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Subjective qualitative evaluation of the sound of factory-made and luthier-crafted guitars

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Abstract The subjective qualitative evaluation of factory-made and luthier-crafted guitars is an experimental study aimed at presenting research on instrument sound evaluation. The study included both factory and luthier guitars of varying construction, age, and price class. Recordings were made at the recording studio of the Department of Acoustics, Adam Mickiewicz University. In the recording process, a professional guitarist maintained maximum performance consistency while playing short fragments of "Fantasie Dramatique Le Depart" Op. 31 by N. Coste. Fifty-seven listeners, including 29 musicians and 28 non-musicians, participated in the sound evaluation, tasked with choosing the preferred guitar from pairs and selecting subjectively the "best" and the "worst" instrument. The primary goal was to test the common belief that luthier guitars are rated highest, regardless of evaluators' professional backgrounds. The experimental evaluation revealed that both luthier and factory guitars were chosen, with the bracing pattern being the most critical factor affecting guitar sound quality.

Keywords: sound, timbre, subjective assessment, classical guitar, factory guitar, luthier guitar, musicians, non-musicians.

1. Introduction

The classical guitar is often referred to as a "small orchestra." This designation stems from the instrument's capability to generate a wide range of timbres, making it a unique instrument in terms of sound manipulation and quality. Although the guitar's range spans from E in the great octave to c in the three-lined octave (E-c3), it is distinguished by its extensive timbral possibilities. The sound of a classical guitar is complex and depends on several factors: (1) the construction of the instrument (type of wood and bracing used), (2) the type of strings used (tension strength and materials), and (3) the player's technique, including how the string is plucked (e.g., tirando, apoyando, picado) and the preparation of the playing apparatus, particularly the shaping and polishing of the right-hand fingernails.

Although in the general public, the classical guitar is often associated only with pleasant accompaniment to melodies, its capabilities are highly valued and emphasized in the musical community. Thanks to its extensive possibilities, guitarists' repertoires include not only pieces originally composed for the guitar but also transcriptions from other instruments.

The initial inspiration for this experiment was the Leonardo Guitar Research Project (LGRP), conducted from 2014 to 2017, which involved studies on classical guitars with various constructions. During the LGRP project, sound samples recorded on each instrument by the same guitarist were presented and evaluated by listeners using an online questionnaire [1]. This idea was adopted and expanded upon in this study by incorporating a novel element. Eleven classical guitars of different constructions and quality levels were used to record sound samples. A trained musician was invited to play three short (approximately thirty-second) fragments of the classical piece Fantasie Dramatique "Le Depart" op. 31 by Napoleon Coste. The evaluation of the instruments' sound quality was conducted using a three-part program. The participants in the sound evaluation included both musically trained individuals (referred to as musicians in subsequent sections) and those without such training (non-musicians). Unlike the LGRP project, the listening sessions took place in a room specifically adapted for this purpose rather than online.

Given the complexity of the instrument's sound, the influence of human factors, and the subjectivity of the evaluation, it was impossible to eliminate all variables affecting the experiment's course and results entirely. Minimizing unwanted variables was achieved by appropriately preparing the instruments (using the same type of strings on each guitar), selecting and preparing the guitar sound recordings, and planning a reliable program for subjective evaluation. Moreover, minimizing the influence of the human factor (i.e., the performer/guitarist) on the instrument's sound was a significant challenge in such experiments.

During the recording of the sound samples, the same fragments of the piece were played by a single performer who aimed to execute the material in the most repeatable manner possible.

Furthermore, as the title of this study suggests, the experiment's assumptions are based on the subjective evaluation of classical guitars. This subjectivity implies that each listener provides responses based on their thoughts or feelings, and no assessment can be categorized as "wrong" or "right." To limit the influence of visual suggestions and personal preferences on the sound evaluation, participants were not informed about the appearance or specifications of the guitars. Additionally, to reduce self-suggestion regarding the order of the instruments, the sound samples were presented in random order. Due to the insufficient number of experiments on the timbral characteristics of classical guitars in the scientific papers at the time of this study, the theoretical basis primarily involves violin studies, which are the most extensively researched musical instruments.

The expected results of the experiment hypothesized that luthier-crafted guitars would be rated more favorably, regardless of the evaluators' professional background. Additionally, it was possible that the values obtained from non-musically trained listeners could be significantly different and skewed due to different auditory attention and sensitivity to music perception.

