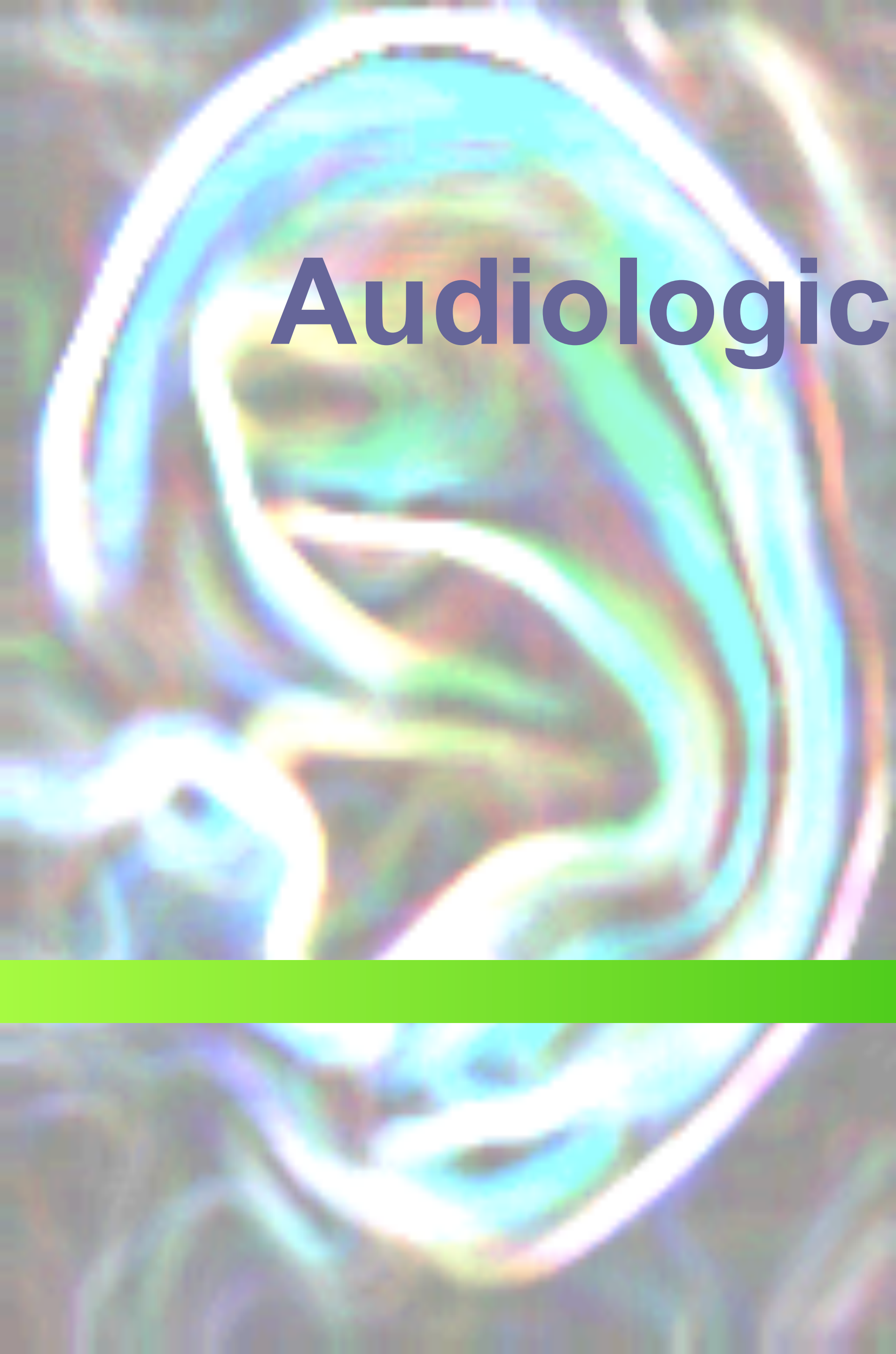
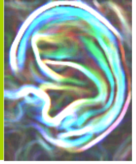


Audiological Evaluation A to Z

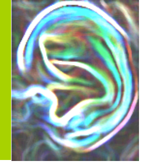
Dr.Osama Hamed
Audio-Vestibular Medicine Specialist
KAUH



ENT 429 Team

One star slides the doctor read it

Two stats slides is very Important

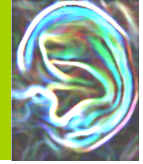


AUDIOLOGY

The study of sound and hearing

Sound=physical stimulus that evoke sensation of hearing.

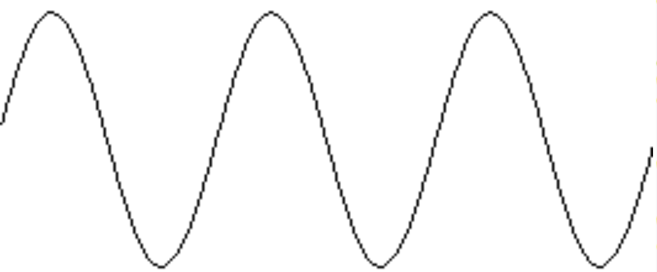
Audiometry=the measurement of hearing sensitivity.

