TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

INAIL
ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO

ADVANCED ACOUSTICS FOR DIAGNOSTIC APPLICATIONS TO AUDIOLOGY AND BEYOND

PhD admission to 3rd Year

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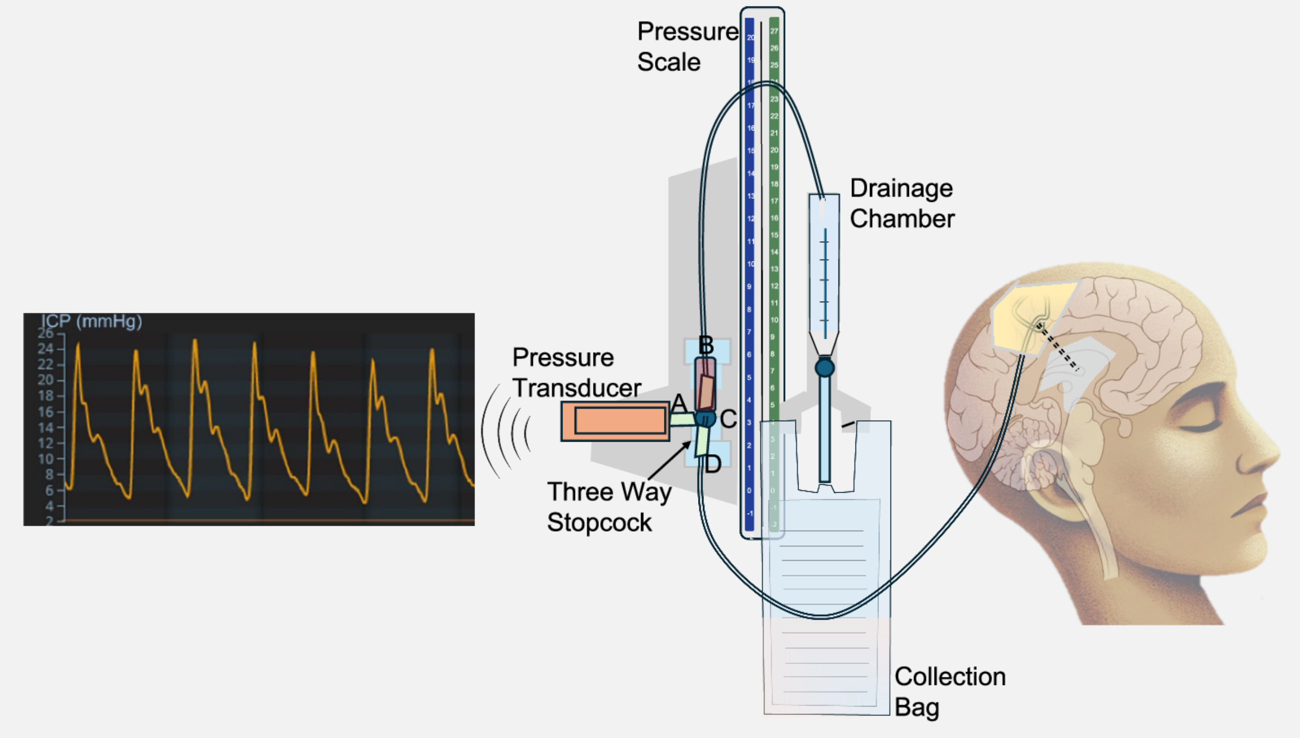
15th October 2025



INTRODUCTION

- The International Space Station (ISS) is a unique stationary free-falling frame, which permits studying the effects of long-term microgravity on the astronauts' physiology.

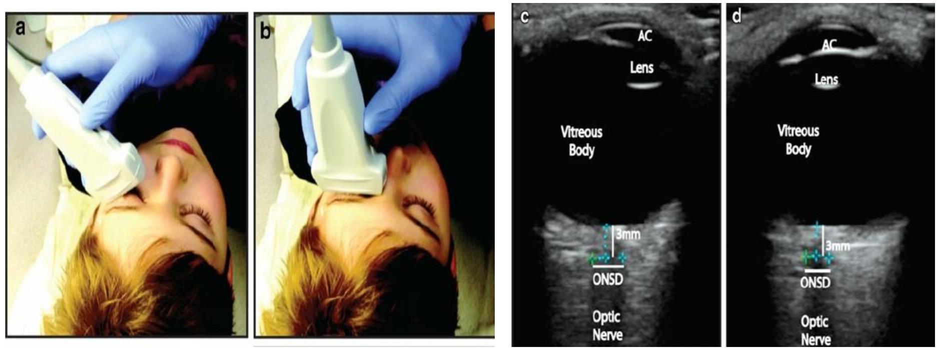
- Microgravity conditions have various effects on human physiology, including increased Intracranial Pressure (ICP), which poses risks to vision, especially for long-duration space missions.

- Current methods for measuring ICP are invasive and carry risks.

NON-INVASIVE INDICATORS OF ICP

1 Ultrasound-Based Internal Jugular Vein Pressure

2 Ultrasound of Optic Nerve Sheath Diameter (ONSD)

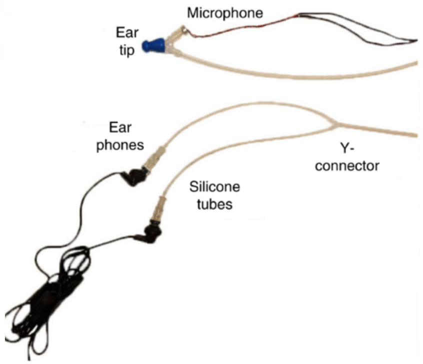


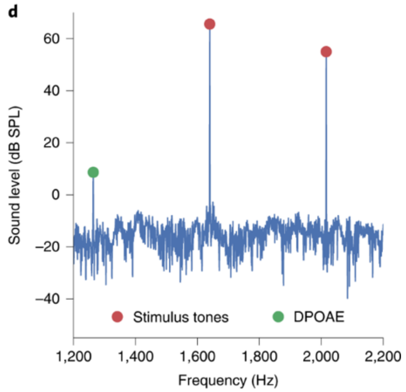
3 Otoacoustic Emissions (OAE)

The phase of OAEs is dependent on the middle ear transmission. The relationship between OAE responses and direct ICP measures is based on **pressure communication between perilymph and cerebrospinal fluid (CSF), and on the dependence of the middle ear transmission on intracochlear pressure.**

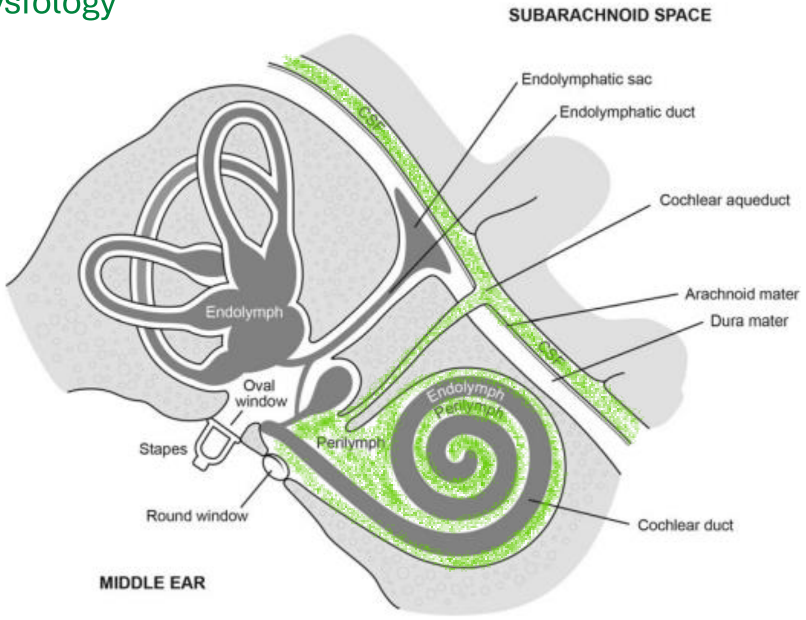
Avan and coworkers reported a linear relationship between DPOAE phase change and ICP change:

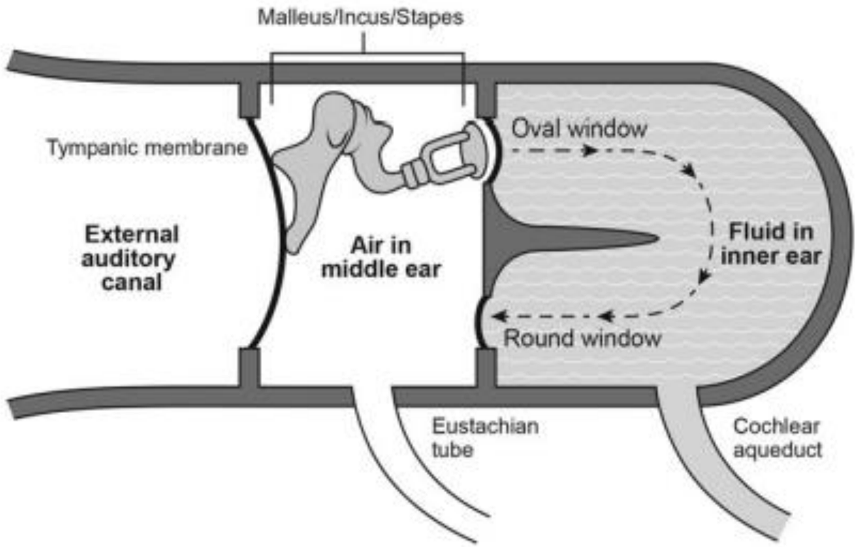
$$\frac{\partial \Phi}{\partial \mathrm{ICP}} = 2.72\ \mathrm{deg/mmHg}$$

