From Music to Non-Invasive Therapies via COMSOL Multiphysics® Models

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Abstract: Vibration and Music Therapies are non-invasive treatments having effective results although their basics are still disputed. By the application of COMSOL Multiphysics® modules capacities of modeling and analysis some of the nonlinear physical phenomena laying on these applications may be clarified.
Acoustic environmental stimuli at different intensities are continuously interacting with our bodies, some of them becoming a 'background noise' of our daily life although their intensities are beyond any safety limits.
This study reveals, through few models, the effects of these stimuli on the human body, and the relationship between the surrounding area geometry, acoustic stimuli and human sensitivity. Somehow this could be a invitation to Concert or Music Therapy supported by a detailed COMSOL Multiphysics® analysis.

Keywords: acoustic pressure, nonlinear stimuli, non-invasive therapy

1. Introduction

Either from the exposure to environmental stimuli or from the existing non-invasive medical therapy models [1] there are strong evidences on the effects of Low Intensity Vibrations [2] and low-frequency electromagnetic field [3] on humans, although the mechanism that modulates the cellular responses is still largely unclear.

Having evidences on the meaningfulness of the non-equilibrium processes and about the long range interactions from both electromagnetic field and acoustic field this study aims to design an analytical model able to synergistically corroborate these complex phenomena acting upon and within different human body parts and systems.

2. Model Definition

Within this study there are few models that are correlating or exporting data:

- A *2D Head Model* that contains, for simplification, only: skull (bone), brain (soft tissue), a fluid buffer between the two (water) and thin muscles (soft tissue)
- A *2D Body Model* that considers the contour of a human body (soft tissue) under the effect of the acoustic pressure
- A *2D Opera Hall Model*, and a *3D Opera Hall Model* studying the acoustic pressure distribution within the concert hall, with and without a human on the stage (*2D Body Model*)
- *A 3D Therapy Room Model* having the 3D structure of a human body on a treatment platform armchair

All these models have in common Pressure Acoustics, Frequency Domain with either harmonic or nonlinear variations of the pressure field (Appendix).

For harmonic sound waves, in the frequency domain, each model solves the Helmholtz equation defined in the Pressure Acoustics, Frequency Domain interface [6].

The equations for the acoustic pressure are like Equation 1 and Equation 2, but for all models they are described in Appendix (Models A, B, C, D):

$$\nabla \cdot -\frac{1}{\rho_c}(\nabla p_t - q_d) - \frac{k_{eq}^2 \cdot p_t}{\rho_c} = Q_m \qquad (1)$$

$$k_{ef}^2 = \left(\frac{\omega}{c_c}\right)^2 - k_z^2 \qquad (2)$$

where: ρ_c is the density of the medium (kg/m^3), ω is the angular frequency (rad/s), c is the speed of sound (m/s), p_t acoustic load for unit area (N/m^2), K_{eq} is the wave number for equation and Q_m is monopole source (1/s^2).

The objective of these models is to offer reliable data for Acoustic Therapies Practitioners, Architects designing new concert halls and humans exposed to different linear or nonlinear environmental acoustic pressure intensities.

Considering Music a nonlinear environment acoustic stimulus, all these models may be seen as analyzing the effects of music as a manifestation of the acoustic field pressure on humans. Thus, regardless the usual hearing pathway and ignoring any cultural background these models may offer support for Music and Vibration Therapies.

3. Use of COMSOL Multiphysics

In order to map the effective acoustic density of energy impacting on the different parts of the human body, nonlinear vibration stimuli having average frequencies ranging from 10 Hz to 16 kHz were focused towards a body contour thus simulating some specific environmental exposure condition.

A Human Body, a Human Skull, and an Opera Hall model contour (2D) were imported from SolidWorks® in COMSOL Multiphysics® through the use of LiveLink™ module. As well a 3D Therapy Room with a Human Body and a 3D Opera Hall were defined directly in COMSOL Multiphysics®, Acoustic Module. For the low-frequency electromagnetic radiation the density of energy was considered as a function of the average quantity of energy absorbed in the tissue (SAR) and it was analysed using RF Module and Heat Transfer Module in COMSOL Multiphysics®.

