Application of Acoustic Immittance Measures in Audiology Today

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Electroacoustic Measurements:
A New Look at Some Old Procedures

- Immittance/Admittance Measurements
  - Tympanometry
    - ✓ Conventional (226 Hz)
    - ✓ High frequency
    - ✓ Theta Y (θY)
    - ✓ Gradient
  - Acoustic reflexes
    - ✓ Ipsilateral versus contralateral
    - ✓ Pure tone versus noise signals
- Wide-band reflectance (WBR)
- Otoacoustic emissions

Rationale … Why are electro-acoustic measures important in audiology today? (1)

- ❑ Abundant clinical evidence in support of the diagnostic value of electro-acoustic measures
  - 30+ years of clinical experience
  - Hundreds of publications in peer-reviewed journals
  - Electro-acoustic measures add value to the clinical test battery
- ❑ Numerous clinical advantages of electro-acoustic measures
  - Fast
  - Objective
  - Non-invasive
  - Clinical available to all audiologists
  - Portable devices
  - No need for sedation
  - In U.S.A.
    - ✓ Equipment is approved by FDA
    - ✓ CPT codes available for billing

Rationale … Why are electro-acoustic measures important in audiology today? (2)

- Electro-acoustic measures are highly sensitive to peripheral auditory dysfunction
  - Problems with integrity of tympanic membrane
  - Mechanical abnormalities of the middle ear
  - Cochlear abnormalities (inner and outer hair cell)
  - 8th cranial nerve dysfunction
  - Auditory neuropathy
- Most hearing loss in children or adults is caused by peripheral auditory dysfunction
- Peripheral hearing loss is most effectively treated medically or non-medically (audiologically)
- Electro-acoustic measurement can contribute to better patient outcome

Electroacoustic Measurements: A New Look at Some Old Procedures

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AURAL IMMITTANCE MEASUREMENT: Historical Perspective

- **Luscher (1929)** in Germany observed acoustic reflex
- **Otto Metz (1946)** in Denmark developed mechano-acoustic impedance bridge and measured impedance and acoustic reflexes clinically
- **Jepsen (1951)** confirmed stapedius muscle acoustic reflex
- **Knut Terkildson (1956)** developed electro-acoustic impedance device
- **Josef Zwislocki (1962)** introduced mechano-acoustic impedance bridge to U.S.A.
- **James Jerger (1970)** applied electro-acoustic impedance device clinically in U.S.A.

Aural Immittance (Impedance) Historical Perspective: Otto Metz (1903-1995)

"In October 1943, just as the Nazis were preparing to intern all Jews in Denmark, Otto Metz had the good fortune to be one of the more than 6,000 Jews spirited across the sea to Sweden by the Danish Resistance. Thus escaping capture, Metz was able to continue his pioneering research at the University Hospital of Lund.

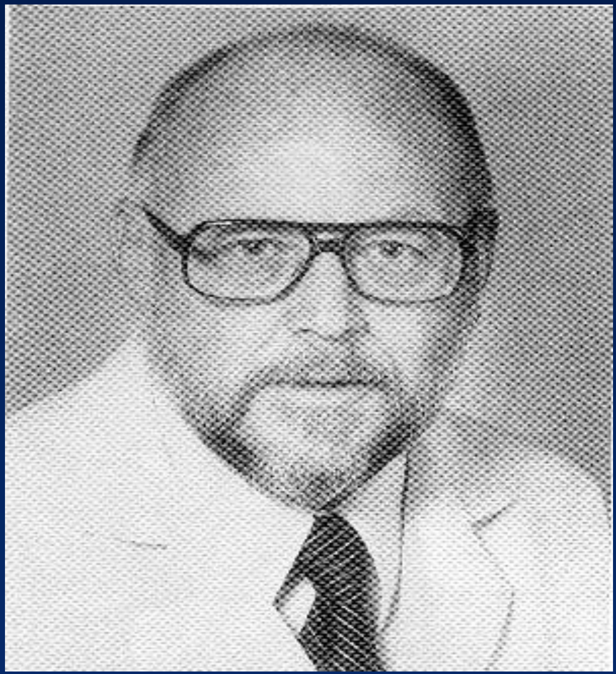
After returning safely to Copenhagen in 1945, Metz formulated the basic principles of tympanometry in his dissertation of 1946: "The acoustic impedance measured on normal and pathological ears". This constituted the earliest substantial set of acoustic impedance measurements in normal and pathological ears – and obtained using a mechanical bridge.

Continuing this work at Rigshospitalet, Metz also published the seminal "Threshold of reflex contractions of muscles in the middle ear and recruitment of loudness" in the Archives of Otolaryngology in 1952. This was the first study of the acoustic stapedius reflex in patients with ear disease." (GN Otometrics Website)

Aural Immittance (Impedance) Historical Perspective: Otto Metz (1905-1995)

Scott-Nielsen and Terkildsen With Madsen ZO61 Impedance Bridge

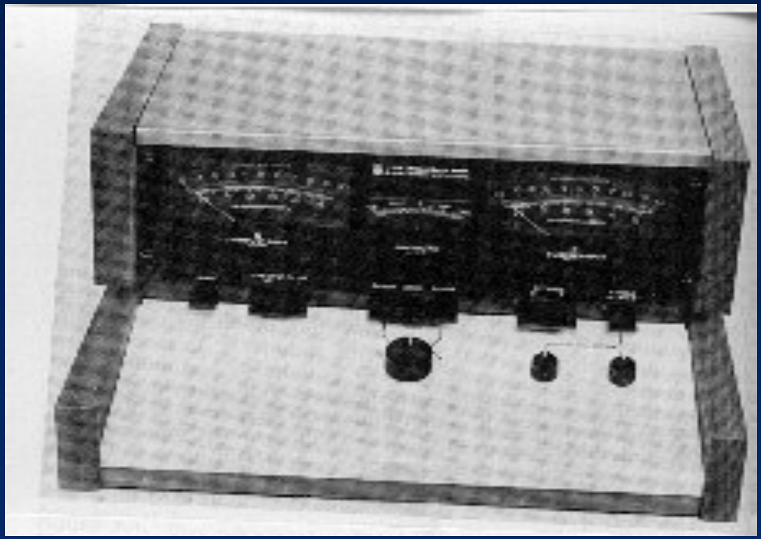
James Jerger
"Father of Diagnostic Audiology"
Observed Impedance Measurements in 1960 in Denmark



AURAL IMMITTANCE MEASUREMENT:
Relations among impedance components

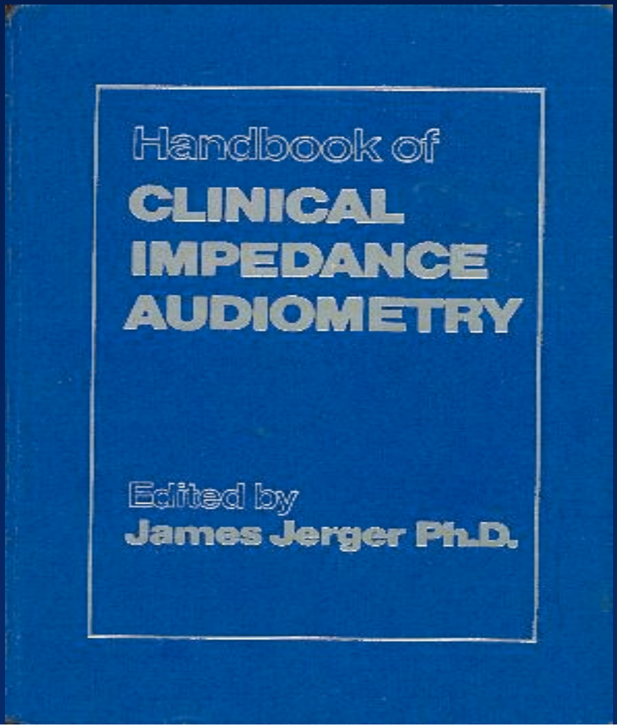
- $Z_a = \sqrt{R_a^{\,2} + X_a^{\,2}}$, where Xa = 2π f M (-k/2π f)
  - R_a = acoustic resistance, i.e., impedance due to **friction**
  - X_a = acoustic reactance, i.e., impedance due to **mass** and **stiffness** (or **compliance**) components

