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Noninvasive methods for quantifying sound post placement in a cello

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The position and orientation of the sound post in violin family instruments has long been known to color the sound of the instrument. Small changes in the position of the sound post relative to the top and back plates of the instrument can result in audible changes in the instrument's tone. Quantifying the effect of the sound post's placement on tone requires precise localization of the sound post. Luthiers have developed simple techniques to localize the post relative to the top of the instrument. Precisely localizing the post relative to the back, however, typically requires disassembly of the endpin. In this study, a noninvasive technique was developed using a force hammer to localize the sound post relative to the back of the instrument. This method was verified on a wooden box model and subsequently applied to two cellos, one with a laminate construction and the other carved. The sound post was localized well in the wooden box and laminate cello, but not as well in the carved cello.

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1. INTRODUCTION

Instruments in the violin family create their unique sound through a complicated interaction between their various components. Plucking or bowing one or more of the four strings causes the string to vibrate at its resonant frequencies. The vibrations from the string are transferred to the front plate of the instrument through the bridge, made from carved spruce or laminate wood. The top and back plates are coupled both acoustically (through the air cavity inside the body) and mechanically (through the sound post). The sound post is a small wooden dowel wedged in between the front and back plate located slightly below the treble side of the bridge. Due to the off-axis location, the sound post introduces asymmetry to the vibratory modes of top and back plates. Therefore, sound posts are crucial to the sound the instrument creates.

It is well known to luthiers and professional musicians that slight adjustments of the sound post position can lead to profound changes in the sound produced by the instrument. Heron-Allen et al. described the qualitative effects of moving the sound post in violins and found that subjective characteristics such as brilliance, brightness, and volume correlate well with the sound post position.[1] Some quantitative studies have also observed vibrational responses due to sound post positioning on violins using various techniques. For example, Molin et al. observed transient effects of the violin body using interferometry.[2] After excitation via impulse to the bridge, a dipole-like pattern emerged on the top plate due to rocking motion of the bridge. The back plate, however, was driven by the sound post which resulted in a monopole-like pattern centered on the sound post. Another study performed by Arnold et al. observed the effect of sound posts on the rocking motion of a violin bridge.[3] Results demonstrated that at lower frequencies, the bridge legs rocked almost in phase while at higher frequencies the legs rocked out of phase, caused in part by the sound post. While most studies investigating sound posts focused on violins, there remain some important differences between violins and cellos that should be considered. The dimensions of a cello do not scale proportionally to those of a violin by the frequency range in which they play. In violins, the sound post may well be modeled as a rigid coupling between the top and back plates. But the acoustic parameters of cellos are different from those of violins,[4] and the role of the sound post is not likely to be the same. In fact, a paper by Fang and Rodgers noted that unlike in violins, "one would expect…some vibrating modes involving sound post deformation that would contribute to the sound quality [for cellos]".[5] Therefore, a better understanding of the role of sound posts in cellos is necessary.

To perform quantitative experiments on the effect of sound posts on a cello's sound, however, an accurate method for localizing the sound post on both the front and back plate is needed because of the known sensitivity to position. While simple tools, such as a gauge, are used by luthiers to determine the location of the sound post relative to the top plate of the instrument, such methods do not exist for localizing the post relative to the back plate. To accomplish this, luthiers will typically view the bottom of the sound post through the end pin hole. This method, however, requires disassembly of the instrument, which is not viable for repeatable and quantifiable experiments.

In this study, a noninvasive experimental technique is proposed using a roving force hammer to localize the sound post on the back plate. The hammer provides a spatially concentrated input force at discrete points within the expected vicinity of the post. It is expected that the increased mechanical impedance directly above the sound post will then result in a temporally narrower force impulse. Therefore, the width of the impulse can be used to identify the location of the sound post. This technique is analogous to tapping on a wall to find a stud. The stud is not visible, but by tapping across the wall it is possible to locate the stud because of the spatially varying mechanical properties of the wall and stud system. The specific implementation of this technique was developed through experimentation on a test box and then utilized on two cellos. The method shows good potential for sound post localization but was found to be more accurate on a laminate cello than a carved cello.