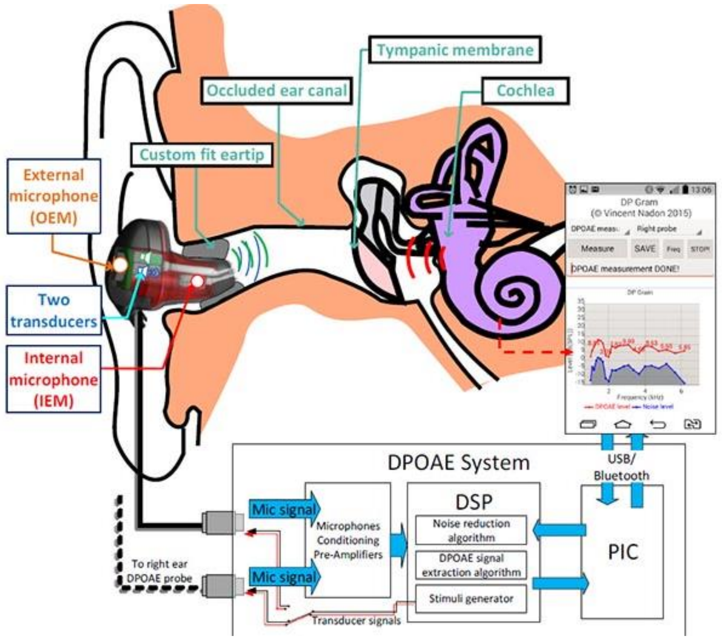


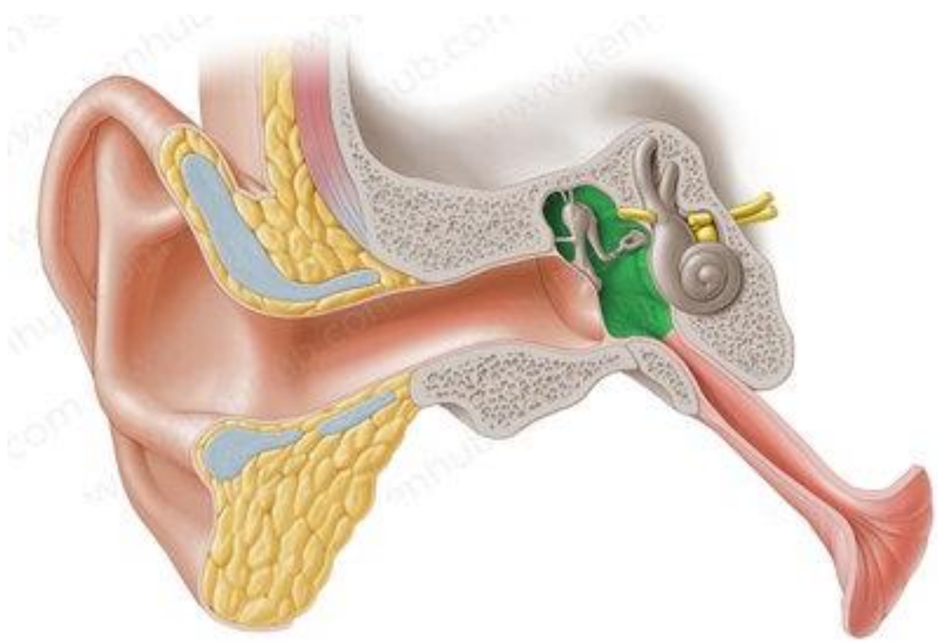


Ear Anatomy and Physiology









What are Otoacoustic Emissions (OAEs)?

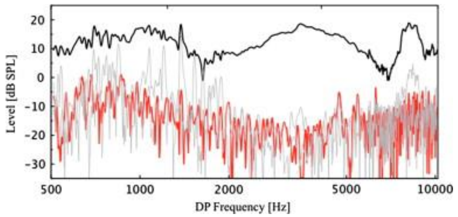
Otoacoustic emissions (OAEs) are low-level sounds generated within the inner ear, specifically by the outer hair cells of the cochlea. cells of the cochlea. These sounds can be measured in the ear canal using sensitive microphones. Their presence indicates healthy indicates healthy cochlear function.

Clinical Applications

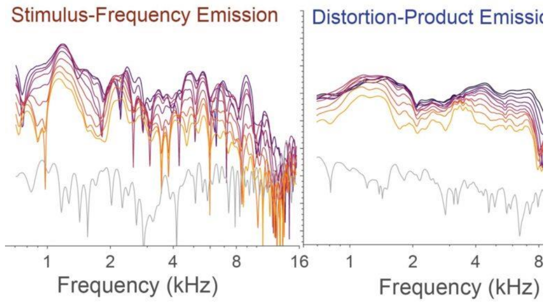
OAEs are used in newborn hearing screenings and to and to diagnose certain types of hearing loss.

Types of OAEs

Spontaneous OAEs **(SOAEs)**, Transient-Evoked OAEs **(TEOAEs)**, and Distortion Product OAEs **(DPOAEs)**



Otoacoustic emission	Notation	Stimulus	Prevalence (by ear)
Spontaneous	SOAE	None	~50%
Evoked:			
Transiently evoked	TEOAE	Click/toneburst	~100%
Stimulus-frequency	SFOAE	Continuous pure tone	~100%
Distortion-product	DPOAE	2 continuous pure tones	~100%

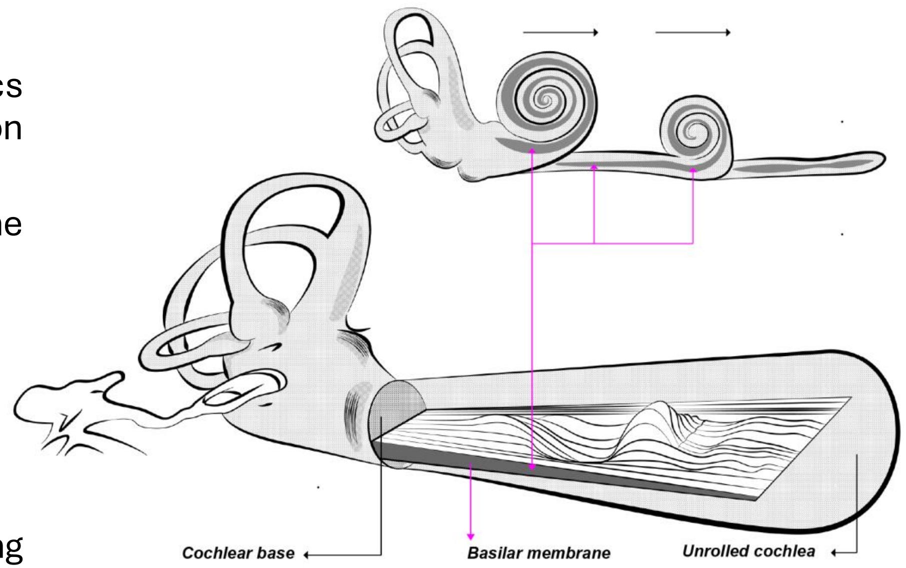


- Cochlear mechanics describes the propagation, reflection and absorption of traveling waves (TWs) along the cochlea.
- Slow transverse TWs are generated by the coupling between the cochlear fluid hydrodynamics and the transverse motion of an elastic complex mechanical structure, the cochlear partition (CP).
- This two-way coupling consists of the mechanical drive by the differential fluid pressure on the CP,

$$\ddot{\xi}(x,t) + \gamma_{bm}(x)\dot{\xi}(x,t) + \omega_{bm}^2(x)\xi(x,t) = -\frac{p_d(x,t)}{\sigma_{bm}}$$

where $\omega_{bm}(x) = \omega_0 e^{-k_\omega x}$

and on the mechanical reaction of the incompressible fluid to the CP movement, which, using Newton's equation for the fluid element yields a TW eq.

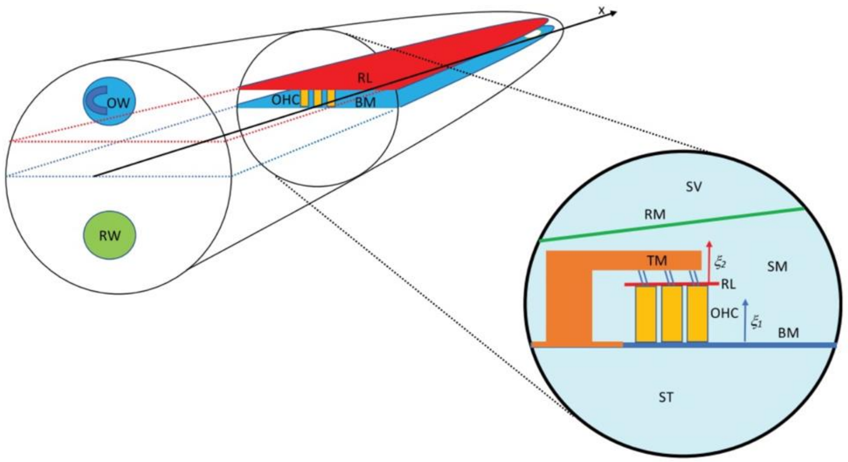


Fluid Volume conservation $H\frac{\partial u}{\partial x} = \dot{\xi}$

Newton's law for fluid element $-\frac{\partial p}{\partial x} = \rho\frac{\partial u}{\partial t}$

$$\frac{\partial^2 p_d}{\partial x^2} = -2\frac{\rho}{H}\ddot{\xi}$$

Propagation of a pressure wave



In the linear approximation, in the frequency domain, these equations yield a transmission line equation

$$\frac{\partial^2 p_d}{\partial x^2} = -k^2 p_d$$

with

$$k^2 = \frac{2\rho}{H\sigma_{bm}} \frac{\omega^2}{\left(\omega_{bm}^2(x) - \omega^2 + i\omega\gamma_{bm}(x)\right)}$$

WKB solution: Traveling waves

- Forward TW:

$$\psi_r(\omega, x) = \sqrt{\frac{k(\omega, x)}{k(\omega, 0)}}\, e^{-i \int_0^x k(\omega, x') dx'}$$

- Backward TW :

$$\psi_l(\omega, x) = \sqrt{\frac{k(\omega, x)}{k(\omega, 0)}}\, e^{i \int_0^x k(\omega, x') dx'}$$

- OAEs are associated with backscattered waves generated by two mechanisms: nonlinear distortion and coherent reflection by randomly distributed impedance perturbation (roughness).

