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Influence of the Electric Guitar's Fingerboard Wood on Guitarists' Perception

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Summary

The sound of a solid body electric guitar comes from the loudspeaker transducing into sound the string velocity. Because of mechanical string-structure coupling, the string vibration, and therefore the sound, substantially depends on the lutherie parameters. This study focuses on the comparison between ebony-fingerboard and rosewood-fingerboard guitars: is a change in the fingerboard wood perceived by the guitar players? In order to test the hypothesis that it is actually perceived, a psychological investigation is carried out. Two experimental methods are used: a free sorting task with recorded stimuli from the guitars (listening test) and a free verbalisation task where the guitarists play the guitars. In the listening test, the guitarists perceive differences between guitars, but the resulting clusters do not show an ebony/rosewood dichotomy. A linguistic analysis of the verbalisations exhibits psychological descriptors that are relevant for the discrimination of the wood of the fingerboard: PRECISION (referring to how each note stands out from others), and to a lesser extent ATTACK (referring to the guitar's response to musician's gesture) and BALANCE (referring to the frequency content). This study is part of a broader project aiming at establishing an explicite relation between mechanics, perception, and lutherie. A physical interpretation of the psychologically-relevant descriptors is eventually proposed in order to use them as hypotheses in a further hypothetico-deductive approach starting from physics and using psychophysical methods.

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1. Introduction

The sound of a solid body electric guitar comes from the loudspeaker transducing into sound the string velocity signal, possibly modified by some effect processing devices. Besides these electrical considerations, the string vibration remains the driving force of the sound. Because of mechanical string-structure coupling [1, 2], the string vibration substantially depends on the lutherie parameters. Wood species, neck and body shapes, fret types…, alter the string vibration, hence the sound.

Some lutherie parameters that are said (by luthiers, players) to have an influence on the sound of the electric guitar were investigated in previous mechanical studies: the wood of the body [3], the neck-to-body junction [4] or the wood of the fingerboard [7]. One of the final goals of mechanical studies of musical instruments is to find the physical parameters that are relevant to the musicians. While the resulting mechanical descriptions (admittance measurement and derivatives) are quite accurate and robust, their connection with perceptual descriptors remains a challenging issue [4].

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The present study is about the wood of the fingerboard. Guitars with ebony or rosewood fingerboard are compared. Informal discussions with electric guitar players and makers suggest that an ebony fingerboard would render "more precise attacks" and would have a spectrum with a little less mids, whereas a rosewood fingerboard would give a "rounder" sound. More information about this informal knowledge can be found in [5, 6]. This knowledge is to be confirmed by this study, because only few guitarists have had the opportunity to play guitars only differing in the fingerboard wood. The leading question of this paper is: is a change of the fingerboard wood of a solid body electric guitar perceived by the guitar player?

One approach consists in testing hypotheses on perception directly derived from concepts of physics. This approach may miss some information for two reasons. First, human perception may be indifferent to some descriptors that are physically relevant. Second, human perception may be sensitive to aspects of sound related to mechanical parameters that mechanical models do not take into account.

This paper aims at providing a new perceptually-relevant basis for the mechanical study of the electric guitar. This work makes use of methods of psychology to identify the relevant parameters from the musician's point of view in an inductive approach: how do the guitar players characterise sounds corresponding to different fingerboard woods? What criteria do they use?

We make the hypothesis that a change in the wood of the fingerboard is perceived by guitarists. Two experimental methods are used in order to access to relevant psychological descriptors (section 2). First a listening task in the form of a free sorting task is proposed. The free sorting task derives from theories making use of the concept of natural category to describe the human cognition process, and was elaborated in the field of cognitive psychology along with the theory of natural categorisation [8, 9, 10, 11]. It is a common method in psychology, especially in the fields of sensory analysis [12], and of sound perception [13, 14, 15, 16]. The second task consists in collecting the free verbalisations of musicians while freely playing the guitars. We insist on the "free" aspect of the tasks: it lets the musician choose his own criteria, expressed with his own words (vocabulary), in absence of a priori already known criteria from the experimenters. Moreover, in a playing task, the players can make use of their other senses, e.g. their sense of touch: two different fingerboard woods may differ in their surface state or in their reaction to humidity, and this may be digitally perceived by the players.

A classic method is used for the cluster analysis of the categorisation data and a linguistic method for a semantic analysis of the verbal data (section 3). The semantic analysis results in the identification of perceptually relevant descriptors for the evaluation of the guitars. Some descriptors are used by the guitarists to discriminate between the two fingerboard woods (section 4).

How can we translate the psychological descriptors — necessarily relevant to the musicians — into hypotheses for mechanical studies? A physical interpretation of these relevant descriptors is eventually proposed in order to use them as hypotheses in a further hypothetico-deductive approach starting from physics and using psychophysical methods (section 6).

2. Experimental methods

This section presents the guitars (also "objects") and the guitarists (also "subjects" or "musicians") of the study. Then it describes the two experimental methods used in order to get to the guitarists' judgements on the guitars.

2.1. The guitars, hardware and guitarists

The present study focuses on the fingerboard material only. Since the electric guitar market hardly provides two identical guitars with a different fingerboard wood, a collaboration with luthiers has been established. Students at Itemm[1] crafted six guitars for the study, following the specifications of the reference model [21] *Les Paul Junior* by manufacturer *Gibson*: original shape, mahogany body and neck. The guitars are equipped with *GHS Boomer .10-.46* strings and *Kent Armstrong P-90 Dog-Ear BK* bridge pickup. The only electronic setting available on the guitars is the "volume" knob controlling the output level of the pickup. The traditional "tone" knob (controlling the cutoff frequency of a low-pass filter on the output signal of the pickup) is disconnected from the electronic circuit.

The same machines and patterns for the automated parts of the instrument-making process, the same technical drawings with geometrical instructions, and wood from the same tree were used for the six guitars, in order to reduce the variability. Three guitars have an ebony fingerboard (guitars numbered G1, G3 and G5), and three have a rosewood fingerboard (guitars numbered G2, G4 and G6). Four of these guitars can be seen in Figure 5. Albeit the only intentional lutherie difference is the wood of the fingerboard, the guitars are expected to exhibit some variations. First they are made of wood, a material known for its high variability in terms of physical parameters. Second, the machines used during the process have a certain geometrical tolerance, and most of the guitar making here is done by hand, causing further variations.