2. EXPERIMENTAL METHODS

To perform the tap test, a PCB Piezotronics Model 086C02 impulse hammer with a medium, 0.25 inch diameter tip (white plastic, Model 084B04) was used to tap at each point on a 9 x 9 grid on 0.25 inch spacing centered on the sound post (Fig. 1). The input force as a function of time, as sensed by the hammer, was acquired with a National Instruments USB-4431 sampling at 10 kHz. The data was then upsampled by a factor of 10 to improve the temporal resolution of the force time series. The full-width-half-maximum (FWHM) duration of the input force was calculated as a single measure of the "sharpness" of each impulse. The FWHM duration was calculated by finding the peak sample and the samples on the leading and trailing edge of the impulse at half of the peak value (Fig. 2). Assuming that the response of the plate to an impulsive force is a linear system, this processing accounts for the variation in the magnitude of the input force due to the manual control of the tapping.

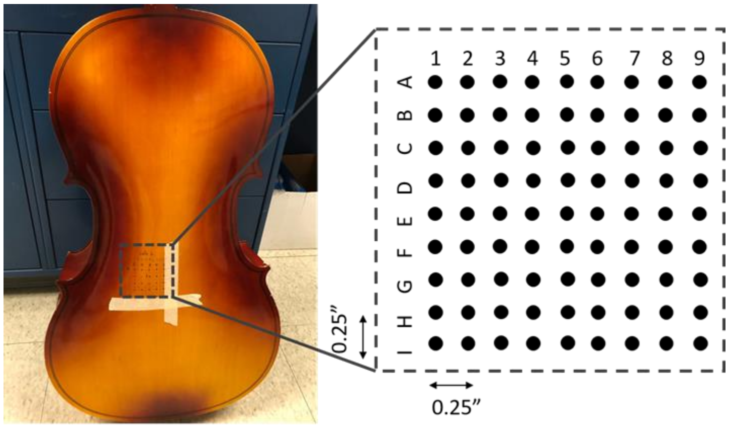

Figure 1. A 9 x 9 grid on 0.25 inch spacing was drawn on the back of each cello, centered on the estimated location of the sound post. A force hammer impacted the plate at each grid point.

The FWHM for each impulse were arranged into a 9 x 9 array corresponding to the point on the physical 9 x 9 grid. This array represents the sharpness of the impulse at each point that was tapped. To increase the spatial resolution of the data set, bilinear interpolation was applied to the FWHM array with a factor of 10 in each direction. This method is only dependent on the relative FWHM values, therefore the scales used in the figures are not the same from trial to trial.

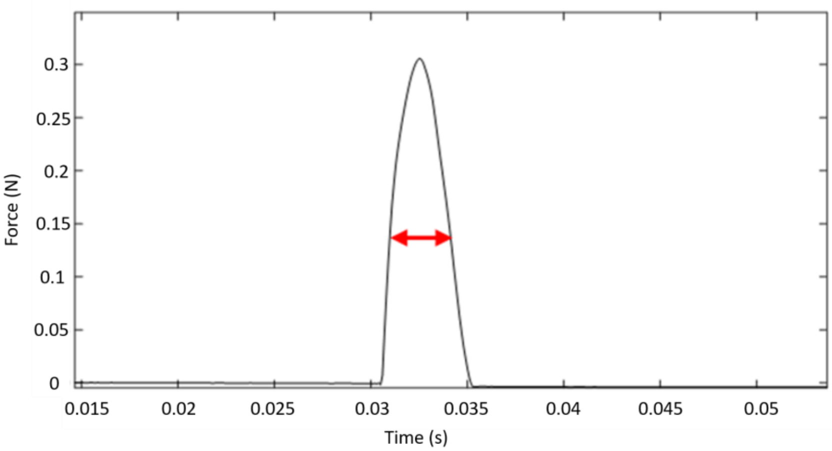

Figure 2. Example of the FWHM for a typical impact from the force hammer. The peak was expected to be narrower at the location of the sound post due to the increased impedance.

A wooden box, sketched in Fig. 3, was constructed to control the placement of the sound post and validate the tap test method. The box was constructed with a 0.08 in thick maple laminate top glued on frame constructed from 0.25 inch wide x 2.5 inch thick poplar. A series of holes were drilled in the sides of the poplar frame to minimize the reduction in compliance of the top plate due to the air cavity. The 9 x 9 grid with 0.25 inch spacing was drawn on the center of the box. The sound post was then placed at a point on this grid and held in place by pressure when the edges of the box were clamped to a base made from a 2 x 4 board. The method was shown to be successful, as will be discussed in Section 3.

The same technique was then applied to two full-sized (4/4) cellos. The first cello (Engelhardt, Model 5544, Serial 69561, 1998, USA) was constructed from wooden laminate while the second cello (Anton Schroetter, unknown model and year, Germany) was constructed from carved wooden top and back plates. Both cellos are designed for students learning to play the instrument. The 9 x 9 grid was drawn with erasable marker on the back of the cello, centered upon the approximate location of the sound post as determined by visual inspection.

