

STUDY OF THE ACOUSTIC PROPERTIES OF VIOLINS IN THE CONCERT HALL VERSUS THE ANECHOIC CHAMBER

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Abstract:

Numerous studies highlight the analysis and modeling of the characteristics of the musical timbre of violins, obtained on the basis of the acoustic perception of the experienced subjects, the acoustic quality of the violins being interpreted on the basis of the statistical analysis of the psycho-acoustic impressions. Also, there are studies on the structural behavior of the violin to determine signature modes. However, the analysis of the radiated frequency response in three overlapping regions, as described in the literature, have been less studied. In this sense, the paper presents the study of the behavior of a historical violin, on the entire audio range, examining the frequency response function. The acoustic signal is produced by the excitation of the strings by the violinist, and the recording of the acoustic signals was made both in a concert hall and in an anechoic chamber. The results in the form of acoustic spectrograms, frequency spectrum, magnitude, and power spectrum density for each receiver were analyzed comparatively between the two acoustic spaces, the sounds emitted by the violins are amplified or dampened.

Key words: concert hall; acoustic spectrograms; frequency spectrum; magnitude; interaural level differences.

INTRODUCTION

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Violin manufacturers are concerned with the acoustic quality of the instruments they produce, especially since they are unique due to the wood used, customized elements and the carefulness with which they are made. One of the acoustic characteristics regarding the quality of musical instruments is the acoustic radiation. The sound radiation of musical instruments is complex due to the interaction between the components of the body of the instrument that vibrate, radiate and reflect, and the air in the space where the acoustic source is (Woodhouse 2014; Gough 2015; Jiang et al. 2020; Hutchins1981; Marshall 1985; Gough 2021). The sound of violins contains numerous spectral, temporal and spatial characteristics, such as: musical scale, dynamics, timbre of sound, temporal envelope of sound, characteristics of sound radiation (Schleske 2002; Bissinger 2008; Stanciu et al. 2022; Nastac et al. 2022). A resonator body radiating with its entire surface in phase radiates as a monopole for wavelengths longer than the radiating body, typically for frequencies below 500Hz. Acoustic sources small compared to the radiated wavelengths can be considered point sources whose wave front is a sphere that grows concentrically around the source.

The amplitude on this wave front can be direction dependent. This directional dependence varies with frequency and is caused by the interference of sound radiation from different areas of the violin body (vibration modes), emissions from f-holes, directional radiation such as diffraction and the acoustic shadow behind the instrument and the instrumentalist. The directional characteristic of a frequency is usually independent of dynamics, but sometimes depends on the key note played, especially in the stringed instrument family (Mihălcică et al. 2021; Stanciu et al. 2022b; Tronchin et al. 2004; Desainte-Catherine & Hanna 2000; Henning 1974). Experimental studies on the resonance body of violins in different cases (without strings or with blocked strings) revealed the existence of normal modes of vibration, specific to the violin as an instrument: vibrations of the resonator (air), vibration of the faceplate, vibration of the back, vibration of the sides. Sometimes the bridge or fingerboard/neck can couple to these modes, increasing the number of modes and values. The most important modes for the frequency range up to 1000Hz are designated as B0, A0, A1, B1-, CBR, B1+ (Schleske 2002; Bissinger 2008; Gough 2015; Stanciu et al. 2022b; Tronchin et al. 2004).

These so-called normal modes are connected to the vibrations of the air inside the violin body and also to different types of vibration modes of it. The values of the frequencies of these modes, as they were identified on the violins analyzed by the researchers, are approximate (B0 = 230Hz, A0 = 279Hz, CBR = 400Hz, B1- = 452Hz, B1+ = 534Hz), with the possibility of deviations of to these values from one violin to another because practically no two violins are identical (due to material changes and small manufacturing changes (Bissinger 2008; Bucur 2016; Zubi 2018; Stanciu et al. 2022c). At frequencies above 700 Hz, when the violinist plays the violin, the total damping increases so much that the modes overlap, giving rise to transition modes (Stanciu et al. 2022b).

