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Subjective descriptive evaluation of instrument timbre - factory-made and luthier-crafted guitars using the semantic differential method

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Abstract This study aimed to subjectively evaluate the timbre of factory-made and luthier-crafted guitars using the semantic differential method based on auditory stimuli. Eleven guitars of different constructions, ages, and price classes, both factory and luthier-made, were included. For each instrument, three short fragments of "Fantasie Dramatique Le Depart" Op. 31 by N. Coste were recorded. The listening experiment involved 57 participants (musicians and non-musicians) who assessed the instruments in pairs of timbral descriptors. The recordings were made at a recording studio. A guitarist performed the fragments on each guitar as consistently as possible. The goal was to verify the hypothesis that participants, regardless of education, would most frequently choose guitars with a warm timbre and prominently sounding bass strings. The hypothesis was confirmed regardless of listeners musical education. Results obtained by non-musicians did not significantly differ from those obtained by the musicians.

Keywords: timbre, timbre determination methods, subjective evaluation, classical guitar, factory guitar, luthier guitar, musicians, non-musicians.

1. Introduction

The subjective evaluation of the timbre of factory-made and luthier-crafted guitars was an experimental research study in the field of psychoacoustics, incorporating elements of musical acoustics. The motivation for undertaking this topic stemmed from the incomplete research on the perception of the sound qualities of classical guitars.

The classical guitar, despite its seemingly small size, is often referred to as a "small orchestra". This epithet arises from the extensive timbral possibilities it offers. Although the guitar's sound range spans from E in the great octave to c in the three-line octave (E-c3), its ability to manipulate sound quality and timbre is unrivaled.

The initial inspiration for the present experiment was the Leonardo Guitar Research Project (LGRP), which investigated classical guitars with varying constructions. In the LGRP, sound samples recorded from each instrument, played by the same guitarist, were evaluated by listeners using an online survey [1].

Experiment described in the present expanded upon the LGRP concept by incorporating a novel element. Eleven classical guitars of different constructions and classes were used to record sound samples. An educated musician was invited to perform three short (approximately thirty-second) fragments of a classical piece. The participants in the timbre evaluation experiment included individuals with musical education (musicians) and those without formal musical education (non-musicians). Unlike the LGRP, the listening sessions were conducted in a specially adapted room rather than online.

Considering the complexity of the instrument's sound, the human factor, and the subjectivity of the evaluation, it was impossible to eliminate all variables affecting the experiment's course and outcome. Variables were minimized through the consistent preparation of the instruments (using the same type of strings on each guitar), the careful selection and preparation of the sound recordings, and the planning of a reliable program for subjective evaluation. Additionally, minimizing the influence of the human factor (i.e., the performer/guitarist) on the instrument's sound was crucial. Therefore, the same musical fragments were performed on each guitar by one player, who aimed to execute the material as consistently as possible.

As the title of this paper indicates, the experiment relied on the subjective evaluation of classical guitars. This subjectivity means that each listener provided responses based on their thoughts or feelings, and no assessment could be deemed "wrong" or "right." To limit the influence of visual cues and personal preferences on the timbre evaluation, listeners were not provided with information about the appearance or specifications of the guitars. During listening sessions, sound samples were presented in random order.

The primary objective of this study was to verify the hypothesis that listeners participating in the experiment, regardless of their musical education, would most frequently choose guitars with a warm timbre and resonant bass strings during the playback of instrument recordings. This study builds upon previous findings [2], which established that listener preferences for classical guitar sound are strongly influenced by warm and resonant timbres.

1.1. Sound and timbre

Basic subjective features characterizing sound are: loudness, pitch, duration, and timbre. For three of the four mentioned parameters, physical (objective) parameters can be used to define them. Simplifying, the loudness of sound corresponds to sound intensity, and pitch corresponds to frequency. This means that loudness and pitch are one-dimensional characteristics. However, timbre is a multidimensional concept, so several parameters influence this feature of auditory perception. Consequently, it is not possible to use a single scale to define timbre.

