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# Analysis of the influence of different construction factors of violin mutes on their effects: a methodological prospection based on the controlled variation of physical characteristics of the devices

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## Abstract

The article describes prospectings carried out in ongoing doctoral research that aims to develop new prototypes of violin mutes, relying on the analysis of quantitative data extracted from violin recordings under the effect of different types of mutes. These prospectings aim to define an adequate analysis methodology to isolate the contributions of specific physical characteristics of mutes in the alteration produced in the sound of the instruments. The physical features that determine the effects caused by the mutes are the mass added to the system, the area of contact between them and the bridge (part of the instrument to which the mutes are attached), and the nature of their building material. The experiments compare the effect of (a) mutes of the same shape and material, but with different sizes and weights; (b) mutes of the same shape, size, and weight, but made of distinct materials; (c) isolated parts of a segmented mute; (d) the use of a combination of more than one unit of the same kind of mute in different configurations. The paper contains a brief description of violin mutes, the sampling methodology of the violin sound developed for the study, and the selected (psycho-)acoustic descriptors: loudness values, LTAS (Long Term Average Spectrum), and percentage of non-harmonic residual, obtained through SMS (Spectral Modeling Synthesis) from samples collected under different study conditions. Previous results have demonstrated the differences in intensity and timbre caused by diverse mutes. The present methodological investigation contributes to the understanding of the influences of distinct physical attributes of different types of mutes on the overall sound quality of the instrument.

**Keywords:** violin, mute, LTAS, SMS, loudness.

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## 1. INTRODUCTION

This article is part of a broad research effort started in a master's program concluded in 2019 [1] that continues in an ongoing doctorate, which investigates the functioning and effect of violin mutes on the instrument's sound. Initially, we developed audio sampling and analysis methodologies that allowed the extraction of objective data under different study conditions: without mute and under the effects of three types of mutes in six distinct violins, with samples performed by three players. Such an approach allowed us to establish the greater relevance of the mute types in the alteration of the violin sounds when compared to the effects caused by different instruments or different players (provided that the established protocol of execution and recording is respected) [1,2].

With the proposal of developing new mute prototypes based on objective data, the doctoral research kept on with the development of sampling methodologies and more effective and comprehensive analysis tools [3,4]. In this sense, the use of SMS (Spectral Modeling Synthesis) allowed the assessment of the impact of non-harmonic components on the mute effect, complementing the data related to harmonic components obtained with the LTAS (Long Term Average Spectrum). A psycho-acoustic descriptor, the Loudness level (a weighting applied to the intensity values, according to the human auditory sensitivity), is also introduced and provides a perceptually more realistic assessment of the intensity variation produced by the mutes in the original sound of the violin. Likewise, the inclusion of more types of mutes has expanded the possibilities of comparing the physical characteristics of the devices and the different effects they have on the violin's sound.

In this context, the present article reports a series of prospectings carried out to isolate the specific contributions of the different physical characteristics of the mutes in the effects produced on the violin sound. It's essential to understand the relationships between these factors (weight, coupling mechanism with the bridge, and their building material) and the different effects produced to create new prototypes.

The article develops with a brief description of violin mutes, followed by a section that explains the entire methodology used in the present study. Sections four and five present and discuss the results obtained from these prospectings.

## 2. VIOLIN MUTES

Violin mutes (Figure 1) are devices of varying shapes and weights that can be attached to the bridge of the instrument to alter the tone color and soften its sound. Other bowing instruments also use similar devices. The first mentions of the mute's use on string instruments date back to the 17th century[1] [5,6].

**Figure 1** – Different types of mutes for violin selected for the research, with an instrument's bridge to reference the size of the devices.

The mutes can be made of different materials: metals, wood, rubber, synthetic materials, solely or in combinations[2]. The device's main function is to change the timbre, and the decrease in intensity is just a secondary effect. Only in the case of Practice Mutes, the main objective is to radically reduce the intensity of the instrument sound, allowing the practice in

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[1] First score to cite them*: Le Triomphe de l'Amour*, by Jean-Baptiste Lully, composed in 1681[5,6].

[2] More rarely, especially in older devices: ivory, bone, and leather (historically informed performance), among others.

circumstances where the minimum possible sound emission is necessary.

As it is well known, the mute effects are produced by the changes they cause in the vibrational behavior of the bridge, an essential device for the timbre of bowing instruments [7-10]. The variety of effects is related to their physical characteristics, such as mass, rigidity, shape, building material, mechanism, and contact area with the bridge. Scientific research on mutes is scarce, being cited mainly as support for studies on other subjects, especially the bridge, like the works of Giltay and Haas (1909), Cremer (1984), Fletcher and Rossing (2012), and Elie, Gautier and David (2014) [12, 8, 11-13]. Few works beyond that, specifically about the mutes, can be found, such as the research of Jansson and Sundberg (1975), Kishi (1998), Tajimi et al. (2011), Loughridge (2016), and Sarch (2017) [5,6,13-15].

