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Influence of the player on the dynamics of the electric guitar

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1 The sound of the electric guitar is strongly dependent on the string vibration. Where
2 a mode of the structure coincides with a mode of the fretted string, coupling between
3 the string and structure occurs at that "deadspot." The coupling significantly lowers
4 decay time, leading to the name (Paté *et al.*, 2014). But how the guitarist affects
5 the dynamic behavior of the structure by grasping the neck, holding the instrument
6 with the strap, or laying the instrument on his/her thigh remains to be investigated.
7 This is the aim of the paper. Two methods are proposed to identify the modal
8 parameters of the electric guitar structure, either by a classical modal analysis in
9 simulated playing configuration, or by an operational modal analysis (OMA) in real
10 playing configuration. For this latter method, modal parameters are identified from
11 dynamic measurements performed when each string is plucked. Both methods are
12 compared and allow us to quantify the modal frequency modification and the added
13 modal damping, that depend on the player's body-part in contact with the structure
14 and on the modal shape considered. Consequences of these modal parameters on the
15 modeled sound show that the player can increase the decay time close to a deadspot.

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16 I. INTRODUCTION

17 The sound of the electric guitar comes from the conversion of the mechanical vibration
18 of the string into an electric signal. Consequently, the sound does not seem to depend
19 on the mechanical properties of the guitar body. However, in the general case of stringed
20 musical instruments, the modal parameters of the instrument body may affect the vibration
21 of the string. While there are few studies on the electric guitar, much research on violin
22 and acoustic guitar dealt with coupling phenomena in the case of the violin or the guitar.
23 For example, Gough ([Gough, 1980](#); [1981](#)) studied the coupling between the string and the
24 body using an analytical model in the case of the wolf-note phenomenon that appears in
25 the violin. Woodhouse ([Woodhouse, 2004a](#); [b](#)) proposed several sound synthesis methods
26 and underlined the connection between the modal parameters of the acoustic guitar body
27 and the sound of the instrument. More recently, Benacchio et al. ([Benacchio et al., 2016](#))
28 experimentally demonstrated the importance of the modal parameters of the guitar body in
29 the sound of the instrument using active modal control. In the case of the electric guitar,
30 body-coupling may also, in some cases, affect the string vibration, mostly when there is
31 a frequency coincidence between string and body modes. Paté et al. ([Paté et al., 2014](#))
32 showed that the decay time of solid body electric guitar tones is due to the combined action
33 of string's intrinsic damping and coupling-induced damping. It was notably shown that for
34 the electric guitar, this coupling mainly occurs at the neck ([Fleischer and Zwicker, 1999](#);
35 [Paté et al., 2014](#)). However, in the classic way of playing the electric guitar, ergonomic
36 studies ([Marmaras and Zarboutis, 1997](#)) showed that the left-hand palm holds the neck and

37 the left-hand finger presses the string against the fingerboard. Thus, the left hand may have
38 consequences on the neck vibration. Similarly, the player's body (e.g. stomach, thigh) is in
39 contact with the body of the instrument and may also modify the instrument's vibration. In
40 order to measure these effects, previous studies used simulated playing configuration while
41 the instrument was excited by a classical system. For the electric guitar, the experimenter
42 held the neck, on which the shaker is fixed, puts the instrument on his knees, and the left
43 hand grasped the neck (Fleischer, 2005; Fleischer and Zwicker, 1998· 1999). For the violin,
44 excited by an impact hammer, the experimenter held the instrument between his chin and
45 his shoulder in a "usual manner" (Marshall, 1986). Results of these first studies clearly
46 show that the player increases the damping of the structure depending on the mode. But
47 this experimental methodology is quite far from a real playing posture. However, musical
48 instruments contain their own excitation system that can be used to identify their modal
49 basis with Operational Modal Analysis method (OMA), as performed recently on a concert
50 harp (Chomette and Le Carrou, 2015).

51 The aim of this paper is to identify the modal basis of the electric guitar when it is
52 played in order to quantify the influence of the player on the dynamic behavior of the
53 electric guitar structure. The operational modal analysis is presented in Section II. The
54 experimental method is proposed in Section III. Results are shown in Section IV and a
55 discussion highlighting the influence of the player both on the electric guitar vibration and
56 on the sound of the instrument is given in Section V.

57 **II. OPERATIONAL MODAL ANALYSIS IN TIME DOMAIN**

58 The aim of the Operational Modal Analysis (OMA) is to identify modal parameters
 59 using only measured data without knowing the excitation. In the case of an unknown
 60 impulse response, OMA methods can use the Linear Square Complex Exponential (LSCE)
 61 algorithm introduced by Brown et al. (Brown *et al.*, 1979). In this method, the time
 62 response of a structure $h_{ij}(k\Delta t)$ at the k th time sample Δt located at point i due to an
 63 impulse located at point j can be expressed as the summation of N decaying sinusoids whose
 64 frequency and damping ratio are associated to the r th structural mode

$$h_{ij}(k\Delta t) = \sum_{r=1}^N \frac{\phi_{ri} A_{rj}}{m_r \omega_r^d} e^{-\xi_r \omega_r^n k \Delta t} \sin(\omega_r^d k \Delta t + \theta_r), \quad (1)$$

