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## The sound field in life-size replicas of human ear canals occluded by a hearing aid

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In addition to the longitudinal sound pressure distributions that form in the human ear canal, large transverse variations can arise in the vicinity of an occluding hearing aid. These effects are being studied, numerically and experimentally, making use of a set of life-size ear canal replicas. Digital representations of real ear canal geometries were used as input to a polyjet fabrication process to form replicas with a spatial accuracy of better than 0.1 mm. A hearing aid test fixture, with vent, receiver and an inner microphone, occludes the replica canal and provides the acoustical input. The sound field inside the canal is measured using a specially-designed 0.2 mm o.d. probe microphone. In parallel, the three-dimensional interior sound field is calculated using a boundary element method (BEM) that inputs the same ear canal geometry as the replicas and accounts for the acoustical boundary conditions presented by the eardrum and the hearing aid. In the current series of ear canal replicas, the eardrum is rigid. Measurements and calculations are in good agreement. Large transverse variations of sound pressure level, as much as 20 dB at 8 kHz, are observed across the inner face of the hearing aid, particularly near the receiver and vent ports.

## 1 Introduction

We are considering the system, shown in Fig. 1, for which a hearing aid is located in a human ear canal. The hearing aid microphone picks up sound and the receiver emits a processed version of the acoustic signal into the ear canal. To avoid occlusion effects, a vent is generally necessary. We also consider the possibility that a second inner microphone could be squeezed into the aid, with the task of actively reducing the occlusion effect [1].

Our interest is in the spatial variations of sound field within the ear canal. A previous series of measurements [2], using a simple model ear canal, suggested that dramatic transverse variations of sound pressure could occur within a few mm of the inner face of the hearing aid. In this article, we extend our investigations to realistic ear canal geometries. Replica ear canals have been fabricated, making use of previously-determined ear canal geometries [3], and the interior sound fields measured with a 0.2 mm o.d. probe microphone [4].

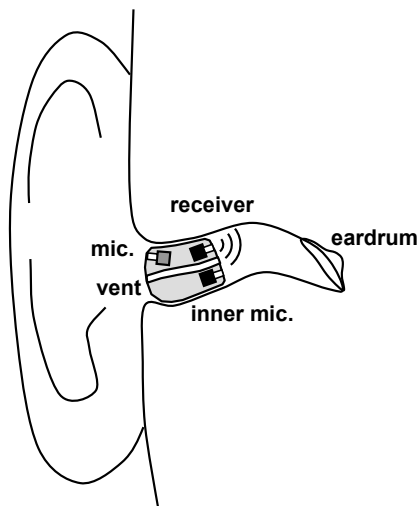


Fig.1 Sketch of a human ear canal with a stylized hearing aid in place, showing microphone(s), receiver, and vent.

## 2 Measurement procedure

The measurement approach is shown in Fig. 2. A replica ear canal is fabricated with inner surfaces having a prescribed geometry. A hearing aid test fixture slides snugly into the base of the replica: it contains a receiver that

generates an acoustic signal and a vent (2.2 mm i.d., 20 mm long). It also contains an inner microphone but this was found not to affect the interior sound field significantly [2]. The openings of the three ports are arranged in an approximately triangular fashion. The interior sound field is measured using the 0.2 mm probe microphone [4] that enters the replica through access holes in the side of the replica.

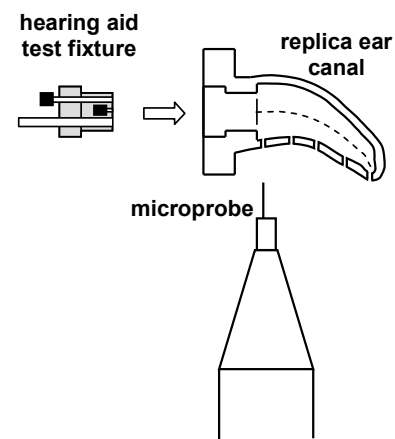


Fig.2 Measurement approach.

