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SUBJECTIVE PREFERENCE OF ELECTRIC GUITAR SOUNDS IN RELATION TO PSYCHOACOUSTICAL AND AUTOCORRELATION FUNCTION PARAMETERS

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The electric guitar is a complex system composed by several elements, such as the bridge, strings, and electromagnetic pickups that interact with each other, giving as a result an amplified version of the captured signal produced by an oscillating string made of nickel plated steel. The aim of this paper is to compare electric guitars on the basis of subjective preference in relation to psychoacoustical and autocorrelation function (ACF) parameters. Two experiments were conducted under fixed condition of performing style. Four different guitars were evaluated in a listening test by 48 people, using the pair comparison method. To confirm the results of the first experiment, one of the electric guitars with two new different set of strings was also used. Another pair comparison test with the six electric guitars was conducted by a different group of subjects. For the purpose of this work, a linear slide mechanism was designed to reduce the influence of the right-hand playing technique. According to the Pearson's correlation coefficient, it was demonstrated that the mean and maximum value of Sharpness were found to be significantly correlated with subjective preference.

Keywords: Electric guitar, psychoacoustics, ACF parameters.

1. Introduction

The first electric guitar was designed and created in 1931 by George Beauchamp and Paul Barth, in collaboration with Adolph Rickenbacker, (they formed the Electro String Company) [1]. Since that date, the construction and elements of the instrument have been changing through the years. From that point, guitarists have developed preferences for different combinations of the elements previously mentioned in order to achieve the desired sound.

Kaieda et al. analysed the timbre of the electric guitar in terms of power spectrum and autocorrelation function (ACF) parameters [2]. The authors found a relationship between spectral centroid and $W\phi_{(0)}$, and between the fluctuation of frequency and ϕ_1. Ando also conducted another research related to the factor extracted from the running ACF contributing to the dissimilarity of sounds [3]. The author found that even if the pitch is the same, timbre is different due to difference of $W\phi_{(0)}$.

Paté et al. investigated about the perception of ebony and rosewood fingerboards by the guitarists, with two different evaluation methods [4]. They found that different electric guitar fingerboard woods produce differences perceived physically by guitarists.

A perceptive study of the neck-to-body junction of an electric guitar was performed by Carrou et al. [5]. They did not found a significant preference according to the type of junction. A similar study of subjective preference of violins has been conducted, where 17 violins were evaluated by musicians and non-musicians through two different paired comparison tests [6]. They affirmed that only total loudness and maximum loudness correlate well with the subjects' preferences.

Atsushi et al. investigated the timbral variations enabled by nonlinear distortion effect processors used in popular music production in relation to subjective perception of dissimilarity, using different values of Sharpness [7].

This work aims to investigate the subjective preference of different electric guitars in relation to psychoacoustical and the ACF parameters. The correlation between those parameters and subjective preference was analysed.

2. Procedure

Subjective preference of four electric guitars was evaluated by the pair comparison method in two different subjective tests. A linear slide mechanism developed specifically for this work was used to reduce the influence of the right-hand playing technique. The electric guitars under test belong to four different manufacturers: PRS, Schecter, SX and Washburn.

2.1 Source signals

In both subjective tests, the electric guitars were recorded using their clear tone (no electric guitar effect was taken into account in this work to limit the number of variables under study). For the purpose of the second subjective test, the Washburn was recorded with old strings (D'Addario EXL110, 2 years old approximately) and new strings (Ernie Ball Hybrid Slinky .09). The guitars' characteristics related to the type of junction, wood of the fretboard and electromagnetic pickups are presented in Table 1.

Table 1: Characteristics of the electric guitars.