65 where ω_r^n and $\omega_r^d = \omega_r^n \sqrt{1 - \xi_r^2}$ are the non-damped and damped frequency respectively.
 66 ξ_r is the damping ratio. ϕ_{ri} is the i th component of the r th mode. A_{rj} , m_r^d and θ_r are a
 67 constant associated to the j th response signal, the r th modal mass and the phase angle of
 68 the r th modal response respectively. The impulse response can also be written numbering
 69 all complex modes and poles including conjugates from $r = 1$ to $r = 2N$

$$h_{ij}(k\Delta t) = \sum_{r=1}^{2N} C_{rij} e^{s_r k \Delta t}, \quad (2)$$

70 where C_{rij} is the complex amplitude of the r th mode for the i th input and the j th output.
 71 The poles $s_r = \omega_r^n \xi_r \pm j \omega_r^d$ associated to the modes of the structure appear in complex
 72 conjugate form. Consequently the complex exponentials $V_r = e^{s_r \Delta t}$ are the roots of the
 73 polynomial Prony's equation of order $2N$

$$\beta_0 + \beta_1 V_r^1 + \dots + \beta_{2N-1} V_r^{2N-1} + V_r^{2N} = 0, \quad (3)$$

74 with $\beta_{2N} = 1$. By multiplying equation 2 by β_k and sum over $k = 0 \dots 2N$, equation 3 gives

75

$$\sum_{k=0}^{2N} \beta_k h_{ij}(k\Delta t) = 0. \quad (4)$$

76 By writing $2N$ times equation 4 starting at successive sample times, the coefficients β_k

77 are the roots of a linear system. In practice, the system is overdetermined to increase the

78 robustness of the method and is thus solved using the least square method. The poles are

79 finally obtained using

$$s_r = \frac{1}{\Delta t} \left(|V_r| \pm j \arg(V_r) \right), \quad (5)$$

80 where \arg denotes the argument of the complex poles. In practice, the stable poles are

81 automatically extracted using a stabilization chart (Chomette and Mamou-Mani, 2018).

82 This diagram is based on several runs of the pole identification process by using models

83 of increasing order N . Physical poles always appear around the same frequency whereas

84 mathematical poles tend to span the whole frequency range. The typical stabilization criteria

85 are chosen as equal to 1% for the frequency and 5% for the damping. Poles are considered

86 to be stable if their identified frequency and damping do not exceed these values between

87 two successive runs at order n and $n + 1$.

88 In the case of a white noise excitation, OMA methods can be based on the Natural

89 Excitation Technique (NExT) introduced by James et al (James et al., 1995). If damping

90 is small, the main assumption of the NExT method is that the correlation function between

91 two sensors located at points i and j can be written as the impulse response function located

92 at point i due to an impulse at point j . Using the correlation function, the method is then

93 similar to the LSCE method. In the case of string instruments, Chomette and Le Carrou

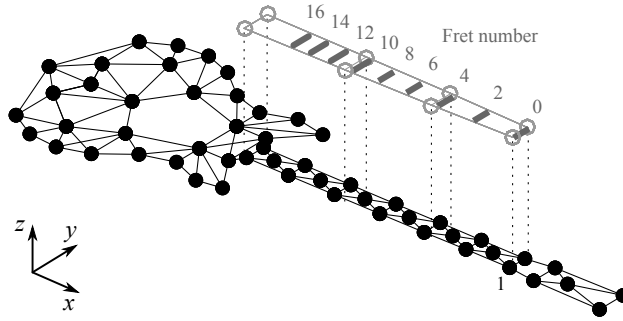


FIG. 1. Two meshes used in the study: 54-point on the whole electric guitar (black) on which point label 1 is shown and 8-point on the neck (gray) on which Frets 0 to 16 are shown.

94 (Chomette and Le Carrou, 2015) have shown that the NExT-LSCE method can be applied
 95 successfully for a plucked string instrument: the concert harp. Indeed, the excitation induced
 96 by a string on the instrument can be considered as a sum of damped harmonic components.
 97 If the harmonic frequencies of the string are well separated from the eigenfrequencies of
 98 the structure, modal parameters can be easily identified. If the harmonic frequencies of
 99 the string are close to the structural mode frequencies, modified methods must be used
 100 (Marshall, 1986; Mohanty and Rixen, 2004).

101 III. EXPERIMENTAL METHOD

102 In order to identify the modal parameters of the electric guitar, two methods are per-
 103 formed: a classical modal analysis and an operational modal analysis (OMA). For the former,
 104 one or a few accelerometers are glued on the guitar while an impact hammer successively
 105 hits different points of the experimental mesh. The classical analysis is performed on the
 106 54-point and the 8-point meshes shown in Figure 1, whereas for the OMA only the 8-point

