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A preliminary study on the influence of violin bow rotational inertia on bouncing strokes

Víctor Salvador Castrillo¹

Équipe Lutheries-Acoustique-Musique, Institut Jean Le Rond d'Alembert, Sorbonne Université, CNRS UMR 7190, 4 place Jussieu, 75005 Paris, France

Frédéric Ablitzer²

Laboratoire d'Acoustique de l'Université du Mans (LAUM), UMR 6613, Institut d'Acoustique – Graduate School (IA-GS), CNRS, Le Mans Université, 72085 Le Mans, France

Claudia Fritz³

Équipe Lutheries-Acoustique-Musique, Institut Jean Le Rond d'Alembert, Sorbonne Université, CNRS UMR 7190, 4 place Jussieu, 75005 Paris, France

ABSTRACT

Prior perceptual tests using an experimental bow whose moment of inertia (relative to the pivot around the thumb) could be modified by moving small masses along the stick have indicated that violinists exhibit significant sensitivity to this parameter. This sensitivity was particularly notable when playing bouncing strokes like sautillé: some players reported perceiving a shift in the bouncing point, which refers to where the bow naturally bounces. Using the same experimental bow, we wanted to investigate further this influence of the bow rotational inertia. Through modal analysis, we examined the influence of moment of inertia on the bow's dynamic behavior. Additionally, a playing experiment involving motion capture was conducted on one player to explore how his control parameters were affected by a change of moment of inertia. This is of interest for bow makers as they can easily adjust the moment of inertia without affecting the stick's integrity by just varying the weight of the tip plate.

1. INTRODUCTION

The art of playing the violin requires a good mastering of all the different bow strokes. In Western violin technique, some strokes involve a bouncing movement with the bow jumping off the string, like *sautillé*. In this particular bow stroke, the bouncing movement is left principally to the stick, with minimal intervention of the violinist to this behavior [1]. However, the *sautillé* may fail if it is attempted at a wrong place, which violin pedagogue Lucien Capet [2] fixed at the third, fourth and fifth eighths of the bow depending on the desired speed (Figure 1).

Participants in a previous study [3] were found to be significantly sensitive to changes in the moment of inertia of the bow. Under this modification, many of them noticed a change in the

¹victor.salvador_castrillo@sorbonne-universite.fr

²frederic.ablitzer@univ-lemans.fr

³fritz@lam.jussieu.fr

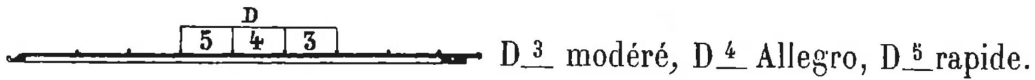


Figure 1: Best divisions for the performance of *sautillé* bow stroke, from [2].

sautillé point (which can also be called *spiccato* point), being more towards the tip for the bow with higher moment of inertia.

Given that this parameter appears to be of concern to many violinists, in the present study we focus on the influence of the moment of inertia on the position of the *sautillé* point. We performed modal measurements of two bows with contrasting rotational inertia, and we conducted a playing test with a violinist in a motion capture system. Finally, we calculated the bouncing frequency from the motion capture data and compared it with the modal measurements.

2. MATERIALS AND METHODS

2.1. The experimental violin bow

For this study, we reused the same experimental bow built by bow-maker Duilio Spalletta for the previous study [3]. This particular bow is very light, so that we can reach the standard weight of 60 g by adding small neodymium magnets along the stick: at the tip, where a small magnetised nickel plate was glued; at the lowest half of the stick, where a metallic clamp was placed 15 cm away of the start of the hair; and at the button, which was also magnetised (see Figure 2).

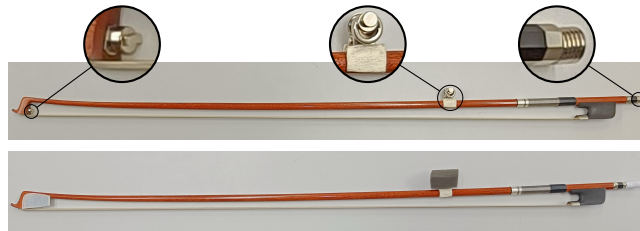


Figure 2: Experimental bow with added masses. Above: detailed view of the magnets. Below: perspective of the bow from participants, showing the paper-covered tip and frog magnets and a lightweight foam covering the magnetic clamp.