- Two DPOAE components are generated by these mechanisms, in different cochlear regions.

Due to cochlear scaling symmetry, the wavenumber is a function of the dimensionless ratio [$\omega/\omega(x)$], so its total derivative is null:

$$0 = \frac{dk(\omega,x)}{d\omega} = \frac{\partial k(\omega,x)}{\partial\omega} + \frac{\partial k(\omega,x)}{\partial x}\frac{\partial x}{\partial\omega}$$

Hence, model-independent prediction of the frequency dependence of the group delay of the two components is possible.
Using this property, one may compute the group delay of a TW element of frequency ω associated with its longitudinal transmission from the base to its OAE generation place $x_g(\omega)$:

Place-fixed OAEs	Wave-fixed OAEs

Place-fixed OAEs

$$\tau_{0,x_g}(\omega) = -\frac{\partial\Phi(\omega,x_g))}{\partial\omega} = \int_0^{x_g}\frac{\partial Re(k(\omega,x'))}{\partial\omega}dx'$$

$$= \frac{1}{k_\omega\omega}\int_0^{x_g}\frac{\partial Re(k(\omega,x'))}{\partial x'}dx' = \frac{Re(k(x_g,\omega)-k(0,\omega))}{k_\omega\omega}$$

$$\approx \frac{Re(k(x_g,\omega))}{k_\omega\omega}$$

Wave-fixed OAEs

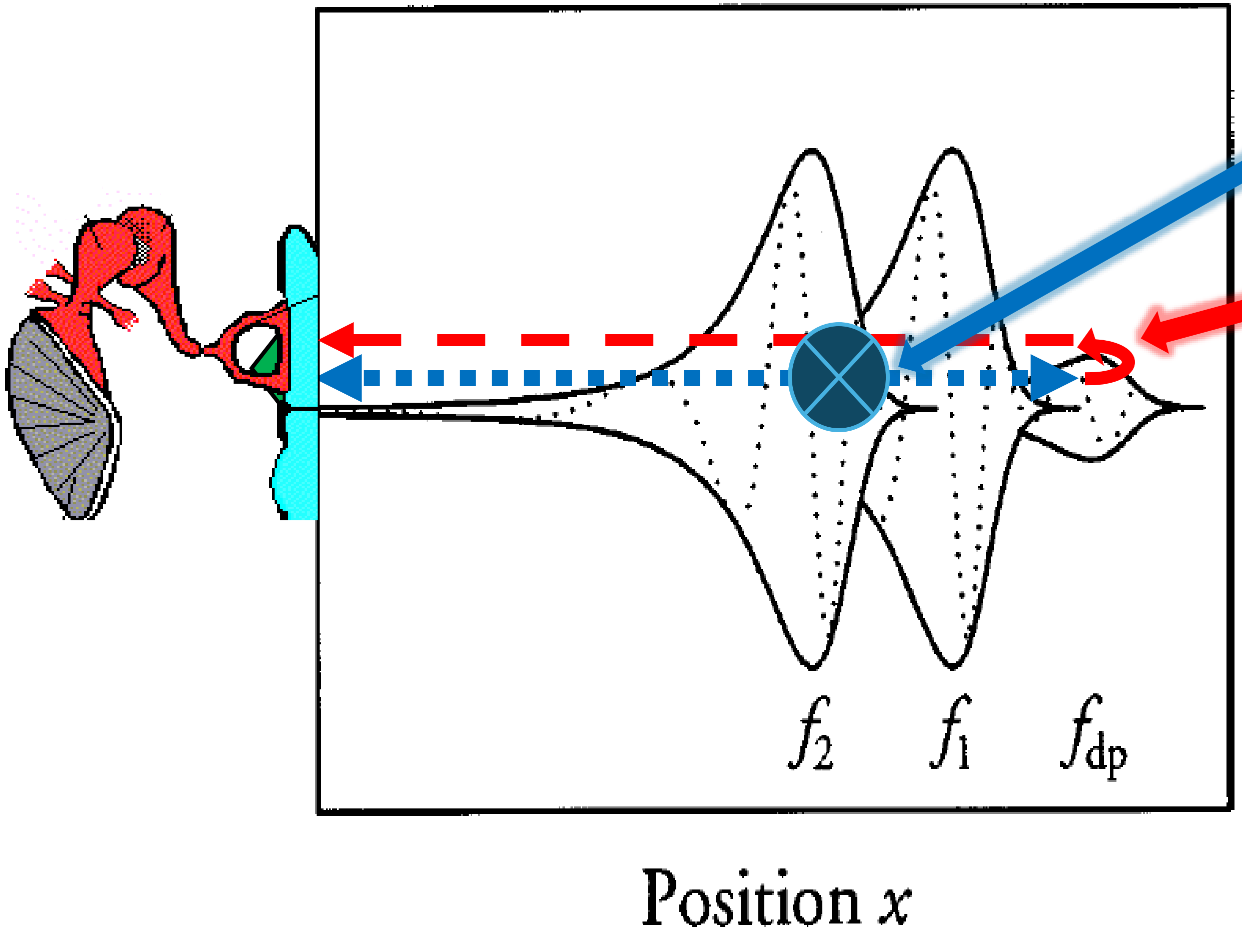
$$\tau_{0,x(\omega)}(\omega) = -\frac{\partial\Phi(\omega,x(\omega)))}{\partial\omega}$$

$$= \int_0^{x(\omega)}\frac{\partial Re(k(\omega,x'))}{\partial\omega}dx' + \frac{\partial x(\omega)}{\partial\omega}Re(k(\omega,x(\omega)))$$

$$= \frac{1}{k_\omega\omega}\left(\int_0^{x(\omega)}\frac{\partial Re(k(\omega,x'))}{\partial x'}dx' - Re(k(\omega,x(\omega)))\right) \approx 0$$

A factor of 2 is associated with the phase accumulated in the OAE backward path

Distortion Product OAE Generation Mechanism



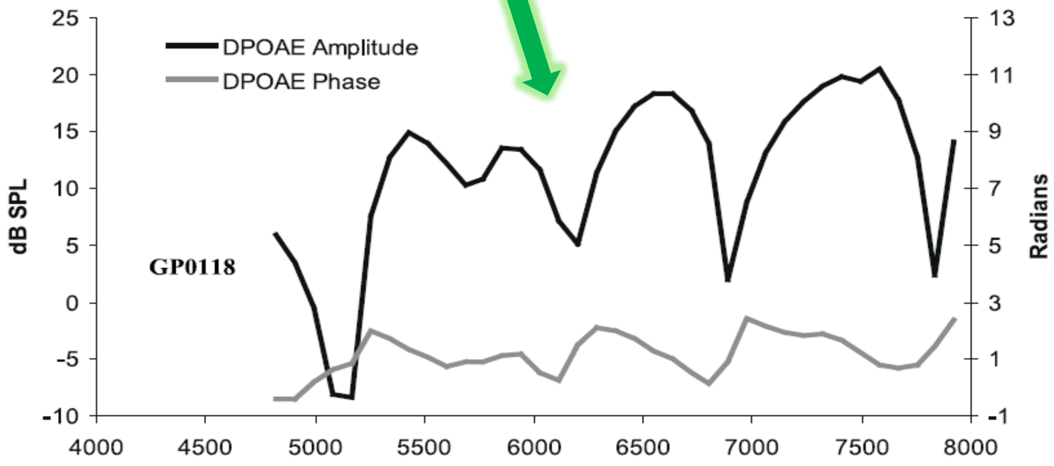
first **wave-fixed** generation of forward and backward DP waves in the overlap region $x(f_2)$.

Cochlear scaling symmetry predicts **NULL GROUP DELAY**

place-fixed reflection of the forward DP wave at $x(f_{dp})$.