According to the ASA [3], timbre is defined as follows: "Timbre is that attribute of auditory sensation in terms of which a listener can judge that two sounds presented in a similar manner and having the same loudness and pitch are dissimilar." Plomp's [4] definition is as follows: "Timbre is that attribute of auditory sensation by which a listener can judge that two steady-state complex tones having the same loudness, pitch, and duration are different." He also found that for sounds with the same pitch and loudness but different spectra and different phase relationships between spectral components, the perception of timbre depended primarily on the energy distribution as a function of frequency [4]. For someone closely associated with music, the essence of timbre is the characteristic that allows the identification of a specific instrument and the expression of differences between instruments. Timbre is also an interpretive attribute that allows for expressing the unique qualities of a musical work and the emotions of the performer.

The auditory sensation feature of timbre can be assessed using four primary methods:

- **Semantic Method**: a descriptive method where the perceived timbre is associated with adjectives describing the auditory sensation (e.g., dark, bright), emotional associations (e.g., calm, velvety), and similar descriptors.
- **Semantic Differential Method**: a modification of the descriptive method where the descriptors are arranged on a one-dimensional scale based on opposing adjectives (e.g., resonant – dull, warm – cold).
- **Source Identification Method**: a method that allows only the determination of timbre for known sounds by recognizing and associating the sound with a specific source (e.g., identifying speech sounds).
- **Multidimensional Scaling (MDS) Method**: a method that allows presenting the relationships between scaled variables as the geometric position of points in an n-dimensional space (e.g., a multidimensional graph of timbre descriptors) [5].

In this study, the descriptive method of semantic differential was used.

The auditory sensation of timbre is also related to elements responsible for an additional perspective of subjective sound quality evaluation. These elements include sharpness, roughness, fluctuation strength, tonality, and others [6]. Each of these parameters adds to the timbral evaluation. Sharpness is the auditory sensation related to the sound spectrum's envelope. Its opposite is the pleasantness of sound related to loudness, tonality, or roughness elements. Roughness refers to the auditory sensation associated with the temporal structure of sound caused, among other things, by amplitude modulation. Fluctuation strength is the auditory sensation related to amplitude or frequency fluctuations. Tonality is the last mentioned component, enabling perceptual differentiation between a sound of a specific pitch and noise [5].

Due to the use of the semantic method and its modification, it should be noted that because of the use of verbal descriptors, there are two discrepancies. The first discrepancy is related to individual interpretations of the epithet, meaning that the same descriptor used to describe sound timbre will have different meanings for different listeners. The second discrepancy results from the limited literature on the problem in Polish, making it challenging to select appropriate vocabulary.

To build the clearest possible database of timbral descriptors, expressions found in English-language papers were considered and compared with available Polish-language descriptors. The primary difficulty was the significant semantic differences between a word used in English and its translation into the native language (in this case, Polish). Fritz et al. [7] largely concerned the selection of semantic descriptors for timbre by musicians and luthiers and organizing these descriptors on a multidimensional scale. The prelude to this work was the most accurate empirical research on violin timbre, conducted by Czech researchers. Using only four timbral descriptors: sharp, dark, clear, and narrow, they correlated the relationship between violin timbre expressed semantically and acoustic properties. Another inspiration for timbre descriptors were the terms from [8]. An interesting aspect discussed in this paper was the clustering of 60 timbral descriptors (also in English) into clusters of similar terms. Participants were tasked with arranging the timbral descriptors based on the string attack location on the guitar. This is significant because one of the characteristics of guitar sound is the ability to produce different timbral shades in various "parts" of the string's active action. If the string is plucked near the bridge, a bright timbre is generated; if plucked near the sound hole, the resulting timbre is clear but not too bright or too dark, with a fairly natural sound. Conversely, plucking the string behind the sound hole, as close to the fingerboard as possible, produces a dark and mysterious timbre. Clusters were created by arranging timbral descriptors according to the string attack locations, and three specific timbral-performance descriptors, borrowed from the Italian language and commonly used by musicians, emerged. These descriptors are:

– Ponticello – at the bridge,
– Tasto – near the fingerboard,
– Estompe – on the fingerboard.

Having English-language inspirations for timbral descriptors concerning both violins and guitars, they were compared with Polish-language nomenclature. Unfortunately, no studies of a similar nature to the described in mentioned above papers have been conducted. However, the semantic description of timbre was described in [9]. The author used the semantic method and the semantic differential method to provide timbral descriptors.