The widespread *Fender Blues Junior III* tube-amplifier is used. It allows control on the gain (output of the preamplifier) via the "volume" knob, the overall volume via the "master" knob, the equalisation via the "bass", "middle" and "treble" knobs, and on a spring reverberation via the "reverb" knob. All knob settings range from 1 (minimal value) to 12 (maximal value).

In order to switch from "clean" to "distorted" sound, the *Fulltone OCD v.3* overdrive pedal is used. Its settings are: a "volume" knob controlling the output volume, a "drive" knob for the amount of distortion, and a "tone" knob, whose behaviour is basically identical to the "tone" knob of the guitar. In the following, the setting of each knob is expressed as a fraction of its full-scale value.

Ten professional guitarists participated in the study: their livelihood and main activity involve many hours a day of guitar playing. Among their activities were concert and studio playing, composing, teaching and guitar testing for magazines. Each guitarist received 25 € for participating in the study.

2.2. Listening task

The first part of the study is a listening task of pre-recorded signals. A free sorting task method is used in preference to traditional psychophysical methods inasmuch the relevant parameters of the sound are unknown for the complex acoustic stimulations of electric guitars. Free sorting task is a classic method [13, 14, 15, 16, 17, 18] based on the theory of categorisation [9, 10, 11]. The free sorting task seems here attractive since the hypothesis describes two guitar types: with ebony or rosewood fingerboard.

2.2.1. Musical excerpts

The electric guitarist is accustomed to listening to a guitar sound through a guitar amplifier. Therefore an amplifier-

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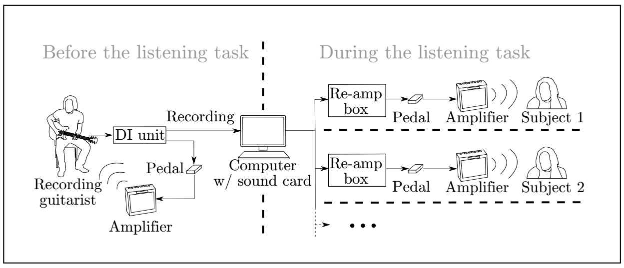

Figure 1. Listening test: sketch of the recording and listening phases. An output of the DI unit is used for the recording of the output of the pickup, the other is connected to the pedal and amplifier for audio feedback. During the listening phase, the recorded signals are sent to the pedal and amplifier.

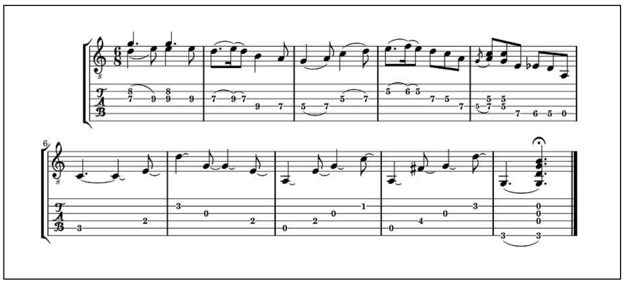

Figure 2. Musical and tablature notation of the 1st excerpt. Tempo is 108 BPM. Amplifier settings – volume 7, treble 7, bass 7, middle 7, master 5, reverb 2. The overdrive pedal is switched off. This corresponds to a "clean" sound.

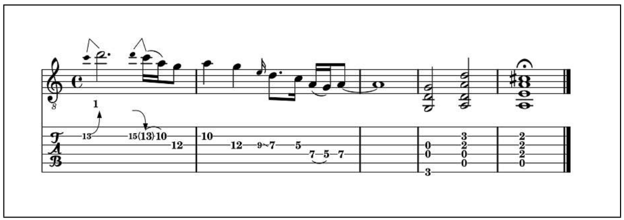

Figure 3. Musical and tablature notation of the 2nd excerpt. Tempo is 120 BPM. Amplifier settings – volume 7, treble 6, bass 8, middle 6, master 2, reverb 2. Overdrive pedal settings – volume 3/4, drive 1/2, tone 1/2. This corresponds to a "distorted" sound.

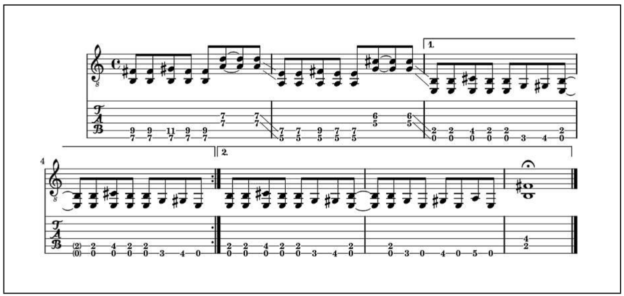

Figure 4. Musical and tablature notation of the 3rd excerpt. Tempo is 164 BPM. Amplifier setting – volume 7, treble 7, bass 7, middle 7, master 2, reverb 2. Overdrive pedal settings – volume 3/4, drive 1/4, tone 1/2. This corresponds to a "crunch" sound.

listening test was chosen instead of e.g. a headphone-listening test. The so-called "re-amping" technique was chosen. Prior to the perceptual test, the output of the guitar pickup is recorded through a DI unit. During the perceptual test, the amplifier and distortion pedal are fed with the recordings through a re-amp box, providing ecologically valid [19, 20] as well as repeatable listening conditions. A sketch of the recording and listening phases is given in Figure 1.

The musical styles of the excerpts had to fit the styles that are usually played on that type of guitar, so three typical rock 'n' roll-like licks have been chosen as excerpts. They were composed and played as identically as possible on each of the six guitars by one of the authors, an experienced electric guitar player. The author knew which guitar (with which fingerboard) he was playing, and did his best to produce an identical performance on each of the guitars. The recordings are sampled at a 44.1 kHz rate and a 16-bit resolution. The output DI unit is sent to the computer for the recording, and to the amplifier via the pedal in order the recording guitarist to get an audio feedback. G3 (ebony) and G6 (rosewood) were chosen to be replicated. The replicas are used to test the sensibility and robustness of the perceptual test. For each of the three excerpts, 8 stimuli are therefore presented to each musician.

The three excerpts are transcribed in Figures 2 to 4. They are not claimed to encompass all the variety of musical styles that are traditionally played on that type of guitar, but they give a good overview of it.