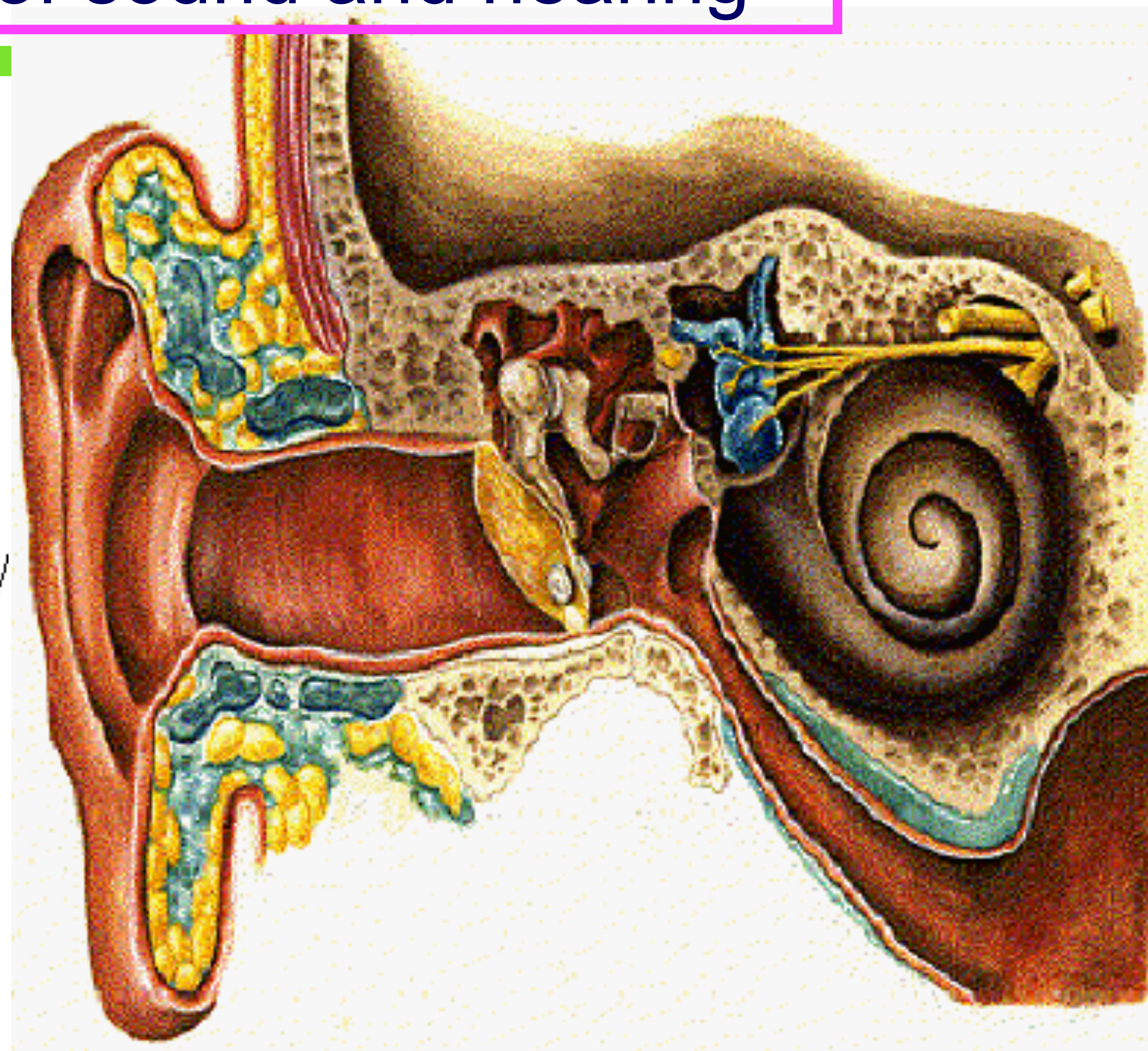


The nature of sound and hearing

