

Music Perception: Paper ICA2016-243**Subjective preference of electric guitar sounds in relation to psychoacoustical and autocorrelation function parameters****Diego Leguizamón^(a), Florent Masson^(b), Shin-ichi Sato^(c)**^(a) Universidad Nacional de Tres de Febrero, Buenos Aires, Argentina, leguizamonde@gmail.com^(b) Universidad Nacional de Tres de Febrero, Buenos Aires, Argentina, fmasson@untref.edu.ar^(c) Universidad Nacional de Tres de Febrero, Buenos Aires, Argentina, ssato@untref.edu.ar**Abstract**

The electric guitar is a complex system composed by several elements 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. Four different guitars were evaluated in a listening test by 45 people, using the pair comparison method. For the purpose of this work, a linear slide mechanism was designed to reduce the influence of the right-hand playing technique. 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. According to the Pearson's correlation coefficient, it was demonstrated that the maximum value of Sharpness and the effective duration of the ACF τ_e were found to be significantly correlated with subjective preference.

Keywords: Electric guitar, psychoacoustical parameters, autocorrelation function parameters, subjective test.

Subjective preference of electric guitar sounds in relation to psychoacoustical and autocorrelation function 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 the type of microphone (single or double coil), the wood of the solid body and fretboard, to the junction (bolt-on, glued and one piece) and the type of bridge (fixed or floating). From that point, guitarists have developed preferences for different combinations of the elements previously mentioned in order to achieve the desired sound. However, these combinations are not always clear at all, and could depend on the type of music style the guitarist prefers.

Ando et al. evaluated the timbre of the electric guitar in terms of power spectrum and autocorrelation function (ACF) parameters [2]. They analysed clean tone of electric guitars with and without vibrato effect. A strong relationship between spectral centroid and $W_{\phi(0)}$, and between the fluctuation of frequency and ϕ_1 was found.

Paté et al. investigated about the perception of ebony and rosewood fingerboards by the guitarists [3]. Two evaluation methods were compared: a free sorting task with recorded stimuli, and a free verbalization task, where guitarists played the guitars. They found that different electric guitar fingerboard woods produce differences perceived by guitarists.

A perceptive study of the neck-to-body junction of an electric guitar was performed by Carrou et al. [4]. Three identical guitars were tested, only differing in the neck-to-body junction (bolt-on, glued and one piece). They compared two evaluation methods: a global evaluation of each guitar and a more precise evaluation, related to a list of criteria. They did not found a significant preference according to the type of junction. Also, they delivered an acoustical study related to the driving-point conductance.

A similar study of subjective preference of violins has been conducted [5]. 17 violins were evaluated by musicians and non-musicians through two different paired comparison tests. They did not found significant differences between musicians and non-musicians in the subjective rankings of investigated violins. Also, they affirm that only total loudness and maximum loudness correlate well with the subjects' preferences.

Pedrielli et al. evaluated just noticeable differences of loudness and sharpness for earth moving machines [6]. The subjects were asked to detect the JND with steps of 0.3 sone for loudness and 0.02 acum for sharpness. The just noticeable difference in sharpness had very small variations with the overall sound pressure level, contrary to the results obtained for loudness. They stated that 75% of the subjects perceived a different sensation when sounds had a sharpness difference of at least 0.04 acum and a loudness difference of 0.8 sone.

Despite this interest, no one as far as the authors know has studied about subjective preference of electric guitars in relation to psychoacoustical and ACF parameters using a pair comparison test. Therefore, this work aims to investigate the subjective preference of different electric guitars in relation to psychoacoustical and ACF parameters. The correlation between those parameters and subjective preference were analysed.

The methodology performed in this work was referred to Koehl et al. who investigated about different assessment procedures in relation to loudspeaker sound quality [7]. They performed a comparison of three different test procedures based on the pair comparison method, one with short music excerpts and the other two with longer music excerpts (with differences in terms of loudness). They found that longer excerpts with reproduction levels set by the test subjects enabled them to give finer quality ratings.