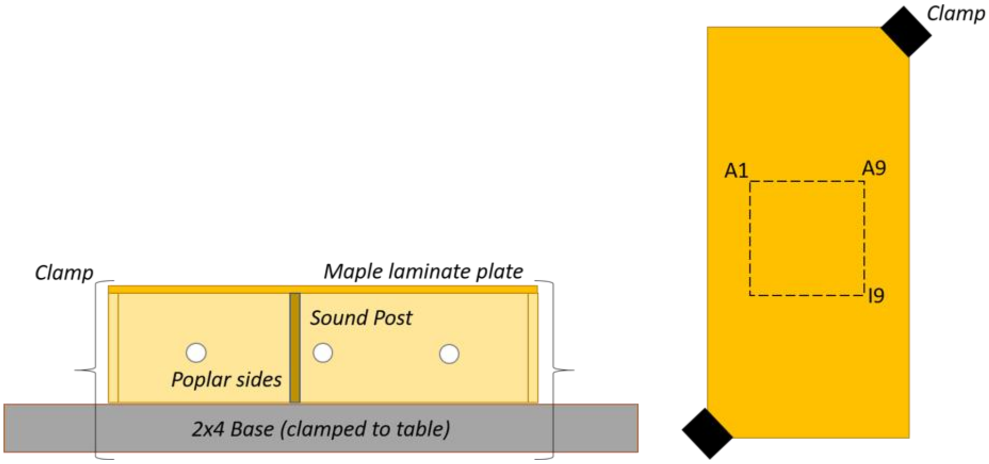

Figure 3. A wooden box was developed to test the sound post localization technique in a system where the post may be readily moved. The box, shown in profile view on the left and top view on the right, consists of a 0.08 inch thick laminated maple top on a frame of 0.25 inch x 2.5 inch poplar. A 9 x 9 grid with 0.25 inch spacing was drawn centered on the top of the box. The sound post was placed at a particular coordinate on the grid and held in place by pressure by clamping the edges of the box to a base.

3. RESULTS AND DISCUSSION

A. WOODEN BOX SOUND POST LOCALIZATION

When the sound post was wedged in the wooden box and placed at different coordinate locations, the FWHM array accurately indicated the sound post position. When placed at coordinate F8, the duration of the impulse was much narrower at and around F8 (see Fig. 4b). The response had a gradient of increasing FWHM values spread radially from the sound post, except near the left edge. Measuring the response while the sound post was located near C5 produced a tight cluster of lower FWHM values at and around coordinates B4/B5. A similar radial gradient from the sound post location was observed (Fig. 4c). The small discrepancy in the expected and measured sound post location is likely due to difficulties in accurately placing the sound post at a specific point on the grid.

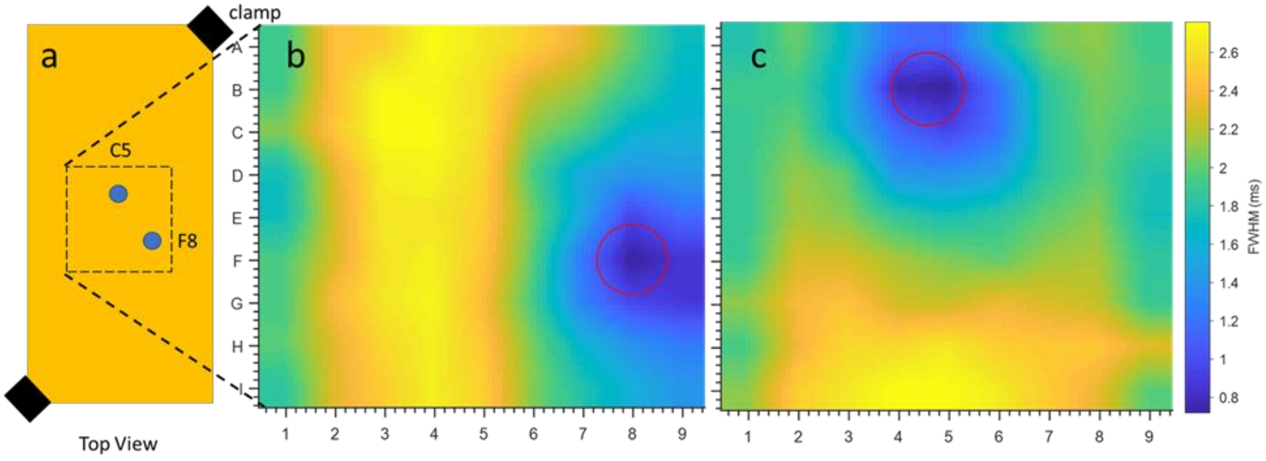

Figure 4. Bilinearly- and spatially-interpolated FWHM values of the set of force impulses provided accurate localization of the sound post in the wooden box. a) After placing the sound post at different locations of the coordinate system, shorter FWHM measurements were located at the respective locations of the sound post near F8 (b) and C5 (c). A red circle shows the expected sound post location (with matching diameter).