## 3. RESEARCH METHODOLOGY

In the following subsections, the methodology adopted for the prospectings is described in detail.

### 3.1 Strategies to isolate the effects produced by specific physical characteristics of mutes

To determine how different physical characteristics of mutes exert influence on the violin's sonority, both in terms of intensity and tone color alterations, the prospectings developed in the present research sought to compare study conditions in which isolated physical aspects of the devices are altered.

(a) The use of similar mutes (shape and material), however, of slightly different width, isolates the weight variable, considering that the contact area between them and the bridge remains practically the same.

(b) The use of equal mutes (shape, weight, contact area with the bridge) made, however, of different materials, seeks to isolate the impact of this variable on the effects on the instrument's sound.

(c) The use of segmented parts of a previously employed mute allows comparing the impact of the segments – separately and in combination – with the effects produced by the unsegmented mute.

(d) And finally, the use of more than one identical mute (bearing the same weight, shape, and building material) adds more mass to the system and expands the contact area of the devices with the bridge.

### 3.2 Mutes and usage configurations employed in the prospectings

### 3.2.1 Small and large ebony mutes

Small mute weight: 6,44 grams

Large mute weight: 8,38 grams

Classical mute with three prongs made in ebony (Figure 2). The smaller is a violin model, and the bigger one is a viola model.

**Figure 2:** Small (EbSm) and large (EbLg) ebony mutes.

### 3.2.2 Small ebony mute resin replica

Weight: 6,45 grams

Small ebony mute replica made of epoxy resin (Figure 3). It preserves the main characteristics of the original mute, including the weight that is practically the same. It makes it possible to check the construction material as the only variable, and is employed in a single-use configuration.

**Figure 3:** Small ebony mute resin replica (EbSmRep).

### 3.2.3 Parts of segmented small ebony mute

Weight: 2,00 grams (each prong)

Parts of segmented small ebony mute (Figure 4), used in the study in 7 different configurations:

- One unit between each pair of strings (EbSeg_GD[3], EbSeg_DA, and EbSeg_AE);

- Two units between each pair of strings in all possible combinations (EbSeg_GD_DA, EbSeg_GD_AE, and EbSeg_DA_AE);

- Three units between the three pairs of adjacent strings (EbSeg_GD_DA_AE).

**Figure 4**: Parts of segmented small ebony mute.

### 3.2.4 Trimmed one-hole rubber mute

Weight: 1,53 grams (each unit)

One-hole rubber mute with one prong (Figure 5) that can be used on each string separately. The sides of four units have been trimmed to allow placement of up to four of them, one on each string. Used in the study in 15 different configurations:

- One unit on each string separately (rubber_G, rubber_D, rubber_A, and rubber_E);

- Two units on two strings in all possible combinations (rubber_GD, rubber_GA, rubber_GE, rubber_DA, rubber_DE, and rubber_AE);

- Three units on three strings in all possible combinations (rubber_GDA, rubber_GDE, rubber_GAE, and rubber_DAE);

- Four units on four strings (rubber_GDAE).

**Figure 5:** Trimmed one-hole rubber mute.

## 3.3 Recording audio samples

All the samples in the present analysis were recorded with a single violin and bow. The recordings were always performed in the same place by a single violinist, a research team member. Due to the considerable variations that may occur in the sound production and emission of musical instruments, we adopted a protocol of instrumental execution and recording that seeks to standardize as much as possible the records obtained from each reproduction of the sample model, thus allowing comparisons between the different study conditions.

The sample model used in the research consists of an audio file with a recorded sequence of eight glissandos per string, with four seconds in duration each, alternately ascending and descending. Each glissando (recorded with four metronome beats at 60 bpm) starts from the open string and ends at its octave, except for the E string, in which the range goes to the B6 (one 12th). So, the samples include 32 glissandos each, from G3 to B6, distributed over the four strings, from low to high (Figure 6). There is an overlap of frequencies (one perfect 4th) between the initial part of each string and the final part of its lower neighbor, except for the G string. This procedure increases the representativeness of the instrument's sound, marked by the characteristics of each string.

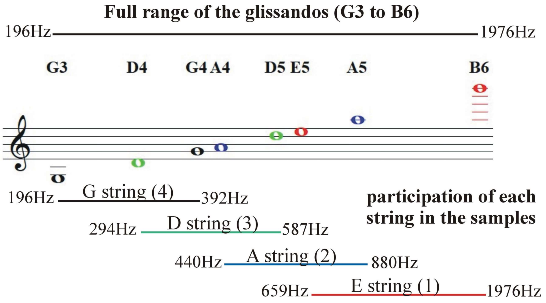

**Figure 6:** Full range of analysis, including the fundamental frequencies of the notes used in the glissandos and their distribution by the violin strings.

