MEASUREMENT AND ANALYSIS OF ACOUSTIC INDICATORS ACROSS TRUMPET PLAYERS SPECIALISED IN DIFFERENT MUSICAL STYLES

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Abstract

This study investigates the relationship between the trumpet player stylistic orientation and the acoustic features of the radiated sound. Thirteen professional trumpet players participated in controlled anechoic recordings. For the analysis, performers were grouped according to their principal musical background into classical and modern categories. Each performer played the same musical excerpt on three trumpets associated with different stylistic conceptions, covering the instrument's playable range at piano and forte dynamics. The measurement setup enabled multipositional acquisition, while the present analysis considers the frontal reference microphone to provide a consistent representation of the radiated sound. Acoustic and psychoacoustic descriptors were calculated for each dynamic condition, including A-weighted sound pressure level, spectral centroid, high-frequency energy above 2 kHz, loudness and sharpness. The results reveal measurable differences in acoustic output between the classical and modern performer groups. Differences are particularly evident in spectral distribution and high-frequency content, indicating variations in harmonic enrichment. These findings provide a quantitative framework for comparing stylistic traits in trumpet performance and contribute to understanding how musical background influences brass-instrument radiation. They also support the development of style-specific acoustic models and more realistic virtual representations of musical instruments.

Keywords: *musical acoustics, brass instruments, trumpet, performance style, psychoacoustics*

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1. Introduction

Musical performance results from a complex interaction between the performer and the instrument, in which the excitation mechanism, the resonating air column and the player's control collectively determine the resulting sound [1], [2]. In brass instruments, sound production arises from the nonlinear coupling between the player's lips and the resonating air column, while the resulting sound is further influenced by the acoustic characteristics of the instrument and by the actions of the performer [3], [4]. While the influence of the instrument itself has been extensively investigated, the musical background of the performer is rarely considered as an experimental variable. This distinction may be particularly relevant for the trumpet, which is widely used across markedly different performance styles.

The characteristic sound of brass instruments has been extensively studied over the last decades. One of its most distinctive features is the progressive enrichment of the harmonic spectrum as the playing level increases, producing the bright or "brassy" timbre characteristic of loud brass playing. This spectral enrichment is associated with nonlinear wave propagation along the instrument bore, resulting in increased energy at higher harmonics [5], [6].

Several objective descriptors can therefore be used to characterize relevant properties of brass sound, including spectral centroid, brightness and measures of spectral energy distribution [3], [4]. Spectral centroid is particularly associated with perceived brightness and increases as higher-frequency harmonics become more prominent [3]. Objective characterization of brass instruments has consequently been approached through physical measurements, analysis of produced sounds, physical modelling, artificial players, and, more recently, data-driven methods relating instrument properties to sound and performance descriptors [4], [7], [8].

The mouthpiece introduces an additional source of variability by modifying the acoustic response seen by the performer and may therefore influence both playability and timbre [3], [5]. Since the mouthpiece is normally selected by the performer, the complete playing system cannot be characterized solely through the geometry of the instrument itself.

The musician is therefore a central element of the sound-production process. Performers can modify the spectral content of brass sounds through changes in embouchure even when maintaining approximately the same dynamic level [5]. Experimental investigations have also examined the influence of performer-related factors such as the lips, vocal tract, mouthpiece force and other aspects of playing technique [9], [10].

Most scientific studies evaluating a specific family of brass instruments, such as trumpets, either control performer variability through artificial excitation or treat the player primarily as a source of experimental variability when comparing instruments [4], [7], [10]. In contrast, the present study considers performer variability itself as the object of investigation and distinguishes professional trumpet players according to their principal musical style, separating Classical and Modern performers. The objective is to investigate whether the principal musical style of professional performers is associated with measurable differences in the radiated sound. To this end, recordings obtained using several instruments and two dynamic levels are analysed by combining conventional acoustic descriptors with psychoacoustic metrics.

