The Portuguese Guitar Acoustics: Part 2 – Subjective Acoustical Quality Evaluation

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ABSTRACT: The evaluation of the quality of musical instruments has been the quest of researchers and manufacturers for several decades. One common feature on the studies performed so far is the attempt to correlate the subjective response of musicians or other listeners to objective measurements that may enlighten the desirable physical features of a good instrument. In a companion paper we explored the results of the dynamical properties of the soundboard of two distinct models of the Portuguese Guitar. This analysis enabled the recognition of some modal characteristics of both instrument types which help set a basis of comparison between subjective and objective measures of the instrument sound quality. In this paper we present the results of a series of listening tests performed on 60 individuals (all academically or professionally related to music) for 10 Portuguese guitars of different ages and built by distinct luthiers. After describing the methodology and the quality parameters used, we compare the results obtained with the characteristics of the frequency response functions acquired for each instrument. The results do not show a significant correlation between the all subjective and objective parameters chosen, however, a trend for preference over lower natural frequencies of the first three resonances is detected.

1. INTRODUCTION

One of the main aims of Musical Acoustics is the understanding of the physical phenomena that control the production of sound by musical instruments. One immediate application of this field of research is the attempt to improve the instrument sound quality by controlled modifications of its structural components. Such attempt, however, would be useless if the exact meaning of “sound quality” for a particular instrument is unknown. Instrument makers (*luthiers*) have relied on the opinion of musicians and their own experience to form a judgment of this subjective characteristic, and tentatively improve the quality of their work. A more scientific approach (whether more efficient or not is still a matter of discussion) is to perform a statistical analysis of the opinions of a great number of listeners to the sound of such instruments and correlate them with measurable physical parameters. This last approach, relevant for the present work, has been thoroughly developed by several authors in relation to the sound quality evaluation of classical guitars. Nonetheless, the measurable physical parameters that serve as the basis to this correlation procedure can differ significantly for different authors. Jansson [1,2] and Meyer [3], established several different objective parameters for this purpose based on the characteristics of the sound decay of each partial for a particular note; the modal properties of the instrument body; or even the radiated sound pressure level for a specific range of 1/3 octave bands. Orduña-Bustamante [4] followed a similar approach using the measurement of attack and decay times as well as sound pressure level in wider frequency bands, while Boullosa *et al.* [5] based their research on the tuning characteristics and the radiation efficiency of the guitars. More recently, Hill *et al.* [6] defined a set of acoustical parameters based on standard input impedance measurements at string positions on the bridge as well as sound radiation properties measured by spherically travelling microphones surrounding the instrument driven at different resonant frequencies.

In this work a first attempt is made to correlate the subjective preference of a number of listeners to some objective measures of the Portuguese guitar vibroacoustic properties. However, due to the time-scale of duration of this project, the detailed research of the relevant objective and subjective parameters for this particular instrument had to be postponed for future projects. The Portuguese guitar shares, as well as other plucked chordophones, some of the basic organological features of the classical guitar: strings stretched over a fingerboard transmitting, through a bridge, mechanical vibration energy to a resonator (also called sound-box). The latter, although pear-shaped, is also composed by a soundboard, back plate and ribs, with a round sound-hole opening the air cavity to the exterior. Although the resemblances are only of a more general character it was then decided to make reference to the work related to the classical guitar and apply some of the subjective and objective parameters referred in the literature to the quality evaluation of the Portuguese guitar. For this purpose we have done accelerance and vibroacoustic frequency response measurements to a set of 10 Portuguese guitars. Some of the results from these tests are reported in [7]. This paper is related to the description of the subjective tests and the correlation of its results with a set of chosen objective parameters. We will start by characterising the objective parameters chosen and proceed with describing the methodology used to perform the listening tests. After a short analysis of the results obtained we conclude with the discussion of the correlation between both sets of results.

