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Introduction

an improper probe fit [1].

ments.

Methods

methods of in-situ calibration for acoustic probe measure-

ments are undergoing rapid innovation. Normative values for

these wideband measures are emerging and being reported

as acoustic absorbance. Acoustic absorbance is a measure of

how much sound power is absorbed by the middle ear, as op-

posed to how much is reflected back into the ear canal and

recorded at the probe. These measurements are later utilized

in stimulus corrections for other measurements of auditory

function, such as otoacoustic emissions (OAEs) and behavior-

al thresholds. The validity of these estimates of middle ear

and cochlear function can be compromised by leaks due to

by Keefe et al. (1993) [2] when high power reflectance was

measured at frequencies below 0.5 kHz. Later, Groon et al.

(2015) [3] determined that air leaks could be reliably detected

using low-frequency absorbance measures in the frequency

band between 0.1 and 0.2 kHz, with average absorbance of

0.2 or higher suggesting a leak. Such a method for the detec-

tion of air leaks may be used to alert clinicians and experi-

menters to the presence of a leak allowing for the probe to be

reseated to achieve an air-tight seal for optimal measure-

absorbance from a relatively large sample of human subjects.

We also investigate the utility of these ear canal acoustic mea-

• In-situ calibrations with an ER10B+ (Etymotic Research, Inc)

probe were performed on 432 human subjects (Table 1

Acoustic immittance characteristics were estimated from 0.1

to 10 kHz. Ear canal length and volume were estimated from

the sound pressure recorded in the ear canal. The stimulus

was a digitally generated, wideband, linear-swept, frequency

The presence of an air leak was suspected when absorbance

at low frequencies (A<sub>Low</sub>) was 0.2 (-7 dB) or higher based on cri-

teria recommended by Groon et al. (2015) [3]. A<sub>low</sub> was calcu-

lated by averaging the respective quantities over 0.1 to 0.2

Behavioral thresholds (21 frequencies from 0.125 to 20 kHz)

[4] and distortion product otoacoustic emissions (DPOAEs)

 $(L_1/L_2=75/75 \text{ dB FPL}, f_2/f_1=1.22, f_2 \text{ frequencies from } 0.75 \text{ to } 20$ 

kHz)[5] were obtained using stimuli calibrated in forward

pressure level (FPL) [6]. Thresholds, DPOAE levels, and noise

floor levels from subjects aged 55 to 65 years were examined

to determine potential consequences of air leaks due to inad-

equate seals of the probe tip in the ear canal.

shows the breakdown of gender and age groups).

chirp with a sampling rate of 44.1 kHz.

sures in determining goodness of the probe seal in the canal.

Here we report ear canal characteristics and wideband

The effect of a good probe seal in adults was observed

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Background. Wide frequency band measures of middle ear transmission and methods of in-situ calibration for acoustic probe measurements are undergoing rapid innovation. Normative values of wideband acoustic immittance (WAI) are emerging as are population characteristics of different types of otoacoustic emissions. All of these measures are only valid and reliable when the measurement probe is tightly sealed in the ear canal. Air leaks can compromise the validity of the measurements, interfere with calibration, and increase variability. Here we report ear canal characteristics and WAI from a relatively large sample of human subjects. We also investigate the utility of these ear canal acoustic measures in determining goodness of the probe seal in the ear canal.

**Methods.** In-situ calibrations of a custom acoustic probe were performed in 432 human subjects between the ages of 10 and 68 years. Acoustic immittance characteristics were estimated between 0.1 to 10 kHz. Ear canal characteristics (e.g., length and volume) were also estimated from each ear evaluated. Finally, various acoustic properties were examined to determine the presence of air leaks due to inadequate seals of the probe tip in the ear canal.

Results. The influence of age and gender on ear-canal geometry and WAI measures will be reported. Additionally, admittance and absorbance will be used to assess and characterize the presence of acoustic leaks marking suboptimal probe seals. Conclusions. These results will add to the extant information about normative values for WAI measures as well as provide critical information about the dependence of these measures on age and gender. Markers of failed or suboptimal probe seal in the ear canal can also be useful in automatic flagging so the clinician has an opportunity to revise the probe seal prior to initiating clinical measurements. Such warning systems will improve the quality of data collected.