1.1. Qualitative sound evaluation

The qualitative evaluation of a musical instrument's sound is strongly influenced by variables. Variables are understood as features or properties that allow for the adoption of specific values and, in the next step, the differentiation between musical instruments [2]. The classification of variables can be based on various criteria, resulting in pairs such as: continuous – discrete, qualitative – quantitative, nominal – ordinal, interval – ratio, and dependent – independent [3]. The last pair of variables was used to declare the variables in this study. An essential element was distinguishing the variables in the described experiment. The key dependent variable was the timbre of individual classical guitars. Independent variables included factors such as guitar construction (a multifactorial variable concerning both the type of wood used and the bracing system), guitar class (understood in terms of factory-made or luthier-crafted, as well as quality and price subcategories), and the precision and repeatability of the guitarist performing the piece being recorded. Independent variables also included a group of factors related solely to the listeners evaluating the instrument's sound. Possible variables to be specified were the diversity of musical education among the evaluators and their familiarity with classical guitar sound, listeners' concentration, the potential occurrence of fatigue, and the broad concept of subjective evaluation.

The subjectivity of sound quality evaluation is based on personal sensations that can be expressed literally through appropriate descriptors and subjected to further analysis. This subjectivity relates to understanding and interpreting verbal timbral descriptors, sound preferences of the instrument, and the manner of expressing opinions.

Subjectivity in evaluation is also influenced by the order of presentations (in this experiment, the order of the instrument recordings). The broad impact of presentation order on evaluation has been addressed [4], showing mechanisms affecting the distortion of subjective evaluation. Paper [4] was based on the analysis of data from live performances in the talent show "Idol," covering performances over five years (2002 - 2007). The researchers focused on the influence and quality of evaluations concerning the order of performances. As mentioned by the authors, the variability of performance evaluation pertained to situations where judgment had to be made based on brief exposure to the presented content. The problem of sequential bias impacts two significant factors – the efficiency and fairness of evaluation. Efficiency and fairness are understood as minimizing deviation errors in the evaluation process for both the evaluator and the evaluated, ensuring maximum clarity and lack of subjective bias. Therefore, when ordering performances according to a set sequence, sequential bias is certain to occur. The authors [4] categorized sequential bias into two subcategories: sequential order bias and sequential history bias. The first bias considers situations where evaluators do not remember previous scores accurately. The second bias results from evaluators changing evaluation criteria and subjective perceptions across successive performances.

From the sequential order bias, the authors distinguished the primacy effect and the recency effect. The primacy effect refers to the tendency that, with constant additional factors, initial and final performances are best remembered by evaluators. The recency effect pertains to the probability of remembering certain performances [5]. Researchers also addressed the comparison effect [6]. This effect is based on seeking unique features in subsequent performances (compared to the first performance). Additionally, evaluators tend to focus on positive rather than negative features of subsequent performances, leading to inflated subsequent evaluations.

The second sequential bias, sequential history bias, involves evaluators judging a performance based on the preceding one [7]. The authors also referenced selective accessibility model, where the evaluation of successive participants was based on contrast or assimilation [8]. This means each subsequent performance were compared to and dependent on the previous one. Furthermore, Damisch et al. [7] proved that assimilation was more likely to occur than contrast in evaluations, meaning that the quality of earlier performances would similarly influence the evaluation of subsequent performances. The subjectivity of musical instrument sound quality evaluation using violins as an example was also explored [9]. Authors conducted a two-stage experiment where musicians first familiarized themselves with the instruments and ordered them from least to most preferred. Subsequently, they attempted to find relationships between players' preferences and attributes influencing the instrument's sound.

In another inspiring paper [10] on the subjective evaluation of violin sound the experiment aimed to differentiate and notice the presence of violinists' preferences for antique and new violins when participants were unaware of the instruments' ages, was presented. Despite the evaluators being trained musicians, the experiment showed that historical violins (despite their high value) were not the most frequently chosen by the evaluators.

Taking into account the complex issue of subjective evaluation, the following assumptions were introduced into the conducted experiment: equipping the instruments with an identical set of strings; differentiating the guitars in terms of class, quality, price and age; recording the same fragment of a piece on all tested instruments by the same guitarist; using musicians and non-musicians as listeners without providing them with any information about the guitars, described in details in [11].