2. OBJECTIVE PARAMETERS

From the vast quantity of objective parameters that are described in the literature [1-6] to evaluate the quality of classical guitars, our choice was subject to limitations on the equipment available to measure them, and also on the time available for the execution of this project (this work was carried as part of an undergraduate degree final project). It was decided to make use of the low-frequency modal characteristics reported in [7], and calculate a set of objective parameters based on the research by Jansson and Meyer [1-3]. The parameters chosen were the following:

f_i and L_i – The frequency and amplitude of the first three major resonances, where *i* stands for the resonance number (1, 2 or 3);

a_1^i – The frequency interval between the first two major resonances and the frequency of the closest musical notes, in cent, where *i* stands for the resonance number (1, 2 or 3);

a_2 – The presence of a lower amplitude resonance below the first major resonance;

a_3 – The difference from an octave of the frequency interval between the first and the second major resonances, in cent.

3. LISTENING TESTS

Listening tests were performed to a set of 60 individuals, a random opportunistic sample [8], all with an academic or professional relationship with music: students and teachers of music

technologies, classical music, jazz or composition, from the School of Music and Performance Arts of the Polytechnic Institute of Porto. This was an important requirement since the subjects should be able to recognise the meaning of some musical terms used during the tests. All were subjected to a sound recording of a 20 seconds fragment of "*Estudo de Dedilho*" by Pedro Caldeira Cabral, played by the composer on the 10 different guitars. The duration of the music sample was chosen according to [3] where experiments demonstrated that this period of time is long enough to induce a definitive sound pattern in the listener's memory but not to long that previous samples could be forgotten. The choice of the piece of music to be reproduced was selected from a set of other possible alternatives, for its counterpoint character and the existence of several low and high frequency tones, which covered a considerable broad frequency spectrum. The addition of further musical examples was considered, but the duration of listening tests would then become prohibitive.
The musical piece was recorded in a small recital hall with a reverberation time (T_{30}) of approximately 0.9 s in the 500 Hz octave band. Although other researchers who performed listening tests have chosen to record their music samples in sound absorbing rooms [4], our choice was to play the instruments in a more natural environment, which for the player and the listeners was more close to their usual listening references. The stereo recording technique used [9] was an A-B pair located at approximately 1.5 m from the instrument with a near-coincident (17 cm) arrangement as can be seen in Figure 1 (left part of the figure). The microphones positions and the guitar positions were maintained the same throughout all the recordings. A sound level meter was also placed at 1 m from the instrument in order to measure the time averaged sound pressure level for each guitar, which allowed the calibration of the reproduced sound level during the listening tests.

Figure 1 – *Picture of the recording setup, showing the A-B microphone pair (on the left side of the picture) and the sound level meter location.*

3.1. Tests conditions

The 60 subjects listened individually to the sound sample through a stereo loudspeaker set. The loudspeakers were placed inside a highly sound absorbing chamber so that any influence for the listening room acoustics would be negligible. This arrangement allowed all the listeners to be in the same acoustical conditions for evaluating the subjective response of the instruments. This approach is preferable to a live performance done simultaneously for all the

subjects such as the one used in [5]. Furthermore, the fact that they could not see the instruments excluded the possibility of preference over different visual characteristics.
Defining the questions to be made to the subjects about their listening experience is one of the most important steps in a subjective quality evaluation of this kind. They should be clear and objective enough so that the statistical analysis carried subsequently is not contaminated with ambiguous answers. For this reason, and also as suggested in [3], the most relevant question to this work was a simple option of preference for one guitar among a choice of two.
However, for the purpose of trying to unfold the reason for the choice of a particular instrument, other aspects, defined by subjective parameters, were taken into account.

3.1.1 Subjective parameters used

Apart from the most important question of which guitar was preferred, the subjects were also asked to choose one of the guitars in relation to three subjective parameters. These were clearly explained to the listeners as following:

- Timbre: one of the subjective characteristics of sound that allows us to differentiate between two sounds of the same pitch and intensity. Timbre results from the subjective correlation of all the properties of sound that do not influence directly the pitch and the intensity, such as: temporal envelopment, energy spectral distribution, degree of partials inharmonicity. The attack transient is also fundamental to the characterization of the timbre of an instrument [10];
- Volume: considered as the subjective correlate to sound pressure level at the point of listening, as a result from the direct sound and reflections inside a room;
- Clarity: considered as a subjective measure of the degree of perception of each individual note produced by the instrument as clear and distinct from each other.