### Acknowledgements

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product otoacoustic emission in a normal hearing population. The Journal of the Acoustical Society [6] Souza, N. N., Dhar, S., Neely, S. T., & Siegel, J. H. (2014). Comparison of nine methods to estimate

ear-canal stimulus levels. The Journal of the Acoustical Society of America, 136(4), 1768-1787. [7] Rasetshwane, D. M., & Neely, S. T. (2011). Inverse solution of ear-canal area function from reflectance. The Journal of the Acoustical Society of America, 130(6), 3873-3881.

# Wideband measures of the ear canal and middle ear properties: Quality Markers for Probe Fit

## Results

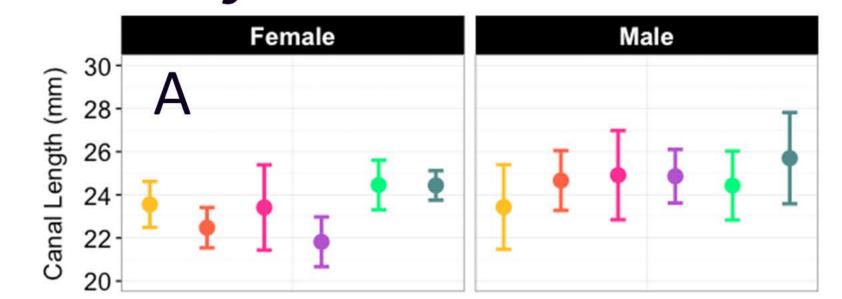
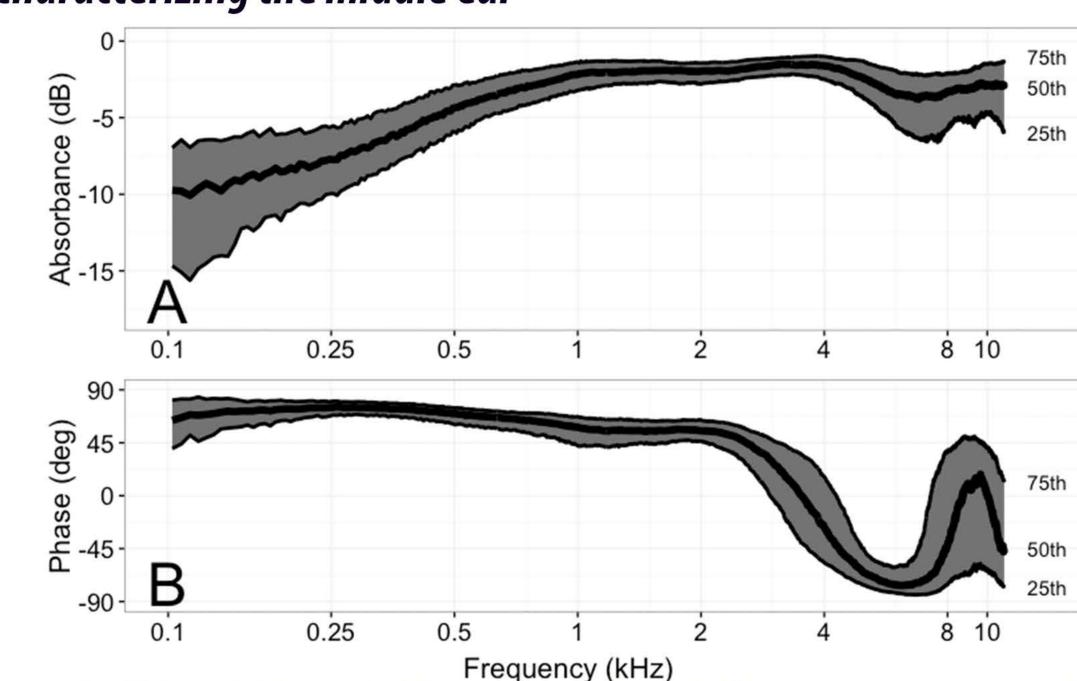
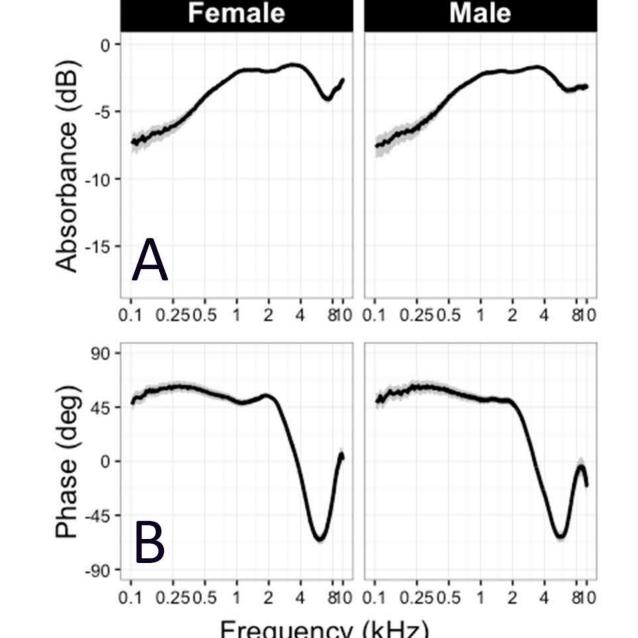