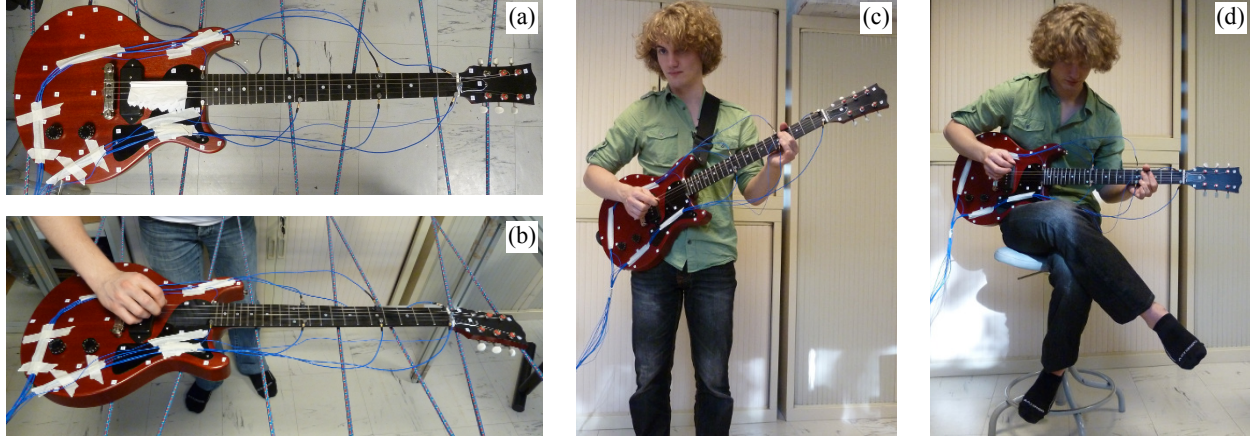


FIG. 2. Experimental configurations for classical modal analysis when the electric guitar is free to vibrate with damped strings (a) and for operational modal analysis in free-free configuration (b) and when the player is standing (c) or sitting (d).

107 mesh is used. For the classical modal identification, the Least Square Complex Frequency
 108 (LCSF) algorithm (Guillaume *et al.*, 2003) (implemented in *Modan* software) is used. For
 109 the OMA, the 8-point mesh is composed of eight accelerometers (PCB M352C65) glued on
 110 the neck and another one (PCB 352B10) is moved on the symmetrical axis close to the
 111 played fret as shown in Figure 2-(a). This latter accelerometer provides the reference signal
 112 for the OMA identification. Note that the location and the size of the eight accelerometers
 113 do not allow the first and the sixth string to be mounted on the guitar. Throughout this
 114 study, 1d-accelerometers were used, so that only out-of-plane (vertical, i.e. perpendicular to
 115 the fingerboard plane) accelerations are measured and shown in this direction only in the
 116 following.

117 In order to quantify the dynamical modification of the instrument when playing, three
 118 configurations are tested: with sitting or standing player (i.e. two usual playing configu-

119 rations) and with nobody touching the instrument. For the first two configurations, the
120 right-handed player holds the electric guitar with the strap or lays it on his right thigh. For
121 both configurations, the left hand holds the neck and a finger presses the string on the fret
122 to set the vibrating length of the string, as shown in Figures 2-(c) and 2-(d). The last con-
123 figuration is used as a reference by laying the electric guitar on elastic straps supported by
124 a frame as to simulate free-free boundary conditions (Paté, 2014), as shown in Figure 2-(b).

125 For the OMA, the player is asked to play several notes along 4 strings (A_2 , D_3 , G_3 and B_3 -
126 string). The left-hand middle finger presses the string against the fingerboard successively
127 at frets 2 to 16 every two frets. At the nut (denoted F0), the left hand does not hold the
128 neck. The other strings are blocked with the other fingers of the left-hand (this is a common
129 practice for guitar players). All fundamental frequencies of each note played are gathered
130 in Table I.

131 IV. RESULTS

132 A. Classical modal analysis

133 1. *Free-free configuration*

134 A classical modal analysis of the complete electric guitar was performed by using an LSCF
135 method as previously explained. Until 500 Hz, 6 modes are identified. Their modal shapes
136 are displayed in Figure 3. First, two kinds of mode are present: global (1) and local modes
137 (2 to 6) with only neck displacement. Second, among these modes, two are perfect bending

Fret	String 5	String 4	String 3	String 2
0	110.00 (A ₂)	146.82 (D ₃)	196.00 (G ₃)	246.94 (B ₃)
2	123.47 (B ₂)	164.81 (E ₃)	220.00 (A ₃)	277.18 (C# ₄)
4	138.59 (C# ₃)	184.99 (F# ₃)	246.94 (B ₃)	311.12 (D# ₄)
6	155.56 (D# ₃)	207.65 (G# ₃)	277.19 (C# ₄)	349.23 (F ₄)
8	174.61 (F ₃)	233.08 (A# ₃)	311.13 (D# ₄)	391.99 (G ₄)
10	196.00 (G ₃)	261.62 (C ₄)	349.23 (F ₄)	440.00 (A ₄)
12	220.00 (A ₃)	293.66 (D ₄)	392.00 (G ₄)	493.88 (B ₄)
14	246.94 (B ₃)	329.22 (E ₄)	440.01 (A ₄)	554.36 (C# ₅)
16	277.18 (C# ₄)	369.99 (F# ₄)	493.89 (B ₄)	622.25 (D# ₅)

TABLE I. Fundamental frequency in Hz and name of played note for each string and each fret.

138 modes (1 and 6), two are perfect torsional modes (2 and 5) and two are a combination of
139 bending and torsion which are modes 3 and 4.

140 2. *Simulated playing configuration*

141 A first approach to quantify the player's impact on modal parameters of the electric guitar
142 is to carry out a classical modal analysis on an electric guitar. The guitarist then mimics
143 a playing situation on an instrumented guitar with accelerometers glued on the fingerboard
144 whereas an impact is provided by the hammer close to the nut (on point 1, see Figure 1).