Early Impedance Devices (“Bridges”)



- GSI 1720 Immittance Meter
- Madsen ZO 70
- American Electromedics
- Amplaid

Impedance Audiometry Ushers in the Modern Era of Audiology (1975)



AURAL IMMITTANCE MEASUREMENT: Definitions

- Immittance = impedance + admittance
- Impedance (Z_a) = opposition to acoustic energy flow through middle ear system (in acoustic ohms)
- Admittance (Y_a) = ease of acoustic energy flow through middle ear system (in acoustic mmhos); reciprocal of Z_a

AURAL IMMITTANCE MEASUREMENT:
Relations among admittance components

- $Y_a = \sqrt{G_a^{\,2} + B_a^{\,2}}$, where

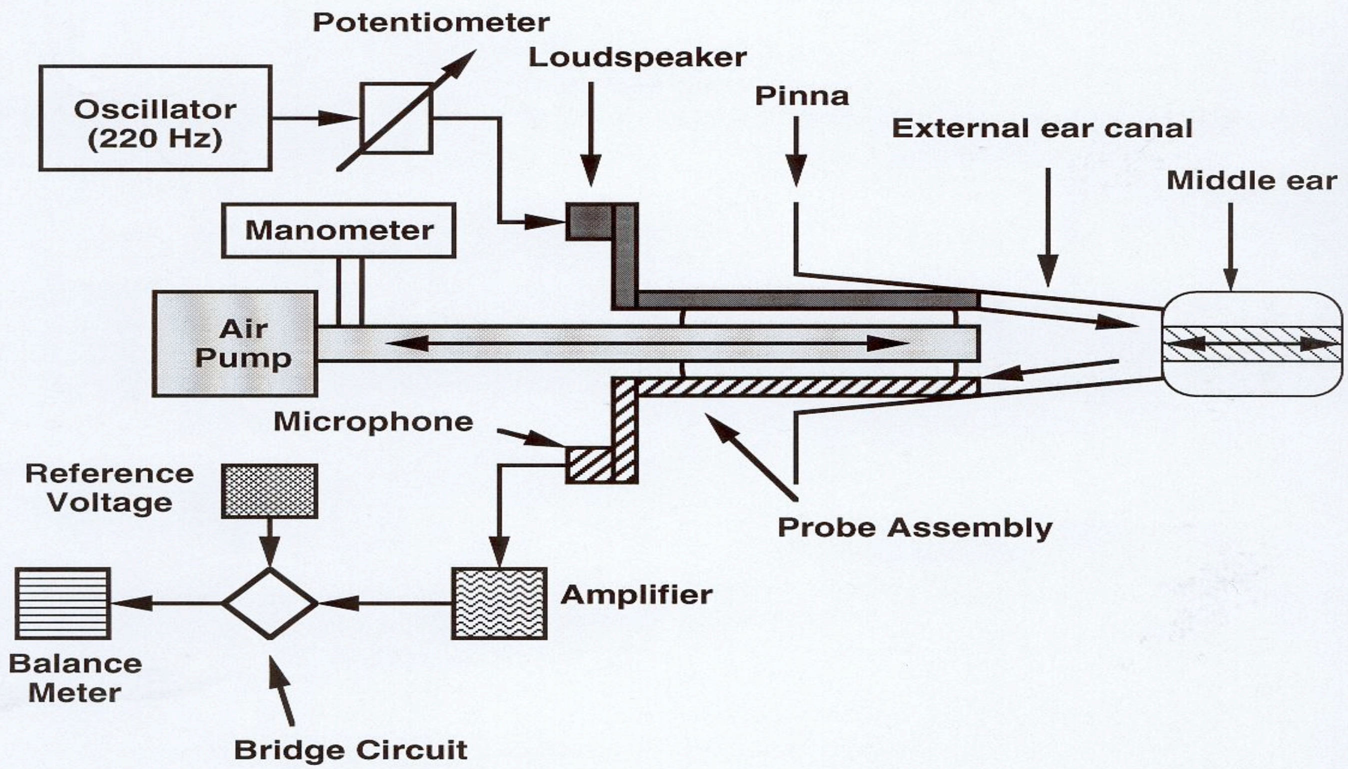
  Y phase angle = arctan (B_a / G_a)

  - G_a = acoustic conductance (admittance due to **friction**)
  - B_a = acoustic susceptance, i.e., admittance due to **mass** and **stiffness** (or **compliance**) components

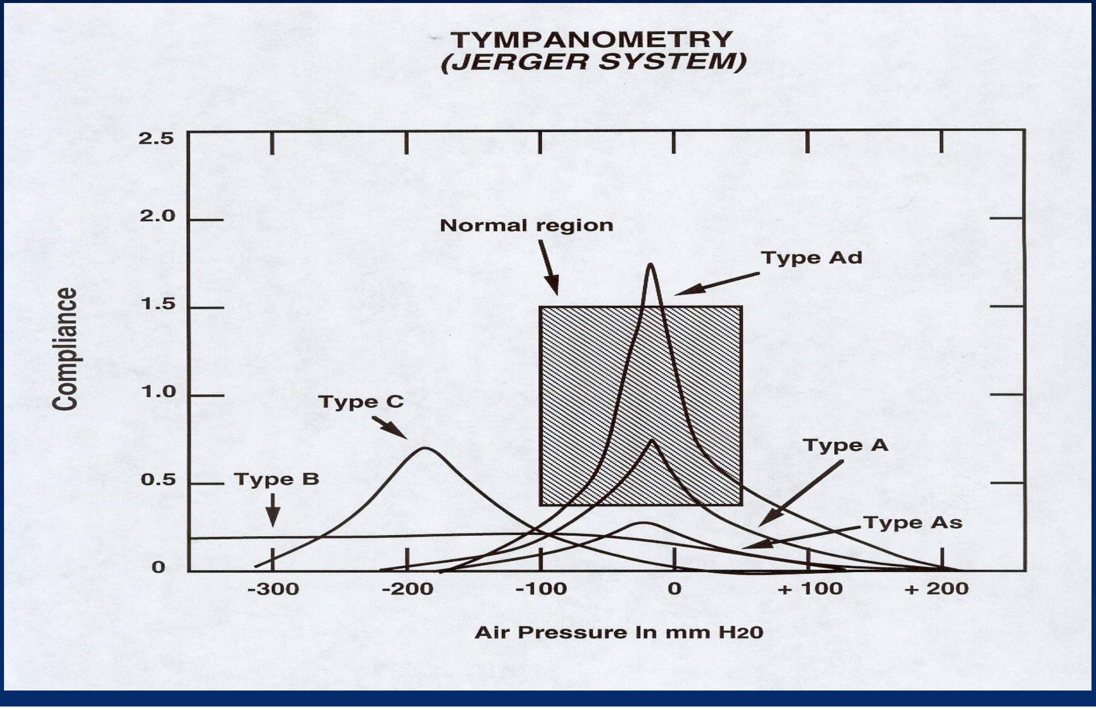
AURAL IMMITTANCE MEASUREMENT: Clinical Measurements

- Instrumentation
- Ear canal volume
- Static compliance
- Tympanometry
  - 220 vs. 1000 Hz probe tones for adults vs. neonates
  - Toynbee and Valsalva procedures
  - Fistula test acoustic reflexes
- Acoustic reflexes
  - ipsi - and contralateral
  - reflex decay