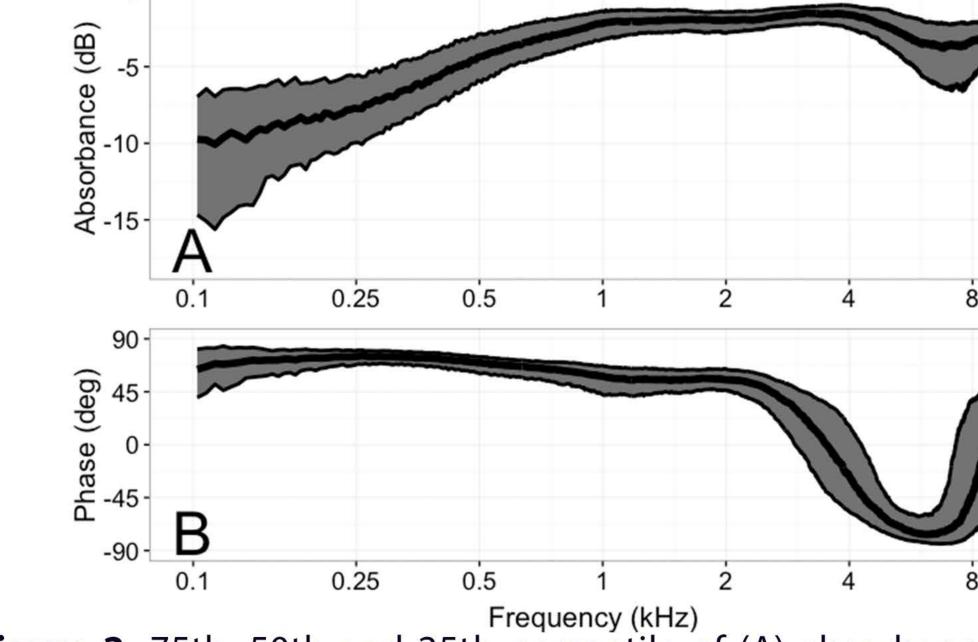


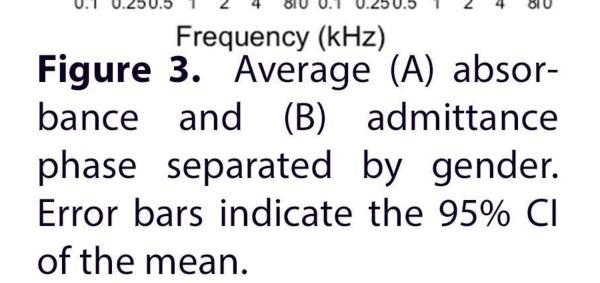
Figure 1. (A) Average ear canal residual length determined using sound propagation delay from the plane of the probe to the eardrum measured using the autocorrelation of the time-domain pressure measurement. (B) Average ear canal volume for acoustic admittance which takes acoustic measurements at the entrance of the ear canal and calculated reflectance in the time domain to determine the cross-sectional area of the ear canal as a function of axial distance from the eardrum [7]. Error bars indicate 95% CI of the mean.

