Effects of static negative middle-ear pressure on wideband acoustic immittance

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Negative middle ear pressure (NMEP)

- NMEP can affect other acoustic measurements of hearing (e.g. otoacoustic emissions)

- Static NMEP is very common
  - It is typically due to Eustachian tube dysfunction
  - It often occurs concurrently with middle ear fluid or infection

- Middle ear pressure in normal ears varies often
  - It is slightly negative during waking hours
  - A NMEP smaller than -100 [daPa] is considered ‘normal’

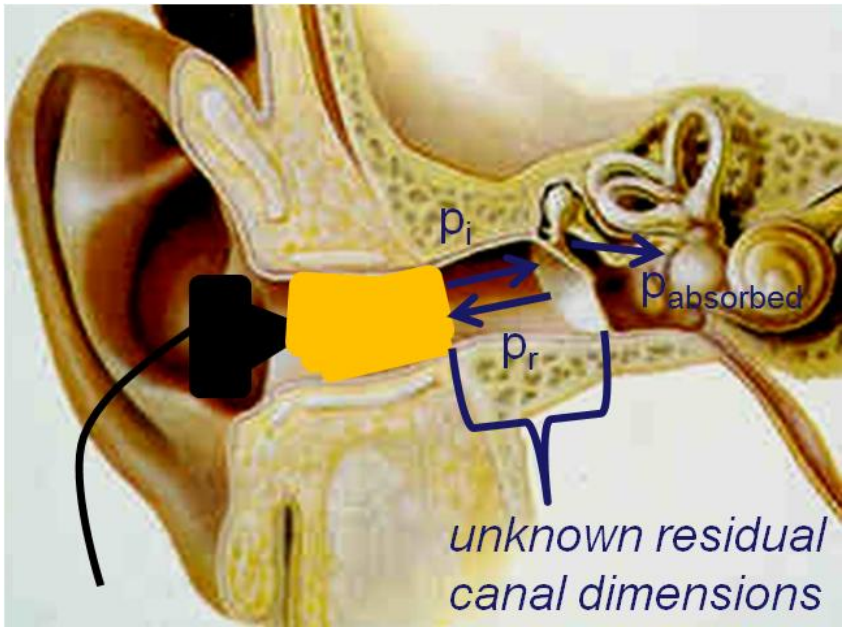
Wideband acoustic immittance (WAI)

- WAI refers to a set of quantities, including the admittance, impedance, reflectance, absorbance, etc.
- Many applications consider the power reflectance and absorbance (≈ independent of ear canal length)

$$|\Gamma(f)|^2 = \left|\frac{p_{reflected}(f)}{p_{incident}(f)}\right|^2$$

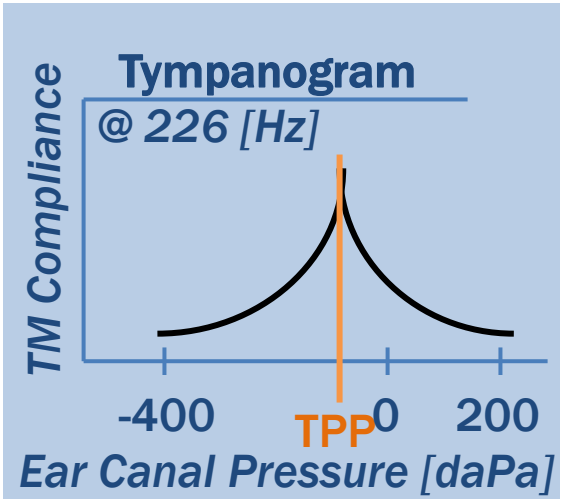
$$|\Gamma(f)|^2 \approx |\Gamma_{tm}(f)|^2$$

$$A(f) = 1 - |\Gamma(f)|^2$$

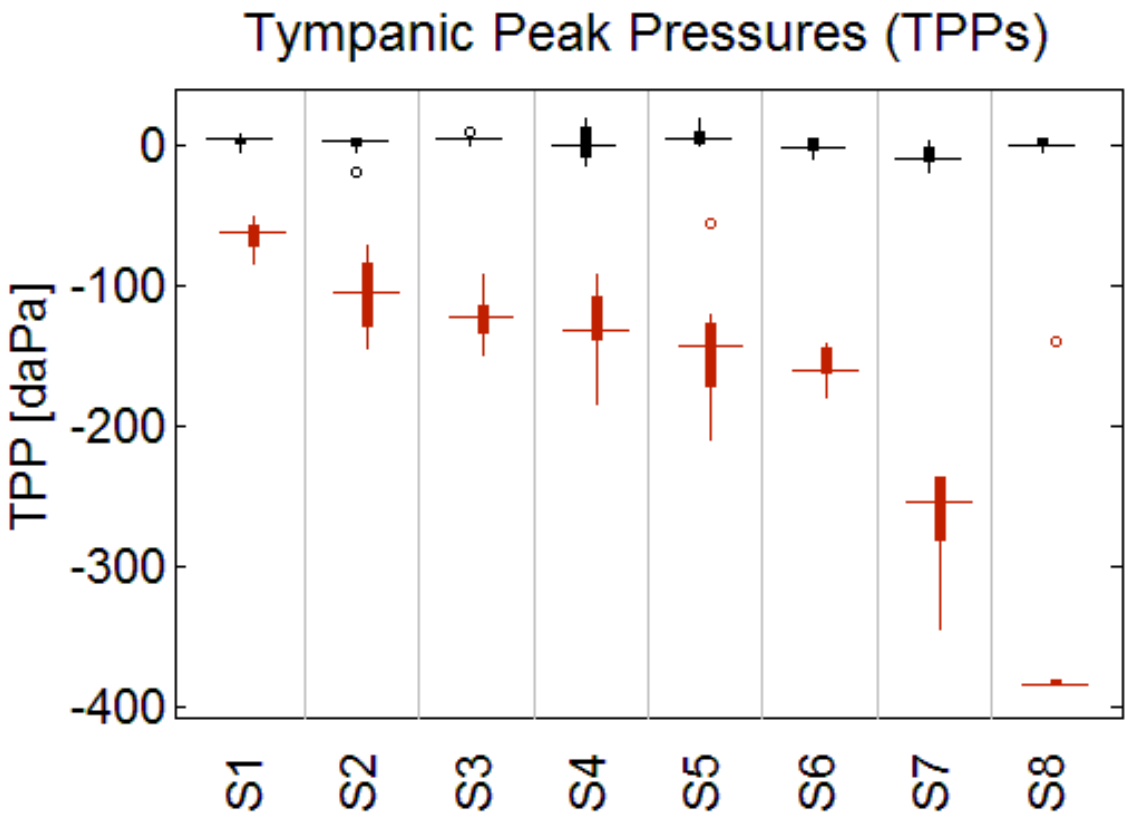


Methods

- WAI was measured with ambient ear canal pressure
- Subjects with normal middle ears induced negative middle ear pressure (NMEP) via the Toynbee maneuver
- Middle ear pressure was assessed separately via tympanometry
  - Middle ear pressure = tympanic peak pressure (TPP)
  - 8 trials at ambient middle ear pressure (AMEP) were alternated with 8 trials at NMEP
  - Subjects were able to induce consistent NMEPs
- We focus on individual ears (lots of retest data)