The violinist played without vibrato, employing *détaché*[4], as loud as possible

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[3] The letters refer to the tuning of the violin strings, from high to low E, A, D and G (see section 3.3).

[4] Most common and basic bow stroke: the played notes are separated from each other only by the change of bow

(keeping the typical sound of the instrument), at a point of contact of the hair bow and the strings halfway between the bridge and the end of the fingerboard[5], using the whole bow, trying to keep the conduction of the bow as regular as possible[6].

A DPA condenser microphone, model 4099-DC-1-199-V[7], with a super-cardioid directional pattern was used for the recordings. The device was fixed to the instrument using its own clip, positioned approximately 10 cm away from the top of the violin, and pointed at the bridge.

Each sample generated an audio file, measuring 2:08 minutes, with a sampling rate of 48 kHz and 24 bits of depth, in mono format. Two samples were recorded for each study condition for the present article, making a total of 52 samples collected in 26 study conditions: without mute and with 5 different types of mute in 25 different usage configurations.

### 3.4 Employed acoustic and psycho-acoustic descriptors

#### 3.4.1 LTAS (Long Term Average Spectrum)

LTAS is a tool for analyzing the global spectral characteristics of sound records, providing a representation of the average spectral energy of the entire analyzed signal [13,18]. It is a tool widely used in phonetic studies, also with applications in musical acoustics. Such an approach is quite suitable for the present research, which has as one of its objectives the evaluation of the general effect of mutes on the harmonic components of the violin's sonority.

The present study adopted the implementation of LTAS for the MATLAB platform, version 2020a, developed by the Institute of Sound Recording, University of Surrey, England[8]. Like most existing implementations, it uses FFT, which can be thought of as a fixed-bandwidth filter bank, determined by the size of the window in use. The analysis runs through the entire audio file, calculating the spectra of each segment before performing the overall average. The final result is a graph with the frequencies on the horizontal axis and their respective amplitudes on the vertical axis. A window of 4096 points was used, which at a sampling frequency of 48.000Hz, gives us a resolution of 11,72Hz around the center frequencies of each filter, adequate to represent the general contours of the different frequencies covered by the glissandos used in the samples. The spectra were not normalized since the comparative study also involves aspects of sound intensity.

#### 3.4.2 Percentage of non-harmonic residual, obtained by SMS (Spectral Modeling Synthesis)

Spectral Modeling Synthesis was proposed by Xavier Serra and Julius Smith in 1990 [19], consisting of the decomposition of the audio signal into a deterministic and a stochastic part. Assuming that the signal contains these two components, the deterministic part consists of the sum of the sinusoidal components, where each sinusoid corresponds to a component of the original sound, described by a function of amplitude and frequency (implemented through FFT). The stochastic part comprises non-sinusoidal portions of the signal, noise in general, transients, and other non-harmonic components of the sound, as indicated in Equation (1):

$$s(t) = \sum_{r=1}^{R} \mathrm{A}_r(t) \cos\left[\theta_r(t)\right] + e(t), \qquad (1)$$

where $\mathrm{A}_r(t)$ and $\theta_r(t)$ are the instantaneous amplitude and phase of the r^th^ sinusoid, and $e(t)$ is the noise component at time t (in seconds) [19].

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direction, without interruption other than the change itself.

[5] It's the ebony piece that stretches from the nut (below the pegbox) to the middle part of the violin sound box, on which the player presses the strings with his fingers.

[6] For more information about the criteria for defining instrumental performance, see previous publications mentioned. [1-3].

[7] Manufacturer's handbook with technical specifications and response curve available at: https://www.dpamicrophones.com/DPA/media/DPA-Manual/DPI-4099-C-QG-web-091120.pdf?ext=.pdf access in 12/05/2022.

[8] Available at: https://github.com/IoSR-Surrey/MatlabToolbox, access in: 29/04/2020.

In the present study, SMS was also implemented in the MATLAB platform, using the frequency domain approach – as described in detail in DAFX Digital Audio Effects by Bonada et al. [20] – using the codes provided by the same publication. The algorithm extracts the deterministic part of the signal (a set of stationary sinusoids) and synthesizes a new signal. In the frequency domain approach, the stochastic signal is obtained by the estimation of the spectrum of the difference between the original signal and the deterministic signal, and its synthesis is done using white noise filtering. The main parameters adopted for the *hprmodel.m* code (Bonada et al., p. 417 [20]), which returns the harmonic and residual components as separate signals, in addition to the integral resynthesis, were: Blackman-Harris analysis window of 1024 points, FFT resolution of 4096 points, and maximum utilization of 40 harmonics.

For comparing the impact of the use of different mutes on the residuals extracted from the samples, we adopted the strategy of calculating the RMS value of the residual signal of a given sample and comparing it to the RMS of the original integral audio of the same sample, thus estimating a percentage of residual participation in the respective original audio. In this way, it was possible to compare the impact of the different study conditions on residuals.