The A0 normal mode refers to the first air resonance mode, or Helmholtz resonance, of the violin body being characterized by strong acoustic radiation. The A1 mode is the second air resonance mode and the first longitudinal mode (according to (Green & Kahle 2018), it is also an important vibration mode). Mode B0 is the first bending mode of the instrument body. The B1- and B1+ modes are bending modes of the strongly radiating corpus. The CBR mode (rhomboidal mode) is a corpus mode with shear-like motion between the top and back plates and has relatively low acoustic radiation. Next in order is mode C4, which is a corpus mode, and after that, other higher modes, e.g. C5, A2, A3 (Hutchins 1981; Marshall 1985; Gough 2021). These modes, which constitute the instrument's acoustic signature, are an important criterion for controlling its quality, or for dating and determining its origin.

OBJECTIVE

The objective of the paper is to study the acoustic quality of a violin in a concert hall versus in anechoic chamber, the frequency spectrum, as well as the magnitude and power spectrum density for each receiver being investigated and analyzed comparatively, highlighting the fact that depending on the position of the receivers in the concert hall, the sounds emitted by the violins are amplified or dampened.

MATERIAL, METHOD, EQUIPMENT

Material

In this study, the acoustic behavior of a historical violin, the Klotz 1747, was analyzed (Fig.1). The researchers believe that Joseph Thomas Klotz (1743–1819), the son of Sebastian Klotz, one of Stainer's best disciples and followers, having his workshop in Mittenwald (Germany), built violins after his father's system-but knowing the qualities of the wood better, he obtained instruments superior in tone, but with a less shiny varnish (Mihălcică et al. 2021; Stanciu et al. 2022c). Regarding the anatomical features of spruce and maple wood from top and back plates of Klotz violin (denoted Klotz 1747), the average value of annual rings widths for spruce plate is 1.251mm and for back plate, 1.063mm. Imaging analysis of old violins using CT scanning, reported by (Mihălcică et al. 2021) from a constructive point of view, the resonant bar is made by roughing the front plate, being a volumetric element on the inside of the top plate (Fig. 1).

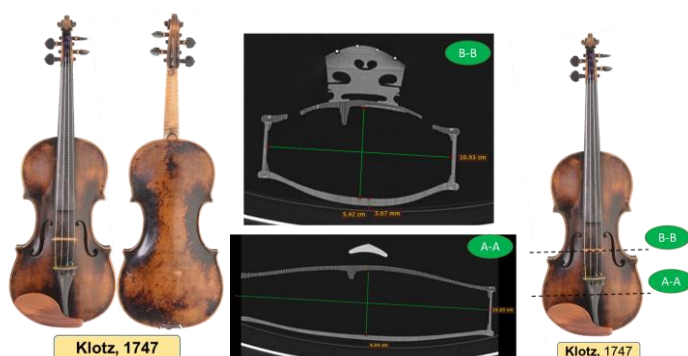


Fig. 1.
The Klotz 1747 violin.

Recording in a Concert Hall

The studied violin is part of a private collection of a violinist. In the first part of the test, the open strings (G# 196Hz), D# 293.7Hz), A# 440Hz), E# 659.3Hz) were excited with the bow; in the second part, open chords were excited in Pizzicato style consisting of plucking the chords; in the third part, a fragment from Max Bruch - Concerto no. 1 in G minor op. 26, PI (first Cadence for solo violin) and an excerpt from Jules Massenet – Méditation for violin and orchestra from the opera Thaïs, as can be seen in Fig. 2 (Nastac et al. 2022). The obtained recording in *.wav format was processed using a program code developed in MATLAB. Fig. 2 shows the time domain for the recorded acoustic signals. The position of violonist and microphones in the concert hall are shown in Fig. 3.

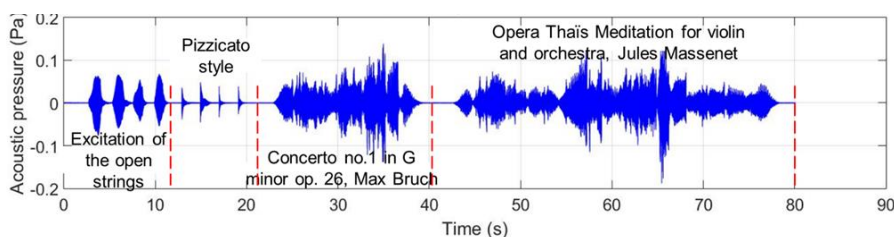


Fig. 2.
The musical signals.

According to (Woodhouse 2014), the frequency response of a violin obtained in a sound field and recorded with several microphones, must be correlated with the response of the violin recorded in the anechoic chamber. Therefore, in this study, the Klotz 1747 violin was recorded both in the Brasov Philharmonic Concert Hall and in the anechoic room.