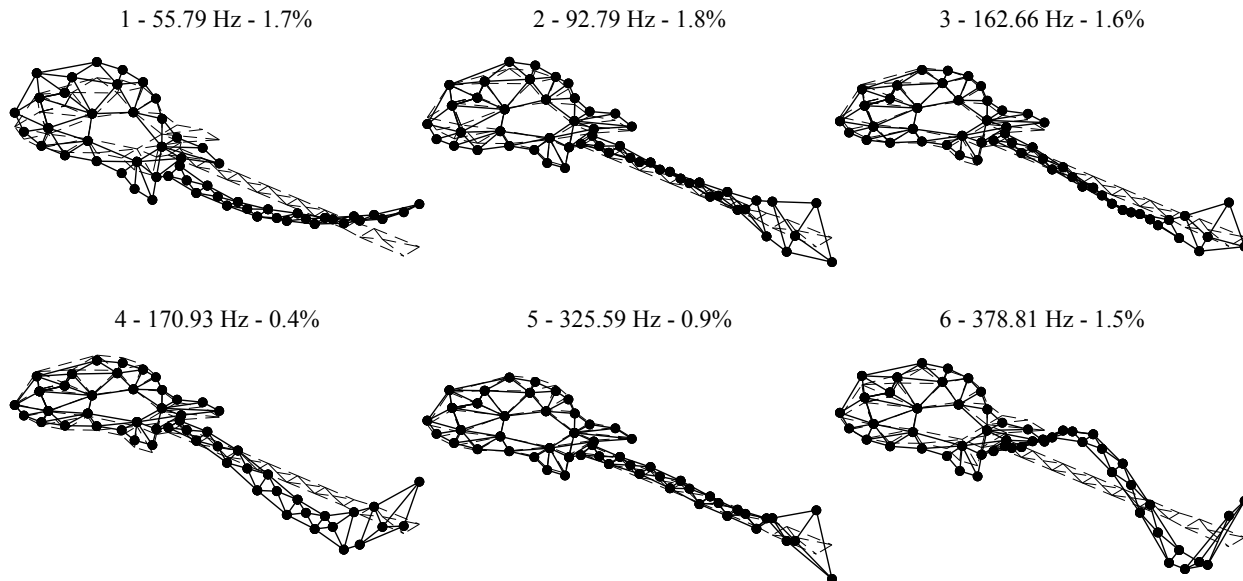


FIG. 3. Modal frequencies, modal damping and modal shapes of the electric guitar in free-free configuration. Dashed lines represent the mesh at rest position, black dots connected by solid lines represent the deformation corresponding to the modal shape.

145 Results are synthesized in Figure 4 showing each co-localized FRF measured for each left-
 146 hand position. In addition, the FRF in free-free condition is also plotted highlighting modes
 147 4 and 6 to be particularly present in the instrument's response. Modal parameters for modes
 148 4 and 6 are gathered in Figure 7.

149 Results clearly show that holding the electric guitar or letting it lie globally affects the
 150 damping of the electric guitar in a similar way for the two player positions. In details, this
 151 modification depends on the left-hand position along the neck. Mode 4 is more affected
 152 when the guitarist's hand is close to the neck head than mode 6, for instance. The closer
 153 the left-hand to the anti-node of the mode, the higher is the damping. Between the two
 154 configurations, subtle differences can be seen in terms of damping, especially for mode 4.

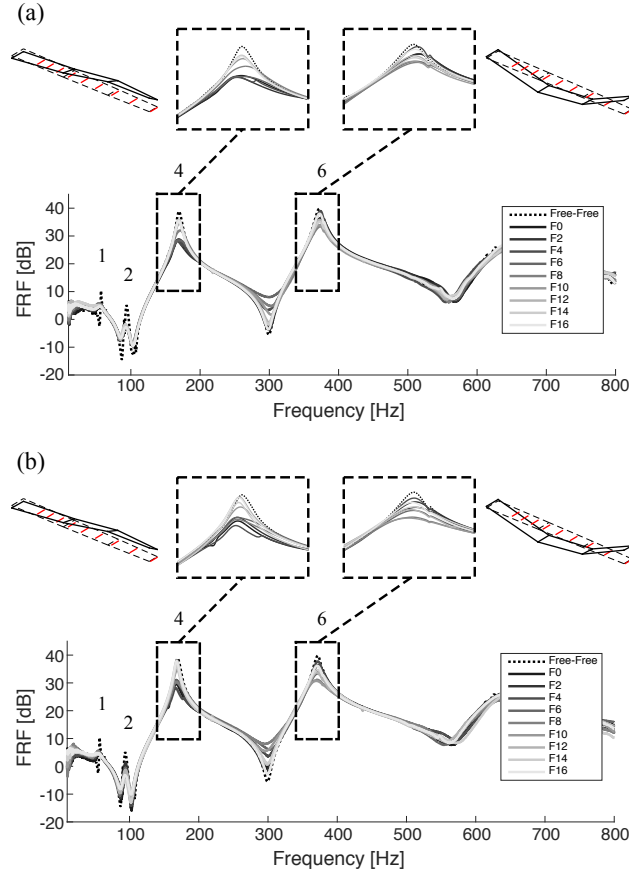


FIG. 4. Co-localized FRF measured at point 1 of the mesh (see Fig. 1) for sitting (a) and standing configurations (b). Numbers refer to mode numbers in Figure 3. FRFs are magnified around the frequency of modes 4 and 6 (corresponding modal shapes are also plotted).

155 Modes 1 and 2, whose displacement amplitude at point 1 is already low, are also affected
 156 by the left hand position along the neck, adding some damping and lowering the FRF
 157 amplitudes even more. Note that modes 3 and 5 are not visible in the co-localized FRF,
 158 as for these modes the displacement amplitude at point 1 is much lower than for the other
 159 modes, as shown in Figure 3.