## 2. Characterizing the middle ear









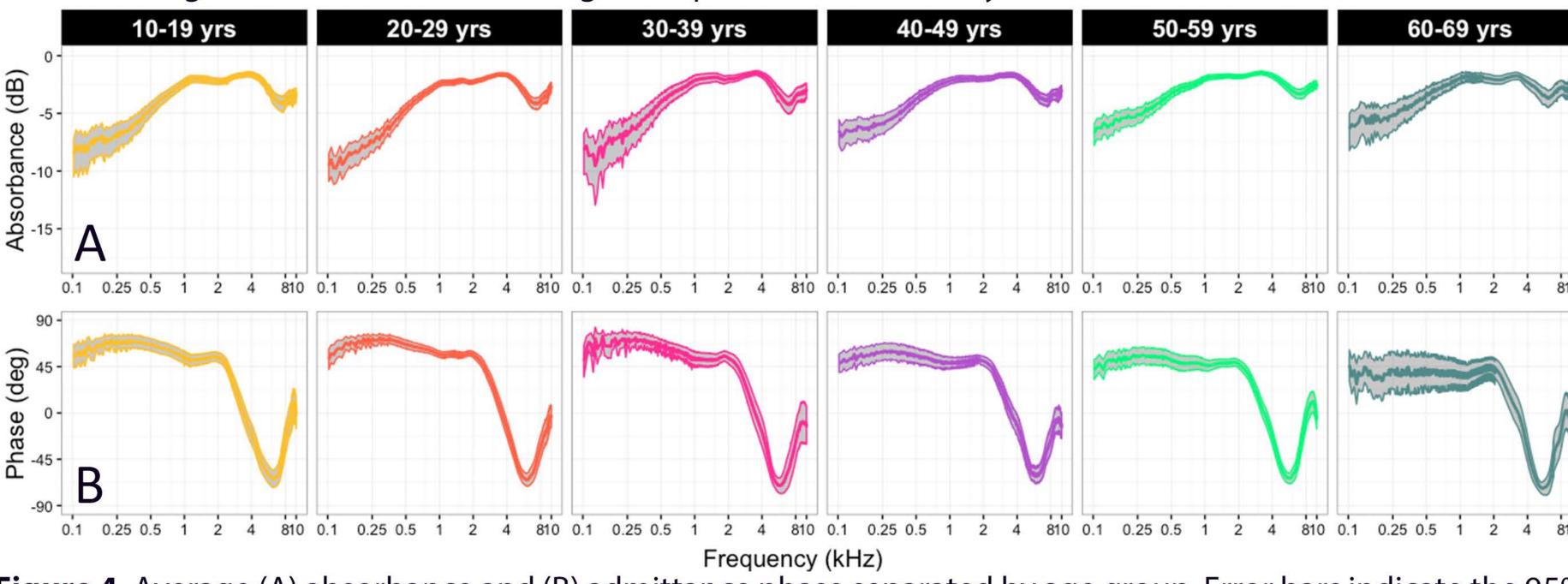
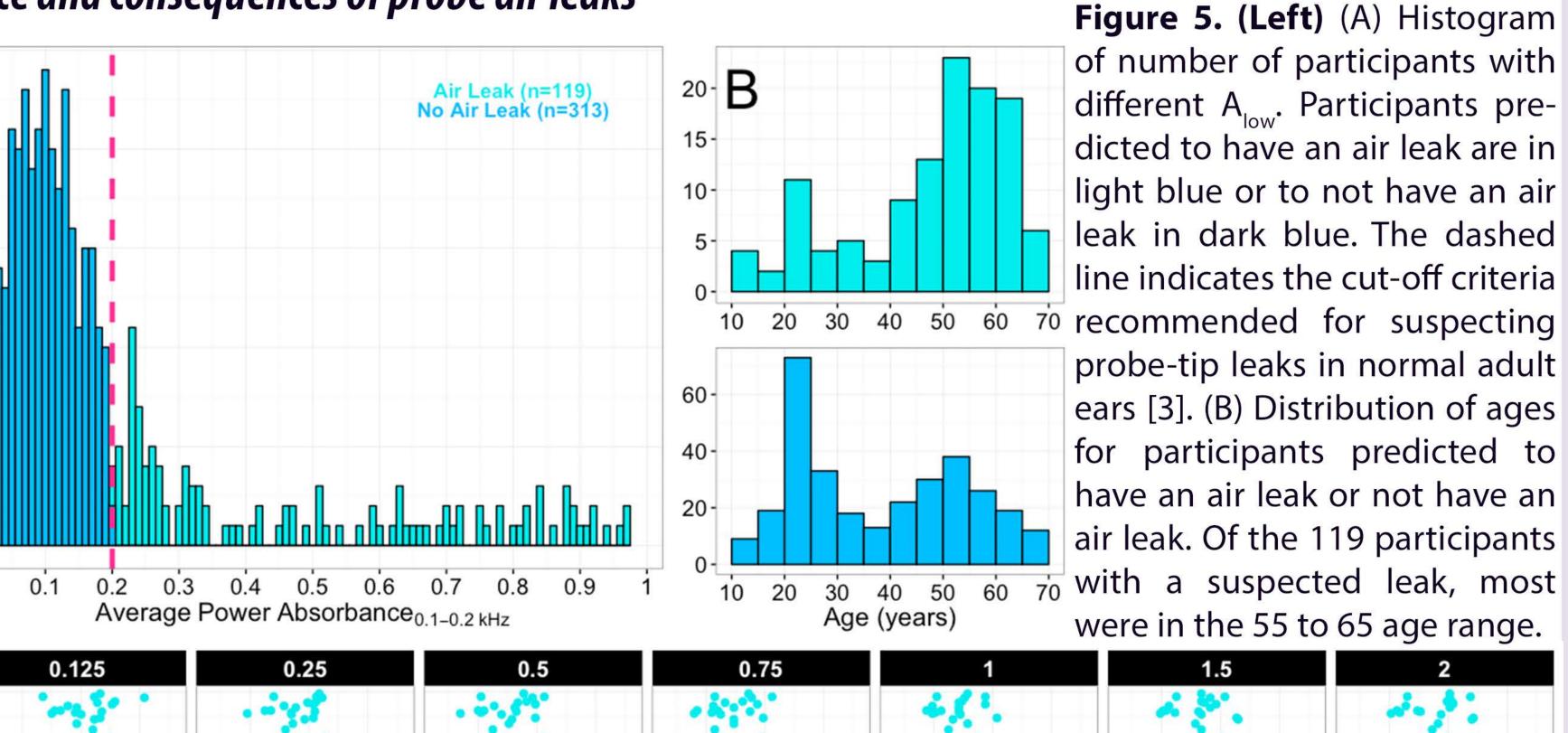