The superposition of field effects were analysed aiming to reach models able to explain the plethora of the associated effects reported on the medical literature, from those values considered able to damage the brain tissue, up to those used on different non-invasive medical therapies.

The models selected for the environmental stimuli varied from the focalized ones that mimic the lab therapeutic exposure, to the complex nonlinear ones occurring in concert halls or at the indoor use of different home appliances able to generate vibrations and/or associated electromagnetic field effects.

Acoustic Module of COMSOL Multiphysics® and Equation-Based Models have been used to define the interactions between Human 2D model and the eigenmodes of a *Therapy Room* or the eigenmodes of a large *Concert Hall*.

4. Experimental Results

The first Model (Model A, Appendix) is placing a human skull under acoustic pressure stimuli on a surrounding geometry similar of similar sizes with a metro station or a large concert hall. For Figures 1-6 the monopole source was considered in front of the 2D Head model.

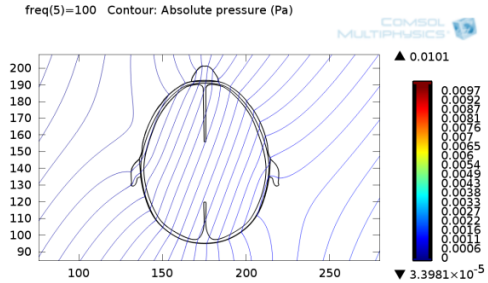

Figure 1 Heat cross section structure under acoustic pressure stimuli (f=100Hz)

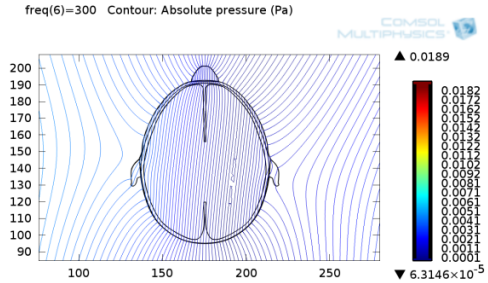

Figure 2 Heat cross section structure under acoustic pressure stimuli (f=300Hz)

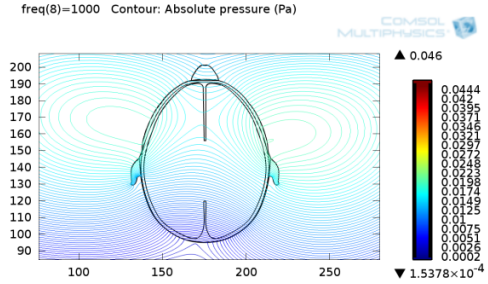

Figure 3 Heat cross section structure under acoustic pressure stimuli (f=1000Hz)

Frequencies ranging from 100Hz to 4000Hz are usual in concert halls, but those beyond 10 kHz occurring in metro station or industrial areas are obviously impacting the human tissues as well.

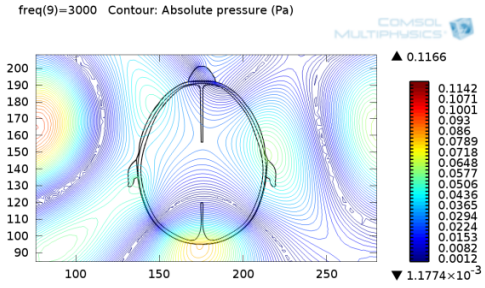

Figure4 Heat cross section structure under acoustic pressure stimuli (f=3000Hz)

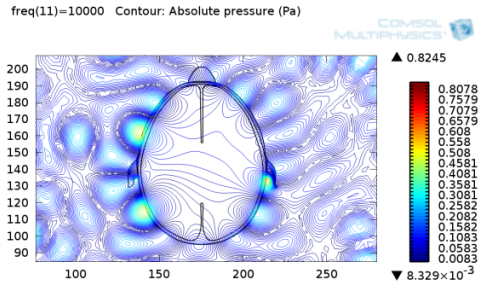

Figure 5 Heat cross section structure under acoustic pressure stimuli (f=10000Hz)