### 3.4.3 Loudness level (perceived loudness of acoustic signal)

In previous works, RMS values were used to compare the differences in average intensity generated by the use of mutes in relation to the original sound of the violin. However, the introduction of a psycho-acoustic descriptor, which takes into account the difference in sensitivity of human hearing to sound intensity according to its frequency, from a perceptual point of view, allows a better evaluation of the impact of the use of mutes in loudness. Having as a reference the concept of "equal Loudness contours" initially developed by Fletcher and Musson in 1933 [16], the Loudness level makes a specific weighting of the energy registered in the different critical bands encompassed in the audio records. We employed the function *acousticLoudness,* available in the MATLAB platform, version 2020a. This function returns a Loudness value in sones for each sample, according to the ISO 532-1 (2017) technical standard, based on the Zwicker model [17], and allows a general comparison between the different study conditions.

## 4. RESULTS AND DISCUSSIONS

These results are averages of data obtained from the two takes recorded for each study condition. For the LTAS and Loudness Level, the two takes of each study condition were processed together since these tools present an overall average of the analyzed audios. In the case of the percentage of non-harmonic residual, the numbers obtained are averages from the results of each of the two takes of each study condition.

### 4.1 Strategies (a) and (b)

In Table 1, we can see that the larger ebony mute caused a greater loss of intensity[9] concerning the condition without mute than the small ebony mute.

**Table 1:** Strategies (a) and (b) data.

| Single usage configuration | Non-harmonic residual (%) | Loudness (sones) | Intensity reduction (%) |
|---|---|---|---|
| without mute | 0,74 | 34,18 | - |
| small ebony mute (6,44 g) | 0,62 | 27,33 | 31% |
| large ebony mute (8,38 g) | 1,62 | 23,49 | 46,35% |
| small ebony mute resin replica (6,45 g) | 1,79 | 26,30 | 35,26% |

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[9] For the intensity loss calculation, it is used the equation dBA = 33.22 × log (sones) + 28, with a possible accuracy of ± 2, which converts the values in sones to dBA, which is then converted into signal amplitude to calculate the percentage of loss of intensity compared to the without mute condition.

This effect may be directly related to the greater weight of this viola mute since the other physical characteristics of the two devices are similar. This well-known effect, which relates the mutes' action directly to the mass added to the system [7,10,12,14], considers that this extra weight shifts energy to the lower frequencies.

It is possible to observe this effect in the LTAS graph shown in Figure 7, in which there is an increase of lower frequencies energy, between approximately 196 and 280 Hz, produced by the mutes; this effect is more pronounced in the case of the viola mute. However, in the same graph, it is possible to note that the action of the device is more complex than the mere transmission of energy to the low frequencies. We can see that in the range 560-600 Hz, only the small mute produced an energy peak. Likewise, in the graph in Figure 8, which shows the distribution alteration of spectral energy up to 18 kHz, we can see very different behavior between the two ebony mutes in the range 8-14 kHz. In this range, both devices showed an energy gain compared to the condition without mute. This effect produced by ebony mutes was already registered from the beginning of the research [1,3]. In the present case, however, it was reinforced by the heavier mute that caused a greater concentration of energy at the end of this range than the smaller one.

When comparing these results with those of the replica of the small ebony mute, it becomes evident that other factors determine the effects of the devices.

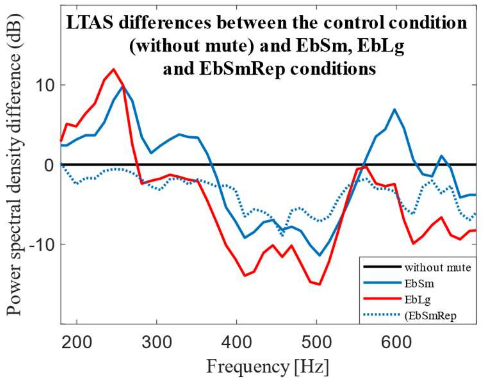


**Figure 7:** Graph of the difference between LTAS with the use of the small ebony mute, larger ebony mute, and small ebony mute resin replica compared to the condition without mute (180-700 Hz).