The first excerpt (Figure 2) is a "shuffle"-like (somewhere between duple and triple metre) lick combining the legato technique [21] with double-stops for the solo part, and arpeggios with open strings for the rhythmic part. Amplifier and pedal settings produce a "clean" sound.

The second excerpt (Figure 3) is a typical blues-rock solo phrase including typical blues rock electric guitar vocabulary such as the use of the pentatonic scale, "powerchords" (chord only consisting in the root and the 5th) and playing techniques like bends [21], slides, hammer-ons and pull-offs. Amplifier and pedal settings produce a "distorted" sound.

The third excerpt (Figure 4) is a common rock 'n' roll rhythmic "riff" based on variations on powerchords. It includes slide technique and syncopated rhythm. Amplifier and pedal settings correspond to a "crunch" sound (somewhere inbetween the clean and distorted sounds) but the omnipresence of chords within the excerpt makes it sound quite more indistinct and fuzzier than the previous excerpt.

2.2.2. The musician's task

The listening test takes place in a quiet room (see Figure 5) with no particular acoustic treatment. The guitarist sits at a workstation running the program *TCL-LabX* [22, 23] that leads him through the listening task. The sound comes from the loudspeaker of the amplifier, whose position is freely chosen by the musician. For ease-of-listening reasons, amplifier's "master" and "reverb" settings can be modified by the musician, but the other amplifier and overdrive pedal settings are not allowed to be changed. For each of the 3 excerpts, the guitarist is asked to perform the tasks described below.

First the subject is asked the following question (in French): *Please sort these eight stimuli. Could you please group the similar ones, and put into different groups those which seem different to you? You are free to create as many groups as you want.*

Each stimulus is represented by an icon on the screen of a computer. The subject is free to move each of the eight icons wherever he wants within the space of the window. The stimuli can be played back and listened to *ad libitum* by clicking on the icons. No information about the stimuli is given, not even that the stimuli come from different guitars. The stimuli numbering does not correspond to guitar numbering and changes between the excerpts but not between the subjects.

When the subject has placed all the icons, he is asked to write a short comment about each category he produced. The procedure is repeated for the other excerpts. The overall duration of the listening test was approximately one hour.

2.2.3. Output of the task

The sorting of stimuli into clusters by subjects produces an extensional description of the guitars within categories along their similarities and differences. The categories are then verbally depicted to give access to an intensional description in terms of perceptual and semantic properties, to be later matched to physical descriptors are listed. The ouput data of the listening task consists in clusters of stimuli and verbal comments upon these categories. The analysis is described in sections 3.1 and 3.2.

2.3. Free playing task

The next task adds to the audition other sensory modalities that the guitarist actually uses in his expertise of guitar. It is another way of getting ordinary judgements, which are both holistic and polysensorial, in order to induce hypotheses for the physical analysis within the acoustic domain.

2.3.1. The musician's task

After the listening task, the guitarist is asked to freely play the guitars: he can play each guitar as long as he wants and switch guitars whenever and as often as he wishes. The playing phase takes place in a room with reduced light, in order to visually hide the differences (colour) between the fingerboards. Indeed none of the guitarists saw the difference between the fingerboards. Use, settings and position of amplifier and overdrive pedal are let totally free. During the playing, the guitarist is asked to express his sensory experience about the guitars. Figure 5 shows a guitarist in playing condition. Note that light has been turned on for photograph quality purpose.

Only four guitars, two of each type, are to be played, in order to reduce the duration of the test and the fatigue of the musicians. G1 and G2 were discarded by the experimenters because they were found to have too different geometrical features, altering the ergonomics. In particular, neck profiles of G1 and G2 were too different. This

Figure 5. A guitarist sitting in playing condition during the playing phase of the test. Note that light has been turned on for photograph quality purpose.

parameter, of great importance to the guitar player, is finished by hand, hence it is very difficult to maintain a constant neck profile among a guitar production involving several luthiers. During the playing test, only a few remarks have been done about potential differences in neck profile between the other four guitars. This ergonomics criterion has been selected in order to let the guitarist focus on other aspects of the sensory experience.

2.3.2. Output of the task

Each of the one to two-hour long interviews was recorded and transcribed. The whole verbal data is the "corpus" which linguistic analysis is described in section 3.2.

3. Data processing

3.1. Data from the free sorting task

For each of the 3 musical excerpts of the categorisation task, the 10 musicians sorted 8 stimuli into a certain number of categories.

In the absence of hypothesis about the dimensional nature of the attributes that define the categories, a distance analysis was preferred to a dimensional analysis such as e.g. multi-dimensional scaling. Each sorting led to a co-occurence matrix, whose values are 1 at the intersection between row i and column j if stimuli i and j are in the same categories, and 0 if not.

For each excerpt, the total co-occurence matrix $\mathbf{M}$ is the sum of the $N = 10$ individual co-occurence matrices. A total distance matrix can be computed as $\mathbf{D} = 1 - \mathbf{M}/N$ [18].

A tree additive distance (that is, a distance measure satisfying the additive inequality [24]) can be fitted to this distance in order to represent the stimuli on an additive tree. The method is now well and comprehensively described in many references [25, 26, 27, 28]. The additive tree representation is computed with the software *AddTree* [23]. All terminal nodes (or "leaves") of an additive tree

Table I. Stress S and rate of well designed quadruples R_q for the three tree representations.

	Excerpt 1	Excerpt 2	Excerpt 3
S	0.1103	0.0967	0.1026
R_q	0.8857	0.9429	0.9357

represent a stimuli. The leaves are connected together via paths following several edges of various lengths. The total length of a path between two leaves is proportional to the dissimilarity, or distance between the two corresponding stimuli. No information is given by the euclidian distance (direct path not along edges) between two leaves.

The additive trees representing the consensual categories corresponding to excerpts 1 to 3 of the listening test are shown in Figures 6 to 8. Guitar recordings and their replicas are naturally denoted with the same label.

Some criteria for the evaluation of the quality of the tree representation of the data are given in [25, 29]. They are shown in Table I. The stress S is a function of the root mean square of the difference between the data distance and the additive tree distance. This difference has low values if the additive tree distance fits the data distance. Table I shows that S values are close to 0 for the three excerpts. The rate of well designed quadruples R_q is the rate of 4-object sets whose distance relationships have an additive tree topology: the more the data distance is close to a tree distance, the closest R_q is to 1. This is what happens for R_q for the three excerpts. One can therefore have confidence in the trees of Figures 6 to 8.