3.1.2 Conditions of the guitars

Not all of the guitars were played regularly by the musician. Apart from the fact (or myth?) that instruments that are not played frequently cannot perform adequately, this could induce some difficulty on the musician ability to obtain the “best” sound as he does on an instrument that he is used to play on a daily basis.
Only three instruments were played and tuned regularly. The rest were either frequently played in the past and are not at the present time, or they were not ever significantly played. Furthermore, not all the instruments had new strings which were only placed on the ones with poorer string conditions. It can be concluded that it was not possible to have all the guitars under the same playing conditions.

3.2. Test procedure

Following a similar procedure to the ones used in [3] and [5], the recorded music samples were reproduced in pairs. Each pair corresponds to two successive recordings made with two different guitars. However, control pairs with the same guitar were also used to give more reliability to the results. The two musical samples in each pair were separated by 1 second interval and a 5-10 seconds interval was used between pairs, so that the listeners could erase the memory of the previous pair. The test procedure consisted of the following steps:

a) Each individual listened to a set of 6 comparisons of guitar pairs, in which 5 pairs were of different guitars and a 6th consisted of a pair of samples of the same guitar. The 12 (10 + 2x1) guitars were randomly combined to form 10 different sets of comparisons to be attributed to different listeners. The extra pair of equal guitars was repeated the same number of times in all the comparisons sets;

b) From each pair of music samples, the listener gave a preference opinion over one of them. This resulted in a choice for 6 instruments, which in turn would compose another set of 3 comparisons. Preferences according to the subjective parameters referred were also registered;

c) The next comparison gave origin to the choice of 3 guitars, which would then be compared all together. The music samples were then played twice so as to minimize the possible *short memory effect*[1].

d) After the choice of one guitar was achieved, the following subject was called (without contact with the previous one) and a different set of comparisons was presented using the same procedure as described.

A B C D E F G H I J K L

Timbre	A	C	F	G	I	K
Volume	B	D	E	H	J	L
Clarity	A	C	F	G	J	K
Overall choice	A	C	F	H	J	L

Timbre	C	F	J
Volume	C	F	L
Clarity	A	H	J
Overall choice	C	F	L

Timbre	F
Volume	L
Clarity	C
Overall final choice	C

Figure 2 – *Diagram describing one of the sets of guitar pair comparisons, with possible (arbitrarily chosen for this example)*

Figure 2 shows an example of one of the sets of comparisons and of possible results. The 10 guitars are labelled from A to J as described in [7], and in the extra pair the same guitars are

[1] Effect through which the subject's memory unconsciously loses the hearing reference to the first music sample in the pair comparison. This effect is usually appreciable when the second music sample is frequently preferred to the first one, even after changes in the pair order are realized.

labelled K and L. It should be emphasised that the listeners had no prior knowledge of what guitars corresponded to the lettering chosen to identify them.

4. RESULTS

4.1. Subjective tests

Figure 3 presents the results of the overall choice votes for each guitar. Guitar D is the most voted instrument while guitar E was not voted in any of the comparisons. The majority of the votes are comprised in the first 4 guitars (of the Coimbra type – see [7]).

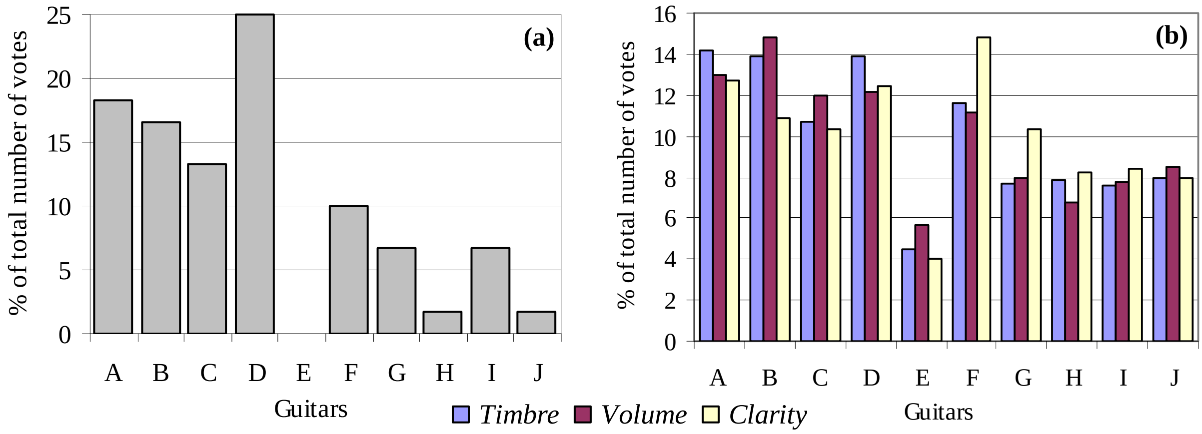

Figure 3 – *Results of the (a) overall choice votes and (b) subjective parameters preferences.*