Stimulus:
sound

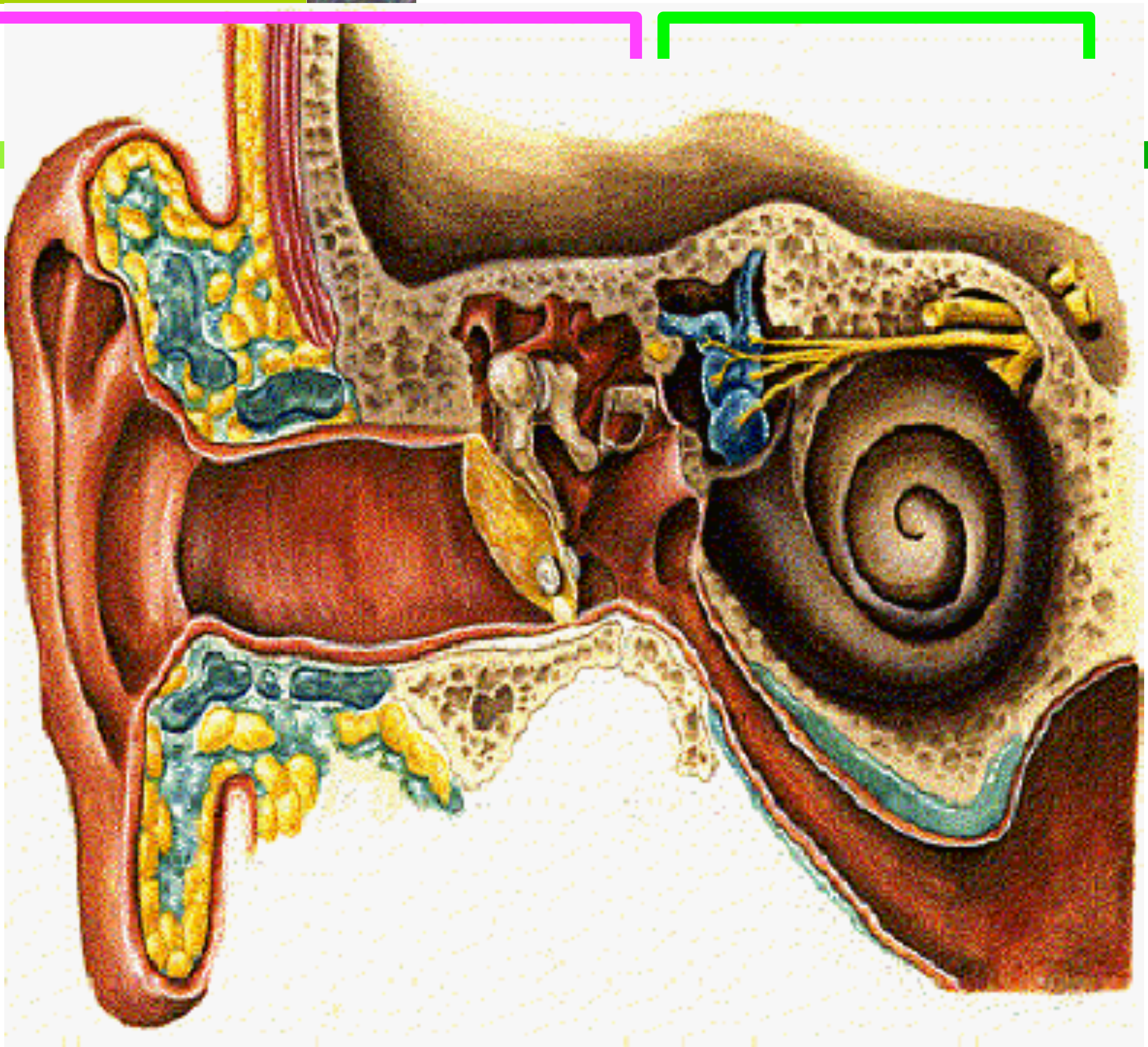
(sine wave)

