Improving the Diagnosis of Conductive Hearing Loss in Children with Otitis Media

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TRANSLATIONAL AUDITORY PHYSIOLOGY & PERCEPTION LAB

ARO Seminar Series, May 2024

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Lauren Crowther
Hannah Green
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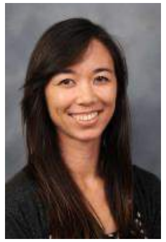
Anna Schulte







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Mechanisms of hearing loss resulting from middle-ear fluid ☆

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[b] Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
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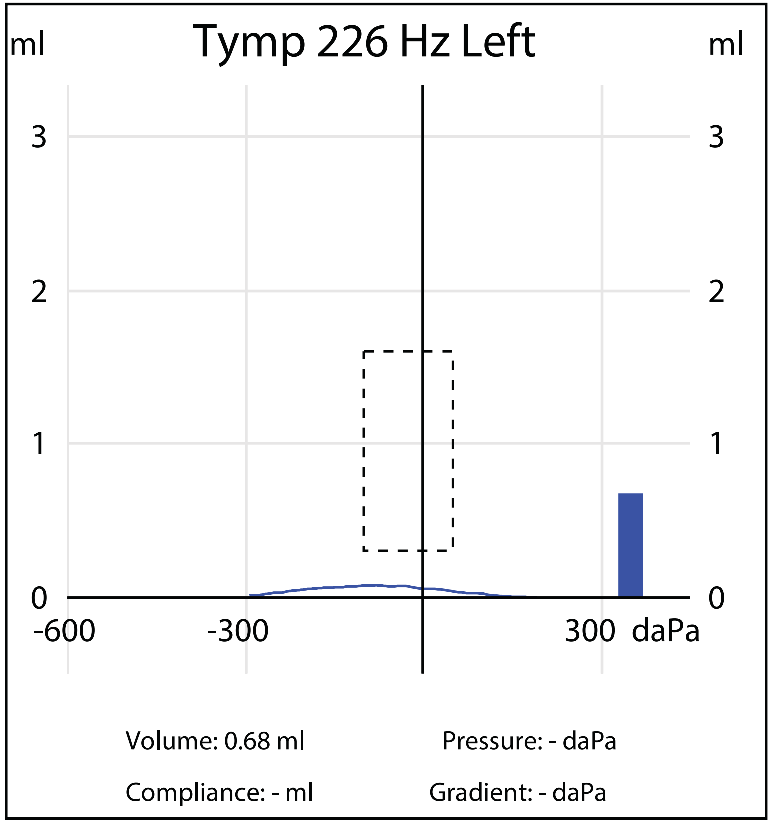
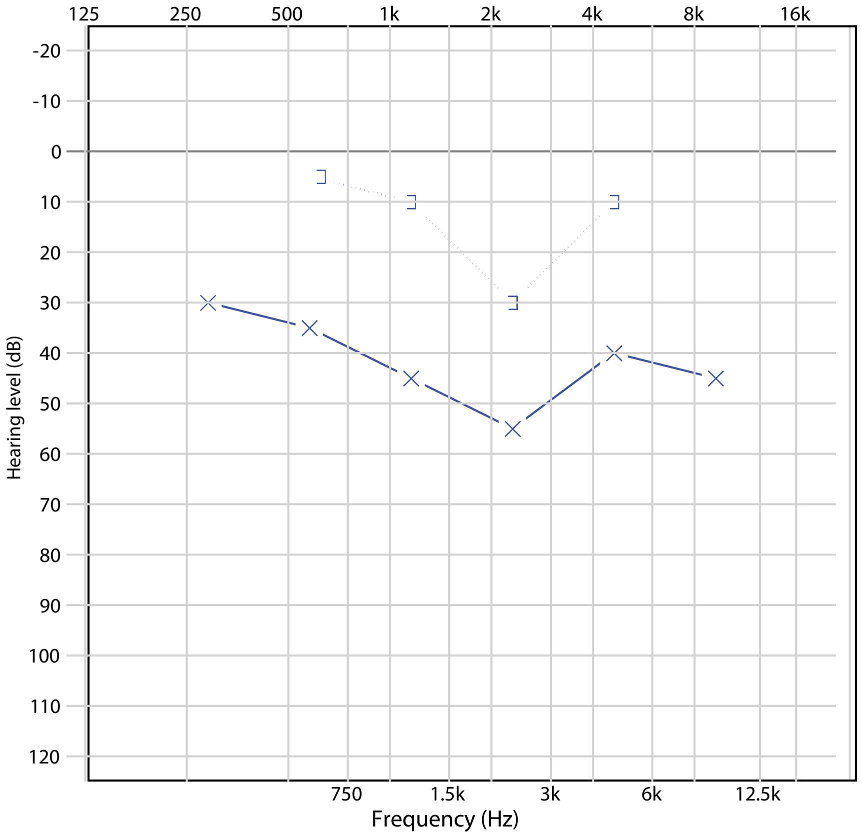
Available online 15 July 2004

Subject	Age	Ear Side	Fluid?	Mucoid/ Serous	Amount	SO Prediction	PO Prediction
P001	**6 yrs**	L	Y	Mucoid	Full	MEE	MEE
		R	Y	Mucoid	Full	MEE	MEE
P002	**11 mos**	L	Y	Mucoid	Full	MEE	MEE
		R	Y	Mucoid	Full	No Fluid	No Fluid
P003	**2 yrs**	L	Y	Serous	Full	Retracted TM	MEE
P004	**5 yrs**	L	Y	Mucoid	Full	Retracted TM, MEE	n/a
		R	Y	Mucoid	3/4 Full (A-F Line)	Serous Fluid	n/a
P005	**10 mos**	L	N				serous fluid, immobile TM
		R	N				mobile, dry
P006	**14 mos**	L	N			Serous Fluid	Fluid
P007	**10 mos**	L	Y	Mucoid	Full		immobile, mucoid, full
		R	Y	Mucoid	Full		mobile, mucoid, full
P008	**3 yrs**	L	Y	Mucoid	Full		mobile, mucoid, full
		R	Y	Mucoid	Full		mobile, mucoid, full
P009	**1 yr**	L	Y	Mucoid	Full	MEE	effusion, complete
		R	Y	Mucoid	Full	MEE	effusion, complete

A Clinical Dilemma: Patient A





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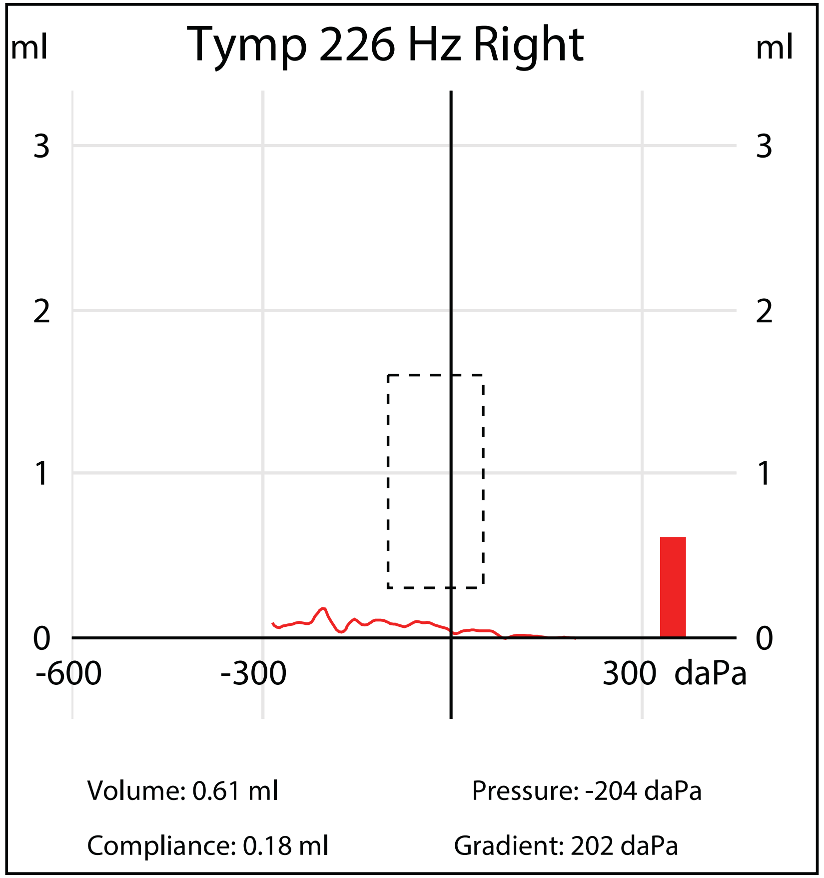
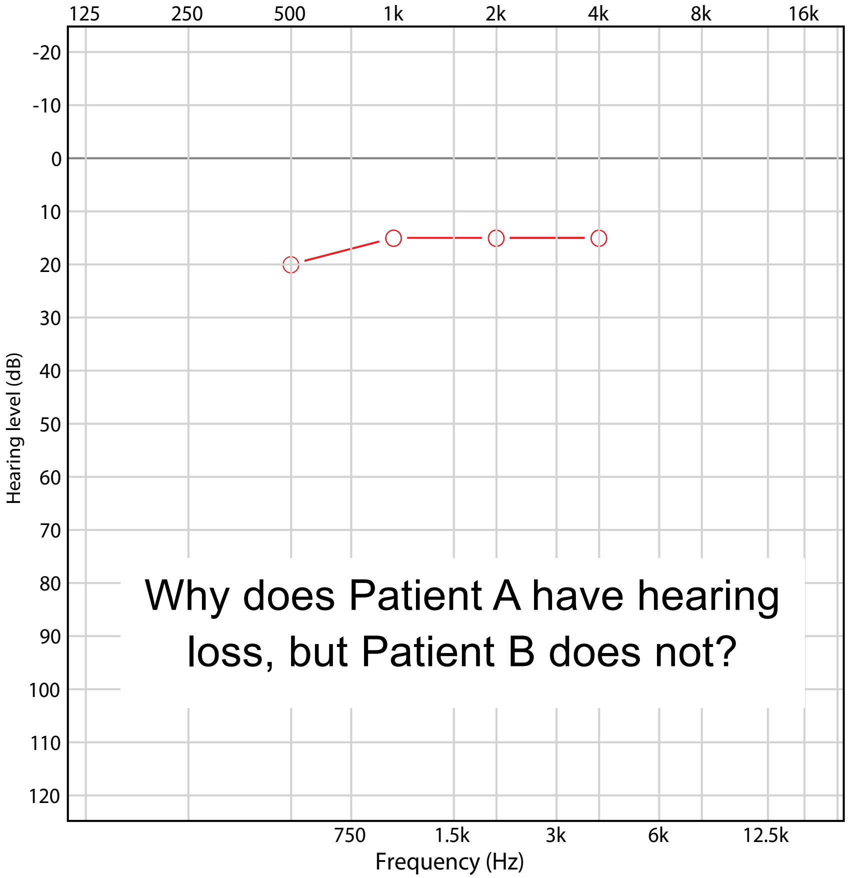
A Clinical Dilemma: Patient B





Why does Patient A have hearing loss, but Patient B does not?

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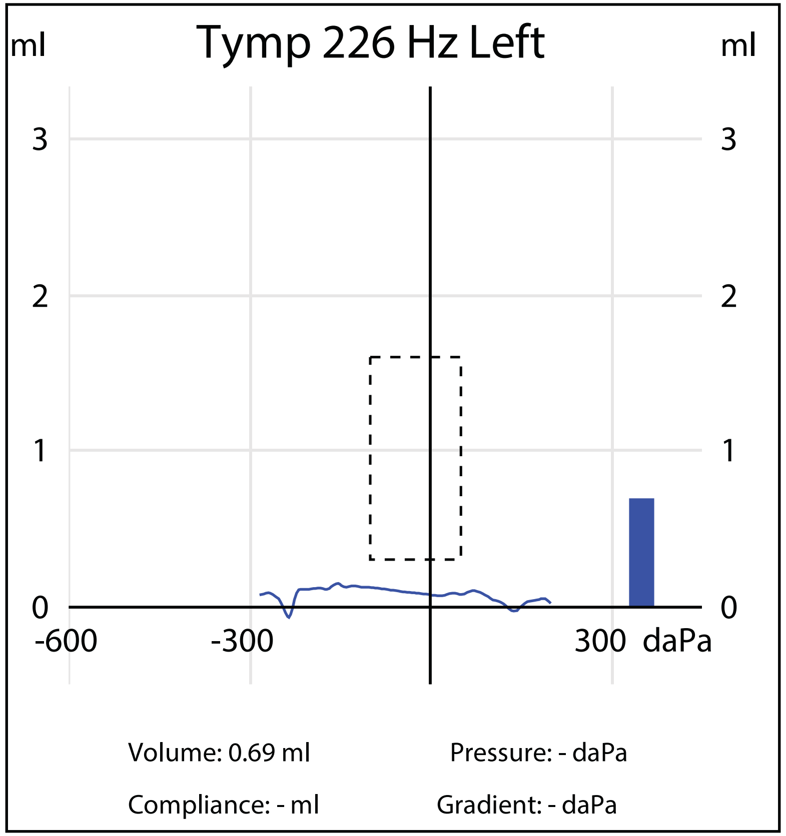
A Clinical Dilemma: Patient C



No reliable behavioral thresholds could be obtained

- Do they have hearing loss? Do they not?
  - Does it matter?

JARO 12: 535–546 (2011)
DOI: 10.1007/s10162-011-0271-6

JARO
Journal of the Association for Research in Otolaryngology

Invited Review

Evaluating the Perceptual and Pathophysiological Consequences of Auditory Deprivation in Early Postnatal Life: A Comparison of Basic and Clinical Studies

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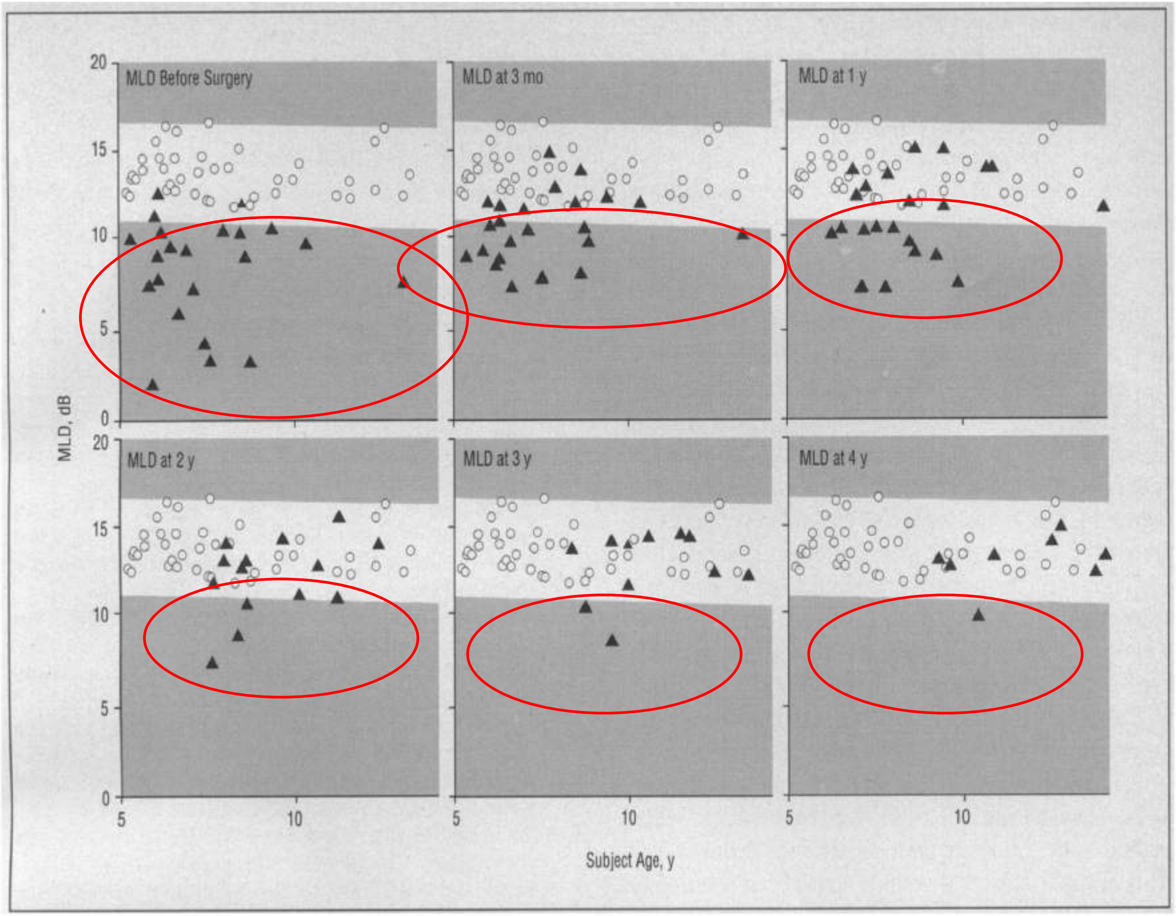
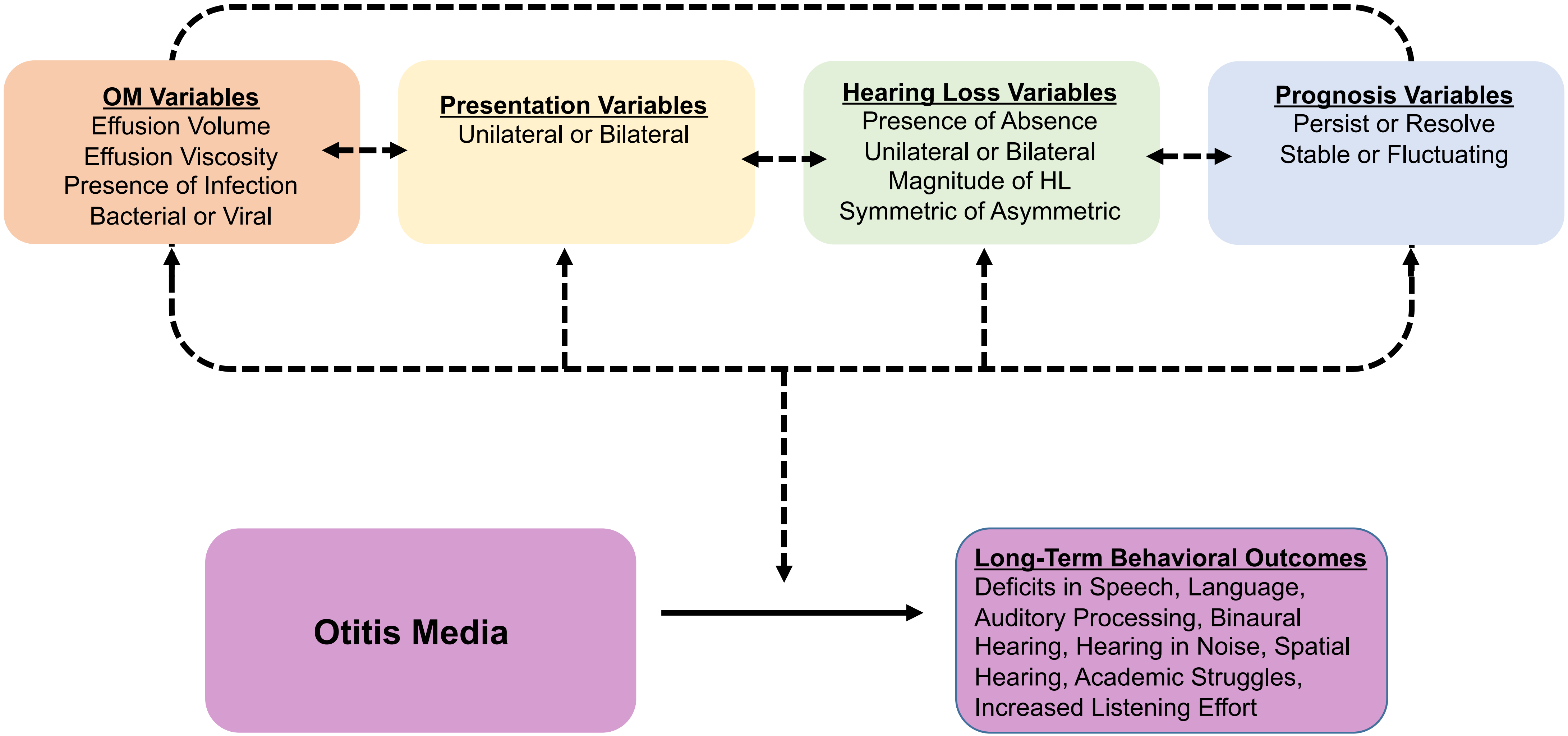