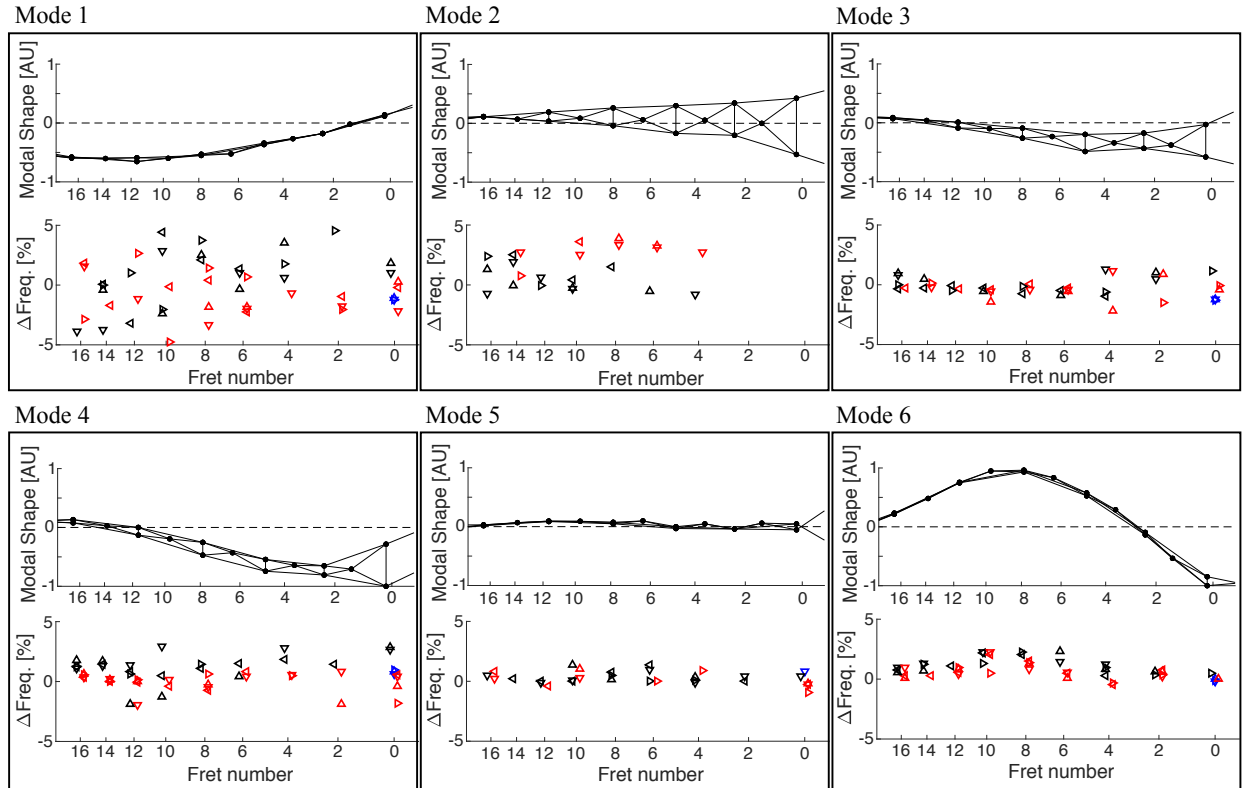


FIG. 5. [Color online] Frequency deviation identified by the OMA. For each mode, Δ Freq. is the frequency deviation, in percentage, from the modal frequency identified by the classical method (see Table 3). The results for standing player are plotted in black and for sitting player in red whereas the free-free configuration is plotted in blue. Different markers are used for the identification results on each plucked string: A2-string with \triangleleft , D3-string with ∇ , G3-string with \triangle , B3-string \triangleright . Dashed lines represent the mesh at rest position, black dots connected by solid lines represent the deformation corresponding to the modal shape on the xz -plane.