Cochlear scaling symmetry predicts **LONG GROUP DELAY** inversely proportional to frequency

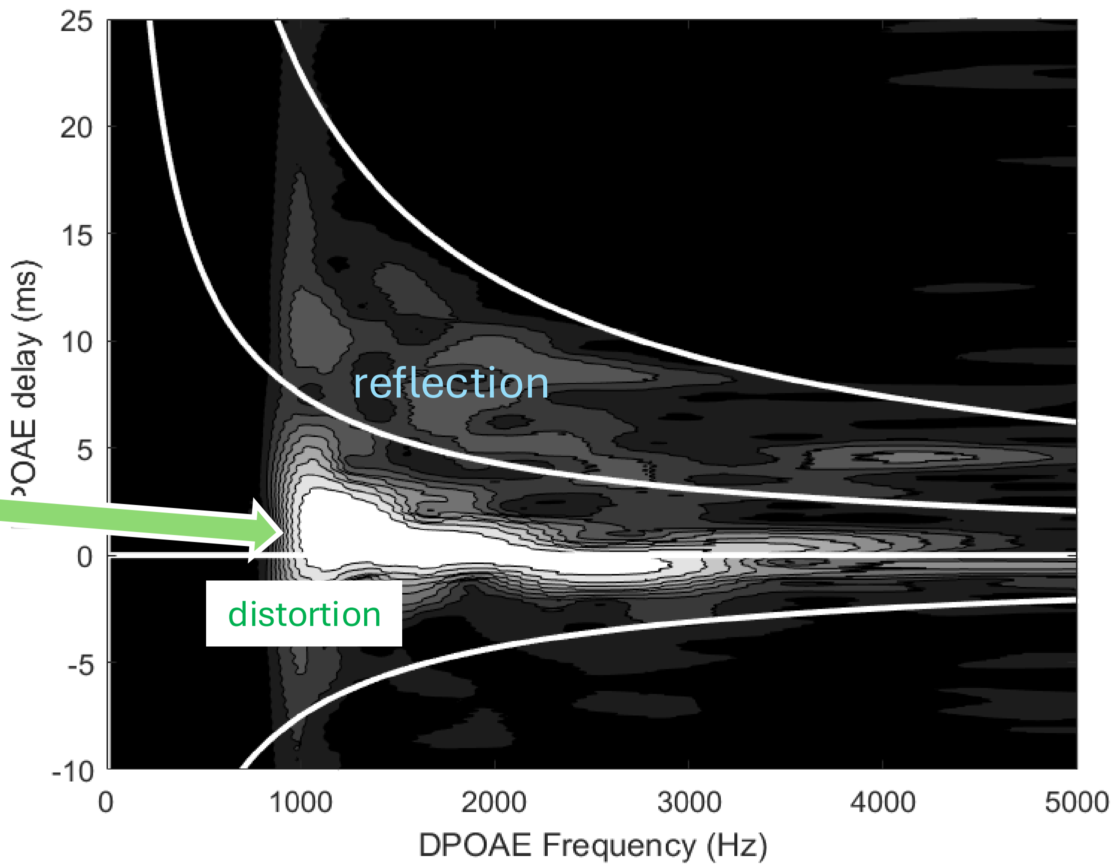
linear superposition of the two components yields DPOAE spectral fine-structure

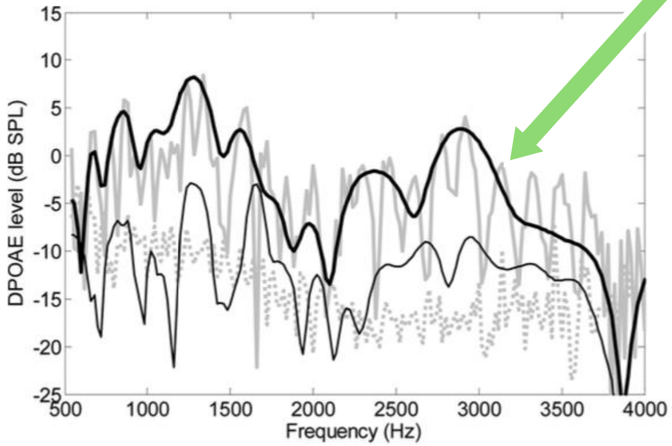


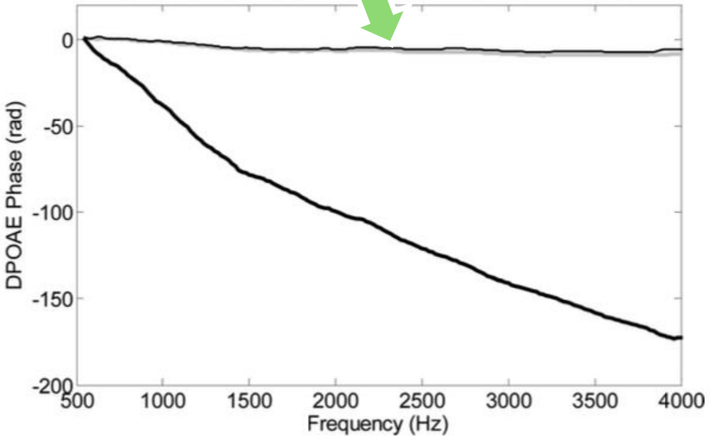
$$Group\ delay: \tau = -\frac{\partial \varphi}{\partial \omega}$$

phase shift per unit frequency

- Separation between the two components based on their different group delay is optimally performed in the time-frequency domain using the **scaling-symmetric** wavelet transform.
- Analyzing the two components **separately improves the specificity of the technique and increases the SNR**, due to the localization of the signal and the homogeneous distribution of noise in the t-f plane.
- The intrinsically constant phase of the DPOAE **distortion component** allows unambiguous averaging of small phase differences over a broad frequency band, with further SNR improvement.







EXPERIMENT WITH POSTURAL DIFFERENCES ON GROUND

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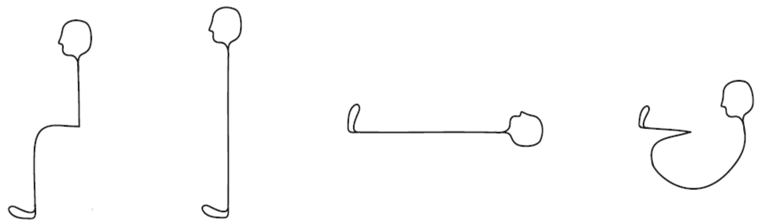


Ground Experiments (20 subjects) 4 postures: Seated, Standing, Supine, Fetal (Lateral recumbent)

DPOAE Technique

- Swept-tone chirps: 1–6 kHz
- Stimuli: 65 & 55 dB, FPL-equalized
- Recorded via ER10B+ otoacoustic probe
- High-resolution time-frequency analysis (wavelet-based)

Calibration & Reflectance Analysis

- THEVENIN-BASED FPL CALIBRATION
- ESTIMATION OF EAR CANAL IMPEDANCE AND ENERGY REFLECTANCE
- REFLECTANCE SHIFT AND IMPEDANCE CHANGES WERE ANALYSED

Energy Reflectance And Impedance

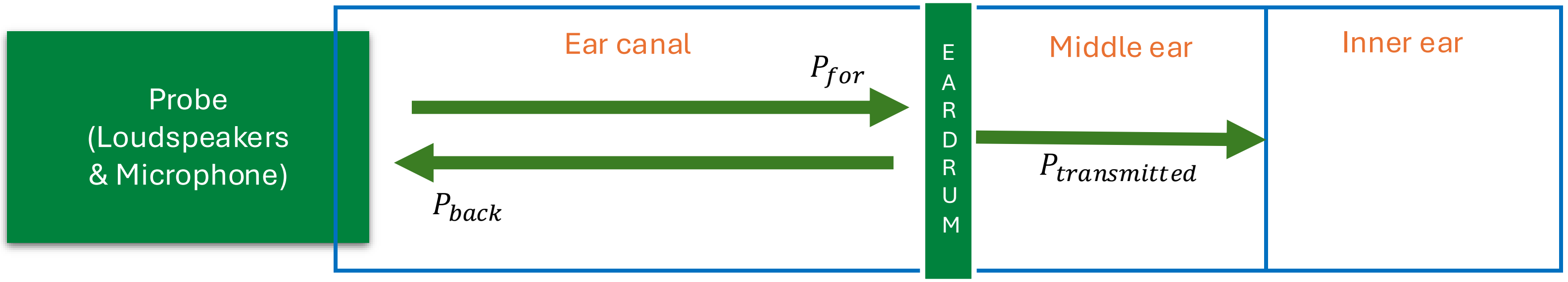
$Pressure\ (P)$ has been measured into the ear canal by an Etymotic ER-10B+ microphone equipped with two ER-2 loudspeakers.

Preliminarily, the probe was calibrated, measuring its Thevenin equivalent parameters in terms of pressure P_{Th} and specific impedance Z_{Th}, using five cylindrical cavities of known acoustic impedance. Once P_{Th} and Z_{Th} are known, Z is computed from P and the eardrum energy reflectance is expressed in terms of Z :

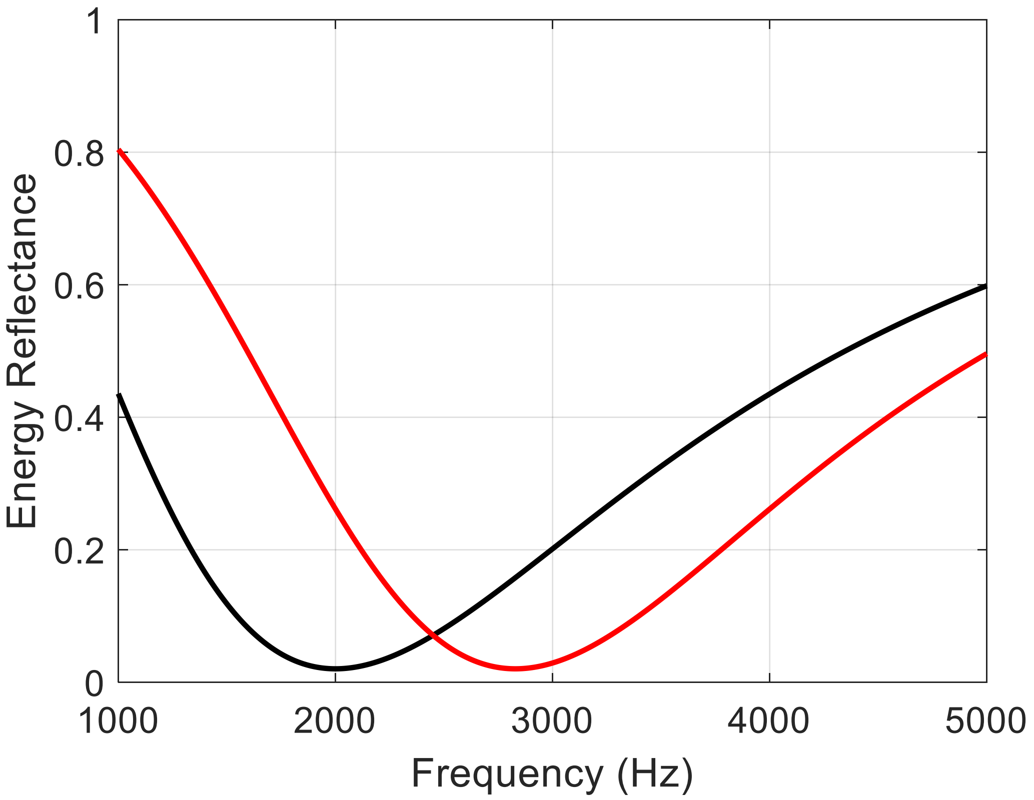
$$Z(f) = \frac{P(f)\, Z_{Th}(f)}{P_{Th}(f) - P(f)}$$

