Studying the effect of bow vibration on violin sound production using an automated bowing machine

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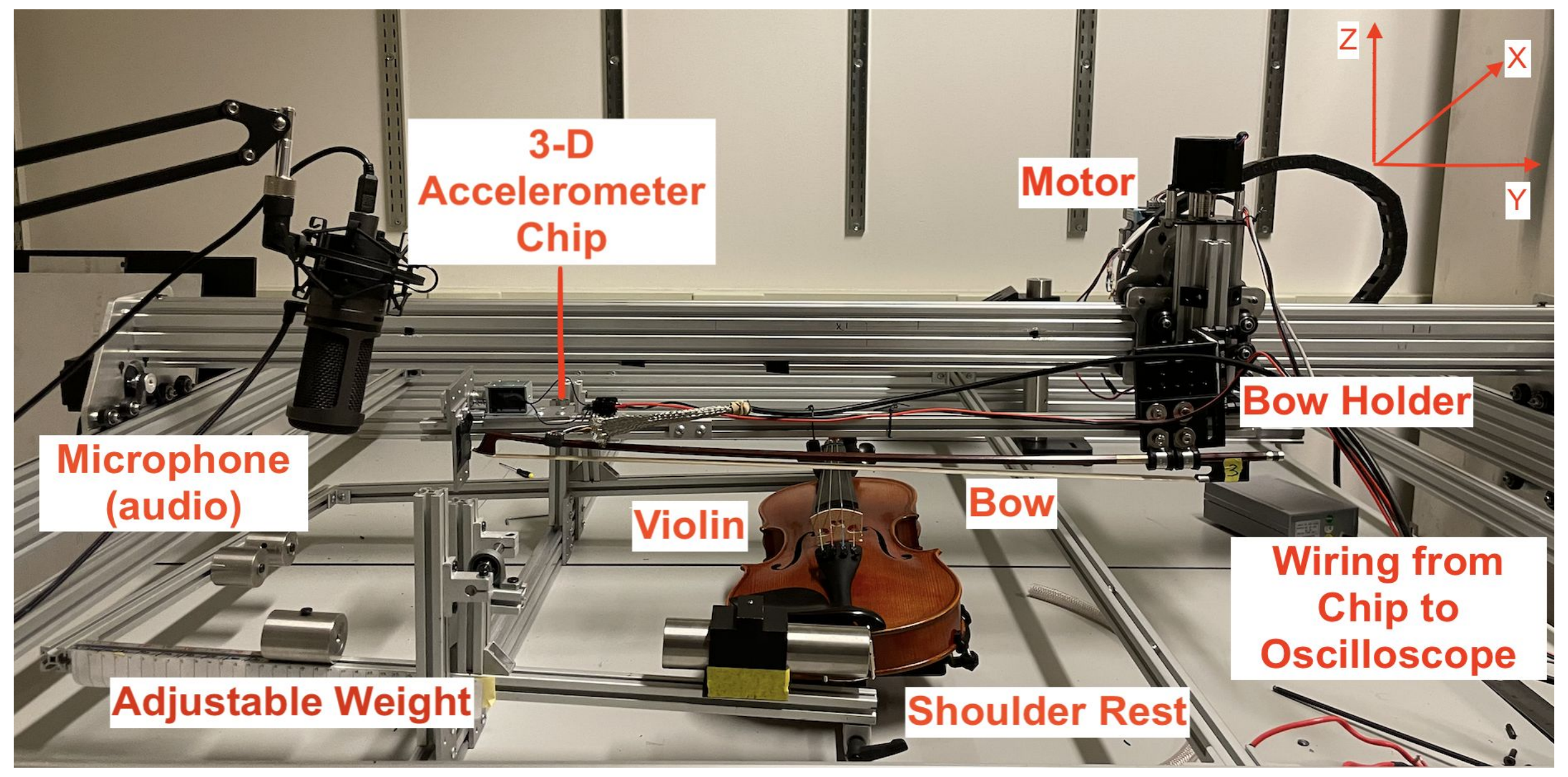
Introduction