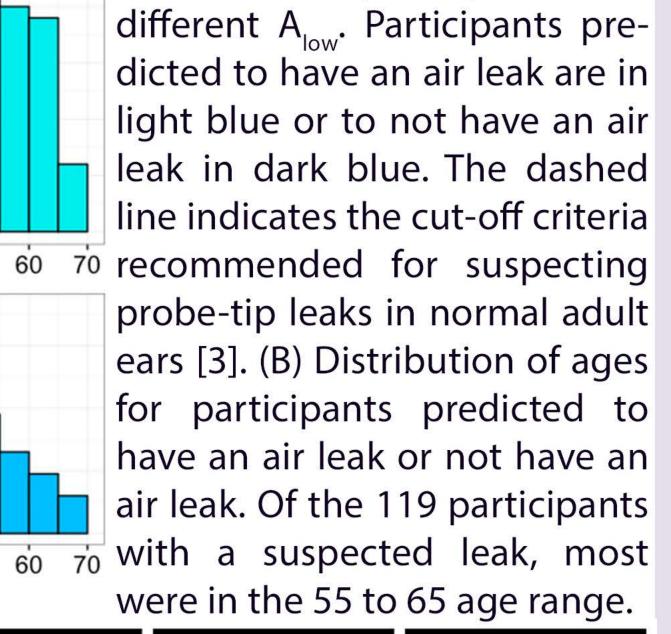
Figure 4. Average (A) absorbance and (B) admittance phase separated by age group. Error bars indicate the 95% CI