The rest of the paper is organized as follows: section 2 describes the methodology, section 3 introduces the acoustic indicators considered in the analysis, section 4 presents and discusses the results, and section 5 summarises the main conclusions.

2. Anechoic recordings and measurement procedure

Thirteen professional trumpet players with different stylistic background participated in the study. For the present analysis, performers were classified according to their principal musical background into two groups: classical and modern, the latter comprising performers primarily associated with jazz and commercial styles. Of the 13 participants, 5 were classified as Classical and 8 as Modern, based on their main professional field of work. Since each performer was recorded using three trumpets, the sample sizes reported in the following analyses refer to individual performer–trumpet measurements rather than to the number of performers. Not all measurements were included in the analysis due to the presence of outliers or insufficient usable material. Each performer played the same musical excerpt using the three B♭ trumpets listed in Table 1. The selected instruments were chosen to represent three distinct design philosophies commonly associated with classical, commercial and jazz performance, while also differing in manufacturer, construction and production period. These trumpets are shown in Figure 1. To minimise potential bias arising from fatigue or adaptation, the order in which both the trumpets and performers were recorded was randomised. Each trumpet player was allowed to use their own mouthpiece throughout the experiment. The mouthpiece geometry substantially modifies the input impedance and can consequently influence the frequency content of the radiated sound [2], [11], [12], [13]. Rather than representing an experimental limitation, the use of each performer's habitual mouthpiece was considered an intrinsic component of their playing configuration and may therefore be essential for identifying sound characteristics associated with each stylistic group.

Figure 1: Three B♭ trumpets selected for the study, representing different design philosophies and intended musical applications.

Table 1: Selected trumpets used in the study.

Trumpet	Manufacturer	Model	Music style
1	Bach	Stradivarius 43	Classical
2	Yamaha	6335-RC	Commercial
3	Monette	993	Jazz / Overall

Recordings were conducted in the anechoic chamber at the Escuela Técnica Superior de Ingeniería y Sistemas de Telecomunicación (ETSIST), Universidad Politécnica de Madrid (UPM). For each trumpet, participants performed the excerpt twice, at piano and forte dynamic levels, while maintaining their usual playing technique and musical interpretation. The excerpt was specifically designed to cover a representative range of the instrument, including low, middle, and high registers, as well as both harmonic series commonly used in trumpet performance. Figure 2 shows the musical excerpt that the players were asked to perform. The whole notes represent sustained notes, and the players were not required to maintain a specific tempo. The indications (0) and (123) correspond to the valve combinations and were selected to represent the minimum and maximum tube lengths of the trumpet.

For the subsequent analysis, a DPA 4006A microphone located on the trumpet bell axis at a distance of 1.5 m and oriented towards the centre of the bell was considered. Performers were positioned at the same reference location for all recordings and instructed to maintain the trumpet aligned with the frontal microphone throughout each performance. This arrangement was maintained between takes and instrument changes to minimise variations in source–microphone distance and orientation. The signals were acquired using an RME Fireface UFX audio interface. All recordings were adjusted to absolute sound pressure using a Brüel & Kjær 2270 sound level meter positioned next to the frontal microphone. The full experimental setup and a player in the recording position are shown in Figure 3.

3. Acoustic indicators

Prior to the acoustic analysis, each recording was segmented into individual notes. The onset transient of each note was excluded by discarding the first 0.5 s, after which a stationary segment of 2 s was retained for analysis. This procedure ensured that all descriptors were computed under steady-state playing conditions while minimizing the influence of articulation transients. The same processing was applied to all recordings and to both dynamic levels.

Each audio signal was calibrated to absolute acoustic pressure using a reference sound level meter before computing the acoustic indicators. The following descriptors were extracted from every analysed segment.

Sound pressure level

The overall A-weighted sound pressure level was computed from the calibrated time-domain pressure signal and expressed in decibels relative to the reference pressure of 20 μPa. The A-weighting was applied according to the IEC standard frequency weighting.

