Real ear measurements: Diagnostics and calibration via Wideband Acoustic Admittance

Comparisons of Tympanometry & Middle Ear Reflectance

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Outcome results:

By the end of this presentation you should understand:

1. The operational principles of tympanometry
2. The impact of MEP on TM admittance
3. The operational principles of Middle ear impedance/reflectance
4. The operational principles of wide-band reflectance
5. The relative utility of Reflectance vs. Tympanometry
6. The importance of wide-band TM admittance to the clinical diagnostic utility of middle ear pathologies,
7. How to compensate for the residual ear-canal volume on the TM compliance/admittance estimate,
8. Practical differences between clinical Tympanometry and Reflectance
9. Key literature on middle ear diagnostics

Abstract

The middle ear (ME) is the window into the cochlea. Middle-ear pathologies, especially with cochlear-impaired ears, are common, and objective diagnostic methods over relevant speech frequencies (0.3-7.3 kHz) are limited. Wideband Acoustic Immittance (WAI) of the ME (aka: Admittance/reflectance) is of special importance because it can more reliably provide key diagnostic information across a wider frequency range than tympanometry.

- WAI can accurately estimate tympanic membrane (TM) compliance. The ear canal compliance may be estimated based on the delay to the first significant (i.e., TM) reflection. We will explain why such an estimate is more reliable.
- WAI provides valuable ME diagnostic information for differential evaluation of TM perforations, otosclerosis, disarticulations, dehiscence, hypermobile TMs, ME reflex, and other TM and ME conditions through non-invasive and objective measurements.
- WAI allows for greatly improved real ear calibrations [forward pressure level (FPL) calibration], by removing the effect of ear-canal standing waves. These standing waves can range from 3-8 kHz, and cause errors up to 20 dB. Only a free-field calibration (FFC) can compete with FPL, but it is not a viable clinical option.

Thus WAI has many advantages, strongly impacting on our ability to diagnose ME pathology and to obtain more accurate audiometric measurements, hence more accurate long-term monitoring of auditory status.

Can TM Reflectance/Admittance supplement existing clinical methodology?

We will attempt to answer these questions.

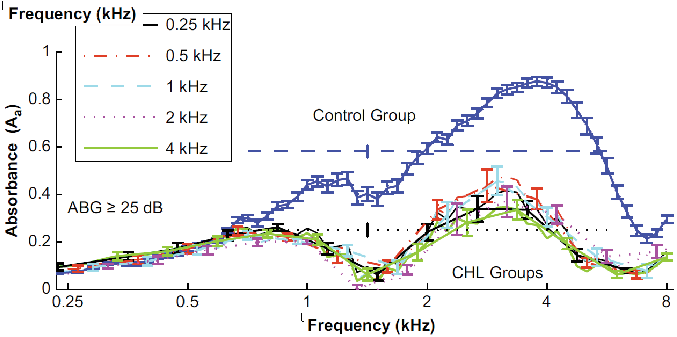
1. What is the evidence?
2. Is it practical?
3. To what extent?
4. When can we have it?

Review of Reflectance/Admittance literature (2013)

- Wide-band power reflectance/admittance has been shown to be useful in diagnosing many sources of Conductive Hearing Loss (CHL):
  1. TM Perforation Allen et al. [2005], Feeney et al. [2003], Voss et al. [2001]
  2. Ossicular disruption [Feeney et al., 2003, 2009]
  3. Analysis of Reflectance in clinical-CHL subjects [Rosowski et al., 2011]
  4. Semicircular canal dehiscence [Nakajima et al., 2012]
  5. CHL and DPOAE [Sanford et al., 2009]
  6. CHL in infants Prieve et al. [2012]
  7. Cadaver studies of CHL [Voss et al., 2008, 2012]
  8. Otitis media [Beers et al., 2010]
  9. Otosclerosis [Shahnaz et al., 2009, Feeney et al., 2003]
  10. Biofilm (chronic condition) [Nguyen et al., 2013]
  11. Reduction of False Positives for OAE Infant Hearing Screening [Hunter, 2007, Hunter et al., 2010]
  12. ...