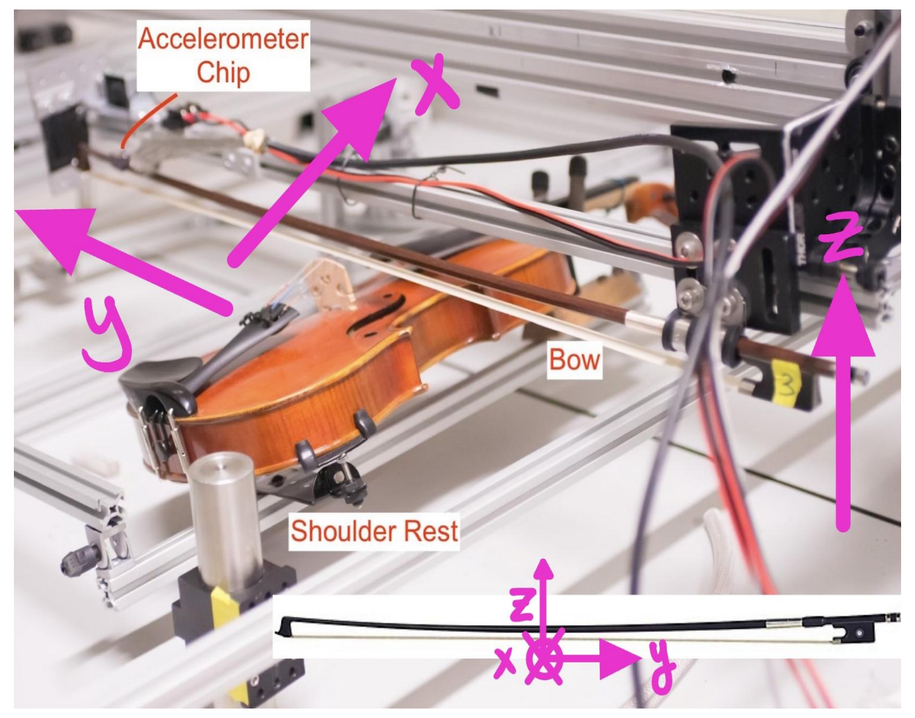
- During playing of a bowed string instrument, the rosin-coated bow hair is drawn against the string, causing the string to repeatedly stick to and be suddenly released by the hair, a phenomenon known as stick-slip oscillation.
- These oscillations create vibrations in the bridge and instrument, which radiate sound into the air.
- For a clear tone to be generated, the stick-slip oscillation must generally occur at the fundamental frequency of the string.
- It is widely believed that bows strongly affect a violin’s tonal properties.
- Despite nearly a century of study, how the different tonal qualities of violin bows are related to their physical properties is poorly understood.
- To investigate the role of the bow’s physical properties in sound generation, we constructed a bowing machine capable of playing the violin with a well-defined velocity, downward force, and position.
- A MEMS accelerometer mounted to the bow measures the vibrations of the bow.
- To modulate the bow vibration, we attach a piece of rubber tubing to the bow shaft, increasing its mass and damping. In this manner we test the effect of bow vibrations on the violin sound.
- We performed these tests in different regimes: (1) Raucous sound due to high bow force, (2) normal sound due to moderate bow force, and (3) surface sound due to low bow force.

Hypotheses

- **We hypothesize that vibrations of the bow influence the stick-slip oscillation of the bow-string system, causing a difference in sound amplitude and/or spectrum.**
- A note with a raucous-like sound should exhibit a more complex spectrum than a normal note, and a surface sound should exhibit a higher harmonic to total sound ratio than that of a normal note.