2 Procedure

Subjective preference of four electric guitars was evaluated by the pair comparison method. A linear slide mechanism developed specifically for this work, was used to excite the strings reducing 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

The four electric guitars were recorded using their clear tone, i.e., no electric guitar effect was taken into account in this work to limit the number of variables under study. Their characteristics related to the type of junction, wood of the fretboard and 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	EMG81/EMG85
SX Thinline Telecaster	Bolt-on	Maple	SX Pickups
Washburn WE-10TS	Bolt-on	Rosewood	Washburn Pickups

All the guitars were tuned in E standard, and with the selector key in the neck pickup position. The output guitar level was set to the maximum possible value allowed by the volume knob of each guitar.

The stimulus played was a melody of 12.5 s, composed by three chords: C, D and E minor in that order, with a tempo of 40 bpm.

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. This mechanism 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. The DC source of 12 V was connected to the three resistors, and then to the DC motor. This motor was attached to the metal

structure of the printer, allowing the movement of the reel. Limiting the current with the three resistors, the desired travel speed of the linear mechanism was achieved. All the system works in a linear way as a normal printer mechanism, but with a lower speed in order to obtain the tempo desired for the musical excerpt. Figure 1 shows the electric circuit designed in order to control the travel speed of the linear slide mechanism. R1, R2 and R3 are resistors of 15 W, with values of 10 Ω, 47 Ω and 47 Ω respectively. V1 is the DC source of 12 V and 1 A, while M1 is the DC motor that drives the linear slide mechanism. With this circuit, the travel speed of the system allowed to perform the test in optimal conditions.

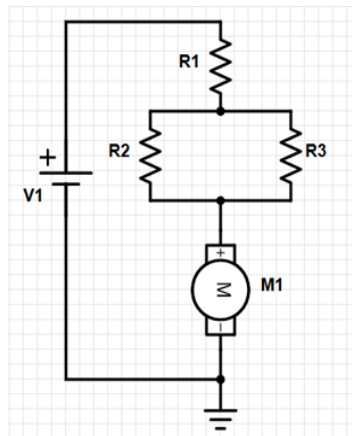


Figure 1: Electric circuit of the linear slide mechanism.

As can be seen in Figure 2, a wood stick with a pick of 1.5 mm 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 arbitrarily.



Figure 2: Linear slide mechanism.

Figure 3 shows the frequency response of each guitar in one-third octave bands considering all the played chords. The Washburn has more energy in high frequencies than the other guitars; it also has significant energy in low frequencies in relation to the other guitars, presenting similarities

with the PRS in this case. The Schecter guitar shows less energy in low frequencies, with a similar behaviour in high frequencies, while the SX guitar shows a frequency response similar to the PRS, but with a bit more energy in high frequency.

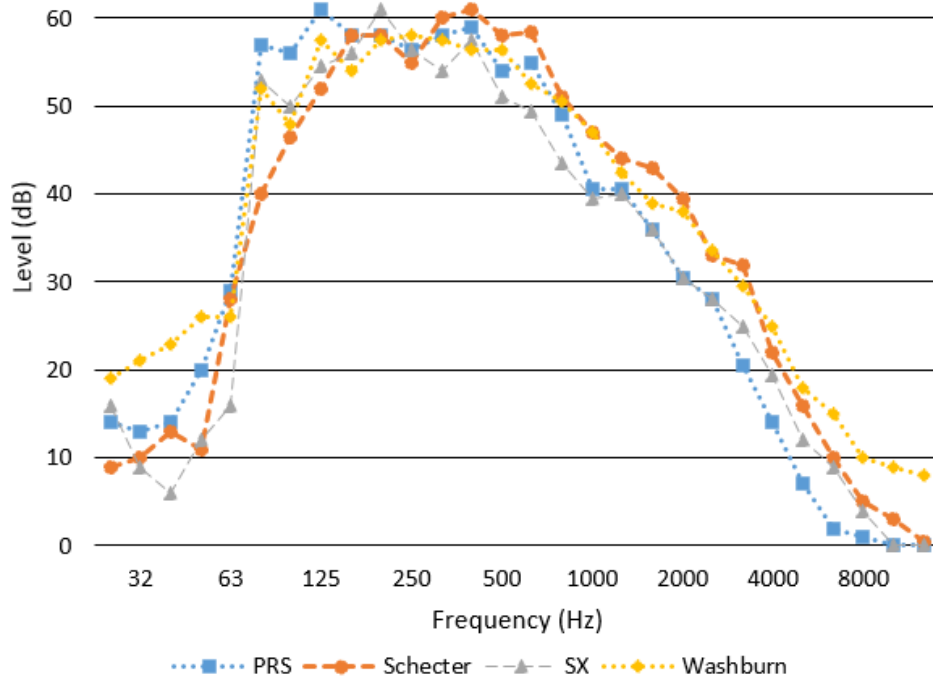


Figure 3: Frequency response of each guitar.