ELECTROACOUSTIC IMMITTANCE METER



A Simple System for Categorizing Tympanograms



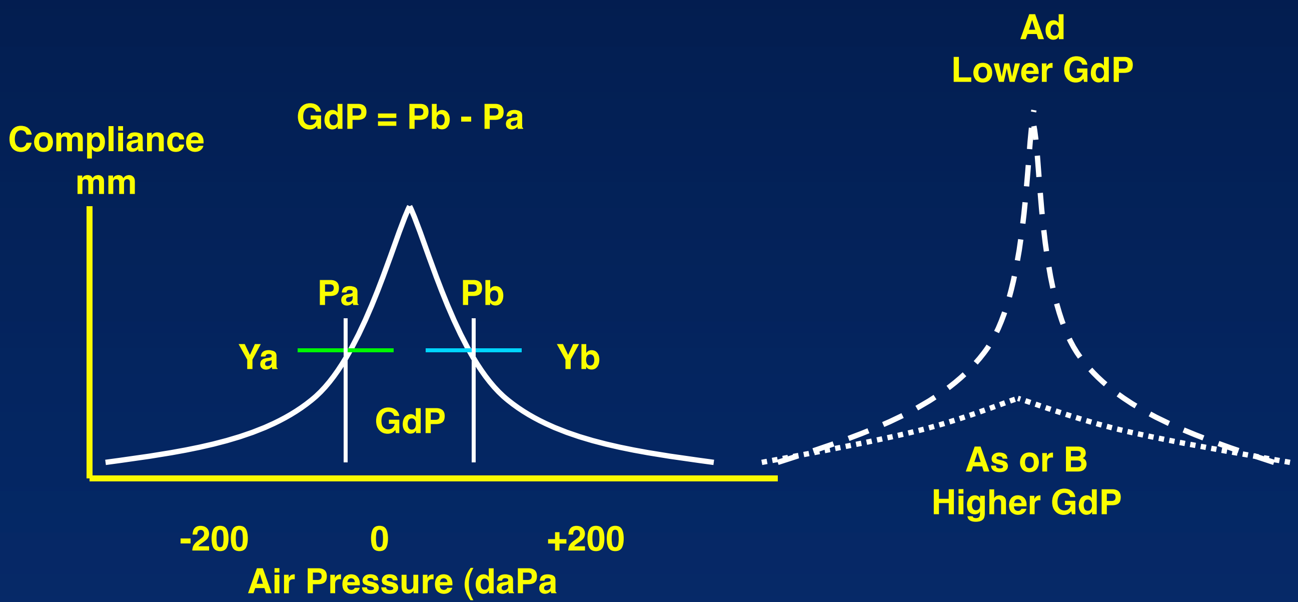
Tympanogram Type as a Function of Pressure Change Direction in 186 Ears (Hall & Chandler, 1994)

Descending Pressure (+ to -)	Ascending Pressure (- to +)					
	A	As	Ad	B	C	Cpos
A	123	0	4	0	7	0
As	7	4	0	0	0	0
Ad	1	0	4	0	0	0
B	0	0	0	2	0	0
C	4	0	0	0	17	0
Cpos	0	0	0	0	0	6

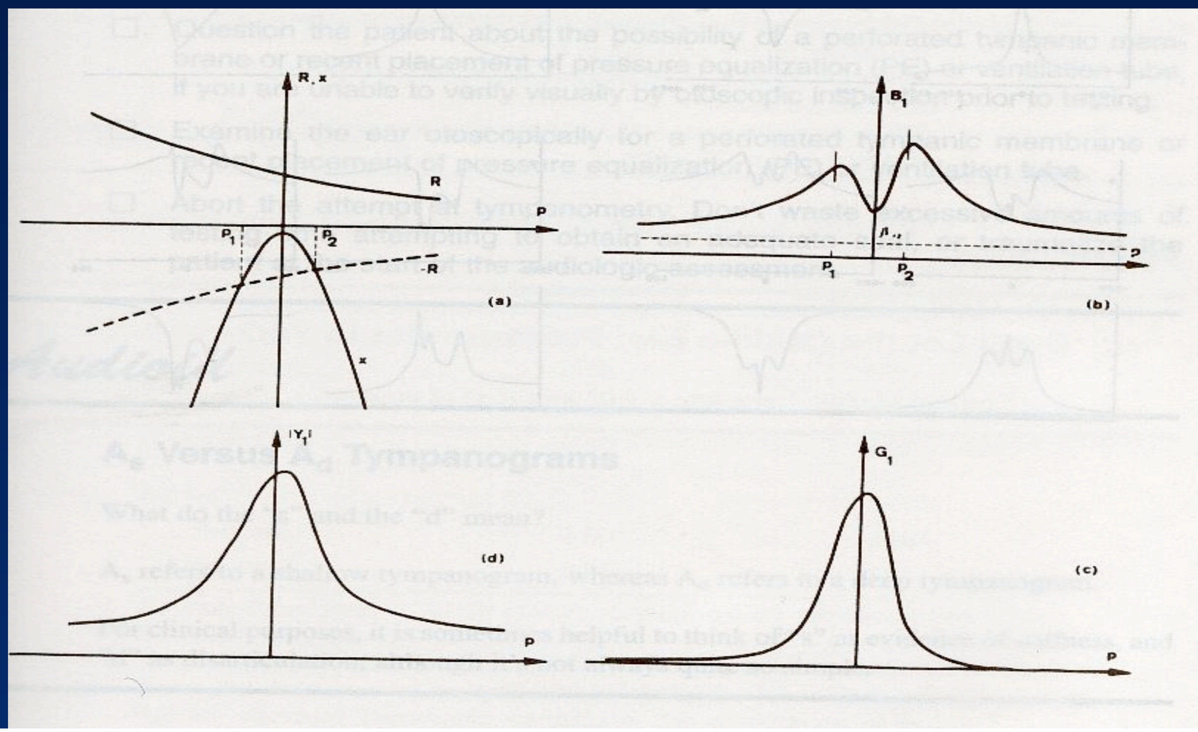
Tympanogram Gradient

- Computation of tympanogram admittance relative to pressure range
- First reported by
  - Cooper et al, 1982
  - de Jonge, 1986
  - Koebsell & Margolis, 1986
  - Tompkins & Hall, 1990
- A half-amplitude admittance (Y) point is determined on the positive and negative side of the tympanogram
  - Total amplitude on each side is divided by two
  - The difference in air pressure between each of these points on the slope of the tympanogram is referred to as delta (difference) pressure (dP) and expressed in daPa

Tympanogram Gradient

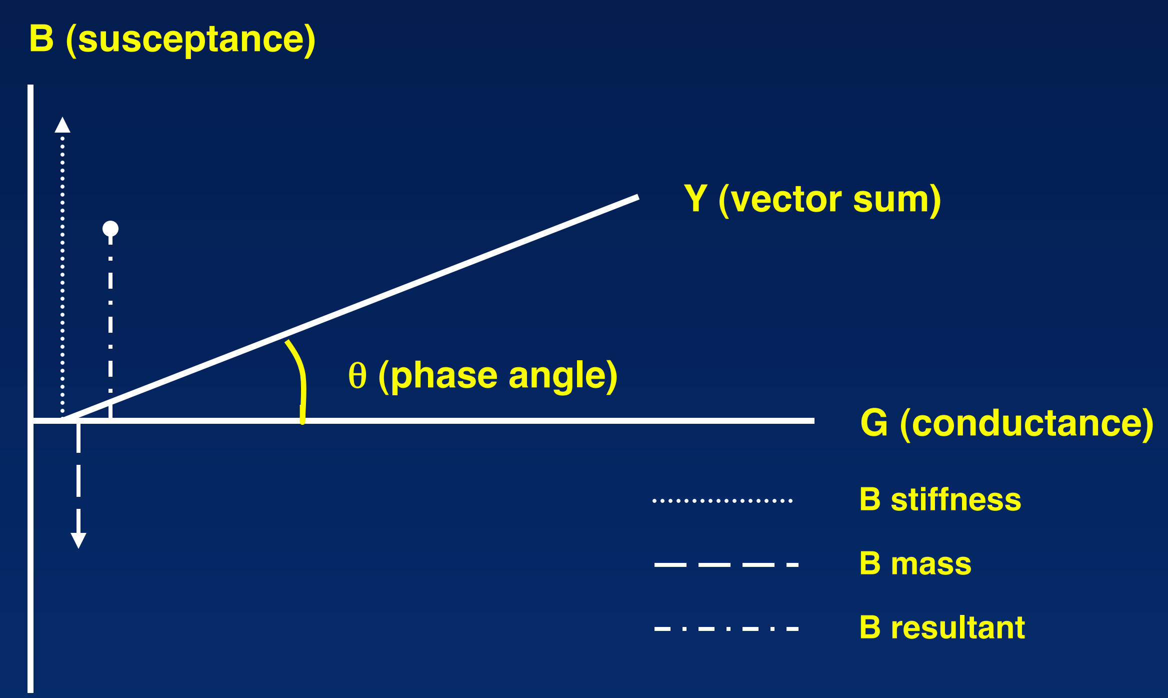


Multicomponent Tympanograms:
Admittance (Y), Susceptance (B), Conductance (G)