Comparing these results with the number of choices on the individual subjective parameters (Figure 4), suggests that the *timbre* is the most relevant (of the three used in this study) to evaluate the preference over one instrument. Interestingly, guitar A has a higher number of votes in each subjective parameter than the most preferred guitar.

4.2. Objective tests

Table 1 shows the results of the analysis carried to the frequency response measurements reported in [7], according to the parameters defined in section 2. This analysis was not straightforward since in some of the guitars a large number of modes bundled together at certain frequencies. Nevertheless, a careful attempt was made to obtain relevant results.

Table 1 – *Results of the objective parameters*

Guitar	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]	L_1 [dB]	L_2 [dB]	L_3 [dB]	a_1^1 [¢]	a_1^2 [¢]	a_2	a_3 [¢]
A	135	295	322	31	51	55	45	8	yes	153
B	132	285	310	33	47	59	16	48	yes	132
C	121	270	291	35	52	54	35	45	yes	189
D	132	274	370	34	51	46	16	20	yes	64
E	159	365	420	27	54	49	38	24	yes	239
F	129	263	355	36	55	38	24	9	no	33
G	142	305	336	30	46	54	42	34	no	123
H	131	279	341	37	57	53	3	11	no	109
I	160	348	391	21	43	58	51	6	no	145
J	127	255	386	38	52	37	49	44	no	7

4. DATA ANALYSIS AND DISCUSSION

Figure 4 shows a comparison between the results of the subjective tests, in terms of the number of votes on the *overall choice*, and the results for some of the objective parameters. A linear regression fit was attempted in order to find if some kind of trend could be envisaged by the results. It can be seen that no significant correlation exists in the examples shown. However, if the subjective results are based not on the *overall choice* votes but on the sum of the subjective parameters votes, a clearer trend can be seen for some cases, although far from conclusive.

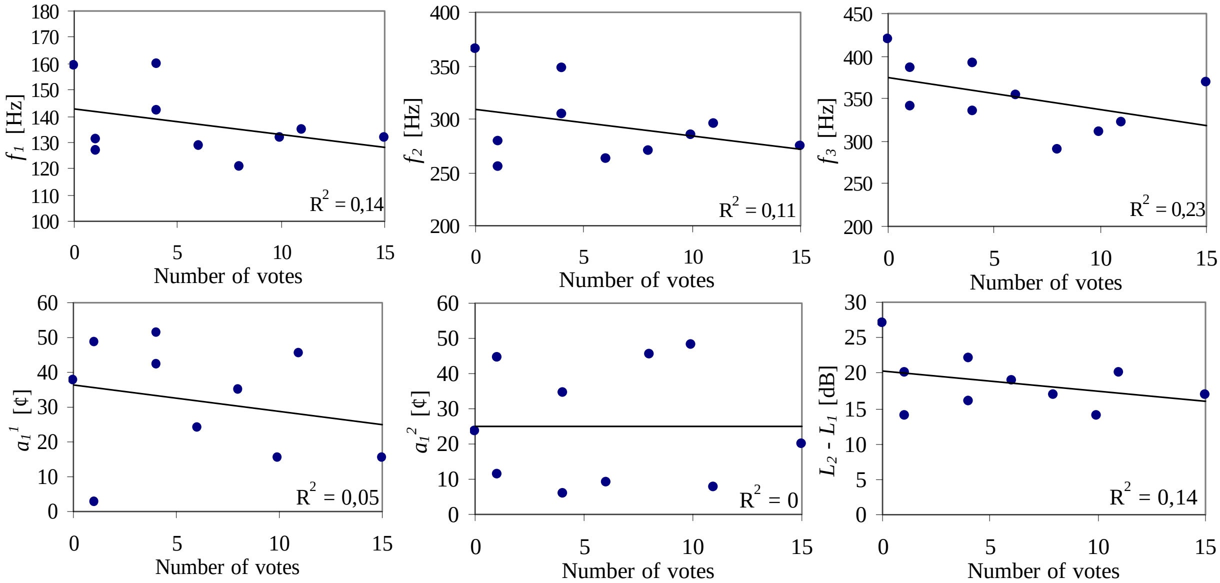

Figure 4 – *Comparison between the overall choice votes and some objective results.*

