Numerical modeling of the ear canal: benefits and challenges

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Health risks — [Feder, Michaud et al. Statistics Canada, 2013]

- 42% of Canadians from 16 to 79 years
  - 22% used always HPD
  - 39% used HPD often, sometimes or rarely
  - 39% never did

Wearing earplugs assiduously can reduce this important health public problem
Motivation

- Acoustic attenuation is not often optimised as desired
- Comfort: static mechanical pressure, occlusion effect
- Improve HATS and ATF similarities with humans

Current important issues for recent and future research projects:
ETSPA2 (2010-2014) & ETSPA3 (2018-2022)

Synthesis of numerical modeling research work 2012-2018
Presentation Scope

Presentation of 4 practical cases

Study 1
ATF transmission pathways

Study 2
Earplug material effects

Study 3
Ear canal’s transfer functions

Study 4
Designing lab tools
Presentation scope

Characterisation of ear canal transmission pathways in the acoustical test fixtures CB45

[Viallet et al. (2014, journal of the acoustic society of america): “A finite element model to predict the sound attenuation of earplugs in an acoustical test fixture “]
Study 1: What system to be modeled?

ATF 45CB – G.R.A.S.

Ear canal with silicon lining

IEC 711 coupler

Under the pinna
Study 1: Model details

Cylindrical silicon earplug

Ear canal with silicon lining

IEC 711 coupler
Study 1: Insertion loss simulations

Acoustic attenuation: **Insertion Loss** (documented in ANSI S12.42-2010)
Study 1: Insertion loss simulations

Acoustic attenuation: **Insertion Loss** (documented in ANSI S12.42-2010)

\[ \text{TFopen} - \text{TFoccluded} = \text{IL (dB)} \]
Study 1: Model validation
Study 1: Dissipated and transmitted power
Study 1: Energy exchange artificial skin - EP

![Graph showing power transfer vs frequency for different EP thicknesses (5.8 mm EP and 8.5 mm EP).]
Presentation scope

1) Characterisation of ear canal transmission pathways in the acoustical test fixtures CB45

2) Quantification of the earplug material’s effects on the earplug attenuation and mechanical skin contact

[Viallet et al. (2016, Canadian acoustic proceedings)]: “Custom molded silicon earplugs: effect of material properties on acoustic attenuation and mechanical skin contact and mechanical skin contact“

On going publication with additional works and results, 2018
Study 2: Model details

Same as study 1 but different types of silicone for the earplug

Cylindrical silicon earplug

Ear canal with silicon lining

IEC 711 coupler
Study 2: Silicon mechanical properties measurements

- Which earplug’s properties are measured and how?
  - Young’s modulus: $E$
  - Poisson’s ratio: $\nu$
  - Density: $\rho$
  - Isotropic loss factor: $\eta$

Methods detailed in [Langlois & al., 2001]
Study 2: Design of experiments

- Which earplug’s properties are measured and how?
  Young’s modulus: $E$
  Poisson’s ratio: $\nu$
  Density: $\rho$
  Isotropic loss factor: $\eta$

- Design of Experiment (DOE) [Montgomery, Douglas, 2013]:
  16 runs for $2^4$ : complete factorial design

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Study 2: Ear canal sensitivity indicator

Choice of the indicators?

**Mechanical contact:** *Mechanical impedance*

\[
Z_{\text{occ}} = \frac{\vec{F}}{\vec{v}_{\text{occ}}}
\]

\[
Z_{\text{op}} = \frac{\vec{F}}{\vec{v}_{\text{op}}}
\]
Study 2: Ear canal sensitivity indicator

-choice of the indicators?

Mechanical contact: Mechanical impedance Difference

\[ Z_{occ} = \frac{\vec{F}}{v_{occ}} \]

\[ Z_{op} = \frac{\vec{F}}{v_{op}} \]

\[ \Delta Z = |Z_{occ}| - |Z_{op}| \]
Study 2: Acoustic attenuation - All run results

Main parameters effect – Variation around the mean IL value
Main parameters effect – Variation around the mean $\Delta Z$ value – Influence of the Zone

Study 2: Mechanical contact - All run results
Presentation scope

1) Characterisation of ear canal transmission pathways in the acoustical test fixtures CB45

2) Quantification of the earplug material’s effects on the earplug attenuation and mechanical skin contact

3) Modeling the in ear transfer functions to help the development of an in-ear dosimeter device

[Sgard, Viallet et al., proceedings of ICV22, 2015]: “Using finite element modeling to predict the effect of ear canal microphone positioning on the sound attenuation of hearing protectors”
Study 3: In-ear transfer function computation

- Context: development of a dosimeter device including an in-ear microphone
- Scientific question: compensation for individual in ear’s transfer functions

\[ \Delta T_F = T_F x - T_F' x \]

\[ \Delta T_F x \to 0 \]

Open ear canal

- SKIN
- Soft tissues
- Bone

Occluded ear canal

- SKIN
- Soft tissues
- Bone
- CMER

\[ x? \]
Study 3: In-ear transfer functions - Results

Up to $x = 4$ mm
$\Delta TF < 1$ dB

Results in accordance with [Gilman and Dirks, 1986] and [Chan and Geisler, 1990]
# Presentation scope

1) Characterisation of ear canal transmission pathways in the acoustical test fixtures CB45

2) Quantification of the material’s properties effect on the earplug attenuation and mechanical skin contact

3) Modeling the in ear transfer functions to help the development of an in-ear dosimeter device

4) 3D modeling benefits for developing laboratory tools
Study 4: 3D modeling benefits for developing laboratory tools - Examples

- Pinna with special ear canal features

B&K HATS 4128

Integration of a realistic 3D shaped ear canal

Pinna 3D scan

Ear canal impression 3D scan
Study 4: 3D modeling benefits for developing laboratory tools - Examples

- Pinna with special ear canal features

3D printed mold and silicone injection

Developed ATF

On the HATS
Study 4: 3D modeling benefits for developing laboratory tools - Examples

- Eartrode project: in and behind the ear device for EEG recording
  - Regular CMEP
  - 3D scan
  - 3D modification
  - Electrode tree 3D printed or conductive silicone
  - Instrumented CMEP earplug
Conclusion

- Cover 4 practical cases when numerical modeling or 3D modeling/printing can benefit to a in ear research laboratory:
  - Quantify the transmission pathways in an ATF
  - Better understand the impact of the earplug’s material
  - Quantify in ear transfer functions
  - Design tools that are useful for an in-ear technologies research laboratory
Future works

- Study 1 – linked these results with similar models on real ear to improve the features of ATF
  - Results to be confirmed in a more realistic auditory canal (geometrically and anatomically)
  - Integration of earplug geometrical parameters in the sensitivity analysis

- Study 2: Pilot study concerning the implementation of an objective mechanical contact indicator
  - link with the comfort still to be proved
  - Combining statistics results to couple the indicators

- Study 3: in ear transfer functions quantification
  - Improving the model by introduced the effect of a probe tube

- Study 4: designing lab tools:
  - lots of CRITIAS on-going projects that requires modeling & 3D printing
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