As expected, narrower FWHM values of the force responses were found to align with the location of the sound post on the wooden box top plate. This can be attributed to the increased stiffness the sound post imposes onto the top plate at its contact point. The FWHM gradually increased for points further away from the sound post suggesting that the circular geometry of the sound post base affects stiffness in a larger area around the contact point of the sound post. In general, this model validates the proposed tap test localization method for detecting repositioning of the sound post.

B. CELLO SOUND POST LOCALIZATION

The sound post localization technique was then applied to two full-size cellos. The results for the laminate cello are shown in Fig. 5. The spatially interpolated FWHM array indicated a region of higher stiffness, approximately the size of the sound post base, around the point F4 that decreased in stiffness approximately radially, similar to what was seen in the wooden box model. Therefore, it is likely that the laminate cello sound post location was near coordinate F4. However, the results were not as distinct as for the wooden box. One possible explanation is that the opposite end of the sound post is connected to the top plate of the cello, which is relatively compliant compared to the 2 x 4 base used in the box. The bridge of the cello also creates a localized boundary condition on a portion of the top plate, further differing from the model box.

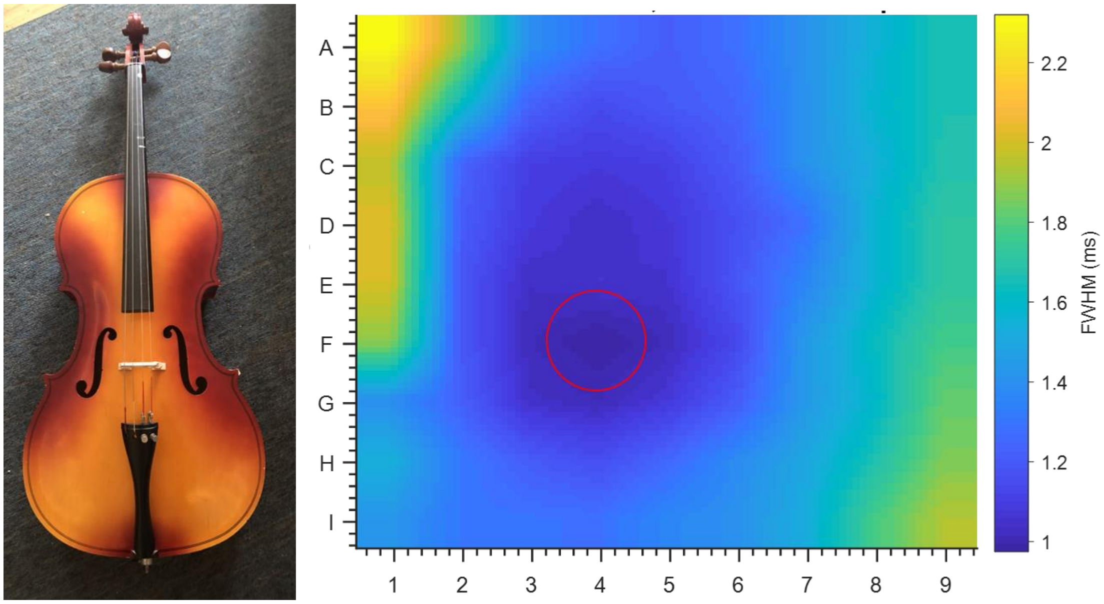

Figure 5. Laminate cello measurements of the FWHM force responses. The method provides good localization of where the sound post is likely positioned. (Red circle is a prediction of sound post location with matching diameter)

The results for the carved cello are shown in Fig. 6. There were multiple regions of high stiffness that are all possible locations of the sound post, making precise localization of the sound post difficult. Similar to data from the laminate cello, however, the area of high stiffness near the center of the grid decreases towards the edges. The construction of the cellos could explain the relative localization quality between the laminate and carved cellos. The wooden laminates are likely more homogeneous than the carved wood and would have more isotropic material properties. The thickness of the carved cello may vary while the laminate cello likely has constant thickness. These two differences may make the localized change in mechanical impedance due to the sound post more noticeable for the laminate construction.