Conductive Hearing Loss in Children

1. Minimal overlap between 0.75-6 kHz for normal-hearing and CHL infants, diagnosed with an *air bone gap* (ABG) Keefe et al. [2012]



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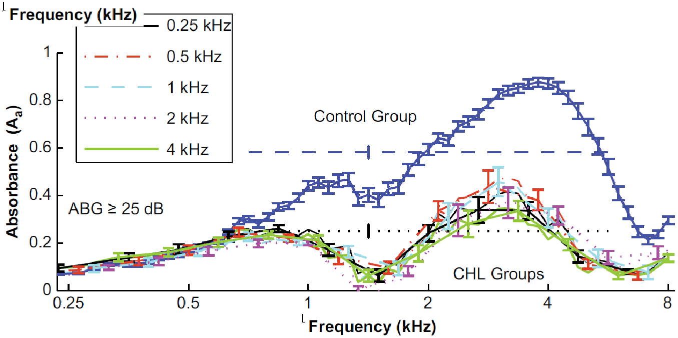
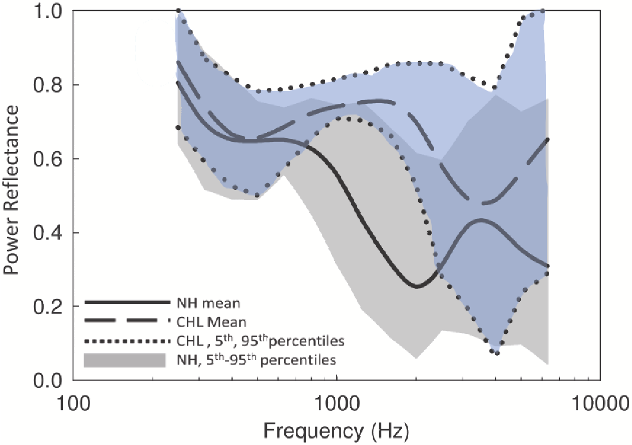


2. The key frequency region is 1-5 [kHz].

Reflectance results: Infants

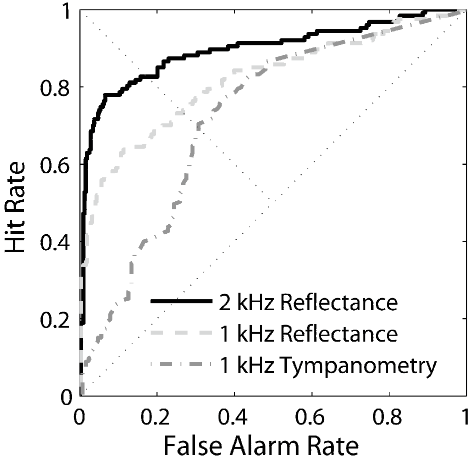
1. Excellent discrimination between normal and CHL ears within 1-2 kHz.



Composite from Fig 3 Prieve et al. (2013)

DPOAE Infant Hearing Screening (ROC)

- ROC curves:[1] Reflectance @ 2 [kHz] vs Tympanometry @ 1 [kHz]
- Reflectance discriminates better than Tymp

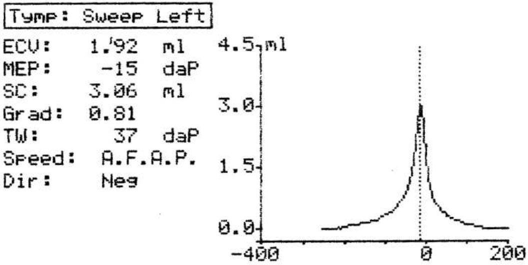


[1][Hunter et al., 2010, Fig. 5]

The basic assumption of Tympanometry

- At 226 Hz, estimate the *residual canal compliance* $\widehat{C}_{canal}$

$$C_{probe} = C_{canal} + C_{tm} \rightarrow \widehat{C}_{canal}\Big|_{\pm 200 \text{ daPa}}$$



