Ears Project Newsletter No 4

January 2014

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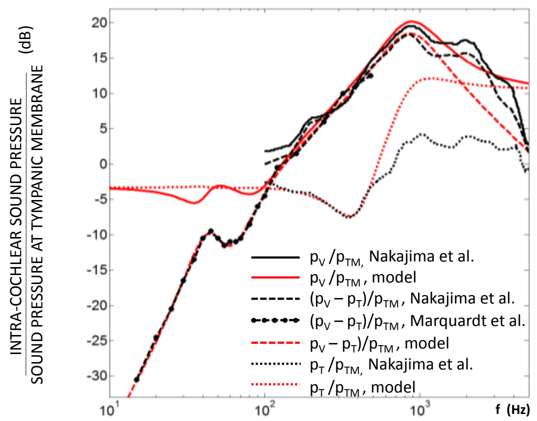

Measured and simulated sound pressures in the inner ear relative to the ear canal (see page 2).

Welcome

The first half of the project "*Metrology for a universal ear simulator and the perception of non-audible sound*" (*EARS*) is over and we are pleased to present the fourth newsletter. The project has made serious progress in different parts of the work and several aspects are presented within this newsletter.

The newly developed infrasound source was successfully applied to the determination of hearing thresholds in the frequency range between 1 and 20 Hz. First measurements for the determination of brain response thresholds in this frequency range were carried out too. The designing phase of the new ear simulator was completed and a challenging proposal was developed which for the first time includes parameters of anatomical structures into the construction. The manufacturing of the first prototype is now under way.

An important issue of this project is the dissemination of the knowledge achieved. An important component of this process is the organization of two international workshops on 26 March 2015 in Teddington and on 16 April 2015 in Berlin. We cordially invite you to join us and to take these dates to your diaries.

I hope you find the newsletter valuable, and that you enjoy the material we present in this issue. As always, we are interested to keep in contact with you as stakeholders, users, or interested persons, so please do not hesitate to contact us.

Christian Koch
Coordinator

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News and facts

- The new researcher excellence grant (REG) for determination of brain responses using fMRI has been awarded to Max-Planck institute for Human Development.
- Two international workshops will be organised in Teddington and Berlin to discuss and publish the results of the EARS project, see section *Dissemination* of this newsletter.
- Wolfson Inc. became a new collaborator of the EARS project for intensifying the project work in development of MEMS transducers.
- The next project meeting will take place in Berlin on 28/29 April 2014. Collaborators are invited to join the second day of the meeting. Registration details will be sent out shortly.

Highlights from the work packages

A simple electrical lumped-element model simulates intra-cochlear sound pressures and cochlear impedance below 2 kHz

In order to better understand the perception of low-frequency sounds, an electrical analog of the principle acoustical properties of middle and inner ear below 2 kHz has been developed.

In a first step the model parameters were determined by fitting to available physiological data measured in cats and guinea pigs. With the aim to simulate the human ear, the model was then tuned to fit human data (see figure at title page). Published data from human cadaver ears show cochlear input impedance and intra-cochlear pressures for scala tympany (p_T) and scala vestibuli (p_V), however, only down to 100 Hz (Nakajima et al. 2008). To verify the model parameters down to 10 Hz, these absolute pressure data were combined with the shape of the middle-ear transfer function, defined here as the differential pressure across the cochlear partition (p_{V-T}) divided by the pressure in the ear canal (p_{TM}). This shape was derived from non-invasive measurements in human ears between 15 Hz and 450 Hz, which were based on the suppression of otoacoustic emissions (Marquardt et al., 2007). Alignment of the two data sets allowed an extrapolation of the absolute pressure data by Nakajima and colleagues, and, for the first time, an estimation of the cochlear input impedance down to 10 Hz.

Of great importance for understanding low-frequency hearing is to study the effects of the helicotrema, a small opening at the apical tip of the cochlea that connects the fluid chambers on either side of the cochlea partition. At acoustic stimulation below approximately 50 Hz, the wave, travelling along the cochlear partition, reaches the helicotrema, and the differential pressure between both fluid chambers is shunted. This is generally assumed to underlie the sharp decline of human hearing sensitivity below 50 Hz. Our simulation confirmed this assumption and showed that the often experimentally observed resonance-feature around this transition frequency is a combination of two resonance phenomena. The resonance at 40 Hz is caused by an interaction between the compliant apical end of the cochlear partition and the mass inertia of the fluid within the helicotrema. The anti-resonance at 60 Hz is due to an interaction

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of this apical compliance with the inertia of the fluid in the cochlear chambers located basally.

It has previously been shown that this resonance feature can affect the loudness perception of low-frequency tones. The model will therefore be the basis of a physiologically motivated loudness model for low-frequency sounds, which will be developed within the framework of this JRP. Further details to the model can be found in the Journal of the Acoustical Society of America (Marquardt and Hensel, 2013).

