DOI: 10.61782/fa.2025.0676

PERCEPTUAL COMPARISON BETWEEN A LOW-COST GUITAR AND A 3D-PRINTED GUITAR

Espinoza, Carolina[1*] **Ibánez, Tania**[2] **Adasme, Claudio**[1]
Denzer, Milenko[2] **Díaz, Catalina**[2] **Moreno, Timoteo**[2]
[1] Departamento de Sonido, Facultad de Artes, Universidad de Chile, Santiago, Chile
[2] Departamento de Música, Facultad de Artes, Universidad de Chile, Santiago, Chile

ABSTRACT

This study evaluates perceptual and acoustic differences in timbral characteristics between two guitars: (1) a wooden, mass-produced, low-cost guitar designed for beginners and (2) a 3D-printed guitar. Blind listening tests were conducted with seven students specializing in musical performance, composition, and music theory. An experienced performer played identical musical pieces on both instruments—strumming, arpeggios, open strings, and harmonics—under controlled recording conditions. Participants rated the perceived timbral characteristics in low, mid, and high-frequency ranges and sustain for each recording using a five-point Likert scale.

Results showed considerable variability in participant responses, suggesting that the timbral differences between instruments were not easily distinguishable. The most significant difference was observed in the sustain rating, which was generally lower for the printed instrument. A preliminary acoustic analysis was conducted using the same evaluated recordings, and the results aligned with the perceptual findings. These results highlight the timbral characteristics of the 3D-printed guitar that require further development and demonstrate the potential of 3D printing in musical instrument manufacturing.

Keywords: *3D-printing, 3D-printed guitar, timbre*

[1]****Corresponding author***: *carolinaaespinozao@uchile.cl*

1. INTRODUCTION

The application of digital fabrication techniques, including 3D printing, has expanded into musical instrument manufacturing [1-3]. Given the increasing interest in 3D-printed instruments, it is important to assess how their timbral characteristics compare to those of traditional materials instruments. An example is presented in [4], where the sound quality of a 3D-printed ukulele and a wooden one is compared.

This work presents the results of perceptual evaluation and acoustic characterization of the timbre in two guitars: a mass-produced, low-cost acoustic guitar and a 3D-printed guitar made of PLA+. The evaluation was conducted through an acousmatic listening test, where participants evaluated pre-recorded performances of identical musical excerpts played on both instruments.

2. METHODS

The instrument under evaluation was a 1/4-scale 3D-printed guitar made of PLA+ with a vibrating string length of 480 mm. This instrument was designed to be a functional, low-cost alternative that could be produced quickly. The printing process required 50 hours using a Bambu Lab X1 Carbon Combo 3D printer, followed by approximately 5 hours of manual assembly. The total material consumption was 1 kg of PLA+ filament, with an estimated cost of 35 USD (see Fig. 1).

As a reference, we selected a 3/4-scale, mass-produced acoustic guitar designed for beginners, with a vibrating string length of 540 mm. This model was the smallest commercially available, and it had a price comparable to the manufacturing cost of the printed guitar (approximately 50 USD).

An acousmatic blind listening test was conducted with seven advanced music students to evaluate the sound of the printed guitar. A professional guitarist performed the same musical excerpts on both instruments, including strumming, arpeggios, open strings, and harmonics, which were referred to as 'categories' of playing. The recordings were made on the same day and location, using Dayton Audio EMM-6 microphones placed 50 cm from the instruments' soundholes. For each recording, participants used a five-point Likert scale to rate four perceived timbral characteristics: the frequency content in the low, mid, and high ranges, as well as sustain.

Each pair of recordings was presented twice consecutively for each category while maintaining the same order (e.g., for strumming, first the reference guitar, then the 3D-printed guitar). Across categories, the order was alternated randomly to reduce bias (e.g., a participant might hear the 3D-printed guitar first in the strumming category but the reference guitar first in the arpeggio category). The listening tests took place in a semi-reverberant room, where each participant was positioned approximately one meter in front of a pair of studio monitors. Example recordings of both guitars being strummed can be accessed at the following link.

Figure 1. Professional guitarist recording the 3D-Printed Guitar, Prof. Héctor Sepúlveda.

In order to compare the perceptual evaluations, acoustic analyses were conducted on the recorded audio samples. The spectral magnitude was obtained using the open software Audacity using a Hamming window of size 4096. The analysis was done for the complete audio recordings to provide a general assessment of their frequency content.