Spectral centroid

The spectral centroid was calculated from the one-sided power spectrum as

$$f_c = \frac{\sum_i f_i P_i}{\sum_i P_i}, \quad (1)$$

where P_i is the spectral power contained in frequency bin f_i. This descriptor provides a measure of the spectral balance of the sound and is commonly interpreted as an indicator of spectral brightness.

High-frequency energy above 2 kHz (HFE2k)

The proportion of radiated acoustic energy contained above 2 kHz was computed as

$$\mathrm{HFE}_{f_0} = \frac{\sum_{f_i \geq f_0} P_i}{\sum_i P_i}, \quad (2)$$

with $f_0 = 2$ kHz. This descriptor quantifies the relative contribution of high-frequency spectral energy, which has been associated with perceived brilliance and projection.

Loudness

Stationary loudness was computed according to ISO 532-1 using the MATLAB implementation of the Zwicker model, assuming free-field listening conditions. The model transforms the acoustic spectrum into an excitation pattern over the critical-band rate scale (Bark), accounting for frequency-dependent auditory sensitivity and masking effects. Specific loudness is then determined across the critical bands and integrated to obtain the total loudness, expressed in sones. Loudness therefore provides a psychoacoustic estimate of perceived sound magnitude rather than a direct measure of acoustic energy.

Sharpness

Sharpness was computed according to DIN 45692 from the specific loudness distribution obtained from the Zwicker model. It is calculated as a weighted spectral centroid over the critical-band rate scale, with increased weighting applied to the contribution of the upper critical bands. The resulting value, expressed in acum, characterises the perceptual prominence of high-frequency components relative to the overall loudness distribution. Higher sharpness values therefore indicate a greater perceptual contribution of high-frequency content.

4. Results

The distributions of the acoustic indicators obtained for the Classical and Modern performer groups are presented in Figures 4–8. Each panel shows the individual measurements obtained with the three trumpets, together with a kernel-density representation and a notched boxplot. Results are presented separately for the complete excerpt and for the piano and forte dynamic conditions.

Across most indicators, the Modern group tended to exhibit higher values than the Classical group. The differences were generally more pronounced for the complete excerpt and at forte, whereas the piano distributions showed greater overlap.

4.1. Sound pressure level and loudness

The A-weighted SPL distributions are shown in Figure 4. For the complete excerpt, the Modern group produced a mean level approximately 2.0 dB higher than the Classical group. A similar difference of approximately 2.0 dB was observed at forte. By contrast, the piano measurements exhibited a smaller difference, below 1 dB, and substantial overlap between the two groups.

The loudness distributions, presented in Figure 5, followed a comparable pattern. Mean loudness for the Modern group was approximately 17.6 sone higher for the complete excerpt and 20.4 sone higher at forte. The difference at piano was considerably smaller, approximately 4.6 sone.

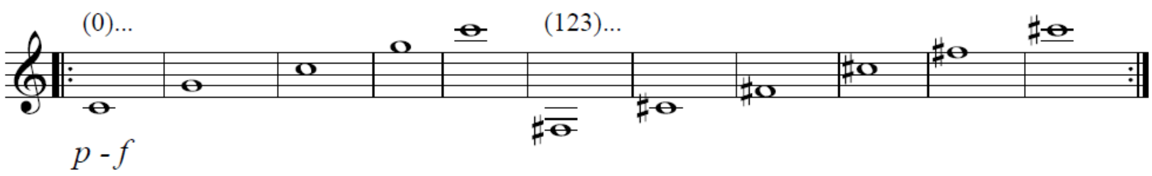

Figure 2: Musical excerpt performed by all participants using each trumpet at piano and forte dynamic levels.