Although the resin replica has practically the same weight as the ebony original, it generated a greater reduction in intensity. When comparing the LTAS in Figures 7 and 8, we can observe that the replica did not cause a similar increase of energy either in the lower frequencies or in the range between 8-14 kHz, as occurred with the two ebony mutes, which may be related to the greater general reduction of the intensity caused by the replica. The three devices showed a similar behavior – a significant energy loss – only in the range between 400 and 5.000 Hz approximately. Such results suggest different acoustic couplings, including resonance, between the mutes and the bridge, determined by the

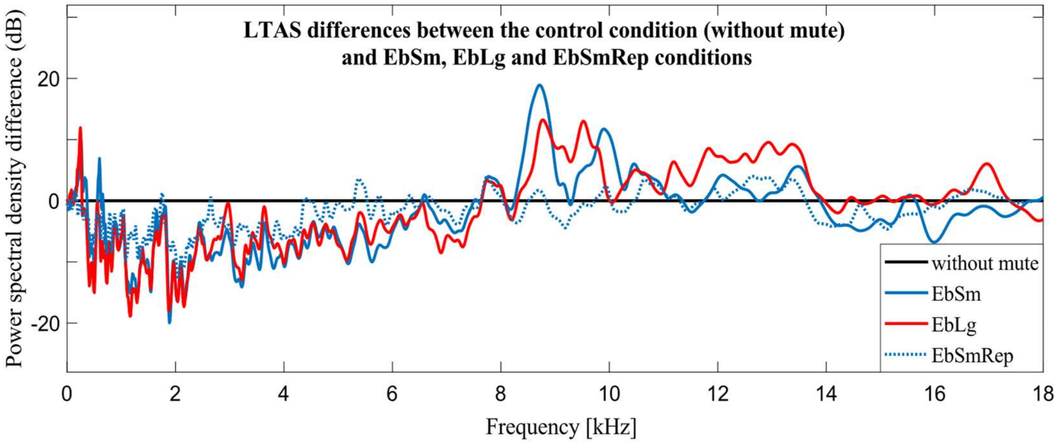


**Figure 8:** Graph of the difference between LTAS with the use of the small ebony mute, larger ebony mute, and small ebony mute resin replica compared to the condition without mute (0-18 kHz).

construction material. Likewise, the large variation in the percentages of participation of non-harmonic residuals of the three mutes suggests other implications since the contact area with the bridge of the three devices is very similar. The reduction of the non-harmonic residual percentage of the small ebony mute and the increase caused by the viola mute may suggest that this factor also depends on the weight. However, the highest non-harmonic residual percentage obtained with the resin replica, which has the same weight as small ebony mute, indicates, as in results obtained previously [4], that the construction material plays a decisive role in this aspect.

## 4.2 Strategy (c)

The use of segmented parts of a small ebony mute resulted in significantly different data from those obtained with the original mute, as depicted in Table 2. The use of a single segment (prong) in each of the three possible positions, between every two strings, caused a reduction in the intensity compared to the original mute. Notably, the use between the D and A strings (EbSeg DA) caused a much greater loss of intensity than in the other two positions.

Considering that each prong has the same weight, it seems that the alteration of the contact area with the bridge in this specific position (DA, in the center of the bridge) compromised the transmission of energy from the strings to the instrument top, leading to a greater loss. Regarding the configuration with two prongs at a time, the three possible combinations had very similar effects, although the EbSeg GD DA combination caused a greater loss of intensity, which may evidence other interactions between the separate segments and the vibrational behavior of the bridge. The use of the three prongs at a time generated an intensity loss practically identical to that caused by the entire mute.

LTAS also showed interesting results. In the graphs of Figure 9, it is possible to observe that the separate use of each of the segmented parts generated a very different spectral energy distribution when compared to the original mute. At the lowest frequencies, up to approximately 300 Hz (graph 9a), it is possible to note that there was a smaller gain in comparison to the original device. Interestingly, to a small extent around 400 Hz, the use of one single segment in the three possible positions generated an increase in energy slightly greater than the whole mute. In the 8-10 kHz range, where the original mute produced a considerable gain, none of the single segment configurations had the same effect, although, between 10-12 kHz, the EbSeg GD and EbSeg DA settings produced a peak, and the EbSeg AE between 12-14 kHz (graph 9b).

**Table 2:** Strategy (c) data.

| **Usage configurations with small ebony mute and segmented small ebony mute** | **Non-harmonic residual (%)** | **Loudness (sones)** | **Intensity reduction (%)** |
|---|---|---|---|
| without mute | 0,74 | 34,18 | - |
| small ebony mute (6,44 g) | 0,62 | 27,33 | 31 |
| EbSeg GD (2 g) | 1,37 | 32,77 | 6,77 |
| EbSeg DA (2 g) | 1,12 | 31,61 | 12,18 |
| EbSeg AE (2 g) | 1,20 | 32,99 | 5,73 |
| EbSeg GD_DA (4 g) | 0,99 | 30,33 | 17,97 |
| EbSeg GD_AE (4 g) | 0,97 | 30,79 | 15,89 |
| EbSeg DA_AE (4 g) | 1,29 | 30,84 | 15,70 |
| EbSeg GD_DA_AE (6 g) | 2,16 | 27,39 | 30,75 |

With two combined segments, an effect similar to the use of one prong in the low frequencies was observed (Figure 10), but the gain greater than that produced by the whole mute occurred in the little lower frequencies, between 350-400 Hz, and was not produced by the EbSeg DA AE configuration, which remained close to the EbSm LTAS.