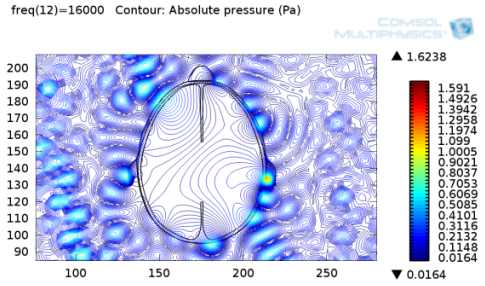

Figure 6 Heat cross section structure under acoustic pressure stimuli (f=16000Hz)

The next study was made running a 2D contour Human Body (Model B, Appendix) that reveals similar pressure/ intensity peaks for frequencies beyond 10 kHz. Actually, for acoustic stimuli ranging beyond 4–6 kHz the surrounding geometry has an outstanding impact on the human body (Figure 10-16)

Running a 2D model of an Opera Hall (Model C, Appendix) this surrounding shape effect can be better understood (Figure 11-16).

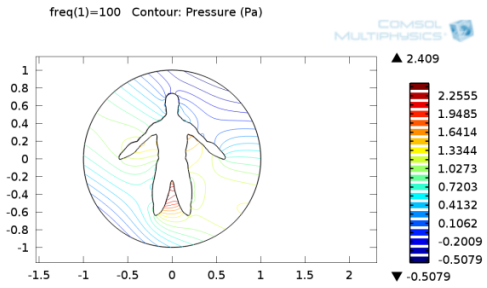

Figure7 Body contour at 100Hz acoustic frequency

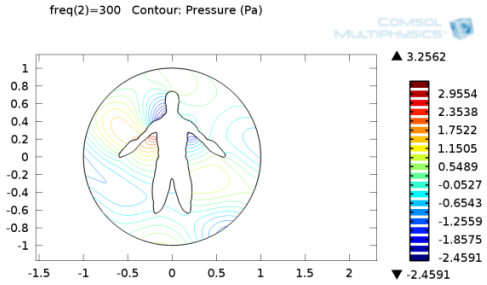

Figure 8 Body contour at 300Hz acoustic frequency

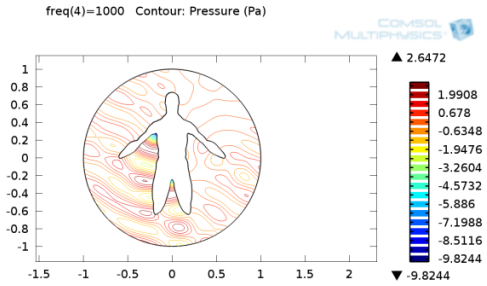

Figure 9 Body contour at 1000Hz acoustic frequency

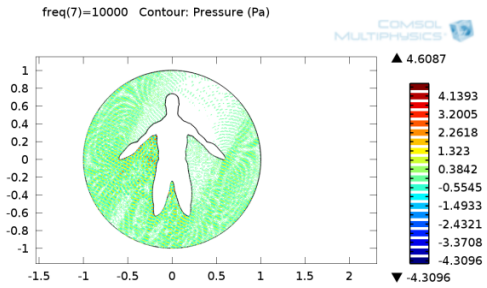

Figure 10 Body contour at 3kHz acoustic frequency

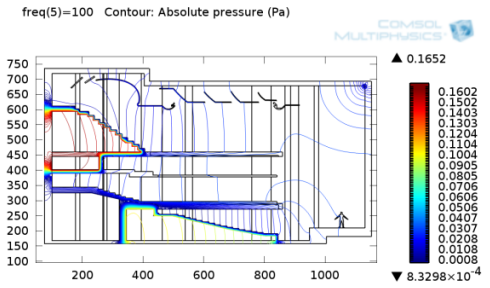

Figure 11 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=100Hz)