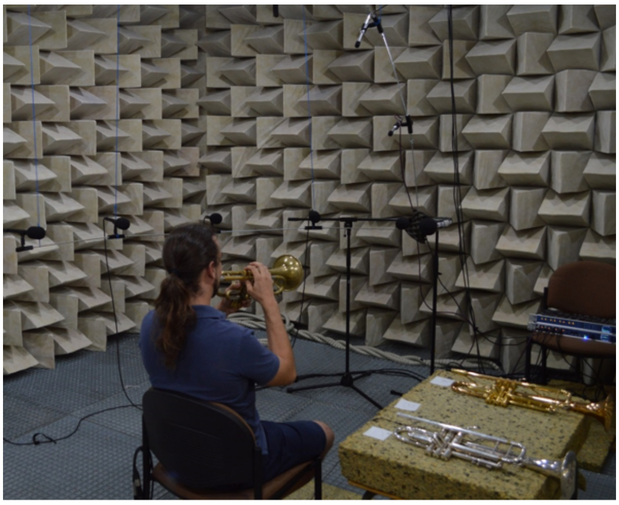

Figure 3: Experimental setup and player in the recording position.

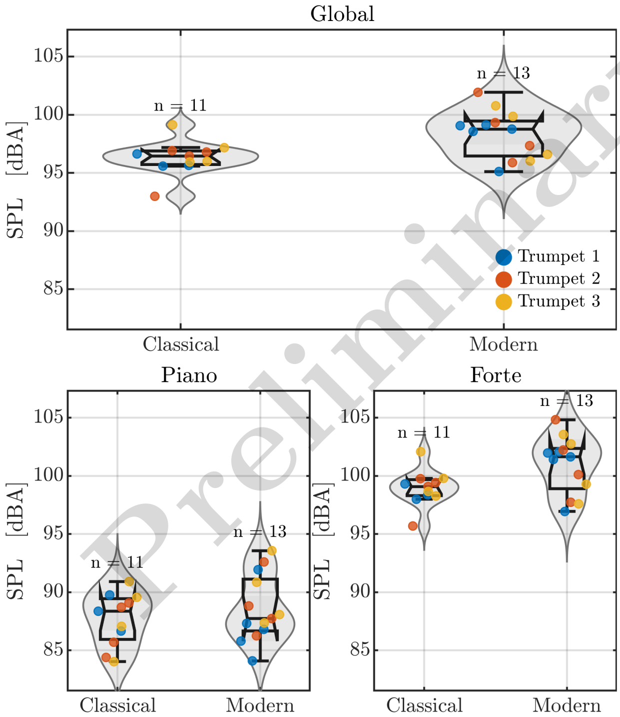

Figure 4: A-weighted Sound Pressure Level.

4.2. Spectral content

Figure 6 shows the spectral centroid. For the complete excerpt, the mean spectral centroid was approximately 330 Hz higher for the Modern group. A similar difference was observed at forte. At piano, however, the mean difference decreased to approximately 93 Hz. These results indicate a displacement of the spectral energy towards higher frequencies in the Modern group, particularly under forte playing conditions. This might indicate differences between the two groups in the control of harmonic enrichment as the dynamic level increases.

The high-frequency energy distribution showed additional differences between the two performer groups. Figure 7 presents the proportion of spectral energy above 2 kHz. At piano, the Modern group exhibited a mean value approximately 5.5 percentage points higher than the Classical group, corresponding to the clearest separation observed for this descriptor.