$$R(f) = \left| \frac{Z(f) - Z_0}{Z(f) + Z_0} \right|^2$$

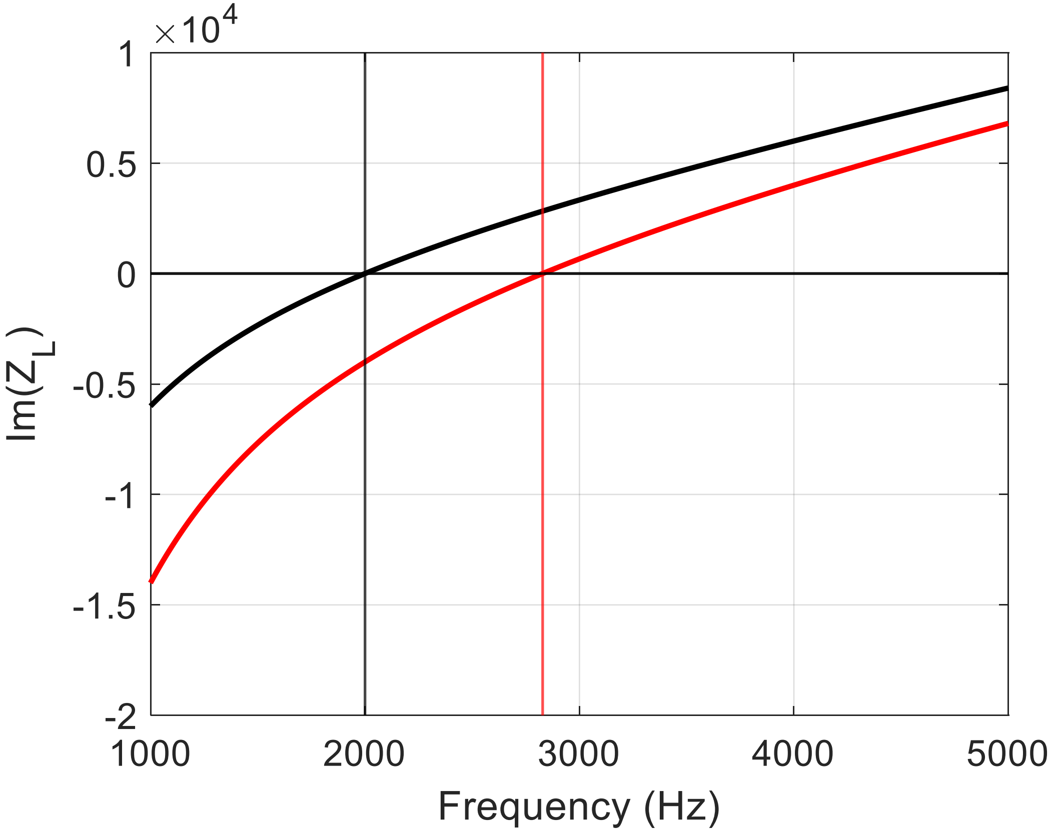
$Z_0 = \rho c$: air specific characteristic impedency;
f: stimulus frequency;
ρ: air density;
c: sound speed in air.



Expected change of the middle ear resonance frequency for a twofold increase of the middle ear stiffness (black to red line)

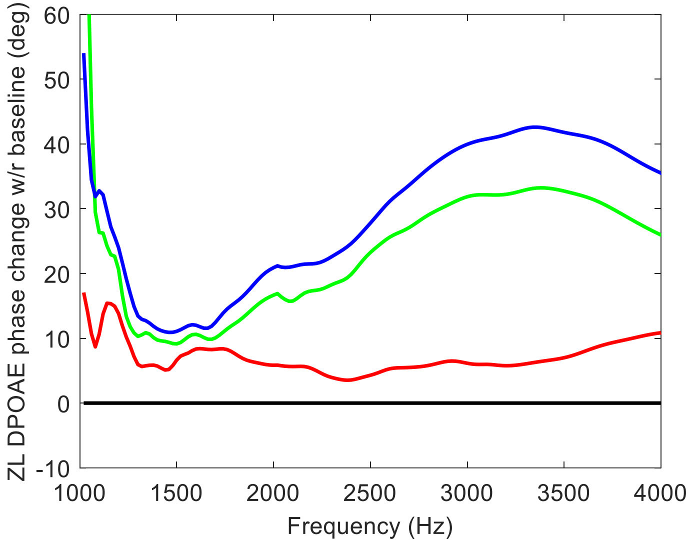


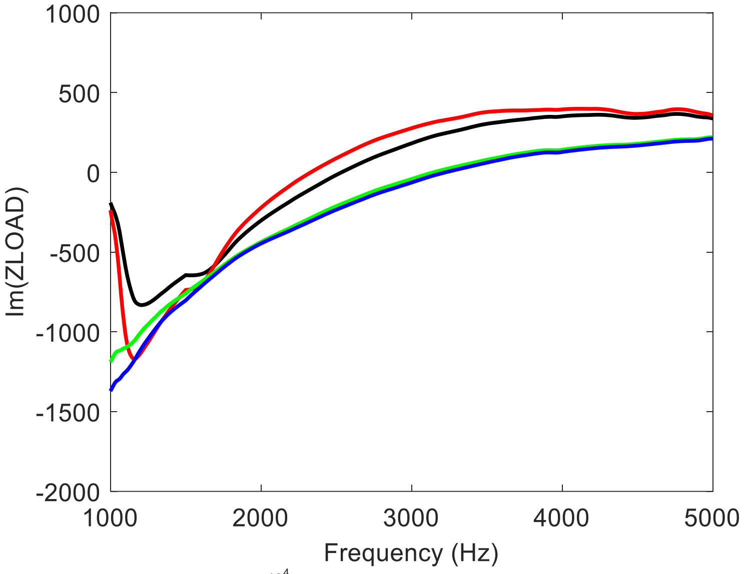
Expected change of the imaginary part of the middle ear impedance for a twofold increase of the middle ear stiffness (black to red line)

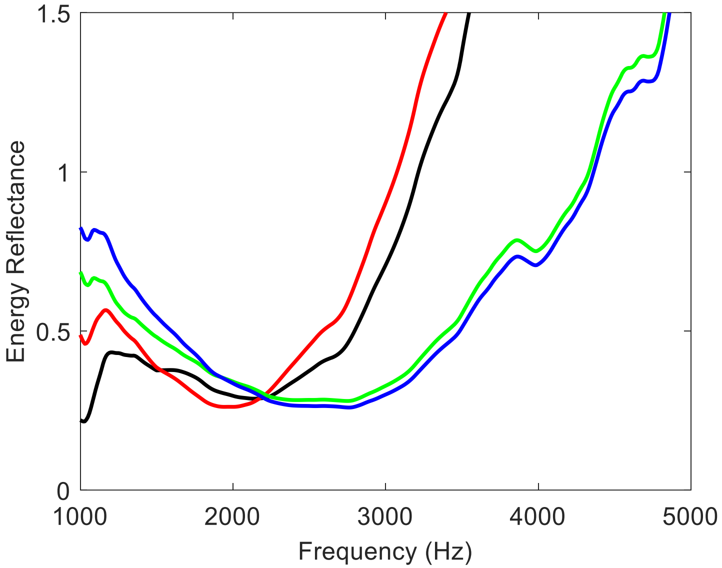


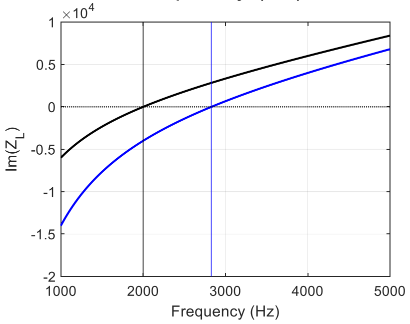
SAMPLE RESULTS - GROUND POSTURE EXPERIMENT

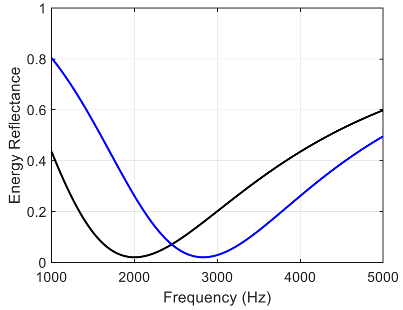
- Clear shift in: DPOAE phase, Energy reflectance minima, imaginary part of the load impedance between vertical postures (black and red lines) and horizontal postures (green and blue)
- Using Avan’s relationship, ICP estimated to increase 6–10 mmHg in horizontal postures with respect to vertical ones











EXPERIMENT WITH THE ASTRONAUTS IN MICROGRAVITY

DPOAE Recordings at different time intervals

1 Pre-flight/ Baseline → 6 In-flight → 2 Post flight

OAE tests were performed pre/post and **during** ISS spaceflight by **5 astronauts**

- **Distortion Product OAE**
- Advanced analysis tools based on theoretical cochlear mechanics
- Normal Hearing Sensitivity

Journal of the Association for Research in Otolaryngology
https://doi.org/10.1007/s10162-024-00962-1
JARO

ORIGINAL ARTICLE

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Otoacoustic Estimate of Astronauts' Intracranial Pressure Changes During Spaceflight

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Abstract

Purpose To investigate the potential correlation between prolonged exposure to microgravity on the International Space Station and increased intracranial fluid pressure, which is considered a risk factor for the astronauts' vision, and to explore the feasibility of using distortion product otoacoustic emissions as a non-invasive in-flight monitor for intracranial pressure changes.