Guitar	Junction	Fretboard	Pickups
PRS SE Singlecut	One piece	Rosewood	PRS Pickups
Schecter Damien Elite 6-fr	Bolt-on	Rosewood	EMG 81 / EMG 85
SX Thinline Telecaster	Bolt-on	Maple	SX Pickups
Washburn WE-10TS	Bolt-on	Rosewood	Washburn Pickups

The stimulus played was composed by three chords: C, D and E minor in that order, with a tempo of 40 bpm and a total duration of 12.5 s. The tunning of the guitars was E standard (EADGBE). For the purpose of both subjective tests, the selector key was in the neck pickup position; this is the only type of electromagnetic pickup analysed (middle and bridge pickup were not taken into account).

A motorized linear slide mechanism was developed in order to apply an equivalent force in each stroke. Otherwise, the results would have been subjected to the influence of the manual playing technique. The system consists of a DC motor, three power resistors to control the current, a DC source and a metal structure with a reel from a common printer. Limiting the current with the resistors, the desired travel speed of the mechanism was achieved. The electric circuit designed to control the travel speed of the linear slide mechanism is shown in Fig. 1. R1, R2 and R3 are resistors of 15 W, with values of 10 Ω, 47 Ω and 47 Ω respectively. V1 is a DC source of 12 V and 1 A, while M1 is the DC motor that drives the linear slide mechanism.

A wood stick with a pick was attached to the linear slide mechanism to hit the strings of the electric guitars. The desired picking point was selected halfway between the neck and the bridge pickup, at 12 cm from the bridge position. Figure 2 show this set up.

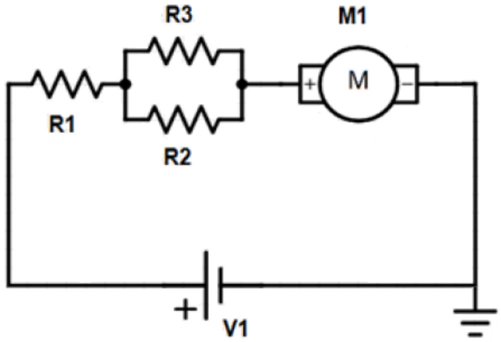


Figure 1: Electric circuit of the linear slide mechanism.

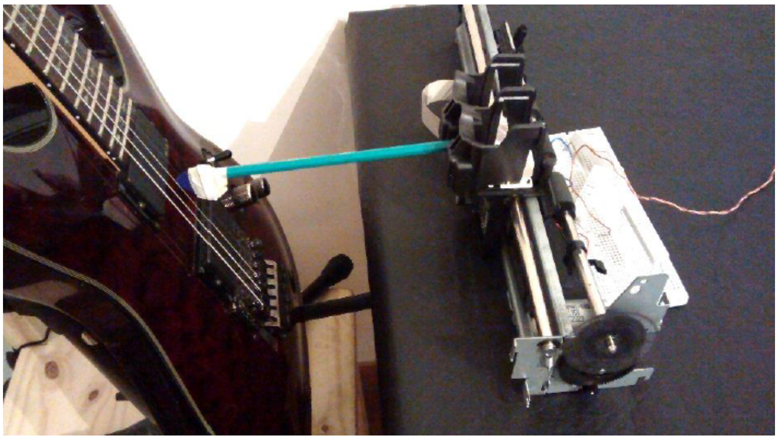


Figure 2: Linear slide mechanism.

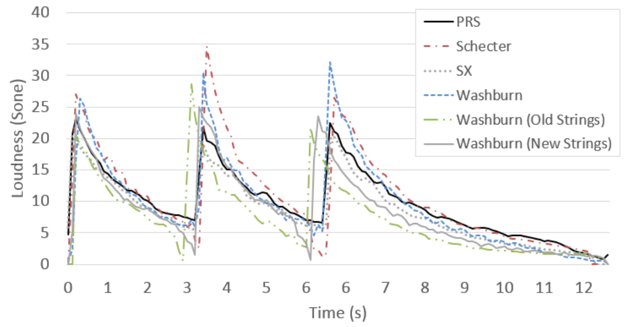
2.2 Objective Parameters

Two psychoacoustical parameters (Loudness and Sharpness) and one ACF parameter, W$\phi_{(0)}$ (the delay time at the first 0.5 crossing of the normalized ACF) [3] were analysed to evaluate the objective characteristics of each electric guitar.