Methods

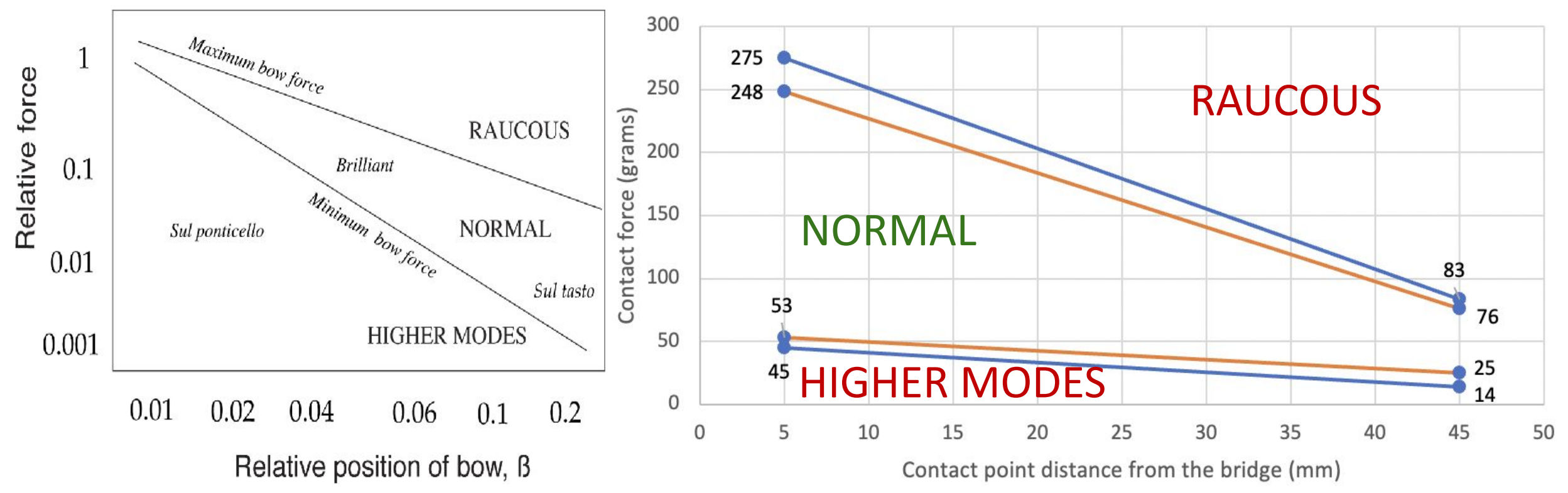




- A bow was attached to a motorized stage controlled by a brushless DC motor, which was powered by a pulse and function generator, allowing us to vary velocity, distance and direction of bow travel.
- The violin was mounted on a balance to adjust the force of the bow against the string.
- A 3-D accelerometer chip was attached to the bow with Sugru adhesive and wires soldered onto the chip connected to a DS1054Z Rigol oscilloscope, which was then connected to a PC for MATLAB analysis.
- Data from the accelerometer and a microphone were captured by the oscilloscope was analyzed through a discrete Fourier transform.

