Tympanometry and Reflectance in the Clinic. The how, what and why.

How to do it, what the results mean, and why we need measurements at multiple frequencies

SHEENA JESSEE and ROBERT WITHNELL
Abstract

Tympanometry and reflectance both assess how the middle ear receives sound. Critical to their interpretation is an understanding of how the resonance/s of the middle ear change with middle ear pathology or static pressure changes in the ear canal. This talk will provide the theory behind the generation of the tympanogram/reflectance curves obtained, provide hands-on demonstrations of using each type of system, and show how to interpret the results diagnostically.
Learning Outcomes

Participants will learn:

1. how to interpret tympanograms obtained at multiple frequencies and what the different tympanogram shapes mean in terms of middle ear resonance.

2. how to make a reflectance measurement and how to interpret the results.

3. what tympanometry and reflectance have in common and how they differ.
Finding the Input Impedance of the Ear

Outer and middle ear act to impedance match sound in air to sound in fluid

\[ P_m = P_i + P_r \]

If \( P_r = 0 \)  \hspace{1cm} \text{perfect impedance match}

If \( P_r = P_i \)  \hspace{1cm} \text{100% impedance mismatch}

Tympanometry:  \[ P_m = P_i + P_r \]

Reflectance:  \[ R = \frac{P_r}{P_i} \]

Static pressure change in ear canal

Static pressure changes in the ear canal increases the stiffness of the middle ear

see Rabinowitz (1981)
Huang et al (2000)

\[ \text{Resonance} = \frac{1}{2\pi} \sqrt{\frac{\text{stiffness}}{\text{mass}}} \]

Increase stiffness \rightarrow increase resonance

\[ \uparrow \text{static pressure} = \uparrow \text{middle ear resonance} \]
Demonstration

Tympanometry @ 226, 678, and 1000 Hz
What do these results mean?
Tympanogram with a different x-axis

Middle ear frequency response

Can think of static pressure axis on tympanograms as middle ear resonance rather than pressure
Model fit to data for tympanograms

Model tympanograms normalized to fit tail at +200 daPa at each frequency.

To get asymmetry in tympanograms, had to have R vary for negative static pressures (in addition to k).
Model-generated family of Tympanograms - relationship to resonance
What is the inverted W?

Peaks associated with static pressure change shifting first resonance of middle ear to probe frequency.

Probe frequency is above the first resonance of the middle ear.
• Multiple tympanogram frequencies better describes filtering of ME

• Shape of tympanogram reflects proximity to ME resonance
Pathologies of the Middle Ear

Tympanogram shapes represent a continuum with respect to resonance of the middle ear.

For a 226 Hz probe tone:

A flat, type B tympanogram, is a long way from resonance.

A shallow type A tympanogram is far from resonance.

The bigger the peak, the closer the probe tone frequency is to resonance.
Demonstration

1. calibration for
   i. tympanometry &
   ii. reflectance

   then

2. Tympanometry @ 226, 678, and 1000 Hz
   and

3. Reflectance
   
   on the same ear
Calibration

Tympanometry

Reflectance

A number of cylinders of constant diameter, with different lengths

0.5, 2 and 5 cc cavities calibrates 226 Hz
0.5 and 2 cc cavities calibrates 678 Hz
0.5 cc cavity calibrates 1000 Hz  (GS Tympstar)
• Volume calibration
  • Limited to low frequencies (up to 1500 Hz)
• Cylinder calibration, known radius and lengths
  • Upper frequency limit depends on radius
  • Probaby at least 10 kHz
  • Standing waves in cylinders complicate calibration
  • Radius of cylinder must be similar to ear canal (bony portion)
Reflectance

Provides a broad spectrum measure of the impedance mismatch between the ear canal and middle ear
Does not require static pressure changes in the ear canal
The reflectance transfer function alters predictably with middle ear pathology
Stiffness dominated region of middle ear

POWER REFLECTANCE

|\Re|^2

0 0.5 1

10^2 10^3 Hz

|M| dB

0 -10 -20

10^2 10^3 Hz
Increase in stiffness of middle ear

Power reflectance results from a subject with otosclerosis (Allen et al., 2005)
Decrease in stiffness of middle ear

Power reflectance results from a subject with middle ear disease as a child (Mimosa data)
OME

Power reflectance results from a subjects with otitis media with effusion (Allen et al., 2005)

mostly INCREASE in M.E. stiffness

middle ear not fluid-filled
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how to do it
what the results mean
why multiple frequencies

Questions?....
Sheena Jessee Au.D., and Robert Withnell Ph.D. are faculty members of the Department of Speech and Hearing Sciences at Indiana University, Bloomington, Indiana.
Abstract

Tympanometry and reflectance both assess how the middle ear receives sound. Critical to their interpretation is an understanding of how the resonance/s of the middle ear change with middle ear pathology or static pressure changes in the ear canal. This talk will provide the theory behind the generation of the tympanogram/reflectance curves obtained, provide hands-on demonstrations of using each type of system, and show how to interpret the results diagnostically.

Tympanometry and reflectance are clinically available tests that evaluate middle ear status by measuring sound pressure in the ear canal.

Tympanometry is clinically available at 226, 668, and 1000 Hz; Reflectance measures over the frequency range of 0.2 to 6 or 10 kHz.