Overall, the preliminary experimental results demonstrated that a roving force hammer technique may be used to locate the position of the sound post. Several factors may limit the accuracy. First, the resolution of the grid spacing is presently limited by the diameter of the hammer tip. Using a finer tip on the force hammer could provide more precise localization. The geometry of the cello may also limit the accuracy as the back plate is a curved surface. This creates challenges in both laying out the grid accurately and ensuring the force hammer is normally incident upon the plate during testing.

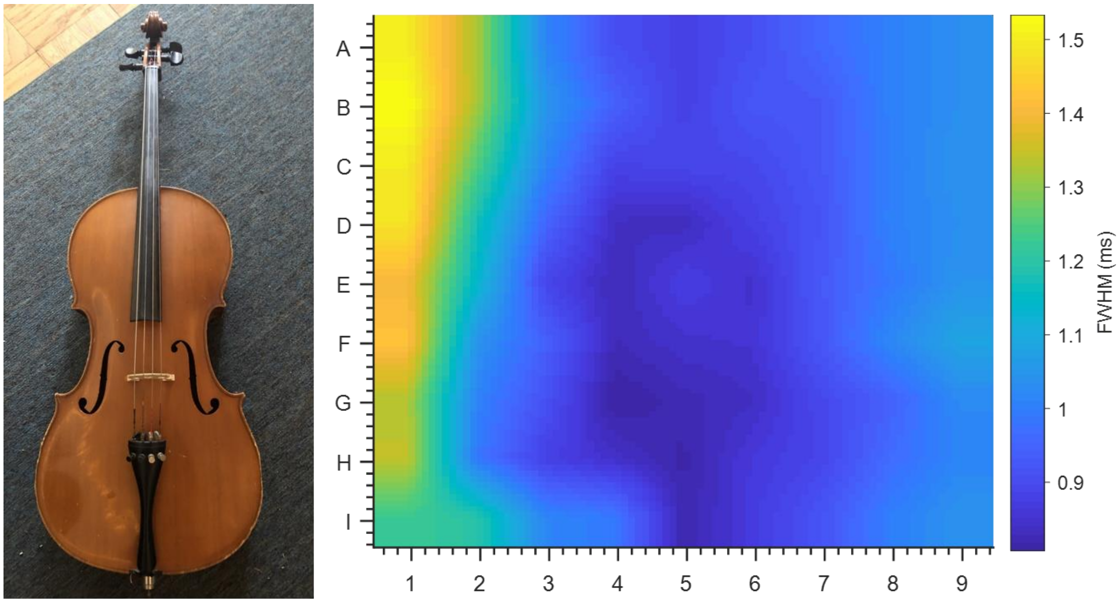

Figure 6. Carved cello measurements of the FWHM force responses. By visual inspection, carved cello measurements of the FWHM force responses were not as clearly identifiable to locate the sound post position.

4. CONCLUSIONS

In summary, a noninvasive method using a force hammer was used to locate the sound post of a cello. The procedure utilized the bandwidth of the impact which is narrower at the location of the sound post due to the higher impedance. The technique was demonstrated on a generic wooden box with material properties similar to a real cello. The method was then applied to a laminate and carved cello. The sound post was localized reasonably well for the laminate cello, but not as well for the carved cello. The reasons for the difference in localization ability between the laminate and carved cello may be a result of the variable plate thickness and is currently under consideration.

Future work will include improvements of the localization approach, possibly using interferometry or acoustic beamforming to validate the approach. Finite element modeling may also be pursued to further investigate the impact of laminate and carved wood on the localization procedure. Finally, experimental measurements will be obtained to quantify the influence of the sound post on the sound produced by cellos.

ACKNOWLEDGMENTS

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REFERENCES

[1] E. Heron-Allen, *Violin-making as it was, and is,* 2nd ed. (Ward, Lock & Co. Ltd., 1885), Chap. 8, pp. 149-152.

[2] N. Molin and A. O. Wåhlin, "Transient wave response of the violin body," J. Acoust. Soc. Am. **88**, 2479 (1990).

[3] E. B. Arnold and G. Weinreich, "Acoustical spectroscopy of violins," J. Acoust. Soc. Am. **72**, 1739 (1983).

[4] C. M. Hutchens, "A 30-year experiment in the acoustical and musical development of violin-family instruments," J. Acoust. Soc. Am. **92**, 639 (1992).

[5] N. J. Fang and O. E. Rodgers, "Violin sound post elastic vibration," J. Catgut Acoust. Soc. **2**(1), 29-30 (1992).