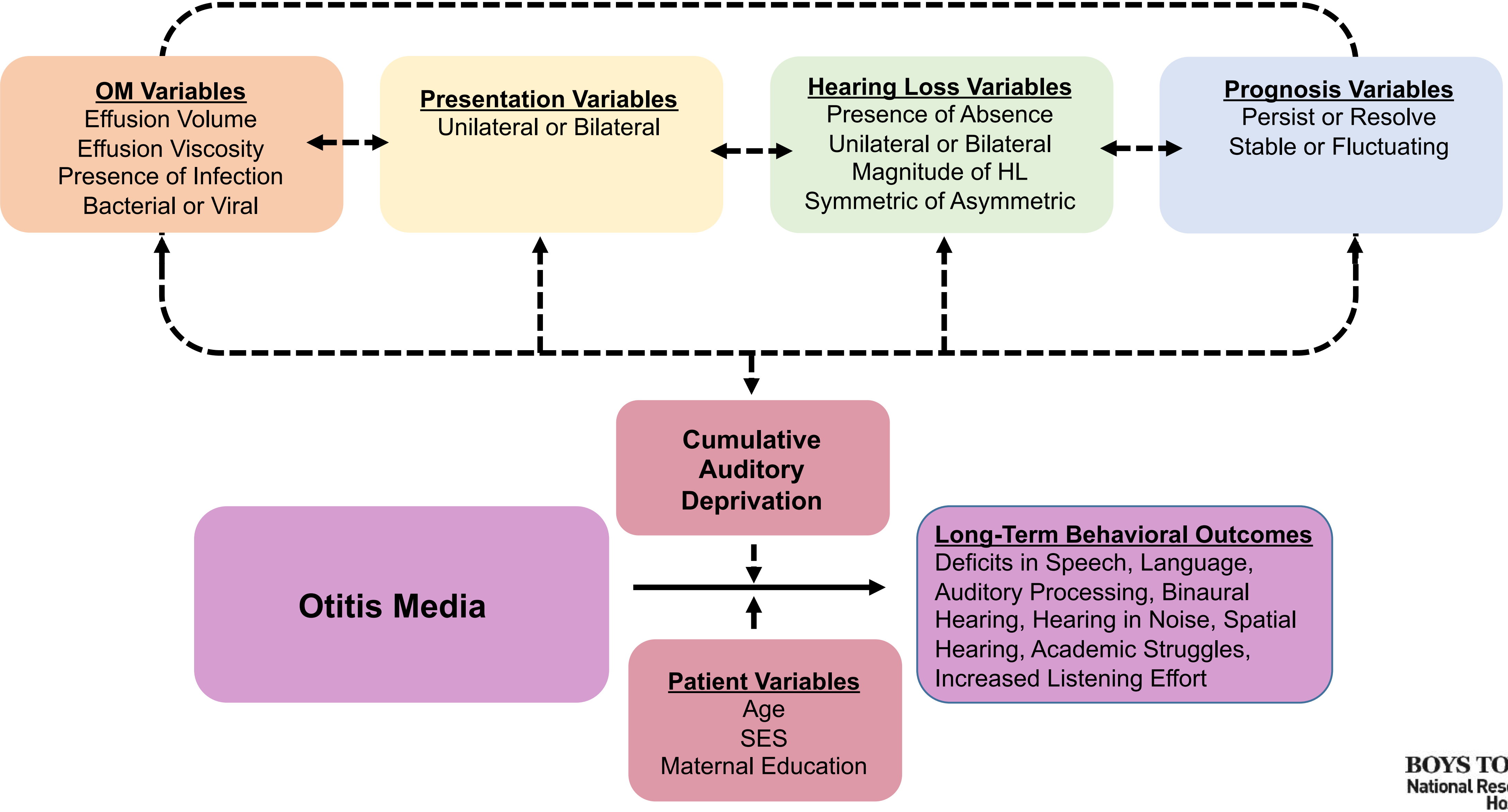
Figure 3. *Masking-level differences (MLDs) as a function of age. Panels show data from the sequential tests. Circles represent children in the control group, and triangles represent children with a history of otitis media with effusion. The white region depicts the 95% confidence interval for the normal group.*

From Hall et al., 1995

The Problem (s)

- OM has many forms
  - Tons of variability
- Limited knowledge of how these variables are related
  - Do effusion characteristics impact hearing loss? Prognosis/resolution?
- What variables are important to consider for management and how do we identify/measure them?
- How does variability influence whether there are long-term behavioral (or otherwise) consequences of OM?


OM Variables
Effusion Volume
Effusion Viscosity
Presence of Infection
Bacterial or Viral
Presentation Variables
Unilateral or Bilateral
Hearing Loss Variables
Presence of Absence
Unilateral or Bilateral
Magnitude of HL
Symmetric of Asymmetric
Prognosis Variables
Persist or Resolve
Stable or Fluctuating
Otitis Media
Long-Term Behavioral Outcomes
Deficits in Speech, Language, Auditory Processing, Binaural Hearing, Hearing in Noise, Spatial Hearing, Academic Struggles, Increased Listening Effort


OM Variables
Effusion Volume
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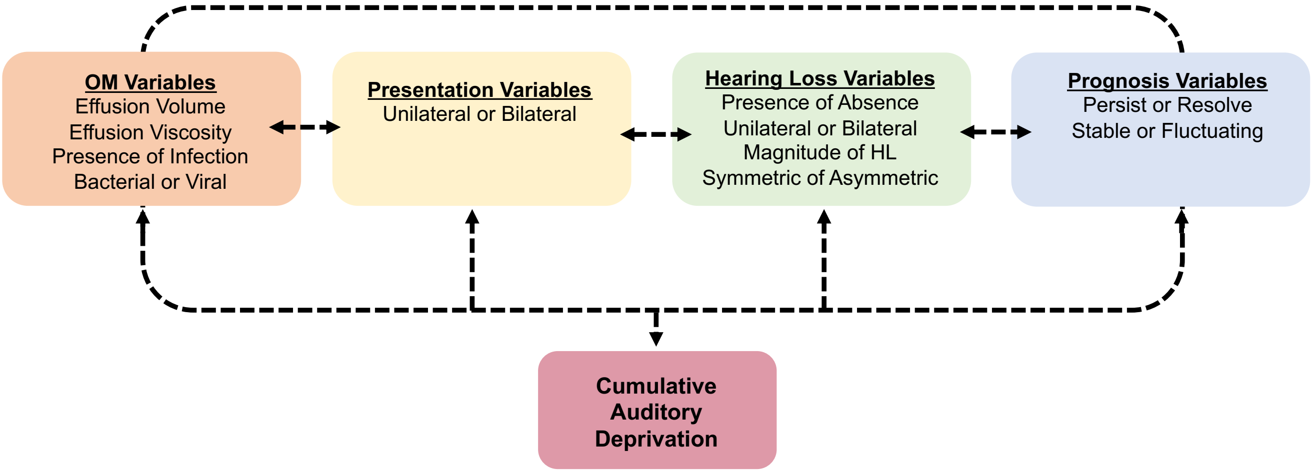
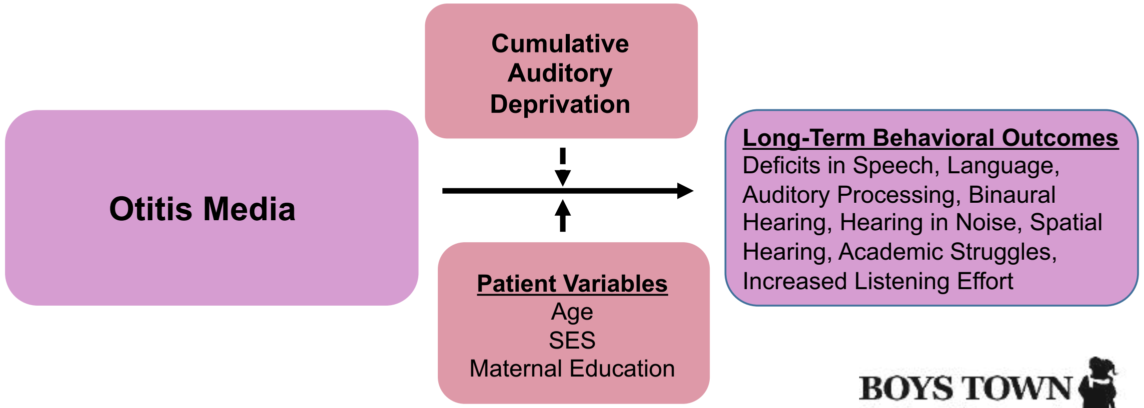
Magnitude of HL
Symmetric of Asymmetric
Prognosis Variables
Persist or Resolve
Stable or Fluctuating
Cumulative Auditory Deprivation
Otitis Media
Long-Term Behavioral Outcomes
Deficits in Speech, Language, Auditory Processing, Binaural Hearing, Hearing in Noise, Spatial Hearing, Academic Struggles, Increased Listening Effort
Patient Variables
Age
SES
Maternal Education

Research Plan

- **Short-Term Research Plan**: Understand how variables in OM are related and influence cumulative auditory deprivation and determine ways to measure variables that are important to cumulative auditory deprivation.



- **Long-Term Research Plan**: Determine what factors of OM put children are at risk for long-term deficits and develop ways to identify them in clinic as early as possible to better inform management decisions



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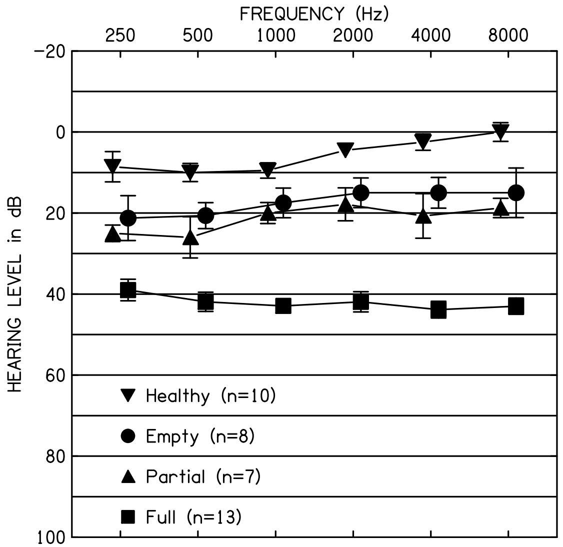
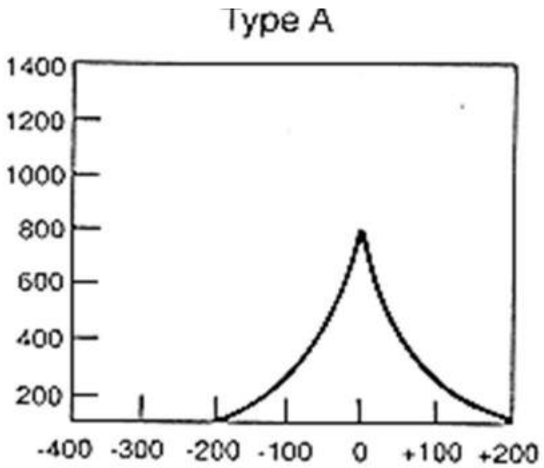
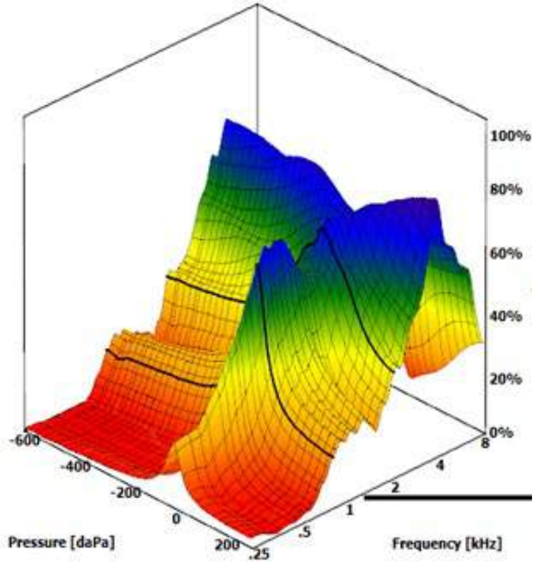
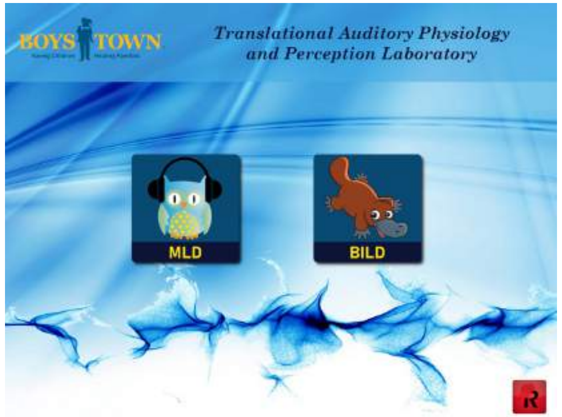
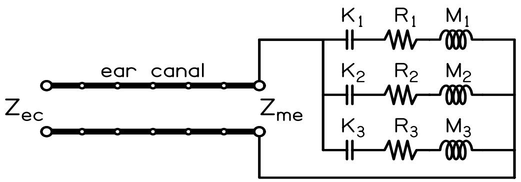
Research Program Approach

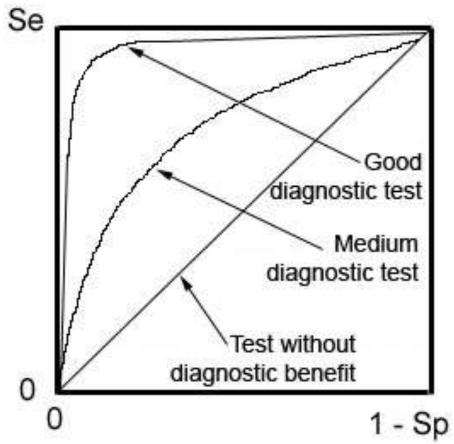


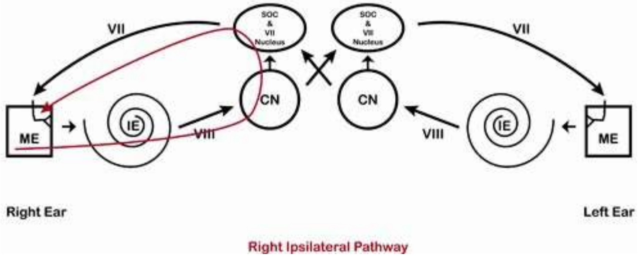


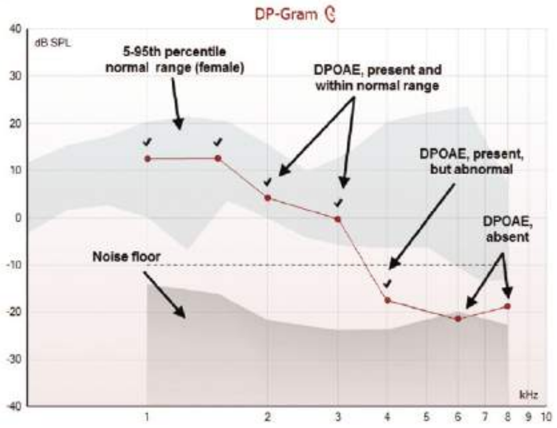


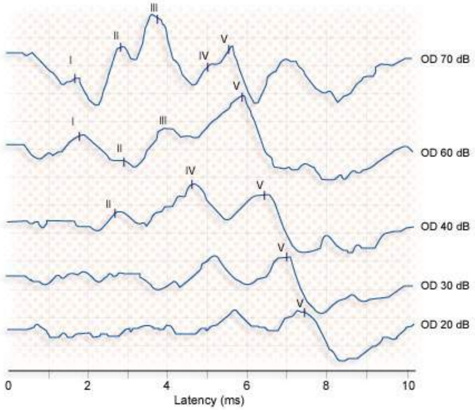












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Participants

- Children with OM (primarily OME) having tubes placed (mean age 34 months)
  - Participate in a large battery of assessments within 48 hours of tube placement, with repeated measurements of middle-ear status on the morning of surgery to confirm no change. We then characterize several OM-related variables during surgery.
- Age matched normal hearing control children with no recent history of OM
- SNHL ruled out in all participants