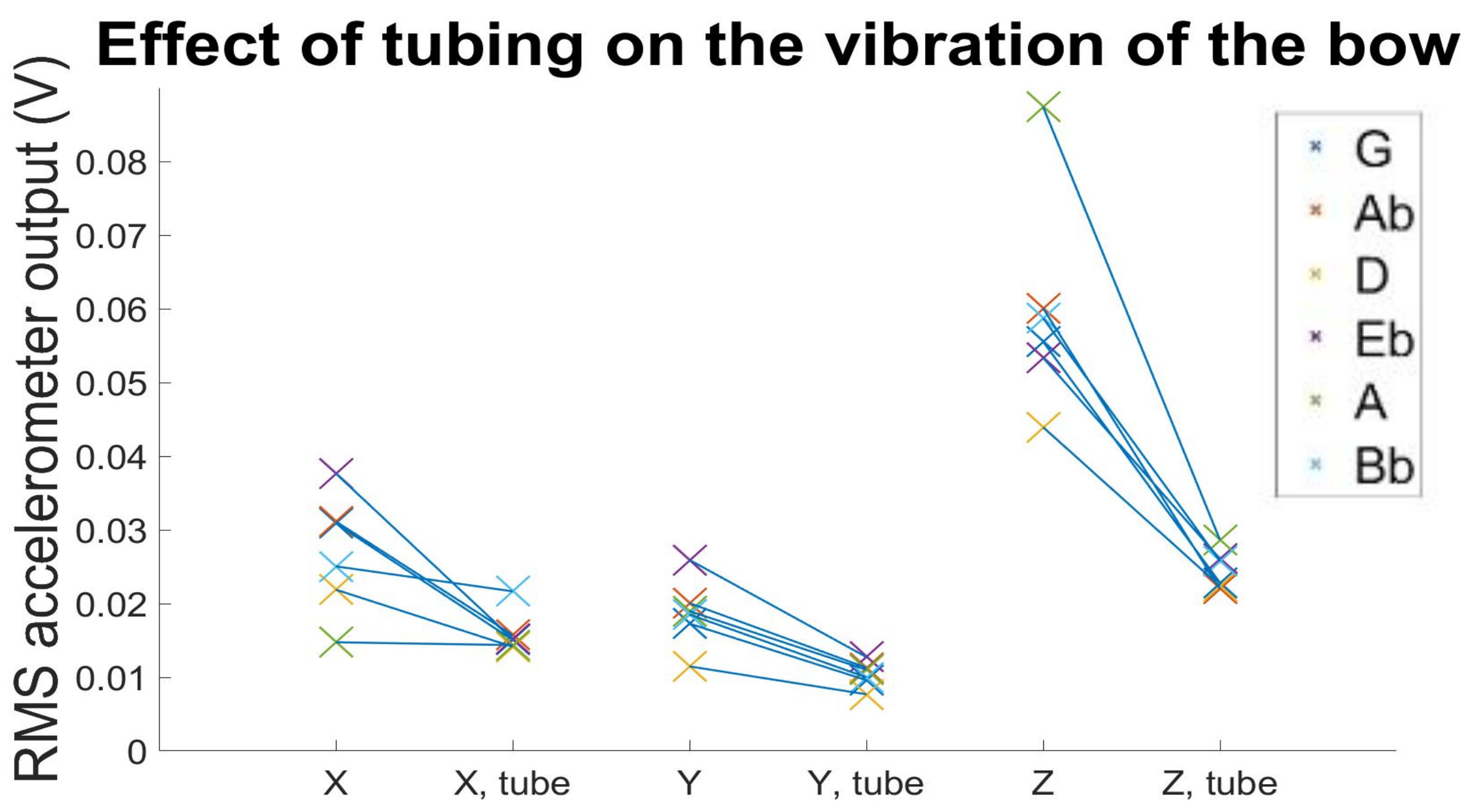
Results

We first verified that our bowing machine worked properly by reproducing a well-known result in violin acoustics.