Recording in a Full Anechoic Chamber

The second set of recordings was obtained in a full anechoic chamber (denoted AC), from 5 microphones placed around the violinist at 1.5m height and distance, as can be seen in Fig. 3 and 4. For the current study only the signals obtained on the 1st microphones (M1), for both Concert Hall and anechoic chamber were processed, since they were seated in similar positions for the recordings, both in front of the violinist.

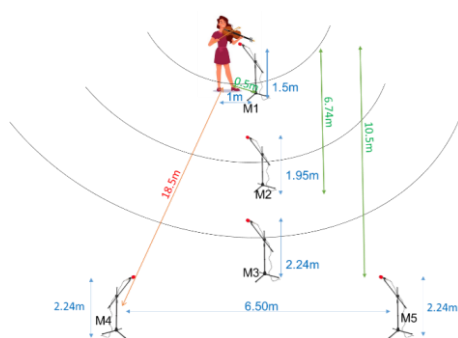


Fig. 2.
The positions for the violinist and the microphones within the Concert Hall.

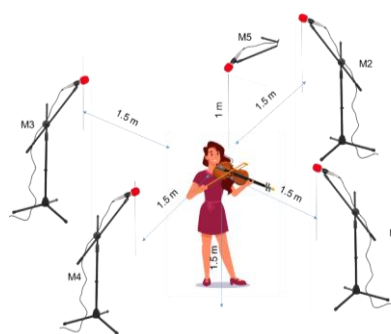


Fig. 3.
The positions for the violinist and the microphones within the Anechoic Chamber.

Signals processing

To process the recordings, a program code was developed in MATLAB. In this phase the signals were sampled based on time and frequency, as displayed in Fig. 5. From the time analysis resulted spectrograms (3D mappings) for each segment of the musical signals, FFT analysis, statistical analysis based on short time Fourier transform (STFT) and then, the interaural level differences (ILD) (Green & Kahle 2018; Carabias Orti 2011; Otondo & Rindel 2004). The Short Time Fourier Transform (STFT) is a sequence of Fourier transforms of a signal. The STFT provides time-localized frequency information for situations where the frequency components of a signal vary over time, while the standard Fourier transform (FFT) provides the frequency information averaged over the entire time interval of the signal (Hartmann & Constan 2002; Pätynen & Lokki 2016).

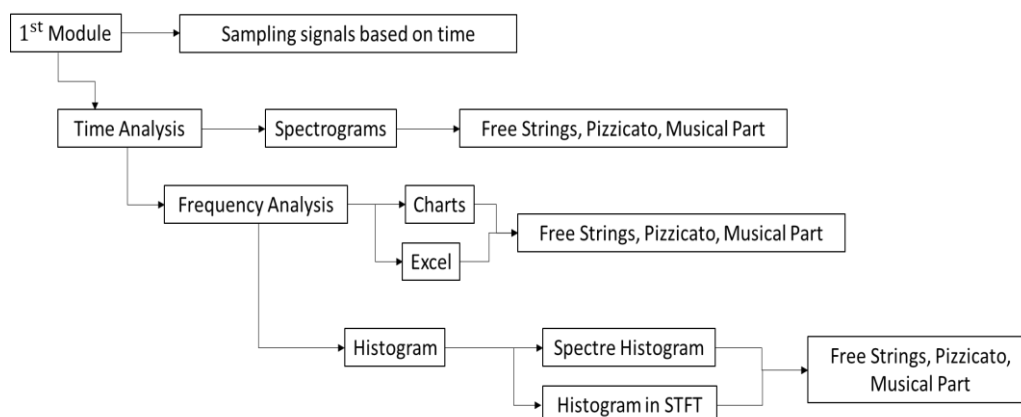


Fig. 5.
The design strategy of acoustic processing.