In Table 1 are depicted the two different mass distributions that were considered for the present study. In order to keep consistency with our prior investigation [3], we kept the same labels for both bows: *A* for the bow with lower moment of inertia and *C* for the one with higher moment of inertia. Refer to the same paper for further details on the bow and how its mechanical properties were measured.

Using Steiner's theorem to calculate the moment of inertia about an axis passing through the center of mass, the position of the center of percussion from the pivot point is calculated as:

$$x_{COP} = x_{CM} + \frac{I - m_b x_{CM}^2}{m_b x_{CM}}, \quad (1)$$

where I is the moment of inertia about the pivot point of the bow, m_b the total mass of the bow and x_{CM} the distance between the center of mass and the pivot.

2.2. Modal frequencies of the bow on a simple support

The modal measurements were largely inspired by the work of Gough [4], but instead of placing the accelerometer at the tip, it was placed at the frog in order to not artificially increase the moment of inertia. Moreover, instead of using a rigid support at the frog, we chose to use a simple support by

Table 1: Bow mass configurations tested by the musician in the study, along with their corresponding mechanical attributes. $\Delta m_t, \Delta m_c, \Delta m_f$: additional masses at the tip, clamp, frog. The masses of the clamp, foam, and paper covering the magnets (see Figure 2, bottom) are accounted for. m_b : total bow mass; x_{CM} : distance from the center of mass to the pivot point (showed in Figure 3); I : moment of inertia relative to the pivot point; x_{COP} : distance from the center of percussion to the pivot point.

Bow	Δm_t (g)	Δm_c (g)	Δm_f (g)	m_b (g)	x_{CM} (cm)	I (gm ²)	x_{COP} (cm)
A	+0.14	+6.88	+0.77	60.05	19.5	4.95	42.3
C	+1.75	+1.91	+4.27	60.15	19.5	5.52	47.1

hanging the bow from a hook at the same point where violinists typically place their thumb. This adjustment aimed to create conditions more closely resembling those of actual playing.

However, for the sake of simplicity, we chose not to use a string support for the hair-string contact point. Instead, we used a simple support as shown in Figure 3. This implies that the modal frequencies obtained from this measurement follow the assumption that the string is completely rigid under the vertical force of the bow, which is not the case in reality. The hair tension remained consistently at 46.5 N, and it was measured from the stick deflection using the software PAFI [5, 6].

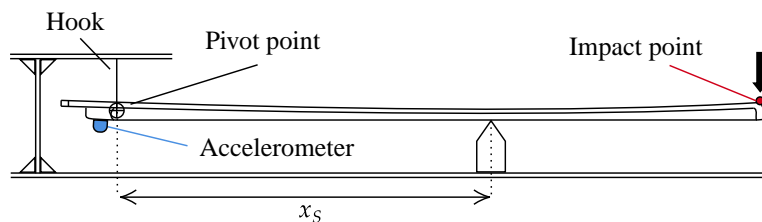


Figure 3: Set-up for the modal measurements.

The procedure to measure the modal frequencies was as follows. First, the bow was suspended from the pivot point using a metallic hook, with a velvety fabric attached to prevent undesired bouncing of the stick. Then, a mobile rigid wedge was placed at the first distance x_S of interest, ranging from 30 to 64 cm at 2 cm intervals. The wedge's tip was a flat surface measuring 2 mm in width. A lightweight accelerometer was affixed to the frog of the bow, as illustrated in the figure, recording at a sampling rate of 51200 Hz. Subsequently, a soft impulse was applied to the bow's tip with a light impact hammer, ensuring that the bow did not rebound off the wedge upon impact and maintaining continuous contact between the hair and wedge.