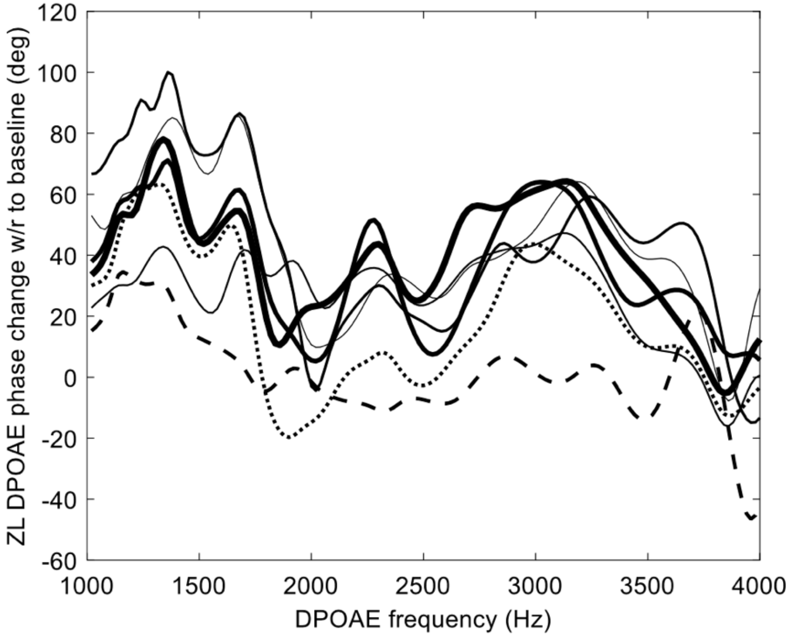
Methods Distortion product otoacoustic emission phase measurements were taken from both ears of five astronauts pre-flight, in-flight, and post-flight. These measurements served as indirect indicators of intracranial pressure changes, given their high sensitivity to middle ear transmission alterations. The baseline pre-flight ground measurements were taken in the seated upright position.

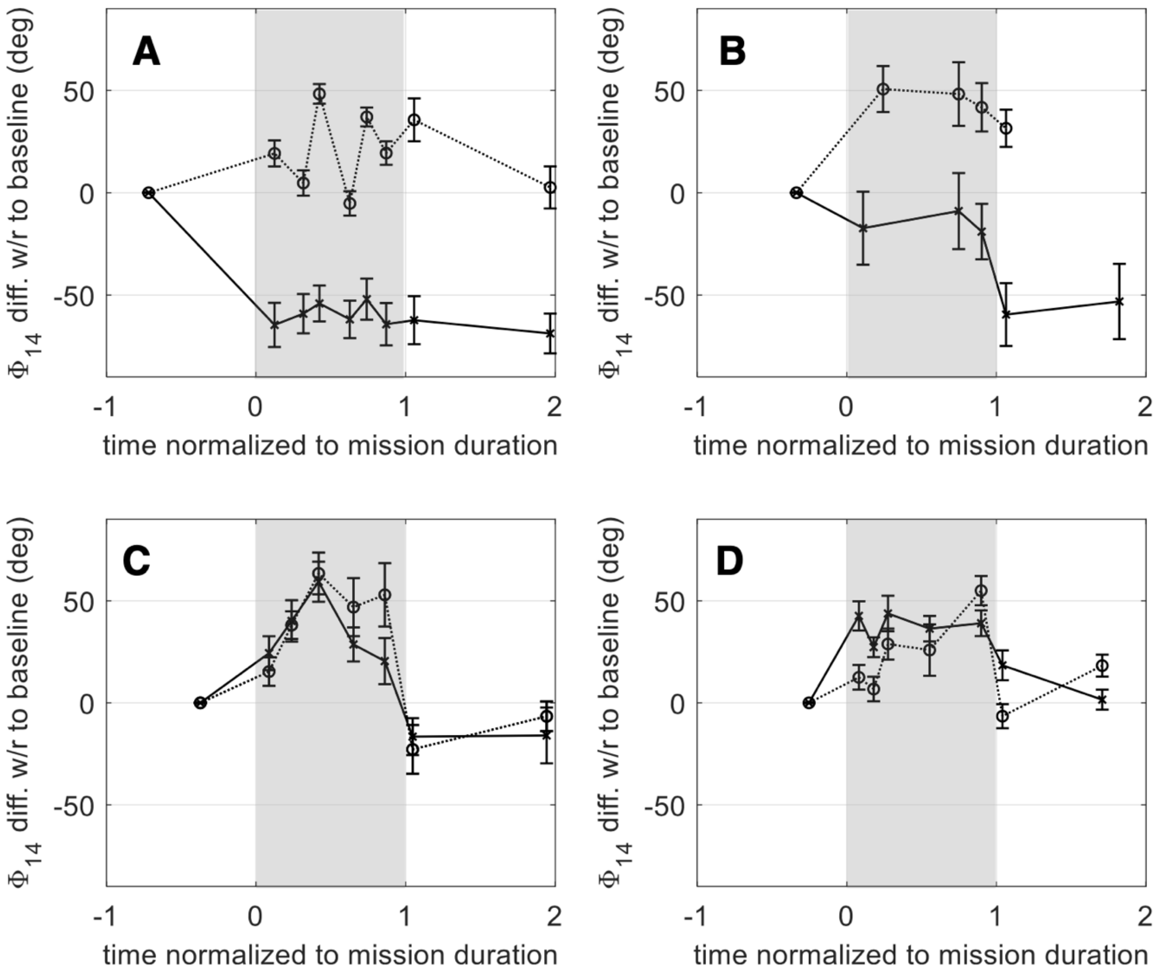
Results In-flight measurements revealed a significant systematic increase in otoacoustic phase, indicating elevated intracranial pressure during spaceflight compared to seated upright pre-flight ground baseline. Noteworthy, in two astronauts, strong agreement was also observed between the time course of the phase changes measured in the two ears during and after the mission. Reproducibility and stability of the probe placement in the ear canal were recognized as a critical issue.

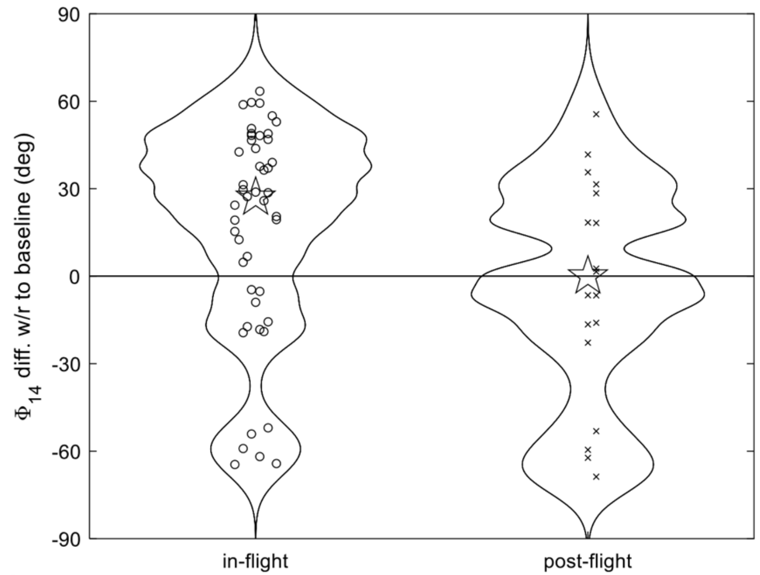
Conclusions The study suggests that distortion product otoacoustic emissions hold promise as a non-invasive tool for monitoring intracranial pressure changes in astronauts during space missions. Pre-flight measurements in different body postures and probe fitting strategies based on the individual ear morphology are needed to validate and refine this approach.