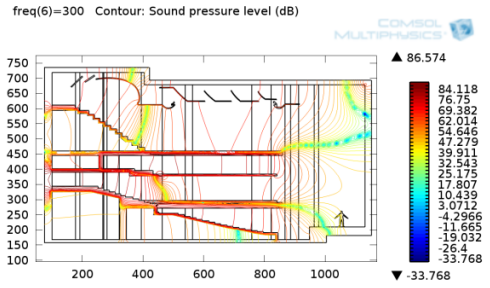

Figure 12 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=300Hz)

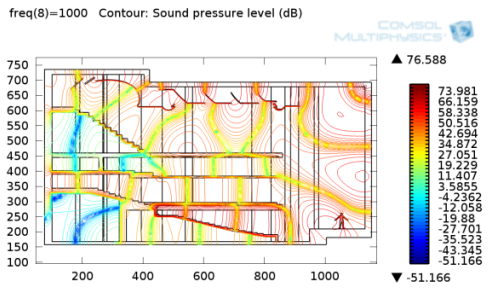

Figure 13 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=1000Hz)

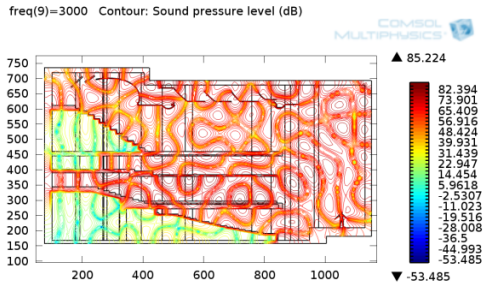

Figure 14 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=3kHz)

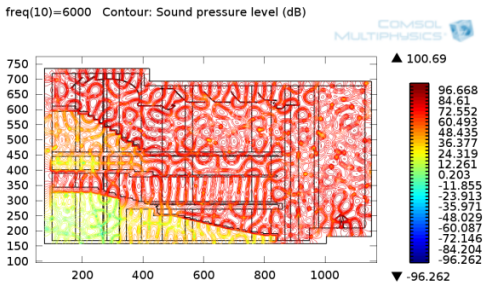

Figure 15 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=6kHz)

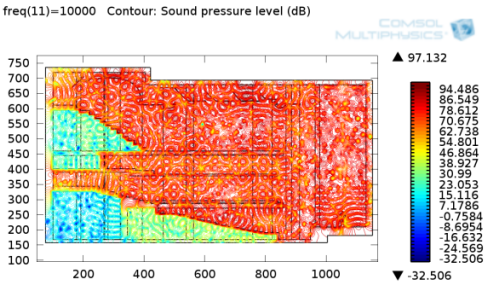

Figure 16 Opera Hall cross section with Human Body on stage under acoustic stimuli impact (f=10kHz)

It becomes obvious that the best places from the Opera Hall are effective only up to frequencies below 3 kHz.

As for the human staying on stage, if it is the Orchestra Conductor his body would be acoustically impacted at a higher level than the bodies of the audience.

The last study was designed for a Therapy Room (Model D, Appendix), here acoustic stimuli could come from surroundings (monopole source on walls) or from the therapy armchair. In the last case the model refers to vibration therapy, and the same frequency spectra were selected for the human laying here.

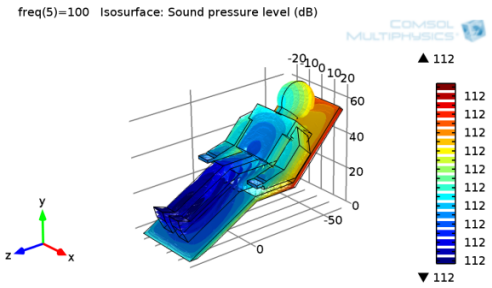

Figure 17 Vibration therapy - armchair (f=100Hz)

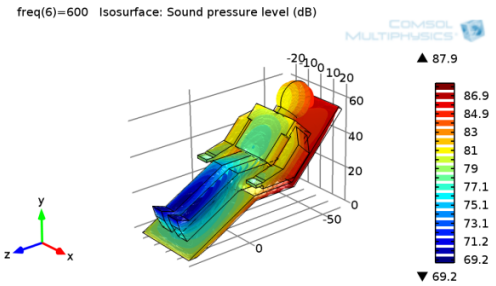

Figure 18 Vibration therapy - armchair (f=600Hz)

Again, from a different model approach, emerge the 'attention frequency threshold' of 4-6 kHz. Either expressed as sound pressure level (dB) or as total acoustic pressure (Pa) the acoustic energy transmitted to the human body is far beyond its comfort values (Figure 19, 20, 22).