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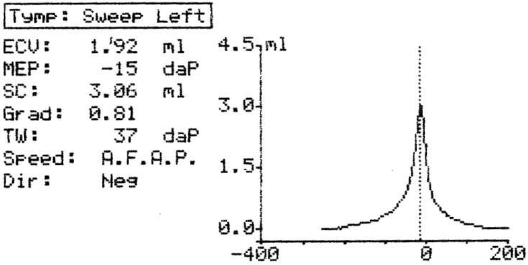

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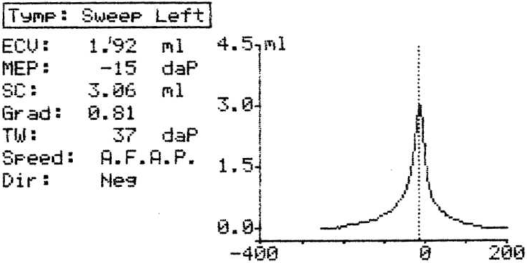

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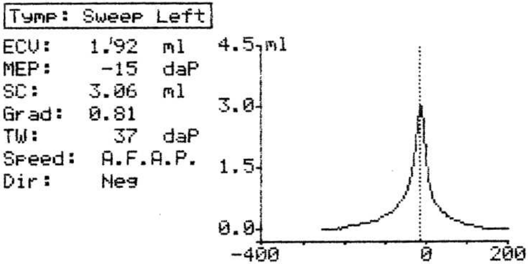

  - Subtracting $\widehat{C}_{canal} \to$ TM compliance: $C_{tm} = C_{probe} - \widehat{C}_{canal}$

- The key objective is to measure SC: the volume of the TM
  - MEP is the second objective

Objective of tympanometry

- Estimate the TM compliance C_{tm} from the canal compliance C_{probe}:

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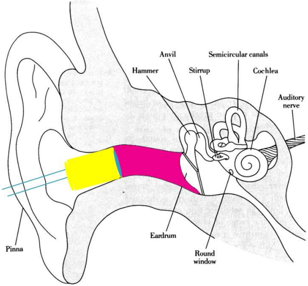

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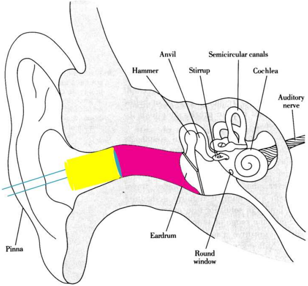

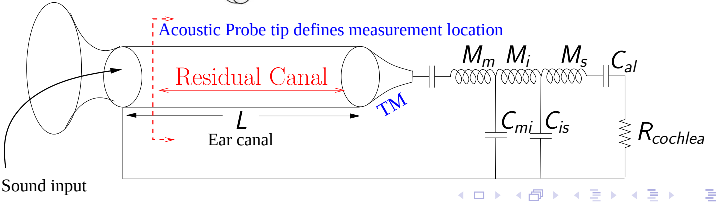

Tympanometry at higher frequencies

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3. In what way does Tympanometry help you?

Tympanometry at higher frequencies (0.5-2 [kHz])

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[2] Details in presentation today by Robinson, Pod.III.A 2:45PM [Robinson et al., 2014]

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- Possible Solution:
  1. Measure wide band Admittance/Reflectance between $0.2 - 6$ [kHz] [2]

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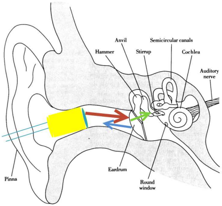

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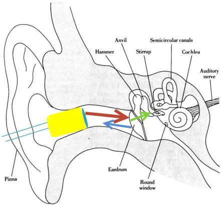

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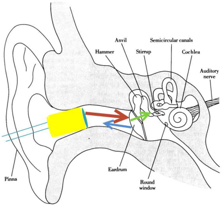