## **Conclusions:**

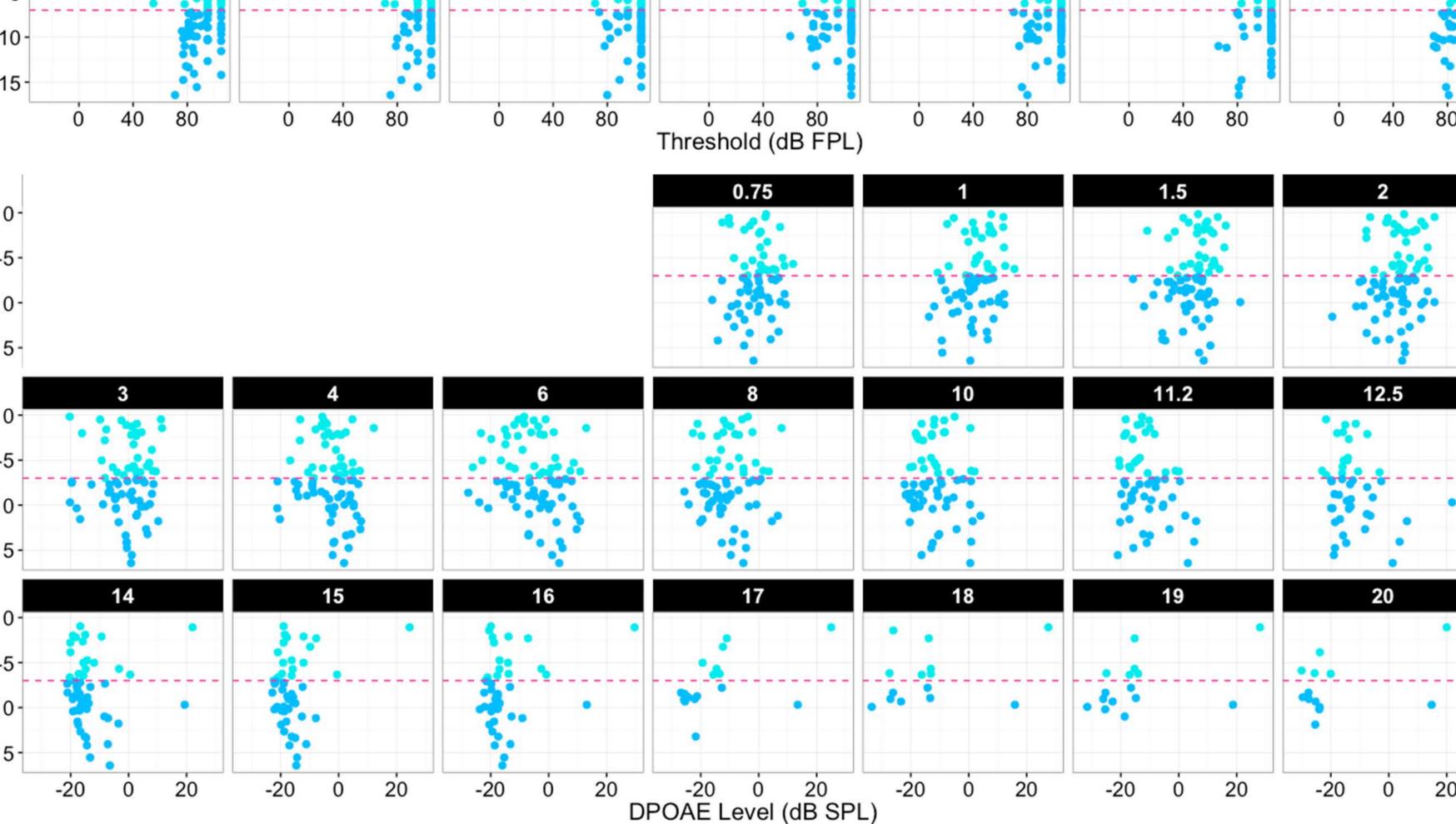
- Ear canal residual length and volume increased with age with males having larger canals than females with the exception of female canal length which did not start to increase until the 50 to 59 year age range (Fig. 1).
- Change in absorbance with frequency was similar between males and females (Fig. 3) and also similar to previous reports (Fig. 2)[3].
- $A_{low}$  of  $\geq 0.2$  (Fig. 5), taken to indicate a leak [3], was seen in 119 participants (27%).
- Median absorbance increased at low frequencies as age increased suggesting that air leaks were more common at older ages (Fig. 4). In fact, an A<sub>low</sub> of ≥ 0.2 (Fig. 5) was most common in the 55 to 65 age range.
- Hearing thresholds, DPOAE levels and noise floor levels were significantly different when a leak was indicated (Fig. 6).
- Data were recorded in a clinical setting by practicing audiologists. The presence of a leak in a substantial number of participants, especially the age group typically seen in audiology clinics, suggests a need for clear warnings/indicators of goodness of fit in clinical interfaces.