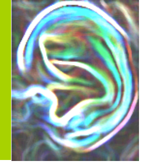




MECHANICAL

ELECTRICAL/SENSORY

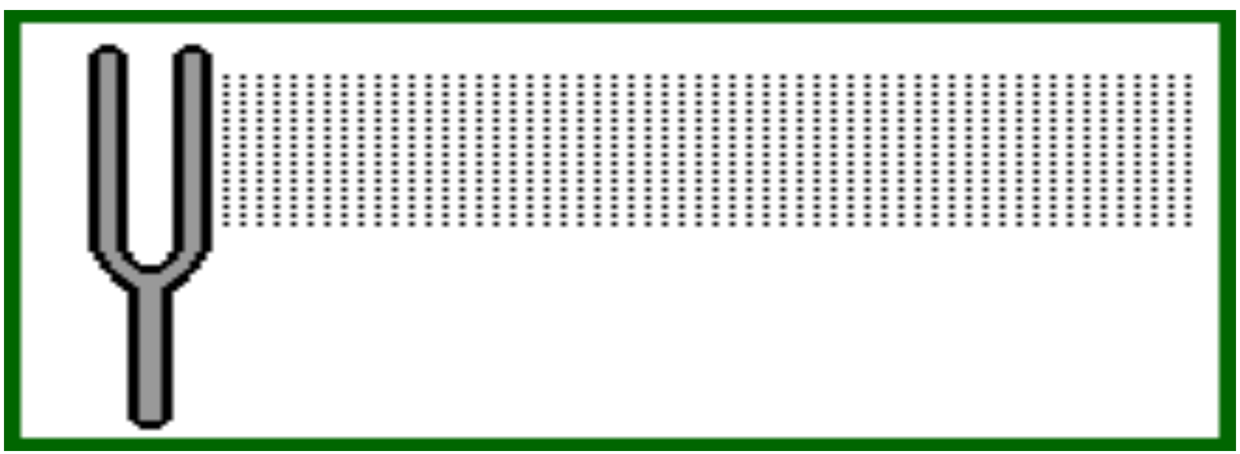


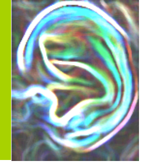


SOUND

Sound is a form of **vibration**

Vibration is the to-and-fro motion of an object (guitar string, vocal folds, diaphragm on an earphone or loudspeaker, tuning fork)





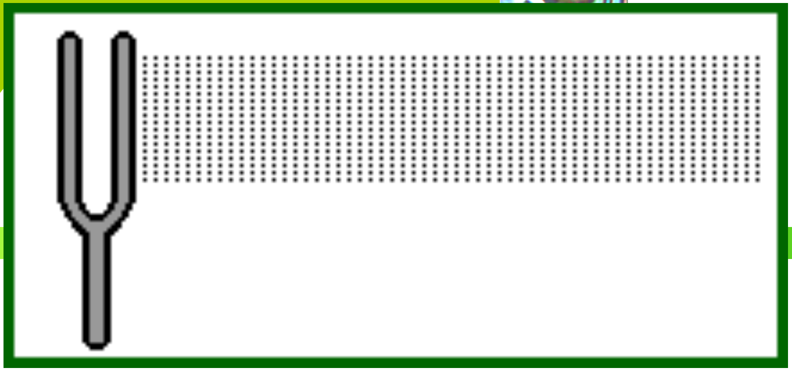
SOUND

For sound to occur, must have a

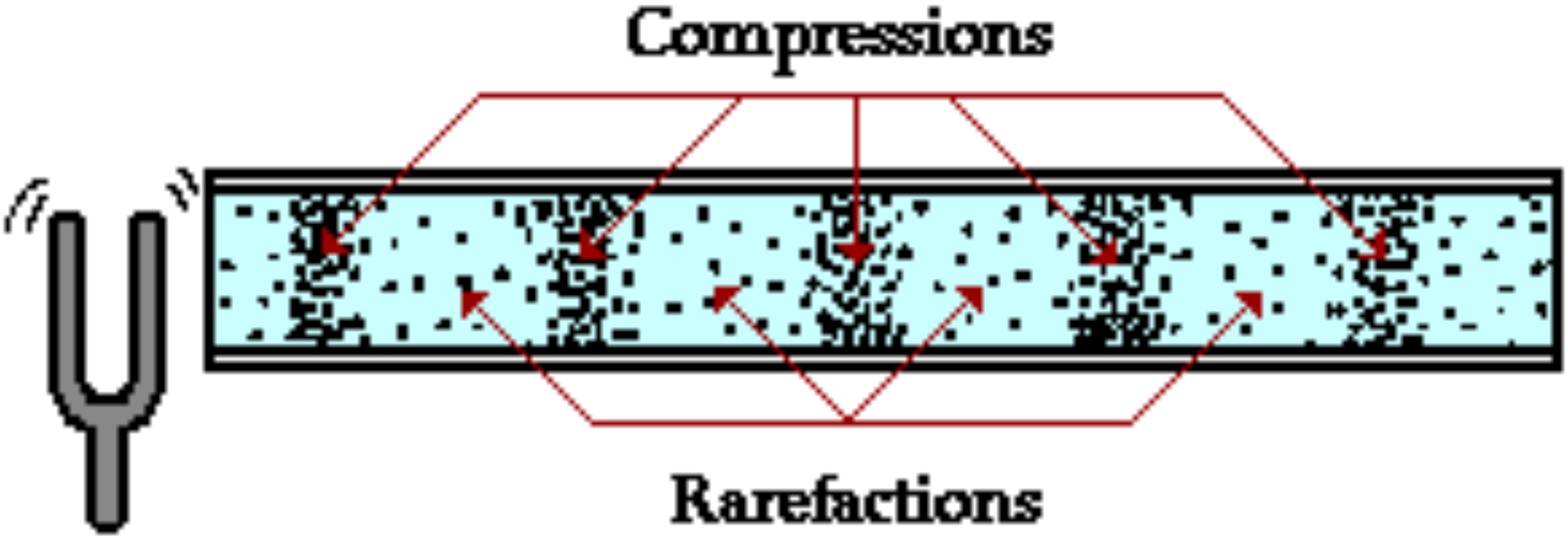
SOURCE: Something has to be disturbed.

FORCE: Something has to disturb it.

MEDIUM (e.g. air): Something has to carry the disturbances.