For each position of the wedge, three impulses were applied to the bow, and the resulting acceleration responses were recorded. Modal frequencies were identified using a peak-picking algorithm applied to the averaged discrete Fourier transform. For the purposes of this study, we only focused on the first two modes.

2.3. Motion capture and bowing parameters

Bow and violin motion data were recorded using an OptiTrack motion capture system with 9 Flex 13 cameras, operating at a frame rate of 120 Hz. A set of reflective markers were strategically placed at different points of both elements (see Figure 4), highly inspired by the thesis of Schoonderwaldt [7]. However, we carefully chose a smaller marker for the tip in order to keep the values of the moment of inertia as less altered as possible. Additionally, like in [7], four calibration markers were placed at the ends of the G string and of the bow's hair during the solid body identification. These markers were removed for the test, and their positions were inferred from the fixed distances

relative to the other markers.

In this study we focused on three bowing parameters, which were calculated geometrically from the calibration points. The bowing point on the string was calculated as the intersection between the string and the projection of the hair on the plane containing the string and parallel to the hair. The bowing point on the hair was calculated analogously.

- Bowing point-bridge distance x_H : distance between the bowing point on the string and the marker at the bridge, that is, where the Hair is located in the string's reference frame.
- Bowing point-frog distance x_S : distance between the bowing point on the hair and the marker at the frog, that is, where the String is located in the hair's reference frame.
- Hair-string distance x_{HS} : minimal distance between the hair and the string. It is positive when the hair is not in contact with the string (that is, when the line containing the frog and tip markers is above the line containing the bridge and nut markers, see Figure 4), and negative when it is in contact (due to the hair and the string deflection).



Figure 4: Markers placed at different points of the violin and the bow. The markers on the string and on the hair were used just for calibration, and removed for the test.

2.4. Measurement of bow's bouncing frequency on the string from hair-string distance

The *sautillé* stroke involves two phases [2]: on-the-string and off-the-string. In the first one, the hair is in contact with the string and both deflect, leading the hair-string distance to follow an approximately sinusoidal pattern. In the second phase, corresponding to the off-the-string phase, the bow jumps off the string.

It may be possible to calculate the frequency of the on-the-string phase from the measured hair-string distance, by simply fitting a sinusoidal function to the negative x_{HS} points (Figure 6). The average frequency of this phase could be compared with the modal frequencies calculated from the set-up shown in Figure 3, as a function of the bowing parameter x_S which is also measured using the motion capture system.

2.5. Playing test

We have designed a playing test in which violinists are instructed to find the point (x_H, x_S) where they perceive the greatest comfort when making the *sautillé* stroke, in order to understand how the moment of inertia affects it. For this purpose, we consider the two bows presented in Table 1.

Two test cases are considered for each bow: *sautillé* in *piano* and in *forte*. For each of them, violinists perform six trials in total: three where they start searching from the tip, and three from the clamp (visual reference located 15 cm above the frog, see Figure 2). At the beginning of each trial, musicians are asked to position the bow at the corresponding point and to start bowing the string up and down at a constant pace. The rhythm defined for the test is 8 notes per second. To set this rhythm, a metronome is played at 120 bpm, so that participants must adjust their bowing to play 4 notes between each beat of the metronome. Keeping this rhythm, musicians are invited to move the bow until finding the “sweet spot”. Once they have found the bouncing point, they have to sustain the *sautillé* for at least five seconds.

This paper presents the results obtained with the first participant (a semi-professional violinist with 18 years of experience) while only playing on the G string. During the test, the tension of the hair was fixed to 46.5 N, the same as for the modal measurements, and no adjustment to this parameter was allowed.

3. RESULTS AND DISCUSSION

3.1. Motion capture

3.1.1. Estimation of x_S and x_H

The results of the playing test are shown in Figure 5. In both cases, the distance is represented as a smoothed signal, to avoid the periodic oscillations corresponding to the back-and-forth motion of the bow during *sautillé*. The smoothing was performed using a Savitzky-Golay filter with a window length of 51 samples and a second degree polynomial (the sampling rate of the motion capture system was of 120 Hz). At the end of each curve, a horizontal line is plotted, representing the average smoothed distance in the last five seconds of the test for each trial. The averages and standard deviations (error bars) shown at the right of both figures are calculated considering only the last 5 seconds of the smoothed function corresponding to all trials.