Six replica ear canals were fabricated using a polyjet method. The inner replica geometries were based on canal geometries determined previously [3]. This original data consists of sets of approximately 1000 position points that define the surface of each cadaver ear canal mold. Smooth surfaces patches were "shrink-wrapped" around these, for each canal, saved in IGES format files, and used for subsequent manipulation. The interior volumes were truncated at the assumed position of the inner face of a hearing aid. Three of the replicas were based on the same ear canal but truncated at different positions corresponding to shallow, average and deep insertion of an aid. The other replicas were chosen to represent different widths and curvatures of ear canals. Using Altair HyperMesh, a shell was created around the canal volume and a base incorporated. The final surfaces were meshed to produce STL files that were submitted to Redeye Prototyping for fabrication. Subsequently, the 0.2 mm access holes were drilled and the opening for the test fixture machined in-house.

For measurements, replica canals were mounted on a turntable that rotates about a horizontal axis. Figure 3 shows a photograph of this arrangement for replica canal 3L. The series of access holes is just visible along the left

side (as viewed) of the replica canal. The microprobe is poised nearby.

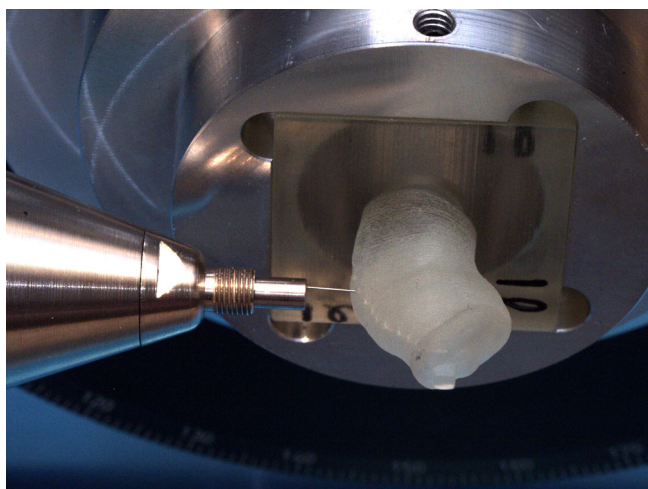


Fig.3 A replica ear canal mounted on the turntable, with microprobe nearby.

The microprobe assembly is attached to a 3-axis motorized translation stage. Frequency responses were obtained at each measurement position using a Stanford Research SR785 analyzer. The spectra contain 1024 frequencies logarithmically spaced from 200 Hz to 10 kHz. Subsequently, data for specific frequencies is pulled out for various positions to generate the spatial pressure distributions. To aid in the positioning of the microprobe, two video cameras are used to display enlarged views of the microprobe and replicas on monitors. A photograph of this apparatus is shown in Fig. 4.

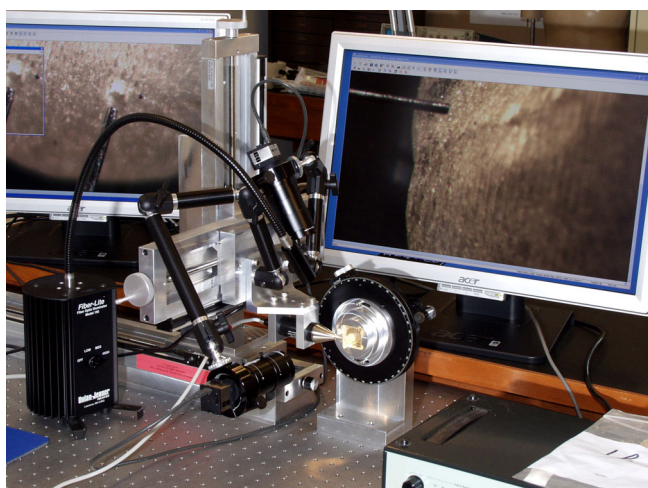


Fig.4 The measurement system, showing replica canal, microprobe assembly, video cameras and display monitors.

### 3 Numerical predictions

In parallel with the measurements, numerical calculations of the interior sound fields were performed. The boundary element method was applied, using the LMS SYSNOISE application. The boundary element mesh started with the mesh used for the fabrication, keeping only those elements corresponding to the inner ear canal surface, then created new elements to represent the inner face of the hearing aid test fixture. The mesh elements used for the BEM

simulations for replica canal 3L can be seen in Fig. 5. Close examination will reveal three circular areas of element at the entrance end corresponding to vent, receiver port and inner microphone.