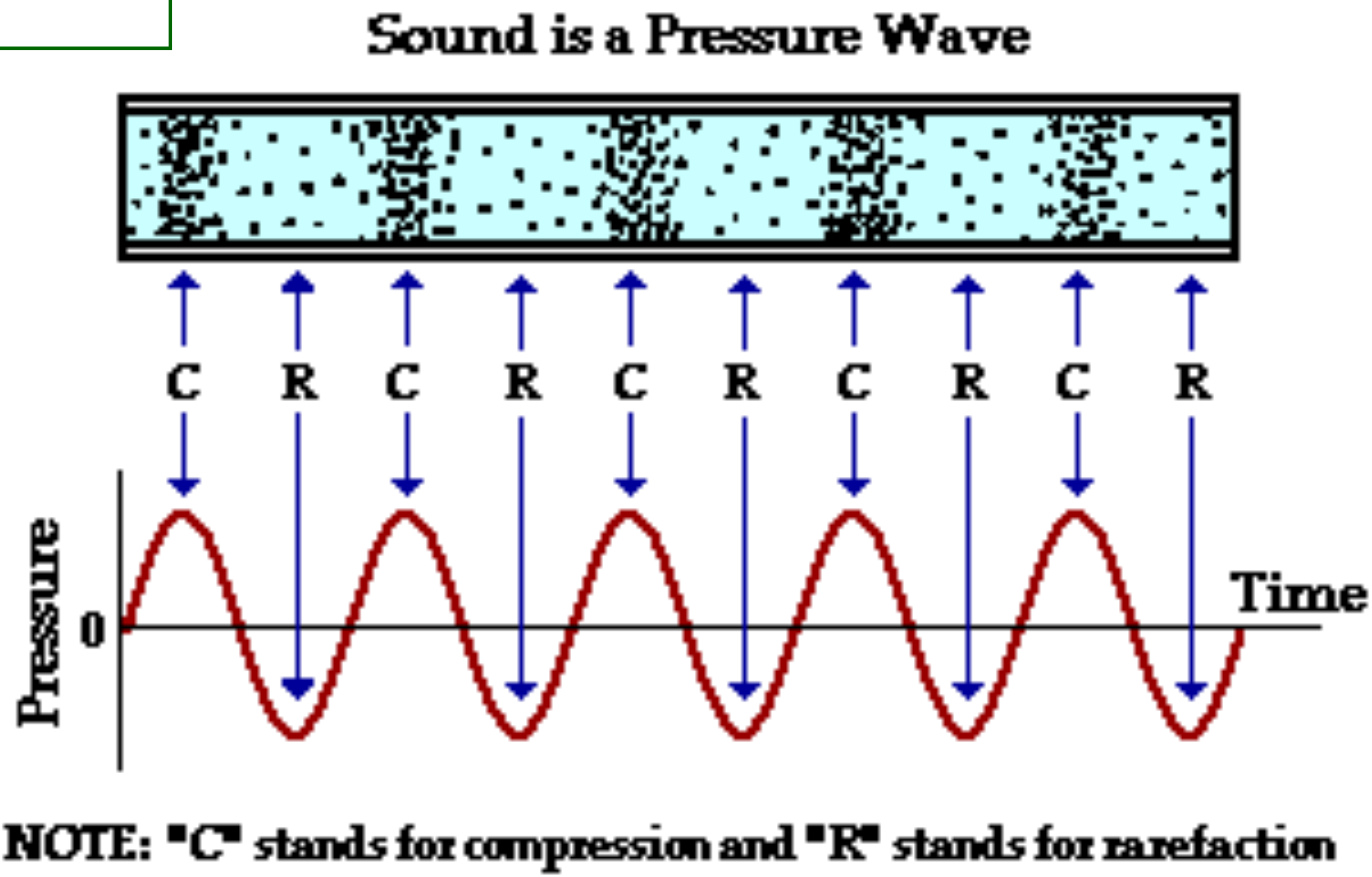


When air molecules are displaced, pressure waves occur



http://www.glenbrook.k12.il.us/gbssci/phys/Class/sound/u11l1c.html

SOUND: PRESSURE WAVE



Characteristics of the waveform (amplitude x time)