3.2. Verbal data

3.2.1. General considerations

The corpus analysis accounts for results from previous research. Dubois [30] showed that, unlike what happens with visual objects and colours, there is only a few simple forms in the lexical resources of French language to describe sounds.

Second, the same lexical unit can be used either as a "word" or as a "term" [31, 32]. In the former case, the same "signifier" is used for different "signifieds" [33], and electric guitarists make different use of the lexical resources of the language, depending on their own history and musical practice [32]. In the latter case, there is a consensus among the electric guitarists' community about the use of a particular lexical unit for a particular sensory experience: the same "signifier" is used for the same "signified".

In both cases, the meaning of the word as constructed in discourse may differ from its common sense use, in particular from the experimenter's use. The corpus analysis should therefore make no a priori assumption about the word meaning that will be inferred from the word use within the individual verbal productions.

A method, inspired by previous work [18, 30, 34], is proposed in this paragraph for the production of semantic relationships between the words, such as synonymy, antonymy, etc. The words used by the players are given in their mother-tongue, that is French. English translations follow the French words in this section, and next sections uses only English words, for communication purpose. English words are only given as a guide, and do not necessarily strictly correspond to what the players meant. Translations of whole sentence may sound a bit strange to English speakers, but a word-to-word and naive (minimising the experimenter's interpretation) translation has been preferred to a more literary translation that necessarily brings some interpretation. When the French (resp. English) words are quotation of the musicians' verbalisations, they are given in quotes (resp. in italic letters).

3.2.2. Analysis method

The method is applied to the transcribed data of the playing task, and not to the comments of the listening task, because the latter consist rather in isolated words than in sentences. In a first phase, we extract the parts of the discourse describing the guitar and/or the sound:

1. in the corpus, we automatically identify and select the occurrences of the same sequence of letters, with and without flexion marks such as singular plural or gender (e.g. search for "son" a French word for "sound"),
2. we discard homographs not relevant within this context (e.g. the French word "son" for "sound" can also be the possessive adjective "his/her"),
3. for each of the words, we pick the textual context in which it occurs and keep track of who is speaking, in what playing condition and of course about which guitar.

Within these parts of discourse, the meaning of each word can be evaluated:

- from the syntactic context of each word, produced by one or a set of guitarists (identification of individual or group specificity, of terminological use of the same significant, of the differential use of words according to the situation),
- through contrast or equivalence (differential meaning) identified from the use of words in context,
- through linguistic marks such as reformulations, appositions, oppositions or indications from the speaker himself about how he uses the word,
- from adverbs allowing to identify the structure in the judgement: comparative in a monadic description of each guitar, or more generic in free sorting task referring to the commonalities between properties.

3.2.3. Examples

An illustration of the method is given with three examples directly extracted from the corpus. Subject 1 said: *A much brighter sound. Brighter, more higher harmonics* ("Un son beaucoup plus brillant. Plus brillant, plus d'harmoniques aiguës"). Here the words *bright* and *high harmonics* are inferred to be related one to another.

Another example of use of both appositions and oppositions and of the reference to a context is a sentence by subject 9: *So this* [the sound] *is less bright... this* [the guitar]

Table II. English translation. Identified semantic proximities and corresponding labels/meta-criteria (capital letters). Within a category, positive words (normal font) are opposed to negative words (bold font). For each category, the depicted object is given.

Label of the category (meta-criterion)	Words of the category	Object
PRECISION	*precision, precise, distinction, definition, clear, clarity, broad spectrum, inertia, straight, distinct* ≠ ***invasion, rich, muddy, to dribble, dribbling, mess, dirty, mire, uncontrollable, shitty, to distort, blurred***	sound
ATTACK	*attack, to attack, dynamic, response, respond, expressivity, impact, lively* ≠ ***soft, flabby***	guitar & player
BALANCE	*balance, well-balanced, homogeneous* ≠ ***unbalanced***	sound
BRIGHTNESS	*bright, brightness, treble, biting, to bite, dry, dryness, tight, sour, nervous, striking, incisive, rich, twangy, piercing, to scream, tinsel, attack, clear, clarity, sparkle, metallic, level, inaudible* ≠ ***remove some brightness, lighter treble***	sound
MIDDLE	*middle, present* ≠ ***duck, thin***	
	high-middle, wild ≠ ***hollow***	sound
	low-middle, thick ≠ ***twangy, nose***	
BASS	*bass, bass, low, round, thick, loud, warm, body, full, dark, dull, soft, muffled, velvet, to appear* ≠ ***the low-frequencies sink***	sound
SUSTAIN	*sustain, resonance, to live, long, long, to last, duration* ≠ ***short***	sound
AGRESSIVENESS	*agressive, cold* ≠ ***mellow, charm, charming***	sound

is the dullest [...] hence the middle frequencies stand out a bit more... hence it [the guitar] *has less twang with distorted sounds* ... ("Alors ça c'est moins brillant... c'est la plus mat [...] du coup il y a un médium qui ressort un peu plus... du coup elle a moins de claquant en saturé..."). It is induced that the words *bright* and *twang* are close one from another and are opposed to the words *dull* and *middle frequencies*... at least in the context of a *distorted sound*.

The last example, by subject 2, is about the relation between a "round sound" and the low-frequencies content. *Roundness* and *body* are semantically very close one to another and opposed to *twangy* and *tight*: *for me the roundness is a bit related with the equalisation [...] when I say roundness I'd put it rather in the lower range, you know, of a spectrum, if one talks about bass, middle, treble, and at the same time the body of the sound [...] what seems to me twangy and tight a bit unpleasant, this is what has a lack of roundness for me, and what has roundness, it would be precisely something that is... that has more body, and therefore less tight* ("pour moi la rondeur c'est lié un peu à l'équalisation [...] quand j'dis rondeur j'situerais ça plutôt vers le bas, tu vois, d'un spectre, si on prend grave, médium, aigu, et en même temps le corps du son [...] c'qui m'semble nasillard et tendu un peu désagréable, c'est c'qui manque de rondeur pour moi, et c'qui a de la rondeur, ce serait plus justement quelque chose qui est... qui a plus de corps, et donc moins tendu").