From these results, we observe that the biggest difference in the x_S and x_H values correspond to the difference of dynamics: in *forte*, the player approached the bridge and played at a x_S distance of about 25 cm, whereas in *piano*, he approached the fingerboard (*sul tasto*) and got closer to the tip. Concerning x_H (Figure 5a), we did not observe a significant difference between both bows: the violinist seems to play at the same x_H spot no matter which bow he is using, for a given dynamic. Regarding x_S (Figure 5b), however, there seem to be a difference between both bows when playing *sautillé* in *piano*, with the bow *C* having a bouncing point closer to the tip (higher x_S) than the bow *A*. Although the difference is not statistically significant, bow *C* appears to be more controllable in a higher x_S (about +4 cm) position than bow *A*. This could be caused by the difference in the position of the center of percussion x_{COP} (+4.8 cm for bow *C*) as suggested by Gough [4].

3.1.2. Estimation of the bouncing frequency from x_{SH}

An example of sinusoidal curve fitting to the hair-string x_{HS} distance in the on-the-string phases is shown in Figure 6. From these fits, we calculated the average bouncing frequency of these phases in the last 5 seconds of all six trials for each one of the four cases. These values and their standard deviation are plotted alongside the modal measurements in Figure 7.

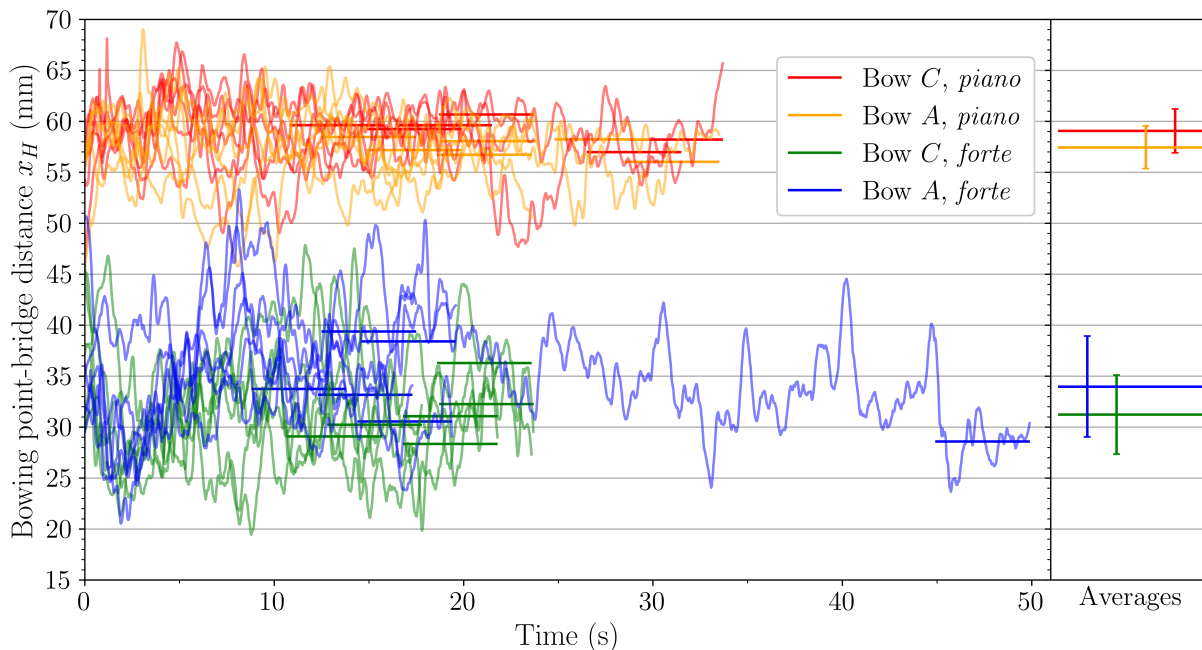
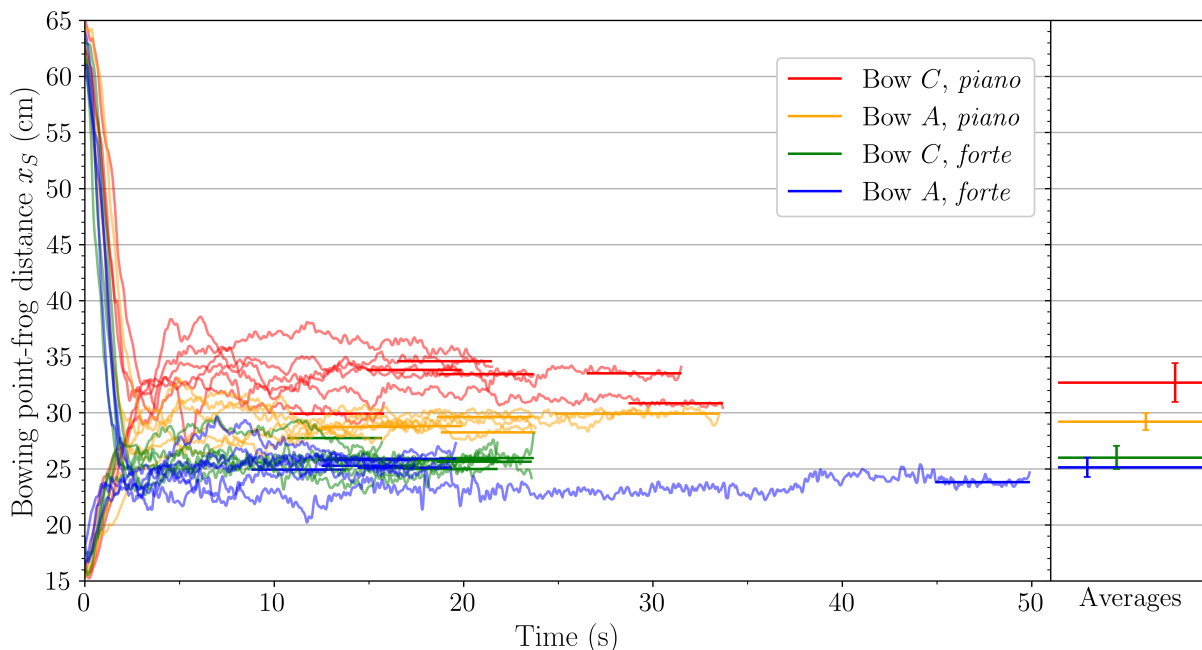

 (a) Position of the hair on the string x_H .

 (b) Position of the string on the hair x_S .

 Figure 5: Results of the playing test, consisting in finding the *sautillé* point.

3.2. Modal measurements

The modal frequencies of the first two modes of the bow on a simple support (made with the setup shown in Figure 3) are depicted in Figure 7. We obtain results very similar to those of Gough [4]. The differences between both bows are very subtle for the first eigenfrequency, whereas bow A has a slightly higher second eigenfrequency than bow C for most of the bowing point positions. The predictions of Askenfelt and Guettler's quasi-static rigid-stick model [8] are represented as a discontinuous lines for both bows, which differ only in their moments of inertia since their hair tension is the same. We observe that the first eigenfrequencies predicted by this model are slightly lower than the measured values in the middle of the bow (x_S between 30 and 36 cm), as illustrated