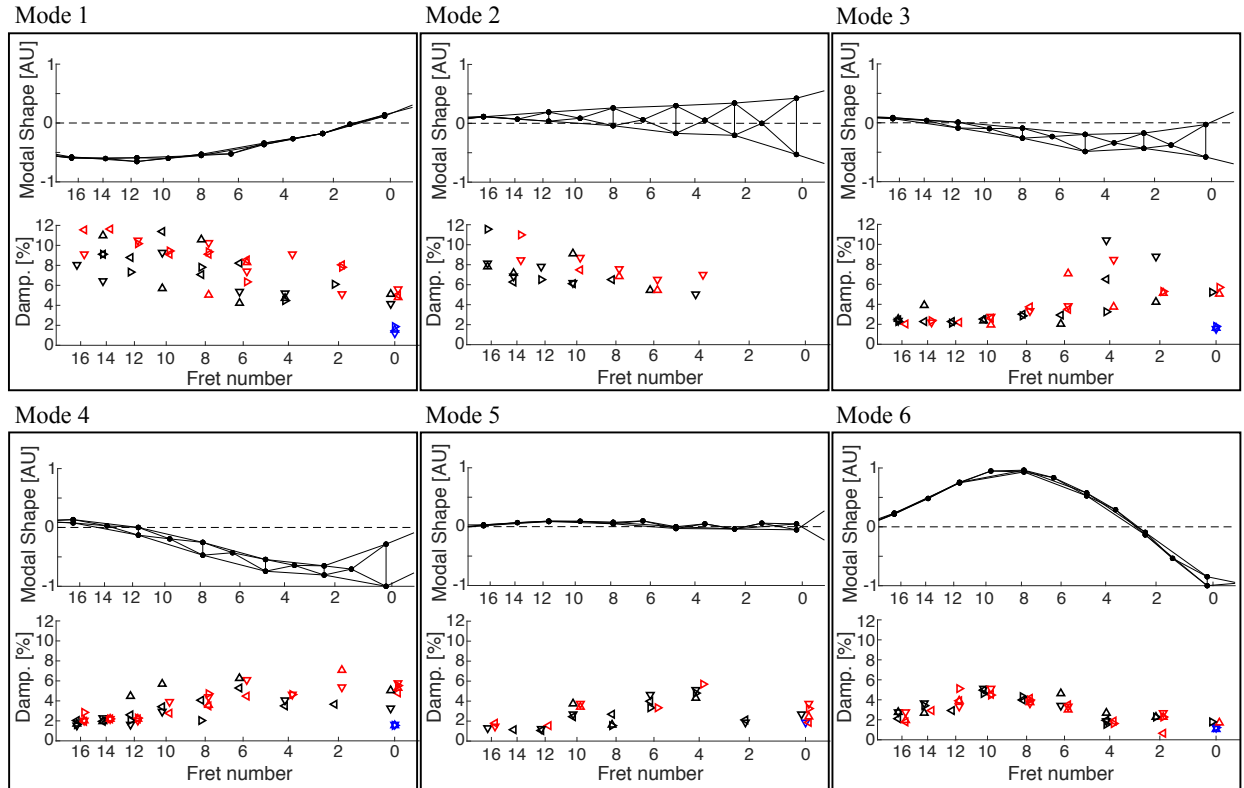


FIG. 6. [Color online] modal damping identified by the OMA. The results for standing player are plotted in black and for sitting player in red whereas the free-free configuration is plotted in blue. Different markers are used for the identification results on each plucked string: A2-string with \triangleleft , D3-string with ∇ , G3-string with \triangle , B3-string \triangleright . Dashed lines represent the mesh at rest position, black dots connected by solid lines represent the deformation corresponding to the modal shape on the xz -plane.

160 B. Operational Modal Analysis

161 1. Free-free configuration

162 The OMA is applied on response signals measured on the electric guitar neck for four
 163 strings. In order to test the method, the OMA is first performed on an electric guitar on

164 free-free conditions. For each of the four strings plucked, most of the modes are identified.
165 Figure 5 and Figure 6 show modal frequency deviation and modal damping, with a marker
166 for each string, and in blue for the free-free measurement at the nut (fret 0). Blue markers
167 are generally superimposed, showing that OMA for structural modes of the instrument do
168 not depend strongly on which string is used for the excitation and, therefore, a perfect
169 reproducibility of the method. Moreover, modal frequency and damping are found to be
170 very close to those of the classical modal analysis in comparison to previous results obtained
171 for a concert harp (Chomette and Le Carrou, 2015). Note that for torsional modes, no
172 physical poles are found for mode 2 and only one with D3-string for mode 5 by the OMA
173 algorithm. These modes seem to be not well excited by the strings contrary to bending
174 modes.

175 2. *Playing configuration*

176 The OMA is then applied on accelerometer measurements when the electric guitar is
177 played by a person standing or sitting. Modal frequency deviation and damping for all
178 left-hand positions along the neck and for all player configurations are gathered in Figures 5
179 and 6 for the first six modes. On these figures, the color of the marker defines the player's
180 configuration, "standing" in black and "sitting" in red, and the markers' shape indicates
181 which string was played for the OMA identification. In order to facilitate the interpretation
182 of the modal frequency deviation and damping, the modal shape of each mode is also shown
183 according to the neck cross-section on xz -plane (see Figure 1) between the 16th fret and the
184 nut.

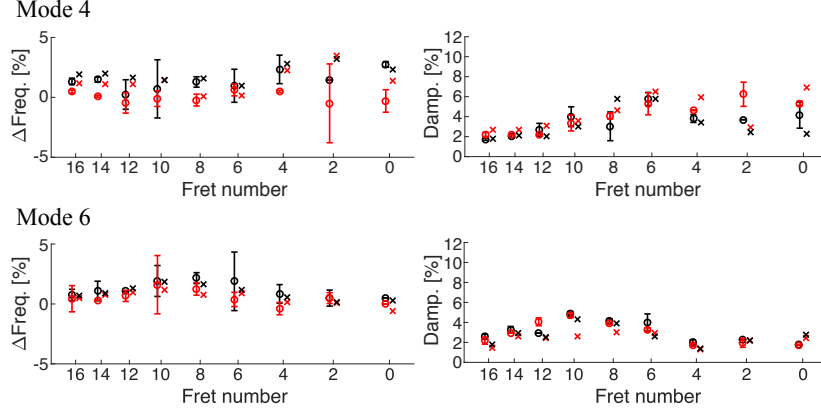


FIG. 7. [Color online] Comparison between modal frequency deviation (Δ Freq.) and modal damping identified by the OMA (circles) and by the classical modal analysis (crosses) for standing (black) and sitting (red) player. For OMA, the circles are the mean value of 4 measurements (on 4 strings) and the error bars show the expanded uncertainty with 95% confidence.

185 All modes are well identified by OMA with each of the four strings as an excitation.
 186 Some modes are however better identified than others, and this is due to a) the string/neck
 187 coupling point location with respect to the modal shape, b) the fact that torsional modes
 188 are generally excited less than bending modes. Modal frequencies are then found close to
 189 modal frequency in free-free condition by OMA or classical modal analysis with a variation
 190 less than 5% for modes 1 and 2 and less than 2.5% for modes 3 to 6. This small impact of
 191 the player on the modal frequencies has already been noted for local modes on an electric
 192 bass (Fleischer, 2005). The variation range across frets in modal frequency and damping i)
 193 depends on the mode, and ii) is much higher than for free-free conditions.