Loudness is related to the way in which the levels of sounds are perceived by the human auditory system influenced by frequency, sound pressure level and also masking (spectral and temporal), and is defined as the perceptual intensity of sounds [8]. Sharpness is related to the high frequency content of a determined signal; it was of interest for this study to evaluate if there are any influence of this harmonic content in the subjective preference of electric guitars. Loudness was calculated according to the Moore model [11] while Sharpness was calculated using the Zwicker and Fastl model [8], both with the same software [10]. Figure 3 shows the results for Loudness and Sharpness, both as a function of time.

Shimokura et. al. stated that the parameter W$\phi_{(0)}$ indicates the spectral centroid of a signal. They affirmed that high values of W$\phi_{(0)}$ mean that the low spectral components are strong, while low values of W$\phi_{(0)}$ indicate that the high spectral components are strong [9]. Another software was used to calculate the autocorrelation function values [12]. The integration interval was set to 0.5 s, same as in the Loudness and Sharpness calculation. A running step of 0.1 s was used for this analysis.

As it can be seen in Fig. 3 a), the Washburn with old strings has the lower values of Loudness while the Schecter guitar has the higher values of Loudness among all the guitars. It is worth mentioning that the Schecter has an active circuit for its electromagnetic pickups, leading to a higher output level than the other guitars. In Fig. 3 b), it can be seen that the Washburn guitar has the highest value of



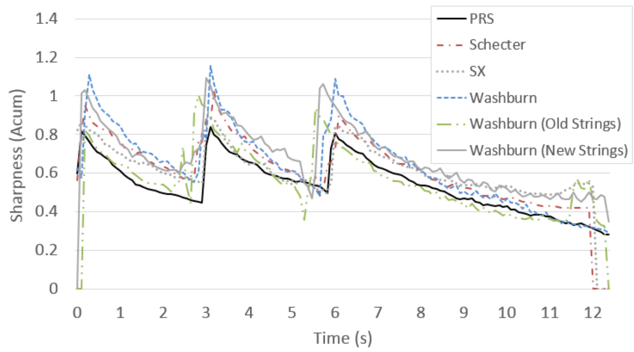


Figure 3: a) Loudness and b) Sharpness values for each guitar.

Sharpness among all the guitars (with a major peak near 1.2 Acum), while the SX and the PRS show the lowest values.

Then, a similar analysis is presented for the $W\phi_{(0)}$ parameter. Using a running autocorelation function analysis, the values of $W\phi_{(0)}$ for the three different chords are shown in Fig. 4.