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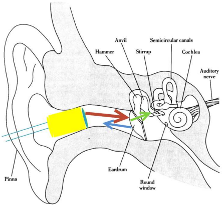

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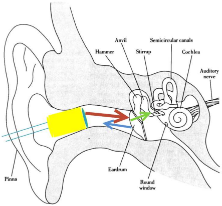

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5. resulting in quality estimates of the TM admittance Y_{tm}

Characterization of "normal" middle ear admittance

- Goal: Characterize the effect of Negative middle ear pressure (NMEP) on the wide-band (0.2-6 kHz) Tympanic membrane (TM) admittance[3]

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    1. Tympanometry $Y_{tm}(P_{induced}, @226\text{ Hz})$, i.e., admittance vs. induced pressure
    2. Reflectance/Admittance $Y_{tm}(P_{induced}, f)$ $0.2 \leq f \leq 6$ [kHz];

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- Does everyone understand the experiment?

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Effect of the Residual Ear Canal on $Y_{tm}(f)$

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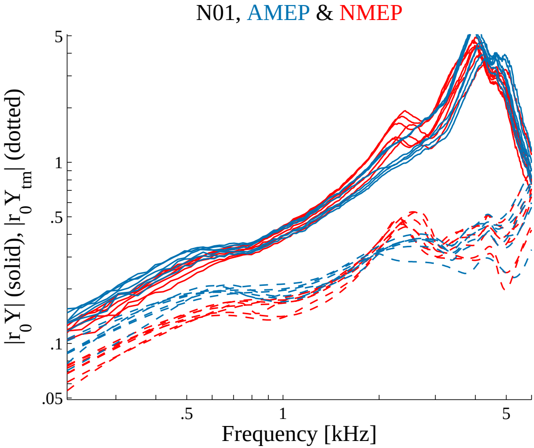
- The canal admittance $Y_{canal}(f)$ significantly modifies $Y_{tm}(f)$
- Note large standing wave at 4 kHz @-probe (not present @-TM)

Solid: @-Probe, Dashed: @-TM;

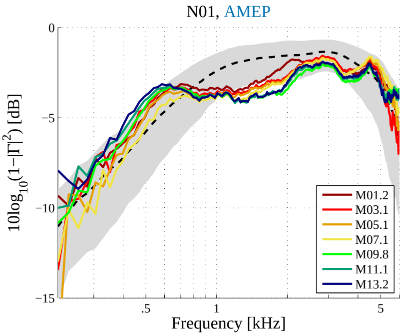
Blue: Ambient; Red: Pressurized



Effect of NMEP on Absorbance: Subj N01

- Ambient AMEP and Pressurized NMEP Absorbance [dB] (N01)

NOTE: Absorbance = 1- Power Reflectance = Transmittance in dB units



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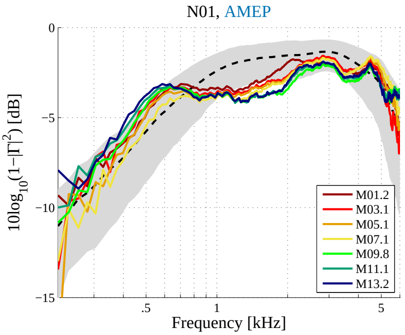

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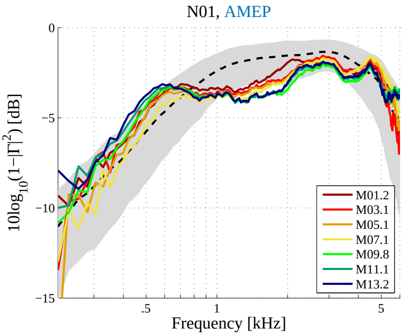
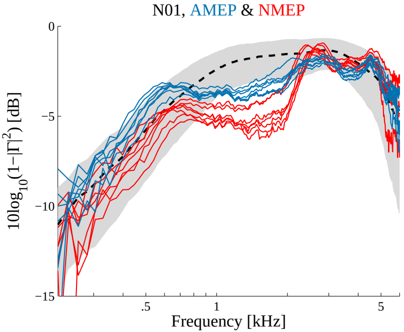