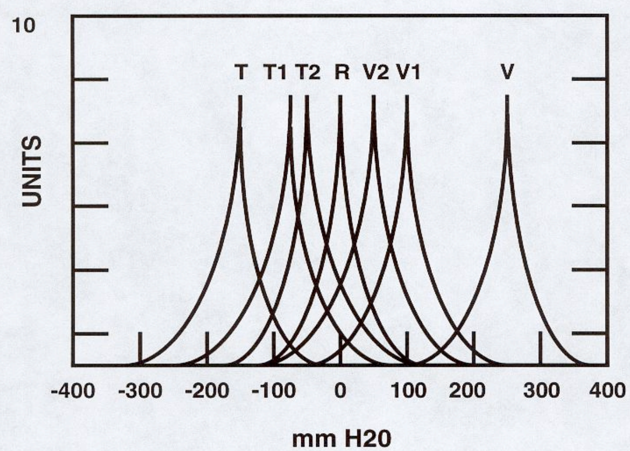
"Distribution of Theta Y_{226} in A Clinical Population"

(Bishop & Church, JAAA 19: 2008)



Toynbee and Valsalva Tests

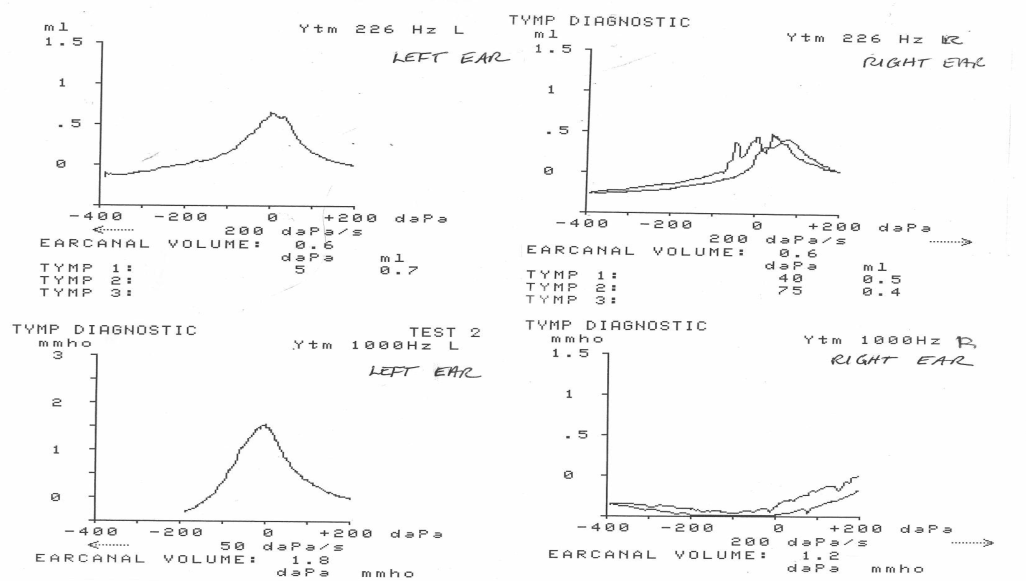
R = RESTING PRESSURE
T = PRESSURE AFTER TOYNBEE
T1 = PRESSURE AFTER ONE OPEN-NOSE SWALLOW
T2 = RESIDUAL PRESSURE AFTER MULTIPLE OPEN-NOSE SWALLOWS
V = PRESSURE AFTER VALSALVA
V1 = PRESSURE AFTER ONE SWALLOW
V2 = RESIDUAL PRESSURE AFTER MULTIPLE SWALLOWS



Diagnosis of Hearing Loss: Protocol for Confirmation of Hearing Loss in Infants and Toddlers (0 to 6 months)
Year 2007 JCIH Position Statement

- Child and family history
- Otoacoustic emissions
- ABR during initial evaluation to confirm type, degree & configuration of hearing loss
- Acoustic immittance measures (including acoustic reflexes) *using high frequency (1000 Hz) probe tone*
- Supplemental procedures (insufficient evidence to use of procedures as "sole measure of auditory status in newborn and infant populations")
    - Auditory steady state response (ASSR)
    - Acoustic middle ear reflexes for infants < 4 months
    - Broad band reflectance
- Behavioral response audiometry *(if feasible)*
    - ✓ Visual reinforcement audiometry *or*
    - ✓ Conditioned play audiometry
    - ✓ Speech detection and recognition
- Parental report of auditory & visual behaviors
- Screening of infant's communication milestones

Low (226 Hz) versus High (1000 Hz) Probe Tone for Infant Tympanometry



Tympanometry in Infants and Young Children: Clinical Recommendations and Cautions

- The middle ear system of a newborn infant is mass dominated with a lower resonant frequency (Kei et al, 2007)
- The adult middle ear system is stiffness dominated with a higher resonance frequency
- External ear canals of neonates "are distensible under applied air pressure because of the underdeveloped osseous portion of the ear canal" (Kei et al, 2007)
- "Compensating for the ear canal contribution by making measurements of admittance at extreme ear canal static pressures (I.e., +200 or - 400 daPa) may introduce errors in estimating the static admittance." (Kei et al, 2007)
- Use a 1000 Hz probe tone with infants up to the chronological age of at least 4 months
- Calculate ear canal volume with a 226 Hz probe tone
- Ear canal volume measurements at extreme positive or negative pressures may not be accurate in neonates.

Wideband Power Reflectance (WBR)

- New concept for middle ear assessment
- Wideband power reflectance (impedance and admittance)
- Uses broad band stimulus
- Measured at ambient pressure or with induced ear canal pressure
- Takes a few seconds to record averaged response

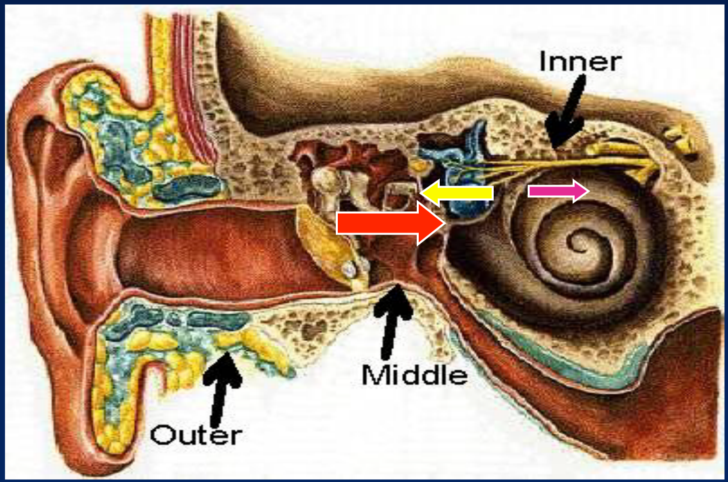
Wideband Power Reflectance (WBR): Measurements in 6 Domains

- Power reflectance (%)
- |R|2 Power absorption (%)
- 1 –|R|2 Transmittance (dB)
- 0 ×log10[1 –(|R|2)] Normalized resistance (real (Re) component)
- [Re(Z) / Zc] Normalized reactance (imaginary (Im) component)
- [Im(Z) / Zc] Normalized impedance magnitude (|Z /Zc|)

What is Power Reflectance?