1.2. Construction of the classical guitar

The classical guitar is constructed from a resonating body with a soundhole, which includes the top plate, sides, and back plate (also known as the back or bottom). Other components include the neck with the fingerboard and frets, the bridge, the saddle, the head, and the tuning keys. The strings, an essential part of the guitar, are six nylon strings tuned in perfect fourths and a major third for the classical guitar.

Due to the scant research on the instrument's sound, both mass-produced instrument companies and luthiers handcrafting instruments select the guitar's construction individually or according to the buyer's preferences. This means that various bracing systems, double top and back plates, reduced scale lengths, and unconventional modifications such as altering the position or shape of the soundhole can currently be found.

2. Experiment

2.1. Characteristics of instruments

Eleven classical guitars of varying characteristics were selected for the experiment, on which the same fragments of a piece were recorded. These instruments differed significantly in terms of construction, origin, age, and price range, Table 1. Common elements included the type of instrument and the use of the same type of strings on each. Medium tension bass strings and high tension treble strings were used, chosen for their excellent quality-to-price ratio and appropriate thickness and tension, to which the guitarist was already accustomed.

To ensure a maximally similar level of string break-in, each set was installed and properly prepared approximately 1 hour before recording in the studio. This time was considered because strings change their sound as they are played over time. By ensuring the same level of string preparation, comfort of play was achieved for the performer, and differences in the sound of the same string sets were minimized as their usage increased.

To avoid influencing the listeners (both musicians and non-musicians) with the reputation of the guitar manufacturer or the renowned name of the luthier who crafted the guitar, only the number and type of guitar (factory-made (F) or luthier-made (L)) were provided for the selected guitars.

Table 1. Basic Information about the eleven factory-made and luthier-made guitars used in the study.

No.	Guitar Type	Age	Country of Origin	Distinctive Features	Price Range (PLN)
1	Factory F1	~3 years	China	Spanish neck joint	1000 – 1500
2	Factory F2	~15 years	Spain	Spanish neck joint	2000 – 2200
3	Factory F3	~10 years	Spain	Adjustable truss rod	3000 – 3500
4	Factory F4	~3 years	China	Spanish neck joint	5500 – 6000
5	Luthier L1	~44 years	Japan	Construction inspired by Spanish Ramirez	2500 – 5000
6	Luthier L2	~33 years	Germany (GDR)	Oval sound hole, concave top plate	8000 – 10000
7	Luthier L3	~4 years	Poland	Asymmetrical neck, resonating tube	15000 – 18000
8	Luthier L4	~10 years	Poland	Double top plate	10000 – 11000
9	Luthier L5	~10 years	Poland	Double top plate, double back, additional sound hole	15000 – 16000
10	Luthier L6	~3 years	USA/Germany	Innovative bracing calculation method	18000 – 20000
11	Luthier L7	~9 years	Poland	Double top plate and double back	30000 – 35000

By selecting these eleven specific guitar models (including 4 factory-made and 7 luthier-made), a wide spectrum of instrument sounds was achieved while maintaining the appropriate duration of the experiment. It is worth noting that the division into factory-made and luthier-made guitars is overly general and often misleading, potentially leading to the hypothesis that a luthier-made guitar may (but does not necessarily) sound subjectively "better" than a factory-made guitar and vice versa.

2.2. Guitar bracing pattern

The bracing of classical guitars is as varied in design as the types of wood used [12]. Bracing used for all guitars used in the experiment are shown in Table 2. Notably, factory-made guitars F1 and F2 have identical bracing, as shown in Table 2. Similarity, but not identity, is seen between factory-made guitars F3 and F4 . All mentioned guitars have bracing similar to or inspired by the Torres method.

The most well-known and widespread bracing, characteristic of the classical guitar, is represented by luthier-made guitar L1. Similarity in bracing is also seen between luthier-made guitars L3 and L7, with significant symmetry in both horizontal and vertical perspectives.

Bracing less reliant on Torres' design but maintaining symmetry is evident in luthier-made guitars L2 and L4. Like guitars L3 and L7, the bracing is symmetrical, but luthier-made guitar L2 has the most braces (11) extending from the sound hole along the top plate. Luthier-made guitar L4's bracing symmetry involves five braces on each side, intersecting to form characteristic diamonds, increasing towards the sound hole. The most complex and innovative bracing approaches are seen in luthier-made guitars L5 and L6, with the latter using the Fibonacci sequence to calculate the bracing elements. The bracing in luthier-made guitar L5 resembles an extended version of the bracing in factory-made guitar F4, with additional triangular braces connecting near the sound hole.

