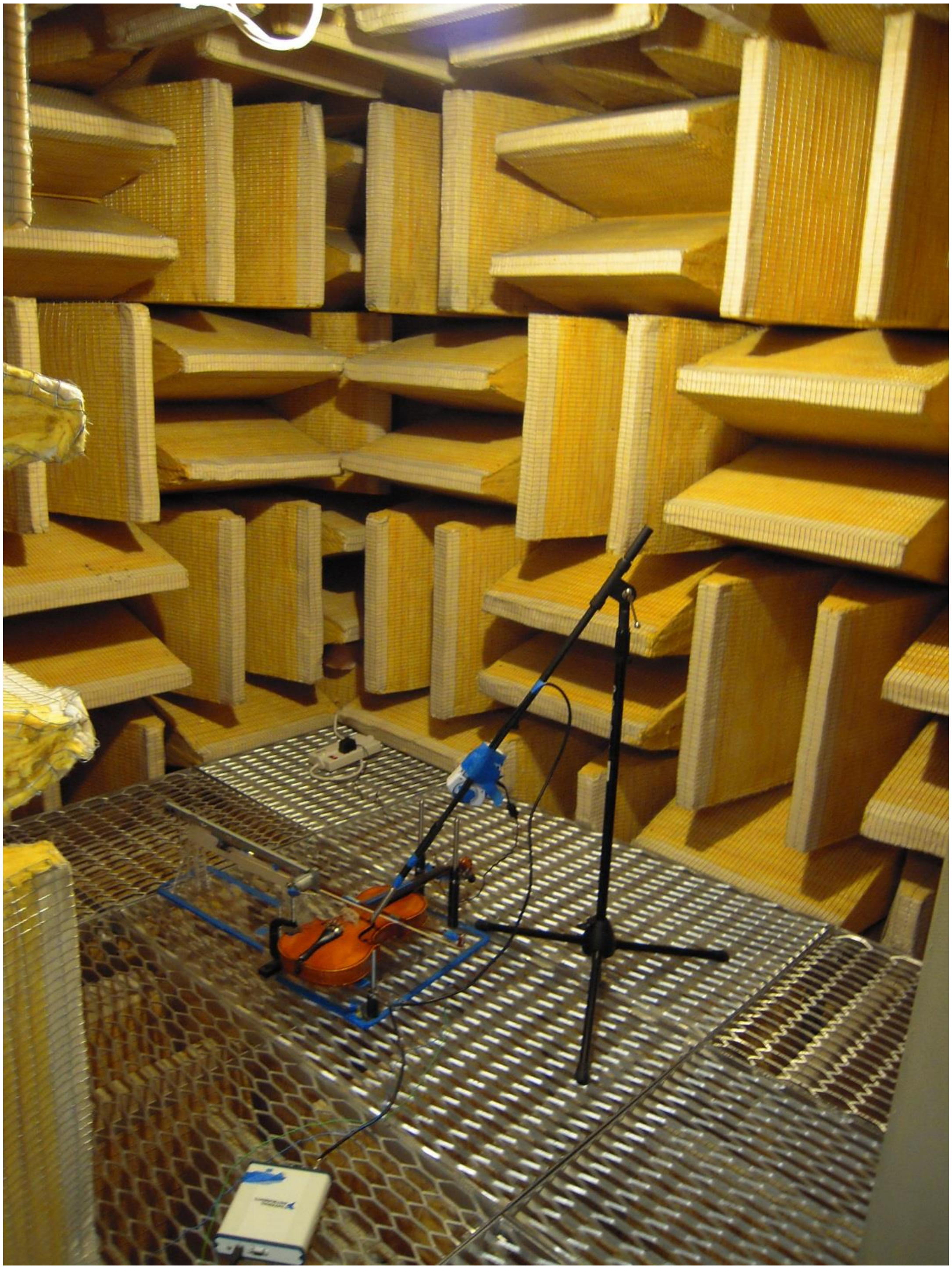


Fig 4. The bowing machine. The setup is controlled from outside the anechoic chamber; flipping a switch causes the belt and the bow to move back and forth. A camera mounted on the microphone stand allows the viewer to watch the tape markings on the bow and record data at the same point every time.

Consistency was crucial for the setup because the test should optimally reflect any change in the amplitudes of the harmonics. To determine the experimental variation, the violin was taken out from the stand and re-clamped at the same location several times. Within each test, the variation in peak amplitudes was minimal (no more than 5 dB). From test to test, the variation was larger and was at most 10 dB (Fig. 5).