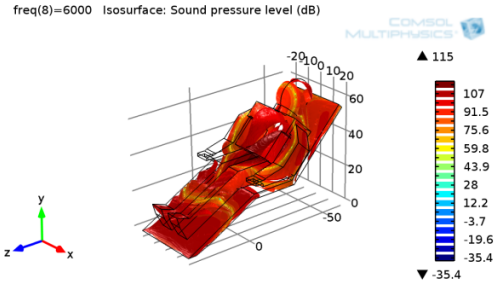

Figure 19 Vibration therapy - armchair (f=6kHz)

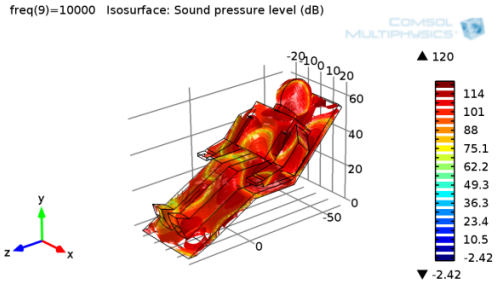

Figure 20 Vibration therapy - armchair (f=10kHz)

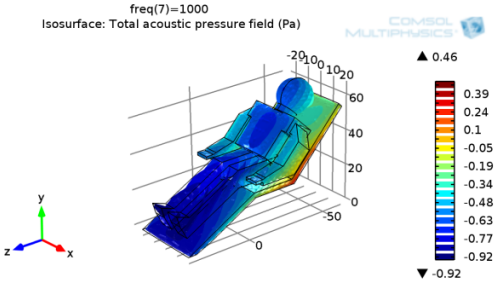

Figure 21 Vibration therapy - armchair (f=1000Hz)

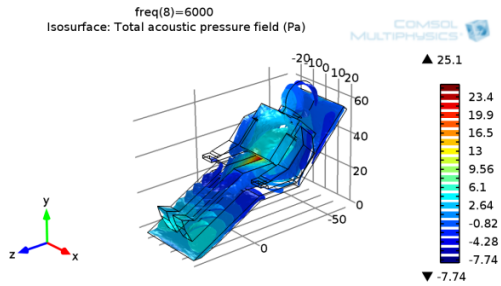

Figure 22 Vibration therapy - armchair (f=6kHz)

5. Discussion

Based on the present analysis performed using COMSOL Multiphysics® modules and according to the cellular proactive energy harvesting model [1] the previous achievements on non-invasive treatments for osteoporosis and for systemic and regional blood flow [4] fit well to the simulation model. Thus the existing local different values of the density of energy (Figure7-10, Figure 17, 18) are able to explain the effective production of growth factors, modulating stem cells proliferation and differentiation and increasing bones mass.

Similar results were obtained reassessing on objective experimental data basis the effectiveness of music therapies, as well as the potentially damaging effects of too low or too high acoustic pressure levels signals.

6. Conclusions

Far from being just a collection of analytic methods and modelling tools COMSOL Multiphysics® clarifies the interdisciplinary models associated to non-invasive acoustic-electomagnetic therapies thus giving a real multiphysics support to the acknowledged therapeutic results.

Moreover, unexpectedly COMSOL becomes an effective tool for reassessing the meaningfulness of the environmental stimuli upon humans and reopens a millenary debate related to the Music: is it basically designed for soul or for body?