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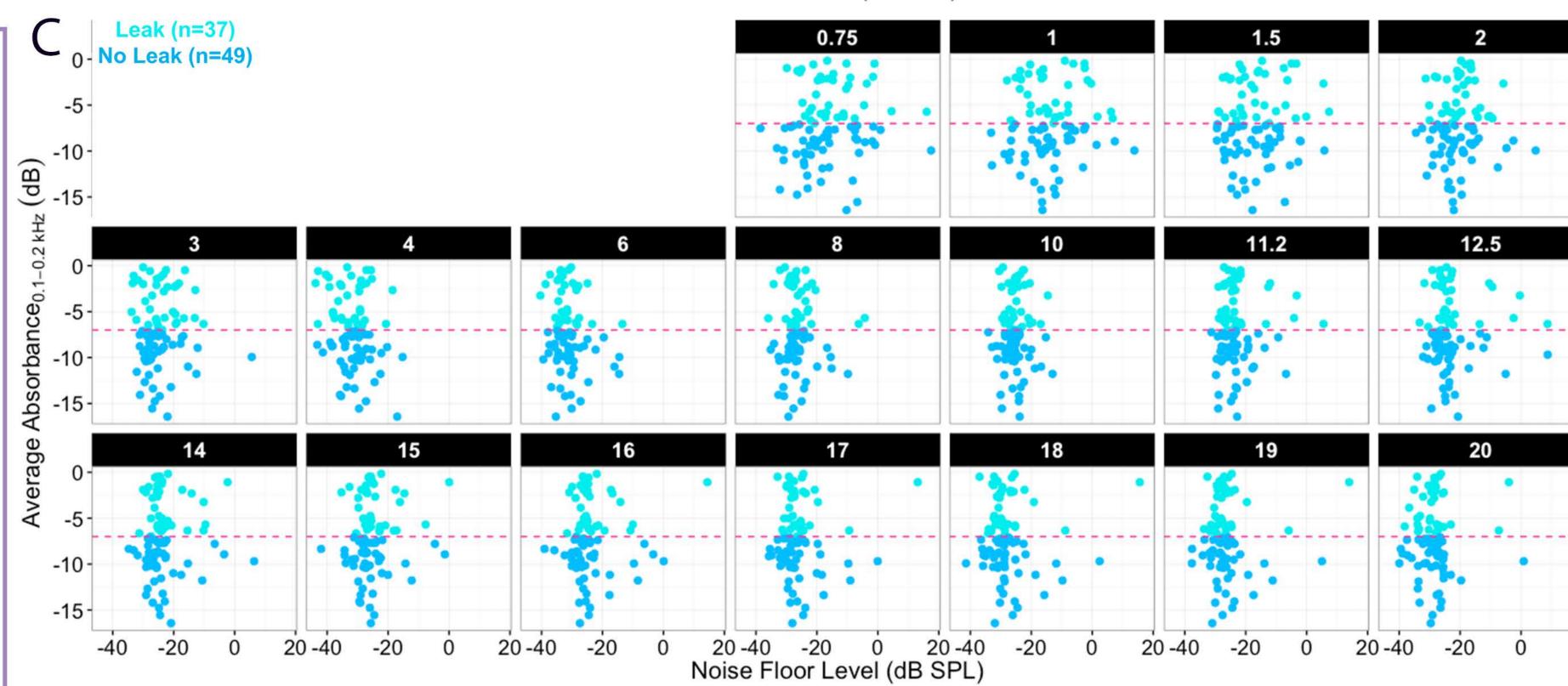
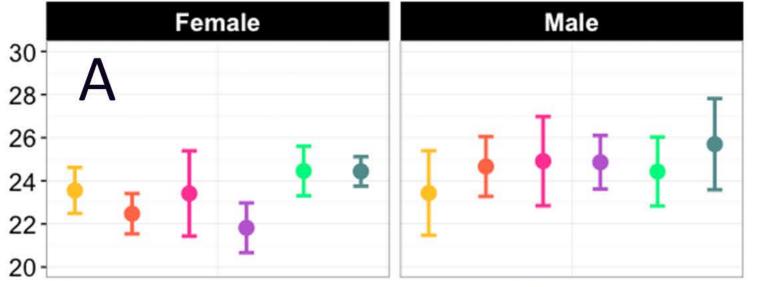
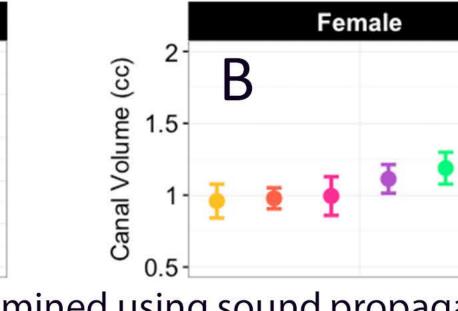