An attempt to systematize the semantic description of timbre, which often resulted in verbal misunderstandings was described in [10]. The experiment involved musicians and non-musicians from artistic professions. An anonymous questionnaire was conducted, collecting basic data on the participants. Participants were tasked with spontaneously describing timbral descriptors without specific guidelines or restrictions. The authors mentioned a sociological aspect also encountered in similar studies [11]. This aspect pertained to differences in the success of obtaining information indirectly (online) versus directly. Only about 10% of the participants who received the questionnaire online were willing to participate and respond. However, the group approached directly nearly entirely fulfilled the goal [11]. It was also noted that the type of descriptor chosen and its frequency of occurrence were strongly correlated with the specific professional group [10]. The authors confronted results of 10 musicians using the indirect method (online). The following pairs of timbral descriptors were selected:

– cold - warm,
– dark - light,
– dull - resonant,
– smooth - rough,
– velvety - metallic,
– matte - bright.

In the present paper the selection was limited to the above six pairs of descriptors. This decision was based on the experiment's assumption that the listening time for a specific classical guitar model would be a maximum of 30 seconds. Selecting a larger number of timbral descriptor pairs could prolong the experiment and complicate the evaluators' decisions, particularly for the group of listeners not associated with music.

1.2. Subjectivity and sound evaluation

The evaluation of the timbre of a musical instrument is strongly influenced by various variables. Variables are understood as features or properties that can assume specific values and subsequently allow differentiation between musical instruments [12]. The classification of variables can be based on different criteria. Therefore, pairs of variables such as continuous – discrete, qualitative – quantitative, nominal – ordinal, interval – ratio, and dependent – independent are distinguished [13]. The last pair of variables was used to declare the variables in this study. Distinguishing variables in the described experiment is crucial. However, in this study, it was not a straightforward issue. The key dependent variable was the timbre of individual classical guitars. Independent variables included factors such as guitar construction (a multifactor variable involving both the type of wood used and the bracing system), guitar class (understood in terms of factory-made – luthier-crafted and subcategories of build quality and instrument price), and the precision and consistency of the guitarist performing the piece being recorded. Independent variables also encompassed factors related solely to the listeners evaluating the sound of the instruments (e.g. their musical education, familiarity with the sound of the classical guitar, the concentration, the possibility of fatigue, and the broadly understood subjectivity of evaluation).

The subjectivity of sound quality evaluation is based on personal feelings, which, through appropriate descriptors, can be expressed literally and subjected to further analysis. This subjectivity pertains to the understanding and interpretation of verbal timbral descriptors, the preference for the instrument's sound, or the way of expressing one's opinion.

Considering the broadly developed concept of subjective evaluation, the following assumptions were introduced into the conducted experiment:

1. Each instrument used for the recordings had the same set of strings, installed and prepared in a similar timeframe.
2. Classical guitars selected for the experiment varied in class, quality, price, and age.
3. The sound samples consisted of short (thirty-second) fragments of the same piece, played by an educated musician in the most consistent manner on each guitar.
4. The experiment was conducted directly.
5. The listeners included both musicians and non-musicians.
6. The only information about the instruments provided to the participants during the listening session was the sound sample of the individual guitar.

2. Experiment

2.1. Instruments

Eleven classical guitars of different characteristics were used for the recordings in the experiment, on which the same fragments of the piece were recorded. In order to maintain the anonymity of luthiers and producers, the guitars in Figure 1 are presented in a random order, which does not correspond to the numbering of the instruments later in the paper. After attaching the strings, the instruments were played for approximately 1 hour before recordings. For more information see [13]. The instruments significantly differed in construction (type of wood used), origin, age, and price class. The common elements were the type of instrument and the use of the same strings on each. Sets of strings medium tension of bass strings and hard tension treble strings were used. To avoid influencing the listeners (both musicians and non-musicians) by the reputation of the factory guitar manufacturer or the luthier, the nomenclature was limited to specifying the number of a given guitar type – factory (F) or luthier (L) from the set of guitars selected for the experiment.