3. RESULTS, ANALYSIS, AND DISCUSSION

Tables I–IV show the means and standard deviations σ of the participants' evaluations. In the Strumming category (Table I), the most significant difference was observed in the sustain evaluation, where the 3D-printed guitar scored 3.0 ± 0.0, while the reference guitar scored 3.7 ± 0.5. These results suggest a clear perception of longer sustain in the reference guitar. The treble, midrange, and bass ratings were relatively close, with only minor differences.

For the Arpeggio category (Table II), the sustain rating again showed the most significant difference, with a mean of 2.4 for the 3D-printed guitar compared to 2.9 for the reference guitar. Although this suggests a perceptible difference, the higher standard deviation (0.9) for the reference guitar reduces the statistical significance of this result. Interestingly, although the difference is small, the bass frequencies were rated slightly higher for the 3D-printed guitar (3.1) than for the reference guitar (2.9).

In the Open Strings category (Table III), the most pronounced difference was observed in the sustain rating, with the reference guitar scoring 4.1 ± 0.9, compared to 3.1 ± 1.2 for the 3D-printed guitar. Additionally, the treble rating was noticeably lower for the 3D-printed guitar (2.7 ± 1.0) than for the reference guitar (3.3 ± 0.8), indicating that the printed instrument may have a perceived loss of brightness in open strings.

Finally, in the Harmonics category (Table IV), the most significant difference again appeared in the sustain rating, where the reference guitar scored 4.1 ± 0.7, while the 3D-printed guitar scored 3.4 ± 1.0. The ratings for treble, midrange, and bass, with minor variations, remained pretty close.

Overall, the results indicate a consistent trend of lower sustain ratings for the 3D-printed guitar across all categories. Additionally, the printed instrument's treble ratings tend to be slightly lower, particularly in open strings. However, midrange and bass frequencies showed comparable ratings; in some cases, the 3D-printed guitar matched or slightly outperformed the reference instrument. Despite these tendencies, the large standard deviations in several evaluations suggest that individual perceptions varied significantly, making it difficult to establish definitive conclusions.

Table 1. Results for the Strumming category

Category: Strumming				
Frequency Range	3D-Printed guitar		Reference guitar	
	Mean	σ	Mean	σ
High	3,0	0,8	3,1	0,7
Mid	3,9	0,7	3,7	1,1
Low	3,4	0,8	3,4	0,5
Sustain	3,0	0,0	3,7	0,5

Table 2. Results for the Arpeggio category

Category: Arpeggio				
Frequency Range	3D-Printed guitar		Reference guitar	
	Mean	σ	Mean	σ
High	2,9	0,7	3,0	0,6
Mid	3,4	0,5	3,6	0,8
Low	3,1	0,7	2,9	0,9
Sustain	2,4	0,5	2,9	0,9

Table 3. Results for the Open Strings category

Category: Open Strings				
Frequency Range	3D-Printed guitar		Reference guitar	
	Mean	σ	Mean	σ
High	2,7	1,0	3,3	0,8
Mid	3,4	1,1	3,6	0,8
Low	3,3	0,8	3,7	0,5
Sustain	3,1	1,2	4,1	0,9

Table 4. Results for the Harmonics category

Category: Harmonics				
Frequency Range	3D-Printed guitar		Reference guitar	
	Mean	σ	Mean	σ
High	3,1	0,4	3,4	1,1
Mid	3,7	0,8	3,7	0,5
Low	3,0	0,8	3,0	0,8
Sustain	3,4	1,0	4,1	0,7

Regarding the acoustic analyses, Figs. 2-5 presents the results for the four categories. The graphs have been divided into three bands: the low range (20 Hz to 200 Hz), the mid-range (200 Hz to 2 kHz), and the high range (2 kHz to 20 kHz). In all categories, the overall response in the low range is similar, except around 100 Hz and 200 Hz, where the response of the reference guitar is greater. In the mid ranges, certain areas stand out for the 3D-printed guitar, particularly between 180 Hz and 1.2 kHz. In the high-frequency range, the response remains similar up to 4 kHz, after which the response of the 3D-printed guitar becomes more prominent.

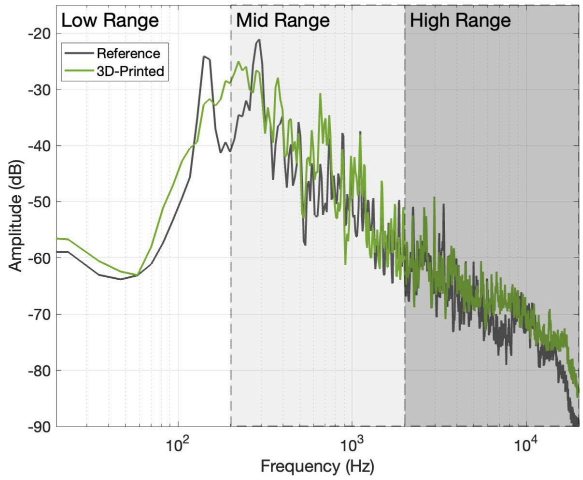

Figure 2. Spectral Magnitude for the Strumming category.