Analyzing all the presented bracing diagrams, it is notable that the bracings of factory-made guitars (F1, F2, F3, F4) and luthier-made guitar L1 are similar to the characteristic bracing of the classical guitar. The next two guitars L3 and L7, show similar bracing in terms of the number and symmetry of braces, with visible inspiration from the Torres method. Luthier-made guitar L2 has the most braces in its construction, while L4 has a bracing pattern entirely different in shape and direction. The most innovative bracing is seen in luthier-made guitars L6 (especially) and L5.

2.3. Characteristics of sound samples

A qualified, active musician with higher musical education, was invited to the recordings. The guitarist's task was to perform 3 short sections of a piece (each approximately 30 seconds long), with the assumption that each fragment would be played in a relatively maximally repeatable manner on each instrument. The fragments came from Fantasie Dramatique "Le Depart" op. 31 by Napoleon Coste and were melodically and rhythmically varied to showcase the guitars' widest range and capabilities. The piece was chosen by the performer to ensure comfort, as the recordings were made on the same day within a short time frame to increase the likelihood of repeatability and minimize variables such as changes in the playing apparatus

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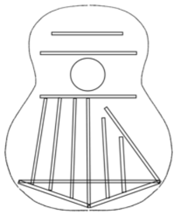
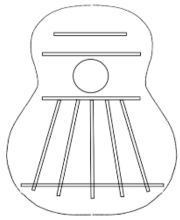
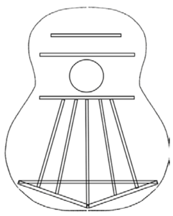
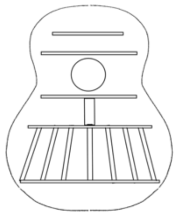
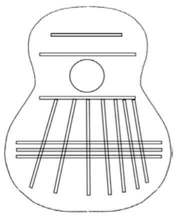
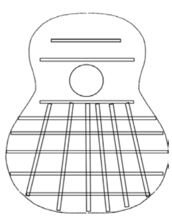
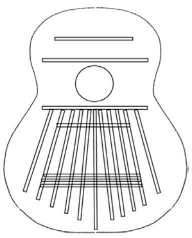
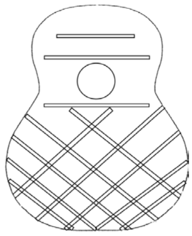
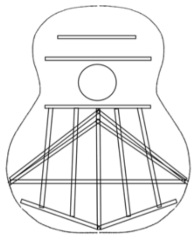
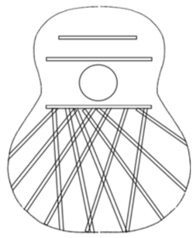
(nails) and the performer's mood affecting the playstyle. Additionally, to ensure minimal personal bias or preferences towards the instruments and potential favoritism of certain guitars, the guitarist did not know which models were included in the recordings, and each guitar was allotted a recording time of up to 15 minutes. The guitarist could repeat sections if dissatisfied with the quality of their performance.

Table.2. Bracing patters of guitars used in the experiment.

Factory guitars							
F1 F2		F3		F4			
Luthiery guitars							
L1		L3		L7			
L2		L4		L5		L6	

The guitar recordings were not normalized for volume levels, and there were no interventions in the sound spectrum to remove additional noises or impurities. The only manipulation of the sound samples involved trimming the fragments and applying appropriate fade-in and fade-out times.

The recordings were made in the recording studio of the Acoustics Department at the Faculty of Physics, Adam Mickiewicz University (AMU). The recording system included a Neumann KU100 dummy head placed approximately 1 meter from the player. 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 on the guitarist's instrument, which was not considered in further parts due to emotional attachment to that guitar. Interestingly, the guitarist identified some instruments by distinctive features (headstock design, decorations, etc.). However, after the 5-hour recording session, he was intrigued as to why most guitars were luthier-made (assumed to be better sounding), which was a misconception since he played on 4 factory-made and 7 luthier-made guitars. According to the musician's initial impressions, only 3 guitars were classified as factory-made, while the rest sounded good enough to be thought of as handmade luthier guitars. The musician's observation was confirmed and expanded upon by the listeners' perspectives in the main experiment.