2.2. Sound samples

Fragments of the recorded piece came from Fantasie Dramatique "Le Depart" op. 31 by Napoleon Coste and were melodically and rhythmically varied in such a way as to show the widest possible register and possibilities of the guitars. The instruments were played by a professional guitarist with higher musical education. His task was to perform 3 short parts of the piece (the duration of one part was approx. 30 seconds), with the assumption that each fragment would be performed as repeatably as possible on individual instruments. The guitarist did not know what models of instruments were intended for recording, and he had up to 15 minutes to get to know each guitar. The guitarist had the option of repeating the recording if he was not satisfied with its quality.

The guitar recordings were not normalized for sound volume, and there was no interference with the sound spectrum to remove additional noises or impurities. The only modifications to the sound samples were truncation and applying appropriate fade-in and fade-out times. The recordings took place in the recording studio. The recording system consisted of Neumann U87 microphones in an XY configuration and a Neumann KU100 dummy head placed about 1 meter from the guitarist. To allow the sound engineer to adjust the recording equipment and settings and for the musician to acclimate to the new conditions, a sound test was conducted using the guitarist's own instrument, which was not included in further parts of the study. According to the musician's initial impressions, who had direct contact with each instrument, he would classify only 3 guitars as factory-made, while the others sounded good enough to be considered hand-made by a luthier.

Figure 1. Guitars used in the experiment.

2.3. Measurement apparatus and methodology

The listening experiment was conducted in an acoustically adapted room with a volume of 7 m^3 and a high absorption coefficient. The room contained a Dell Studio 1555 laptop and Sennheiser HD600 headphones. The experiment was carried out using the "Gitara" program, created A. Sęk. Before the experiment, the headphones were appropriately calibrated and adjusted for frequency corrections. A consistent signal level of 65 dB SPL was set for all listeners.

The experiment involved determining the timbre of the heard instrument. Six pairs of timbral descriptors were presented on a 1-10 scale on the screen. The listener was tasked with marking their response after listening to the fragment, which they could repeat as many times as needed. However, he/she could not return to previously answered questions. The order of instrument presentation was random. A short interview was conducted to gather basic information about the listener, such as age and gender, musical education (and its level, if applicable), contact with the instrument, and professional activity. Each listener was informed about the lack of interference in the recordings regarding the exclusion of unpleasant nuances or impurities and was asked to ignore these aspects and provide an honest evaluation of the instrument's sound. Before starting the experiment, a short (2-3 minute) test was conducted to prepare the listener for the task's specifics. Listeners did not have information about the visual aspects of the instrument. They were informed that all guitars were classical and that there were 11 of them, with their presentation being in random order. After completing the experiment, they were informed about their choices and preferences. The average duration of the experiment was about 11 minutes.

2.4. Listeners

Fifty-seven listeners (41 men, 16 women; average age 27 years; 29 musicians and 28 non-musicians), were invited to the experiment. The group of professional musicians had a minimum of 9 years of musical experience. The non-musicians group included individuals who either had no musical education or had minimal contact with music through additional activities. The musician group included guitarists, violinists, pianists, composers, trumpeters, saxophonists, vocalists, and percussionists. It was expected that musicians, regardless of their specific professional subcategories (related to their instruments), would have significantly higher selectivity and awareness in listening than the non-musicians group. This expectation was supported by earlier studies [14], which confirmed that musicians acquire greater listening skills in both semantic and reduced (musical) modes during their education. This leads to the development of so-called conscious listening and better recognition of minor musical nuances, including those related to timbre.

3. Results and discussion

Given the complexity of the experiment, it was decided to forgo statistical analysis of the data, following the presentation method used in subjective studies on violins [15]. Results of average value with standard deviation values (Mean ± SD) are presented in Tables 1-3. The listeners were tasked with listening to a roughly thirty-second fragment (with the possibility of repetition) and rating it on a scale from 1 to 10 for six pairs of timbral descriptors, e.g. in the pair cold – warm, the number 1 indicated the coldest, and 10 indicated the warmest timbre.

Table 1. Average value with standard deviation value of the descriptor selection in timbral pairs. Results for all listeners.