Marquardt and Hensel (2013). J. Acoust. Soc. Am. 134, 3730–3738.
Marquardt et al. (2007). J. Acoust. Soc.Am. 121, 3628–3638.
Nakajima et al. (2008). J. Assoc. Res. Otolaryngol. 10(1), 23–36.

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Ear simulator design: Dimensions and tolerances

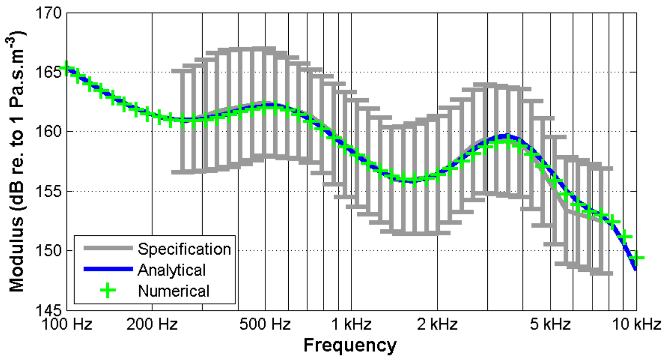
Following the design approach developed within the project frame before, the present working step consists in matching the acoustic input impedance of the new simulator to that of an average of real ears for each of the five identified age groups.

This is done by imposing the appropriate acoustic impedance near the microphone location of the ear simulator. The matched impedance is produced by means of a sophisticated network of Helmholtz resonators.

Both, an analytical model and a numerical model of the ear simulator have been developed in order to determine the dimensions of the Helmholtz resonators. Note that these models take into account the thermal and viscous boundary layer effect.

The modulus (in dB re Pa.s.m^{-3}) of the acoustic input impedance of the ear simulator as a function of frequency (in Hz) for the neonates group is shown in the figure below. Both, the analytical result (blue solid line) and the numerical results (green crosses) show a good agreement with the average input impedance of neonates' ears (gray solid line) between 250 and 8000 Hz.

During the project work five occluded ear simulators (one for each age group) have been designed and dimensioned, and the mechanical tolerances have been determined using a Monte-Carlo simulation.



Modulus (in dB re. to 1 Pa.s. m^{-3}) versus frequency of the acoustic input impedance of the ear simulator for the neonates group. Gray curve: Specifications and standard deviation. Blue curve: Analytical model. Green crosses: Finite element model.

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Threshold of hearing for low and infrasound frequencies

Our hearing threshold measurements link the existing normative threshold data (above 125 Hz) to values in the lower audible frequency range (20 Hz to 125 Hz) and even down to threshold values in the so-called “inaudible” infrasound region (2.5 Hz to 20 Hz).

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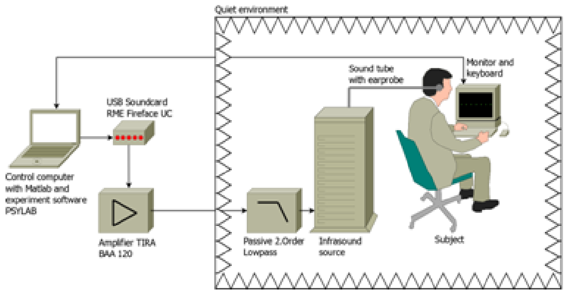
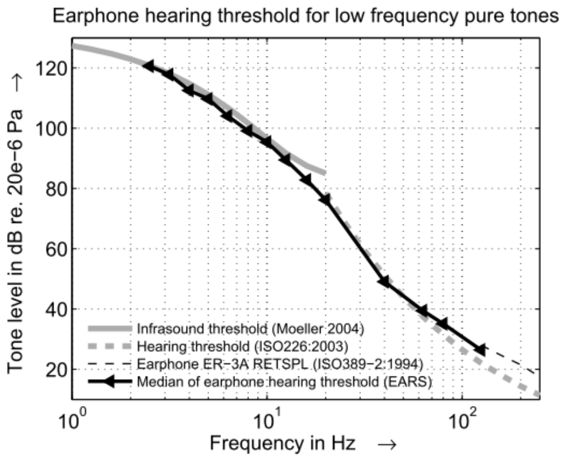
ISO 389-2 defines the reference equivalent threshold sound pressure levels (RETSPL) for pure tones between 125 Hz to 8 kHz for insert earphones. Below 125 Hz no standardized RETSPL values for insert earphones exist up to now. Hence, monaural hearing threshold measurements were performed with 18 otologically normal female and male subjects aged between 18 and 25 years. The measurements took place in an anechoic room as depicted below. The newly developed insert earphone infrasound source (c.f. newsletter no. 3) was used. The thresholds for pure tones were determined at 14 frequencies for the better ear of each subject using a 2-alternative-unforced-choice method. Within this method the weighted up-and-down rule for the 75%-correct-point on the psychometric function was used. The duration of the stimuli was 600 ms - 4000 ms, depending on frequency.