194 V. DISCUSSION

195 But more generally, the variation of modal damping with the note played (pressed fret)
196 seems to exhibit a systematic behavior. This evolution is found to be directly linked to the
197 modal shape: the wider the mode shape displacement is at fingering location, the higher the
198 damping is. When the player's left hand is close to a node of the mode shape, the modal
199 damping is little affected as shown for mode 3, frets 10 to 16, or for mode 4, fret 14 or mode
200 6 frets 2 and 4. Neck modal dampings are modified by the hand grasping the neck and
201 the finger pressing the fingerboard, only if the modal displacement is large enough at the
202 fretting point. For mode 1, the guitar's body has a significant displacement. Therefore, for
203 this mode, the stomach touching the body acts as an additional dashpot. That might be
204 why, for mode 1, the modal damping in playing configuration is found to always be higher
205 than the modal damping without player (classical modal analysis) at about 5% for fret 0
206 (close to the modal node). Note that for a sitting configuration, the thigh also touches
207 the guitar's body and increases the damping for this mode. Given the increased number
208 of player/instrument contact points, this player configuration does not generally imply a
209 higher damping than when the player is standing, as these contact points (see Figure 2-(d))
210 are close to a nodal line of mode 2 (see Figure 3).

211 Concerning the additional stiffness brought by the left-hand and the strap, a detailed
212 analysis of the modal frequencies identified by OMA can provide answers. Indeed, at fret
213 0, the player does not press the string on the fingerboard. Therefore, the increase in modal
214 frequency is only due to the constraint applied by the strap on the guitar body. For the

215 other frets, when the fingers act on the neck close to a node, modal frequency is found
216 to be higher than for the sitting player (see, for instance, Fret 2 of Mode 1 or Fret 14
217 and 16 for mode 4), confirming that the strap brings an additional stiffness at the body in
218 playing configuration. When the finger presses on the fretboard close to an anti-node, no
219 systematic and significant modal frequency evolution is found with respect to the free-free
220 configuration for modes 1, 3, 4, and 6. Torsional mode 2 shows a noteworthy separation
221 between modal frequencies for each playing configuration. Modal frequencies are higher
222 when the player is sitting than when standing. This could be due to changes in grip force
223 between these two configurations. Grip force is presumably higher when the strap does not
224 hold the guitar (sitting configuration, compared to standing configuration with strap). We
225 previously encountered the same modal frequency evolution for torsional modes of more or
226 less strongly held tennis rackets (Chadefaux *et al.*, 2017). This interpretation is consistent
227 with what the player felt during the experiment. For this particular mode, the left-hand
228 seems to bring some additional stiffness at the neck.

229 In this paper, two methods are used to identify the modal parameters of the electric guitar
230 when playing: in real and in mimic situations when the player is sitting or standing. In order
231 to compare them, modal parameters for modes 4 and 6 are plotted in Figure 7. OMA results
232 are gathered, for each fret, as the mean value of the frequency and of the damping computed
233 from those identified from the 4 strings plucked, as shown in Figures 5 and 6. In Figure 7,
234 error bars indicate the dispersion of the results and show, to some extent, that the dynamic
235 behavior of the instrument also exhibits a variability that depends on all the contact points
236 between the instrument and the player (hand-instrument neck, stomach-instrument body,

237 high-instrument body). On the whole, the results obtained by the two methods are found
238 to be very close. In order to have a global estimation of the influence of the player on the
239 modal parameters of the instrument, the mimic situation with a classical modal analysis can
240 be a good approximation.

241 Getting back to sound, we recall that if the electric guitar is heard through a loud-
242 speaker, the sound originates in the mechanical vibration of the string (sensed by the
243 magnetic pickup). The string is attached to the instrument at both ends. In other words
244 string and structure are coupled and the string's modal parameters are modified by the
245 presence of the structure (Fleischer and Zwicker, 1998; 1999; Paté *et al.*, 2014). Former
246 studies showed that the string's modal dampings (much more than the frequencies) depend
247 on the conductance (real part of the admittance) measured at the string/structure contact
248 point on the neck (much more than on the bridge). When some string and structure frequen-
249 cies come close to one another, the corresponding string partial gets abnormally damped
250 (Paté *et al.*, 2014). This results in timbre changes (if string partials are damped) or decay
251 times strong reduction (if fundamental frequency is damped). The latter phenomenon is
252 also called "dead spot", and should be avoided (by e.g. detuning the string or modifying
253 the structure in order to push the frequencies further apart). (Fleischer and Zwicker, 1998;
254 1999) characterized dead spots with the "T30" (time needed by the signal to decrease by
255 30dB from its maximum level). In order to predict dead spot occurrences, (Paté *et al.*,
256 2014) proposed a sound synthesis model for the computation of the T30 that we reuse here.

257

258 The synthetic string signal is computed for G3 string from fret 0 (nut) to fret 16 every
 259 two frets (in order to correspond to the points of vibratory measurement) as a sum of
 260 quasi-harmonic damped sinusoids:

$$s(t) = \sum \frac{\sin(2\pi f_n t)}{n} e^{-2\pi f_n \xi_n t}, \quad (6)$$

261 where (see Equation 22 in (Paté *et al.*, 2014)):