3.2.4. Output of the analysis

Semantic proximities were established from the linguistic analysis of the whole corpus, following the method that has just been exemplified. Tables II (English translations) and III (original French) summarise the resulting semantic proximities and corresponding word categories. The meta-criterion for each category of words is written in capital letters, in order to distinguish this name (chosen by the experimenters among the words of the category) as a label from other words used by the musicians (and not chosen by the experimenters). Interpreting the meta-criteria with the knowledge from the semantic analysis produces psychological "descriptors" associated with the words used. They are a first step in the translation of the semantics of natural languages into physical hypotheses.

A category can group together words that have opposite meanings. In this case "positive" words (in normal font) are defined as the words having a meaning close to the meaning of the label, and "negative" words (in bold font) are antonyms of the label. Words "positive" and "negative" are in no case judgements: they are strictly derived from semantics.

PRECISION sums up natural language words into a descriptor depicting the way different notes (of a chord, for example) are perceived as distinct or as a blend. ATTACK brings together words refering to the way the guitar responds to the gesture of the guitarist's right hand. Words refering to the proportions of low, middle and high frequencies are labelled BALANCE. BRIGHTNESS (resp. MIDDLE, BASS) refers to the physical attributes indicating a predominance of treble (resp. middle, bass) in the sound. SUSTAIN deals with the resonance of the sound. Words expressing the inconvenience induced by the sound to the player fall into the meta-criterion AGGRESSIVENESS.

We can also observe here a regular property of "natural" semantics: the identified semantic categories sometimes overlap (on the contrary to physical concepts). The words under the label BRIGHTNESS are actually very often antonyms of the words under the label BASS. Words of

Table III. French words. Identified semantic proximities and corresponding labels/meta-criteria (capital letters). Within a category, positive words (normal font) are opposed to negative words (bold font). For each category, the depicted object is given.

Label of the category (meta-criterion)	Words of the category	Object
PRECISION	précision, précis, distinction, définition, clair, clarté, large spectre, inertie, droit, net ≠ **envahissement, riche, baveux, baver, bazar, bordel, crade, bourbier, ingérable, merdouilli, tordre, brouillé**	sound
ATTAQUE	attaque, attaquer, dynamique, réponse, répondre, expressivité, impact, vivant ≠ **doux, mou**	guitar & player
EQUILIBRE	équilibre, équilibré, homogène ≠ **déséquilibré**	sound
BRILLANCE	brillant, brillance, aigu, mordant, mordre, sec, sécheresse, tendu, aigre, nerveuse, "percussif", incisif, riche, claquant, criard, crier, clinquant, attaque, clair, clarté, scintillement, métallique, niveau, inaudible ≠ **enlever de la brillance, aigus plus légers**	sound
MEDIUM	médium, présent ≠ **canard, fin**	
	haut-médium, méchant ≠ **creux, creusé**	sound
	bas-médium, épais ≠ **nasal, nez**	
BAS	bas, basse, grave, rond, ample, puissant, chaud, corps, plein, sombre, mat, doux, sourd, velours, apparaître ≠ **s'affaisser dans les graves**	sound
SUSTAIN	sustain, résonance, vivre, long, longtemps, durer, durée ≠ **court**	sound
AGRESSIVITE	agressif, froid ≠ **moelleux, charme, charmant**	sound

BRIGHTNESS such as *piercing, to scream* bear witness of a negative sensation and are therefore close to some words of AGGRESSIVENESS.

One word can appear in two meta-criteria, as *attack*. The word *attack* can refer either to the sound or to the guitar and the player. In the first case, a sound with *attack* is a sound with a lot of energy in the high frequencies. The word *attack* sometimes (and very often for the verb *to attack*) refers to the behavioural interaction between the guitarist and the instrument. This is why Tables II and III also mention the object that is described by the words.

4. Results

4.1. Results from the listening task

4.1.1. Reading the tree representation

The tree representations of the similarity measures from the clusterings of each excerpt are shown in Figures 6 to 8. They prove the robustness of the method: two physically exactly identical stimuli are actually judged as quite close one to another[2]. Nevertheless the trees do not split the stimuli into the two expected (opposed by a single attribute related to the wood of the fingerboard) clear groups: there is not one group for ebony fingerboard and one for rosewood fingerboard. Inter-subject differences in the categories are found. It is still noticed that individual categories group together the physically identical stimuli

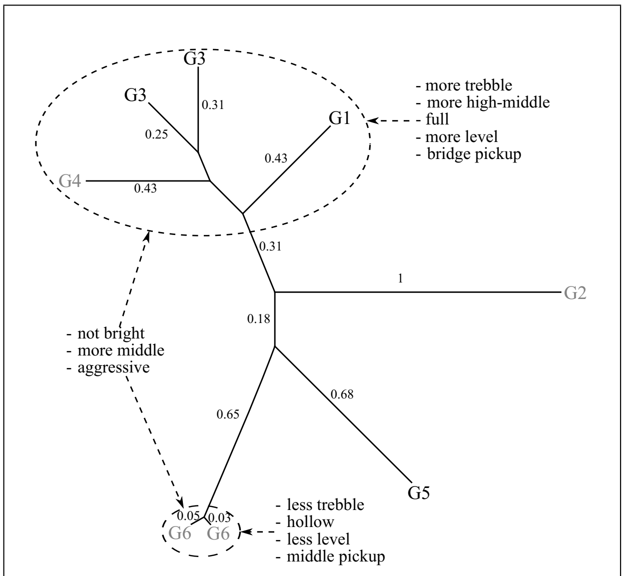

Figure 6. Additive tree representation for the stimuli of excerpt 1. Black (resp. gray) is used for the nodes corresponding to ebony- (resp. rosewood-) fingerboard guitars. Dashed ellipses denote the categories that are analysed. Dashed arrows assign the proper or shared attributes for each category. Note that leaves having the same name represent the replicas (identical copies of recordings). Numbers denote the length of the branches normalised to the length of the longest branch.

(replicas) and show categories close to the categories of the consensual trees of Figures 6 to 8. For giving a synthetic overview of the listening task, only the consensual tree representations are shown and discussed.

[2] However they are not perceived as exactly similar. An explanation for this could be the order in which the musician listened to the stimuli: physically identical stimuli might be judged as different.