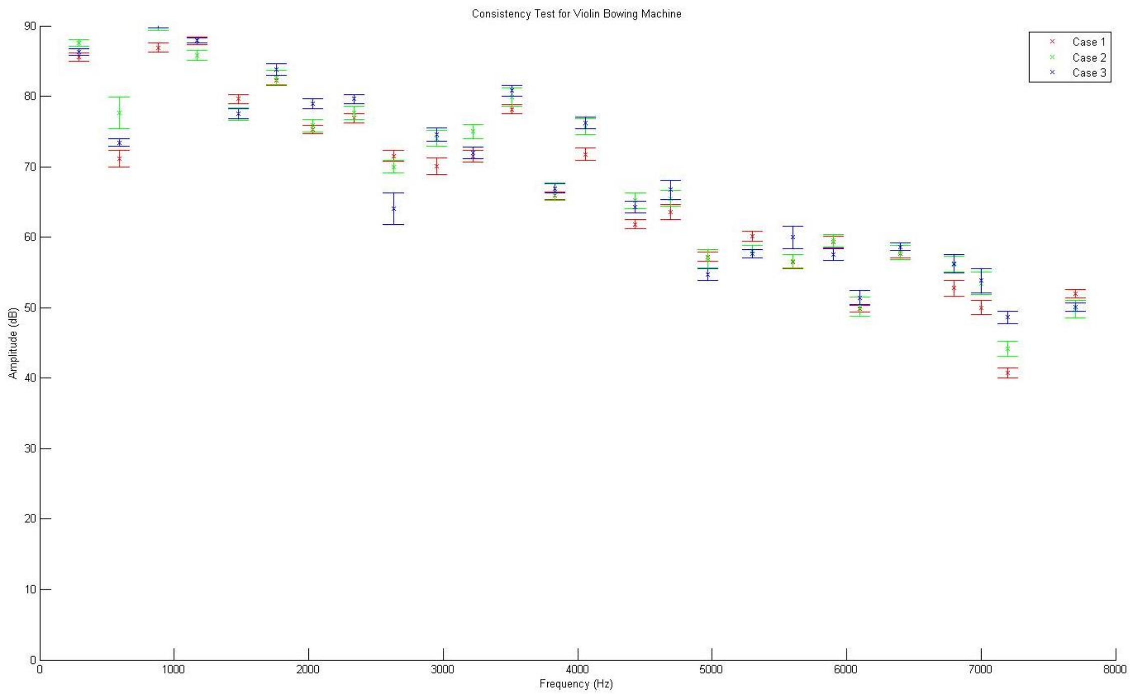


Fig 5. Test-to-test variation. Each band shows the variation in peak amplitude for one test. Moving the violin and placing it back changes the peak amplitude bands slightly, creating more experimental variation.

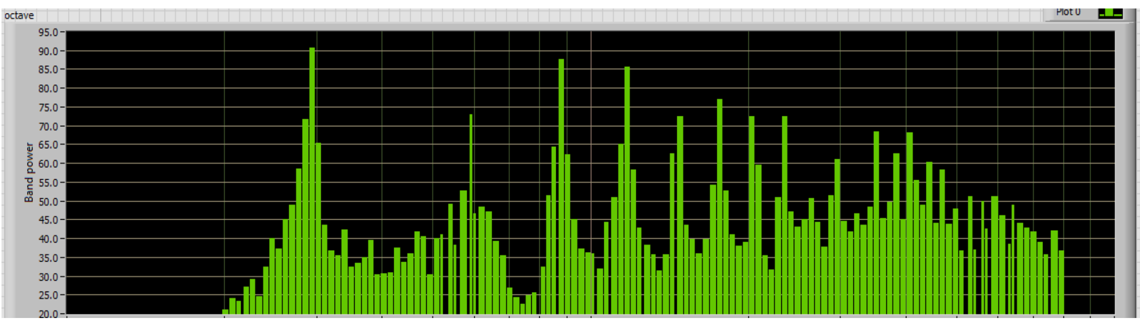
B. Removal of mass from the front plate

Instead of a scraper, a homemade device consisting of sandpaper attached to the end of a long, L-shaped section of coat hanger wire was used. Before and after sanding, an electronic thickness gauge was used to measure the front plate's thickness at a grid of points on and around Stradivari Hole #4. Controlling exactly where the sanding was occurring was difficult, making it hard to replicate Fry's alterations to his violins.

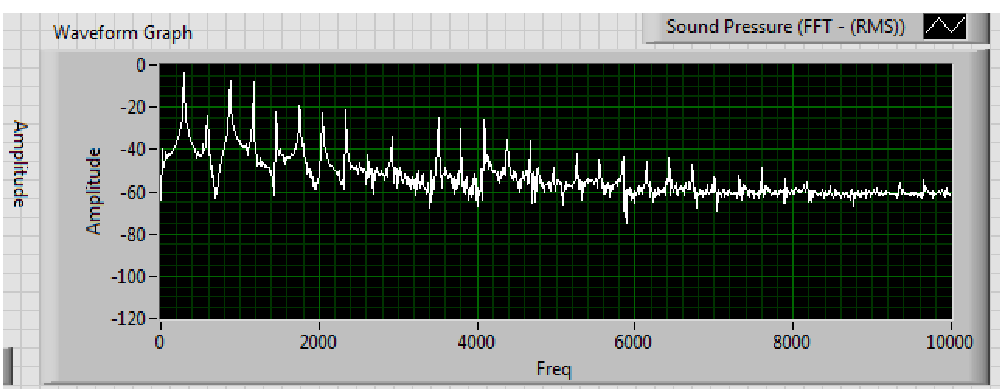
C. Analyzing the violin's harmonics

The sound data was analyzed with 1/24th octave bands. Octave band analysis, which is a method of frequency spectrum analysis, was chosen because it is suitable for sounds without dominant frequencies. [7] Its name comes from the musical term "octave"; if two notes are an octave apart, the higher note has twice the frequency of the lower note. Octave band analysis subdivides the whole range of frequencies into logarithmically scaled equal intervals. A disadvantage of octave bands is that the intervals become quite large towards the high end of the frequency axis, making the data less precise as frequency increases. This issue was disregarded because the resolution is sufficient high in the range we are concerned with (1500 Hz – 4000 Hz). 1/24th octaves provided the highest resolution because its intervals are narrow, compared to 1/3rd octaves or 1/12th octaves.