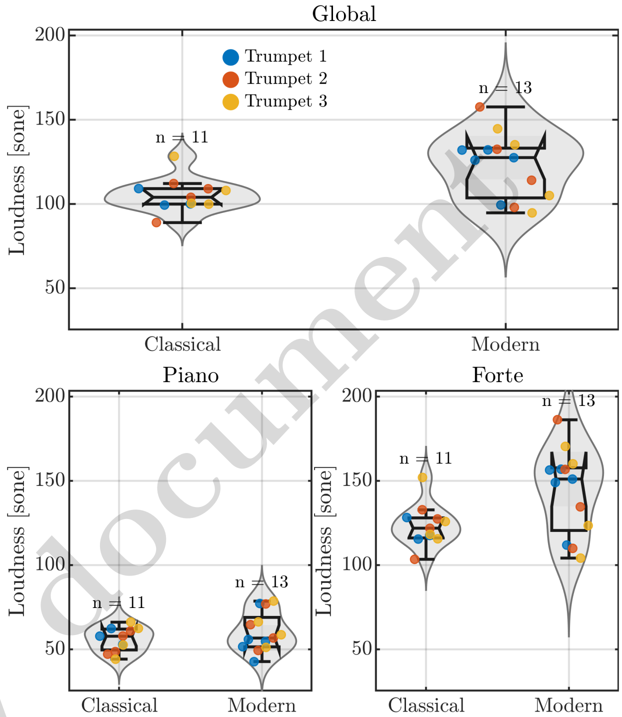

Figure 5: Loudness.

4.3. Sharpness

The sharpness results are shown in Figure 8. The Modern group produced higher mean sharpness values for all three conditions. The mean difference was approximately 0.18 acum for both the complete excerpt and the forte condition, whereas a smaller difference of approximately 0.08 acum was observed at piano.

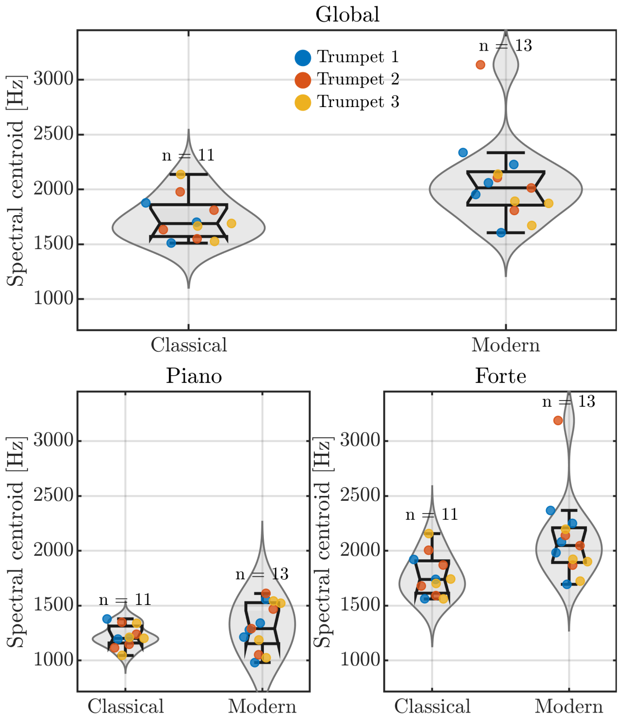

Figure 6: Spectral centroid.

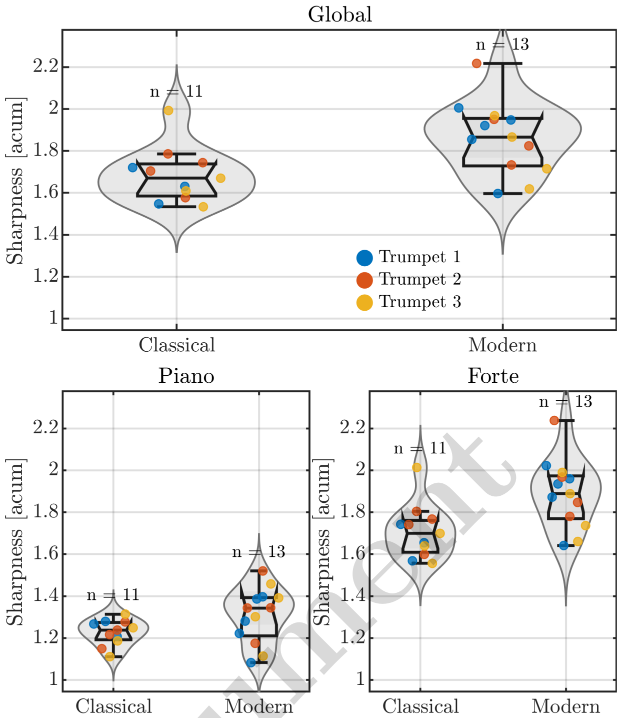

Figure 8: Sharpness, DIN 45692.