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OME Study Protocol

Initial Visit (1-2 hours)
Takes place within 48 hours prior to tube placement

1) WAI
2) 226 Hz Tymps
3) DPOAEs & TEOAEs
4) Behavioral Audiometry (Air & Bone)

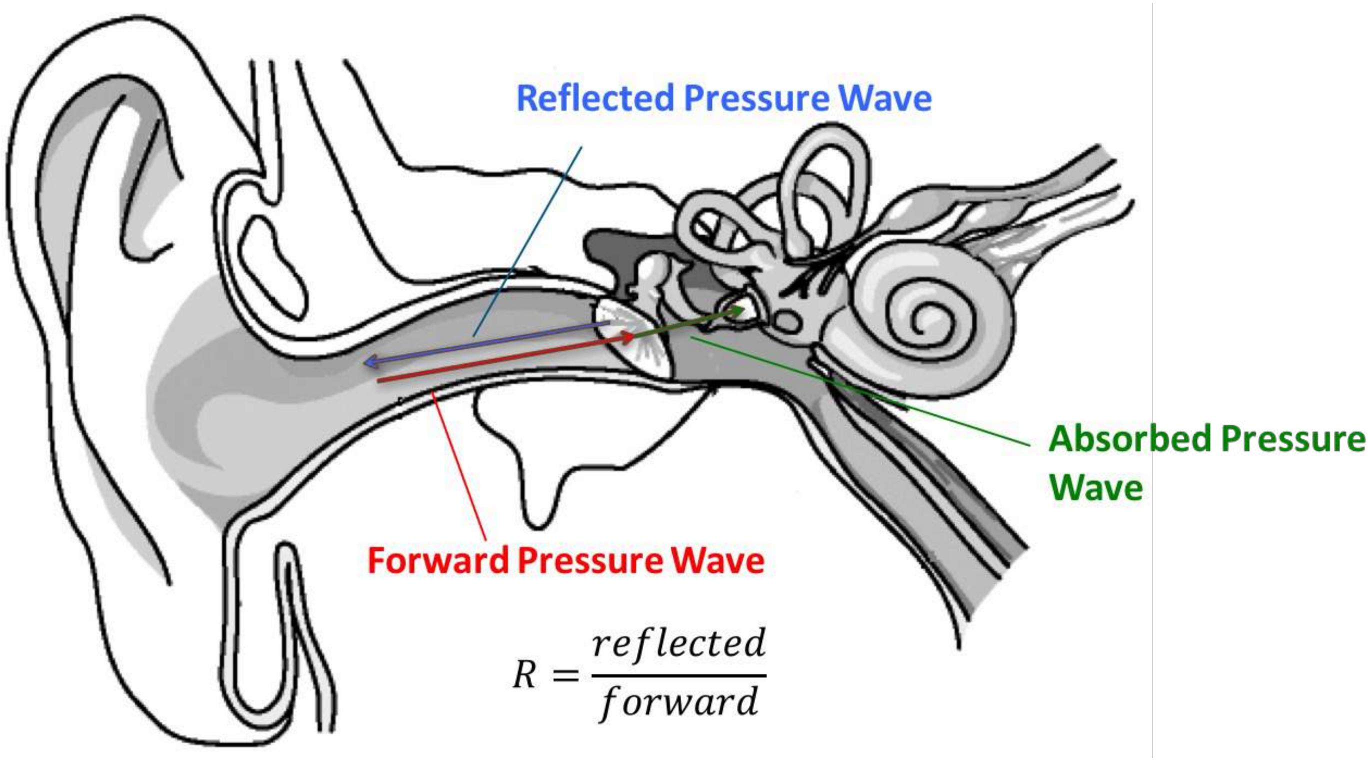
Day of Surgery

1) Pre-Op WAI & 226 Hz Tymps
2) Pre- & Post-Myringotomy 226 Hz Tymps
3) Pre- & Post-Myringotomy Subjective Description of Effusion Characteristics
4) Collection of Effusion
5) Quantification of effusion volume, viscosity, and purulence

Post-Op Visit
Takes place ~1 month post-op

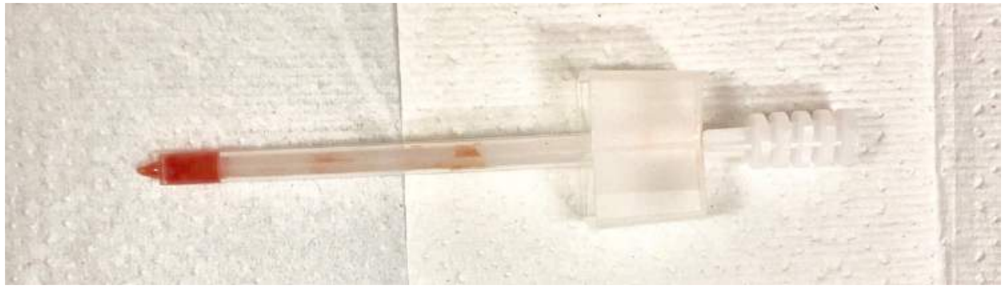
Repeat all testing from Initial Visit

Wideband Acoustic Immittance (WAI)



- Measurements are made in response to wideband sounds (200 – 8000 Hz)
- FDA approved
- **Absorbance**: Portion of the energy being absorbed by the ear

Effusion Collection & Analyses



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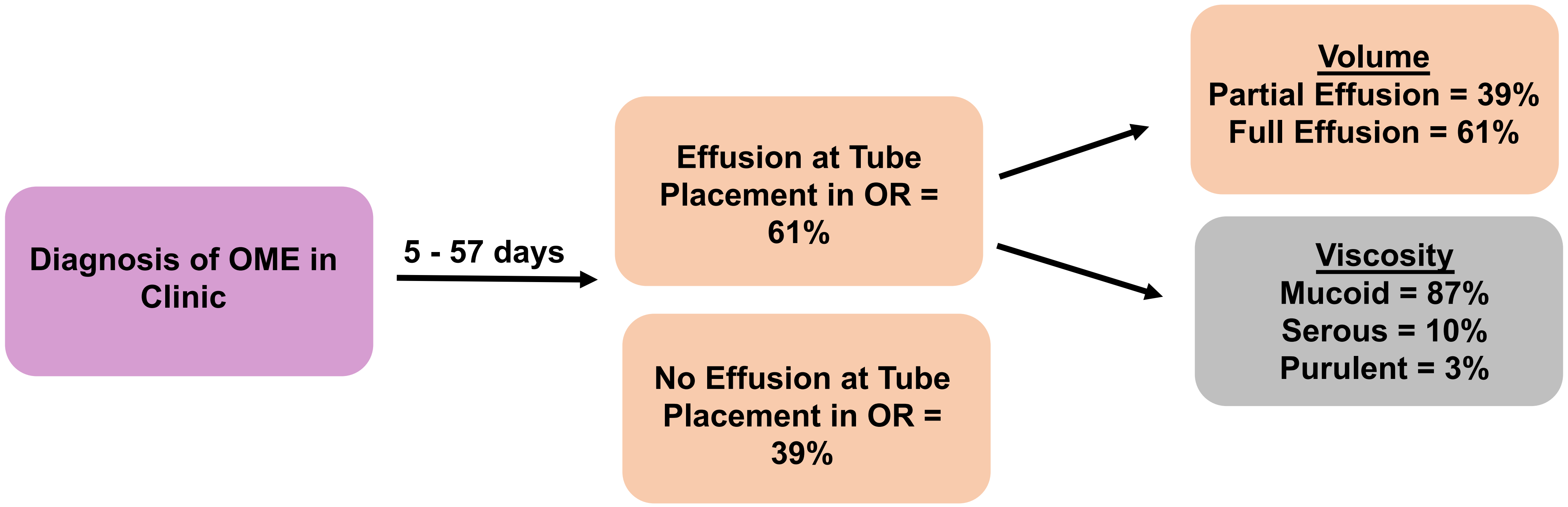
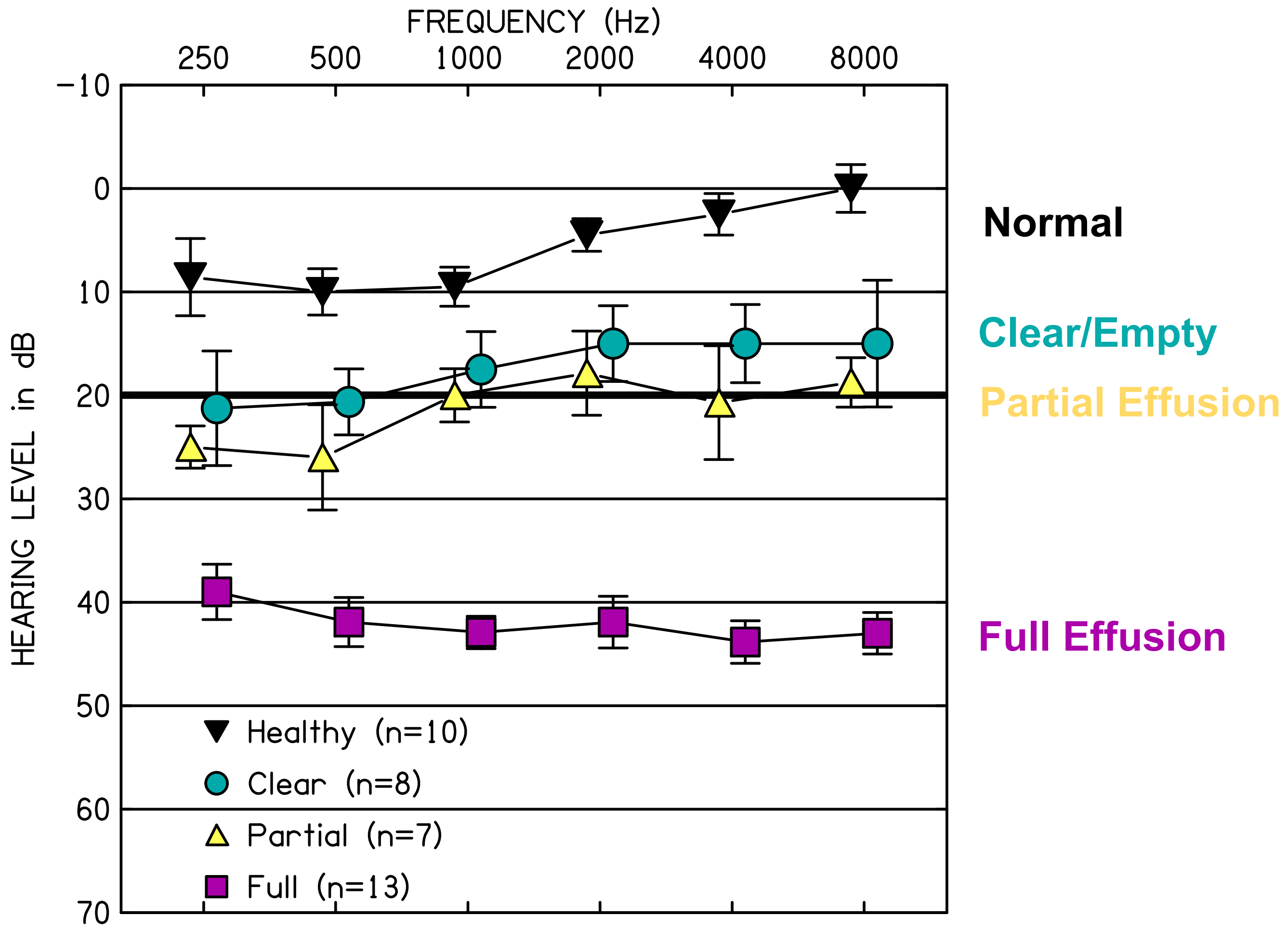
Effusion Characteristic Variability



Effusion volume ultimately characterized as clear, partial, or full.

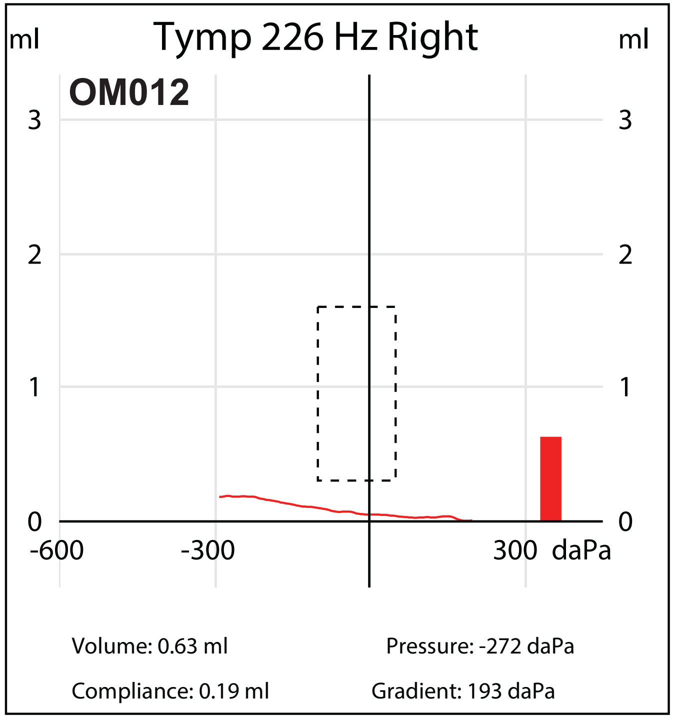
Al-Salim et al 2021

Effusion Volume Drives Hearing Loss

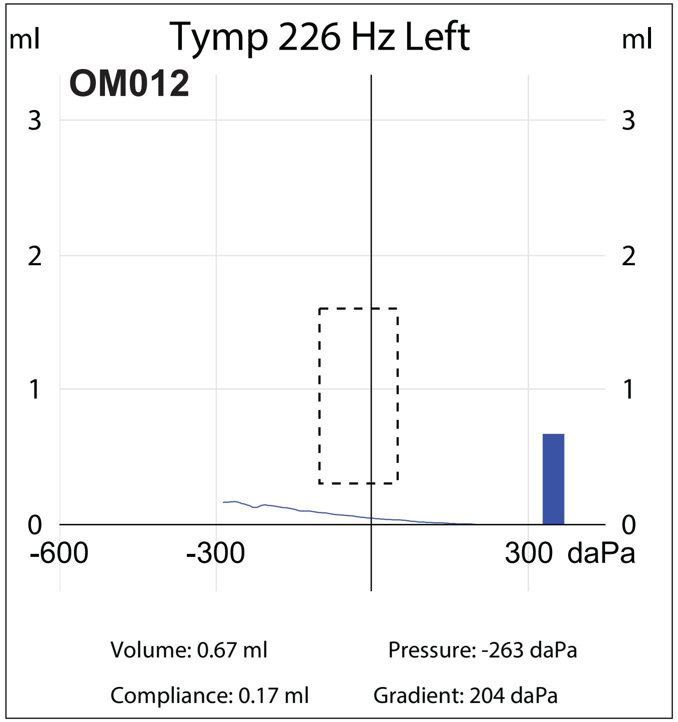


Al-Salim et al 2021

Can’t Predict Effusion Volume from Tympanometry



½ Mucoid Effusion (Partial)



Full Mucoid Effusion

Al-Salim et al 2021

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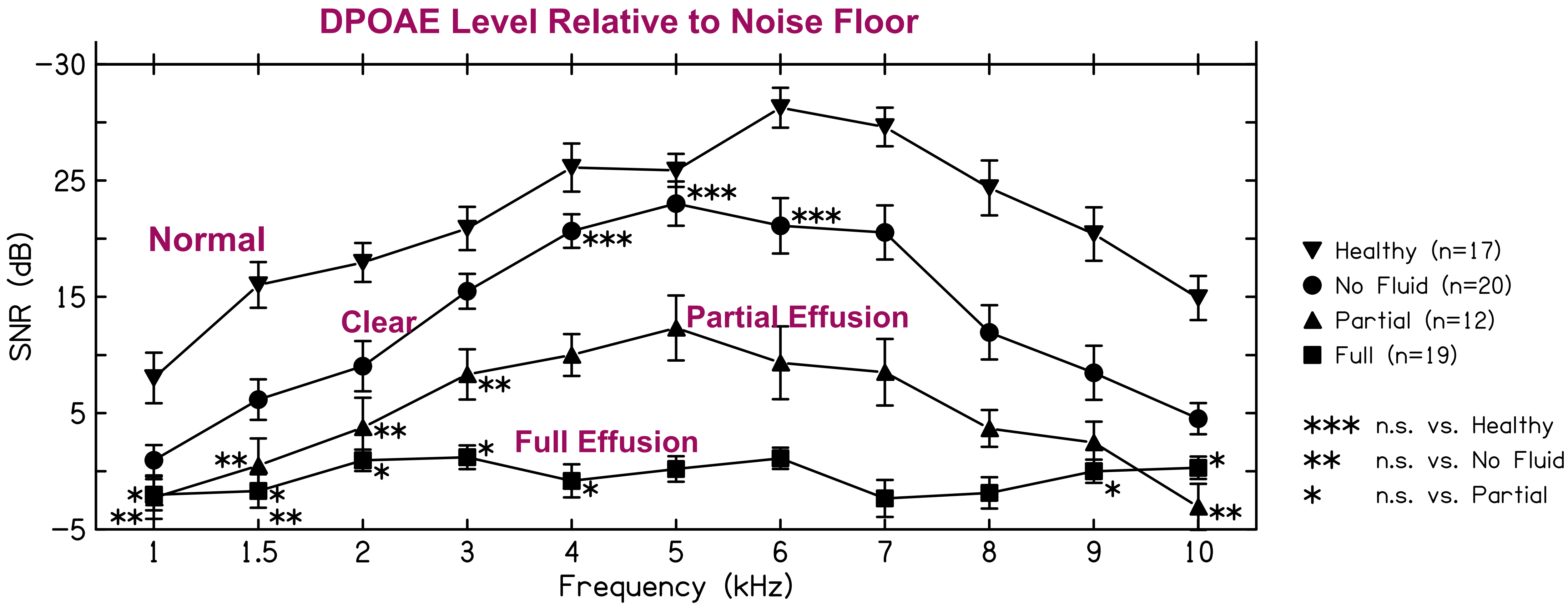
Effusion volume impacts DPOAEs, but somewhat differently than it does for hearing levels



Separation between empty and partial ears, likely due to influence of both forward and reverse transmission for DPOAEs