Keywords Microgravity · Otoacoustic emissions · Middle ear transmission · Astronaut physiology

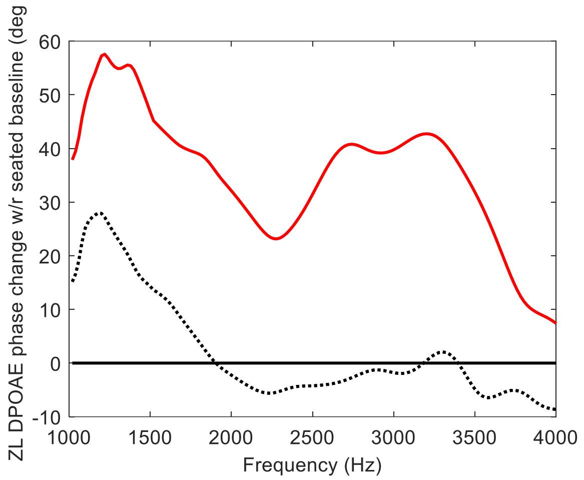
Using these advanced signal filtering tools based on cochlear mechanics improved the accuracy of the DPOAE phase estimates on the ISS, demonstrating significant ICP increase during spaceflight and full recovery after return to terrestrial gravity:

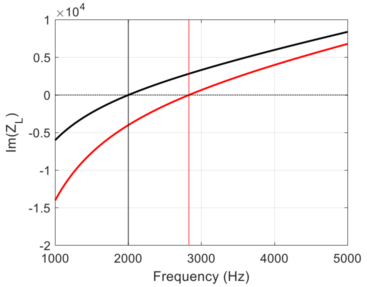


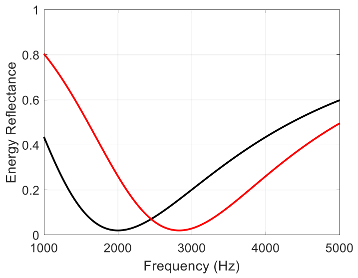


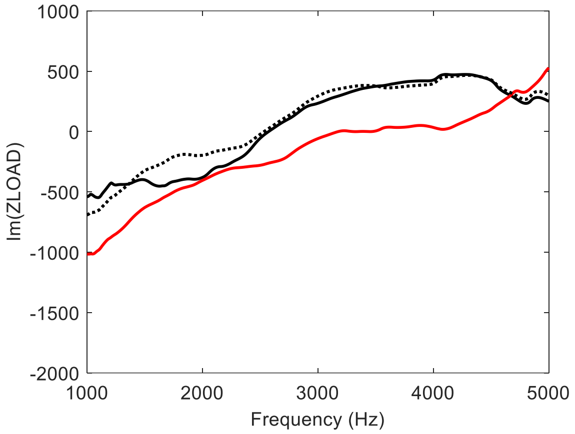


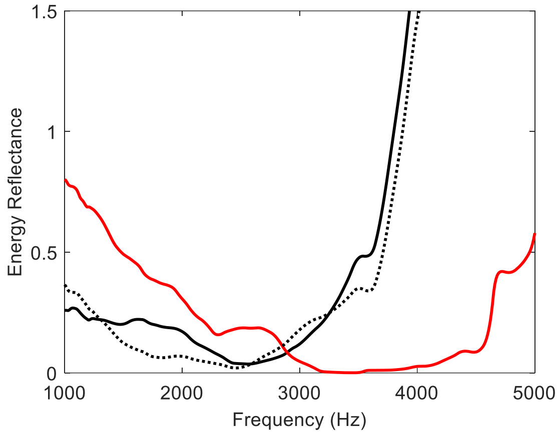
Results from Moleti et al, 2024











SAMPLE RESULTS – ISS SPACEFLIGHT EXPERIMENT

For Reflectance and Impedance

- Consistent changes of the three ICP indicators (DPOAE phase, the imaginary part of the load impedance the middle ear resonance frequency) in microgravity (red line) vs. pre-/post-flight (seated) data (black solid/dotted). Position is seated in the pre and post flight conditions

- Ground experiments showed that acoustic markers are less affected by posture variability than lumbar puncture (LP), which is an invasive method

EXPERIMENT AT CHU MONTPELLIER WITH PEDIATRIC POPULATION

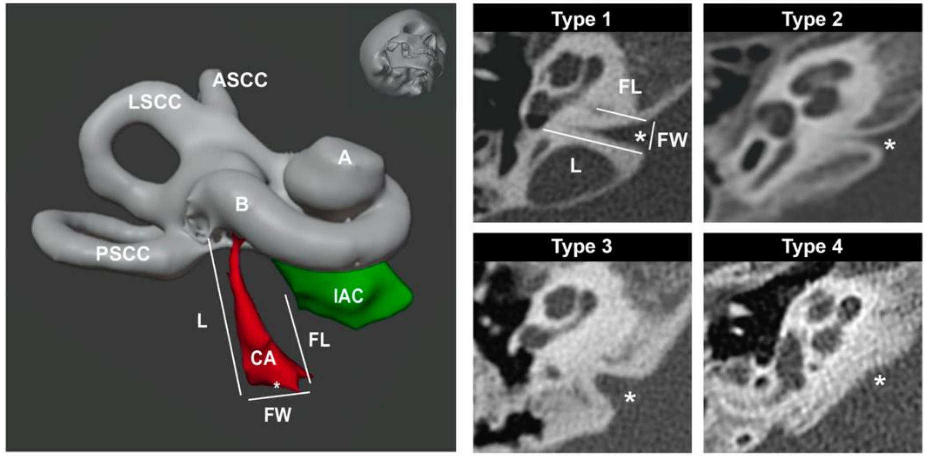
Increased patency of the Cochlear Aqueduct in the paediatric population *(Abbas, M., Wang, J., Leboucq, N. et al., 2024)*

CA is the connection between Cochlea and CSF. If ICP increases, it leads to increased Intra Cochlear Pressure.

Postures (High ICP Vs Low ICP)	2 postures: Vertical/ Tilted and Horizontal
Groups (normal hearing sensitivity)	<1; 1-2, 3-6; 7-10; 10-14, Adults

DPOAE Technique

- Swept-tone chirps: 500–16 kHz
- Stimuli: 65 & 55 dB, FPL-equalized
- High-resolution time-frequency analysis (wavelet-based)



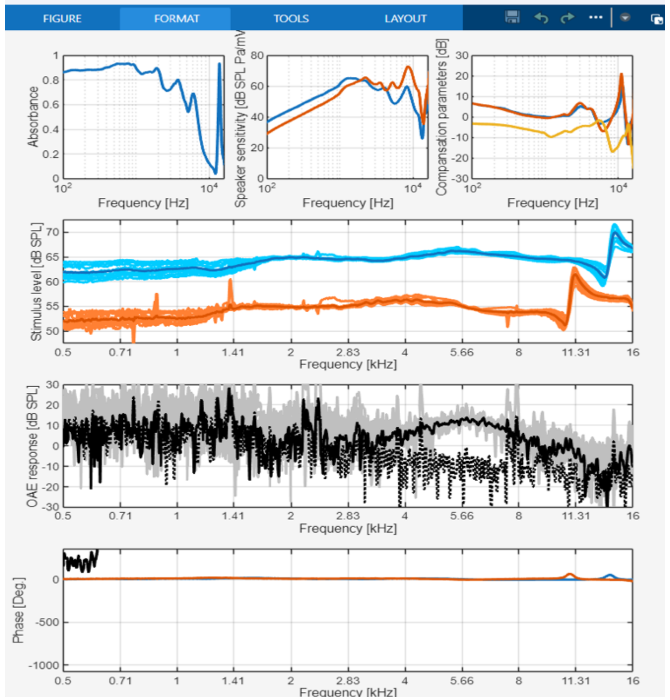
Data Analysis

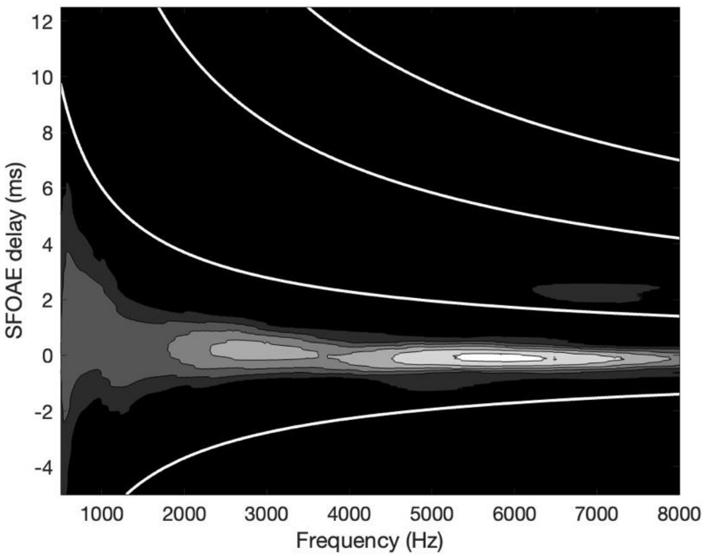
HIGH SNR DPOAE RECORDING

POST DATA COLLECTION (ESTIMATION OF DPOAE PHASE)

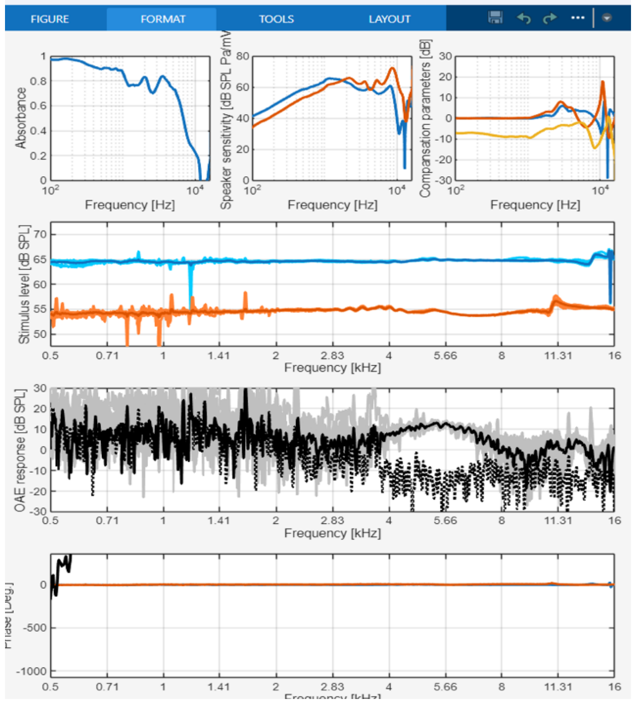
sample results (Seated (low ICP) vs Supine (high ICP))