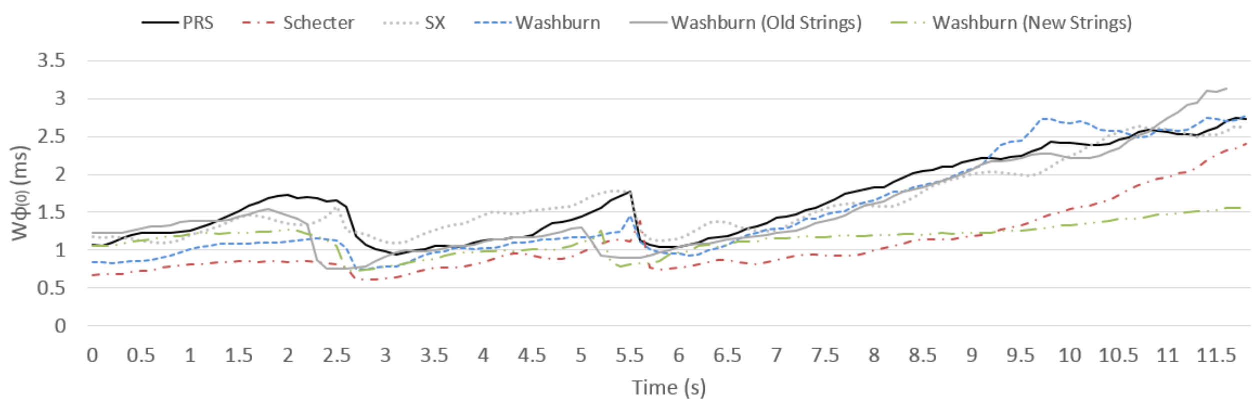


Figure 4: $W\phi_{(0)}$ values for every guitar.

Figure 4 shows that both Schecter and Washburn (New Strings) have the lowest values of $W\phi_{(0)}$, meaning that the high spectral components of those signals are stronger than the high spectral components of the other guitars. The Washburn guitar also presents low values of $W\phi_{(0)}$ in the first two chords, but higher than the values presented in the Schecter guitar; however, the Washburn has also the highest value of Sharpness (as it can be observed on Fig. 3) among all the guitars. It can be seen also that the PRS and the SX guitar lose more energy in their high spectral components than the other guitars; in addition, the PRS also has low values of Sharpness, as it is shown on Fig. 3.

2.3 Subjective test

Two pair comparison tests were performed to evaluate the subjective preference. The listeners were asked about their preference between two electric guitars in every comparison, without tie judgment. For the first subjective test, four guitars were presented, and each test session consisted of six comparisons arranged randomly. For the purpose of a second subjective test, the same guitars were presented but adding two new signals of the Washburn guitar with old (OS) and new strings (NS). In this case, having six different sound signals, each test session consisted of fifteen comparisons. Stimuli were reproduced using headphones in order to minimize the effect of the environment on the test signals.

A total of 48 listeners aged from 18 to 31 years old participated in the first test. For the second subjective test, a total of 29 listeners aged from 19 to 36 years old have participated. None of the subjects suffered from any hearing loss.

3. Results

The consistency of the responses by each subject was evaluated [13]. Then, a test of agreement and a Chi-Square test were performed. For both tests, all subjects presenting circular triads were discarded. According to the Chi-Square test, a significant agreement among the judgments of 34 subjects for the first subjective test, and also a significant agreement among the judgments of 21 subjects for the second subjective test ($p < 0.05$) were obtained.

Then, the mean scale values for each electric guitar were calculated [14] and validated by a goodness-of-fit test ($p < 0.05$) [15]. As shown in Table 2, the most preferred guitar was the Washburn, and the less preferred was the SX for the first subjective test. For the second subjective test, the Washburn remains as the most preferred guitar, while the same Washburn but with old strings was the second less preferred guitar, as it can be seen in Table 3. Since the range between the maximum and minimum scale values is greater than 0.68 in both cases, corresponding to 25 to 75% discrimination, the scale values obtained are reliable.

Table 2: Scale values of preference of the first test.

	PRS	Schecter	SX	Washburn
Scale value	-0.10	-0.02	-0.32	0.43

Table 3: Scale values of preference of the second test.

	PRS	Schecter	SX	Washburn	Washburn (OS)	Washburn (NS)
Scale value	-0.53	0.02	-0.25	0.70	-0.33	0.39

Then, the scale values of subjective preference were correlated with the objective parameters. Table 4 presents the correlation coefficients between the scale values for all the test subjects and the psychoacoustical and ACF parameters.

Table 4: Correlation coefficients between scale values and objective parameters.

Parameters	Subjective Test N°1	Subjective Test N°2
Loudness [Mean]	0.392	0.178
Loudness [Max]	0.698	0.477
Sharpness [Mean]	0.580	0.887*
Sharpness [Max]	0.873	0.921**
$W\phi_{(0)}$ [Mean]	-0.190	-0.468

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

4. Discussion

From the analysis of the scale values obtained, it can be observed that the Washburn was the most preferred guitar in both subjective tests. For the first subjective test, the SX has the lowest scale value while for the second subjective test the PRS has the lowest scale value.