RESULTS AND DISCUSSION

Overall signal spectrogram

It is observed that the signals in the anechoic chamber (Fig. 6, a) are purer, clearer, due to the color gradient and the difference between the signal intensity and the font noise, in comparison with spectrograms obtained for musical signals recorded in Concert Hall (Fig. 6, b). This aspect is predictable for the Anechoic Chamber, where the existence of photo-absorbing walls leads to sound filtering. A spectrogram displays the strength of a signal over time at the various frequencies of a waveform. To create a spectrogram, several Fourier transforms are performed at several time instances (intervals). These Fourier transforms are assembled into a three-dimensional graph: frequency, time and amplitude (Hartmann & Constan 2002; Pätynen & Lokki 2016). Spectral analysis is the process of estimating the power spectrum (PS) of a signal from its time domain representation. Spectral density characterizes the frequency content of a signal or stochastic process. Intuitively, the spectrum decomposes the signal or stochastic process into different frequencies and identifies periodicities (Green & Kahle 2018; Carabias Orti 2011; Otondo & Rindel 2004).

From the frequency spectrum, the resonance frequencies and their amplitudes were extracted, values that were later compared to highlight the difference between the anechoic chamber and the concert hall. Applying FFT, frequency content, phase, and other properties of the signal were obtained and compared. For the first time, it is observed that the acoustic pressure and the frequency amplitude differ in the two halls, being higher in the concert hall for the frequency spectrum between 0 - 1000Hz. Spectral analysis is the process of estimating the power spectrum (PS) of a signal from its time domain representation. Spectral density characterizes the frequency content of a signal or stochastic process. Intuitively, the spectrum decomposes the signal or stochastic process into different frequencies and identifies periodicities (Green & Kahle 2018; Carabias Orti 2011; Otondo & Rindel 2004).

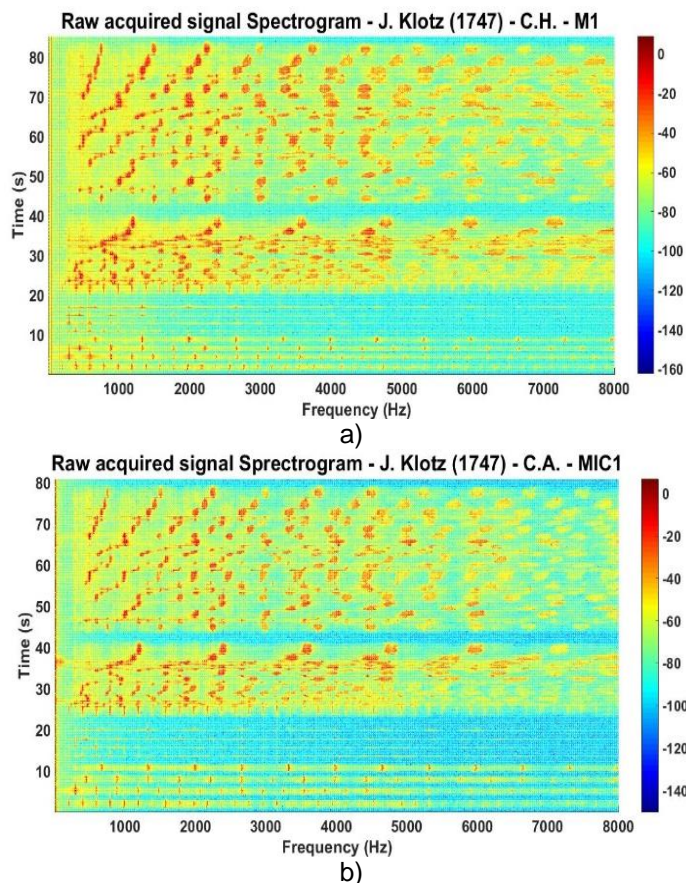
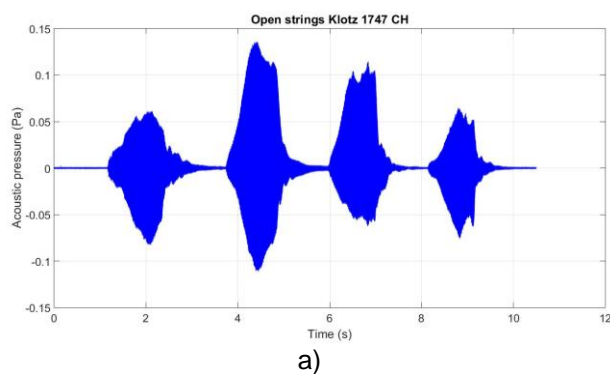


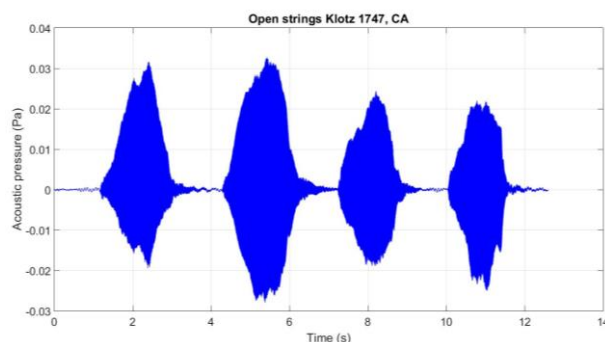
Fig. 6.