Appropriate boundary conditions need to be prescribed. The elements representing the receiver port have been assigned a uniform velocity boundary condition; this generates the internal sound field. The outward looking impedance of the vent was calculated analytically, accounting for viscous and thermal boundary losses and an unflanged termination, and the elements representing the vent assigned the appropriate admittance. Previous work [2] has shown that the inner microphone port has little impact on the sound field, so elements here were assumed rigid. Note that no admittance conditions have been applied to elements at the eardrum position – we are assuming a rigid eardrum.

Fig. 5 shows the results of a calculation at 8 kHz for this canal. The sound pressure on the canal walls is shown according to the color scale. The longitudinal variation of sound pressure is evident, following the curvature of the ear canal. In addition, there are large transverse variations across the face of the hearing aid. High values of sound pressure (red elements) are evident in the vicinity of the receiver port and low values (blue elements) are evident in the vicinity of the vent.

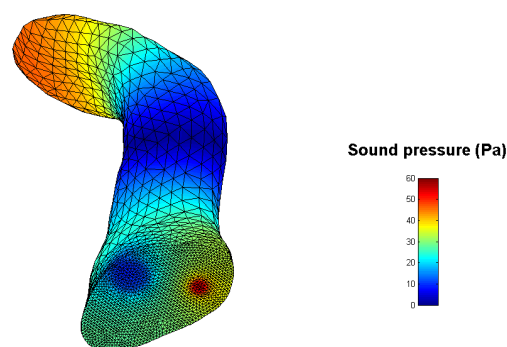


Fig.5 Sample result showing mesh elements for the interior problem indicating the sound pressure at these elements.

## 4 Results

The results are considered here in more detail for replica canal 3L. This canal is 25 mm long, along a curved center axis. The variation of SPL along this longitudinal center axis is shown in Fig. 6, at sound frequencies of 2, 4 and 8 kHz. Measured values are shown as open circles, calculated values as the smooth curves. Theory and experiment are in good agreement. The deep standing wave minimum that is present at higher frequencies arises because of the rigid eardrum assumption, i.e., there is no absorption of sound at this end of the canal.

Significant transverse variations of sound pressure were found at the entrance end of the canal, within a few millimeters of the face of the hearing aid. In Figs. 7 and 8, the transverse variations are shown along radial trajectories at a longitudinal position 0.2 mm away from the hearing aid.

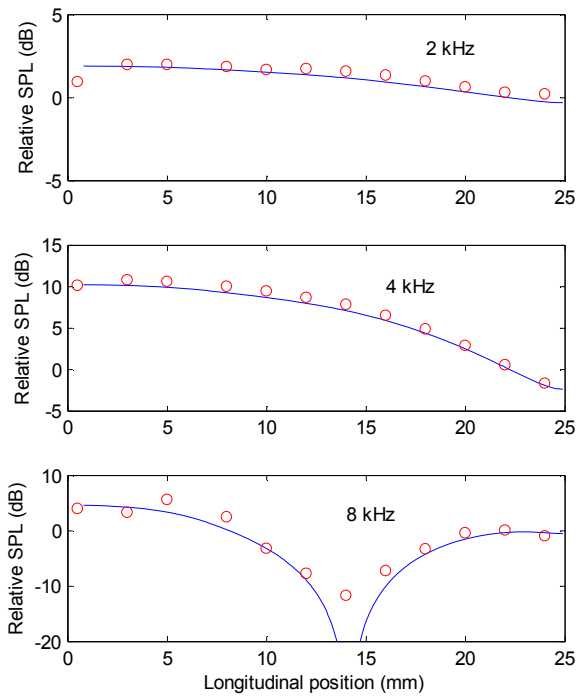


Fig.6 Longitudinal sound pressure variation in ear canal replica 3L. The inner end of the canal is at position 0 mm and the face of the hearing aid is at 25 mm.

The results in Fig. 7 are along a line that passes over the receiver position. Very large differences in SPL occur over just a few mm, as much as 20 dB at 4 kHz for this canal.