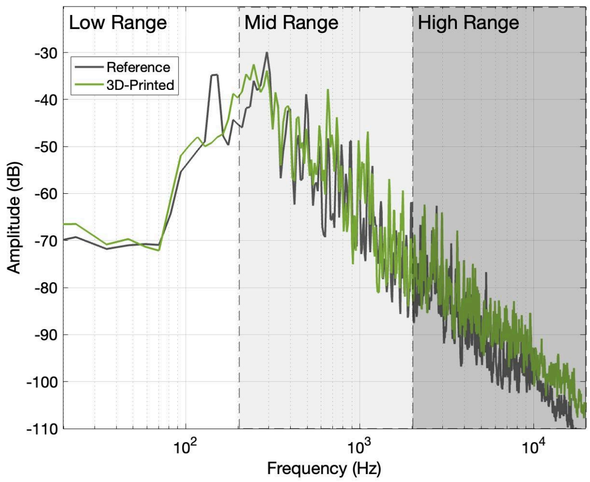

Figure 3. Spectral magnitude for the Arpeggio category.

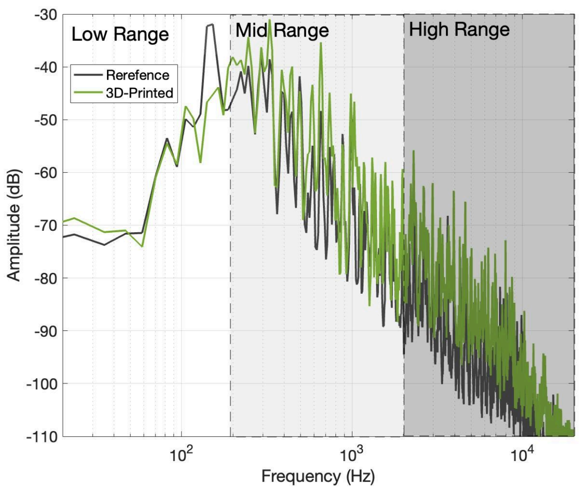

Figure 4. Spectral magnitude for the Open String category.

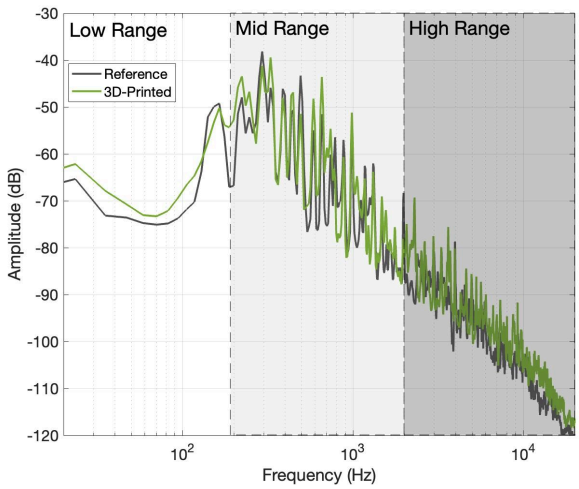

Figure 5. Spectral magnitude for the Harmonics category.

Certain correspondences can be observed between the perceptual and acoustic results. For instance, the spectral analysis showed that both guitars have similar low and middle-frequency responses, with localized differences (a greater response of the reference guitar between 100 Hz and 200 Hz and specific emphasized frequencies in the printed guitar). These results align with the perceptual results, where the ratings associated with bass and mid frequencies were similar across all categories.

The most significant difference is found in the treble response. Acoustic analyses showed that the printed guitar exhibits a more prominent response above 4 kHz. However, the printed guitar received lower treble ratings in the open strings category in the perceptual evaluation. This discrepancy, along with the perception of larger sustain in that category, could be because the perception of treble depends not only on spectral energy in the high-frequency range but also on other factors, such as the distribution of energy over time.