Al-Salim et al 2021

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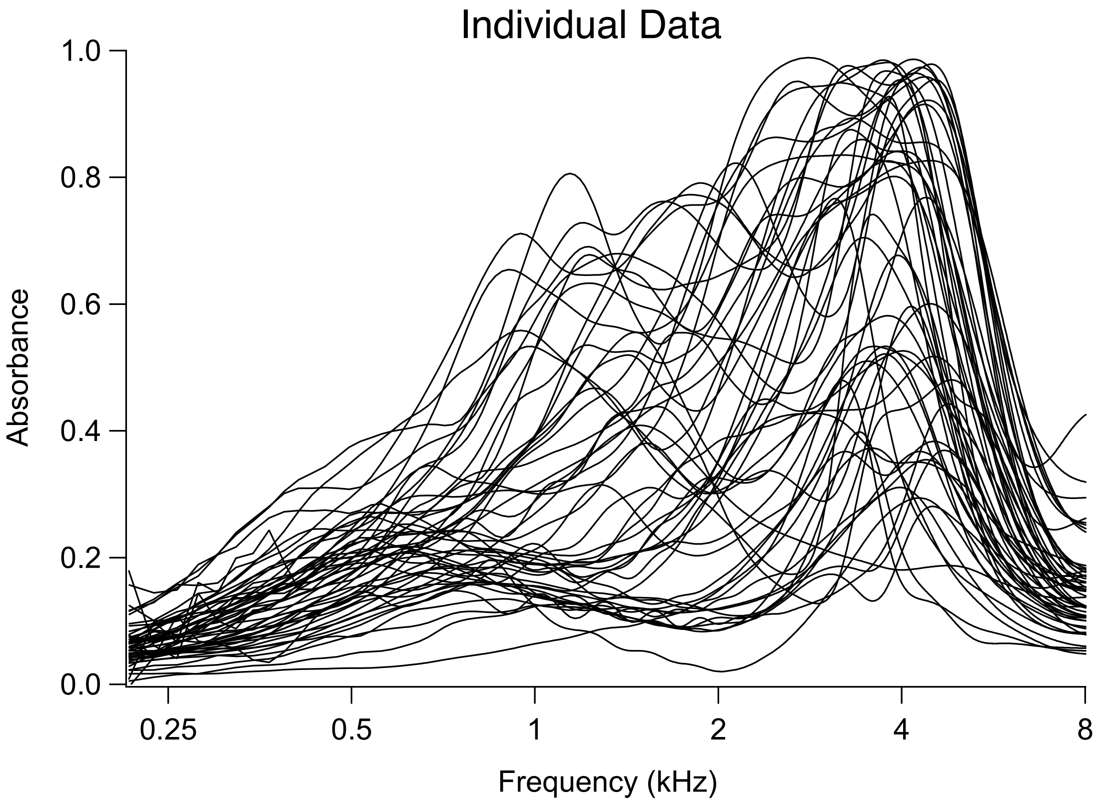
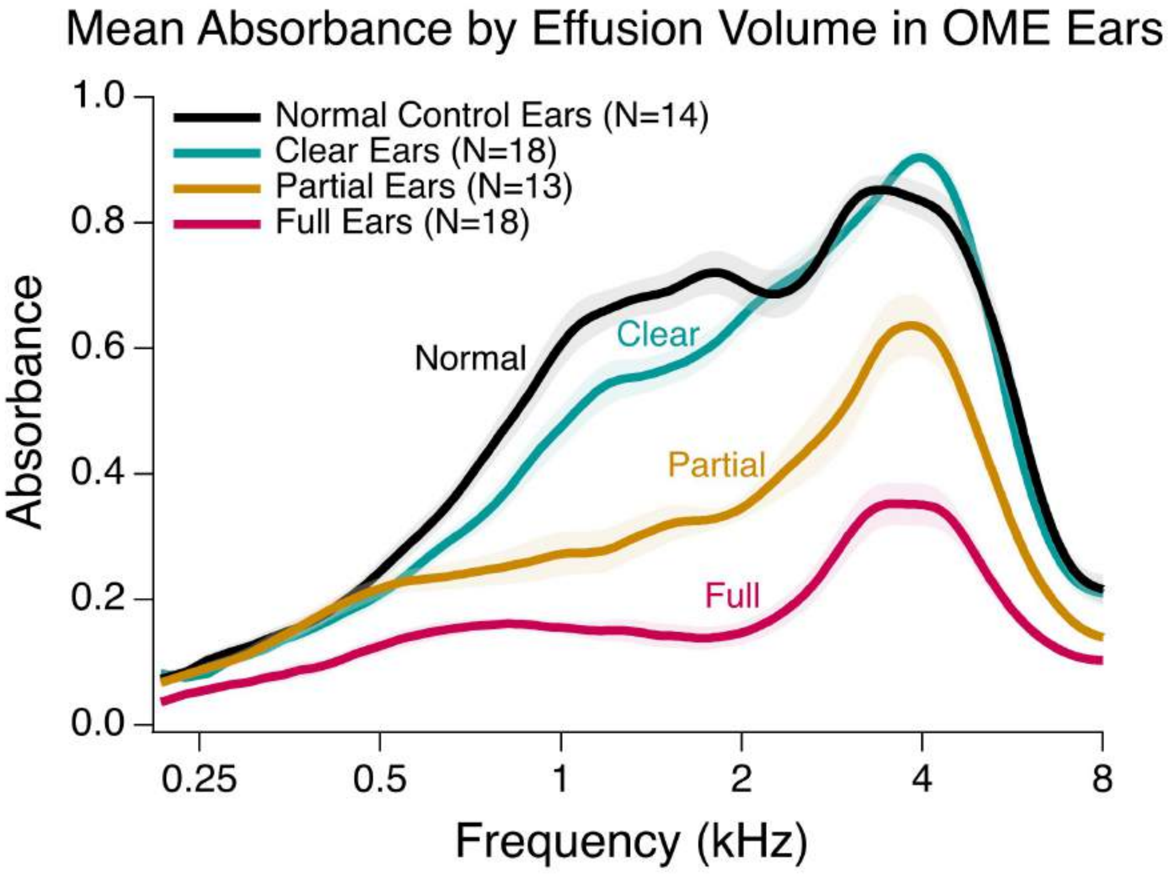
Unlike Tympanometry, WAI Absorbance Shows Significant Promise in Predicting Effusion Volume



The influence of OME on auditory mechanics is highly variable when we look across frequency!

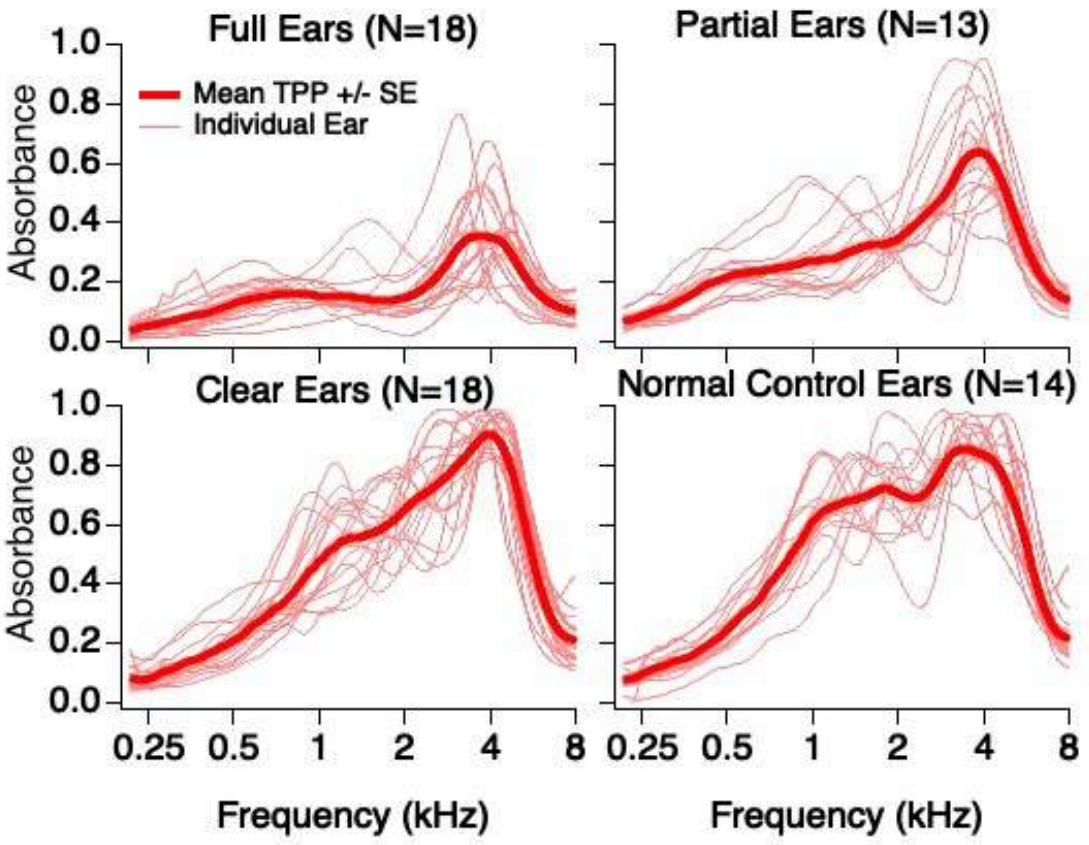


Merchant et al 2021

National Research Hospital

Predictions Are Also Strong in Individual WAI Data

Results of a machine learning algorithm trained on 70% of the data (reduced using a PCA) and validated on 30% of the unseen data: high AUCs for effusion present vs absent and full vs. partial, moderate for clear vs. normal.



Effusion Present versus Absent			Partial versus Full Effusion			Clear versus Normal Ears		
Validation Confusion Matrix			Validation Confusion Matrix			Validation Confusion Matrix		
Accuracy: 95%, Sensitivity: 95%, Specificity: 95%, AUC: 0.988			Accuracy: 89%, Sensitivity: 89%, Specificity: 88%, AUC: 0.944			Accuracy: 65%, Sensitivity: 67%, Specificity: 62%, AUC: 0.689		
	Present	Absent		Full	Partial		Clear	Normal
Present	8459	541	Full	8459	541	Clear	3642	1358
Absent	439	9561	Partial	439	9561	Normal	1788	2212

Merchant et al 2021

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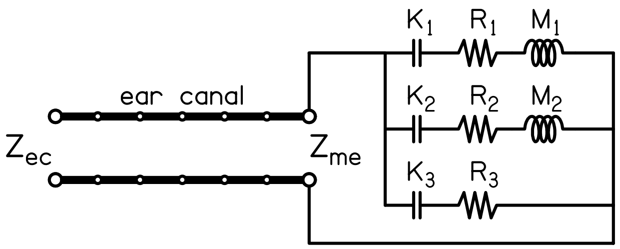
Combining Absorbance with a Computational Model Improves Accuracy



AUC Values for Various Approaches			
Decision Variable	Effusion / No Effusion	Full / Partial	Clear / Normal
Absorbance	**0.986**	**0.934**	0.676
Zme estimate	0.980	0.880	**0.808**

- Computational model (a simple lumped element model) that we fit the WAI data to. Meant to represent the gross underlying mechanics. Parameters represent mechanical aspects that can change due to pathology.
- We use various parameters to isolate specific mechanical changes and improve predictions. Here, isolating middle ear impedance (as opposed to ear-canal impedance) improved AUCs for the clear/normal distinction.

Merchant & Neely, 2021

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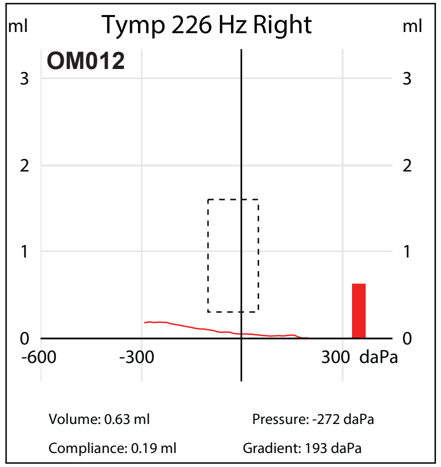
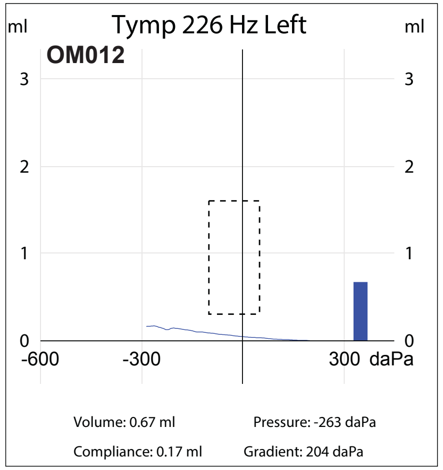
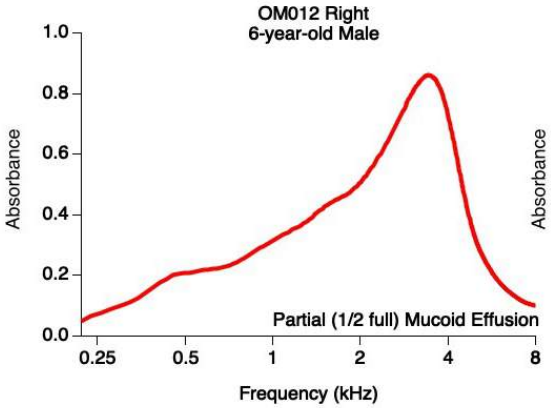
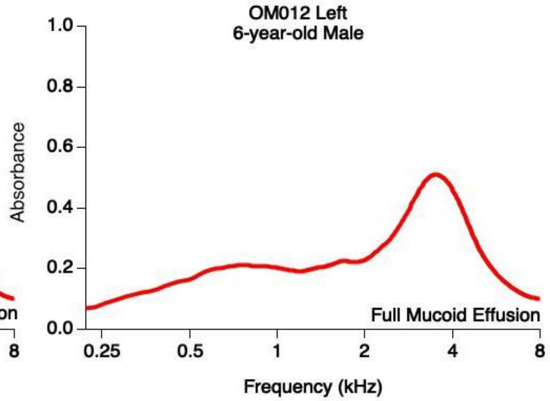
Unlike Tympanometry, WAI Absorbance Shows Significant Promise in Predicting Effusion Volume









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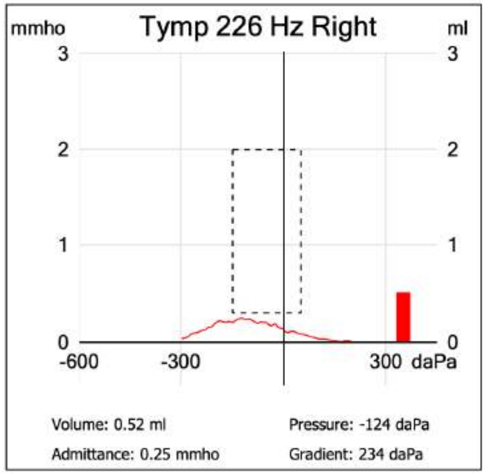
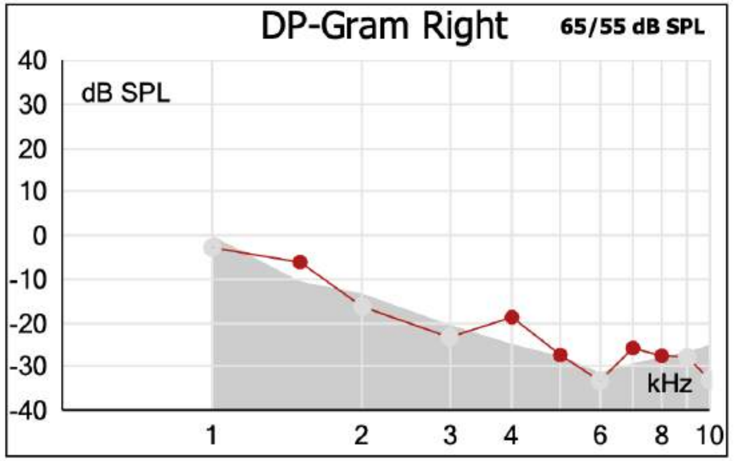
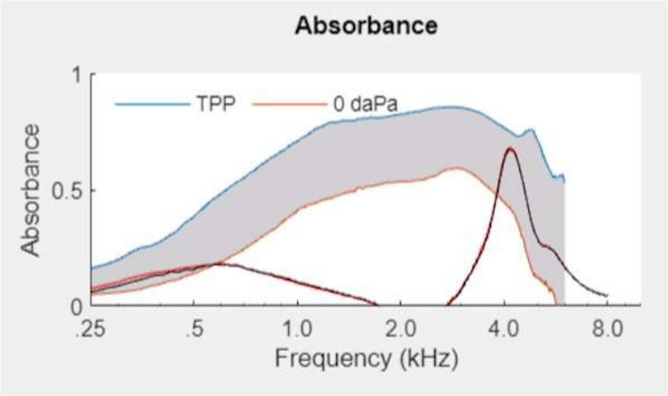
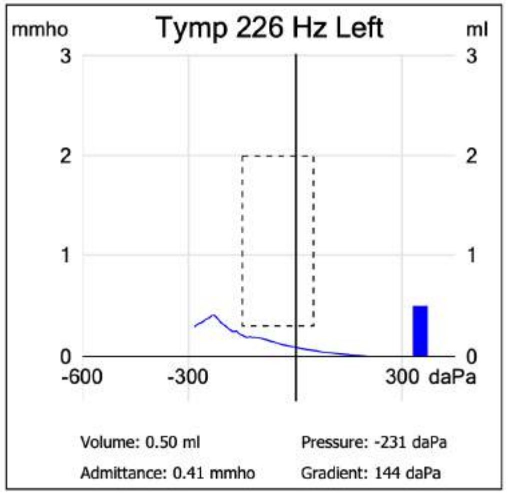
WBT vs Tympanometry, Case 2