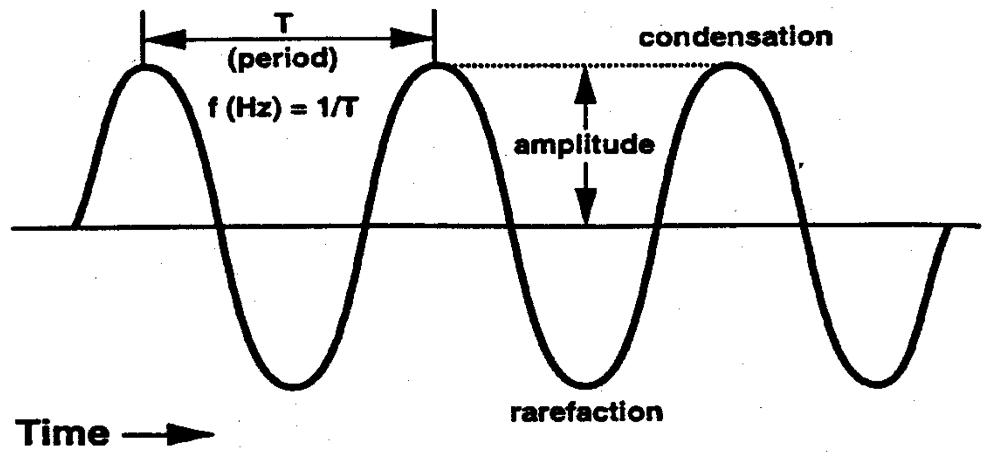


Figure 2-5. A sinusoidal waveform, describing the various properties of sound, including amplitude and frequency (f).

B. A. Stach (1998). Clinical Audiology: An Introduction. San Diego: Singular Publishing Group, Inc.

CYCLE: One complete period of compression and rarefaction of a sound wave

Characteristics of the waveform (amplitude x time)

PERIOD: The amount of time that it takes to complete one vibratory cycle.

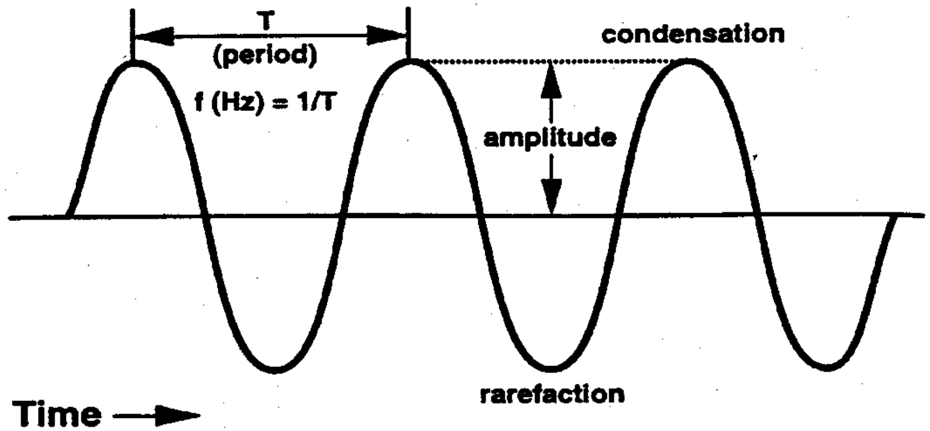


Figure 2-5. A sinusoidal waveform, describing the various properties of sound, including amplitude and frequency (f).

B. A. Stach (1998). Clinical Audiology: An Introduction. San Diego: Singular Publishing Group, Inc.

FREQUENCY: The number of cycles that occur in one second.