Figure 6 (a) is an example of what a typical octave band graph would look like. Figure 6 (b) is the Fast Fourier Transform of the same sample, showing a continuous curve of amplitude versus frequency. A MatLab program was used to compute the peaks in amplitude and their corresponding frequencies in the octave band data. Each peak represented one of the harmonics. This approach of graphing the amplitude peaks versus frequencies would clearly reflect any suppression or augmentation in the violin's harmonics, as long as the change was greater than the experimental variation.



(a)



(b)

Fig 6 (a) and (b). Two graphical representations of a typical sample. The top panel is the octave band analysis, which shows band power vs. frequency. The bottom panel is a Fast Fourier Transform, which breaks the sound wave into its constituent frequencies and plots amplitude vs. frequency.

III. DETAILS OF EXPERIMENT

Prior to removing mass from the front plate, three tests, each with 31 recordings, were taken as the violin played the open A string (frequency = 293 Hz). The violin was taken out of its frame and re-clamped between each test to account for experimental error. LabView's sampling parameters were set to 2000 samples at 20,000 samples per second (20,000 Hz), double the frequency of the maximum frequency. Approximately 0.4 mm to 1 mm of wood was removed from the location associated with Stradivari Hole #4 on the violin, as well as the section of the bass bar passing over the hole. The tests were run again with the altered violin.

IV. RESULTS

Fig. 7 shows a comparison of the peak amplitudes and frequencies, before and after wood removal. Since the variations were within the experimental variation, the results are inconclusive. Relatively large changes occurred in the 5th, 9th, and 12th harmonics.

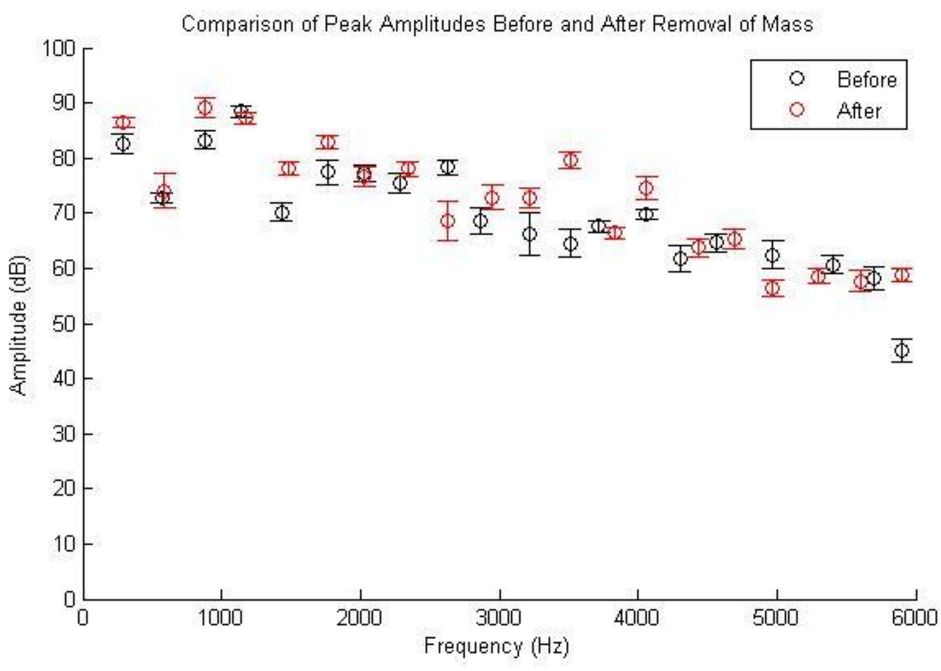


Fig 7. Comparison of peak amplitudes before and after removal of mass.

V. FUTURE WORK

The scope of the experiment was limited due to time constraints; however, the next step in the project is thinning Stradivari Holes #2 and #3 as well. A way to measure the thicknesses of those locations will need to be developed, as the digital thickness gauge can only work on uncovered surfaces (Stradivari Hole #2 is under the neckpiece, and Stradivari Hole #3 is under the bridge.)

In the experimental setup, there was no way to quantify the amount of pressure that the bow applied to the string. How hard the bow is pressing on the string can have a major impact on the timbre of the sound, and a study relating to this could reveal the "ideal pressure" that the bow should exert on the string, or at least the ideal pressure that the bowing machine should exert on the violin.

VI. WORKS CITED

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