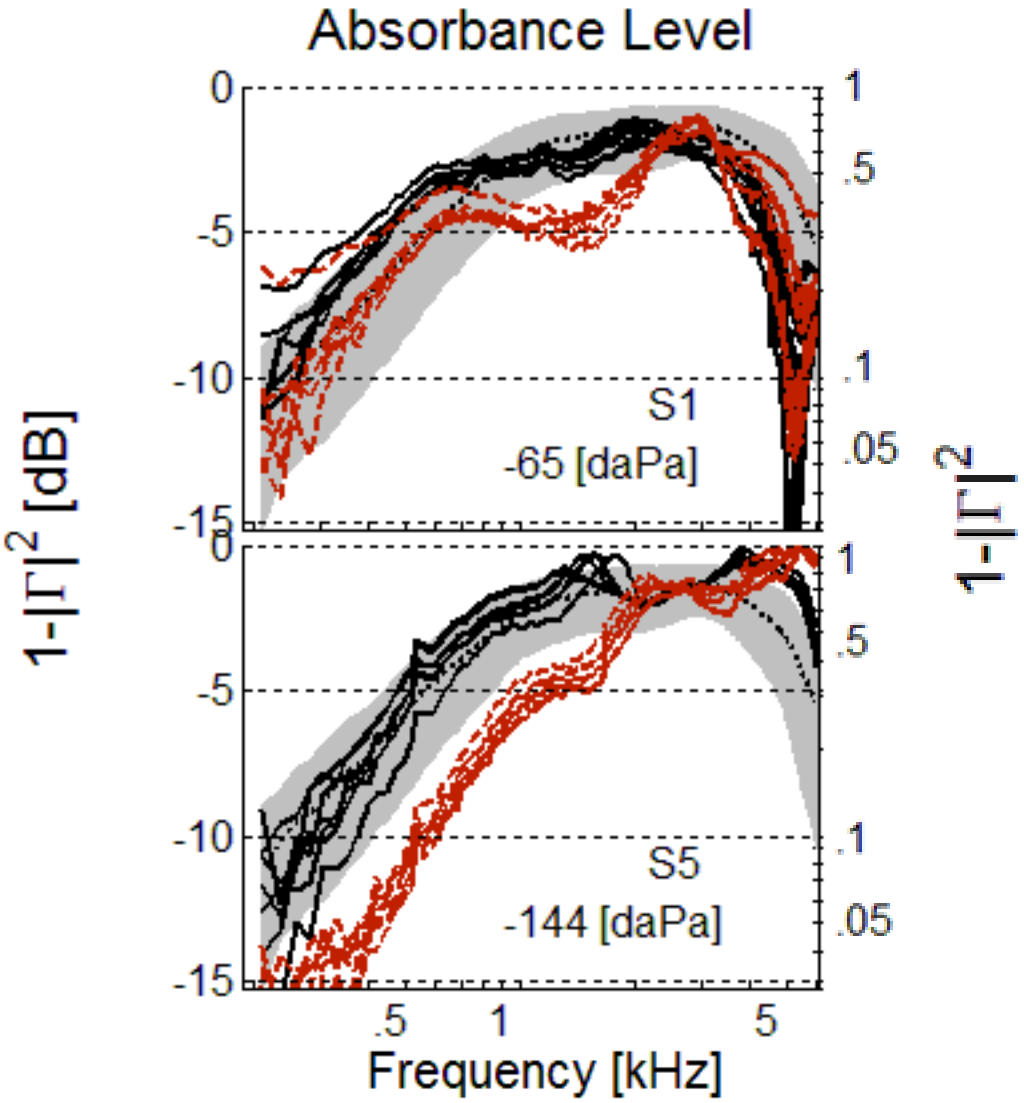
Methods



AMEP

NMEP

WAI Results: Power Absorbance



AMEP

NMEP

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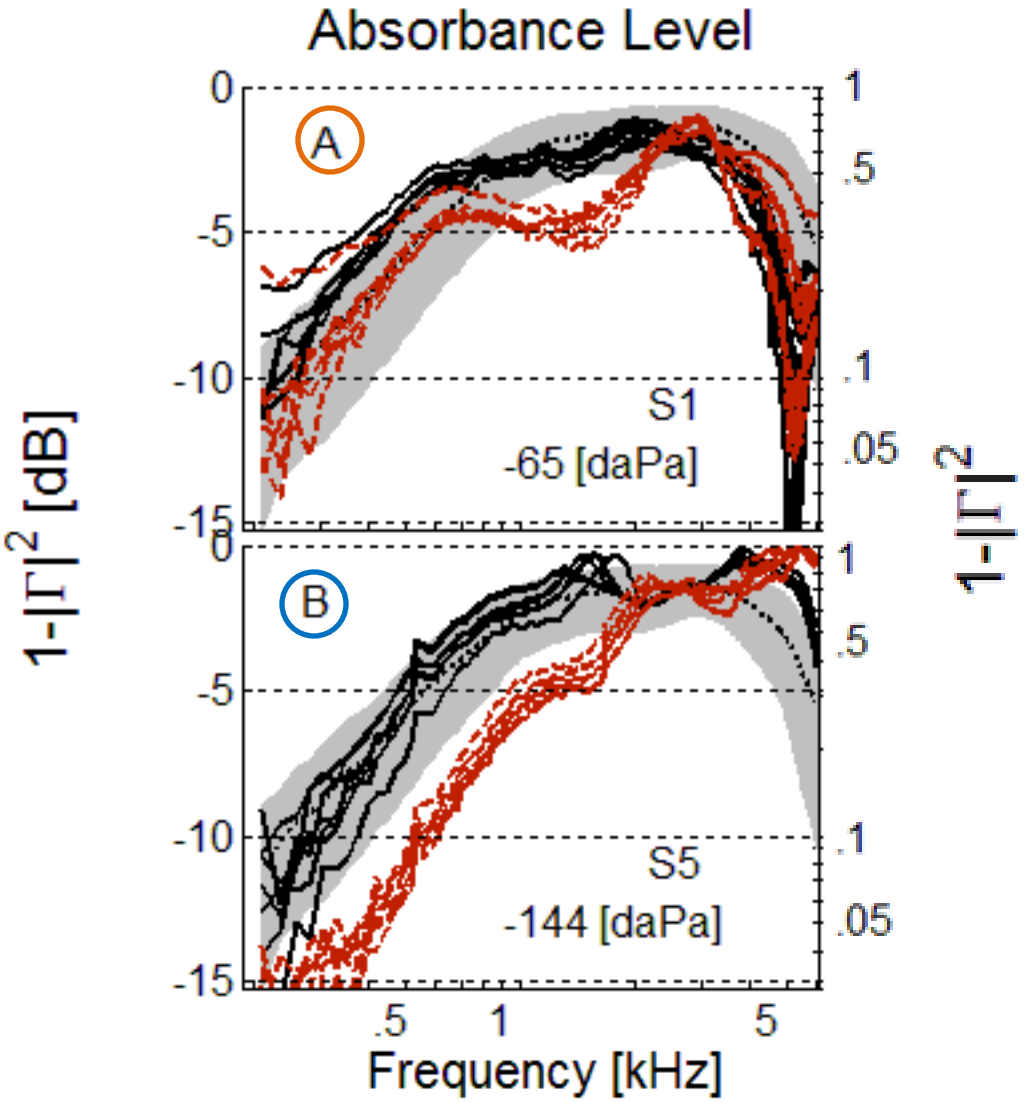
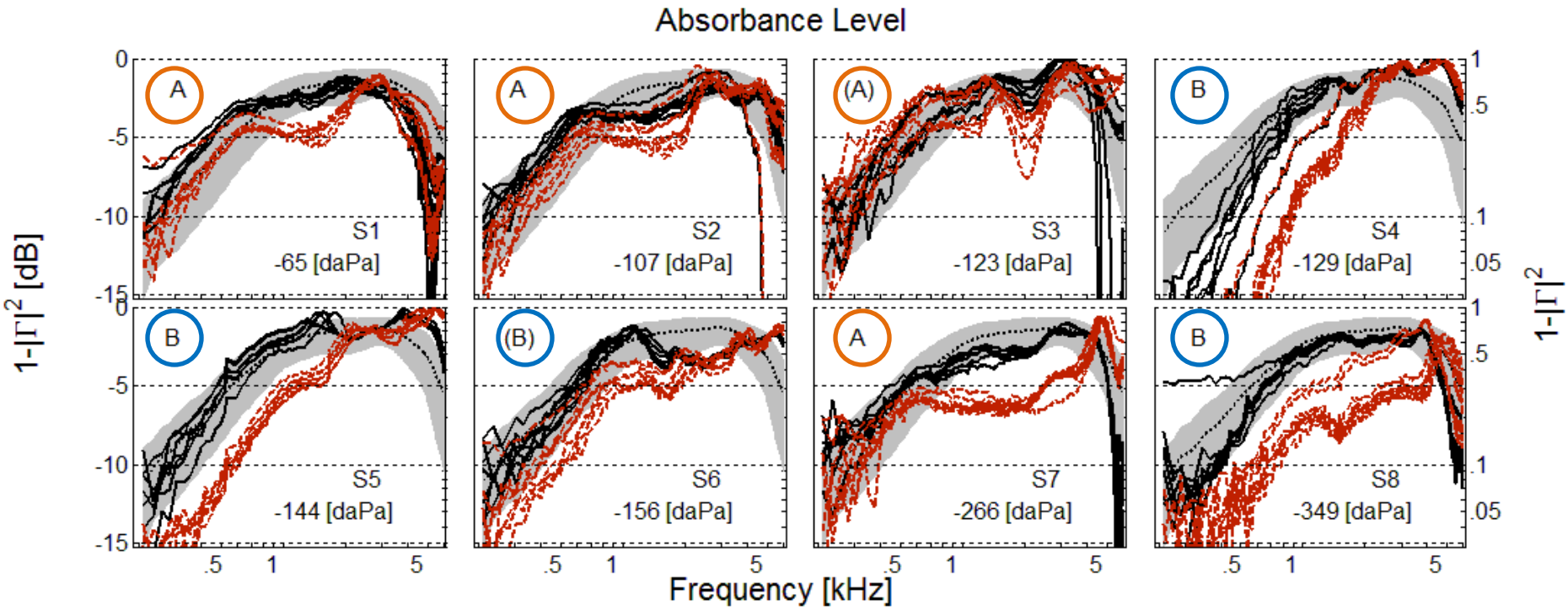