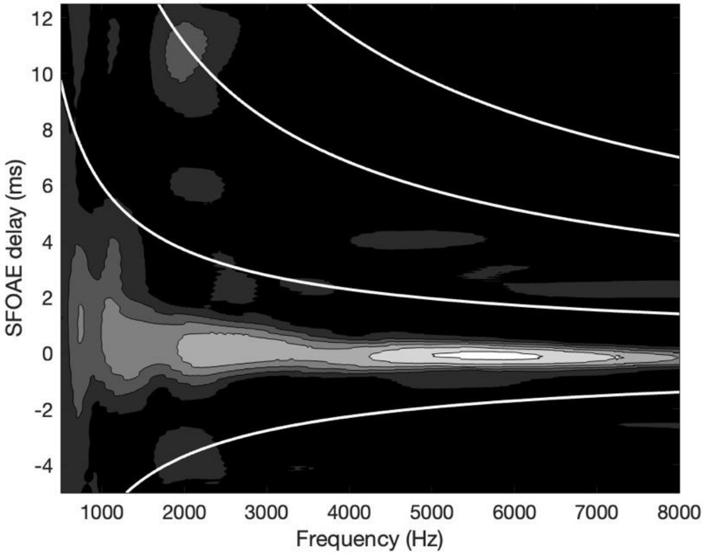
seated



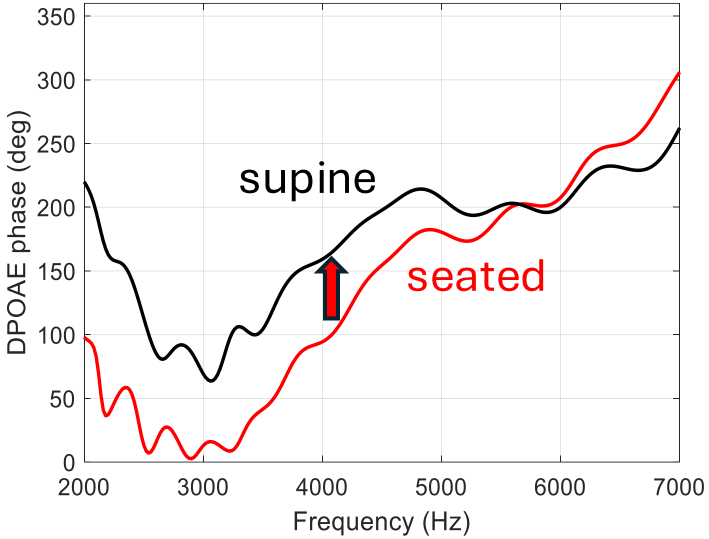


supine





DPOAE Phase



DISCUSSION

METHODOLOGICAL ADVANTAGES

- Non-invasive, objective technique
- Consistency among independent indicators (DPOAE phase, Middle Ear Reflectance, Imaginary part of the impedance) assesses reliability of the OAE phase increase as an indicator of increased ICP.
- Advanced filtering enhances specificity and reduces experimental uncertainties.

Conferences

Oral Presentation | Global Space Exploration Conference, New Delhi, India (07/05/2025)

- Otoacoustic Estimate of the Intracranial Pressure. Authors: **Yoshita Sharma**, Arturo Moleti, Triestino Minniti, Teresa Botti, Luigi Cerini, Filippo Sanjust, Renata Sisto

Oral Presentation | 75th International Astronautical Congress (IAC), Milan, Italy, (14-18 October 2024)

- Advanced audiological tools for non-invasive monitor of intracranial pressure in microgravity. Authors: Arturo Moleti, Triestino Minniti, Altea Russo, **Yoshita Sharma**, Andrea Civiero, Renata Sisto et al.

Poster Presentation | Auditory Science Meeting 2024 in Cambridge, United Kingdom (September, 2024)

- Advanced Otoacoustic Emission Acquisition and Analysis for the Objective Diagnostics of Hearing. Authors: **Yoshita Sharma**, Moleti A, Minniti, T, Botti T, Cerini L, Sanjust F, Sisto R.

Poster Presentation | Inner Ear Biology Conference 2024, Warsaw, Poland (September, 2024)

- Non-invasive monitoring of Intracranial Pressure changes: utilizing Otoacoustic Emissions. Authors: **Yoshita Sharma**, Moleti A, Minniti, T, Botti T, Cerini L, Sanjust F, Sisto R.

Publications and Conference Proceedings

Ongoing: **Sharma Y**, Sisto R, Moleti A, Botti T, Mishra S. Stimulus-Frequency Otoacoustic Emission delay measurements as a model-independent test of cochlear models.

Sharma Y, Moleti A, Minniti, T, Botti T, Cerini L, Sanjust F, Sisto R. Otoacoustic Estimate of the Intracranial Pressure. May 2025
DOI: 10.52202/080556-0012. Conference: Global Space Exploration Conference (GLEX 2025) At: New Delhi, India

Moleti A, Minniti T, Russo A, **Sharma Y**, Civiero A, Sisto R, et al. Advanced Audiological Tools for Non-Invasive Monitor of Intracranial Pressure in Microgravity. January 2024
DOI: 10.52202/078355-0014. Conference: IAF/IAA Space Life Sciences Symposium, Held at the 75th International Astronautical Congress (IAC 2024)

Moleti A, Minniti T, **Sharma Y**, et al. (2024) Otoacoustic Estimate of Astronauts' Intracranial Pressure Changes During Spaceflight. Journal of the Association for Research in Otolaryngology: JARO, 25(6), 563–573

Future Work - Plan for the Third Year

EXPERIMENT IN BELGIUM IN FEBRUARY 2026:

Test the method in **tinnitus and hyperacusis patients** to explore cochlear mechanics and middle ear transmission changes.

EXPERIMENT AT GEMELLI UNIVERSITY POLICLINICO:

Calibrate the OAE–ICP relationship during **controlled ICP changes** in neurosurgical patients during neurosurgeries.

TO BE FUNDED BY ITALIAN SPACE AGENCY:

To refine the OAE technique in microgravity for **astronauts using customised earplugs**.

TO BE FUNDED BY ITALIAN SPACE AGENCY:

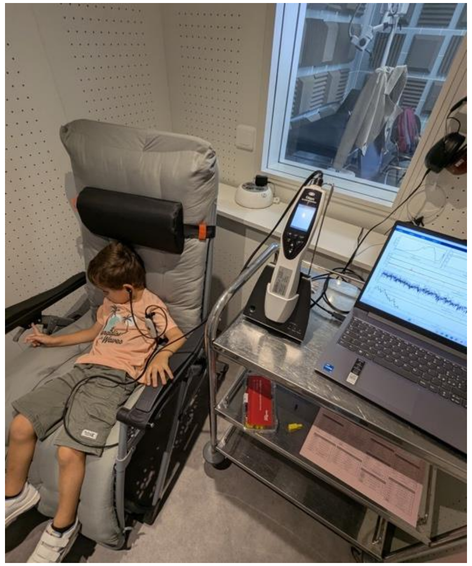
Perform **bedrest study** to monitory long-term ICP elevation on Earth using OAEs.

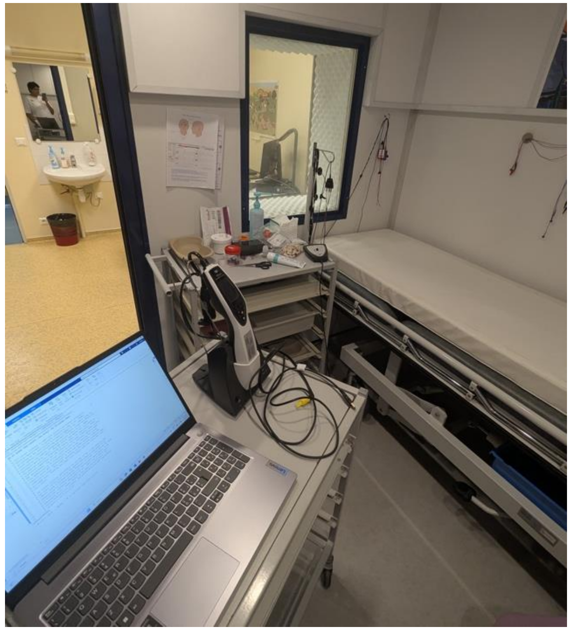
EXPERIMENT AT FONDAZIONE BIETTI:

Apply the technique to **glaucoma patients** with elevated ICP for clinical validation.

Academic Visits

Period Abroad for **2 months** in **CHU, Montpellier, France** from 29th July 2025 to 5th October 2025





ACKNOWLEDGMENTS & REFERENCES

Key references:

1. *Moleti, A., Minniti, T., Sharma, Y., et al. (2024) Otoacoustic Estimate of Astronauts' Intracranial Pressure Changes During Spaceflight. Journal of the Association for Research in Otolaryngology: JARO, 25(6), 563–573*
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3. *Pedersen SH, Andresen M, Lilja-Cyron A, et al. (2021) Lumbar puncture position influences intracranial pressure. Acta Neurochir (Wien) 163 1997–2004*
4. *Abbas, M., Wang, J., Leboucq, N. et al. Cochlear Aqueduct Post-Natal Growth: A Computed Tomography Study. JARO 25, 611–617 (2024).*

THANK YOU FOR YOUR ATTENTION

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