2.2 Objective parameters

To evaluate the objective characteristics of each electric guitar, two psychoacoustical parameters (Loudness and Sharpness) and three ACF parameters: Delay of the first peak τ_1 , amplitude of the first peak ϕ_1 and effective duration of the envelope τ_e were analysed.

According to Zwicker and Fastl, Loudness is related to the way in which the levels of sounds are perceived by the human auditory system influenced by frequency and sound pressure level [8]. It is defined as the perceptual intensity of sounds. It is measured in “Phon” or “Sone”. Sharpness is related to the high frequency content of a determined signal. The greater the energy in high frequencies is, the “sharper” is the sound. It is measured in “Acum”.

Ando defined the ACF parameters as follows: τ_1 is the delay time of the first maximum of the ACF, ϕ_1 as the amplitude of this first maximum of the same function, reflecting the magnitude at which τ_1 is observed, and τ_e is the effective duration of the envelope of the normalized ACF, defined by the ten-percentile delay (it represents a repetitive feature contained in the sound itself) [9].

These parameters were obtained using two different software. The psychoacoustical parameters were analysed in a GUI toolbox called Psysound [10]. Loudness was calculated according to the Moore model [11] while Sharpness was calculated according to Zwicker and Fastl model [8]. A time step of 23.2 ms was used in the analysis. Mean and maximum values for both Loudness and Sharpness parameters were extracted from the software. An autocorrelation function GUI

software was used to obtain the values of the autocorrelation function parameters [12]. The integration interval corresponds to the duration of each signal subtracting 0.2 s to consider the maximum delay time. A running step was 0.1 s and a range of the delay time to detect τ_1 was 10 ms.

Table 2 presents the values of the psychoacoustical and autocorrelation parameters for each guitar.

Table 2: Psychoacoustical and autocorrelation function parameters.

Parameters	Guitar			
	PRS	Schecter	SX	Washburn
Loudness [Mean] (Sone)	8.84	9.15	7.60	7.48
Loudness [Max] (Sone)	23.68	27.23	21.22	28.46
Sharpness [Mean] (Acum)	0.54	0.56	0.58	0.63
Sharpness [Max] (Acum)	1.03	1.01	0.89	1.32
ϕ_1	0.18	0.17	0.26	0.17
τ_1 (ms)	7.69	7.71	5.01	8.10
τ_e (ms)	83.50	85.70	44.50	435.00

In order to evaluate correlation among these objective parameters, Pearson's correlation coefficient was analysed (Table 3). There is a high correlation between the maximum value of Sharpness and τ_e ($r = 0.970$) significant at the 0.05 level, and between τ_1 and ϕ_1 ($r = -0.993$), significant at the 0.01 level. Thus, Sharpness (or the energy referred to the high frequencies) could be related to the duration of the envelope of the normalized autocorrelation function. Correlations among the other objective parameters were not significant.

Table 3: Correlation coefficients among the objective parameters.

	Loudness [Mean]	Loudness [Max]	Sharpness [Mean]	Sharpness [Max]	ϕ_1	τ_1	τ_e
Loudness [Mean]							
Loudness [Max]	0.120						
Sharpness [Mean]	-0.811	0.476					
Sharpness [Max]	-0.328	0.810	0.720				
ϕ_1	-0.488	-0.850	-0.030	-0.664			
τ_1	0.408	0.843	0.088	0.727	-0.993**		
τ_e	-0.533	0.728	0.865	0.970*	-0.476	0.545	

*Correlation is significant at the 0.05 level.