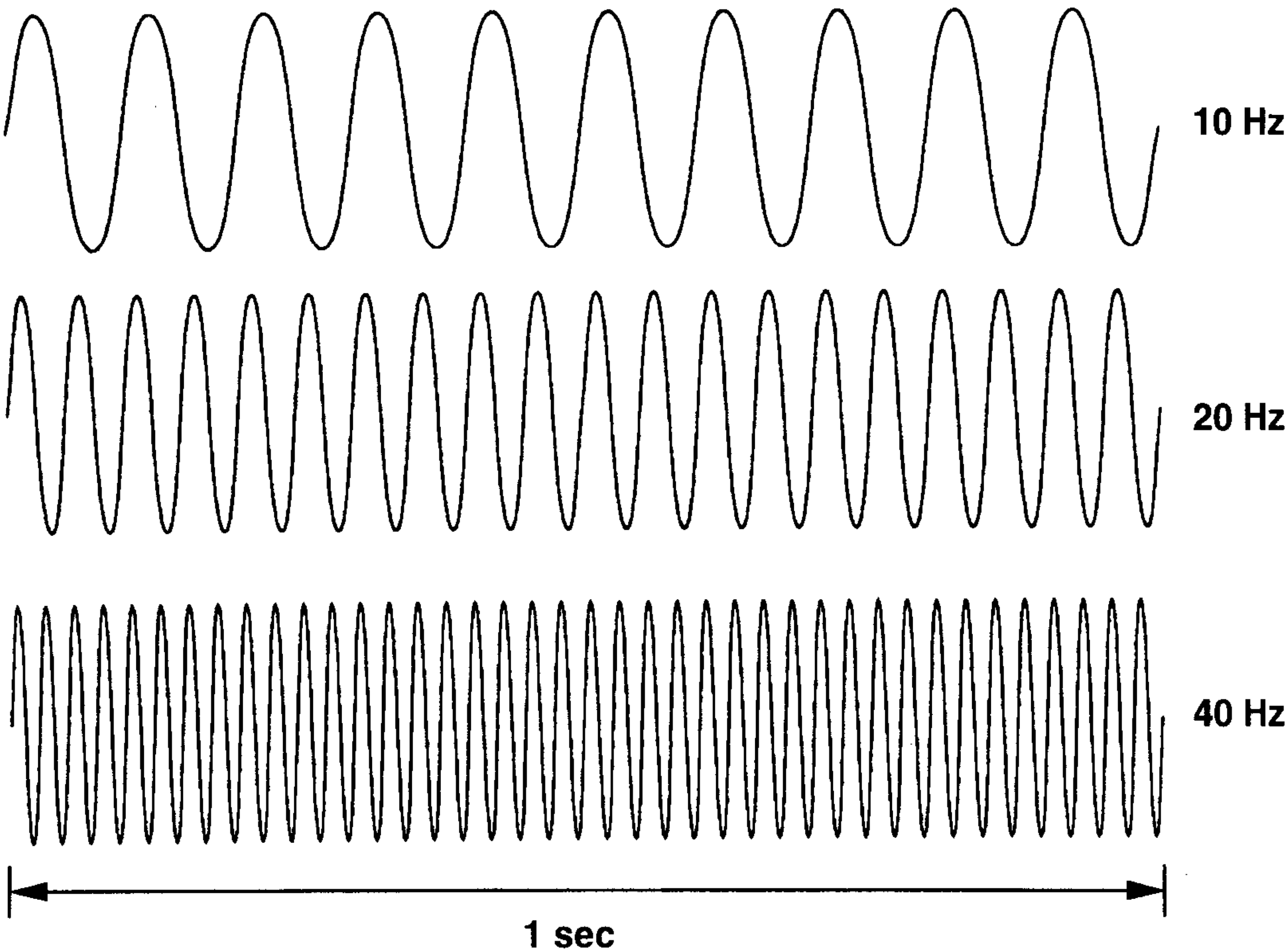


Figure 2-8. Three waveforms that are identical in amplitude and phase but vary in frequency

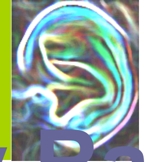
FREQUENCY

<u>Hertz (Hz)</u>: Unit of measurement of frequency

100 cycles per second = 100 Hz

<u>Pitch</u>: Psychological percept of frequency.