The most remarkable results, however, were obtained using the three segments at the same time. At low frequencies (Figure 10), it is possible to note that this use configuration

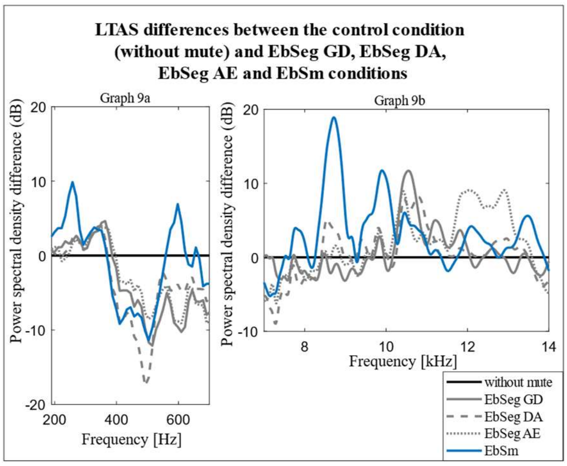


**Figure 9:** Graphs 9a (190-700 Hz) and 9b (7-14 kHz) of the LTAS difference between samples produced with individual parts of segmented small ebony mute (and with the entire small ebony mute) and the condition without mute.

caused transference of energy only between 196-260 Hz, where there was a gain compared to the condition without mute, with a significant peak around 196 Hz (fundamental frequency of the violin G string).

In the Figure 11 stands out an effect between approximately 1.800-3.000 Hz. This region comprises the frequency range of a peak of the violin acoustic response, known as Bridge Hill, linked to the lateral mobility of the bridge [8,9,21]. When the original mute action is observed in this range, a great loss of energy is noticed, which can be directly related to changes in the tone color of the violin. With the use of the three prongs of the segmented mute, this effect does not occur, as with the combinations of two prongs. However, with the three segments used, the mass added to the system is practically the same as that of the whole mute, and this configuration generates the same loss of intensity as the original mute (Table 2). Apparently, the coupling established by the original whole mute between different points on the bridge played a decisive role in the way this one transmits the vibrations to the violin top, determining its spectral distribution.

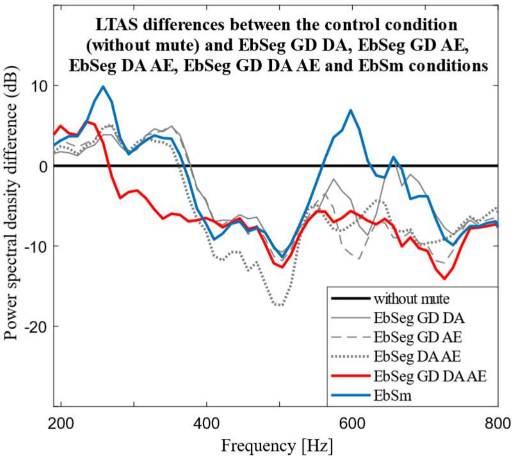


**Figure 10:** Graph of the LTAS difference between samples produced with combinations of two and three parts of the segmented small ebony mute (and with the entire small ebony mute) and the condition without mute (190-800 Hz).

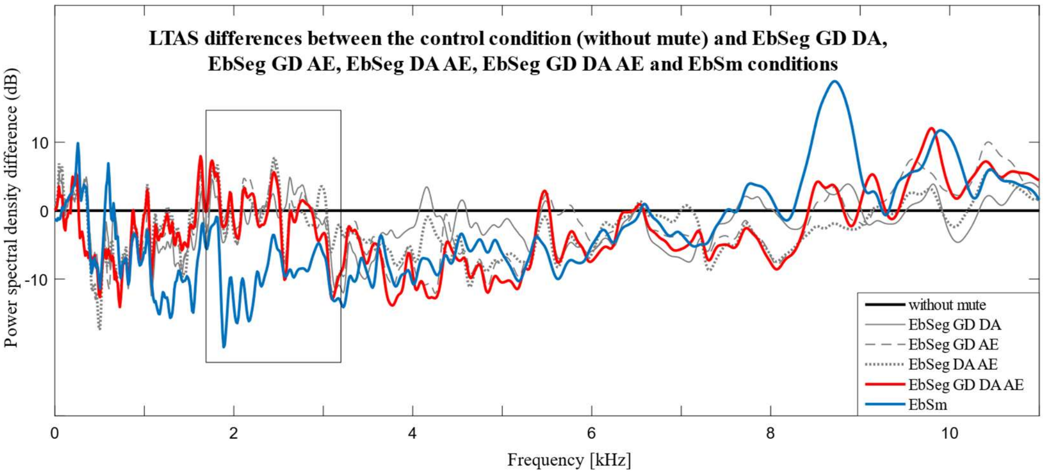


**Figure 11** Graph of the LTAS difference between samples produced with combinations of two and three parts of the segmented small ebony mute (and with the entire small ebony mute) and the condition without mute (0-11 kHz), with the bridge hill area highlighted.