- Sound enters ear canal, propagates down the ear canal, and is partially reflected from the ear drum.
- Power reflectance = energy reflectance
- Reflectance = reflected power / incident power

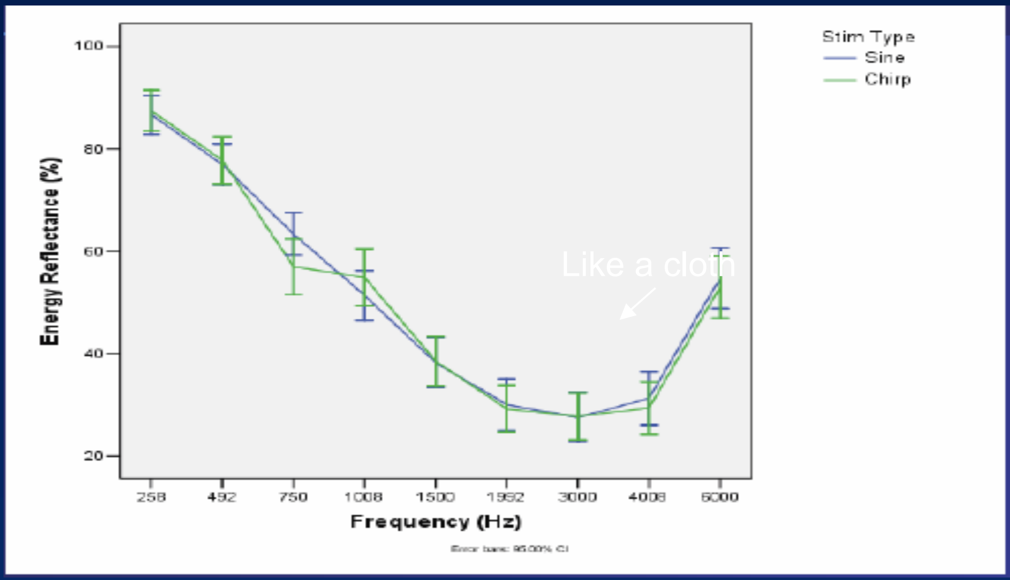
What is Power Reflectance?



Reflectance = Reflected Power / Incident Power

Transmittance = Absorbed Power

Wideband Reflectance lR(f)l: R(f) depends on frequency



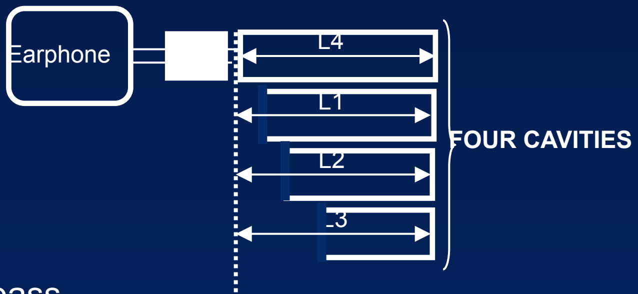
Hunter, AAA convention 2005

Reflectance Measurement

- Probe calibration
- Obtain patient measurement
- Evaluation of results

psj

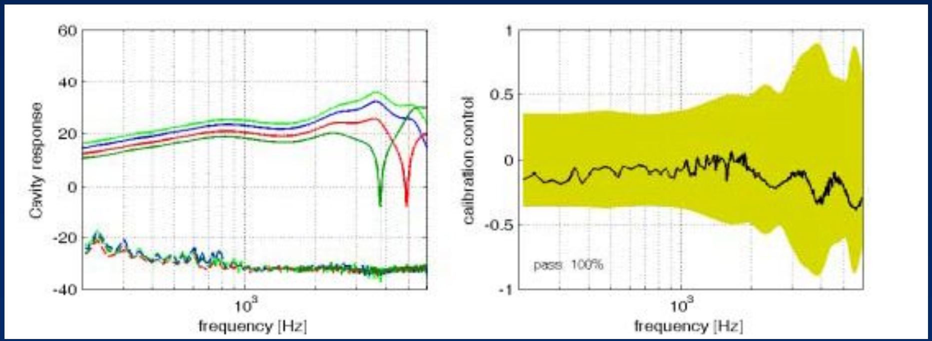
Probe Calibration



Characterize the probe acoustics properties via four cavities

Cavity pressures

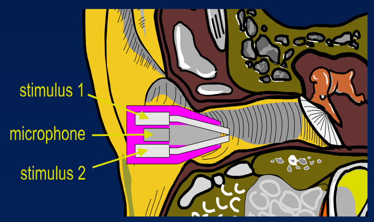
Calibration pass



Cavity set

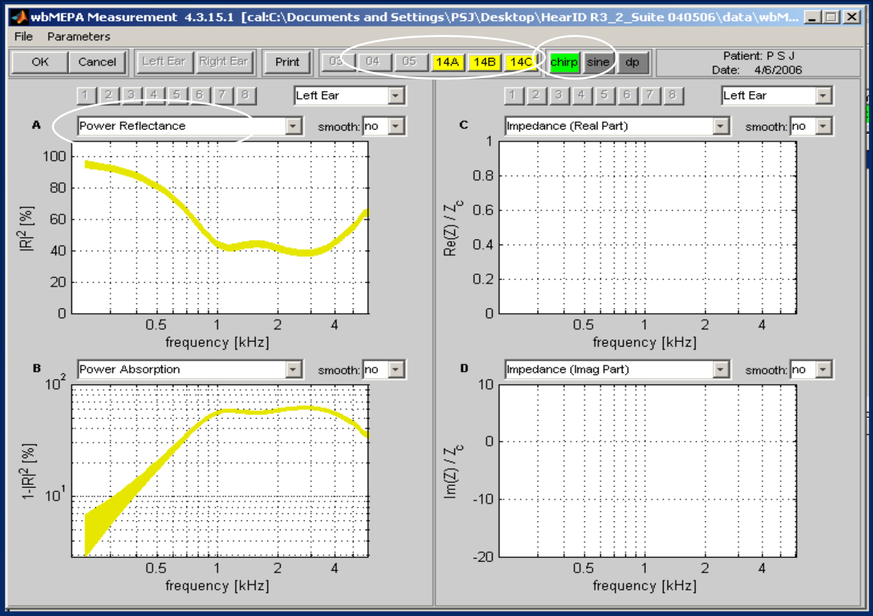
Obtain patient measurement

- Select the probe tip
- Place the probe in the patient's ear canal
- Specify the probe tip size
- Initiate the canal pressure measurement
- Parameters:
  - Stimulus type (Chirp or tone)
  - Stimulus duration (sec)

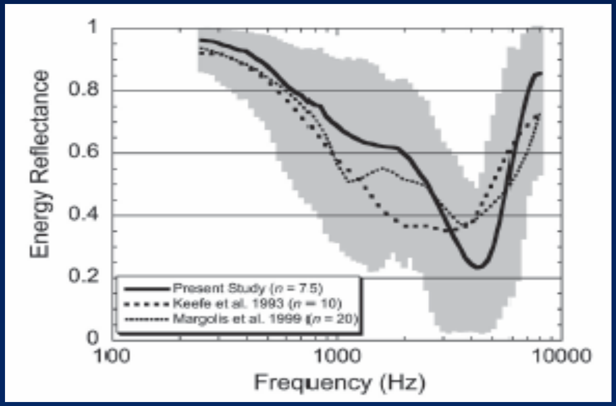


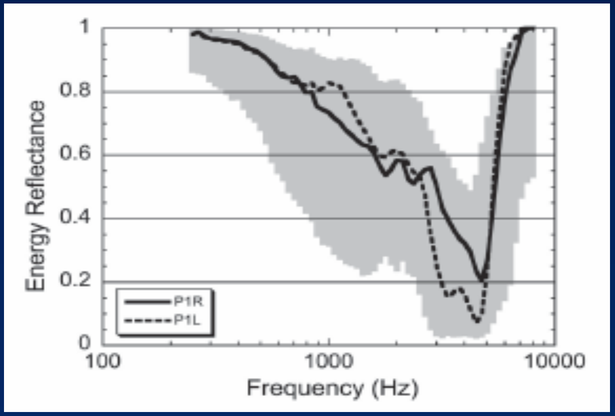
Measure Reflectance

- Ear tip size
- Stimulus type
- Ear to be measured
- Reflectance plot



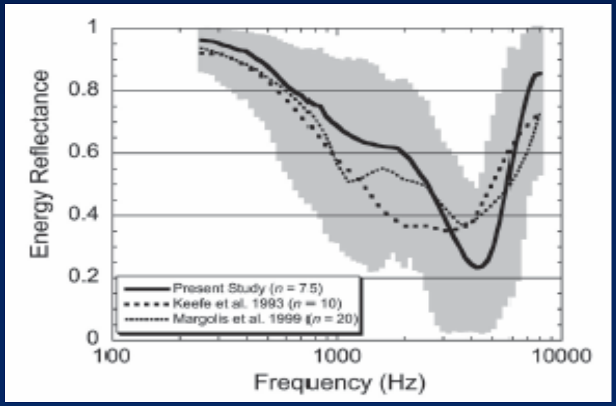
Bilateral Sensorineural Hearing Loss (SNHL)