- Note the separation in $Y_{tm}(f)$ for Ambient and Pressurized vs. f

Comparison across 2 subjects

- Examples of *Power Absorbance*: Ambient vs. Pressurized (NMEP)



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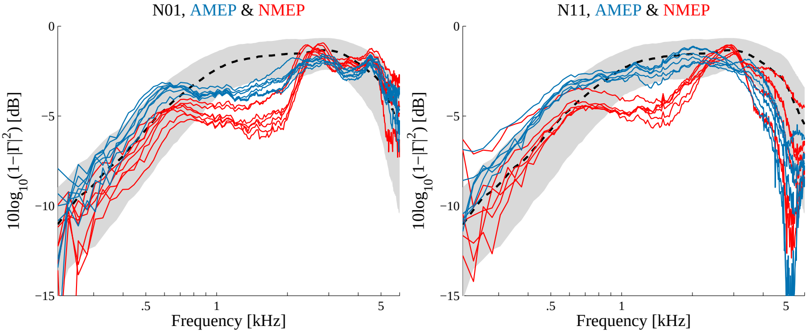
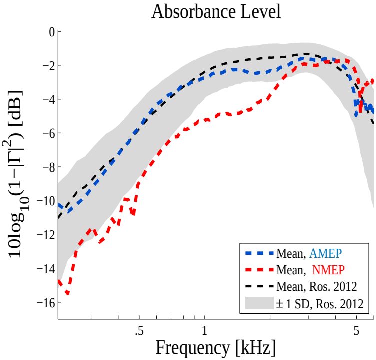


- Two different subjects N01 & N11

Absorbance separation (all ears): Ambient vs. NMEP

- NYC/CUNY Mean same as Boston/MEEI mean (black dashed)



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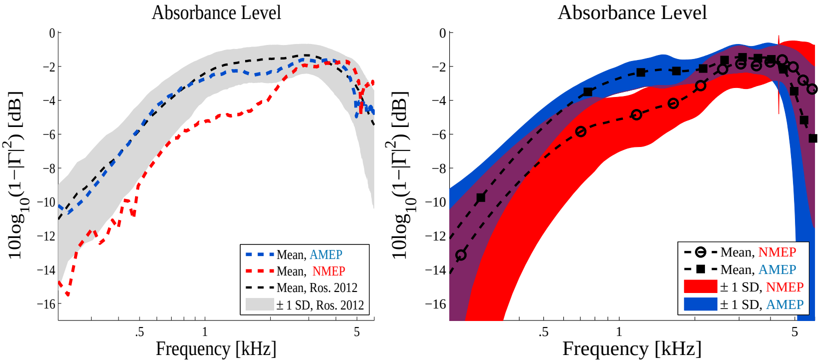
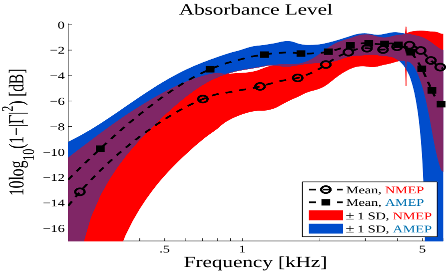


- The means below 500 Hz significantly overlap: $\pm\sigma$ (1-SD)
- The two pressurized conditions separate $\pm\sigma$ over 1-oct (0.75-2.0 kHz)
- For diagnostics, the most useful TM measures are between 0.5-6 [kHz]

$\Delta Y_{tm}(P_{induced}, f)$ 1-2 [kHz] wrt MEP @226 [Hz]



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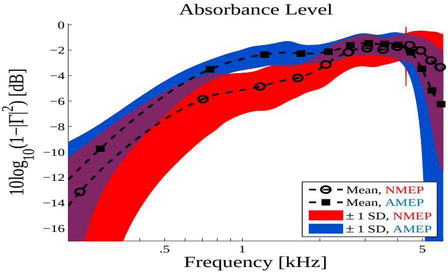