2.4. Measurement equipment and experiment

The listening experiment was conducted in an acoustically adapted room with a volume of 7 cubic meters and a high absorption coefficient, equipped with a Dell Studio 1555 laptop and Sennheiser HD600 headphones. The experiment used the "Gitara" program, created by Aleksander Sęk from the Department of Acoustics, Faculty of Physics, AMU. Before starting the experiment, the headphones were calibrated and adjusted for frequency corrections. A constant output signal level of 65 dB SPL was set for all listeners. This level was sufficiently loud to hear all musical nuances while not exposing the listener to acoustic trauma or permanent hearing damage.

The experiment involved choosing the subjectively "best" (preferred) guitar among pairs. The listener had to listen to all pair combinations (110 pairs, excluding pairs with the same instrument recordings) and make a forced-choice selection of which guitar from the pair was preferred. The listener could not repeat the sound sample or return to a previously given choice. After responding by clicking the "1" or "2" button, the listener had to click the "next pair" button to proceed to the next pair of recordings. The presentation order of the instruments was random, with a 1-second pause between signals.

The listening experiment included 11 guitars, resulting in 110 unique ordered pairs (e.g., AB and BA), with each pair presented twice in both possible orders. This approach ensured the counterbalancing of order effects and allowed for the identification of inconsistencies in listener preferences. While most evaluations were consistent across both orders, some conflicting preferences were observed, reflecting the subjective nature of the task. In cases of conflicting responses, the guitar most frequently selected across both orders was recorded as the preferred choice for that pair. Presenting both orders minimized potential biases related to primacy or recency effects, enhancing the reliability of the results.

2.5. Listeners

Fifty-seven listeners (41 men, 16 women; average age 27) participated in the listening experiment, including both those with musical education (musicians) and those without (non-musicians). It was important to include listeners with varying levels of engagement and connection to music to obtain a wide range of evaluations. The musician group comprised 29 individuals with musical education, long-term musical contact (minimum 9 years of musical experience), and active musicians. The non-musician group included 28 individuals without formal musical education or with limited musical contact through extracurricular activities. The musician group included guitarists, violinists, pianists, composers, trumpeters, saxophonists, vocalists, and percussionists. It was expected that musicians, regardless of their specific occupational subcategories (related to their instrument), would have significantly higher selectivity and awareness in listening than non-musicians. This expectation was supported by studies which confirmed that musicians developed greater listening skills in both semantic and reduced (musical) modes during their education [13]. This led to the development of so-called conscious listening and better recognition of subtle musical nuances, including those related to sound color.

2.6. Research methodology

The listening experiment was conducted from February 2021 to June 2021. Each participant was invited individually and asked to reserve 2 hours for the experiment (including introduction and breaks). Initially, a short interview was conducted to gather basic information about the listener, such as age and gender, and more detailed information such as musical education (and its level, if the listener had any), instrument contact, and professional activity. Each listener was informed that there were no interventions in the recordings to exclude unpleasant nuances or impurities and was asked not to pay attention to this but to accurately assess the instrument's sound. The listening station was then presented, and the user was introduced to the interface. Before starting the listening experiment, a short (2-3 minute) test was conducted to prepare the listener for the task's specifics. It was important that listeners, regardless of their occupational group, did not have information about the instruments' visual aspects, as it would significantly influence the evaluation of the guitars' sound. Additionally, listeners did not have detailed information about the instruments they were listening to, so they would not be subconsciously seeking the relatively "best" / "most expensive" / luthier-made or "worst" / "cheapest" / factory-made guitar. Listeners were informed that all guitars were classical and that there were 11 of them, with their presentation mainly in random order. The sound samples were presented in a sequence designed to minimize biases associated with order effects. The sequence was primarily randomized using a computer-generated algorithm, ensuring a non-repeating and balanced order of guitar presentations for each participant. However, minor manual adjustments were made to address specific experimental constraints, such as preventing consecutive presentations of the same instrument and maintaining participant engagement during extended listening sessions. These adjustments ensured the integrity of the randomization process while accommodating practical requirements.

After completing all parts of the experiment, they were informed about their choices and preferences. The experiment average duration, excluding breaks, was 48 minutes, with the minimum response time for instrument pair selection being 45 minutes and the maximum time being 51 minutes.