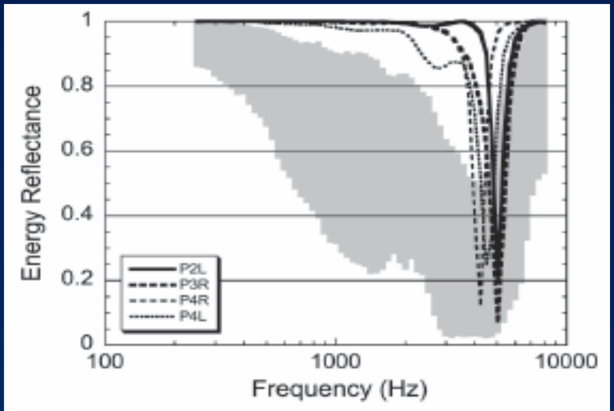




Feeney, JSHR, 2003

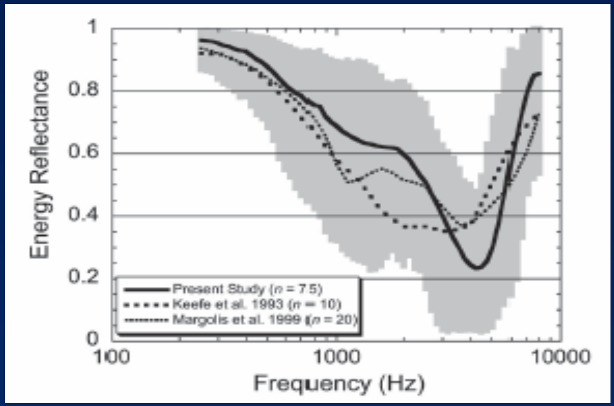
Four Ears with Otitis Media with Effusion (OME)