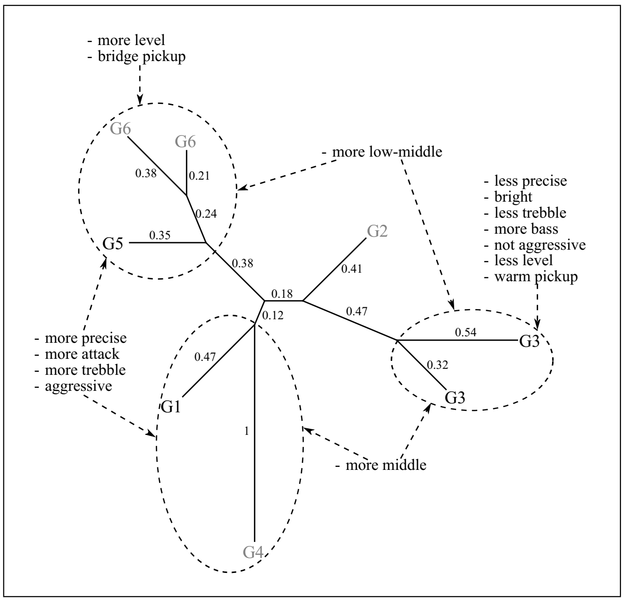

Figure 7. Additive tree representation for the stimuli of excerpt 2. Black (resp. gray) is used for the nodes corresponding to ebony- (resp. rosewood-) fingerboard guitars. Dashed ellipses denote the categories that are analysed. Dashed arrows assign the proper or shared attributes for each category. Note that leaves having the same name represent the replicas (identical copies of recordings). Numbers denote the length of the branches normalised to the length of the longest branch.

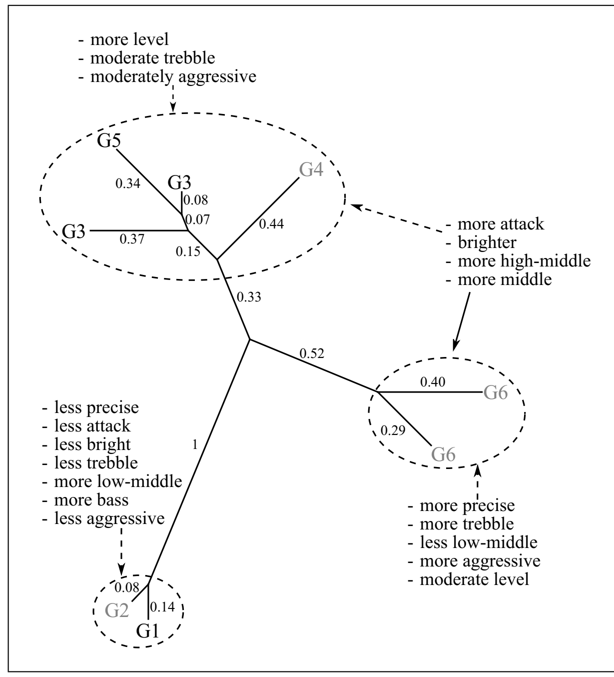

Figure 8. Additive tree representation for the stimuli of excerpt 3. Black (resp. gray) is used for the nodes corresponding to ebony- (resp. rosewood-) fingerboard guitars. Dashed ellipses denote the categories that are analysed. Dashed arrows assign the proper or shared attributes for each category. Note that leaves having the same name represent the replicas (identical copies of recordings). Numbers denote the length of the branches normalised to the length of the longest branch.

4.1.2. Verbal

The clusters give here an extensional description of the guitars. The analysis of the associated comments gives an intensional description.

Items are not described as having proper attributes, but as sharing attributes with the other items within the same category. Isolated guitars are then not taken into account.

The analysis of the comments should reflect the consensual categories shown on the trees (ellipsoids in the Figures 6 to 8). In order to access the intensional description of the categories, it is necessary to go back to the comments on the actual categories. These categories are made by the subjects, and may differ from the consensual categories. Only the actual categories judged as close enough to the consensual categories were considered. For a consensual category containing 2 (resp. 3, 4) stimuli, only the subjects' categories that included at least 2 (resp. 2, 3) stimuli of the tree categories were considered.

Within the comments associated with the considered actual categories, all words are picked up. They are grouped together according to the semantic categories identified in section 3. The few words used during the categorisation task were also used during the playing task, so their meaning could be inferred, being assumed that their semantic did not change between the two tasks. Figures 6 to 8 show, for excerpts 1 to 3, selected words representing each relevant semantic category (if used) characterising the proper attributes of each category and the attributes shared by several categories. Arrows connect the attributes to the corresponding categories.

Stimuli have been categorised by the guitarists during the listening test, according to similarity and dissimilarity judgements. Associated comments gave an intensive description of the categories. However, both extensional and intensional descriptions did not reveal a clear distinction between the two fingerboard woods:

- there is not one category for ebony and one for rosewood,
- accross excerpts, the comments show no regularity in the attributes of the same guitar: for example G3 is found to have *more treble* for excerpt 1 (Figure 6) and *less treble* for excerpt 2 (Figure 7), and G1 is alternatively evaluated as *aggressive* for excerpt 2 (Figure 7) and *less aggressive* for excerpt 3 (Figure 8)

These remarks suggest that

- the groupings depend not only on the guitars, but also on the recording player's interpretation of the chosen musical excerpts,
- each guitar may have its own attributes, not necessarily only related to the fingerboard wood.

The next task addresses these remarks. The verbalisation task should allow more individual characterisation of each guitar. The free playing situation does not impose any musical excerpt or any other's interpretation. Moreover, giving back to the musician his interaction with the instrument, the playing task adds other sensory modalities and may give access to other evaluations. The listening task with pre-recorded stimuli, each of those being performed

Table IV. For each semantic category and each guitar, absolute number of positive and negative evaluations (percentages indicate the same quantities relatively to the total amount of evaluation of each guitar). Black corresponds to ebony-fingerboard guitars (G3 and G5) and gray corresponds to rosewood-fingerboard guitars (G4 and G6).