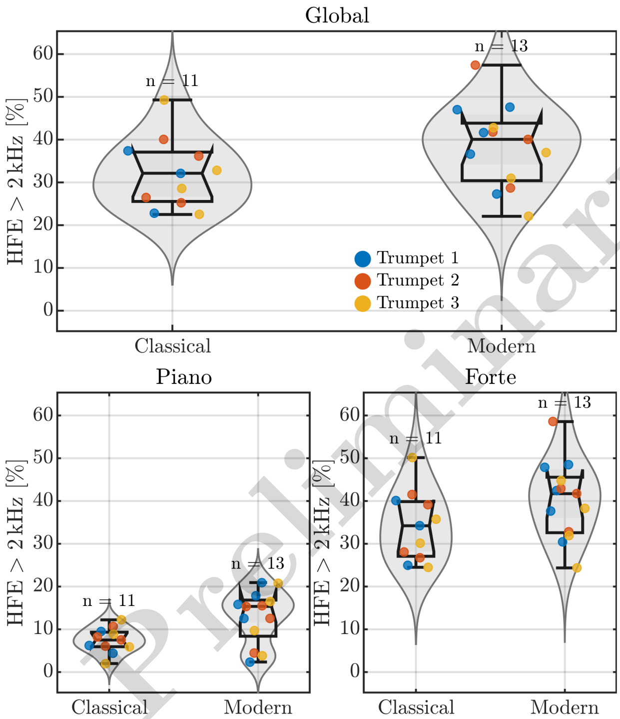

Figure 7: High-frequency energy above 2 kHz.

This behaviour is consistent with the higher spectral centroids and high-frequency energy observed for the Modern group.

4.4. Statistical comparisons

The ANOVA results are summarised in Table 2. Overall, statistically significant differences between the classical and modern groups were identified in 9 of the 15 comparisons ($p < 0.05$). The clearest separation between groups was observed for the complete excerpt and at forte, for which 4 of the 5 acoustic indicators showed significant differences. Specifically, A-weighted SPL, spectral centroid, loudness and sharpness were significant under both conditions. In contrast, the piano condition showed substantially less differentiation between groups, with only 1 of the 5 indicators, HFE2k, reaching statistical significance.

This pattern suggests that the acoustic differences associated with performer style become more apparent at higher playing levels, whereas the two groups exhibit more similar acoustic characteristics at piano. HFE2k showed a different behaviour, with a significant group difference at piano but not for the complete excerpt or forte.

Nevertheless, these results should be interpreted with caution due to the limited number of performers and the repeated measurements obtained from each musician using different trumpets. The present statistical analysis should therefore be regarded as preliminary evidence of style-related differences rather than a definitive characterization of the two performer populations.

5. Conclusions

This study investigated whether measurable acoustic and psychoacoustic differences exist between professional trumpet players with classical and modern performance backgrounds. The analysis combined calibrated acoustic measurements with spectral and perceptual descriptors computed from steady-state

Table 2: ANOVA results for the comparison between the classical and modern performer groups. Significant ($p < 0.05$) values are shown in bold.

Indicator	Global	Piano	Forte
A-weighted SPL	**0.0111**	0.4099	**0.0292**
Loudness	**0.0125**	0.2644	**0.0229**
Spectral centroid	**0.0178**	0.2057	**0.0165**
HFE2k	0.0961	**0.0130**	0.1007
Sharpness	**0.0091**	0.0692	**0.0073**

recordings obtained under controlled anechoic conditions.