WAI Results: Power Absorbance



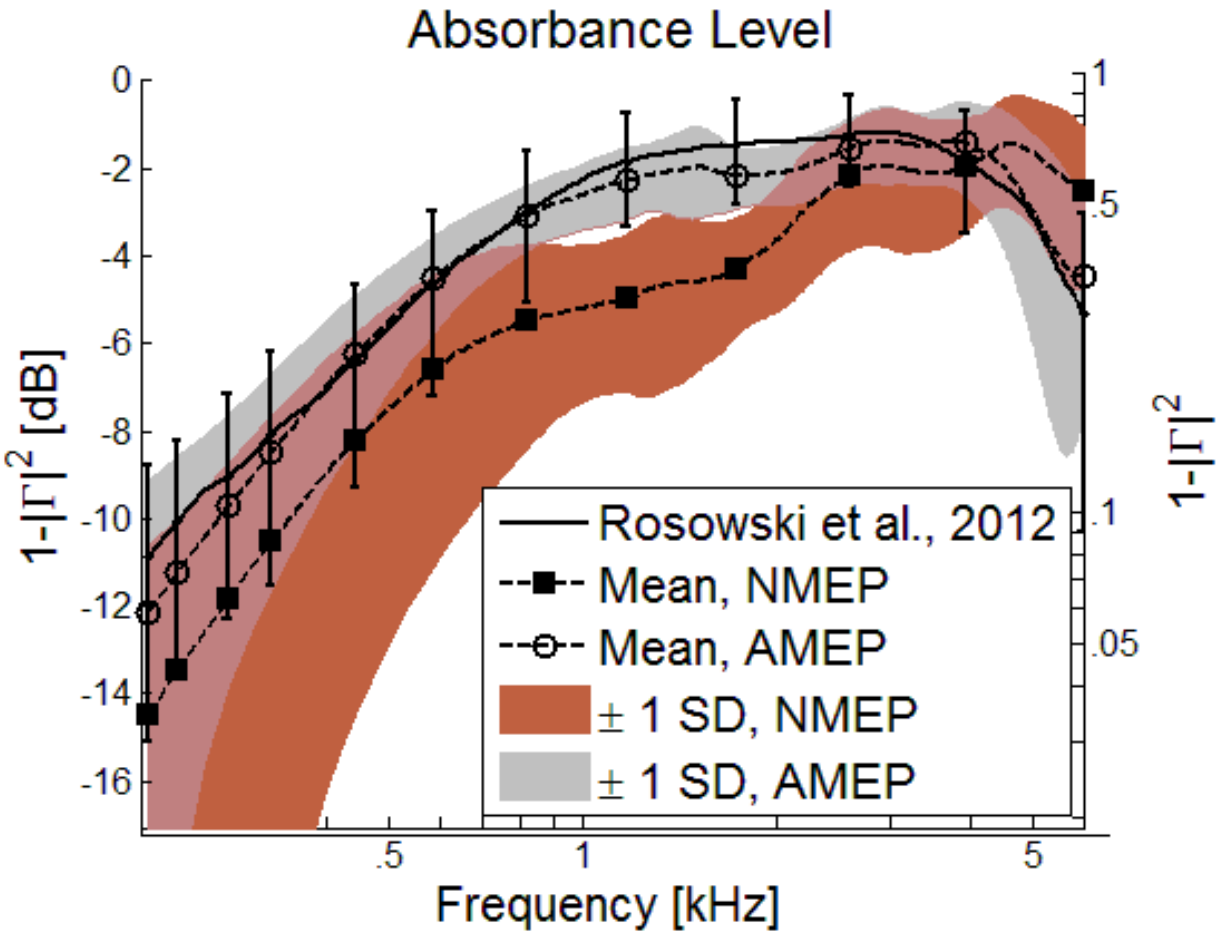
AMEP

NMEP

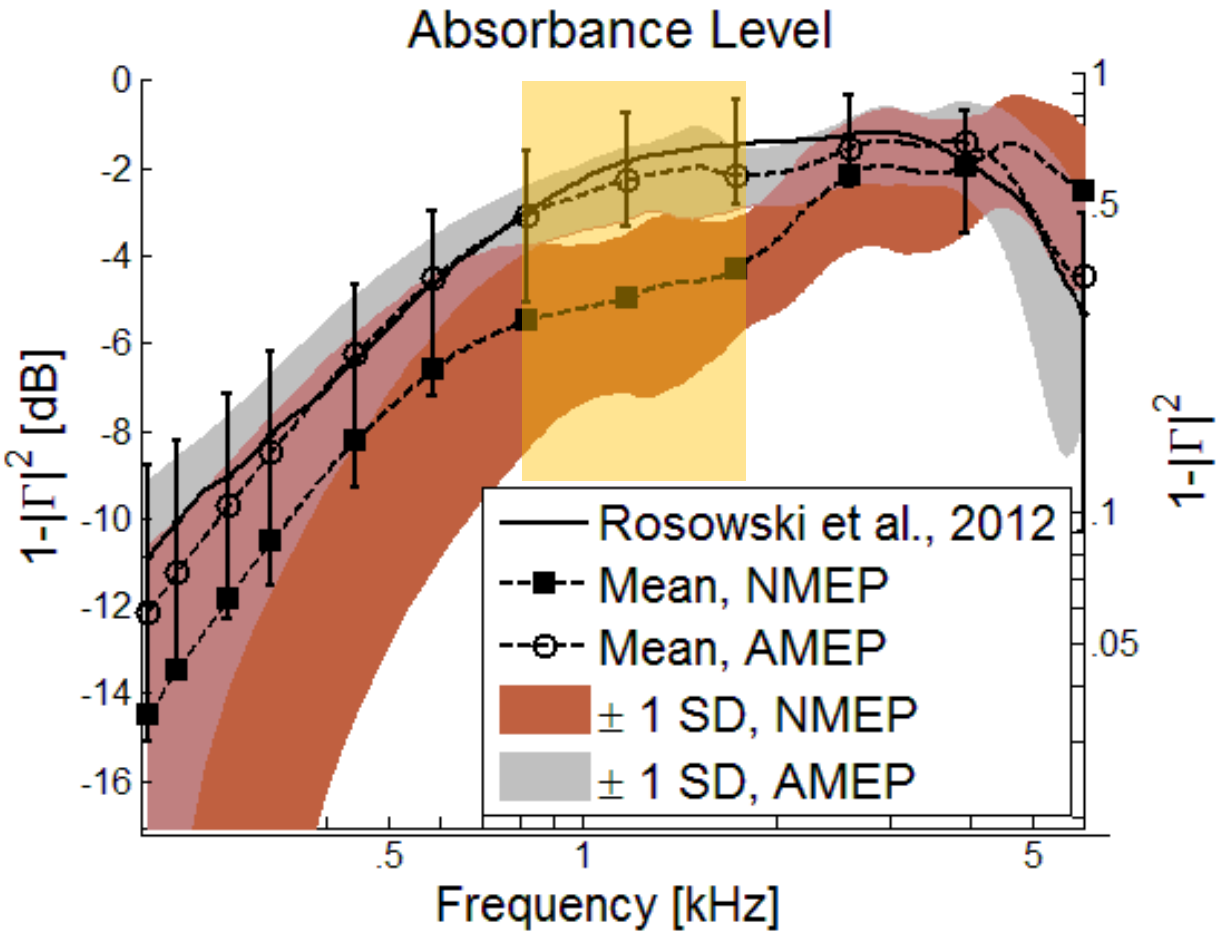
Wideband changes in power absorbance due to NMEP…

- vary in both magnitude and frequency range
- do not appear to have a simple dependence on pressure