- 262 • the amplitude of the fundamental component is set to 1 and the amplitude of rank- n
 263 partial is $\frac{1}{n}$;
- 264 • string modal dampings ξ_n are the sum of isolated string dampings $\xi_{0,n}$ (measured
 265 in (Paté *et al.*, 2014), e.g. Figure 5) and additional damping due to the structure
 266 $\xi_{struct,n} = \text{Re}[Y] \frac{c^2 \rho_L}{2\pi L f_n}$, where Y is the driving-point admittance (defined below), where
 267 c is the wave velocity in the string, L is the vibrating length (changing for each fret),
 268 ρ_L the string's mass per unit length (see Equation 20 in (Paté *et al.*, 2014));
- 269 • the frequency of rank- n partial f_n equals $\frac{nc}{2L} \left[1 + \frac{n^2 \pi^2 EI}{2L^2 T} + \frac{\sqrt{\rho_L T}}{n\pi} \text{Im}[Y] \right]$, that is a stiff
 270 string model connected to a mechanical admittance, E is the Young's modulus of
 271 the string's material, I the string's second moment of area, T the string tension (see
 272 Equation 19 (Paté *et al.*, 2014));
- 273 • Y is the driving-point admittance at string/structure contact point, where both ve-
 274 locity and force are measured at the same point. In practice here, this quantity is
 275 synthesized based on a modal fit of measurements done in free-free condition on the
 276 electric guitar structure in which modal dampings are replaced by the modal dampings
 277 measured in Subsection IV B 2 for sitting and standing musician;

278 • the upper limit of the summation is 800 Hz, which is close to the upper limit of the
279 magnetic pickup (for the present pickup 1000 Hz, see (Paté *et al.*, 2014)), and which
280 roughly corresponds to where modal overlap starts to hinder correct identification of
281 modal parameters.

282 For each of these 9 synthetic signals¹ (frets 0 to 16 by steps of 2), the energy decay curve
283 (EDC) is computed using the backwards integration method (Schroeder, 1965), then the
284 T30s are computed from a linear regression on the EDCs. T30 values are shown in Figure 8.

285 T30 ranges from 3s to 8s for free-free configuration, which is in agreement with results
286 obtained for a similar guitar in (Paté *et al.*, 2014). A deadspot appears at fret 12 (lower
287 T30 value), which is due to a coupling between structural mode 6 at around 373.81 Hz and
288 fundamental frequency of note G4 at 392.00 Hz (see Table I). In general, T30 for sitting and
289 standing musician is higher than for free-free configuration. This shows that the sound of
290 the electric guitar may depend on the presence of a musician. However, differences between
291 musicians' standing and sitting positions are very small, suggesting that the position of
292 the musician has very little influence on the sound. When the electric guitar is held by a
293 musician, the structure is damped and the conductance magnitude is lowered, reducing the
294 influence of the coupling: different positions might well reduce the coupling by the same
295 amount.

296 VI. CONCLUSION

297 In this article, we presented an original work studying the influence of the guitarist on
298 the dynamic behavior of the electric guitar structure and, by extension, on the sound of

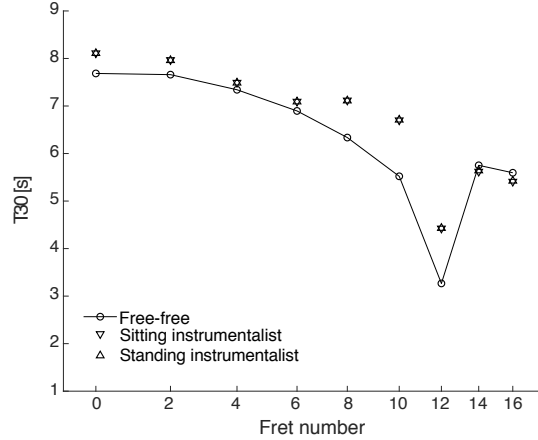


FIG. 8. T_{30} for each measured fret along string G3. Circles, downwards and upwards pointing triangles indicate T_{30} values computed from the synthesized signal for the electric guitar in free-free condition, held by a sitting musician, held by a standing musician respectively.

299 the instrument. Modal parameters, frequency and damping, were derived from accelerom-
 300 eter measurements of the structure when the player plays or simulates to play in different
 301 configurations.

302 As expected, the player damps the structure. But, in details, with his or her left hand,
 303 this additional damping evolves differently along the neck (i.e. at different positions on
 304 the modal shape). When the player is standing, the strap, holding the electric guitar,
 305 applies a constraint that brings an additional stiffness, effective for particular modes, to
 306 the structure. These electric guitar dynamic modifications may have some consequences for
 307 the sound of the instrument. By using a previously developed model, the decay time of
 308 the sound, which is a relevant sound indicator for the electric guitar, is higher in playing
 309 configuration than in free-free configuration, but independent of the guitarist's position. All
 310 these results were obtained by using a specific modal analysis method that is accurate and

311 usable in playing configuration. Although less accurate, a classical modal analysis could
312 be used with a player simulating a playing configuration, in order to estimate with a quite
313 great precision the player's influence on the dynamic behavior of the musical instrument.
314 The OMA approach, for its part, brings subtle variations associated with player-structure
315 interaction, for particular mode and fret combinations.

316 The influence of the player can now be integrated in physically-based sound synthesis
317 algorithms or directly in instruments using active modal control by modifying modal damp-
318 ing or/and modal stiffness. The method developed here can be generalized to other musical
319 instruments, like e.g. the classical guitar or instruments of the string quartet, or other kinds
320 of structures handled by humans such as sport equipments where it is essential to have a
321 knowledge of the dynamic behavior of the object (tennis racket, baseball bat, etc.) when
322 it is held thus modified by the user, so as to quantify the vibration to which the user is
323 exposed.

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328 ¹Note that computation of all f_n 's of these synthetic signals in the frequency range of the study showed that
329 ratios between coupled string frequencies and corresponding isolated string frequencies were consistently
330 less than 1.2 cent, which can not be perceived.

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