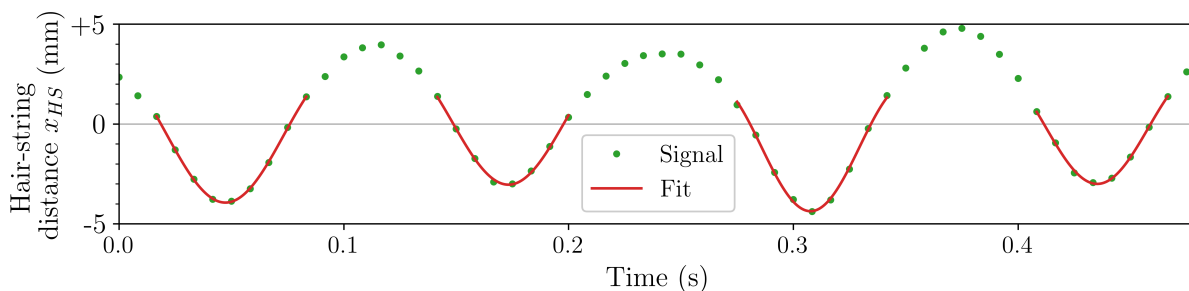


Figure 6: Example of sinusoidal curve fit to calculate the bouncing frequency of the bow in contact with the string from motion capture.

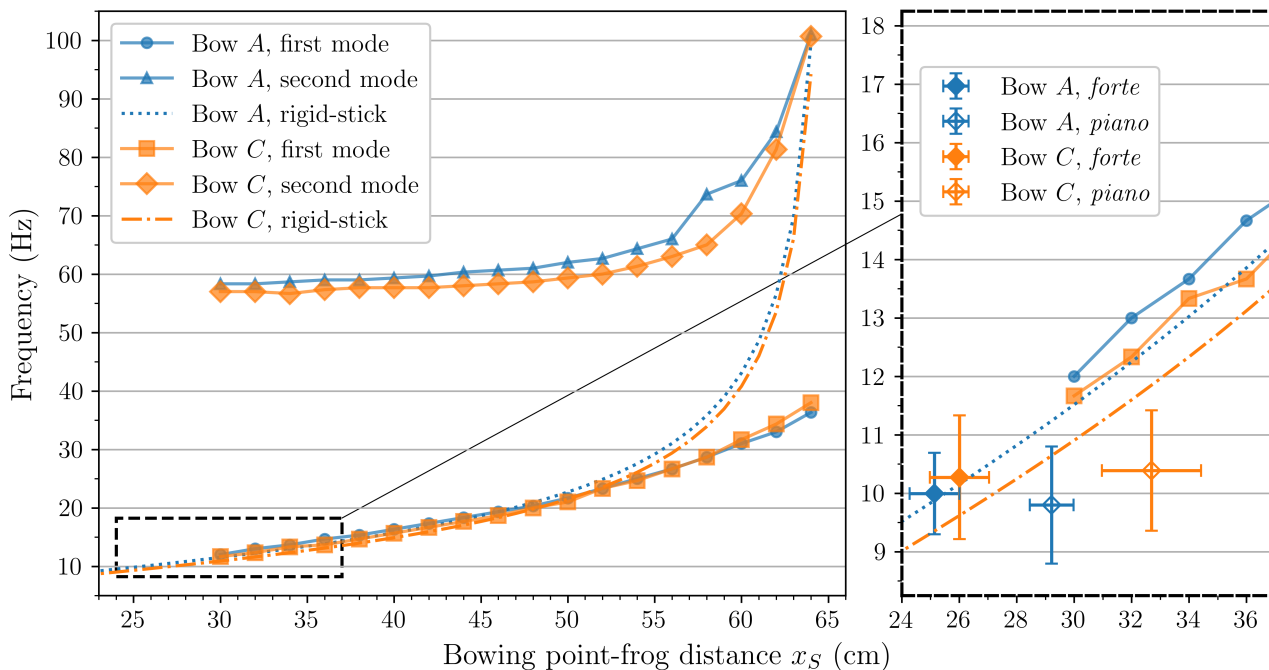


Figure 7: Left: modal frequencies measured from modal analysis. Right: zoom on the x_S positions where the participant performed the *sautillé*, with scattered data points representing the corresponding bouncing frequencies calculated from motion capture. Error bars indicate standard deviation.

in Figure 7 right. This might be caused by inaccurate measurements of the bow's rotational inertia or hair tension.