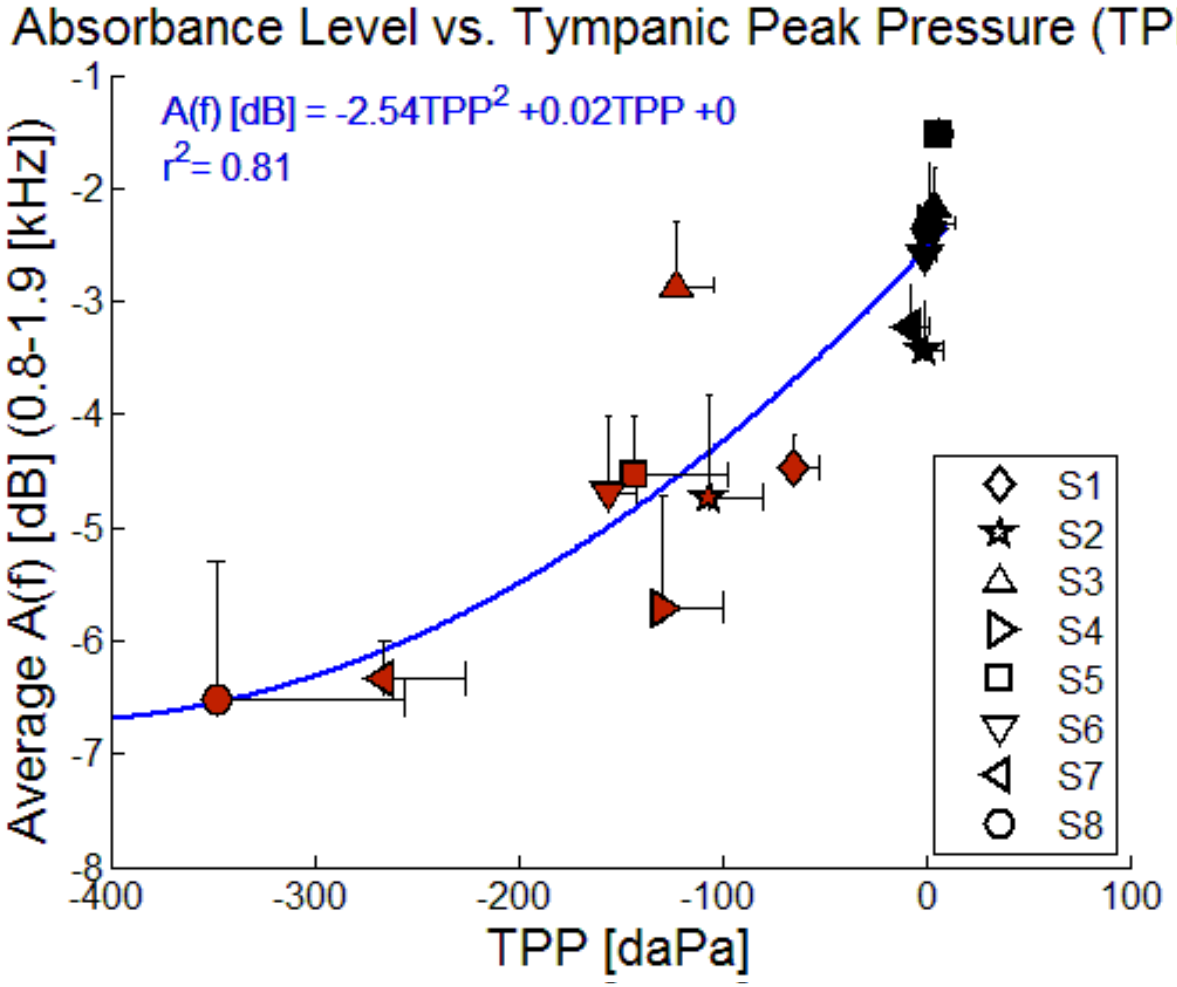
WAI Results: Power Absorbance



WAI Results: Power Absorbance



Dependence on static ME pressure

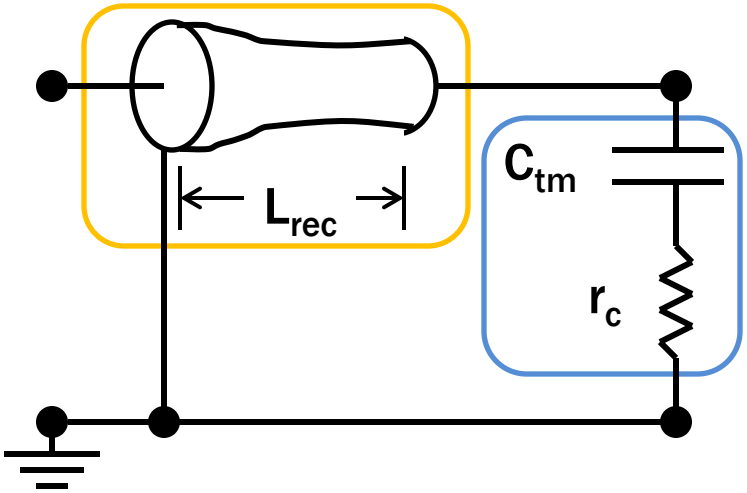


AMEP

NMEP

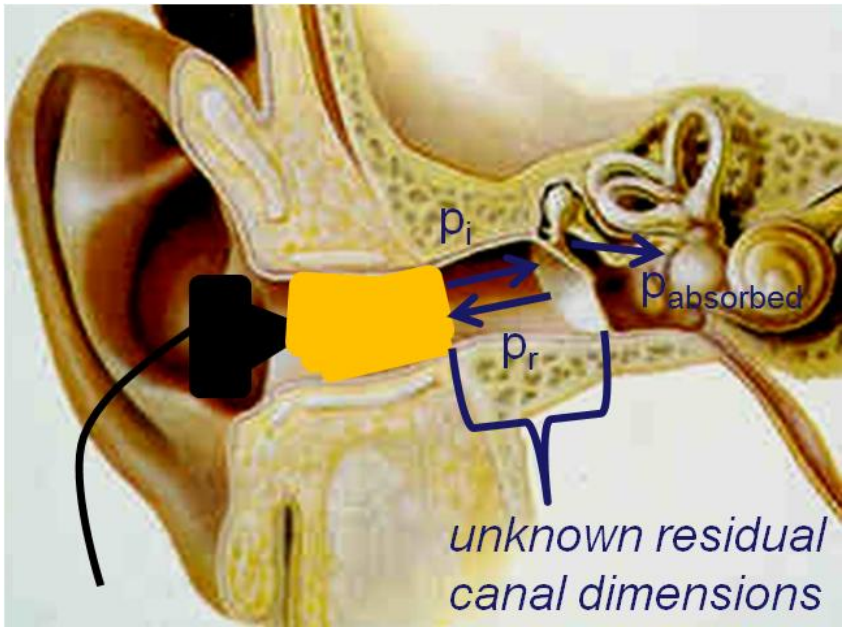
WAI at the tympanic membrane (TM-WAI)

- The unknown residual ear canal (REC) delay may removed from the reflectance phase (Robinson et al., 2013)
- Using our methods, $\Gamma_{rec}(f)$ may account for a lossless REC of varying area



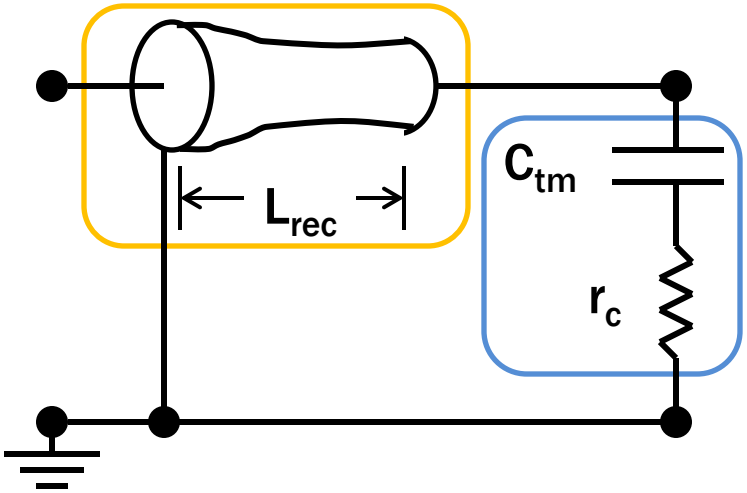