3. Results

Considering the complexity of the experiment, which was based on the subjective evaluation of listeners, it was decided to forego statistical data analysis, modeling the presentation of results on the subject tive studies concerning violin instruments [10]. The results are presented in categories: for non-musicians (28 individuals) and for musicians (29 individuals).

3.1. Instrument selection from pairs

In the experiment, listeners were tasked with listening to two approximately ten-second fragments (without the possibility of repetition) with a one-second pause between them and subjectively choosing the "better" sounding instrument from the pair. Each guitar could be chosen/indicated a minimum of 0 times and a maximum of 20 times. Results are shown in Tables 3 and 4. In Tables 3-4 the guitars are ranked from "the best" to "the worst". The median value of the scores was assumed as the basis for the ranking of instruments. The median value of listener scores was used as the basis for ranking the instruments, as it is less sensitive to extreme values and better suited for the ordinal nature of the data. While the mean assumes an interval scale, the median more accurately reflects the central tendency of listener preferences, particularly in the context of subjective evaluations where variability across participants is expected. A comparison between median-based and mean-based rankings revealed a high degree of similarity (Spearman rank correlation coefficient: 0.97). However, minor differences were observed for guitars with greater variability in listener scores, such as Guitar L3, which was ranked slightly lower using the median due to its polarizing characteristics. These findings support the choice of the median as a more robust and representative measure for the purposes of this study.

Table 3. Score values for the task of instrument selection from pairs. Results for non-musicians.

Guitar Type	Median of indications	Minimum number of indications	Maximum number of indications	Rank
L 6	12.0	4	17	1
L 5	11.0	5	18	2
F 1	10.5	5	18	3
F 4	10.0	1	19	4
L 7	10.0	3	20	4
L 4	10.0	2	17	4
L 3	9.0	1	15	5
L 1	9.0	2	19	5
F 2	9.0	1	15	5
L 2	8.5	0	14	6
F 3	8.5	0	15	6

Table 4. Score values for the task of instrument selection from pairs. Results for musicians.

Guitar Type	Median of indications	Minimum number of indications	Maximum number of indications	Rank
L 6	14.0	5	19	1
L 5	11.0	6	18	2
F 1	11.0	6	18	2
L 4	10.0	5	17	3
F 3	10.0	2	14	3
F 4	10.0	2	15	3
L 7	9.0	0	18	4
L 1	9.0	4	16	4
F 2	8.0	1	15	5
L 3	6.0	0	20	6
L 2	6.0	0	14	6

The presentation of each guitar pair in both possible orders (AB and BA) enabled the detection of inconsistent preferences, defined as cases where a listener reversed their choice depending on the order. Across all participants, inconsistent responses were observed in 14% of pairs, with musicians exhibiting lower rates of inconsistency (8%) compared to non-musicians (20%). These results highlight the influence of musical training on auditory consistency.

A subtle primacy effect was identified, with the first guitar in a pair being preferred in 54% of cases. This effect was more pronounced among non-musicians (57%) than musicians (51%), suggesting that non-musicians relied more on initial impressions, while musicians demonstrated greater resistance to order effects. The results demonstrate that musicians are more consistent in their evaluations, likely due to their trained auditory selectivity. Non-musicians exhibited greater variability, reflecting their less defined auditory preferences. These findings emphasize the importance of accounting for listener status in subjective sound evaluations and suggest that future studies could explore methods to mitigate the influence of order effects.

The phenomenon of cyclic preferences, where a listener's pairwise judgments form a loop (e.g., A > B, B > C, C > A), was analyzed to assess consistency in evaluations. Across all participants, cyclic preferences occurred in 6% of responses. A significant difference was observed between musicians and non-musicians:

– Musicians exhibited cyclic preferences in only 3% of cases, indicating greater consistency in their evaluations.
– Non-Musicians showed cyclic preferences in 9% of cases, reflecting greater variability and less structured decision-making.

These results suggest that formal musical education enhances evaluative consistency by providing listeners with refined auditory frameworks for judgment. Non-musicians, lacking such training, may rely more heavily on immediate impressions, leading to a higher incidence of cyclic preferences.