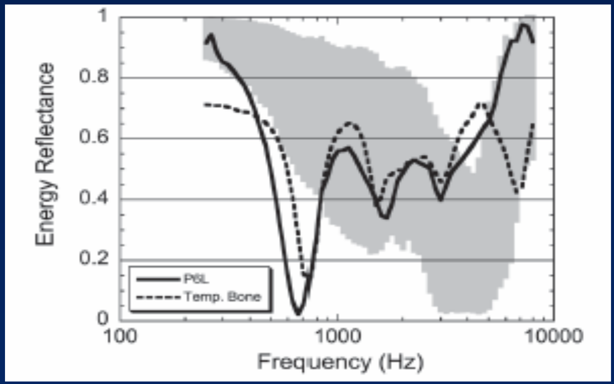




Feeney, JSHR, 2003

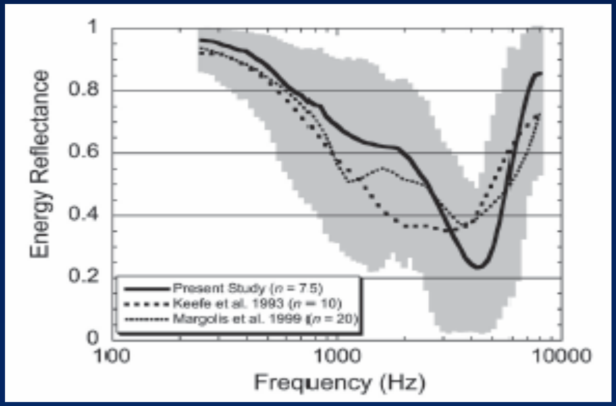
Ossicular Discontinuity

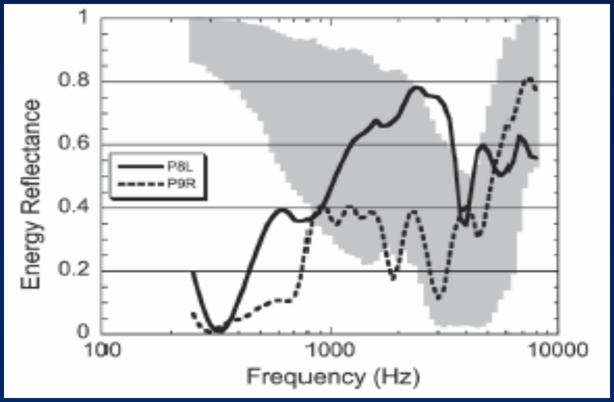




Feeney, JSHR, 2003

Tympanic Membrane Perforation



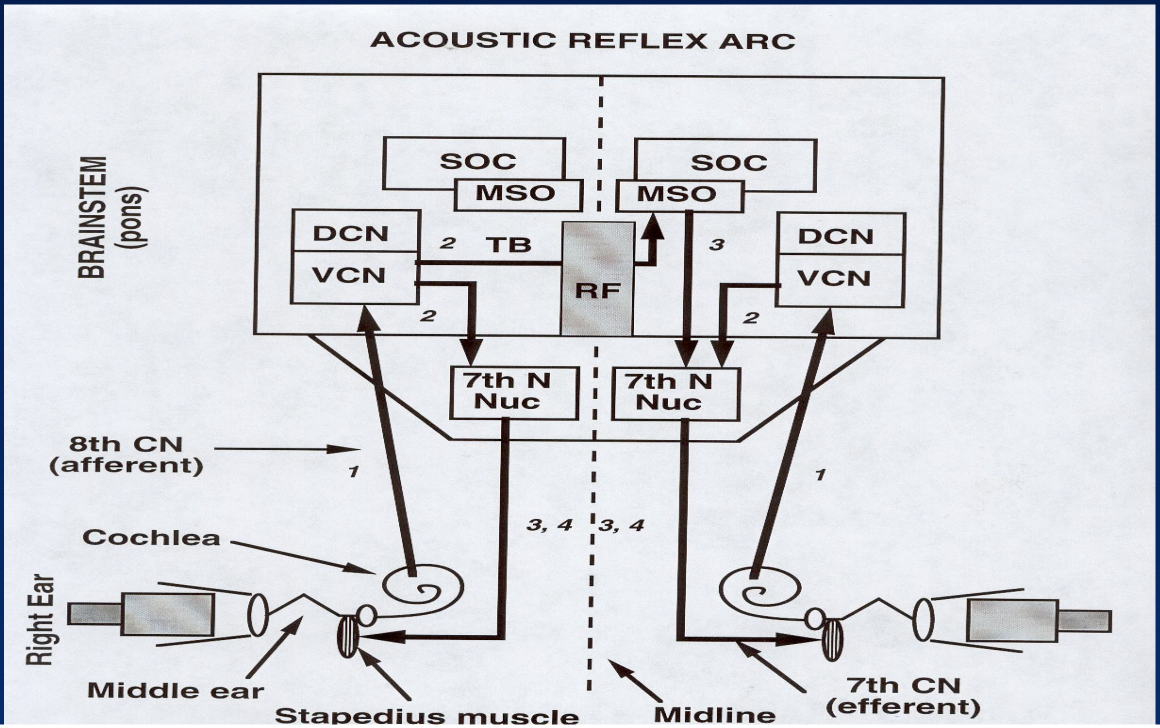


Feeney, JSHR, 2003

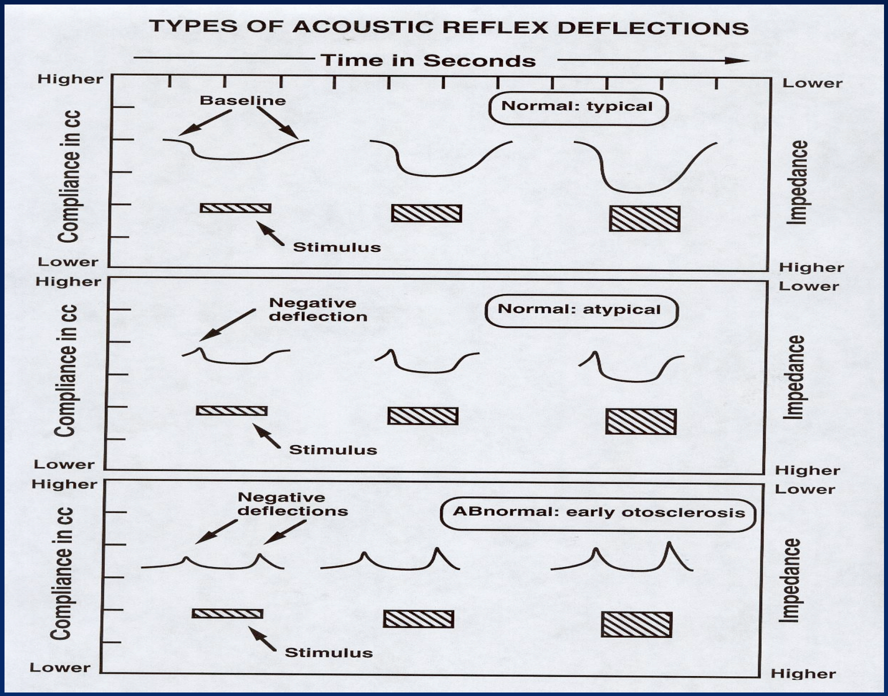
Wideband Power Reflectance (WBR): Findings in Healthy Newborn Infants (Hunter et al, 2007)

- Strong relationship between WBR and referred DPOAEs
- Reflectance and OAEs combined in portable device
- FDA approved instrument (Mimosa Hear-ID)
- Reflectance is broad-band across entire audiometric range
- Measurement is rapid and easy to complete in neonates

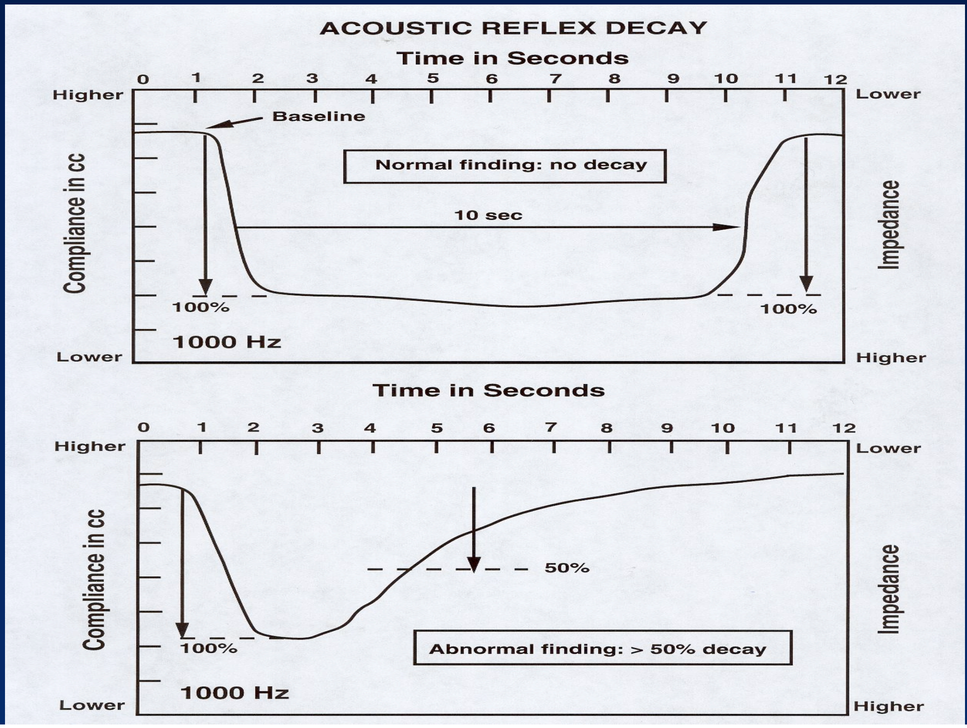
Acoustic Stapedial Reflex
(Anatomy adapted from Borg)

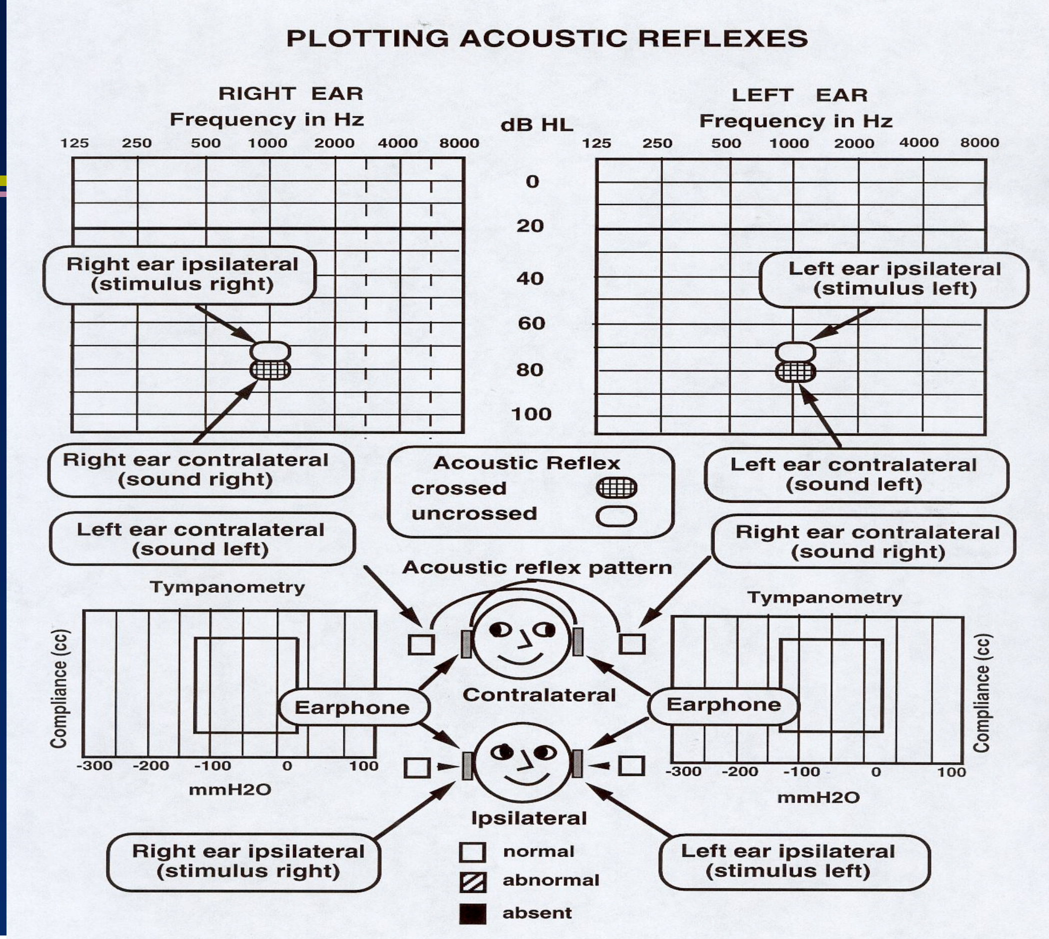


Patterns of Acoustic Reflex Deflections: Normal and Abnormal



Acoustic Reflex Decay:
A Retrocochlear Finding




PLOTTING ACOUSTIC REFLEXES
RIGHT EAR
Frequency in Hz
125 250 500 1000 2000 4000 8000
dB HL
LEFT EAR
Frequency in Hz
125 250 500 1000 2000 4000 8000
0
20
40
60
80
100
Right ear ipsilateral (stimulus right)
Left ear ipsilateral (stimulus left)
Right ear contralateral (sound right)
Acoustic Reflex
crossed
uncrossed
Left ear contralateral (sound left)
Left ear contralateral (sound left)
Right ear contralateral (sound right)
Acoustic reflex pattern
Tympanometry
Compliance (cc)
-300 -200 -100 0 100
mmH2O
Earphone
Contralateral
Earphone
Tympanometry
Compliance (cc)
-300 -200 -100 0 100
mmH2O
Ipsilateral
Right ear ipsilateral (stimulus right)
normal
abnormal
absent
Left ear ipsilateral (stimulus left)