$$\Gamma(f) = \Gamma_{rec}(f) \times \Gamma_{tm}(f)$$

$$|\Gamma(f)| = 1 \times |\Gamma_{tm}(f)|$$



WAI at the tympanic membrane (TM-WAI)

- At low frequencies, the REC volume is approximated by a compliance
- A resistor is necessary to match the transmission lines of the middle ear and cochlea (Zwislocki 1962, Lynch 1982)



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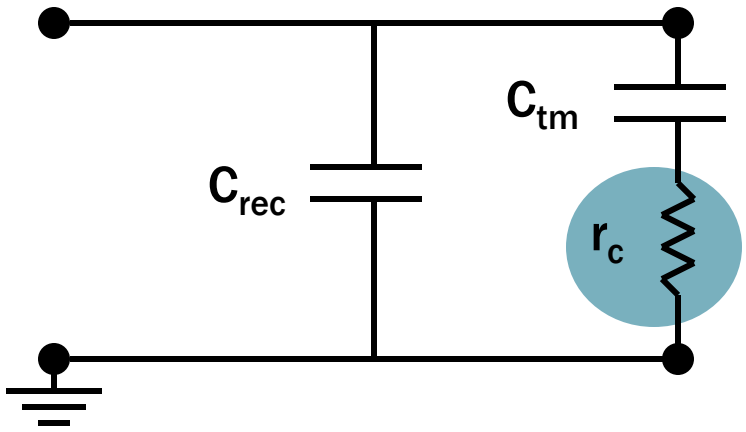
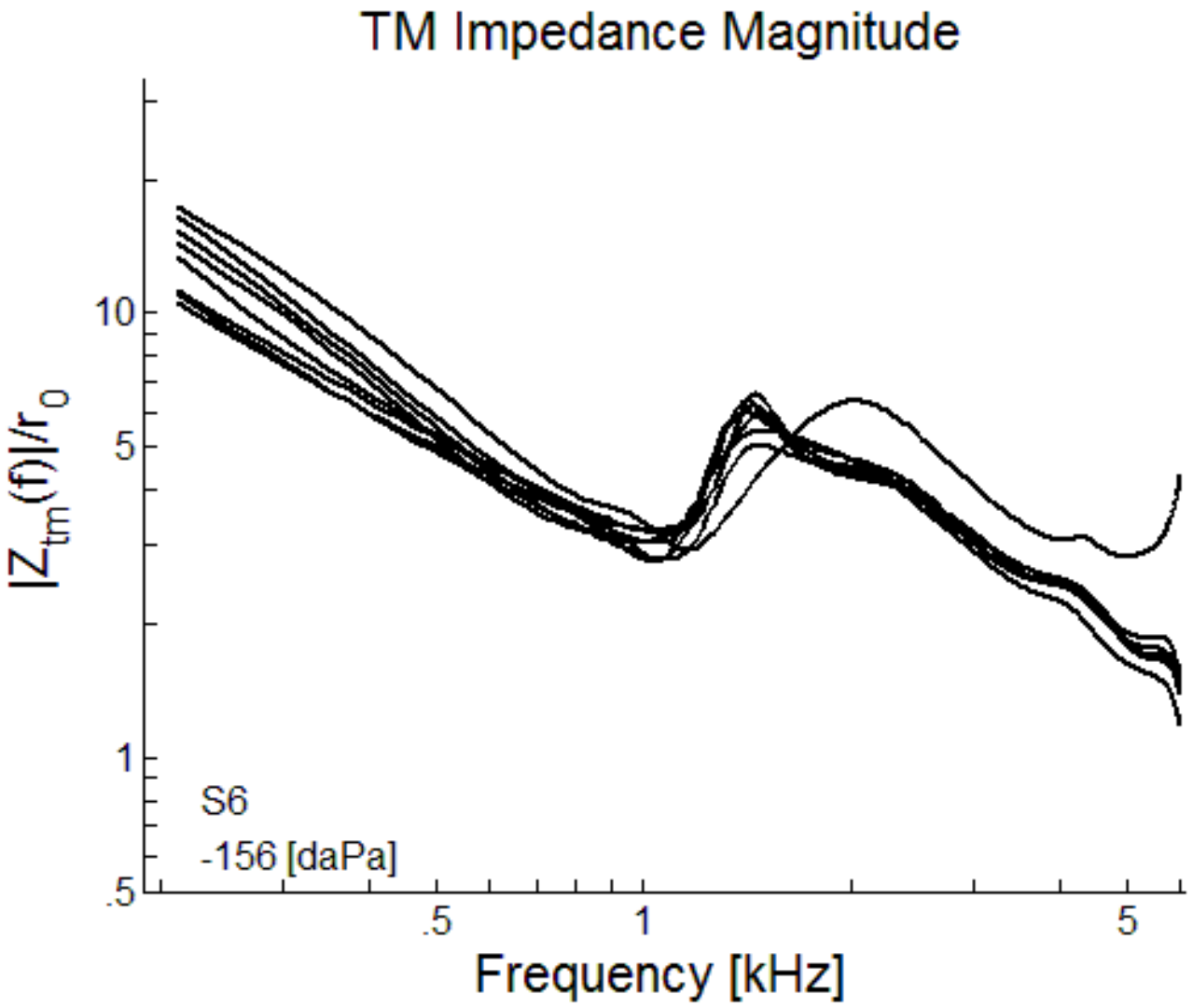
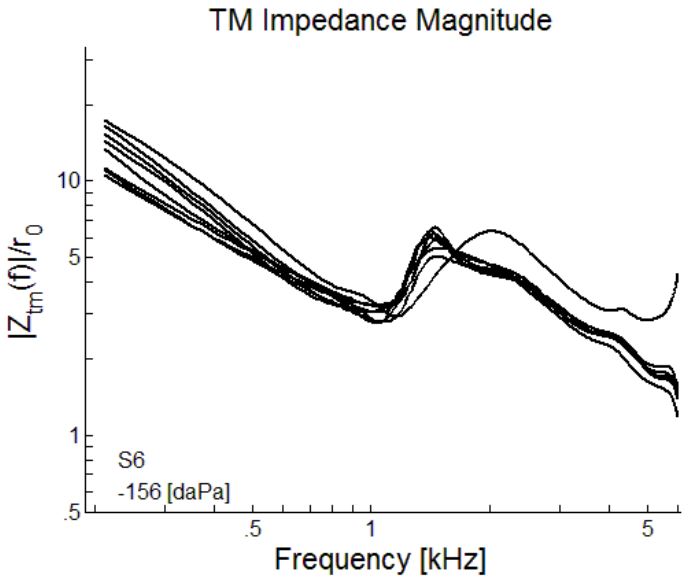