In Figure 7 right, the bouncing frequencies and x_S positions calculated from motion capture data are represented alongside the first mode for both bows. The bouncing frequencies are quite similar between all four cases, but not the bouncing point, which differs significantly between the two dynamics. While the *forte* bouncing frequencies correspond to the predicted eigenfrequencies, the *piano* bouncing frequencies are lower. The reason for this might be linked to the difference in the x_H distance when playing *piano* or *forte*. In *piano*, since the player hits the string further away from the bridge, the vertical stiffness of the string becomes lower. This change lowers the first eigenfrequency of the bow-string system, as was already noted by Askenfelt [9].

Note that, given the very small mass of the motion capture markers (equal to 0.02 g for the one at the tip and less than 0.3 g for the others), their impact on the moment of inertia and on the eigenfrequencies is negligible (less than 0.3%).

4. CONCLUSION AND PERSPECTIVES

This preliminary study aimed at investigating the influence of the bow's moment of inertia on bouncing strokes, specifically *sautillé*. We used an experimental bow whose moment of inertia could be adjusted by adding small masses to different parts of the stick. Two distributions were considered, with contrasting moments of inertia but fixed total mass and center of mass.

Modal measurements were made on the bow in contact with a wedge, from which we extracted the first two eigenfrequencies of the two bows for different positions of the contact point along the hair. We also conducted a playing test during which a violinist had to find the so called "*sautillé* point" of the bow on the open G string. Different bowing parameters were measured with a motion capture system. This allowed the determination of the *sautillé* point's position in *piano* and *forte* for both bows, as well as the calculation of the bouncing frequency of the bow in contact with the string.

The position of the bow on the string (between the bridge and the fingerboard) varies between *piano* and *forte*, but not between the two bows. The position of the string on the bow (between the frog and the tip) varies as well between *piano* and *forte*, but there seems to be a difference of this position between bows in *piano* of 4 cm. This difference might be influenced by the distinct position of the center of percussion of both bows, separated by 4.8 cm: a closer-to-the-tip center of percussion would lead to a closer-to-the-tip *sautillé* point, since it would be easier to control.

In *piano*, the bouncing frequencies were found to be lower than the measured first eigenfrequencies, which was not the case in *forte*. We speculate that this may be caused by a lower vertical stiffness of the string when playing in *piano* (far from the bridge). Further research is needed to understand the role of the position of the bow on the string when playing this kind of strokes. A larger sample of participants could also help understand the consistency among violinists of the position of this "sweet spot".

REFERENCES

1. Ivan Galamian. *Principles of violin playing and teaching*. Prentice Hall, 1962.
2. Lucien Capet. *La technique supérieure de l'archet*. Ed. maurice Sanart et Cie, 1916.
3. Víctor Salvador-Castrillo, Amélie Picard, Duilio Spalletta, Frédéric Ablitzer, and Claudia Fritz. Towards understanding the influence of mass distribution on the perceived weight and force controllability of a violin bow. In *Forum Acusticum*, page 877, Turin, Italy, September 2023.
4. Colin E Gough. Violin bow vibrations. *The Journal of the Acoustical Society of America*, 131(5):4152–4163, 2012.
5. F Gautier, V Doutaut, and JM Fouilleul. Lutherie tools: projet collaboratif entre ateliers de lutherie et laboratoires. *Musique & technique*, 4:21–28, 2009.
6. Frédéric Ablitzer. *Influence des paramètres mécaniques et géométriques sur le comportement statique de l'archet de violon en situation de jeu*. PhD thesis, Université du Maine, Le Mans, 2011.
7. Erwin Schoonderwaldt. *Mechanics and acoustics of violin bowing*. PhD thesis, KTH, Stockholm, 2009.
8. Anders Askenfelt and Knut Guettler. The bouncing bow: Some important parameters. *TMH-QPSR*, 38(2-3):53–57, 1997.
9. Anders Askenfelt. Observations on the dynamic properties of violin bows. *STL-QPSR*, 33(4):43–49, 1992.