The spectrograms of musical signals recorded by 1st microphone: a) in Concert Hall CH; b) Anechoic Chamber CA.

Open strings sounds

In Fig. 7 you can see the acoustic signals in time domain, of the open strings excited on the bow, both in the concert hall and in the anechoic chamber. The transient processes of the sounds emitted by the chords are based on the attack, development, and extinction of the sound. The acoustic pressure in the anechoic chamber is approximately the same for all strings, compared to the signals recorded in the concert hall. The bow pressure is not high enough to vibrate the entire chords to produce the fundamental sound. Thus, first, the high harmonics appear, then the low ones, and finally the respective fundamental. The concert hall creates additional transient processes, realizing a so-called pre-reverberation that prolongs the duration of the attack, followed by reverberation that prolongs the transient period of sound extinction.





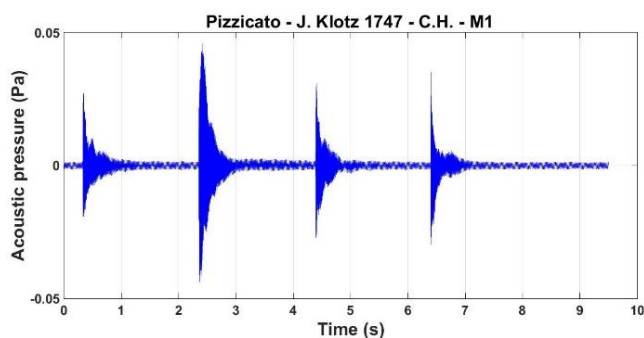
b)

Fig. 7.

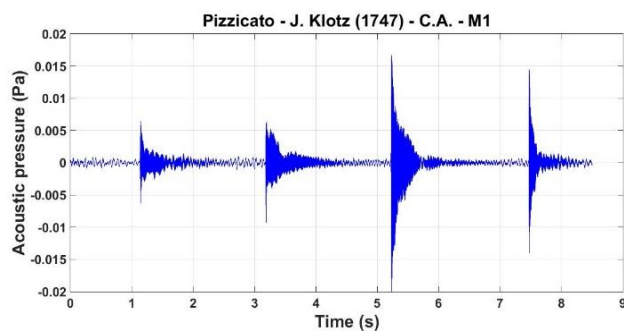
The time analysis for open strings signals: a) recorded in the Concert Hall CH; b) recorded in the Anechoic Chamber CA.

Pizzicato sounds

In Fig. 8, the time-frequency signal analysis for the Pizzicato fragment, in the concert hall and anechoic room and the damping of the signal are observed. In the concert hall, the highest acoustic pressure corresponds to the signal of the D chord (293.7Hz), while in the anechoic room.



a)



b)

Fig. 8.

Time analysis for Pizzicato signals: In the Concert Hall CH; b) in the Anechoic Chamber CA.

It corresponds to the A chord (440Hz). The frequency spectrum and spectral envelope obtained by string plucking differs from bow excitation. Between the signals recorded in the concert hall and the anechoic chamber, the spectral envelope is also different, even if it is the same violin, as can be seen in Fig. 9.