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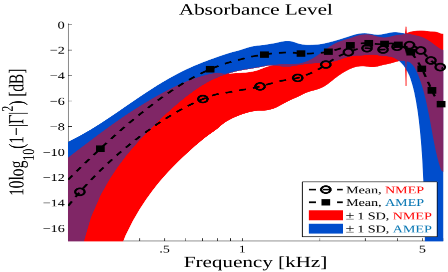

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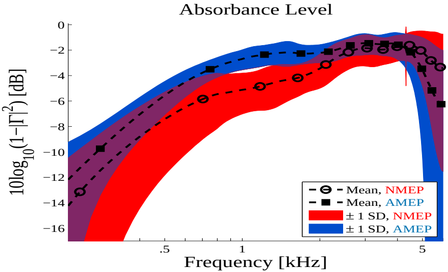

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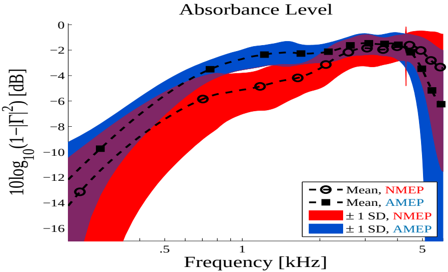
- $\Delta Y_{tm}(P_{induced}, f > 0.5$ kHz$)$ is not predicted from MEP@226
  - One must directly measure $Y_{tm}(f)$ between 0.5-3 [kHz]

$\Delta Y_{tm}(P_{induced}, f)$ 1-2 [kHz] wrt MEP @226 [Hz]



- Given the small separation in admittance @226 Hz, and the larger separation between 0.7-2 kHz, MEP @226 [Hz] & $\Delta Y_{tm}(P_{induced})$ seem uncorrelated
- $\Delta Y_{tm}(P_{induced}, f > 0.5$ kHz) is not predicted from MEP@226
  - One must directly measure $Y_{tm}(f)$ between 0.5-3 [kHz]
  - The reason(s) for this are not known (speculations are possible)

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- Is it practical? Yes: WAI is a working well defined technology.
- To what extent? WAI may be purchased: FDA status
- When can we have WAI? Now, from Mimosa Acoustics.
- For the details see: Hunter, Prieve, Beers, Rosowski, Nakajima, ...

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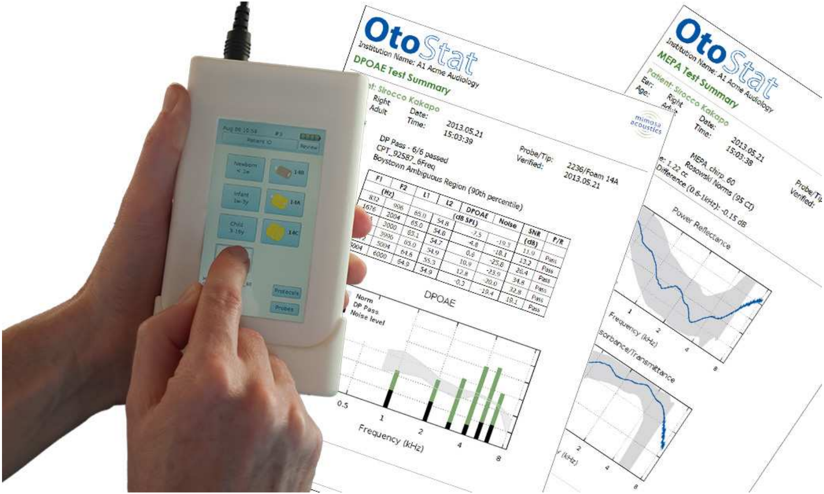
- CUNY study clarifies many of these issues
  Robinson (Pod.IIIA, 2:45PM)

Wideband reflectance on the OtoStat (Handheld Version)



Wideband reflectance on HearID (USB-Desktop Version)

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