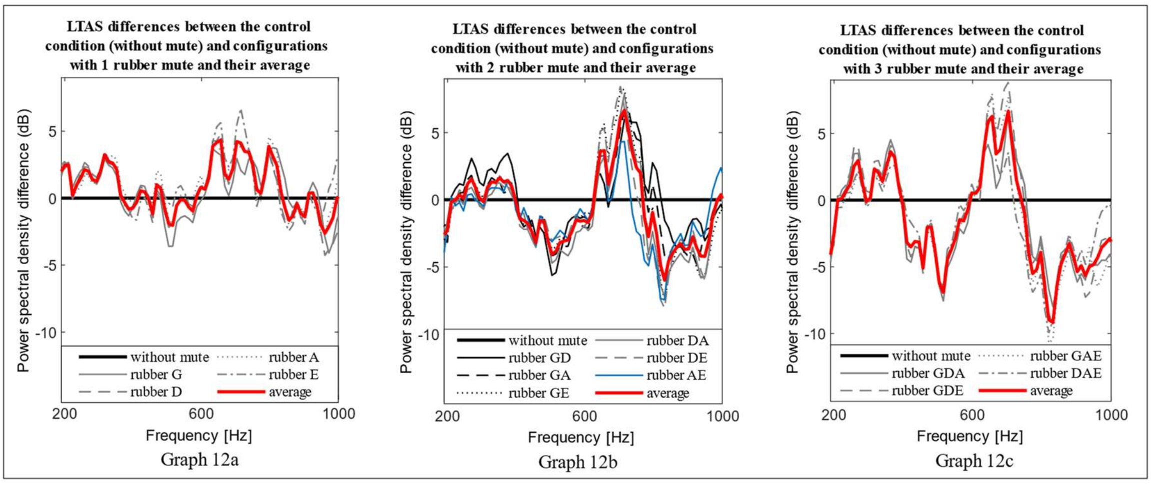
The variation in non-harmonic residual percentages (Table 2) is difficult to interpret. Considering that only the whole mute reduced this parameter, it cannot be associated only with the weight or the construction material, since the isolated prong generated a greater residual than the whole mute. Among the study configurations with the segmented ebony mute, the two lowest percentages are configurations with two prongs (EbSeg GD DA and EbSeg GD AE), which suggests that the point of contact with the bridge is relevant to the way the devices change their mobility. It is also significant that, with the use of ebony mutes and their segments, the highest percentage of non-harmonic residual was obtained with the use of the three segments at the same time, even surpassing the larger ebony mute, suggesting that this parameter depends on the interaction of factors other than weight and building material.

## 4.3 Strategy (d)

The analysis of the intensity loss produced by the use of the one-hole rubber mute (Table 3) displayed a great influence of the location of the contact area with the bridge. The one unit per string use caused a greater loss of intensity in the strings positioned at the edges of the bridge (G and E), which suggests that the overweight at these points causes some imbalance in its vibrational behavior. All configurations of use with two, three, and four units caused greater energy loss than those with one unit. However, it is not possible to relate this effect only to the mass added to the system since the greatest losses occurred with configurations with only three units (in the GDA and DAE strings). The loss produced by two units on the D and A strings stands out (the effect is almost the same as in the configuration with four units) and supports their influence on the three units configurations with larger effects. Considering that these strings occupy the central position of the bridge, it is possible to infer that the increase in mass in this specific region has a greater impact on the energy transmission. One can see in graphs 12a, 12b, and 12c (Figure 12) that the LTAS of configurations using the same number of units showed considerable uniformity in the range 196-1.000 Hz. In addition, the energy transfer in this region is not similar for single and multiple units configurations. With one unit, it is possible to observe a more scattered patterns, while the multiple use cause concentrations around 200-400 and 600-800 Hz. Broadly, the LTAS of the configurations with two and three units were reasonably close to the LTAS of the four units (Figure 13). The use of one unit proved to be more distinct, with less energy loss in most of the analyzed range, excepting peaks in some regions, notably in the range 5.200-5.800 Hz. Between 6.200 and 6.700 Hz, all usage configurations caused gain over the without mute condition (Graph 13b). In the low frequency range, the energy loss caused by the four units use is significantly greater than of the other configurations with fewer units (Graph 13a).