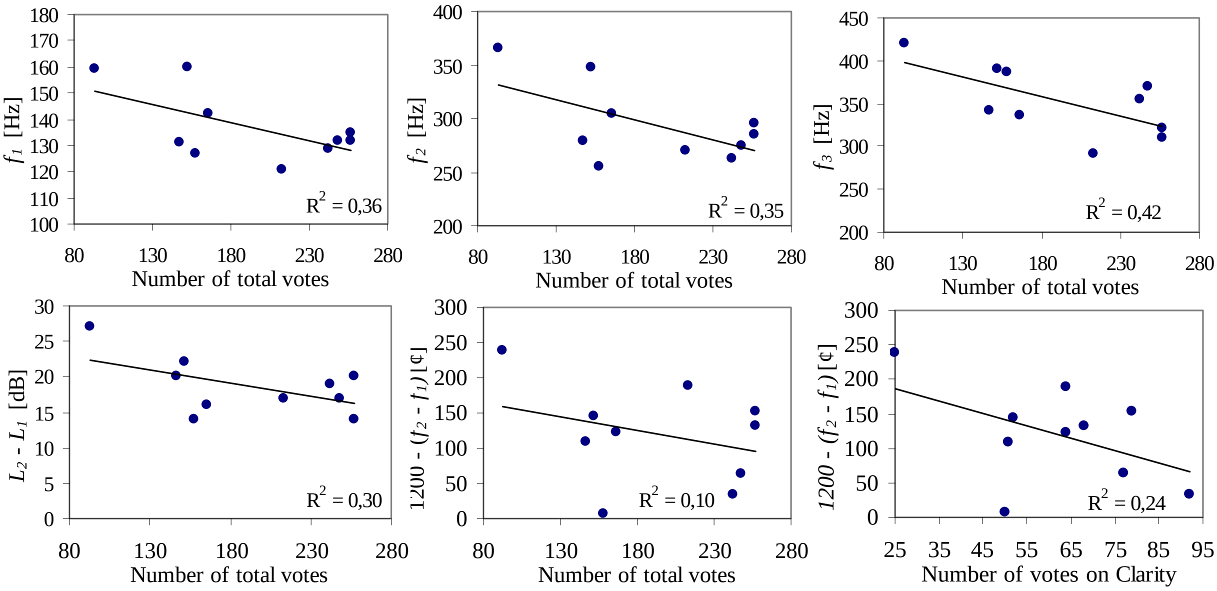

Figure 5 – *Comparison between the subjective parameters choice votes and some objective results.*

It seems that, the lower the frequency of the three major resonances, the better is the subjective preference. A similar relation could be stated for the difference in level between the first two resonances, which could be related to the balance in the lower register of the guitar sound. One of the objective parameters that could have a better correlation is a_2. The presence of a resonance below the first major resonance appears for all the guitars (except for guitar E) that had above 10% of the votes in the overall choice.

5. CONCLUSIONS

In a companion paper [1], we briefly explored some acoustical and vibratory characteristics of 10 Portuguese guitars. The data obtained has been used in the present work to quantify objective quality parameters, which could be correlated to subjective preferences of the guitars sounds. For this purpose, listening tests were performed on a total of 60 individuals, all academically or professionally related to music. The results of the listening tests do not show a significant correlation with some of the objective results. However, in some cases a trend can be envisaged for preference over lower natural frequencies of the first three resonances, found mainly in the Coimbra guitars. These results should be considered with care. The fact that the sound of these guitars might be more familiar to the sample of listeners that was used for the subjective tests could have biased the results. Furthermore, the different tunings between Coimbra and Lisbon guitars could have some negative influence on the final choices. Further developments of this work will take these aspects into account.

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