Plotting the Results of Acoustic Reflex Measurements

Acoustic reflex patterns ("faces")

- Conductive/efferent pattern
- Sensory pattern
- Neural pattern
- Brainstem pattern

	Right	Left
Crossed (contralateral) Sound in ear	☐	☐
Uncrossed (ipsilateral) Probe and sound in ear	☐	☐

Plotting the Results of Acoustic Reflex Measurements

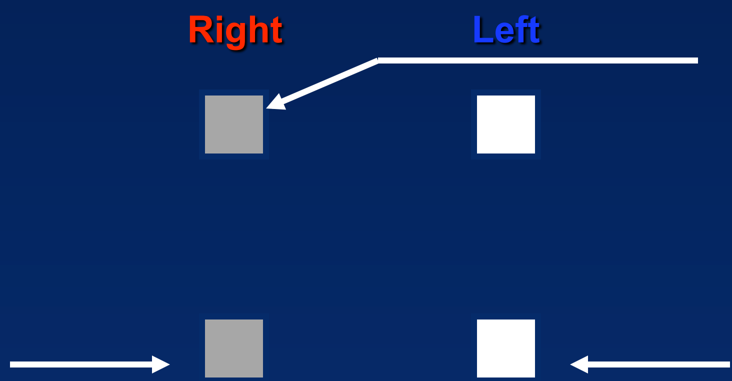
Abnormal Acoustic Reflex

Vertical pattern

- Mild conductive hearing loss pattern or efferent (7th CN) pattern (normal tymp and no air bone gap) on right ear

Contralateral (Crossed)
Sound Right
Probe Left

Contralateral (Crossed)
Sound Left
Probe Right



Ipsilateral (Uncrossed)
Sound Right
Probe Right

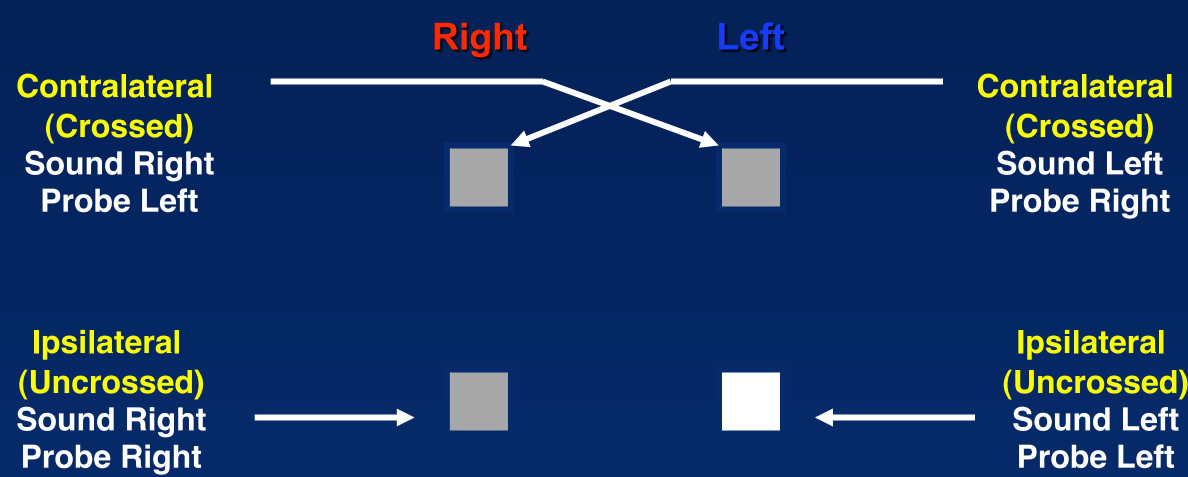
Ipsilateral (Uncrossed)
Sound Left
Probe Left

Plotting the Results of Acoustic Reflex Measurements

Abnormal Acoustic Reflex

Inverted "L" pattern

- Moderate or severe conductive hearing loss on right ear



Plotting the Results of Acoustic Reflex Measurements

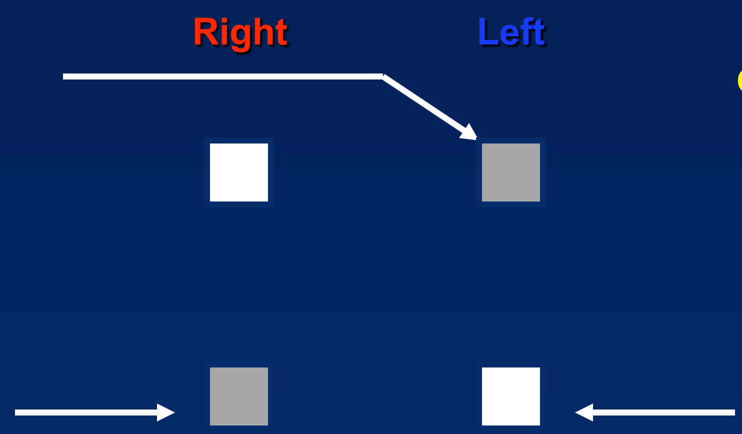
Abnormal Acoustic Reflex

Diagonal pattern

- Severe sensory hearing loss or 8th nerve auditory dysfunction on right ear

Contralateral (Crossed)
Sound Right
Probe Left

Contralateral (Crossed)
Sound Left
Probe Right



Ipsilateral (Uncrossed)
Sound Right
Probe Right

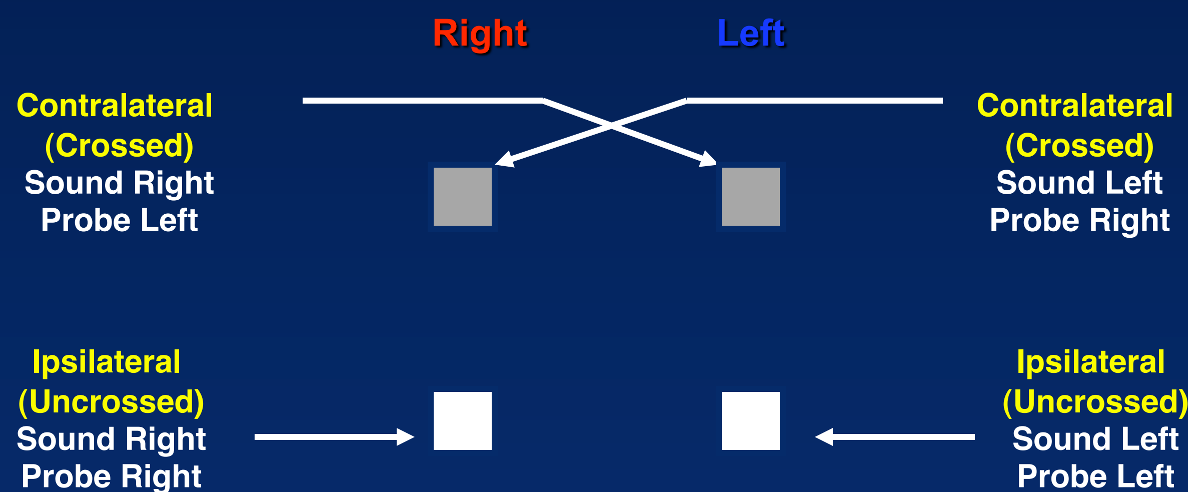
Ipsilateral (Uncrossed)
Sound Left
Probe Left

Plotting the Results of Acoustic Reflex Measurements

Abnormal Acoustic Reflex

Horizontal pattern

- Brainstem auditory dysfunction



Estimation of Hearing Sensitivity with Acoustic Reflex Thresholds for Pure Tones versus Broad Band Noise (BBN): Simplified SPAR (Sensitivity Prediction by the Acoustic Reflex)