	Ebony		Rosewood	
PRECISION	G3	G5	G4	G6
positive evaluation	13 (100%)	10 (83%)	3 (18%)	2 (29%)
negative evaluation	0 (0%)	2 (17%)	14 (82%)	5 (71%)
ATTACK	G3	G5	G4	G6
positive evaluation	15 (75%)	12 (92%)	6 (40%)	7 (54%)
negative evaluation	5 (25%)	1 (8%)	9 (60%)	6 (46%)
BALANCE	G3	G5	G4	G6
positive evaluation	10 (91%)	10 (77%)	10 (63%)	5 (56%)
negative evaluation	1 (9%)	3 (23%)	6 (37%)	4 (44%)
BRIGHTNESS	G3	G5	G4	G6
positive evaluation	30 (55%)	47 (82%)	45 (80%)	51 (86%)
negative evaluation	25 (45%)	10 (18%)	11 (20%)	8 (14%)
MIDDLE	G3	G5	G4	G6
positive evaluation	10 (91%)	10 (100%)	5 (100%)	1 (100%)
negative evaluation	1 (9%)	0 (0%)	0 (0%)	0 (0%)
LOW-MIDDLE	G3	G5	G4	G6
positive evaluation	1 (100%)	9 (90%)	5 (83%)	0 (0%)
negative evaluation	0 (0%)	1 (10%)	1 (17%)	3 (100%)
HIGH-MIDDLE	G3	G5	G4	G6
positive evaluation	1 (50%)	10 (77%)	1 (9%)	0 (0%)
negative evaluation	1 (50%)	3 (23%)	10 (91%)	0 (0%)
BASS	G3	G5	G4	G6
positive evaluation	27 (69%)	9 (30%)	17 (57%)	5 (20%)
negative evaluation	12 (31%)	21 (70%)	13 (43%)	20 (80%)
SUSTAIN	G3	G5	G4	G6
positive evaluation	12 (67%)	22 (88%)	24 (96%)	7 (50%)
negative evaluation	6 (33%)	3 (12%)	1 (4%)	7 (50%)
AGGRESSIVENESS	G3	G5	G4	G6
positive evaluation	1 (12%)	7 (88%)	10 (91%)	7 (88%)
negative evaluation	7 (88%)	1 (12%)	1 (9%)	1 (12%)

in a very similar way, without knowing what was changing between each stimulus (this could have been the guitar, the pickup settings, some digital filtering, etc.), was apprehended as a quite “unnatural” task by the players. The playing task is expected to place the guitar players in a more usual situation.

4.2. Results from the verbalisations

Within the corpus of the playing task, affirmative and negative sentences are distinguished. Affirmative sentences do not contain any negation mark and can include one of the following adverbs: *too much, so much, the most, a lot (more), very, immediately, bloody (more), super, really more, even more, best, better, more, well, good, not bad, a (little) bit more, a little, still, a tiny bit, enough* (“trop”, “tellement”, “le plus”, “beaucoup (plus)”, “très”, “tout de suite”, “vachement (plus)”, “super”, “vraiment plus”, “encore plus”, “meilleur”, “mieux”, “plus”, “bien”, “bon”, “pas mal”, “un (petit) peu plus”, “un peu”, “toujours”, “un poil”, “assez”).

Negative sentences contain a negation mark (e.g. *not*, “pas”) or a mark of any kind of lack of property (e.g. *less*, “moins”), and can include one the following adverbs: *a (little) bit less, less, lack, not enough, not much, not enormously, not too much, not super, not astounding, not very much, the less, not, very little* (“un (petit) peu moins”, “moins”, “manque”, “pas assez”, “pas très”, “pas énormément”, “pas trop”, “pas super”, “pas formidable”, “pas beaucoup”, “absence”, “beaucoup moins”, “le moins”, “pas”, “très peu”).

For each semantic category of Tables II and III, the number of positive and negative evaluation of the category is counted. A ”positive evaluation“ is defined as a use of a positive word in an affirmative sentence, or a use of a negative word in a negative sentence. A ”negative evaluation“ is a use of a negative word in an affirmative sentence, or a use of a positive word in a negative sentence.

Table IV shows the total number of positive and negative evaluations for each guitar of the playing test (G3, G4, G5 and G6).

The evaluations of BASS, BRIGHTNESS, SUSTAIN, (LOW-,HIGH-) MIDDLE, AGGRESSIVENESS in Table IV exhibit individual behaviour of each guitar. The own characteristics of each guitar taken separately can be identified easily and accurately with the discourse analysis, and not — by definition — with the categorisation task/analysis. For example, it clearly appears that G5 and G4 have the best sustain (more than 80% of positive evaluations about the meta-criterion SUSTAIN), or that G4, G5 and G6 have a lot of brightness and high-frequency content (more than 80% of positive evaluations about the category BRIGHTNESS) according to the guitar players. These five categories of criteria are nevertheless not relevant for discriminating ebony- and rosewood-fingerboard guitars: they may exhibit guitar groupings that do not fit the fingerboard wood criterion (e.g. G5 and G6 have more than 70% of negative evaluat ions about the criterion BASS and could be told apart from the group including G3 and G4, which have more than 50% of positive evaluations for the same criterion).

Two meta-criteria seem to be more relevant to distinguish the two types of guitar. The evaluation of the BALANCE indicates clearly that the two ebony-fingerboard guitars are judged as having a better balance (both guitar have more than 75% of positive evaluations). For the rosewood-fingerboard guitars, the consensus appears to be weaker: the negative judgements about the balance of G4 and G6 are of the same order as positive judgements. The evaluation of the ATTACK (words describing the response of the instrument to the gesture of the player's right hand; a good guitar in terms of attack is typically described as (subject 7) *if I give it a strong attack it plays strong, if I give a soft attack it plays softly*, "si je l'attaque fort elle joue fort, si j'attaque doucement elle joue doucement") shows the same tendency, but somewhat clearer. Ebony-fingerboard G3 and G5 undoubtedly have more positive evaluations of ATTACK (more than 75%), whereas rosewood-fingerboard G4 and G6 spark off roughly as many positive as negative evaluations.

PRECISION is the meta-criterion allowing to make the clearest distinction between ebony and rosewood. It clearly appears that ebony-fingerboard guitars concentrate the positive judgements about PRECISION (more than 80% of positive evaluations), and that negative judgements are rather the prerogative of the rosewood-fingerboard guitars (more than 70% of negative evaluations).