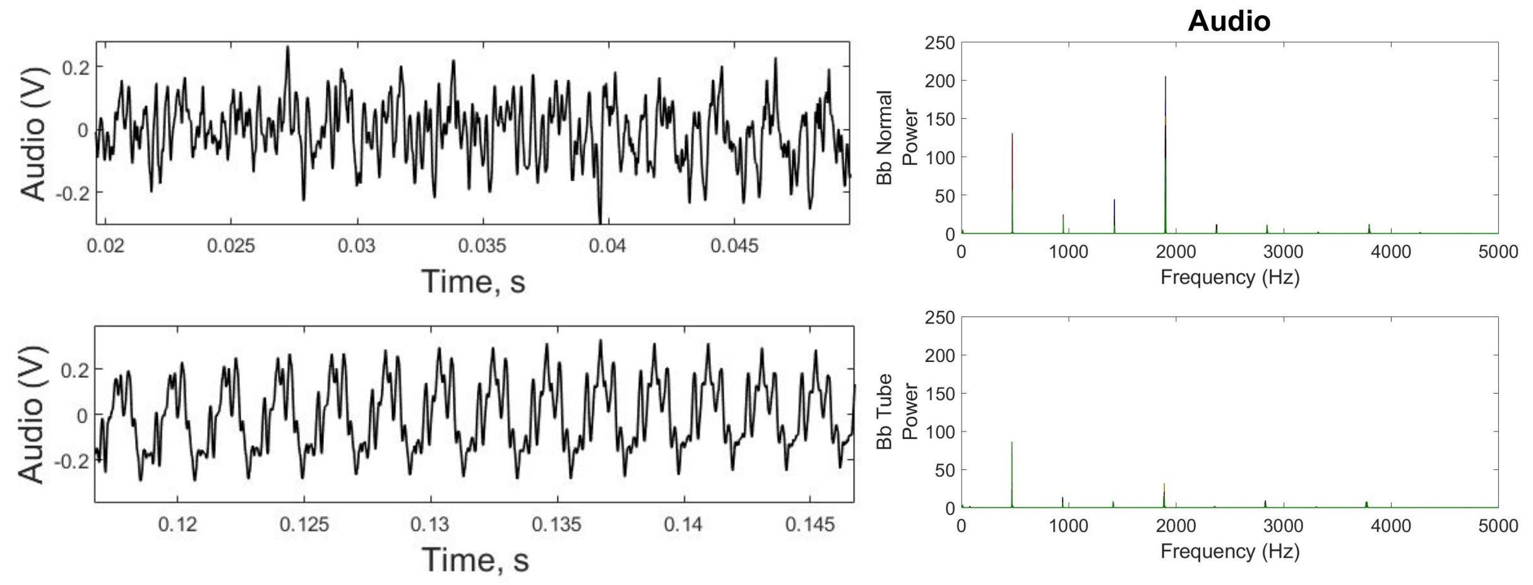
The Schelleng Diagram represents three modes of interaction between the bow and string (normal, raucous, and surface sound). We examined the A (orange) and D (blue) strings.

Tubing decreases bow vibration during bowing



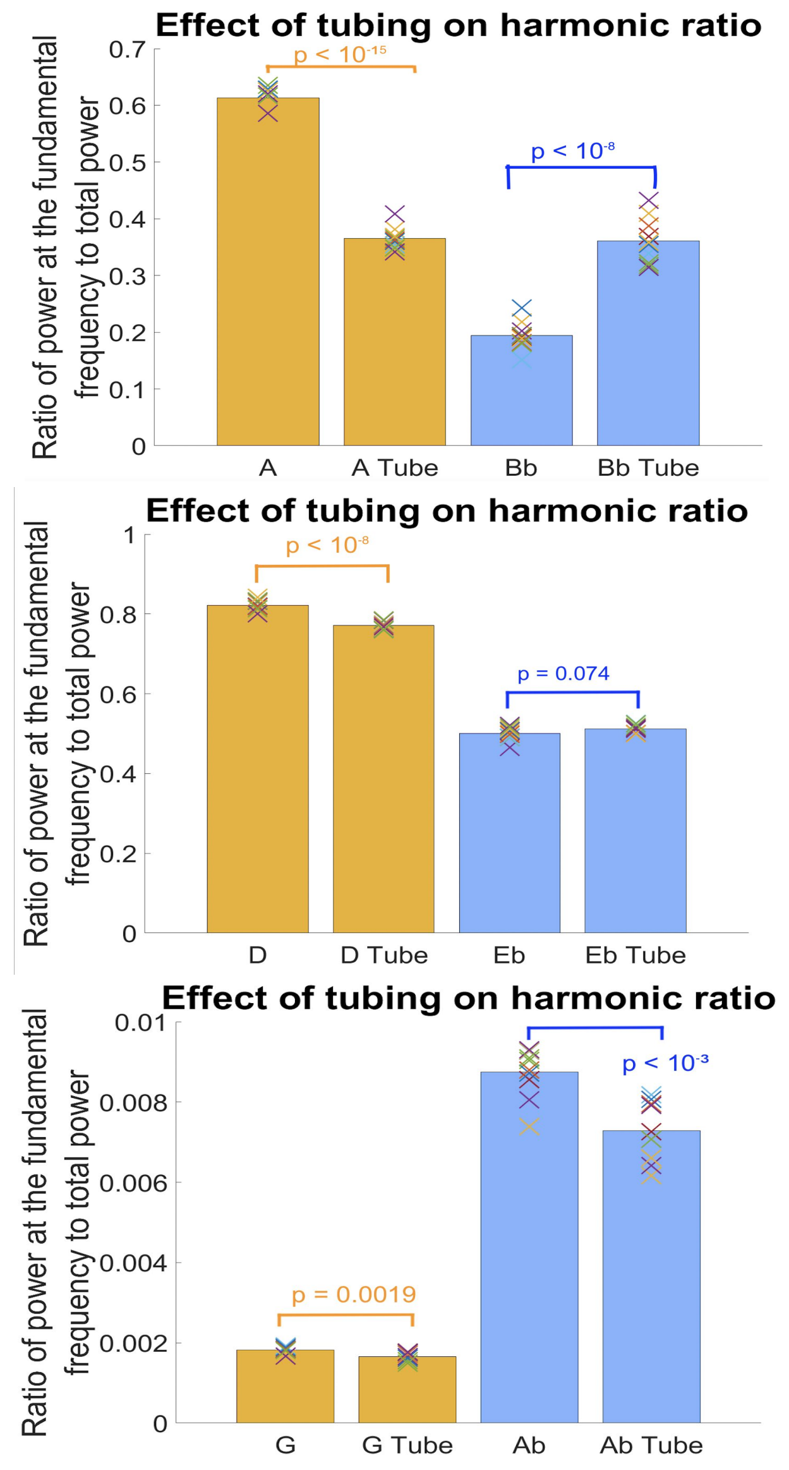
Tubing on the bow dampened the RMS accelerometer output (vibration power) in the X, Y (longitudinal), and Z (largest power) directions. This was consistent for all 6 notes.