Overall, the Modern group tended to produce higher A-weighted sound pressure levels, larger spectral centroids, greater proportions of high-frequency energy above 2 kHz, higher loudness and higher sharpness than the Classical group. These tendencies were most evident for the complete musical excerpt and under forte playing conditions, whereas considerably smaller differences were observed at piano.

Although statistically significant differences were identified for several descriptors, the distributions of the two groups exhibited substantial overlap, indicating that performer style cannot be characterised by a single acoustic parameter. Instead, the results suggest that stylistic differences emerge from the combined behaviour of several complementary acoustic and psychoacoustic indicators.

The present work provides a quantitative framework for investigating stylistic variability in trumpet performance using objective measurements. Such descriptors may contribute to future studies on performer classification, instrument evaluation and musical acoustics. They may also support the adjustment of artificial-lip parameters and provide a basis for future machine-learning datasets and applications.

References

[1] M. Campbell and C. Greated, *The Musician's Guide to Acoustics*. Oxford University Press, 1994, ISBN: 9780198165057. DOI: 10.1093/oso/9780198165057.001.0001.

[2] M. Campbell, J. Gilbert, and A. Myers, *The Science of Brass Instruments*. Cham, Switzerland: Springer, 2021, ISBN: 978-3-030-55686-0. DOI: 10.1007/978-3-030-55686-0.

[3] M. Campbell, "Objective evaluation of musical instrument quality: A grand challenge in musical acoustics," *Proceedings of Meetings on Acoustics*, vol. 19, p. 032 003, 2013. DOI: 10.1121/1.4801037.

[4] J.-F. Petiot, M. Roatta, V. Fréour, and K. Arimoto, "Contribution of machine learning and physics-based sound simulations for the characterization of brass instruments," in *Proceedings of Forum Acusticum 2023*, Turin, Italy, 2023, pp. 375–381. DOI: 10.61782/fa.2023.0199.

[5] L. Norman, J. P. Chick, D. M. Campbell, A. Myers, and J. Gilbert, "Player control of 'brassiness' at intermediate dynamic levels in brass instruments," *Acta Acustica united with Acustica*, vol. 96, no. 4, pp. 614–621, 2010. DOI: 10.3813/AAA.918316.

[6] D. M. Campbell, J. Gilbert, and A. Myers, "Brassiness and the understanding of brass instruments," in *Proceedings of Forum Acusticum 2020*, Lyon, France, 2020, pp. 3169–3175. DOI: 10.48465/fa.2020.0286.

[7] F. Teissier, J. Gilbert, D. M. Campbell, and J.-F. Petiot, "Comparative analysis of brass wind instruments with an artificial mouth: First results," *Acta Acustica united with Acustica*, vol. 89, pp. 974–979, 2003.

[8] M. Mohamed, V. Fréour, C. Vergez, K. Arimoto, V. Emiya, and B. Cochelin, "Prediction of trumpet performance descriptors using machine learning," *Acta Acustica*, vol. 8, p. 65, 2024. DOI: 10.1051/aacus/2024042.

[9] A. Foteinou, S. Spencer, and M. Dalgleish, "Experimental investigation of the contribution of resonant frequency to trumpeter's performance," in *Proceedings of the 23rd International Congress on Sound and Vibration*, Athens, Greece, 2016.

[10] V. Fréour, K. Fujita, and K. Arimoto, "A pocket artificial buzzing system for the trumpet," *Acta Acustica*, vol. 8, p. 46, 2024. DOI: 10.1051/aacus/2024031.

[11] A. H. Benade, *Fundamentals of Musical Acoustics*. New York: Oxford University Press, 1976.

[12] J. Backus, "Input impedance curves for the brass instruments," *The Journal of the Acoustical Society of America*, vol. 60, no. 2, pp. 470–480, 1976. DOI: 10.1121/1.381104.

[13] S. J. Elliott, "The acoustics of brass wind-instruments," Ph.D. dissertation, University of Surrey, 1979.