Guitar					
Cold	Dark	Dull	Smooth	Velvety	Matte
L2 5.6 ± 0.5	L7 4.1 ± 0.4	L2 5.2 ± 0.4	L1 4.0 ± 0.3	L7 4.3 ± 0.4	L7 4.3 ± 0.4
F3 5.5 ± 0.5	L4 4.4 ± 0.4	F3 5.2 ± 0.4	L4 4.1 ± 0.3	L1 4.5 ± 0.4	L4 4.6 ± 0.4
F2 5.8 ± 0.4	L1 4.4 ± 0.4	L3 5.2 ± 0.5	L7 4.1 ± 0.4	L4 4.7 ± 0.4	L1 4.7 ± 0.5
L5 5.9 ± 0.5	L6 4.5 ± 0.4	F1 5.2 ± 0.5	L6 4.4 ± 0.4	L6 4.8 ± 0.4	L5 4.8 ± 0.4
F1 5.9 ± 0.5	F2 4.6 ± 0.4	L4 5.2 ± 0.4	F2 4.5 ± 0.3	F1 5.1 ± 0.4	F2 4.8 ± 0.4
L3 5.9 ± 0.5	F1 4.7 ± 0.4	L5 5.5 ± 0.4	F4 4.5 ± 0.4	L5 5.2 ± 0.5	F3 4.9 ± 0.5
F4 6.0 ± 0.5	F3 4.9 ± 0.4	F2 5.6 ± 0.5	L5 4.6 ± 0.4	L2 5.2 ± 0.5	L6 4.9 ± 0.4
L1 6.1 ± 0.5	L2 4.4 ± 0.4	L7 5.8 ± 0.4	F1 4.9 ± 0.4	F2 5.2 ± 0.4	F1 5.0 ± 0.4
L7 6.2 ± 0.5	L5 5.1 ± 0.4	L1 5.7 ± 0.5	L2 5.1 ± 0.4	F4 5.4 ± 0.5	F4 5.3 ± 0.5
L4 6.3 ± 0.4	F4 5.1 ± 0.4	L6 5.9 ± 0.5	F3 5.1 ± 0.4	F3 5.5 ± 0.5	L3 5.3 ± 0.5
L6 6.3 ± 0.4	L3 5.2 ± 0.4	F4 6.3 ± 0.5	L3 5.7 ± 0.5	L3 6.4 ± 0.5	L2 5.3 ± 0.4
Warm	Light	Resonant	Rough	Metallic	Bright

Table 2. Average value with standard deviation value of the descriptor selection in timbral pairs. Results for non-musicians.

Guitar					
Cold	Dark	Dull	Smooth	Velvety	Matte
F 2 5.8 ± 0.4	L 4 4.4 ± 0.4	L 4 5.2 ± 0.4	L 4 4.0 ± 0.3	L 1 4.5 ± 0.4	L 5 4.9 ± 0.4
L 5 5.8 ± 0.5	L 7 4.5 ± 0.4	L 3 5.4 ± 0.5	L 1 4.1 ± 0.4	L 4 4.6 ± 0.4	L 4 4.9 ± 0.4
F 3 5.8 ± 0.5	L 1 4.6 ± 0.4	L 5 5.4 ± 0.4	F 4 4.1 ± 0.4	L 6 4.8 ± 0.4	L 6 5.0 ± 0.4
L 2 5.9 ± 0.5	L 6 4.7 ± 0.4	F 3 5.5 ± 0.4	L 6 4.3 ± 0.4	L 7 4.8 ± 0.4	L 7 5.0 ± 0.4
F 1 5.9 ± 0.5	F 2 4.8 ± 0.4	F 1 5.8 ± 0.5	F 2 4.4 ± 0.3	F 2 5.2 ± 0.4	F 3 5.0 ± 0.5
L 3 6.0 ± 0.5	L 5 4.8 ± 0.4	L 1 5.9 ± 0.5	L 7 4.5 ± 0.4	L 2 5.3 ± 0.5	L 1 5.0 ± 0.5
L 1 6.0 ± 0.6	F 3 4.9 ± 0.4	L 6 6.0 ± 0.5	L 5 4.5 ± 0.4	F 4 5.3 ± 0.5	F 2 5.1 ± 0.4
L 7 6.3 ± 0.5	L 2 5.0 ± 0.4	L 2 6.0 ± 0.4	F 3 4.9 ± 0.4	L 5 5.4 ± 0.5	L 2 5.2 ± 0.4
L 4 6.3 ± 0.4	F 1 5.0 ± 0.4	F 2 6.0 ± 0.5	F 1 5.0 ± 0.4	F 3 5.4 ± 0.5	L 3 5.4 ± 0.5
L 6 6.4 ± 0.5	L 3 5.5 ± 0.4	L 7 6.1 ± 0.4	L 2 5.1 ± 0.4	F 1 5.5 ± 0.4	F 4 5.4 ± 0.5
F 4 6.4 ± 0.5	F 4 5.5 ± 0.4	F 4 6.5 ± 0.5	L 3 5.7 ± 0.5	L 3 6.3 ± 0.5	F 1 5.8 ± 0.5
Warm	Light	Resonant	Rough	Metallic	Bright