Setup for the measurement of the insert earphone hearing threshold for low and infrasound frequencies

The measured hearing thresholds as a median over 18 ears are shown below (bold solid black line). For a hearing sensation at 125 Hz via earphone a median SPL of 26.4 dB was required. At 2.5 Hz the threshold level was about 94 dB higher: 120.7 dB SPL. A good agreement was found with literature data in both the audible (ISO 226, ISO 389) and the infrasonic frequency range (Moeller and Pedersen [1]).



Determined hearing threshold from 125 Hz down to 2.5 Hz (black line). The gray lines show the free field threshold (broken line) and the estimated threshold for infrasound frequencies from literature [1] (solid line).

[1] Moeller, H. and Pedersen, C.S. (2004); "Hearing at Low and Infrasonic Frequencies", Noise & Health, Vol. 6, No. 23, 37-57

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Dissemination of work

One of the cornerstones of the EMRP is that research projects should *create impact and benefits* for its stakeholders. This section provides a summary of recent dissemination activities.

Two workshops are being planned to consolidate the project dissemination and target particular user groups.

The first workshop will be on the development and application of the universal ear simulator and will be held at NPL, Teddington on 26March 2015. It will introduce users to the device and the concepts that provide for its universal application, and will give users their first hands-on experience with it.

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A second workshop on "Non-audible infra- and ultrasound" is to be held at PTB in Berlin on 16 April 2015. The workshop will present the state of art in psychoacoustics, audiology, and brain imaging of the perception of infra- and ultrasound.

Interested parties from acoustics, audiology, neuroimaging, and psychology are cordially invited. Detailed announcements of both events will follow in the next newsletter.

Presentations

The project team has been particularly active in presenting aspects of the project and progress on specific technical aspects, at a range of scientific conferences and key metrology meetings.

The project featured strongly at InterNoise 2013

Salvador Barrera-Figueroa presented a paper on extending the frequency range of free-field reciprocity calibration of measurement microphones to frequencies up to 150 kHz, which plays an essential part in ensuring all measurements and information derived in the project have a robust scientific foundation.

Dominique Rodrigues presented the design methodology that was developed in the process of specifying the universal ear simulator design, and Thomas Lavergne followed with a presentation of how the methodology was applied to take the specification through to the actual design details of the universal ear simulator.

Martin Bauer presented a poster on the development of a biomagnetic head phantom to investigate deep auditory brain stem sources at the International Conference for Basic and Clinical Multimodal Imaging, and a second poster on magnetoencephalography of deep lying auditory sources using acoustical devices for infra- and ultra-sound stimulation at the BMT conference on biomedical engineering in Germany.

Richard Barham also presented an update on the project to a peer group of metrologists at the CCAUV, the major international meeting on metrology in the acoustics ultrasound and vibration field, at the International Bureau of Weights and Measures (BIPM).

The first journal papers have been published and many are now in preparation. For the latest references please see the project website:

http://www.ears-project.eu/emrp/ears.html

Business card of partners:

In this column of every newsletter we will introduce one of the institutes of the consortium to you. Today: Laboratoire national de métrologie et d'essais (LNE), France.

By developing new measurement techniques and methods and applying them via appropriate standards in all spheres of daily life, LNE plays a key role in promoting a more competitive economy and a safer society. This core activity covers eight key spheres – research and technology transfer, testing and calibration, technical assistance, certification, training and informing – and addresses the

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eight major priorities: safety and health, environmental impact, performance, product reliability, and cost control.

Set up in 1901 to provide services to industry, LNE was initially part of the CNAM technology and research institute. Under a 1978 consumer protection law it became a state-owned enterprise, attached to the French Ministry of Industry. As a reference laboratory, LNE is responsible for helping society to evolve and advance. Its mission is to improve the competitiveness of companies while respecting stringent requirements on consumer safety, public health, environmental protection, and energy management. In 2005 the Laboratory was entrusted with coordinating the French metrology network and representing it in an international context.

The LNE acoustics department is involved both in metrology and in machinery noise measurements. Through its mission of dissemination of metrological standards to the society and industry, LNE is active in a variety of fields in acoustic metrology as pressure and free-field calibration of microphones using primary and secondary methods, type approval and calibration of sound level meters, sound calibrators and audiometers.

LNE's research on Acoustics is heavily oriented to improving calibration methods by working around 3 axes: Experimentation, signal processing and acoustic modeling. The synergy between our core capability and the goals of the EARS project makes LNE the ideal partner to lead WP4.

Visit LNE at http://www.lne.fr

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