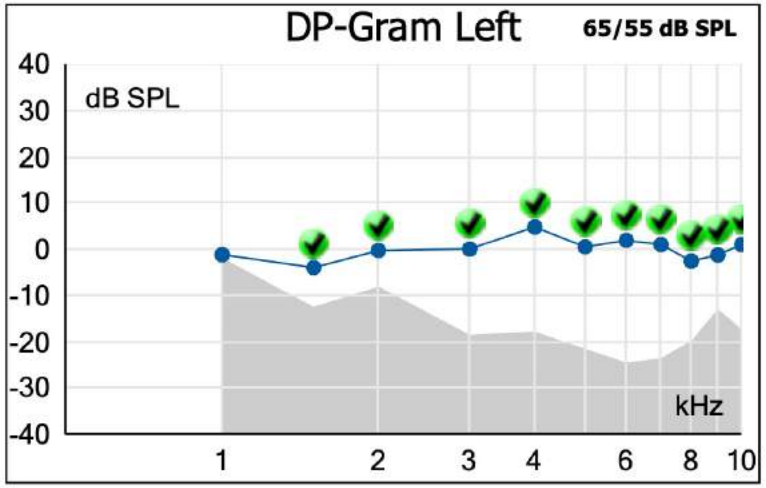


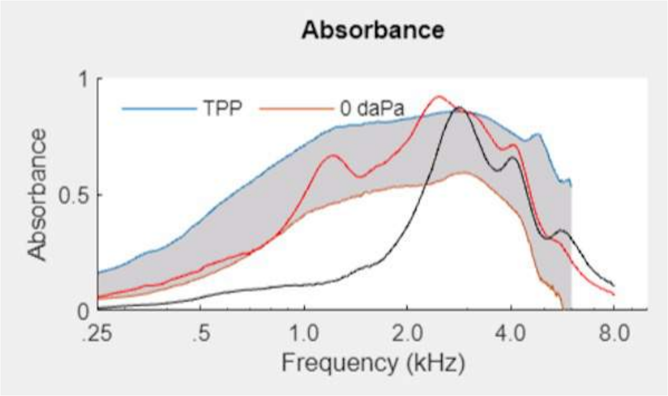




Right: Full effusion/AOM, likely mild to moderate HL







Left: Likely little to no effusion, just negative pressure, normal to near normal hearing

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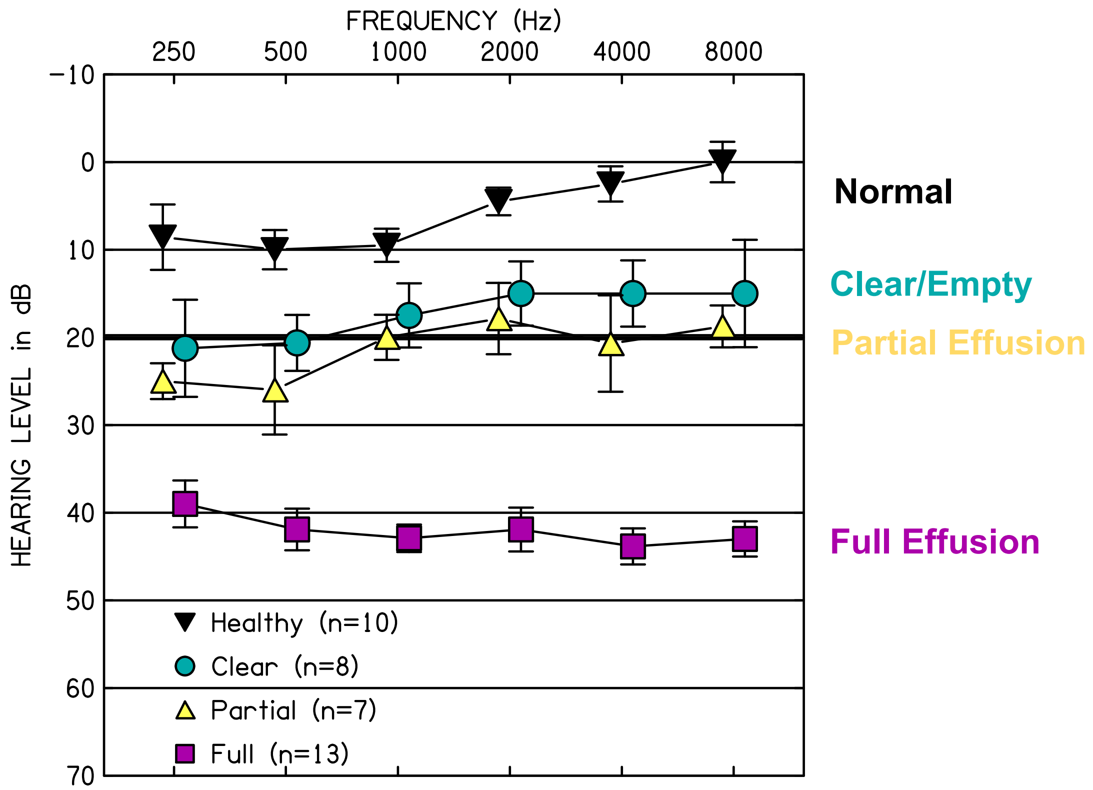
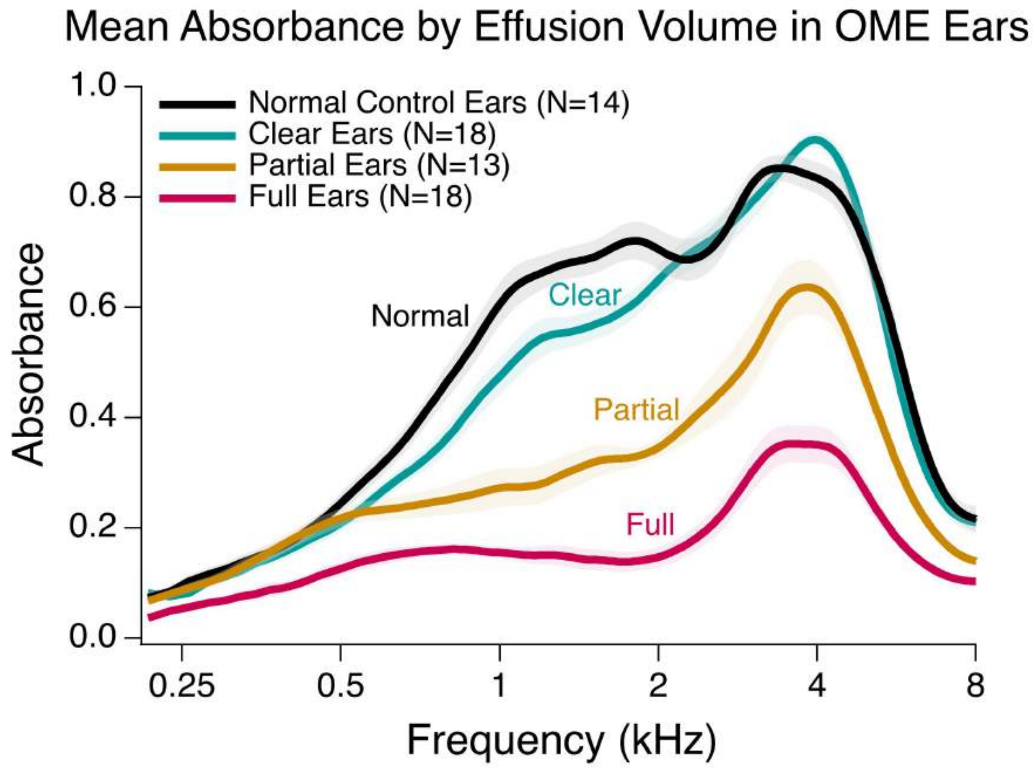
Why are these data exciting to us?





- Wide range of HL for OME. Knowledge of HL is important for management (and likely long-term behavioral outcomes). But testing hearing is hard in this age range!
- Relationship between volume, HL, and WAI absorbance may allow us to infer how a child is hearing.

Al-Salim et al 2021
Merchant et al 2021

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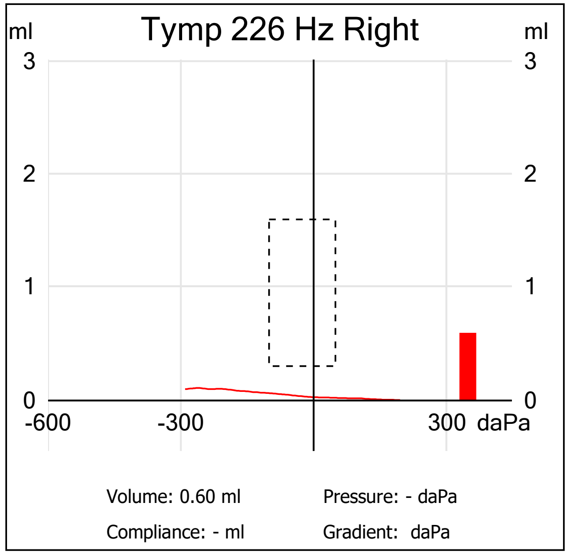

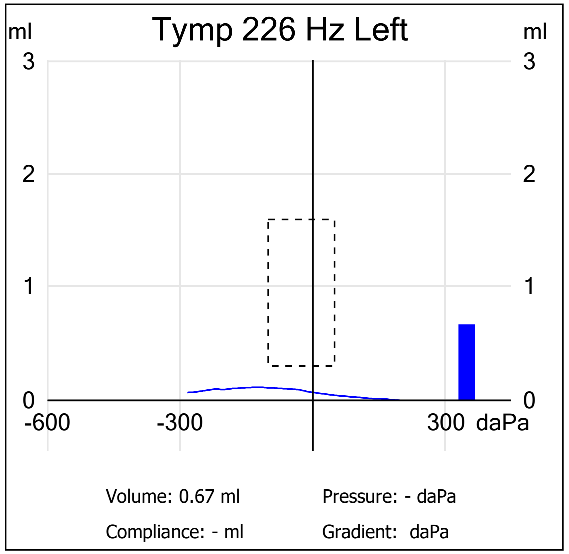

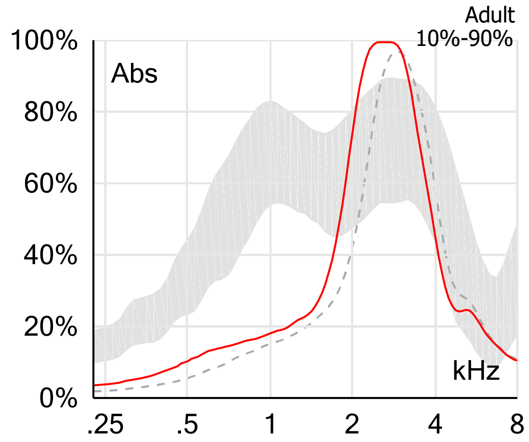

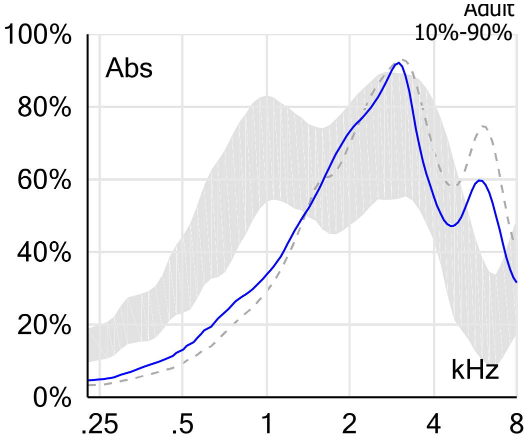

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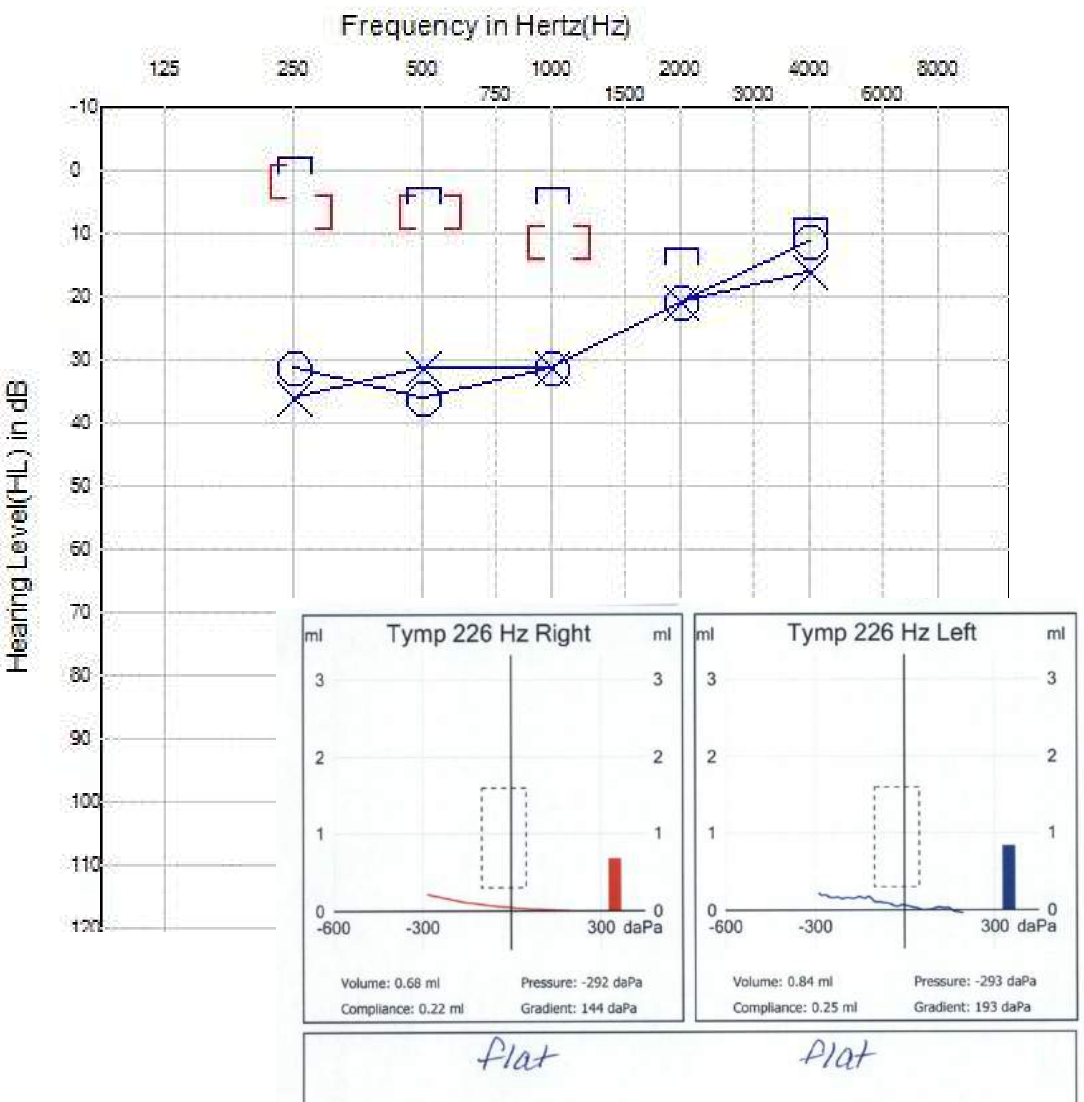
When thing's don't add up…

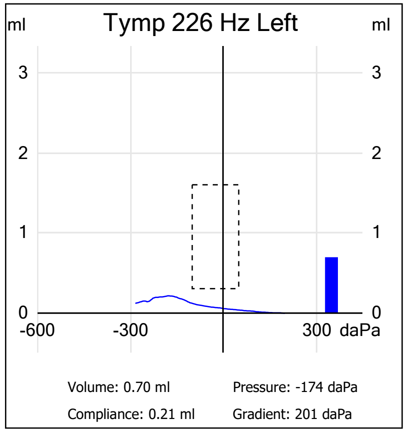
- 8-year-old male
- Seen in clinic for suspected otitis media
- Bilateral Flat Tymps
- Bilateral CHL
- ENT couldn't visualize fluid, but assumed it was present, and scheduled for BMT
- Enrolled in BTNRH OM Study

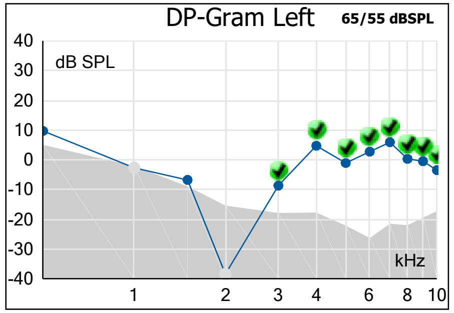
Assessment/Plan

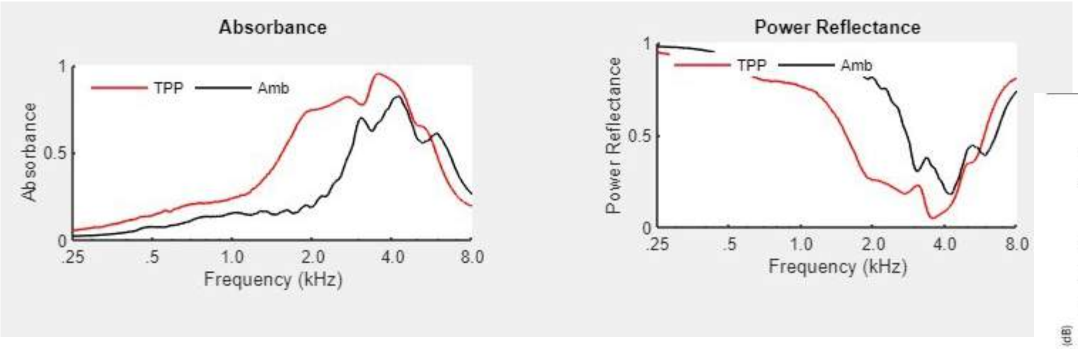
#	Detail Type	Description
1.	Assessment	Conductive hearing loss, bilateral (H90.0).
	Patient Plan	Audiometric studies today demonstrate bilateral low-frequency conductive hearing loss and flat tympanogram. On otologic exam I thought the middle ear was aerated. We repeated his tympanogram flat again. He has had hearing loss identified over the last 6 months. We discussed the common nature of middle ear fluid or dysfunction in this age group. BMT was recommended. We discussed the decision making in the anticipated benefit. I reviewed the risks including need for tympanostomy tube removal and tympanic membrane. We also discussed the importance of postoperative audiometric testing.