3.2. Discussion

Luthier Guitar L6. It had a cedar top, Madagascar rosewood back and sides, and a black teak fingerboard. This guitar used the bracing pattern calculated with the Fibonacci sequence. It was chosen a maximum of 17 and 19 times by non-musicians and musicians, respectively. The average median value of indicating this instrument as the better one in the pair was 12 for non-musicians and 14 for musicians. In the tested set of instruments, the L6 luthier guitar turned out to be the undisputed leader in terms of sound both for musicians and non-musicians who evaluated it.

Luthier Guitar L5. The L5 instrument, equipped with a double top plate (cedar) and back plate (Indian rosewood), ebony fingerboard and additional sound hole, was similarly to the L6 instrument non-standardly braced. The average value of the median indicating the L5 guitar as the better of the pair was 11 for both groups of listeners. According to non-musicians, this guitar took second place in the ranking, and according to musicians it took 2nd-3rd place, ex-equo with the factory guitar F1.

Factory Guitar F1. This guitar, inspired by Torres' bracing method, featured a solid cedar top, mahogany back and sides, and a rosewood fingerboard. Despite being in the lowest price category, its sound was appreciated by both musicians and non-musicians. Most listeners noted that it was relatively quiet but had balanced sound across all registers, contributing to its evaluation as a good-quality guitar. In the instrument pair selection test, it was on average preferred 10.5 times by non- musicians and 11.0 times by musicians out of 21 possible choices, making it one of the subjectively "best" guitars alongside the luthier-made instruments L6 and L5. According to the experimental data, the Guitar F1 was ranked third by non-musicians, and tied with the L5 luthier guitar for second place by musicians.

Factory Guitar F4. It was premium-class guitar made of a spruce top, Indian rosewood back and sides, and an ebony fingerboard. It featured symmetrical Torres-inspired bracing pattern. On average it was chosen of 10.0 times by both non-musicians and musicians in the preferred guitar selection experiment. According to the experimental data, the guitar F4 took 4th place in the assessment of the musicians, and 4th–6th place in the assessment of the second group of subjects.

The remaining instruments were ranked low in the listeners' assessment. It is worth mentioning here that in the evaluation by musicians, the luthier-crafted guitars L2 and L3 were consistently ranked the lowest, indicating a strong consensus regarding their poor performance within this group. The luthier guitar L2 was one of the two oldest instruments in the study, featuring a cedar top, wenge back and sides, an ebony fingerboard, an oval soundhole, and a concave top. It also had very dense bracing pattern. The luthier guitar L3 had a spruce top, ziricote back and sides, and an ebony fingerboard. Notable features included an asymmetrical neck and a resonance tube. Its symmetrical bracing was not as Torres-inspired. In contrast, non-musicians showed slightly different preferences. While the luthier-crafted guitar L2 remained one of the least preferred guitars, the factory-made guitar F3 was also ranked among the lowest for this group. Interestingly, L3, despite its relatively low scores, was rated higher than both L2 and F3 by non-musicians. The discrepancy between the two groups highlights differences in their auditory sensitivity and evaluative criteria. Musicians, with their trained auditory skills, may have been more critical of the specific timbral and tonal qualities of L2 and L3. Conversely, non-musicians might have evaluated the guitars based on broader impressions, leading to a slightly higher ranking for L3 compared to F3.

An analysis of the median score ranges in Tables 3 and 4 reveals that musicians exhibited a significantly larger range (6 to 14) compared to non-musicians (8.5 to 12). This finding underscores the heightened sensitivity of musicians to nuanced differences in timbre, likely stemming from their auditory training and prolonged exposure to music. Non-musicians, on the other hand, demonstrated a more constrained evaluation range, indicative of broader perceptual criteria and less detailed differentiation between instruments. These results align with previous psychoacoustic studies, which have shown that trained listeners tend to exhibit more pronounced and consistent evaluations when assessing complex auditory stimuli. Despite the differences in sensitivity, the median scores for both groups indicate a shared general preference for certain instruments, suggesting some overlap in their overall taste. This may be attributed to universal auditory cues, such as warmth and resonance, that appeal broadly to both trained and untrained listeners. Future studies could further investigate the cognitive and perceptual mechanisms underlying these differences by employing more granular timbral descriptors or exploring the role of familiarity and exposure in shaping auditory preferences.

4. Conclusions

The aim of this experimental research was to investigate the subjective assessment of the sound of classical guitars, divided into factory-made and luthier-made categories. Fifty-seven listeners, including 29 musicians and 28 non-musicians took part in the experiment.