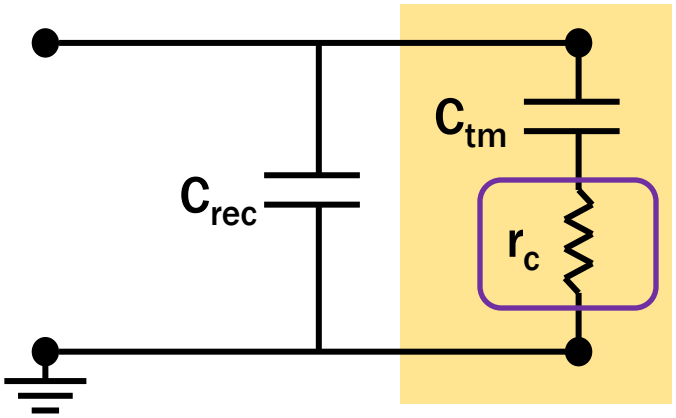
Low frequency approximation

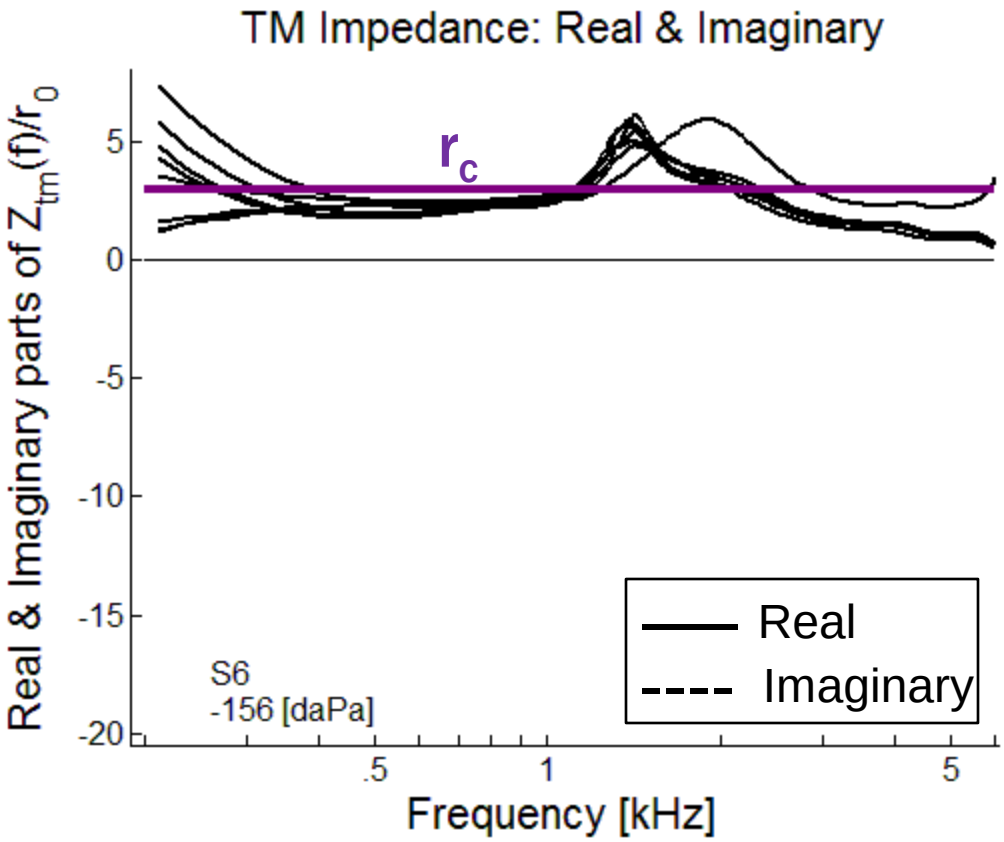
TM-WAI: Impedance



TM-WAI: Impedance







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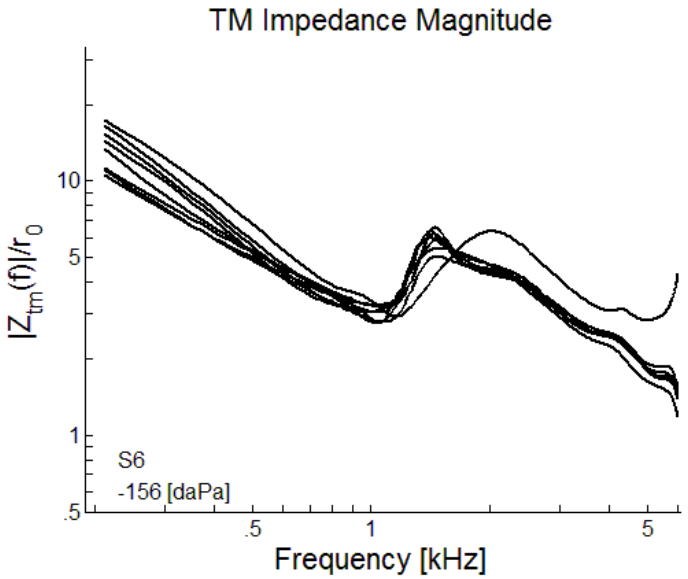