Middle ear pathologies are apparent in both tests, with more differentiation possible via reflectance.
Learning Outcomes

Participants will learn:

1. how to interpret tympanograms obtained at multiple frequencies and what the different tympanogram shapes mean in terms of middle ear resonance.
2. how to make a reflectance measurement and how to interpret the results.
3. what tympanometry and reflectance have in common and how they differ.

A combination of lecture, discussion, and hands-on demonstrations, provide the learning format for this presentation.
The input impedance of the ear is derived from sound pressure measurements in the ear canal. The sound pressure at the microphone is the sum of the wave going in and the wave reflected back. The amount of sound reflected back depends on the impedance of the middle ear.
Static pressure change in ear canal

Static pressure changes in the ear canal increases the stiffness of the middle ear
see Rabinowitz (1981)
Huang et al (2000)

\[
\text{Resonance} = \frac{1}{2\pi} \sqrt{\frac{\text{stiffness}}{\text{mass}}}
\]

Increase stiffness \(\rightarrow\) increase resonance

\[ \uparrow \text{static pressure} = \uparrow \text{middle ear resonance} \]

Tympanometry varies static pressure in the ear canal. Assumption: Increased pressure = increased stiffness. Tympanometry assumes that at most extreme static pressure, TM compliance is zero. Under that assumption:

TM static compliance obtained from two sound pressure measurements in the ear canal. One @ 0 daPa, the other at +200 daPa. From calibration, each sound pressure has an equivalent volume. So, replacing sound pressure values with equivalent volume values, and subtracting pressurized ear canal volume from unpressurized ear canal volume, we get equivalent volume of TM which is directly related to compliance.
Demonstration

Tympanometry @ 226, 678, and 1000 Hz

Demonstration of tympanometry at three probe tone frequencies.
What do these results mean?

An example of tympanometry findings at the three different probe tone frequencies.
Tympanogram with a different x-axis

Can think of static pressure axis on tympanograms as middle ear resonance rather than pressure

Changing static pressure in the ear canal stiffens the middle ear, shifting the resonant frequency/s of the middle ear higher.
Tympanogram shapes can be understood by a model fit to data. A suitable model can be found at Withnell and Gowdy (2013), J Assoc Res Otolaryngol. Oct;14(5):611-22
Model-generated family of Tympanograms - relationship to resonance

Relating tympanograms to the first resonance of the middle ear
What is the inverted W?

Peaks associated with static pressure change shifting first resonance of middle ear to probe frequency.

Probe frequency is above the first resonance of the middle ear.
• Multiple tympanogram frequencies better describes filtering of ME
• Shape of tympanogram reflects proximity to ME resonance

ME pathologies effectively change the stiffness of the ME system.

Assuming that increased pressure = increased stiffness, tympanometry shows how effectively sounds are absorbed via TM at various levels of stiffness. Near zero admittance can be interpreted to mean that the ear is too stiff in comparison to the stimulus and the TM is not effectively passing through the sound.

By presenting more than one frequency, i.e., increasing the frequency of the probe tone, provides a better picture of how “stiff” the ME is.
Tympanogram shapes represent a continuum with respect to resonance of the middle ear.

For a 226 Hz probe tone:

- A flat, type B tympanogram, is a long way from resonance.
- A shallow type A tympanogram is far from resonance.
- The bigger the peak, the closer the probe tone frequency is to resonance.

Tympanogram shapes as a function of probe tone frequency represent a continuum with respect to the first resonance of the middle ear.
Demonstration

1. calibration for
   i. tympanometry &
   ii. reflectance

   then

2. Tympanometry @ 226, 678, and 1000 Hz
   and

3. Reflectance

   on the same ear

A demonstration of calibration for tympanometry and reflectance.

Tympanometry and reflectance performed on the same ear.
Calibration

Tympanometry

Reflectance

A number of cylinders of constant diameter, with different lengths

0.5, 2 and 5 cc cavities calibrates 226 Hz
0.5 and 2 cc cavities calibrates 678 Hz
0.5 cc cavity calibrates 1000 Hz (GS Tymcast)

See ANSI_S3.39-1987_(R2007)

• Volume calibration
  • Limited to low frequencies (up to 1500 Hz)
• Cylinder calibration, known radius and lengths
  • Upper frequency limit depends on radius
  • Probaby at least 10 kHz
  • Standing waves in cylinders complicate calibration
  • Radius of cylinder must be similar to ear canal (bony portion)
Reflectance

Provides a broad spectrum measure of the impedance mismatch between the ear canal and middle ear
Does not require static pressure changes in the ear canal
The reflectance transfer function alters predictably with middle ear pathology

Reflectance does not rely on pressurization assumption.
Measures canal sound pressure via probe microphone.
Magnitude of reflectance gives TM properties, while phase of reflectance is dominated by ear canal properties.

See Withnell et al. (2009), Hearing Journal, 62 (10), pp 36-39
Reflectance shows how sounds are absorbed over a frequency range. Different ME pathologies affect sound absorption in a frequency dependent manner, this is apparent in resulting reflectance curve.

From Withnell et al. (2009), Hearing Journal, 62 (10), pp 36-39
Increase in stiffness of middle ear

Power reflectance results from a subject with otosclerosis (Allen et al., 2005)

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