The factory guitar F1 was described by non-musicians listeners as quite light, rough, metallic and most bright compare to other instruments, meanwhile musicians described this instrument as quite dark, velvety and very matte and dull sounding.

Table 3. Average value with standard deviation value of the descriptor selection in timbral pairs. Results for musicians.

Guitar											
Cold		Dark		Dull		Smooth		Velvety		Matte	
L 2	5.3 ± 0.4	L 7	3.8 ± 0.3	L 2	4.3 ± 0.4	L 7	3.8 ± 0.3	L 7	3.9 ± 0.4	L7	3.7 ± 0.3
F 3	5.6 ± 0.4	L 1	4.3 ± 0.4	F 1	4.7 ± 0.4	L 1	3.9 ± 0.3	L 1	4.5 ± 0.4	F 1	4.3 ± 0.3
F 4	5.7 ± 0.4	F 1	4.3 ± 0.4	F 3	4.8 ± 0.4	L 4	4.2 ± 0.3	L 6	4.7 ± 0.4	L 4	4.3 ± 0.3
F 2	5.9 ± 0.4	L 4	4.4 ± 0.3	L 3	5.0 ± 0.5	L 6	4.4 ± 0.4	F 1	4.8 ± 0.4	L 1	4.6 ± 0.4
L 3	5.9 ± 0.4	L 6	4.4 ± 0.4	F 2	5.2 ± 0.5	F 2	4.5 ± 0.3	L 4	4.9 ± 0.4	F 2	4.3 ± 0.4
F 1	6.0 ± 0.4	F 2	4.5 ± 0.4	L 4	5.2 ± 0.4	L 5	4.7 ± 0.4	L 5	5.0 ± 0.4	F 3	4.8 ± 0.4
L 5	6.0 ± 0.4	F 4	4.6 ± 0.4	L 7	5.3 ± 0.4	F 1	4.7 ± 0.4	L 2	5.2 ± 0.4	L 5	4.8 ± 0.4
L 7	6.1 ± 0.4	L 3	4.9 ± 0.4	L 1	5.6 ± 0.4	F 4	4.8 ± 0.3	F 2	5.3 ± 0.4	L 6	4.9 ± 0.4
L 1	6.2 ± 0.4	F 3	5.0 ± 0.4	L 5	5.7 ± 0.3	L 2	5.0 ± 0.4	F 4	5.4 ± 0.4	F 4	5.2 ± 0.4
L 6	6.2 ± 0.4	L 2	5.0 ± 0.4	L 6	5.9 ± 0.4	F 3	5.4 ± 0.3	F 3	5.6 ± 0.4	L 3	5.3 ± 0.5
L 4	6.2 ± 0.4	L 5	5.3 ± 0.4	F 4	6.1 ± 0.4	L 3	5.7 ± 0.5	L 3	6.4 ± 0.4	L 2	5.4 ± 0.3
Warm		Light		Resonant		Rough		Metallic		Bright	

To enhance the interpretation of results, standard deviation (SD) values are provided alongside mean scores for each descriptor and guitar. This approach highlights variability in listener responses and strengthens the statistical robustness of the analysis. Low standard deviation value indicates high agreement among listeners, implying that the mean reliably represents the group's perception.