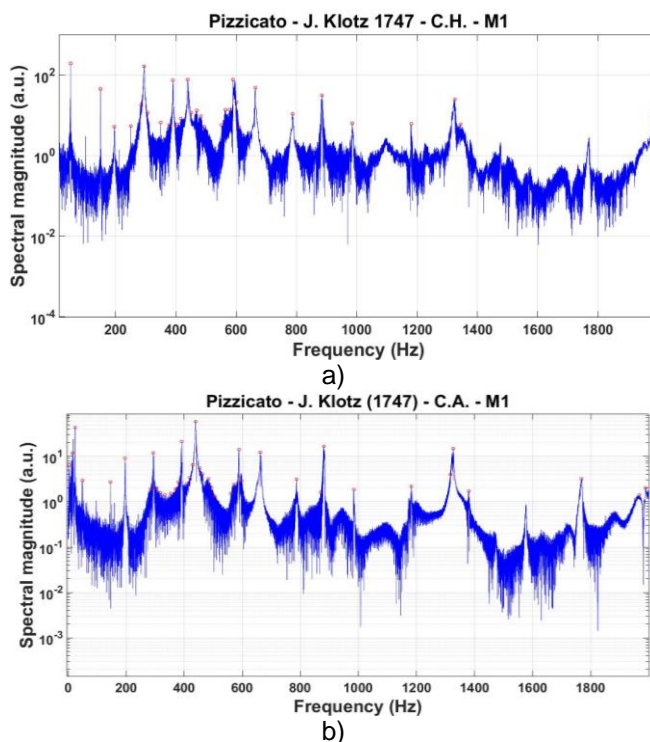


Fig. 9.

Fast Fourier Transform (FFT) of open strings in Pizzicato style recorded in: Concert Hall CH; b) Anechoic Chamber CA.

Musical part

Fig. 10 shows the time analysis of the signals corresponding to the musical fragments performed by the violinist. It can be seen that the signal configuration differs in the two halls, as well as the acoustic pressure, which is higher in the concert hall, compared to the anechoic chamber. In the anechoic room, the spectral magnitude reaches up to 40dB, compared to the concert hall where it reaches 60 dB, the sounds being recorded with a microphone placed at the same distance from the violinist in both rooms (Fig. 11).

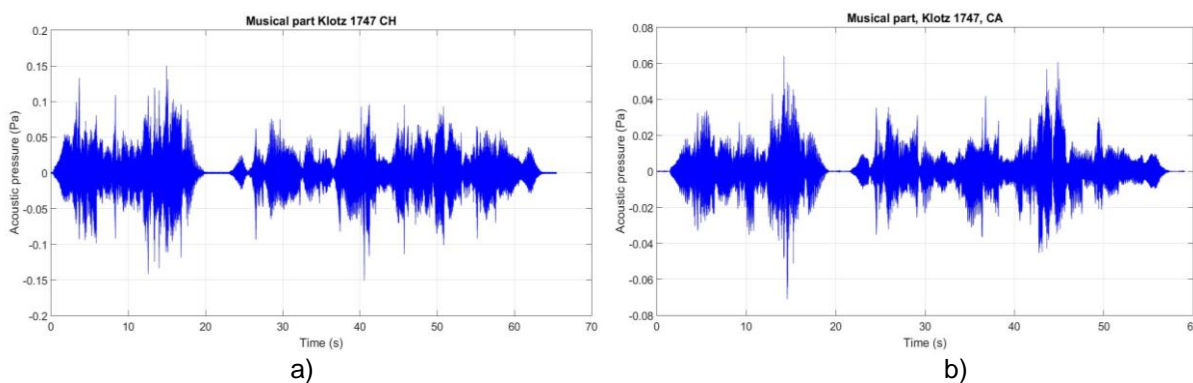


Fig. 10.

Time analysis for musical part signals: Concert Hall CH; b) Anechoic Chamber CA.