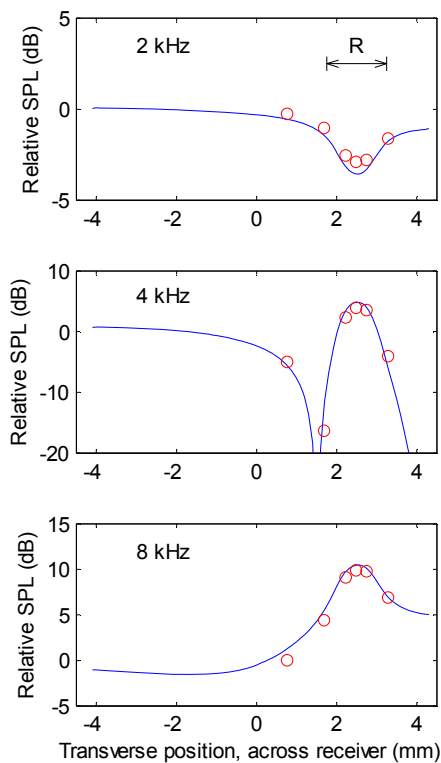


Fig.7 Transverse sound pressure variation in ear canal replica 3L, through a diameter that passes across the receiver.

The largest variations are in the immediate vicinity of the receiver port. The variations in magnitude are accompanied by variations in phase (not shown). For the 4 kHz results, there is a phase change of 180° going through the null at the 1.5 mm position. Theory and measurements are in nice agreement.

Fig. 8 shows the results along a radial line that passes across the vent. Variations of 5 dB are noted at the higher frequencies.

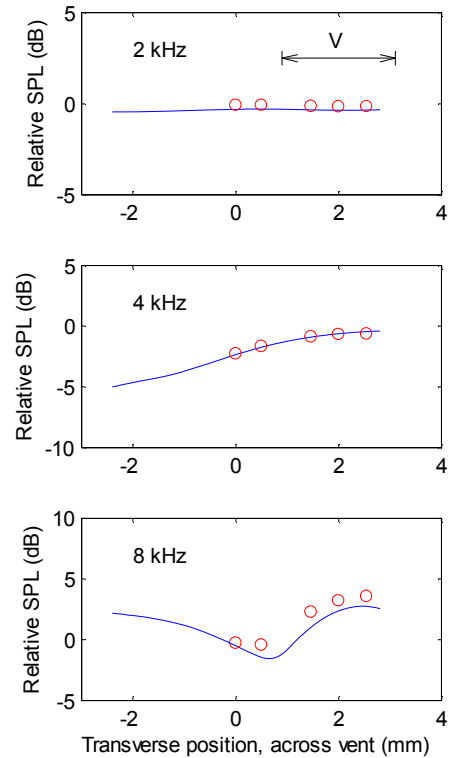


Fig.8 Transverse sound pressure variation in ear canal replica 3L, through a diameter that passes across the vent.

## 5 Discussion

Similar results have been obtained for the other replica ear canals tested, with comparable transverse variations of up to 20 dB being found at the higher frequencies. These other replicas represent a wide range of geometries, some canals being shorter, some being wider, some having more curvature along their length. It is noted that significant variations in the phase component of pressure are also found but not shown here.

These transverse variations would need to be considered in the implementation of an active system for reduction of the occlusion effect. An inner microphone would pick up different signals depending on its location. The variations could also impact on the presumed transfer function from receiver to eardrum.

The results shown here correspond to a rigid eardrum condition. It is known, though, that there is absorption of acoustic energy at the eardrum and the assumption needs to be revised. A new series of replica ear canals that incorporates realistic eardrum absorption is currently being fabricated.

## Acknowledgments

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## References

- [1] J.G. Ryan, B. Rule, S.W. Armstrong, "Reducing the occlusion effect with active noise control", *J. Acoust. Soc. Am.* 119, 3385 (2006)
- [2] M.R. Stinson, G.A. Daigle, "Transverse pressure distributions in a simple model ear canal occluded by a hearing aid test fixture", *J. Acoust. Soc. Am.* 121, 3689-3702 (2007)
- [3] M.R. Stinson, B.W. Lawton, "Specification of the geometry of the human ear canal for the prediction of sound-pressure level distribution", *J. Acoust. Soc. Am.* 85, 2492-2503 (1989)
- [4] G.A. Daigle, M.R. Stinson, "Design and performance of a microprobe attachment for a 1/2-in microphone", *J. Acoust. Soc. Am.* 120, 186-191 (2006)