**Correlation is significant at the 0.01 level.

2.3 Subjective Test

A pair comparison test was chosen to evaluate the subjective preference. The listeners were asked about their preference between two electric guitars in every comparison. Possible answers was “A is preferred to B” or “B is preferred to A” without “tie” judgment.

The test instructions were given orally and in written form. Each test session consisted of six comparisons arranged randomly, in order to achieve all the possible combinations of the four stimuli, without comparing a stimulus to itself. Each pair consists of a 12.5 s audio sample of one guitar, a pause of 2 s and then a 12.5 s audio sample of another guitar. Then, the test subject can start next comparison pair by himself. A complete test session consisting of six paired comparisons had a duration of 4 to 5 min approximately.

Stimuli were reproduced using Sennheiser HD202 headphones in order to minimize the effect of the environment on the test signals. The subjective test was conducted at the UNTREF’s Library, achieving an acceptable background noise level to perform it. The listening level was adjusted in order to achieve a signal to noise ratio higher than 20 dB.

A total of 45 listeners (40 males, 5 females) aged from 18 to 31 years old, with an average of 24 years, participated in the test. None of the subjects suffered from any hearing loss.

3 Results

First the consistency of the responses by each subject was evaluated [13]. All subjects presenting circular triads were discarded. Since 11 people presented circular triads, the subsequent analysis was made by using the responses of the remaining 34 subjects that show consistency. Then, a test of agreement was performed [13]. According to the Chi-Square test, there was significant agreement among the judgments of the 34 subjects ($p < 0.05$).

Then, the mean scale values for each electric guitar was calculated according to the law of comparative judgment (Thurstone’s case V) [14] and validated by a goodness-of-fit test ($p < 0.05$) [15]. As shown in Table 4, the most preferred guitar was the Washburn, and the less preferred was the SX. Since the range between the maximum and minimum scale values is greater than 0.68, corresponding to 25 to 75% discrimination, the scale values obtained are reliable.

Table 4: Scale values of preference for each guitar.

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

Finally, scale value of subjective preference was evaluated through the correlation with the objective parameters presented in Table 2. The scale values used for this procedure are global values of all the 34 subjects. Table 5 presents the correlation coefficients between the scale values for all the test subjects and the objective parameters.

Table 5: Correlation coefficients between electric guitars scale values and objective parameters.

Parameters	Pearson's correlation coefficient
Loudness [Mean]	-0.249
Loudness [Max]	0.890
Sharpness [Mean]	0.709
Sharpness [Max]	0.987*
ϕ_1	-0.717
T_1	0.764
T_e	0.951*

*Correlation is significant at the 0.05 level.

4 Discussion

First of all, most of the subjects are musicians with knowledge of music/audio and they play the guitar and also another musical instrument.

Analysing the scale values obtained, it can be observed that the Washburn was the most preferred guitar. Also, it could be stated that the less preferred guitar was the SX.

The correlation analysis with the scale value showed significant correlations for the maximum value of Sharpness ($r = 0.987$) and τ_e ($r = 0.951$), both at the 0.05 level. Thus, preference of electric guitar could be related to the high frequency energy in the signal, and to the envelope of the ACF.

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. τ_e is the envelope decay of the ACF and is associated with the reverberation being contained in the sound itself. Thus, in a certain way, that the preference of a clean tone in an electric guitar could be significantly correlated with the high frequency content of the signal and with the reverberation containing the sound itself.

In addition, the most preferred guitar, the Washburn, is the one with higher maximum value of Sharpness and higher τ_e values. This guitar has more energy in higher frequencies than the other three guitars.

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 (the system used in this study has a fixed speed). Also, increasing the number of subjects could improve the reliability of the subjective responses. The influence of some elements of the electric guitar should be more controlled, such as type of bridge, strings, wood and neck although the type of junction have less significance in subjective preference according to the previous studies.

An objective analysis of the different pickups has not been done 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 maximum value of Sharpness and τ_e showed significant correlation with the subjective preference. Therefore, clean tone of electric guitars with more energy content in high frequencies and with more reverberation contained in the sound itself are preferred.

During the measurements of the electric guitar sounds, the influence of the right-hand technique was significantly reduced by the linear slide mechanism. It allowed obtaining the stimuli in the same way for each guitar.