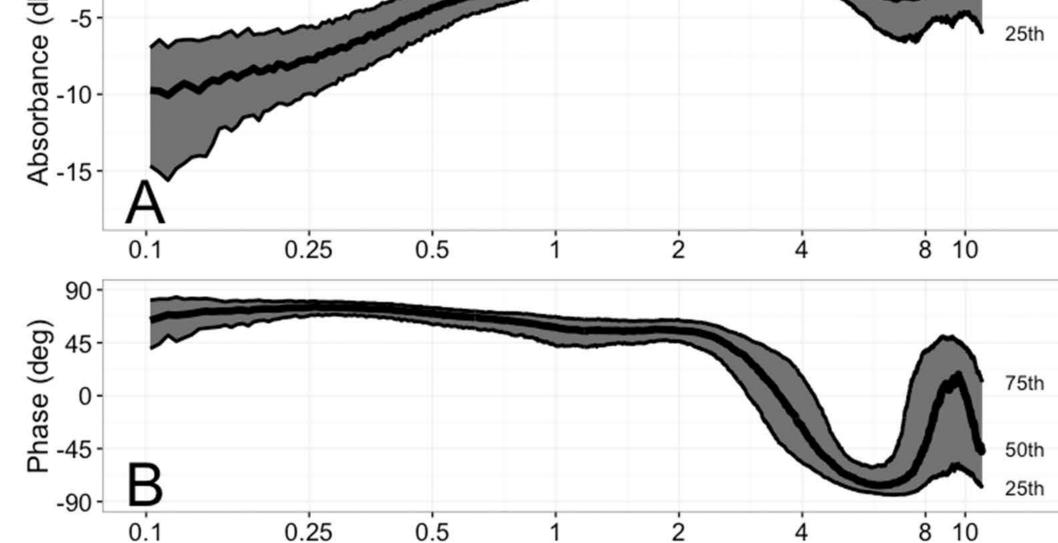
Figure 6. A plotted as a function of (A) threshold, (B) DPOAE level, and (C) noise floor level for participants 55 to 65 years old. Individual panels represent a given test frequency (kHz). The dashed line indicates the cut-off criteria recommended for suspecting probe-tip leaks in normal adult ears [3]. The participant age range was limited in order to control for age-related differences in auditory function. A mixed-model ANOVA (aov function in R) indicated a main effect of an air leak (categorical) on thresholds as well as DPOAE level and noise floor (p << 0.05).

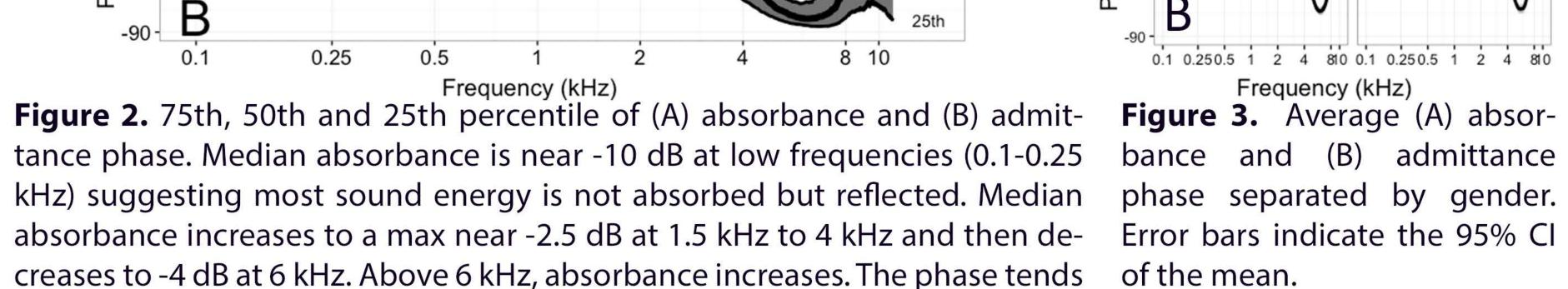
# Wide band measures of middle ear transmission and 1. Characterizing the outer ear











toward 90 degrees below 2 kHz indicating a compliance dominated system.