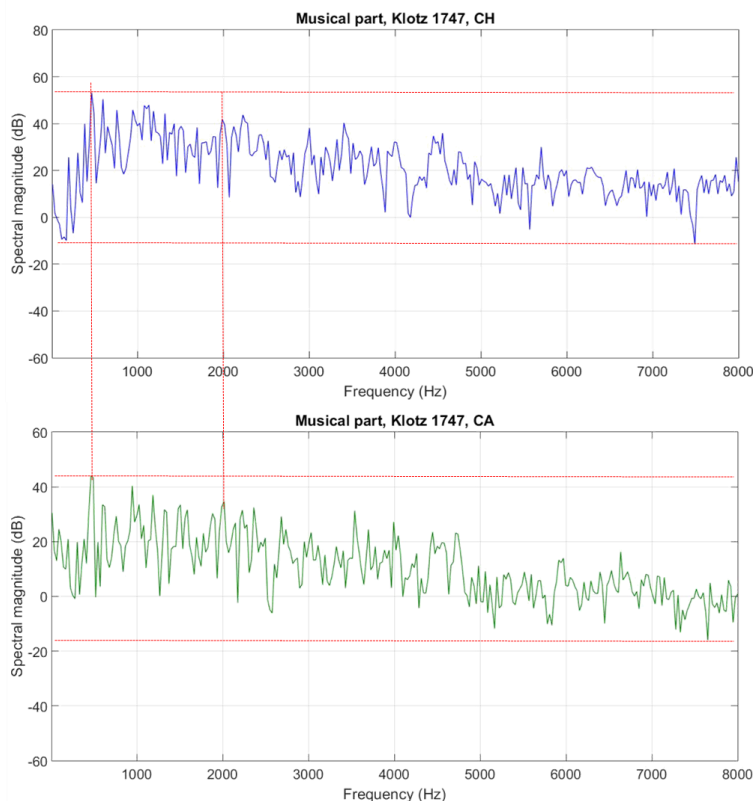


Fig. 11.
FFT analysis for the musical part.

Statistical analysis of Klotz violin acoustics

Histograms highlight the distributions or frequencies of occurrence of resonance frequencies and are applied in the acoustic analysis since the human ear cannot distinguish the differences between close frequency values. Octave bands provide a method of filtering by dividing the audible spectrum into smaller segments called octaves, allowing different noise levels to be identified on individual frequencies. 1/1 octave band measurements can be utilized when it is a need to determine the frequency composition of a sound field (Green & Kahle 2018; Carabias Orti 2011; Otondo & Rindel 2004). Since the histograms are statistical analysis, the following frequency intervals were established when creating the MATLAB program code: 1/1 Octave Band Analysis and 1/3 Octave Band Analysis, as can be seen in Fig. 12. For the open strings signals, the frequency intervals differ from one hall to another, thus, in the anechoic chamber the frequencies reach up to 11313.7Hz, compared to the concert hall where the frequencies reach up to 5656.9Hz (Fig. 12).

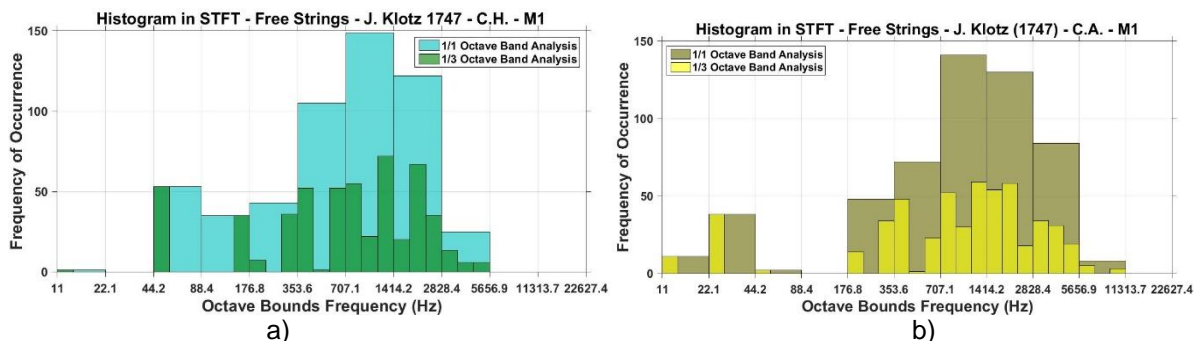


Fig. 12.
Histogram in STFT for open strings sounds: a) for the Concert Hall CH; b) for the Anechoic Chamber CA

Regarding the Pizzicato STFT Histogram, the frequency intervals are similar, both reaching up to 5659.9Hz (Fig. 13). The highest frequency values were obtained for the band between 22.1Hz and 44.2Hz in

the anechoic chamber, while for the concert hall, the highest frequency values resulted for the band between 353.6Hz and 707.1Hz.