7. References

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4. Lacatus E., Ion Channel Path of Cellular Transduction During Acoustic Stimulation, J. Biochimica et Biophysica Acta (BBA)-Bioenergetics, Supplement EBEC 2014,, ISSN 0005-2728, Elsevier, (2014)
5. COMSOL Multiphysics®- Material Library (2013)
6. COMSOL Multiphysics®- Tutorials (2013)

8. Appendix

MODEL LIBRARY

Model Parameters	Head A
Definitions	Boundary System , Global Cartesian
Geometry	Imported -Selected Domain (Brain, Fluid Buffer, Muscle, Skull, Air/Surrounding Environment geometry)
Materials	Brain , Fluid Buffer, Skull, Muscle, Air (Appendix, Table1)
Frequency Domain	Pressure Acoustics Equation 1, Equation 2
Mesh	Extremely fine Number of degrees of freedom (DOF): 961765 (A1) –Frontal source 962861 (A2)- Upper Left source
Frequency Domain	Pressure Acoustics A1_[6-20] Hz
	A2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module
Plot Groups	Acoustic Pressure (acpr) Sound Pressure Level (acpr) 2D Plot Group 3- Absolute Pressure 2D Plot Group 4 – Instantaneous local velocity 2D Plot Group 5 Sound Pressure Level 2D Plot Group 6 – Mesh

Model Parameters	Body B
Definitions	Boundary System , Frequency, Wave direction angle, Incident wave direction vector
Geometry	Imported- Selected Domain (Body Contour, Air/Surrounding Environment geometry)
Materials	Muscle , Air (Appendix, Table1)
Frequency Domain	Acoustic-Solid Interaction Sound Hard Boundary (Walls) Acoustic-Structure Boundary1 (Body Contour) Linear Elasticity (Body) Plane Wave Radiation1(Walls) Incident Pressure Field (inwards)
Mesh	Extremely fine Number of degrees of freedom (DOF): 154949-Upper Left source
Frequency Domain	Acoustic-Solid Interaction [100-16000] Hz
Solver Configurations	COMSOL Multiphysics – Acoustic Module
Plot Groups	Displacement (acsl) Acoustic Pressure (acsl) 2D Plot Group 3 – Contour Pressure 2D Plot Group 4 – Displacement field (Material) 1D Plot Group 5 – Histogram 2D Plot Group 6 – Mesh

Model Parameters	Opera Hall + Body C
Definitions	Boundary System , Global Cartesian (Plane + Spatial) (Opera Hall + Body)
Geometry	Imported- Selected Domain (Opera Hall, Body Contour, Air/Surrounding Environment geometry)
Materials	Concrete, Wood, Muscle , Air (Appendix, Table1)
Frequency Domain	Pressure Acoustics Sound Hard Boundary (Walls) Acoustic-Structure Boundary1 (Body Contour)
Mesh	Extremely fine Number of degrees of freedom (DOF): 255944
Frequency Domain	Pressure Acoustics C1_[1-100] Hz C2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module
Plot Groups	2D Plot Group 2- Absolute Pressure 2D Plot Group 3 Sound Pressure level 3D Plot Group 4- Absolute Pressure 3D Plot Group 5 Sound Pressure level 2D Plot Group 6 – Mesh 3D Plot Group 7 – Mesh

Model Parameters	Relaxing- Therapy Room D
Definitions	Boundary System , Global Cartesian (Spatial) (Therapy Room + Body)
Geometry	Imported- Selected Domain (Therapy Room, Body Contour, Air/Surrounding Environment geometry)
Materials	Concrete, Wood, Muscle , Air (Appendix, Table1)
Frequency Domain	Pressure Acoustics Sound Hard Boundary (Walls) Acoustic-Solid Interaction Linear Elasticity (Body) Spherical Wave Radiation1
Mesh	Extremely fine Number of degrees of freedom (DOF): 114864
Frequency Domain	Pressure Acoustics D1_[1-100] Hz D2_[100-16000] Hz Include geometric nonlinearity
Solver Configurations	COMSOL Multiphysics – Acoustic Module
Plot Groups	Acoustic Pressure (acpr) Sound Pressure Level (acpr) Acoustic Pressure-Isosurfaces (acpr) 3D Plot Group 4 –Absolute Pressure-Isosurface 3D Plot Group 5 Local acceleration (spatial) 3D Plot Group 6 – Mesh