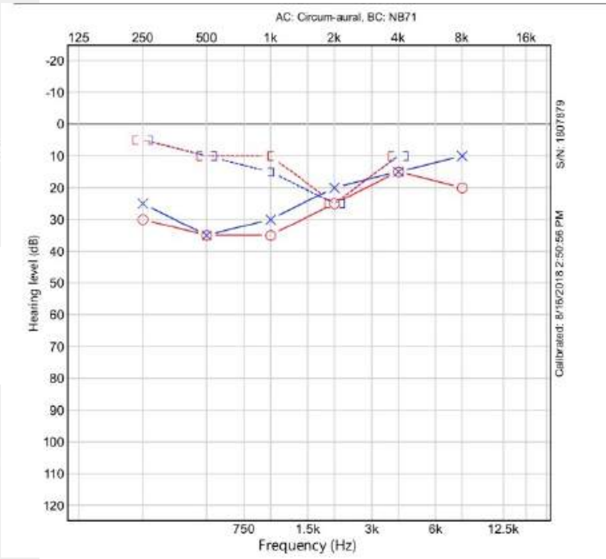


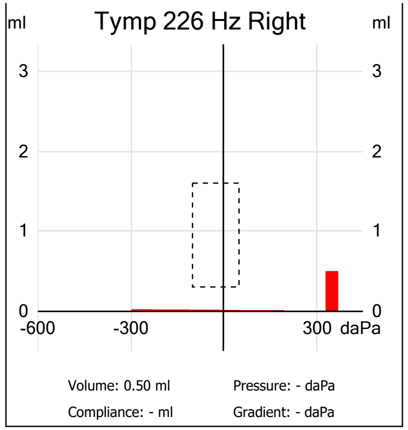
When things don't add up…

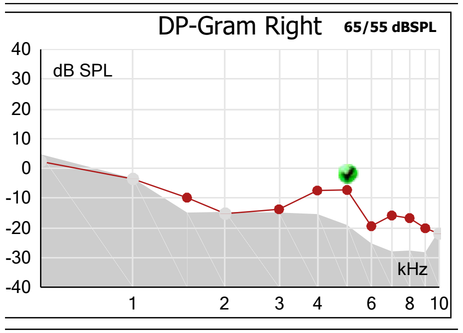


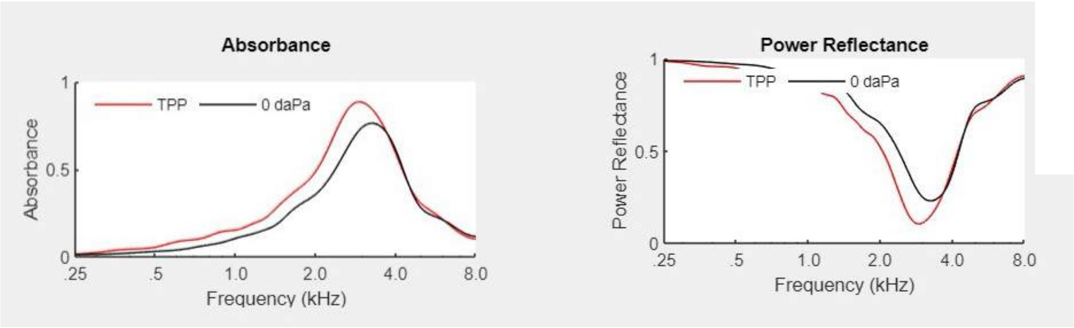












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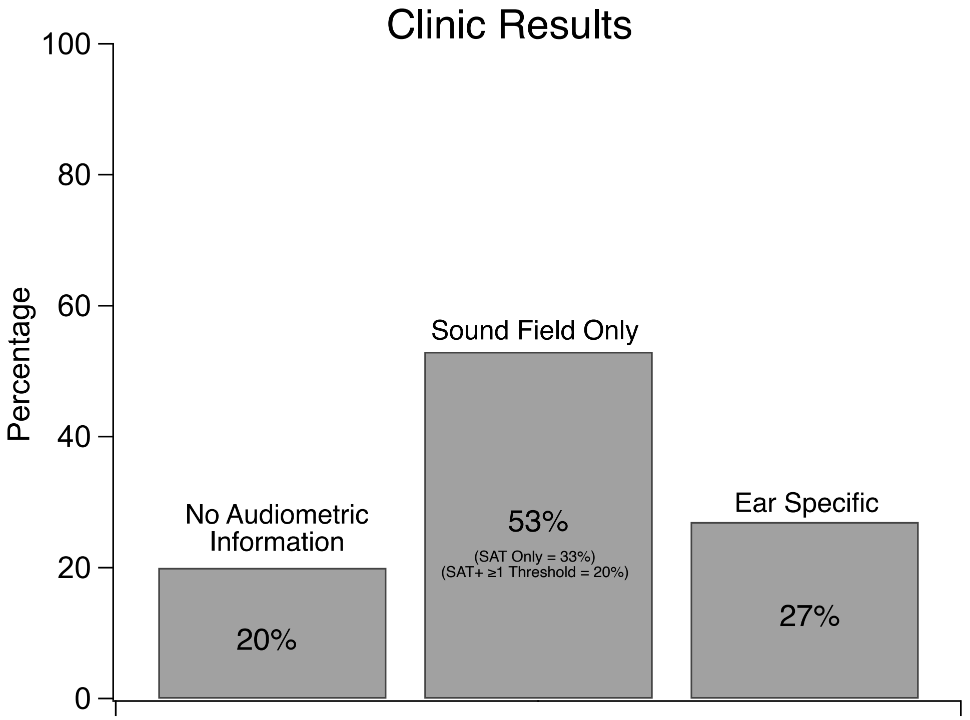
Is audiometric assessment of children with OME challenging? Yes! Especially for ear specific information, even in an ideal research setting.



	Ear Specific Audiometric Test Success					
Visit	***n***	***Age (months)***	**No Ear Specific Information**	**SAT Only**	**≥ 1 Air Threshold**	**≥ 4 Air Thresholds**
Clinic	80	23	73%	4%	23%	15%
Research	80	23	55%	0%	45%	34%

While sound field data is certainly very useful clinically, ear specific information may be particularly important in this population because:

1. OME status in one ear is not well correlated with the contralateral ear.
2. Sound field data could miss a hearing loss in one ear.
3. Deficits in processes like binaural hearing are likely influenced by how both ears are hearing.

Merchant et al., 2024

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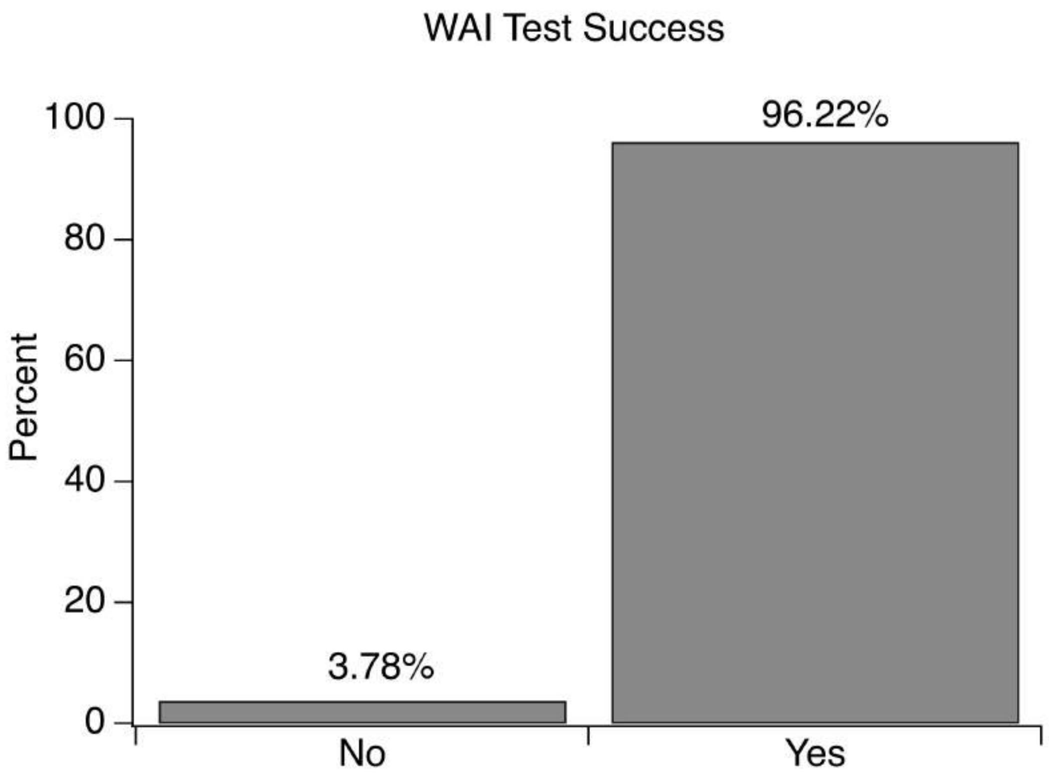
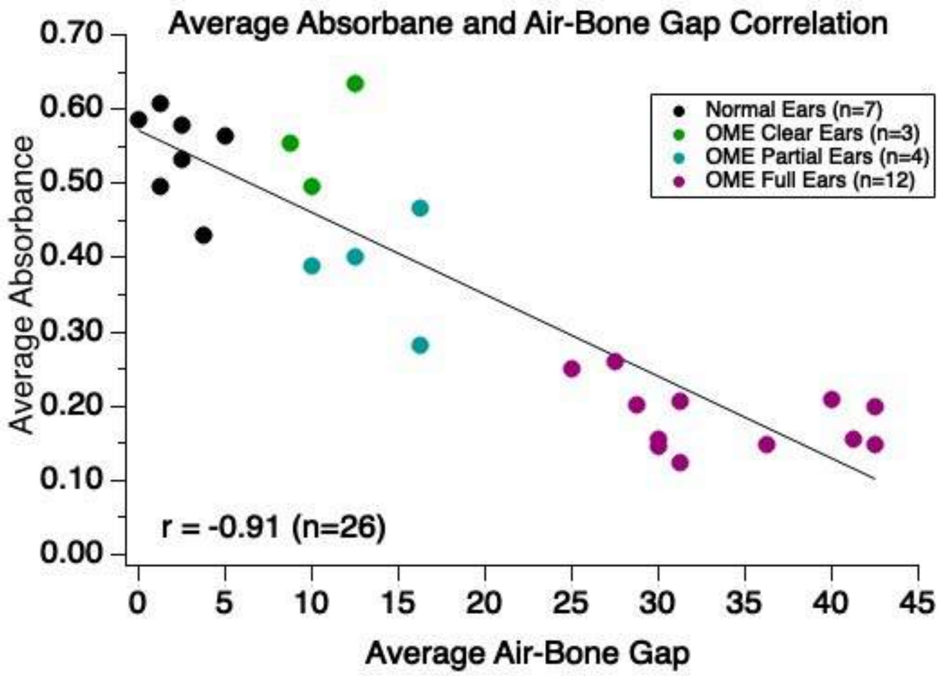
Is WAI Absorbance Easier? (Yes! Much!)



Merchant et al., 2024

In Progress…Directly estimating CHL from WAI



- What if instead of estimating volume from WAI to infer something about hearing, we could directly estimate CHL from an individual WAI Absorbance tracing?
- Goal: Develop a WAI-based acoustic estimate of the CHL caused by OM within 3-5 dB HL. Preliminary data suggests that this is achievable by combining WAI with computational modeling.

Merchant & Neely, 2023

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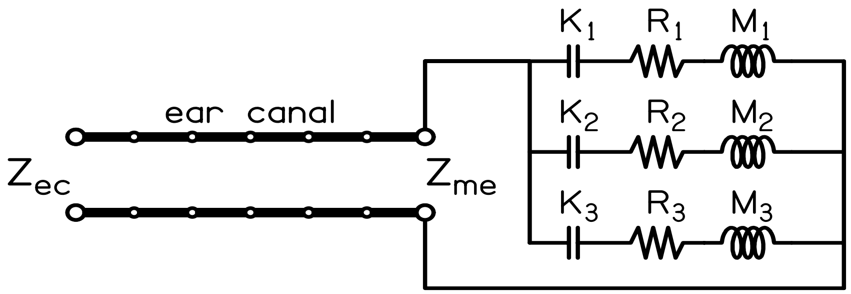
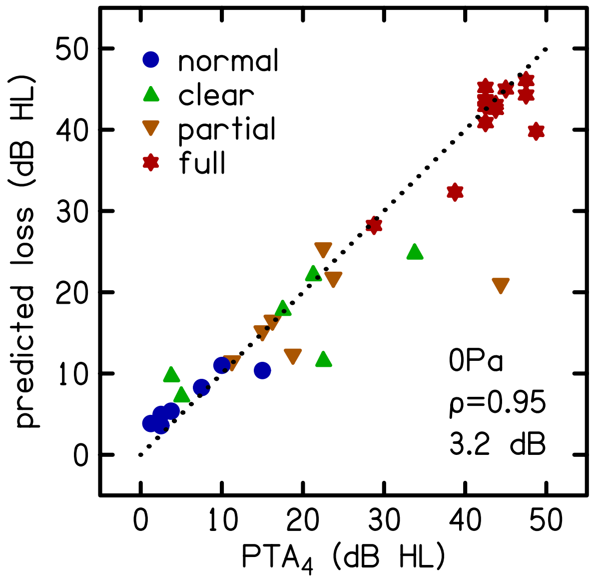
In Progress…Directly estimating CHL from WAI

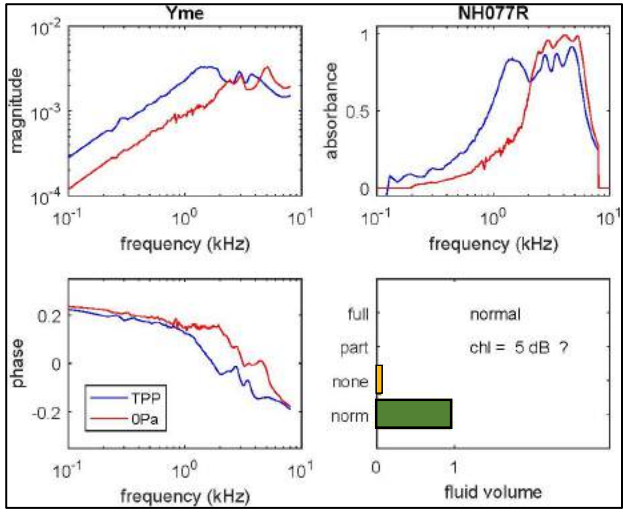
- We used a relatively simple electrical analog model of ear-canal acoustics and middle-ear mechanics to model individual WAI absorbance data and predict the magnitude of the CHL.
- Using this method, we can achieve a correlation between CHL and 4PTA of 95% and a prediction error, quantified as the mean absolute difference, of **3.2 dB.**

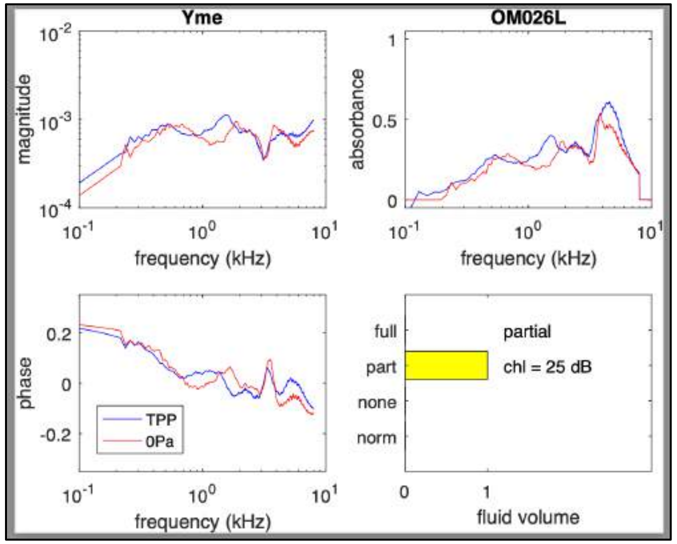


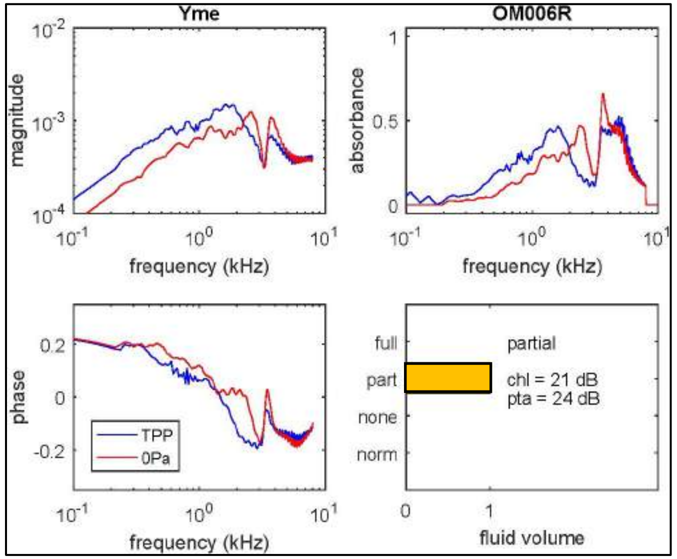


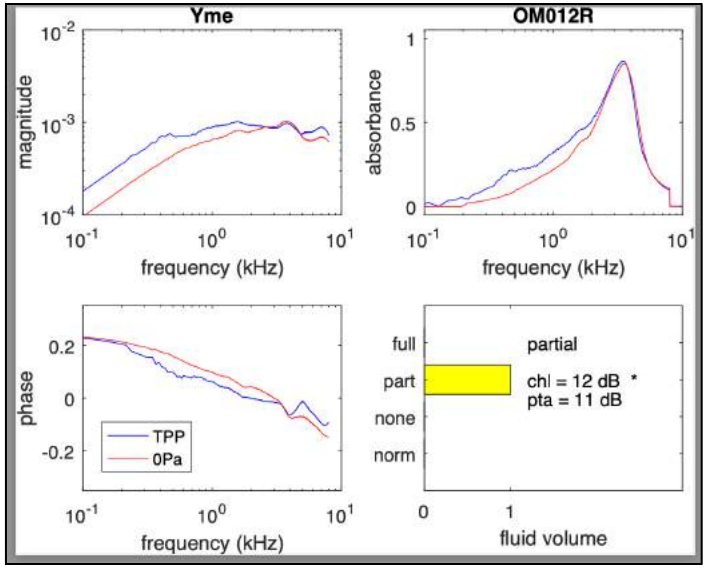
Merchant & Neely, 2023

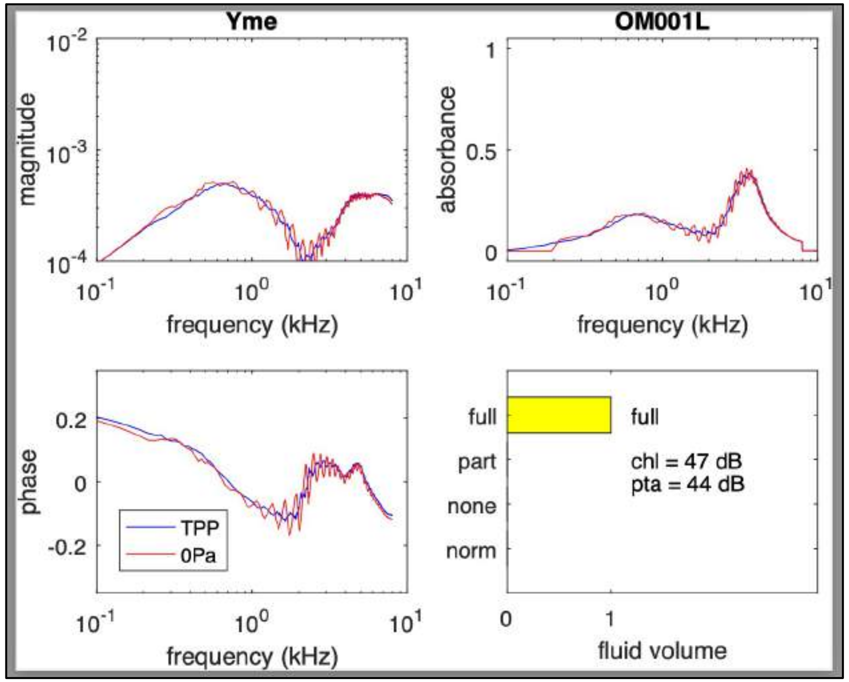
In Progress: (Patented) Machine Learning Outputs for WBT Interpretation











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Reporting

WBT Testing:
"Wideband tympanometry (WBT) testing was completed today. This test utilizes a broadband click stimulus to measure how effectively sound is transmitted through the middle-ear system. WBT absorbance refers to the amount of sound energy that is absorbed by the middle ear across frequencies."