Regarding sustain, due to the characteristics of the playing style, it was impossible to study the strumming, arpeggio, and harmonics categories. However, frequency analysis was conducted for the open strings category. Fig. 6 shows spectrograms for both guitars. Both cases were plotted with the same time scale to facilitate the comparison. It can be observed that the reference guitar sounds for a longer time than the 3D-printed guitar. Although these results agree with the perceptual evaluation and serve for preliminary comparisons, it is necessary to conduct more measurements, focusing on the instrument's timbral properties.

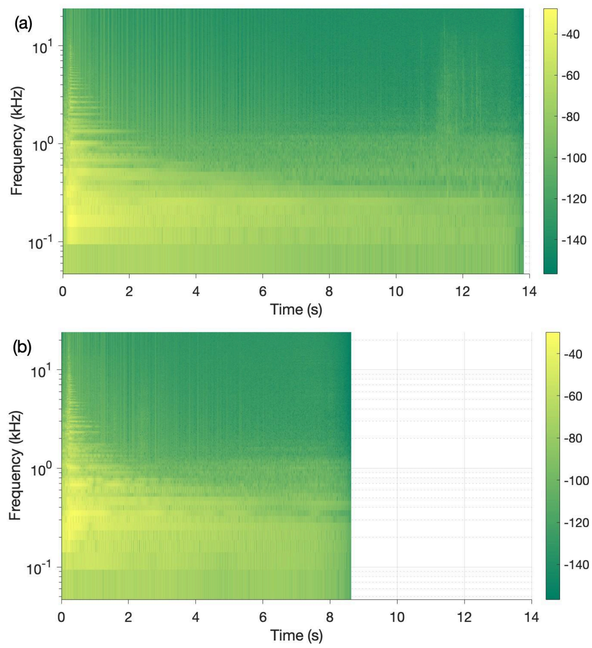

Figure 6. Spectrogram for the Open String category. (a) Reference guitar. (b) 3D-Printed guitar.

4. CONCLUSIONS

The results exhibited substantial variation in participant responses, indicating that the instrument's timbral differences were not easily perceived. Regarding the frequency content, no relevant perceptual differences were evaluated in the midrange and bass frequencies, while the high-frequency content was rated lower for the 3D-printed guitar. On the other hand, acoustic analyses showed differences only in specific frequencies in the low and mid ranges (which aligns with the perceptual evaluation). At the same time, the printed guitar displayed higher content in frequencies above 4 kHz (which differs from the general evaluation). This difference may be due to factors such as the listening conditions. For example, poor performance of the monitors above 4 kHz or background noise.

The most significant difference in the rating of the printed guitar compared to the reference instrument was observed in the sustain criterion, where the PLA+ instrument was evaluated lower in general. This could be solved by using materials with higher density or elastic moduli and optimizing the structural design, particularly of the soundboard and bridge. Although preliminary acoustic results were obtained that align with the perceptual results regarding the sustain, they should be repeated in future stages of the research.

For the perceptual study, several points for improvement were observed. In the future, the number of participants will be increased to improve the statistics. On the other hand, in addition to the evaluations conducted, discrimination tests will be added to assess the randomness of participants' responses. It has also been decided to improve the listening conditions for participants by replacing the studio monitors with hi-fi flat-response headphones so that the listening experience is not affected by the evaluator's position or background noise. Additionally, open-ended questions will be added to assess qualitative responses regarding the sound of each instrument.

Finally, more acoustic analyses remain pending to allow for a deeper study of the acoustic properties of the 3D-printed guitar, which, together with perceptual evaluations, will guide future versions of the instrument.

5. ACKNOWLEDGMENTS

This project was funded by Fondecyt Iniciación 2024 11240044, ANID, Chile. Special thanks to Professor Héctor Sepúlveda, and to the recording assistants Hakeen Mishea and Ignacio Rivera.

6. REFERENCES

[1] A. Zoran: "The 3D Printed Flute: Digital Fabrication and Design of Musical Instruments," *Journal of New Music Research*, vol. 40, no. 4, pp. 379-387, 2011.

[2] J. Savan and R. Simian: "CAD modelling and 3D printing for musical instrument research: the Renaissance cornett as a case study," *Early Music*, vol. 42, no. 4, pp. 537–544, 2014.

[3] R. Simian: "3D-Printed Musical Instruments: Lessons Learned from Five Case Studies," *Music & Science,* vol. 6, p. 20592043231210653, 2023.

[4] P. Qian, N, Xiaoyu, L, Liangzhi, M. Junjie, Y. Shumeng, C. Zhuo, L. Jonghyun and F. Shengxue, "A comparison on sound quality of PLA 3-D printing ukulele and single board wooden ukulele," in *Proc. of Meetings on Acoustics*, (San Diego, California), p. 035007, 2019.