Ebony-fingerboard guitars' precision is evaluated as being better: (subject 5) *more precise, one will hear all* [the notes] *distincly, the harmonics are highlighted, and the notes stand out one from another* ("plus précis, on va entendre tout distinctement, il y a les harmoniques qui sortent, et les notes se détachent plus les unes des autres"). The precision of ebony fingerboard enhances the definition of notes playes simultaneously: (subject 5) *it is immediately a bit more precise when one plays richer chords* ("c'est tout de suite un peu plus précis quand on fait des accords plus riches"). Ebony fingerboard may also change the distorted sounds: (subject 1) *if one plays a saturated guitar, it* [the sound] *won't dribble wild* ("si on met une guitare saturée, ça va pas baver dans tous les sens").

But the "negative" judgements should not be considered as stating that rosewood fingerboard guitars are worse than ebony fingerboard. Rosewood-fingerboard guitars just exhibit another aspect of the attribute PRECISION: (subject 5) *it is warmer because it* [the notes, the sound] *just blends better, therefore there is an aspect it smoothes the rough edges, but as a result it blends and there is less precision* ("c'est plus chaud parce que justement ça se mélange mieux, donc il y a un côté ça arrondit un peu les angles, mais du coup ça se mélange et il y a moins de précision"). Precisely because of its "lack" of precision, a rosewood-fingerboard may add some warmth (hence, after Tables II and III, body and roundness) in the sound while the notes merge together in a more complex combination, producing a sound result that might fit some artistic wills.

Note that during the playing task only, subject 5 has been able to assert that two guitars have a rosewood fingerboard and the two others an ebony one. This happened at the middle of the playing task, and the assertion was justified by considerations about the PRECISION. Subjects 1, 2, 3, 5, 7, 9 and 10 found some commonalities along some meta-criteria between the two ebony-fingerboard and between the two rosewood-fingerboard guitars. The other guitarists contributed anyway in a valuable way to the overall evaluation of the guitars according to the meta-criteria.

5. Discussion

As the linguistic analysis showed, the judgements on guitars refer either to the sound or to the interaction between the guitar and the player. This section discusses these differences between the objects of the judgements and finds that they are related to the experimental methods.

5.1. The sound

The categories from the listening task group together stimuli according to judged similarity in the sound[3]. However, the tree categories (and the individual categories) did not show clusterings corresponding to the fingerboard woods: guitarists focused on sound attributes that might not be appropriate to tell ebony from rosewood.

Among the categories of attributes dealing with the sound as found in section 4.2, only those labelled PRECISION and BALANCE are relevant for the characterisation of the fingerboard wood. But their evaluation may depend on the own way of playing of the guitarist who recorded the stimuli of the listening task: his attack of notes and chords (PRECISION) produced dynamics (ATTACK) and spectral content (BALANCE) that are not controlled by the listeners. In a listening test, the guitarists then evaluate not only the sound, but also the sound "as produced by another guitarist", that is the sound and the recorded player. We think

[3] Only 3 out of 81 comments mentionned a performance-related judgement.

that an increased accuracy in the judgement of the instruments is reached with the playing task, where the player interacts himself with the guitar.

5.2. The musician-instrument interaction

Judgements exclusively based on listening necessarily miss the interaction between the guitarist and the guitar. For example, if judgements about the *attack* are given in the listening task (Figures 7 and 8), they may either refer to the sound and depict its high-frequency content, or to the way the player that recorded the excerpts once played. But they may not refer to the way the guitar responds to pick strokes, as experienced when playing. In a playing task, the guitar player recovers the following abilities (amongst others):

- his sense of touch. Note that during the playing task, no guitar player spoke about any potential difference in the digital sensations he could have had with the two different wood species (players either did not perceive any difference in wood surface or did not find this criterion relevant during the playing task);
- his interaction with the instrument,
- his control on the production of sound,
- his possibility to produce the particular sound he wishes to hear.

This interaction with the instrument lets the guitarist produce other evaluations of the criteria in such a way that more accurate judgements are given. This makes possible the discrimination between ebony and rosewood.

6. Conclusion

This study provides answers to the questions raised in section 1. The central question of this article is clearly answered: different electric guitar fingerboard woods produce differences that are actually perceived by the guitarists when they play.

Even if it conceptually fitted the leading hypothesis of this study (ebony and rosewood as two clearly distinct groups), the categorisation task forced the musicians to group guitars. It turned out to be not adjusted to the judgements of the musicians, who consider each guitar as a singular item. The listening test also showed some limitations: the musical performance, including the choice of sound, attacks, tempo, etc., is imposed and the guitar player loses control on the instrument and then misses some features allowing him to evaluate the guitars. A playing test can give back to the guitar players the faculty to evaluate the instruments in a more accurate way.

Features of similarity can emerge from individual descriptions of the guitars. This monadic description is allowed by the playing and verbalisation task. Based on a series of possibly inter-linked meta-criteria, the evaluations of the guitars are eventually more accurate in playing situation. The psychological descriptors that appeared to be particularly relevant for the discrimination between ebony and rosewood are the PRECISION (each note stands out from other and do not blend with them), and to a lesser extent the ATTACK (the way the guitar responds to the musician's gesture) and the BALANCE (between high, middle and low frequencies). Surprisingly, even if it is often supposed [2], the *sustain* was not a prominent criterion in the evaluation of the electric guitars of this study: although the criterion was used by guitarists in the present study, some other criteria were found to be more relevant.

Clues are given to answer the question of the use of the psychological descriptors as hypotheses for a mechanical study: mechanical variations among the fingerboard woods produce changes in the sound's PRECISION that are relevant to the musicians. This will be the main purpose of the following of this work. In order to supply useful information to the guitar players and makers, focusing on this PRECISION parameter is essential.

According to the identified meaning of the PRECISION (the notes do not blend), an attempt would be to analyse the audio signals from the guitars in the light of audio descriptors. In the context of this study about the solid body electric guitar fingerboard, this could link perception to acoustics. Psychophysical studies are now firmly calibrated and can be used to further investigate these audio descriptors. It is now possible to focus on criteria (*e.g.* the PRECISION) that are relevant to guitar players, as it is done for other instruments [36, 37]. Provided that the perceptive attribute is dimensional (this remains to be validated: is there different degrees of PRECISION? Can guitars be ranked according to their amount of PRECISION?), one can for example think about doing sound synthesis for the investigation of perception thresholds of PRECISION [38, 39], or the investigation of ratin g on semantic scales (e.g. *messy* versus *precise*) [40], using various existing methods [41].

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