WBT Results:

1. **Normal Findings**

   "WBT absorbance findings are generally within normal limits across the frequency range, suggesting normal middle-ear function."

2. **OME (in children)**

   Full effusion
   "WBT absorbance is largely reduced across most frequencies, with a slight peak noted between 4-6 kHz. Findings suggest that the middle-ear space is likely fully filled with fluid, which often leads to a mild-moderate degree of transient conductive hearing loss."

   Partial effusion
   "WAI absorbance is partially, but not completely, reduced across the frequency range, suggesting that the middle-ear space may be partially filled with fluid. On occasion, this finding may contribute to a slight transient conductive hearing loss; however, hearing sensitivity may also remain unaffected."

3. **Patent Tube/Perforation**

   "WAI absorbance is elevated in the low-frequency range, suggesting a patent tube or tympanic membrane perforation. This finding is further supported by the large ear canal volume measured."

In Progress…
Monitoring OME & CHL via Mobile Testing

- **Improved knowledge of what is happening with a given episode of OME is helpful, but may not tell us much about long-term outcomes or cumulative auditory deprivation. Need longitudinal data for that.**
- **Goal of our Mobile OM (MOM) Project: Understand the trajectory of OME episodes and prognostic value of WAI**
- **Initial Audiologic Assessment Battery**
  - Otoscopy
  - 226 Hz Tympanometry
  - Wideband Acoustic Immittance
  - Distortion Product Otoacoustic Emissions (DPOAEs): 1-10 kHz
  - Behavioral Pure-Tone Audiometry
- **Weekly Monitoring Assessment**
  - Otoscopy
  - 226 Hz Tympanometry
  - Wideband Acoustic Immittance
  - Distortion Product Otoacoustic Emissions (DPOAEs): 1-10 kHz

Mobile Testing

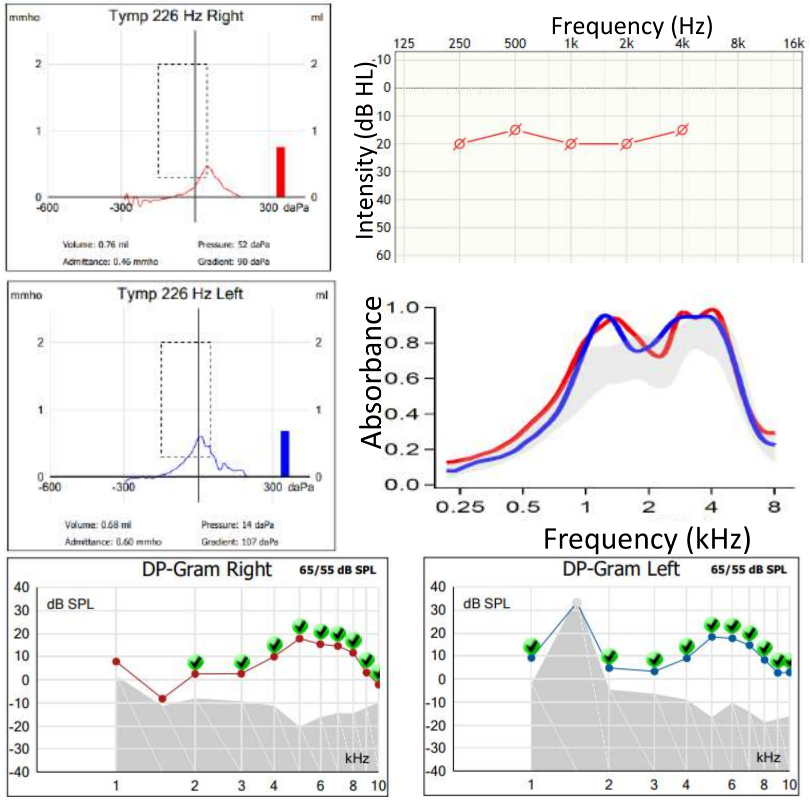
TRANSLATIONAL AUDITORY PHYSIOLOGY & PERCEPTION LAB

Mobile
Otitis
Media

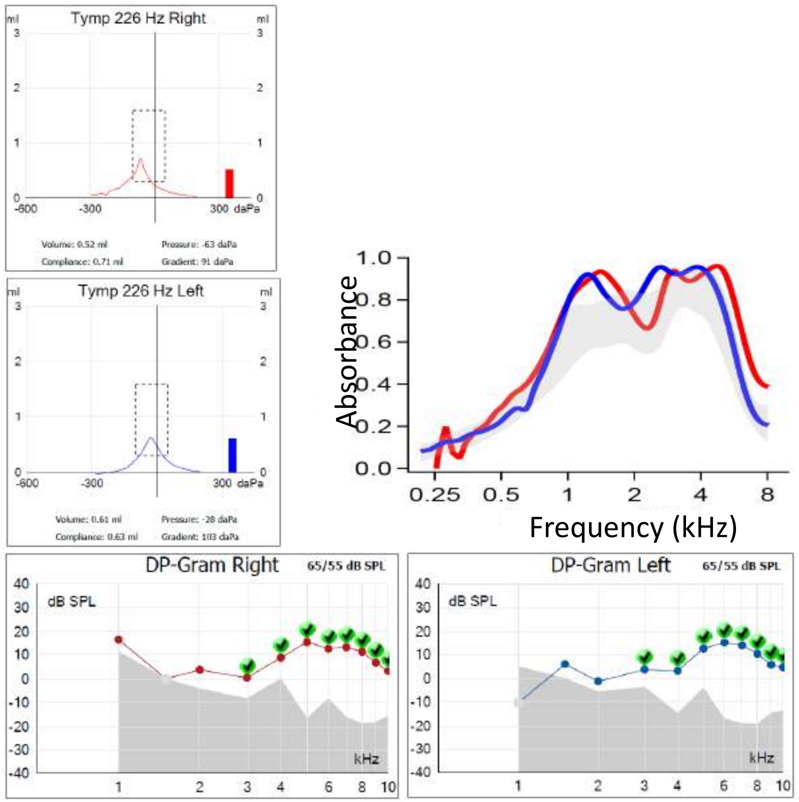
Case Studies

Case Study - Control

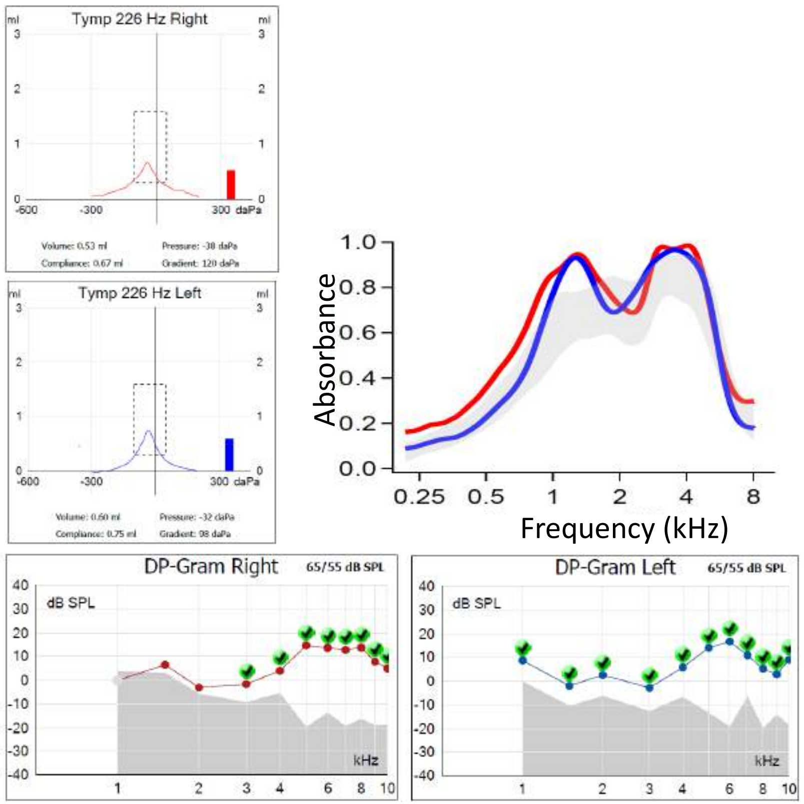
Control 2 - Initial



Control 2 - Week 2



Control 2 - Week 4



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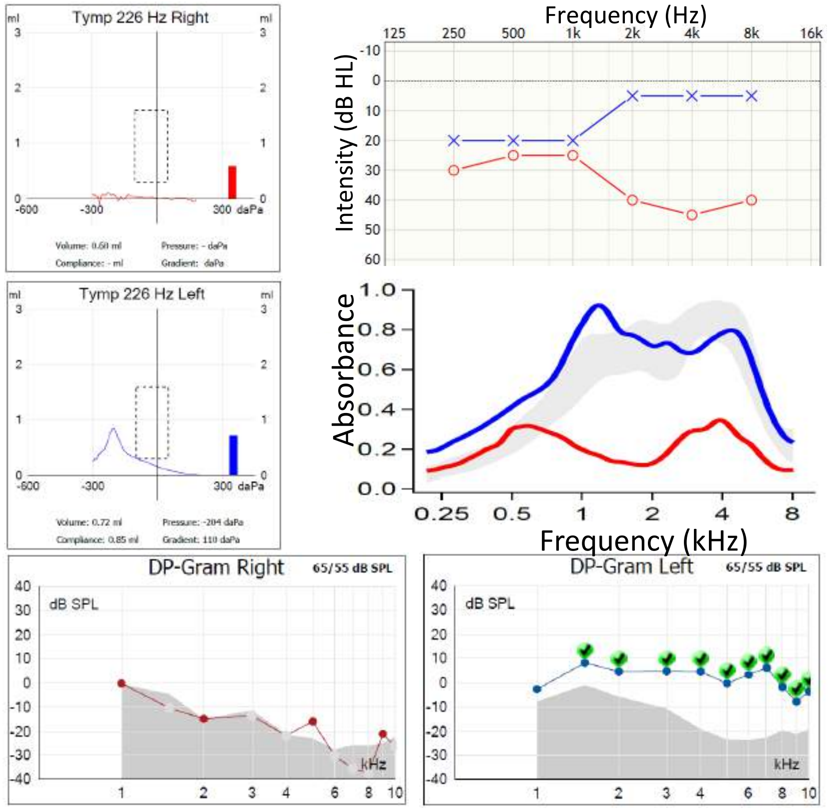
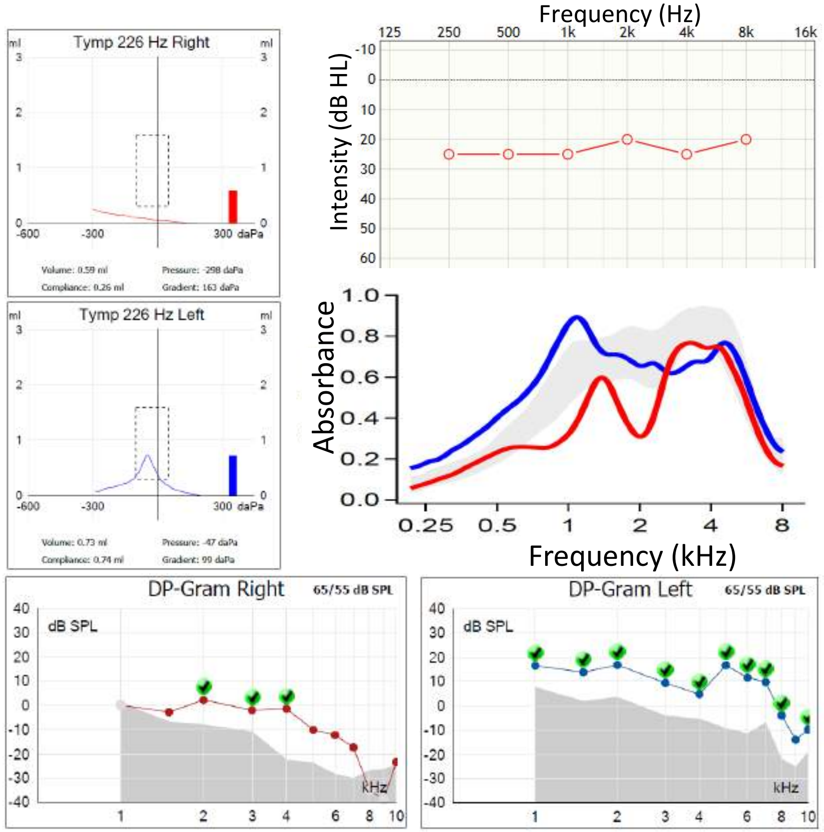
Case Study 1

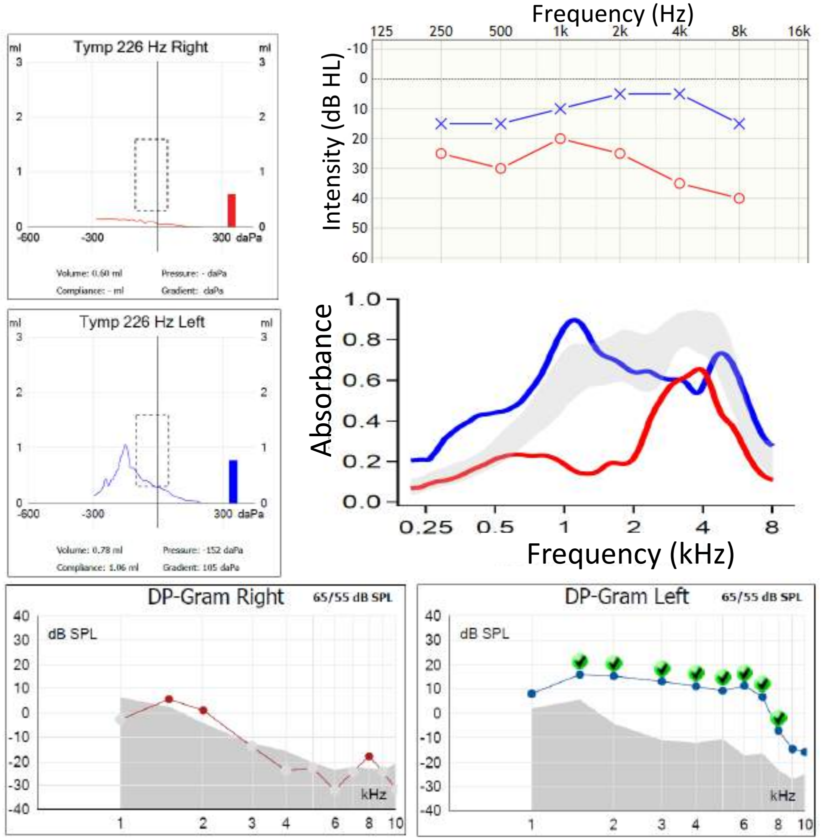
Subject 5 - Initial



Subject 5 - Week 1



Subject 5 - Week 2



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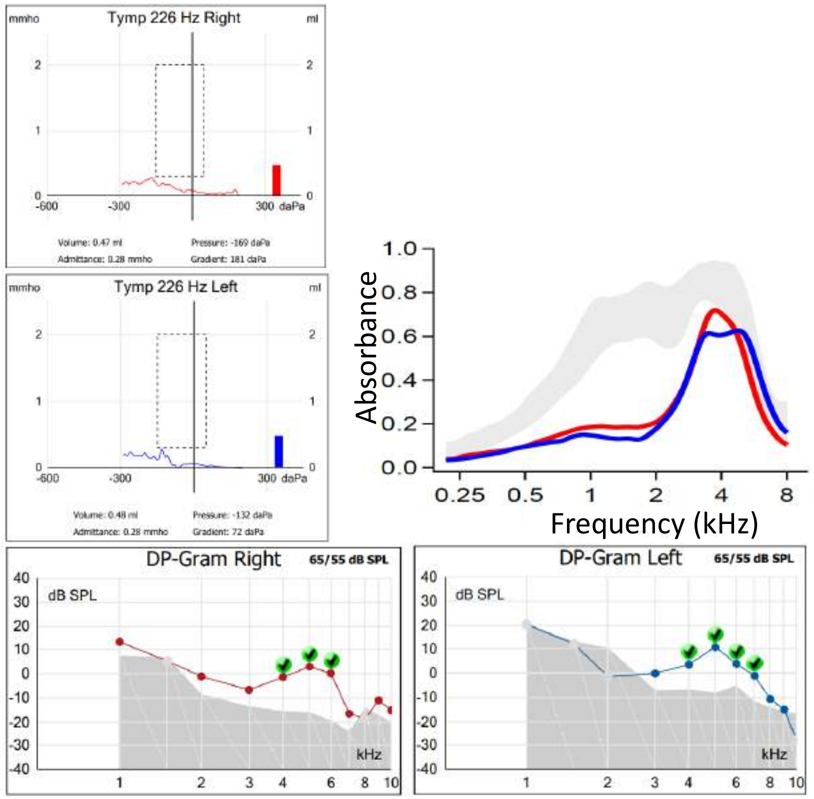
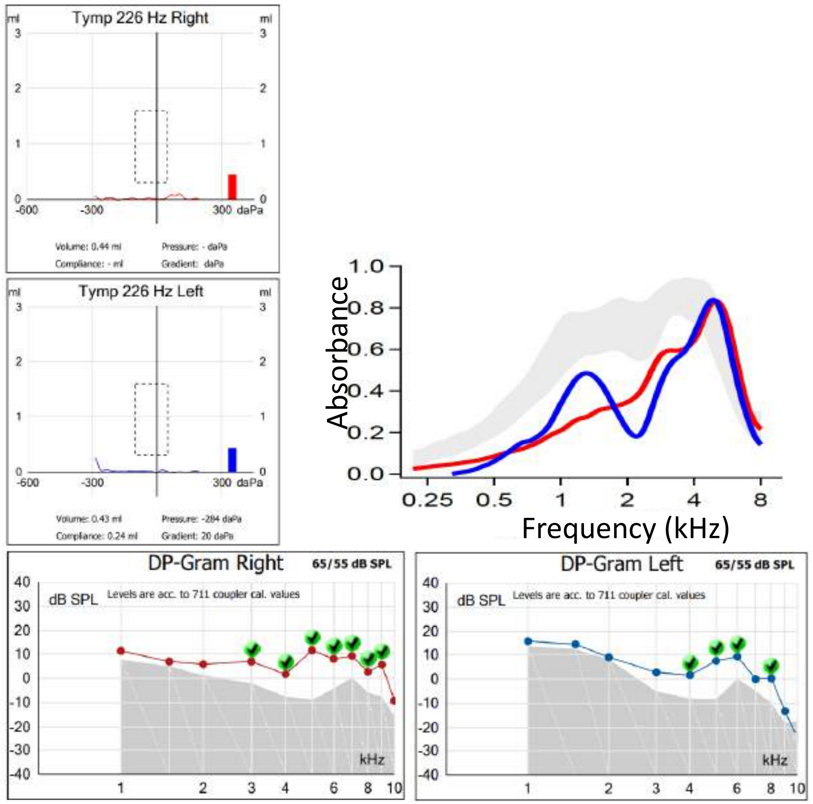
Case Study 2