Tubing decreases acoustic output



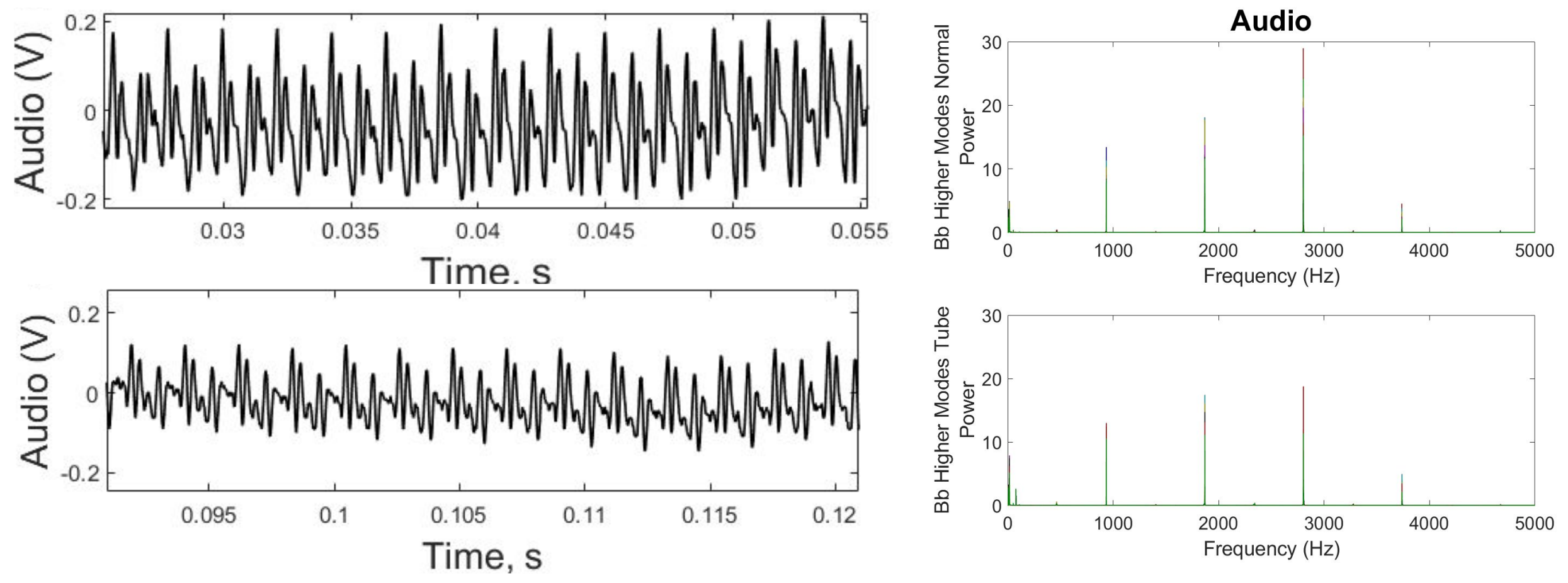
Tubing dampened overall power in both the fundamental frequency of Bb (A-string) and harmonics (>466 Hz). The left shows the audio-domain trace in time, which is decreased with tubing (bottom panel). The spectra (right) shows the fundamental frequency and harmonic frequency peaks.