Initially, it was anticipated that luthier-made guitars would be rated the highest regardless of the professional background of the evaluators. This hypothesis was only partially confirmed, as the most frequently chosen instruments were the luthier-made L6 and L5 guitars. However, alongside these instruments on the podium was also the factory-made guitar such F1. The subjective qualitative evaluation revealed notable differences between musicians and non-musicians in their preferences for classical guitars. Among musicians, the luthier-crafted guitars L2 and L3 consistently received the lowest rankings, highlighting a consensus on their relatively lower appeal within this group. However, non-musicians showed a slightly different pattern, with the factory-made guitar F3 and the luthier-crafted guitar L2 being rated as the least preferred. Interestingly, L3, while still not highly ranked, was perceived more favorably by non-musicians compared to F3. These findings underscore the variability in listener preferences based on musical training and auditory sensitivity.

Moreover, both luthier-made guitars that were most frequently selected as subjectively "best" featured innovative bracing applied by luthiers. The guitar L6 employed bracing calculated using the Fibonacci sequence, while guitar L5 featured a significantly expanded bracing scheme compared to the Torres method. This result is consistent with the recently observed tendency to search for new/better sounds of various musical instruments, different from the existing ones, obtained as a result of their non-standard construction [14-17]. In the case of guitars rated as subjectively "the worst," guitar L2 utilized symmetrical yet very complex bracing, a concave top, and an oval soundhole. The unique bracing pattern of L2, featuring 11 braces radiating from the soundhole and a concave top plate, likely contributed to its lower subjective ratings. While innovative, this design appears to have increased the stiffness of the soundboard, negatively impacting its ability to produce resonant and vibrant tones. This contrasts with guitars such as L1 and L7, which employed more traditional Torres-inspired bracing and were rated higher for their tonal qualities. Future improvements to the L2 design could involve optimizing the bracing pattern to enhance soundboard vibrational efficiency and overall timbre.

The luthier-made guitar L3 had non-Torres-inspired bracing with three distinctive horizontal braces and atypical use of an acoustic tube in its construction. Finally, guitar F3(which was rated as the least preferred by non-musicians) had symmetry bracing, with visible inspiration from the Torres method.

It was expected that the group of listeners without formal musical education might yield significantly different and skewed results due to differing auditory selectivity and sensitivity in music perception. However, this assumption was not confirmed in the experiment in a meaningful way. The hypothesis that non-musicians might yield results significantly different from musicians was based on the assumption that the two groups differ in auditory selectivity and sensitivity. Specifically, musicians, due to their training, are expected to demonstrate more consistent and nuanced evaluations of guitar sound quality. In contrast, non-musicians, lacking formal auditory training, may rely on broader perceptual cues, leading to greater variability in their evaluations. This variability, described as “skewed” refers to potential asymmetry or dispersion in the distribution of their responses, potentially quantified through measures such as skewness indices. The expectation of variability aligns with findings in psychoacoustics, which suggest that training and exposure significantly influence auditory judgments. Musicians tend to exhibit more consistent patterns in sound evaluation, whereas non-musicians rely on subjective impressions, leading to a wider range of responses. This hypothesis was partially confirmed by the experimental results. Non-musicians indeed demonstrated slightly higher variability in their preferences, particularly in the rankings of instruments with distinct tonal characteristics.

Non-musicians had greater difficulty understanding and interpreting tonal descriptions and maintaining concentration, particularly during long listening sessions of the same musical fragment. Nevertheless, their results did not significantly deviate from those obtained by musicians.

Analyzing all the results contained in this study, it would be erroneous to maintain the conventional belief that a luthier-made guitar will sound "better" than a factory-made guitar. The most crucial element influencing the preferred sound quality of a classical guitar was the type of bracing used—an innovative approach to bracing, such as using the Fibonacci sequence for calculating individual bracing elements, acoustically surpassed the traditional symmetrical Torres-style bracing.

This study highlights several important aspects of subjective sound evaluation but also has inherent limitations. The variability introduced by individual listener perceptions, the relatively small and localized sample size, and the exclusive reliance on subjective measures are notable constraints. Future research could expand on these findings by integrating objective acoustic measurements, increasing listener diversity, and exploring additional contextual and timbral factors. These efforts would enhance the robustness and applicability of the insights gained, contributing to a deeper understanding of the subjective perception of guitar timbre.

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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