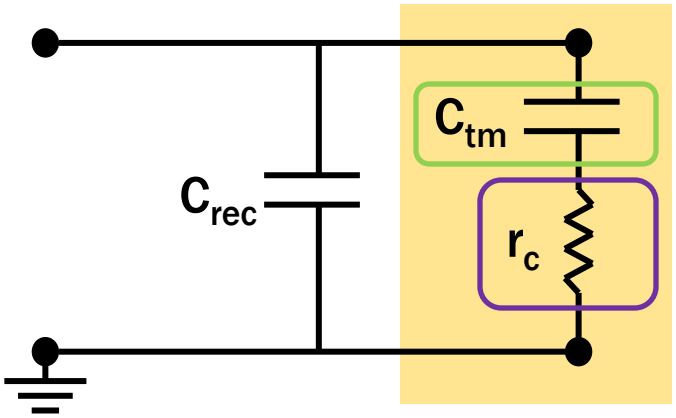

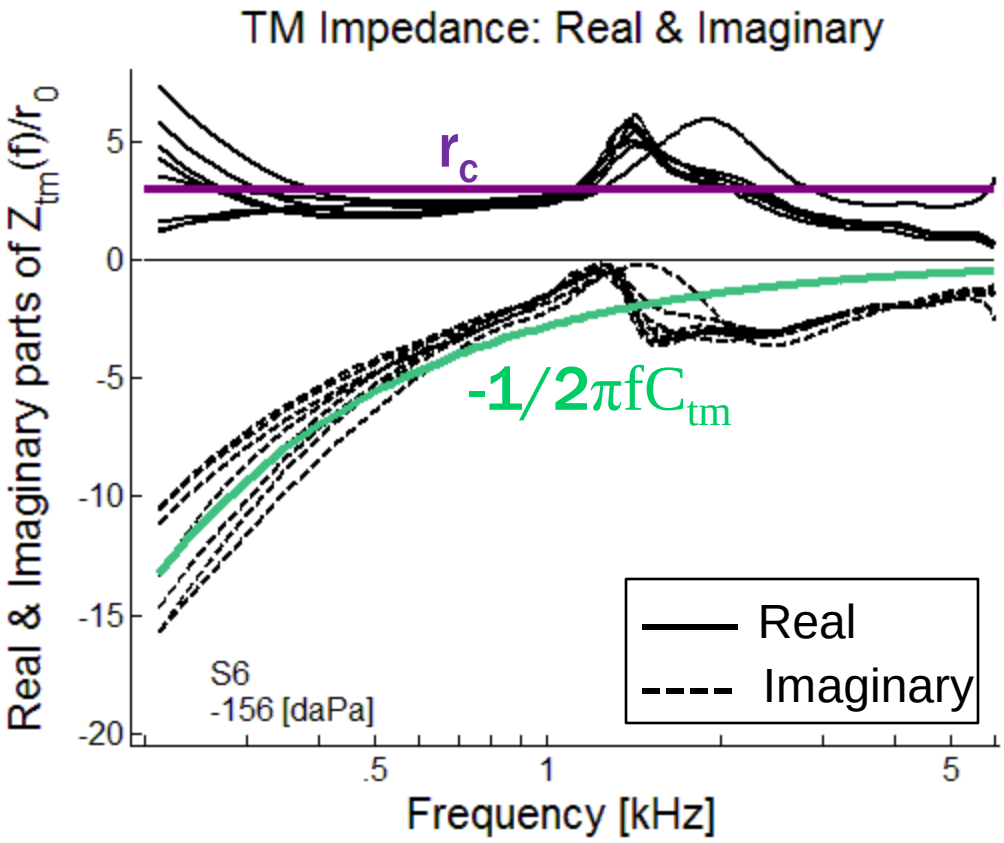

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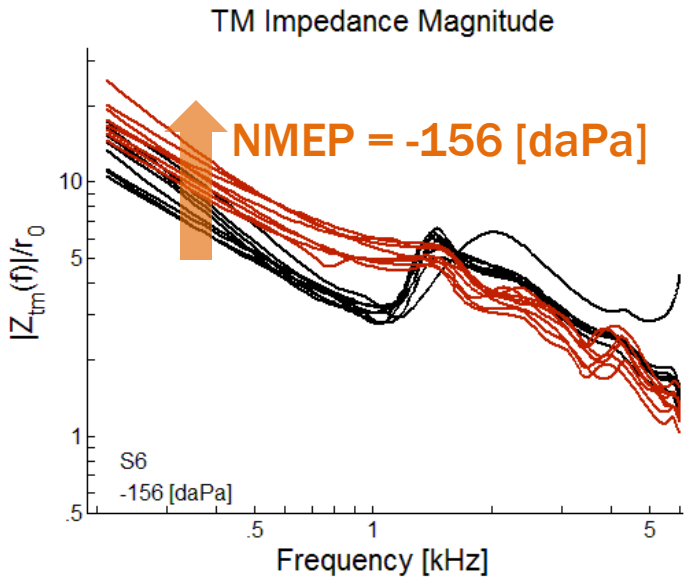
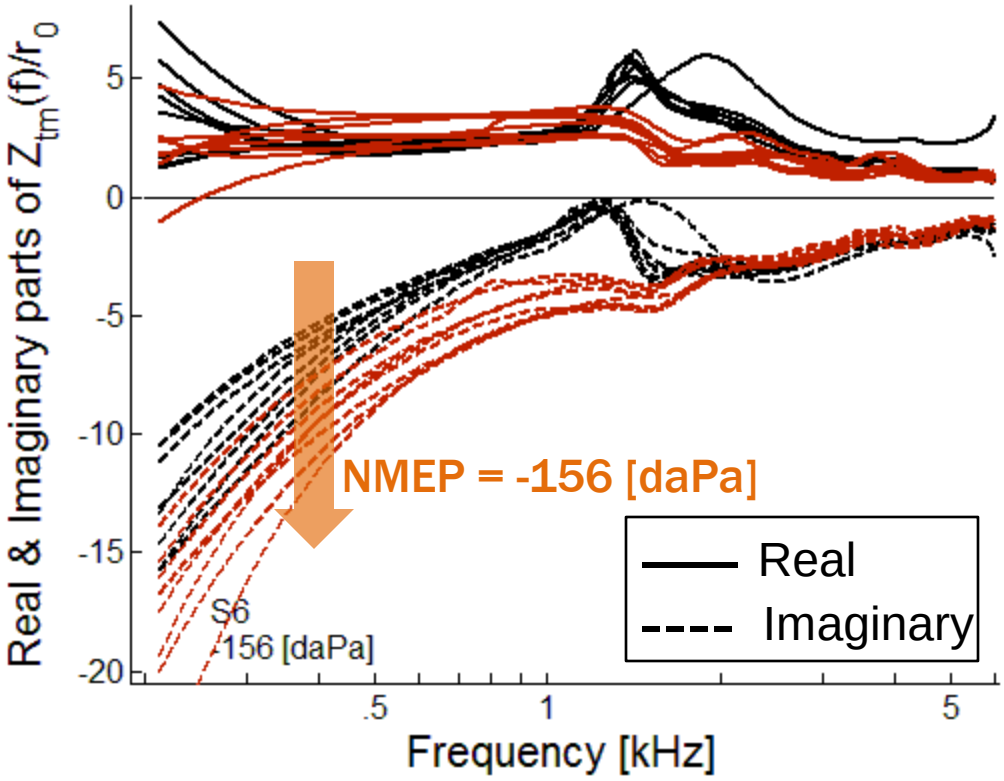
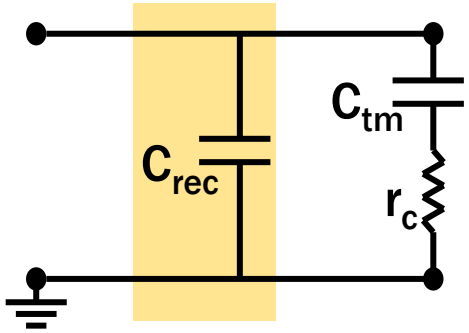
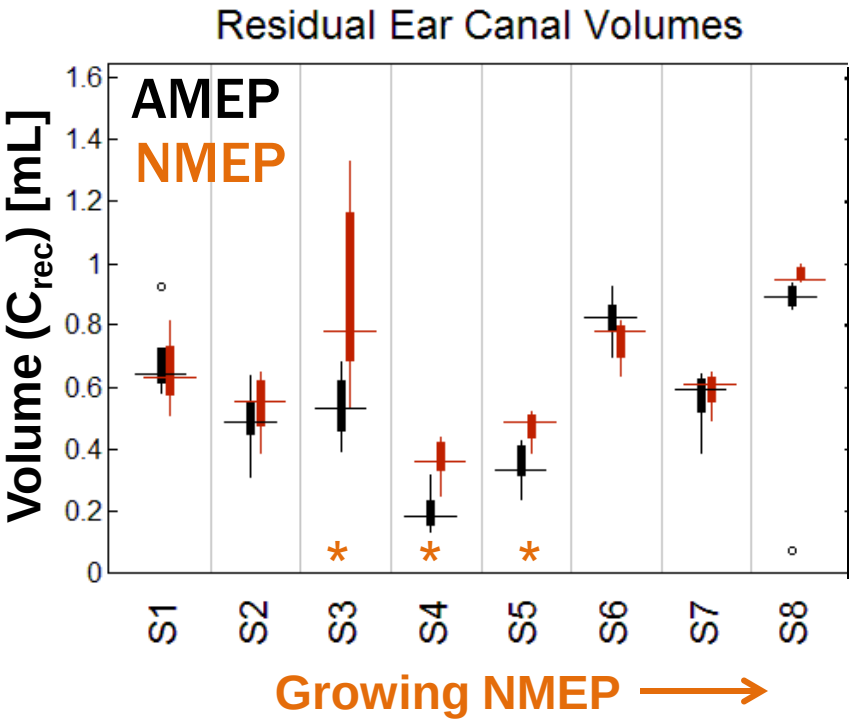