The implications of variability are discussed in relation to listener groups and guitar types: Slightly higher variability observed in non-musicians (e.g., result as most Bright sounding in timbral pair Matte-Bright for Guitar F1: 5.8 ± 0.5) compared to musicians (e.g., result as closer to Matte sounding in timbral pair Matte-Bright for Guitar F1: 4.3 ± 0.3) suggests that auditory training enhances perceptual consistency and assessment accuracy.

– The factory guitar F2 was described by non-musicians listeners as quite resonant, with very cold character, with medium velvetiness and smoothness. Musicians found the instrument warmer compare to no-musicians, with medium dull, smooth and matte.
– The factory guitar F3 was described by all listeners as cold, dull, rought and metallic sound. There were no significant differences between musicians and non-musicians rating.
– The factory guitar F4 was described by non-musicians as warm, light, bright and resonant. However, for musicians, it had a colder, darker and very resonant sound.
– The luthier guitar L1 was described as quite warm, with a dark, resonant sound, but very smooth and velvety. Musicians described this instrument as quite resonant, very smooth and velvety quite similar to non-musicians' group.
– The luthier guitar L2 was described as cold, light, and and bright character. Musicians described it's sound as colder, rougher and brighter compared to the non-musicians' group. Non-musicians found this instrument more resonant.
– The luthier guitar L3 was evaluated as medium warm, very rough and metallic, but with a quaite bright and dull character, possessing significant rough and metallic sound.
– The luthier guitar L4 was described as slightly warm, dark, very smooth, with a velvety and matte sound.
– The luthier guitar L5 was described as slightly warm, dark, resonant, and smooth, with a slightly metallic and bright sound. Musicians rated this instrument as lighter and more resonant, compared to the non-musicians' group.
– The luthier guitar L6 was the warmest (in the given set), quite dark, resonant, smooth, and velvety sound. Musicians rated it as warmer, more resonant and brighter compared to the non-musicians' group.
– The luthier guitar L7 was described as warm, dark, quite resonant, smooth, with a velvety and matte sound. Musicians rated this instrument as warmer, darker, smoother, more velvety and matte compared to the non-musicians' group.
– In summary - for most instruments, the two groups of listeners presented a moderate level of difference due to the lower experience of non-musicians.
– It was anticipated that in the group of listeners without musical education, the obtained values might be extremely different and skewed, due to different auditory selectivity and sensitivity to music perception.

This assumption was not confirmed in the experiment. The terms "different" and "skewed" were used to hypothesize variability in responses from non-musicians due to their potentially lower auditory selectivity and sensitivity. "Different" refers to the expectation of broader variability or divergence in scores among non-musicians. "Skewed" indicates asymmetry in the distribution of responses, implying that scores might cluster towards one end of the scale rather than being symmetrically distributed around the mean. Standard deviation (SD) has been included as a measure of variability. SD provides insight into the spread of scores, highlighting whether responses from non-musicians were more variable (or "indecisive") compared to those of musicians. For instance, the SD values for the descriptor Cold-Warm show:

- Non-musicians: Guitar L1 scored 6.0 ± 0.6 (mean ± SD), indicating moderate consistency.
- Musicians: Guitar L1 scored 6.2 ± 0.4, reflecting higher agreement and less variability.

This demonstrates that while non-musicians showed slightly greater variability, their responses were not significantly "different" or "skewed" compared to musicians. This finding suggests that non-musicians are capable of making consistent and comparable evaluations of timbral descriptors, despite potential differences in auditory selectivity and sensitivity. The use of standard deviation and skewness as measures of variability and distribution provides a robust framework for comparing listener groups.

The results of this study reveal meaningful relationships between the employed timbral descriptors and several objective variables, including guitar class, price range, and musical education of listeners. Luthier-crafted guitars were generally rated higher for timbral warmth and resonance compared to factory-made guitars, reflecting their superior craftsmanship. However, specific tonal characteristics, such as brightness and metallic sound, influenced listener preferences independently of guitar class.

No direct correlation was found between price and listener preferences. Musicians demonstrated greater consistency in their evaluations, as evidenced by lower standard deviations across descriptors. Non-musicians showed more variability and a tendency to rate brighter and metallic timbres more favorably, likely due to differences in auditory training and sensitivity. These findings highlight the complex interplay between timbral characteristics and objective variables, emphasizing the importance of warmth and resonance in shaping listener preferences. Future studies could further explore these relationships by incorporating additional objective metrics, such as spectral analysis or harmonic richness.