**Table 3:** Strategy (d) data.

| **Usage configurations with trimmed one-hole rubber mute** | **Non-harmonic residual (%)** | **Loudness (sones)** | **Intensity reduction (%)** |
|---|---|---|---|
| without mute | 0,74 | 34,18 | - |
| rubber_G (1,53 g) | 0,81 | 31,54 | 12,46 |
| rubber_D (1,53 g) | 0,76 | 32,74 | 6,90 |
| rubber_A (1,53 g) | 0,70 | 32,11 | 9,83 |
| rubber_E (1,53 g) | 0,87 | 31,61 | 12,17 |
| rubber_GD (3,06 g) | 0,70 | 29,21 | 22,93 |
| rubber_GA (3,06 g) | 0,84 | 27,56 | 30,03 |
| rubber_GE (3,06 g) | 0,91 | 27,57 | 30,01 |
| rubber_DA (3,06 g) | 0,85 | 26,52 | 34,35 |
| rubber_DE (3,06 g) | 0,85 | 26,82 | 33,11 |
| rubber_AE (3,06 g) | 0,88 | 26,66 | 33,81 |
| rubber_GDA (4,59 g) | 0,72 | 26,18 | 35,77 |
| rubber_GDE (4,59 g) | 0,77 | 27,54 | 30,12 |
| rubber_GAE (4,59 g) | 0,94 | 26,49 | 34,47 |
| rubber_DAE (4,59 g) | 0,91 | 26,27 | 35,39 |
| rubber_GDAE (6,12 g) | 0,80 | 26,39 | 34,90 |



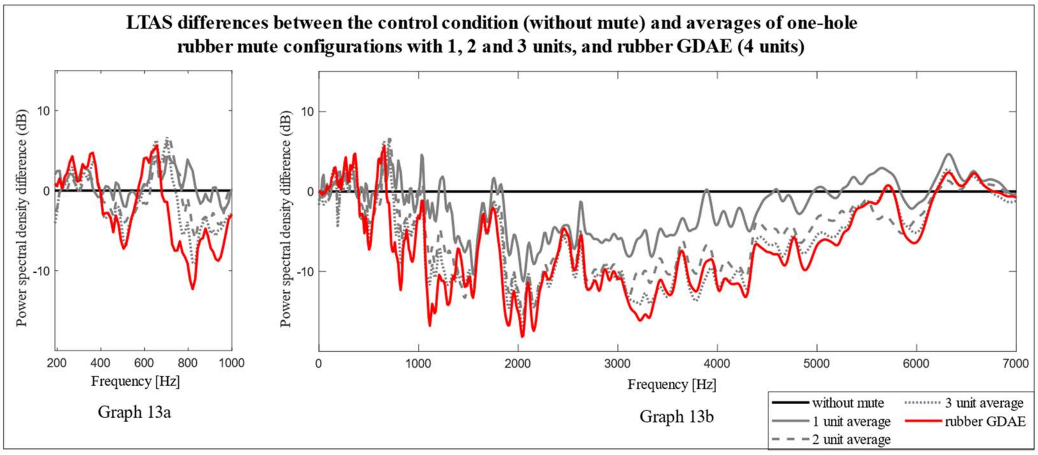
Graph 12a Graph 12b Graph 12c

**Figure 12:** Graphs 12a (1 unit), 12b (2 units) and 12c (3 units) of the difference between LTAS with the use of the one-hole rubber mute in configurations with 1, 2 and 3 units (and their averages) compared to the condition without mute.

The variation in non-harmonic residual percentages was small and inconclusive. Only three study conditions showed a reduction in the percentage compared to the control condition: with one unit on A string, two units on G and D strings, and three units on G, D, and A strings. The highest percentages (above 0,90%) were obtained with usage in GE, GAE, and DAE strings, above the residual estimated for four units (0,80%). Although there was no clear trend of reduction of non-harmonic residual registered in previous studies with the rubber mutes use [4], most of the results obtained remained close to the values of the without mute condition. It is clear that, in addition to the construction material, the interaction between the contact point with the bridge and mass, in this strategy where 15 different study configurations were evaluated, had a significant influence on the results.

## 5. FINAL CONSIDERATIONS

The prospectings developed in the present study proved to be effective for advancing a methodology that relates isolated physical characteristics of violin mutes with their specific effects. The employed methodology generated sufficient data to significantly advance the understanding of the role of each physical characteristic of the mutes in the effects it produces. However, the issue is complex, and drawing solid conclusions from the results is difficult, given that the interaction between the different physical features (weight, construction material, and coupling with the bridge) blurs their isolated effects compared to the specific changes observed in results. It was also found that the extension of the contact area and the different contact points with the bridge are two distinct factors that can produce



Graph 13a Graph 13b

**Figure 13:** Graphs 13a and 13b of the difference between LTAS of the averages of the one-hole rubber mute use in configurations with 1, 2 and 3 units, and the use of 4 units, compared to the condition without mute.

different effects. Concerning the evaluation of changes in the percentages of non-harmonic residual, we felt the need to expand the sampling, possibly using other types of mutes that reinforce specific variables to isolate their impact. Weighting the role that the physical characteristics play separately, enabling a better understanding of how the interaction between the various factors analyzed takes place, is the challenge for the research continuation.

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