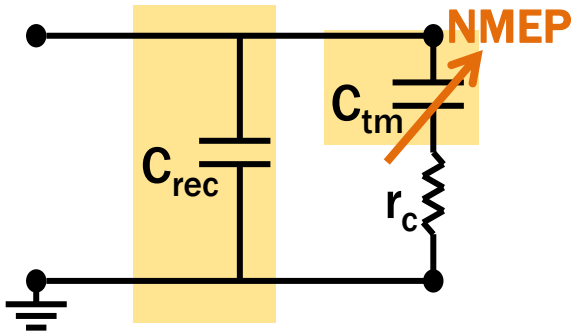
Residual ear canal (REC) volume



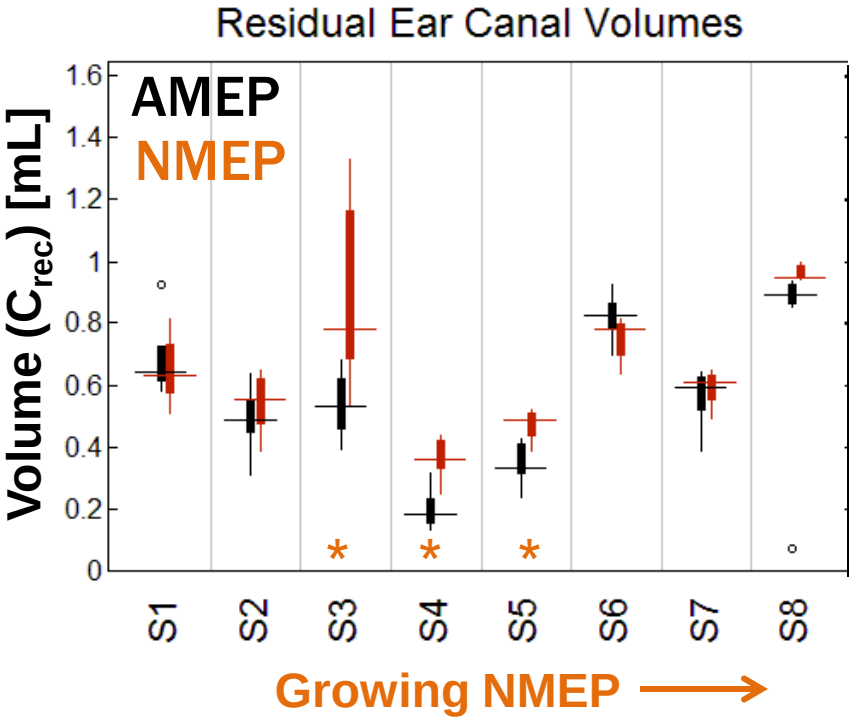
- The REC volume does not depend on NMEP

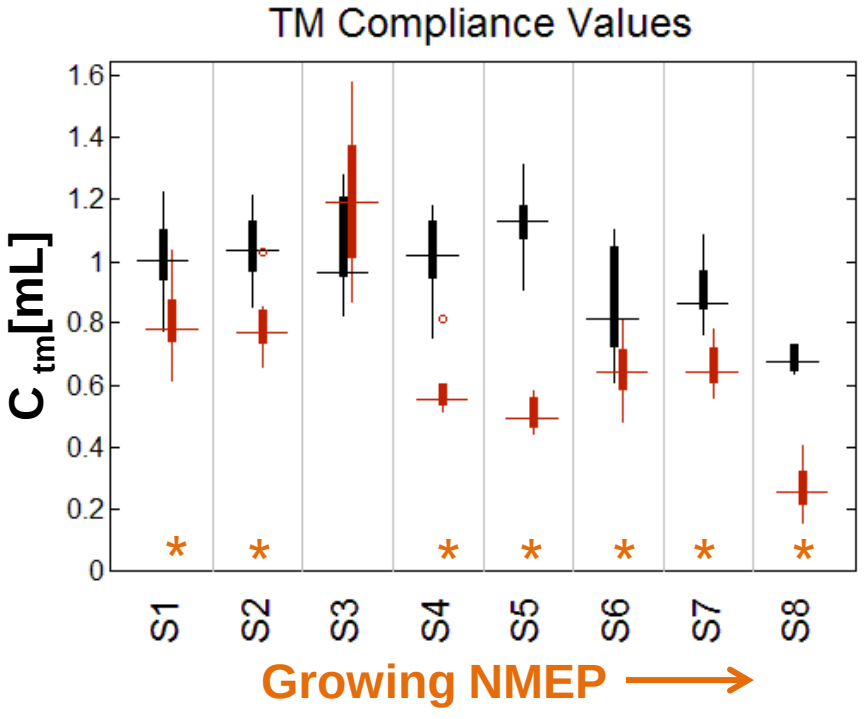


TM Compliance



- The REC volume <u>does not</u> depend on NMEP
- The TM compliance <u>does</u> depend on NMEP





Mechanisms for NMEP-dependent change

- NMEP decreases the compliance C_{tm} at the tympanic membrane (TM)

- The TM is retracted (Shaver & Sun 2013, Voss et al. 2012)
  - Often assumed to be the main source of compliance change
  - The TM acts as a delay line in normal ears (*Puria & Allen 1998*)

- Nonlinear compliance is likely related to middle ear ligaments
  - WAI changes due to NMEP resemble stiffened annular ligament (AL) changes (e.g. acoustic stapedius reflex, Feeney & Keefe 1999)
  - The tensor tympani (TT) may cause similar WAI changes to the AL *(Møller 1983, Bance et al. 2013, Aron et al. 2015)*, but little data exists to quantify this in human ears

Conclusions

- We can directly estimate the complex WAI at the TM
  - The residual ear canal delay (independent of NMEP) is removed
- WAI changes due to NMEP vary in magnitude and frequency range
  - The most significant decrease in power absorbance level occurs from 0.8-1.9 [kHz]
  - TPP is a significant but imperfect predictor of WAI change
- The aggregate middle ear compliance C_{tm} decreases due to NMEP
  - WAI change is well described by a simple model
  - This does not require selective averaging of frequency bands

Clinical Implications

- WAI is not a strong predictor of NMEP level (typically measured by TPP)
  - However, we can evaluate Eustachian tube function using WAI

- WAI provides frequency-specific information about middle ear transmission that tympanometry does not

- Changes in WAI due to NMEP are generally too small to impact hearing thresholds, however…
  - Can affect measurement of otoacoustic emissions (OAEs), due to forward and reverse transmission through the middle ear
  - We predict that frequency-specific changes in DPOAEs/TEOAEs are related to changes in WAI

Thanks for listening!

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