While this study provides valuable insights into the subjective descriptive evaluation of classical guitar timbre, certain limitations must be acknowledged, and future research opportunities should be highlighted.

I. Limitations of the Study.
   a. Subjectivity of Perception.
      The study relied on subjective evaluations using semantic differential scales, which are inherently influenced by individual interpretation and personal auditory preferences. Although the use of a consistent methodology aimed to minimize variability, the lack of an objective timbral measurement may limit the generalizability of the results.
   b. Limited Descriptor Set.
      Only six pairs of opposing descriptors were used in the semantic differential evaluation to ensure the feasibility of the listening test. While these descriptors were carefully selected to represent key timbral qualities, a broader range of descriptors could provide a more comprehensive analysis of guitar timbre.
   c. Sample Size and Demographics.
      The study involved 57 participants, evenly divided between musicians and non-musicians. While this sample size is adequate for preliminary findings, a larger, more diverse participant pool could yield more robust conclusions about listener preferences across broader demographics.
   d. Lack of Detailed Objective Measurements.
      Although the study included subjective evaluations, it did not incorporate detailed objective measurements, such as spectral analysis or harmonic content, to directly correlate subjective impressions with physical acoustic properties. This limits the ability to draw concrete connections between the perceived timbre and measurable acoustic characteristics.

II. Directions for Future Research.
   a. Integration of Objective Acoustic Analysis.
      Future studies could combine subjective evaluations with objective acoustic analyses, such as spectral distribution, harmonic richness, or temporal envelope characteristics. This would provide a more complete understanding of how physical properties influence perceived timbre.
   b. Expansion of Timbral Descriptors.
      Expanding the set of timbral descriptors, potentially through multidimensional scaling or cluster analysis, could capture a wider range of auditory impressions. This would also allow for cross-validation with existing research in violin and other string instruments.

c. Longitudinal Studies on Listener Preferences.
Conducting longitudinal studies with repeated exposure to the same guitar recordings could provide insights into how familiarity and repeated listening affect subjective evaluations.
d. Diverse Listener Demographics.
Including a broader demographic of participants, such as varying age groups, cultural backgrounds, and levels of exposure to classical guitar music, would enhance the generalizability of the findings.
e. Evaluation in Real Performance Contexts.
While the controlled experimental setup ensured consistency, future studies could include evaluations in live performance contexts to explore how real-world acoustics and visual elements influence timbre perception.
f. Comparative Analysis with Other Instruments.
Expanding the methodology to include other instruments, such as violins or cellos, could offer comparative insights into timbral perception across different instrument families.

4. Conclusions

The aim of this experimental research study was to investigate the subjective evaluation of the timbre of classical guitars, distinguishing between factory-made and luthier-crafted instruments. Twenty-nine musicians and 28 non-musicians, were invited to evaluate the sound of 11 instruments.
The primary objective of this study was to verify the hypothesis that listeners, regardless of their education, would most frequently choose guitars with a warm timbre and resonant bass strings during the playback of the instrument recordings. This hypothesis was confirmed, as guitars with characteristic metallic and bright sounds (guitar L3 and L2), despite being luthier-crafted and relatively high-priced, were rated as the least preferred. Consistent with the findings in Ref. [13], the results of this study confirm that Warm–Cold and Resonant–Dull are critical variables reflecting listener preferences. Guitars rated higher for warmth and resonance were preferred, even when other descriptors, such as Dark–Light or Smooth–Rough, exhibited variability among listeners. This reinforces the central conclusion that timbral warmth and resonance are universally appealing attributes in classical guitar sound quality.

It was anticipated that in the group of listeners without musical education, the obtained values might be extremely different and skewed, due to different auditory selectivity and sensitivity to music perception. This assumption was not confirmed in the experiment.

Individuals without musical education had also more difficulty understanding and interpreting timbral descriptors and maintaining concentration, especially during long sessions of listening to the same fragment of a piece. Nevertheless, their results did not significantly differ from those obtained by the musicians.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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