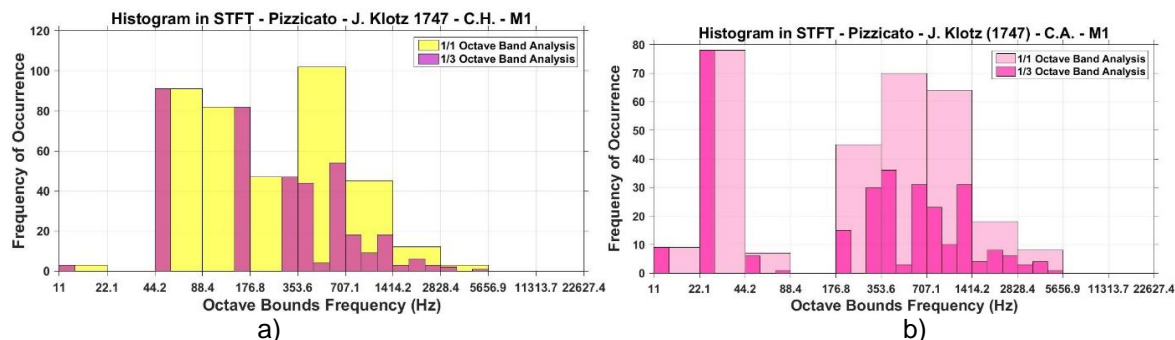


Fig. 13.

Histogram in STFT for the Pizzicato sounds: a) in the Concert Hall CH; in the Anechoic Chamber CA.

For the musical part, the frequency intervals are similar, both reaching up to 11313.7Hz (Fig. 14). For this fragment, the frequency values for the band located between 1414.2Hz and 2828.4Hz, are similar and the highest for both spaces.

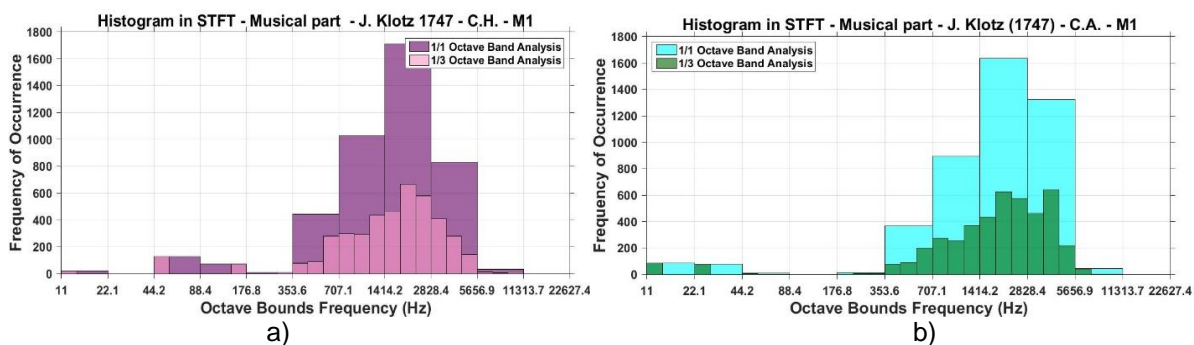


Fig. 14.

Histogram in STFT for musical part: a) in the Concert Hall CH; in the Anechoic Chamber CA.

Unlike the concert hall, where a maximum of 33 frequencies could be captured, in the anechoic chamber, the spectrum is wider, reaching up to 39 frequencies. Amplitudes are higher in the concert hall compared to those in the anechoic chamber for the highest frequencies (1038Hz – CA; 1117Hz – CH). Regarding the Pizzicato fragment, in the concert hall, a maximum of 31 frequencies were received, while in the anechoic chamber, the spectrum reaches up to 45 frequencies. In the case of amplitudes, the results represent the exact opposite, thus the highest values were obtained in the concert hall (4 times higher), while the highest frequencies were recorded in the anechoic chamber.

Compared to the concert hall, where a maximum of 131 frequencies could be captured, in the anechoic chamber, the spectrum is wider, reaching up to 156 frequencies. Similar to the previous cases, the highest amplitude values were obtained in the concert hall, while the most amplified frequencies were captured in the anechoic chamber.

CONCLUSIONS

The paper presents the results of the exploration of the acoustic characteristics of a historical violin in two spaces with different acoustic properties, a concert hall and an anechoic chamber. As a result of the study, the following aspects are relevant:

- The anechoic chamber helps to capture a wider spectrum of frequencies compared to the concert hall, where the frequencies are damped due to the geometry of the hall, the volume, and the absorbent materials used to furnish the space.
- The highest values of the amplitudes were obtained in the philharmonic concert hall, but only for a narrower spectrum of frequencies.
- The highest frequency values were found in the anechoic chamber, proving why such rooms are especially preferred when it comes to recordings in the music industry.

Finally, it can be appreciated that a quality violin presents the acoustic emission capacity and the richness of frequencies in a concert hall.

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