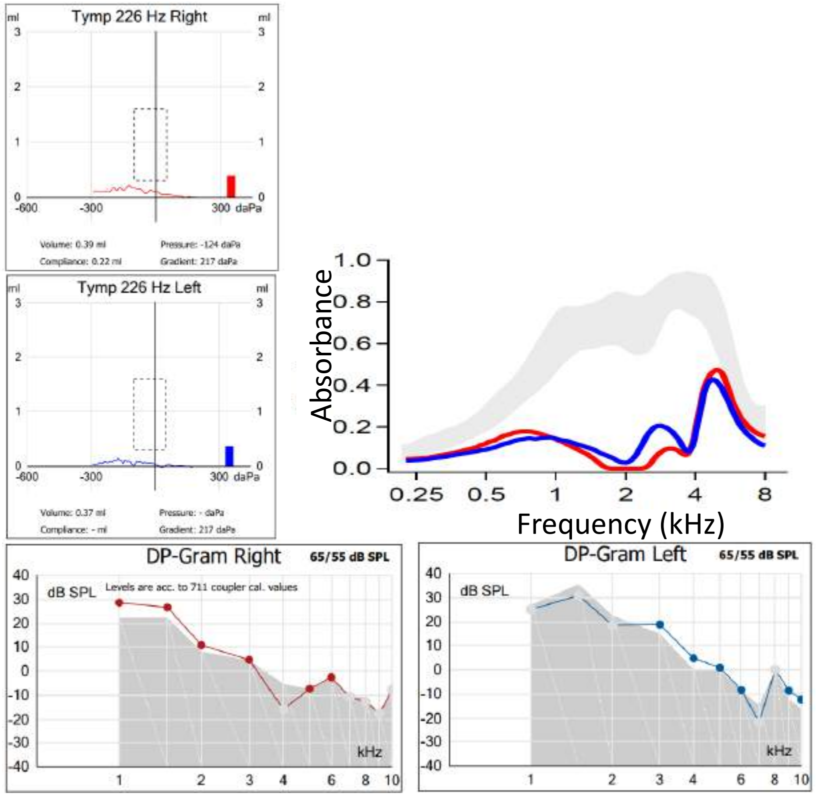
Subject 3 - Initial



Subject 3 - Week 2



Subject 3 - Week 5



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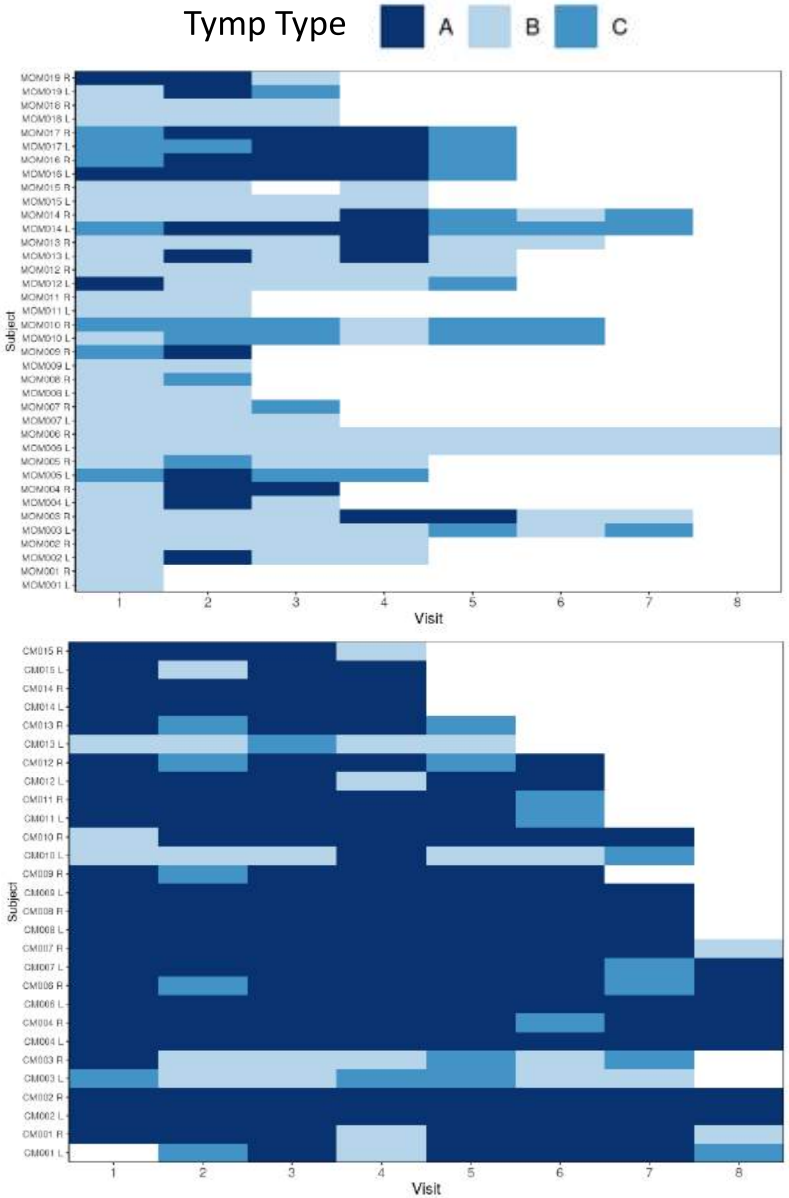
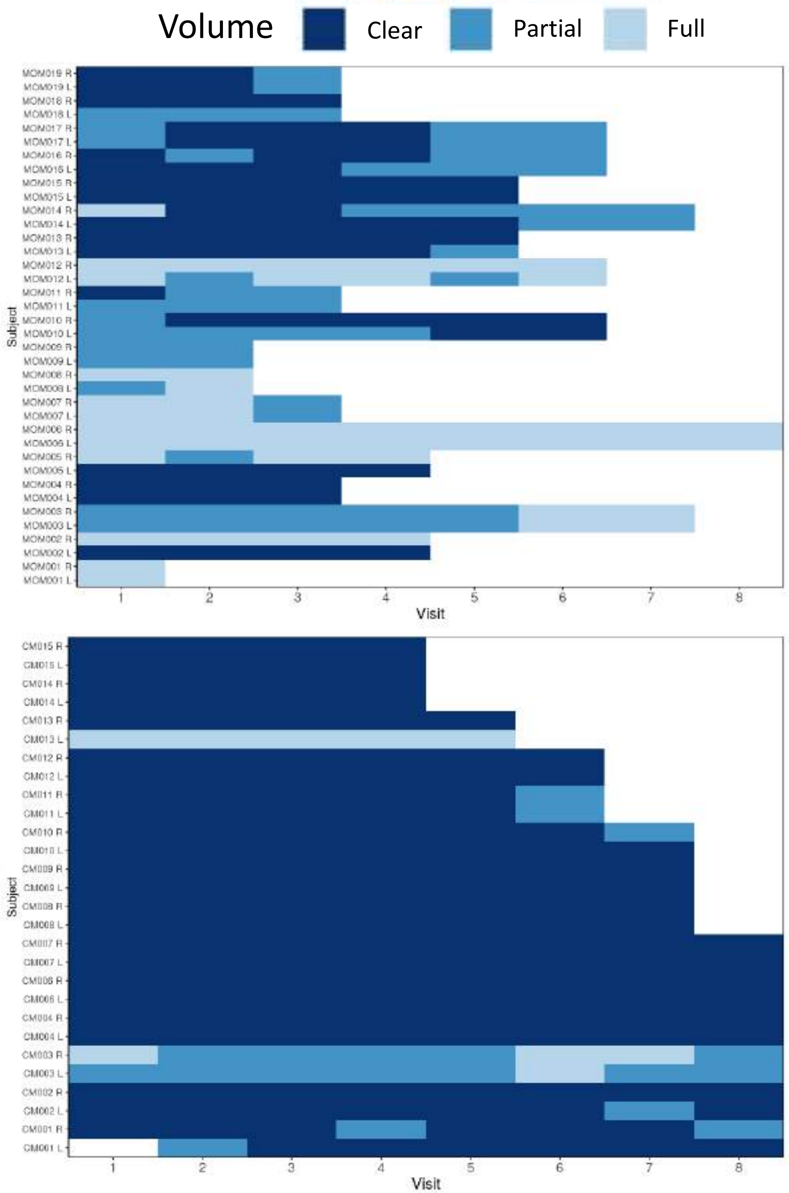
Results

Tympanometry Status Across Visits
(By Jerger Type)



Effusion Volume Across Visits

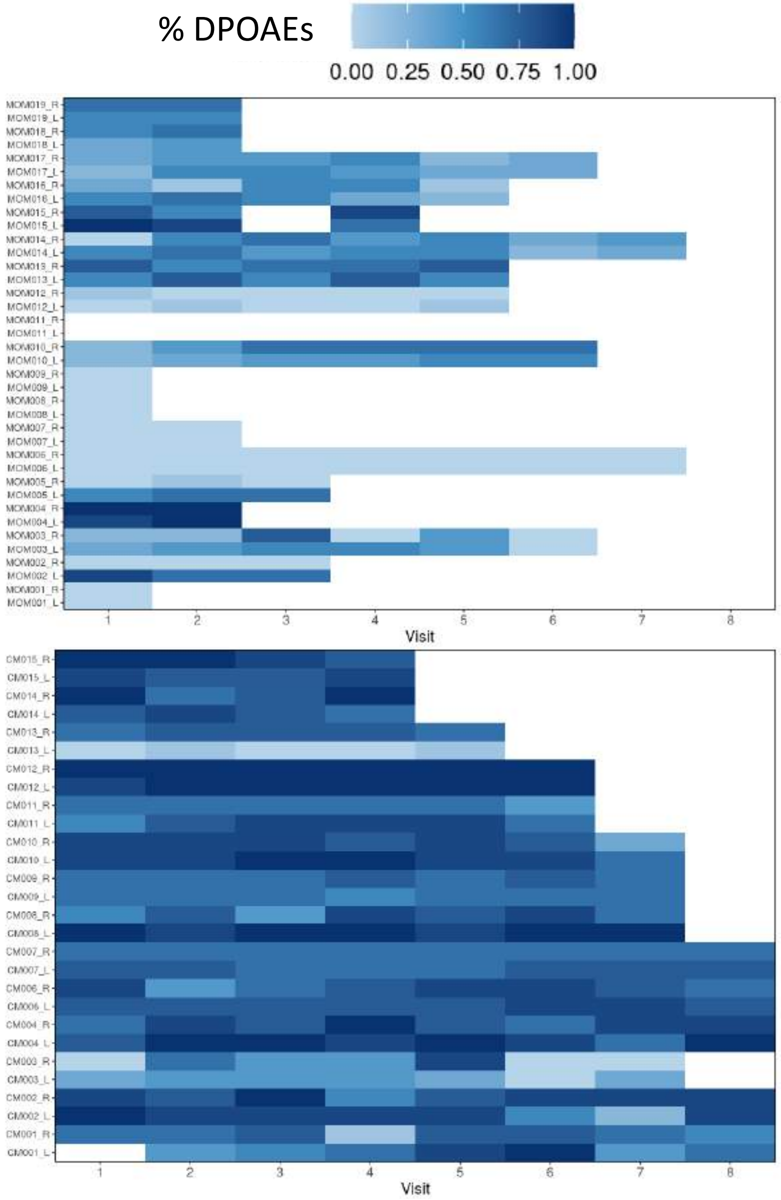


OM Group

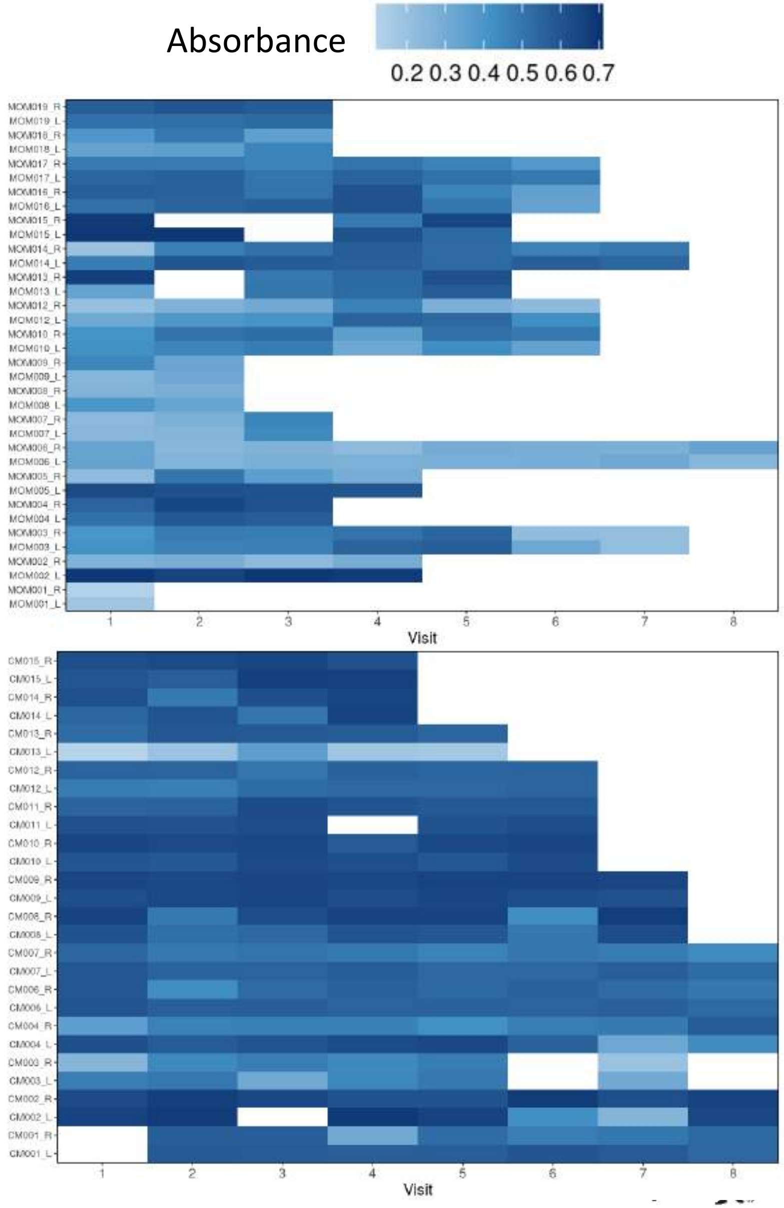
Control

Results

Percent of DPOAEs Present Across Visits



WAI Average Absorbance Across Visits



OM Group

Control

Key Takeaways

- WAI shows strong potential in differentiating **volume** of an effusion.
  - The same cannot be said of 226 Hz tympanometry.
- This is significant, as volume of the effusion also appears to be a driving factor as to whether and how much CHL is present.
  - Having a tool that could predict whether a substantial CHL is present would be valuable given the challenging nature of behavioral audiometric assessment in the age group where OM is most common.
- Preliminary data suggest that WAI may be able to directly predict CHL levels in children with OME, providing an ear-specific estimate of hearing that is otherwise not often available.
- WAI is sensitive to subtle shifts in middle-ear mechanics that are not identified using standard tympanometry.

Thank you for your attention!


BOYS TOWN National Research Hospital | Research

Who We Are | Areas of Research | Faculty and Staff | Res

Research ▸ Careers and Training ▸ Postdoctoral Training

Postdoctoral Training

The purpose of this program, directed by Monita Chatterjee, Ph.D. and co-directed by Karla McGregor, Ph.D., is to furnish postdoctoral fellows an opportunity to develop and broaden their research capabilities in one or a combination of scientific disciplines related to human communication and its disorders. A number of exceptional features associated with the program are particularly advantageous to trainees, including:

- A training faculty of full-time scientists to serve as sponsors
- A staff of research-oriented clinicians with access to a large and varied patient population
- Modern, well-equipped laboratories and diagnostic clinics
- A stimulating mix of fundamental and clinically relevant research projects
- A strong core support staff

A T32 institutional postdoctoral training grant from National Institutes of Health (NIH) provides stipends for three trainees in behavioral and clinical translational research appointments with mentors listed below. Additional positions may on occasion be available in these labs or in other research areas including biology, physiology and genetics based on other funding outside of the T32 grant.

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