Dampening bow vibrations changes acoustic power and harmonic ratio in a note-dependent fashion

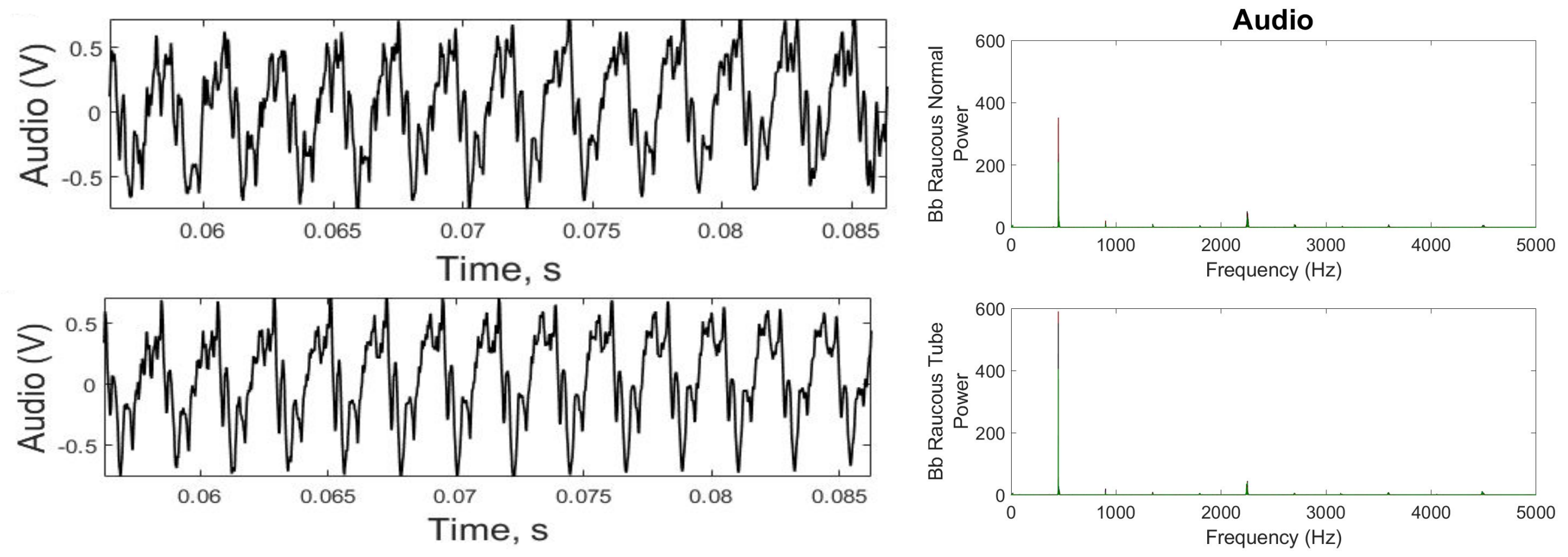


The bar graphs show the ratio of power of the fundamental frequency to total power for various notes (normal sound). *P*-values determined by Student’s *t*-tests (n=10). G, D, A open strings and Ab (G-string) showed statistically significant (p>0.05) increase in harmonics with tubing (decrease in the fundamental frequency power ratio). Eb (D-string) and Bb (A-string) showed insignificant (p>0.05) and significant (p<0.05) dampening of harmonics with tubing, respectively.