As future work, more electric guitars could be evaluated. It would be interesting to analyse other parameters, such as Roughness, Tonal and Spectral Dissonance, Rise time. Different picking points might also be analysed in order to obtain different harmonic content in the signal. 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, wood). Furthermore, other type of musical excerpt could be studied, or each chord could be analysed separately in the same musical excerpt, and see if the results remain the same.

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.

Acknowledgments

The authors would like to thank the Universidad Nacional de Tres de Febrero for the financial support. Also, the authors would like to thank the Federación Iberoamericana de Acústica (FIA), the International Union of Pure and Applied Physics (IUPAP) and the Asociación de Acústicos Argentinos (AdAA) for the financial support. The authors would like to thank all the subjects who participated in the test, and also Federico Luna, Francisco López Destain, Federico Iza and Rafael Dodorico, who helped to develop the linear slide mechanism. The authors would like to thank to Federico Damis, Ernesto Sennhauser and Francisco López Destain, who lent their electric guitars for the purpose of this study.

References

- [1] Denyer, R. *The Guitar Handbook*. Pan Books, London (England), 1st edition, 1992.
- [2] Ando, Y.; Kaieda, S.; Kawai, K.; Yano, T. A study on measures of timbre of electric guitar sounds in terms of power spectrum and auto-correlation function. *Journal of Temporal Design in Architecture and the Environment*, Vol 9 (1), 2009, pp 43-46.
- [3] Paté, A.; Fabre, B.; Carrou, J.; Navarret, B.; Dubois, D. Influence of the Electric Guitar's fingerboard wood on guitarist's perception. *Acta Acustica United with Acustica*, Vol 101, 2015, pp 347-359.
- [4] Carrou, J.; Paté, A.; Navarret, B.; Dubois, D.; Fabre, B. A vibroacoustical and perceptive study of the neck-to-body junction of a solid-body Electric Guitar. *Proceedings of the Acoustics 2012 Nantes Conference*, Nantes, France, April 23-27, 2012, pp 2717-2722.

-
- [5] Preis, A.; Chudzicka, M. Expert and non-expert judgments of musical instruments: subjective evaluation vs. acoustical characteristics of musical sound. *Proceedings of the 18th International Congress on Acoustics*, Kyoto, Japan, April 4-9, 2004, pp 1495-1498.
- [6] Pedirelli, F.; Carletti, E.; Casazza, C. Just noticeable differences of loudness and sharpness for earth moving machines. *Journal of the Acoustical Society of America*, Vol 123 (5), 2008, pp 3164-3168.
- [7] Koehl, V.; Paquier, M. A comparative study on different assessment procedures applied to loudspeaker sound quality. *Journal of Applied Acoustics*, Vol 74, 2013, pp 1448-1457.
- [8] Zwicker, E.; Fastl, H. *Psychoacoustics – facts and models*. Springer, New York (USA), 3rd edition, 2007.
- [9] Ando, Y. Theory of Auditory Temporal and Spatial primary sensations. *Journal of Temporal Design in Architecture and the Environment*, Vol 8, 2008, pp 8-26.
- [10] Cabrera, D. Psysound: A computer program for psychoacoustical analysis. *Proceedings of the Australian Acoustical Society Conference*, Melbourne, Australia, November 24-26, 1999, pp 47-54.
- [11] Moore, B. C. J.; Glasberg, B. R. A revision of Zwicker's Loudness model. *Acta Acustica United with Acustica*, Vol 82, 1996, pp 335-345.
- [12] Sato, S.; Wu, S. Comparison of Different Calculation Methods of Effective Duration (T_e) of the Running Autocorrelation Function of Music Signals. *Acta Acustica United with Acustica*, Vol 97, 2011, pp 432-440.
- [13] Kendall, M. G.; Smith, B. B. On the method of paired comparisons. *Biometrika*, Vol 31, 1940, pp 324-345.
- [14] Thurstone, L. L. A law of comparative judgment. *Psychological Review*, Vol 34 (4), 1927, pp 273-286.
- [15] Mosteller, F. Remarks on the method of paired comparisons: I. The least squares solution assuming equal standard deviations and equal correlations. *Psychometrika*, Vol 16 (1), 1951, pp 3-9.