In relation to the correlation coefficients obtained in the section 3, a significant correlation for the maximum value of Sharpness ($r = 0.921$, $p < 0.01$) for the second subjective test and also a significant correlation for the mean value of Sharpness ($r = 0.887$, $p < 0.05$) for the same subjective test can be observed. Sharpness is related to the high frequency contents of a signal, meaning that the greater is the energy in these frequencies, the “sharper” is the sound. Thus, in a certain way, the preference of a clean tone in an electric guitar could be significantly correlated with the high frequency content of the signal. In addition, the most preferred guitar, the Washburn, is the one with maximum value of Sharpness. It’s worth mentioning that the Washburn with new strings presents high values of Sharpness and that it has been also the second most preferred guitar in the subjective test.

In terms of the $W\phi_{(0)}$ analysis, high values of $W\phi_{(0)}$ indicate that the low spectral components are strong, while the high spectral components are weak; low values of $W\phi_{(0)}$ indicate the opposite. Therefore, it can be stated that in every chord the values gradually increase as the time increases for all the guitars, because the higher harmonics gradually decrease. Despite being the guitar with the maximum value of Sharpness, the Washburn does not have the lowest values of $W\phi_{(0)}$, a possible indicator of the "brightness" of a sound signal [16]. The original Washburn and the same guitar with new strings lose less energy in high spectral components than the PRS and SX for the first two chords; for the last chord, the Schecter and the Washburn guitars with new strings have the lowest values of $W\phi_{(0)}$.

Even though there is a high value for the correlation of the subjective preference with the maximum value of Sharpness for the first subjective test, this correlation is not significant; however, in the second test the correlation is significant for both values of the Sharpness parameter. Correlation also is not significant for the $W\phi_{(0)}$ in any test; thus, preference of clean electric guitar sounds could not be correlated with the spectral centroid of a signal. Results of the second subjective test show that the strings have a strong influence on the subjective preference.

Some limitations of this work can be stated. First, although the linear slide mechanism significantly helped to reduce the influence of the right-hand technique, it is necessary to develop an antivibratory system. The electronic circuit should be able to modify the travel speed of the guide in real time. Also, a system to hold properly the electric guitar could be designed, in order to obtain most accurate measurements. Increasing the number of subjects could improve the reliability of the subjective responses for both subjective tests. It is important for further research to control better the influence of some elements of the electric guitar (type of bridge, electromagnetic pickup, wood and neck).

An objective analysis of the different pickups has not been performed for this study. The subjective preference could be influenced by their time and frequency responses.

5. Conclusions

Subjective preference of electric guitars in relation to psychoacoustical and autocorrelation function parameters was investigated. The mean and maximum value of Sharpness showed a significant correlation with subjective preference in the second subjective test. Therefore, clean tone of electric guitars with more energy content in high frequencies are preferred.

It can be stated that subjects can discriminate between a guitar with different types of strings as their scale values show differences. However, even though two new signals were introduced in the second subjective tests, the Washburn remains as the most preferred guitar.

As future work, it would be interesting to analyse other objective parameters, such as Roughness, Tonal and Spectral Dissonance or Rise time. In order to obtain different harmonic content in the signal, different picking points might also be analysed. Another possible future study could analyse the influence of only the electromagnetic pickup on the subjective preference, remaining all the other parameters fixed (bridge, junction, strings) or also analysing the other pickups present in the electric guitar (middle or bridge pickups). Further analysis in relation to the influence of the type of strings could be made with of different string material such as cobalt (all the strings used in both tests are made of nickel) or different types of windings such as flatwound (in both tests, all the strings are roundwound). In addition, other type of musical excerpt could be analysed.

This research is the first step in the relation between psychoacoustics and the electric guitar industry; further investigations could be useful in the design and characterization of electric guitars.

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