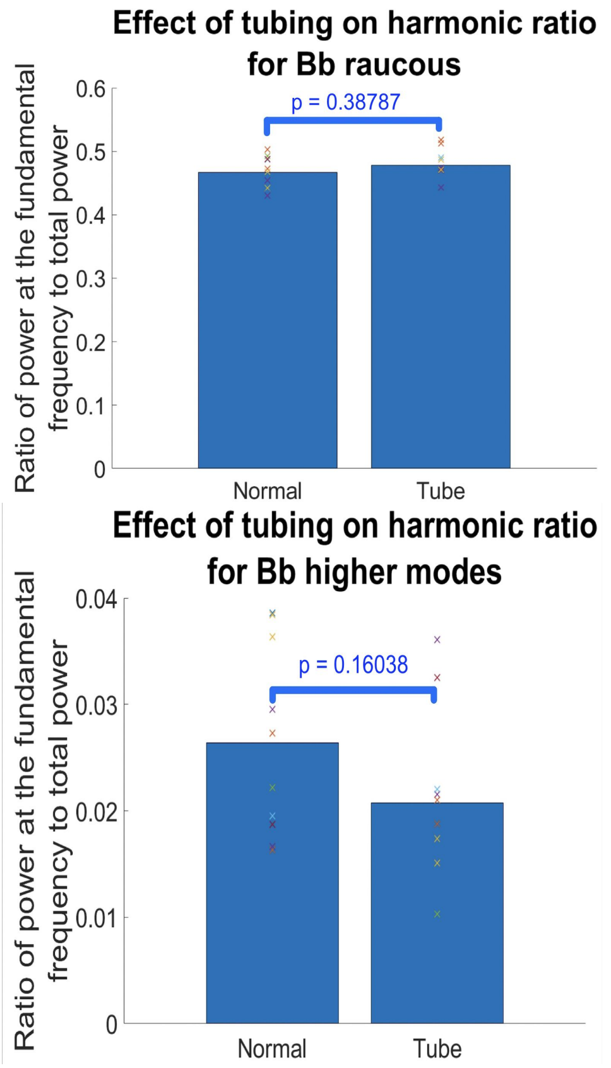
Tubing changes acoustic output for higher mode and raucous sounds



When playing the Bb note with higher mode sounds, tubing (bottom panel) showed lower power in the harmonics peaks.



When playing the Bb note with a raucous sound, tubing (bottom panel) increased fundamental frequency power.



Raucous notes have smaller harmonic power ratios, higher-mode sounds have larger power harmonic ratios

The higher modes of Bb showed a mean ratio of harmonics power to total power of 0.975 while the raucous showed only 0.55 (n=10). Tubing dampened the harmonics for raucous while surprisingly slightly increased that for higher modes, likely due to the fundamental frequency power ratio being so small. For both the raucous and higher modes, we did not find a difference between the normal vs. tube (p>0.05).

Conclusions

- Dampening of the bow using rubber tubing consistently decreased vibrations in all directions.
- Dampening bow vibrations changed acoustic power and the harmonic ratio in a note-dependent fashion.
- Vibration shifted stick-slip oscillations in a complex way and its effect on sound depended on the note being played. These observations supported the idea that bow properties indeed influence violin sound.
- A raucous-like sound showed a smaller harmonic power ratio, and a surface sound showed a higher harmonic power ratio.
- Future work will focus on understanding how bow vibrations interact with string oscillations.
- Variation in harmonic dampening with tubing among different bow materials (wooden, carbon fiber, fiberglass) will be studied in the future.
- Follow-up work will artificially change the vibration of a bow with a speaker to examine how it affects the motion of the string, thereby further testing how vibrations change Helmholtz motion.
- A future project may address how bow properties affect subjective perception of tonal qualities.

Acknowledgements

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