e.g., low frequency sounds = low pitch



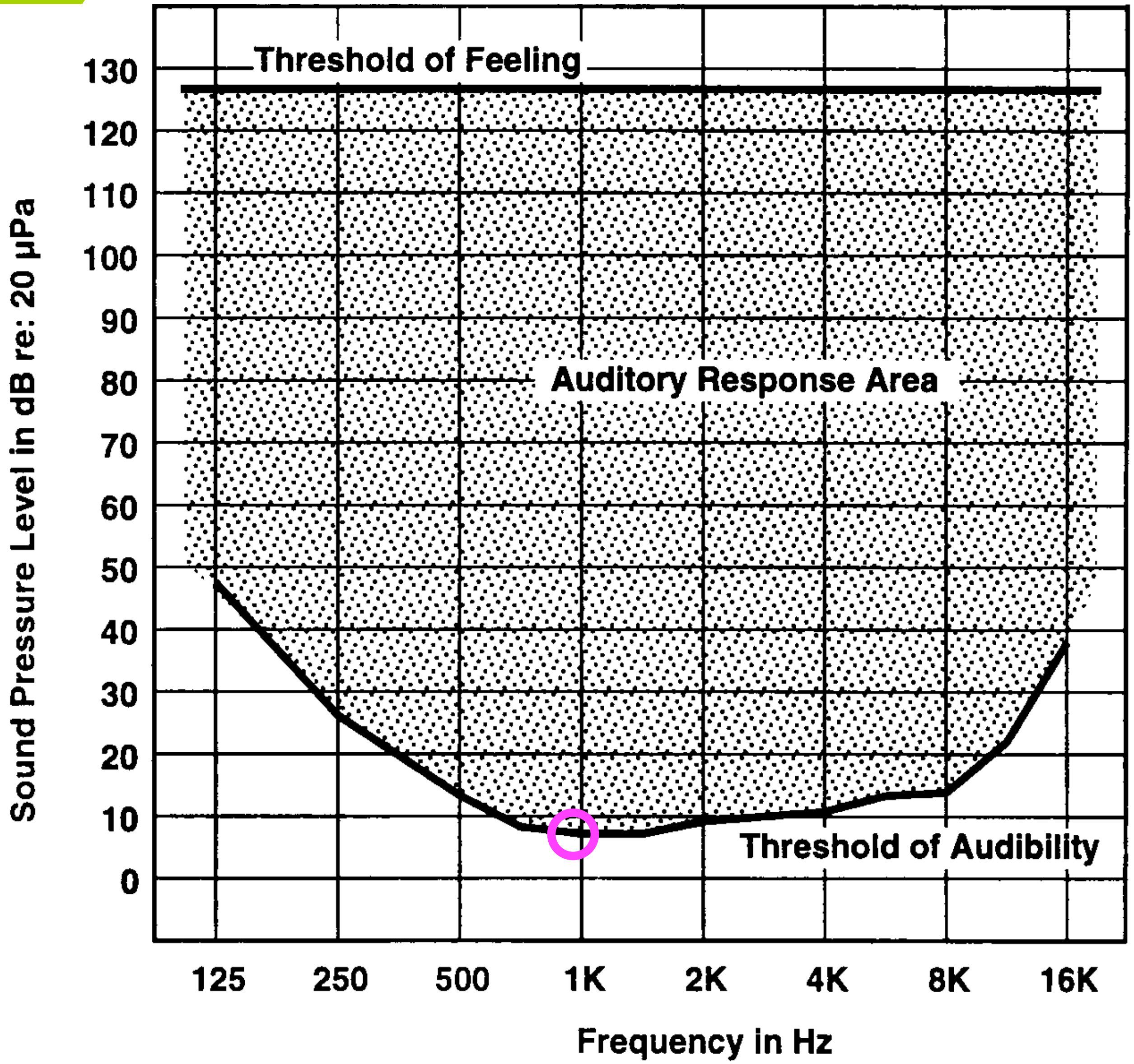
Frequency Range of Hearing Sensitivity

Humans: 20 Hz to 20 kHz.

- Below 20 Hz, we feel a vibration rather than hear a sound.
- Most people have very diminished sensitivity for frequencies > 8000-10, 000 Hz.

Bats (auditory specialists) : 2 kHz-100 kHz.

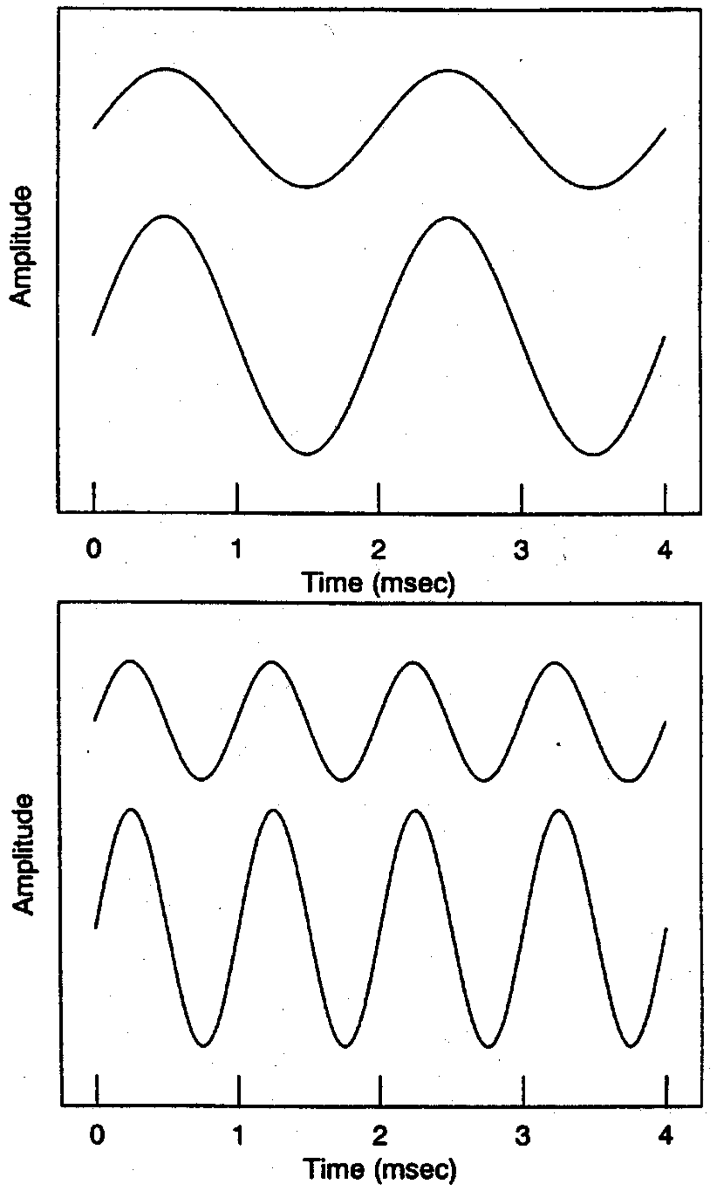
The Minimal Audible Pressure Curve (dB SPL)



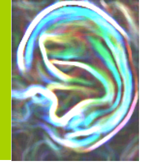
Indicates the minimum average sound pressure levels by frequency for a group of people with normal hearing

Amplitude Intensity

The quantity or magnitude of sound.



S. A. Gelfand (1997). Essentials of Audiology. New York: Thieme



AMPLITUDE/INTENSITY

Decibel (dB): Unit of amplitude used most frequently in clinical audiology.

Loudness: The psychological correlate of amplitude (measured in sones, phons).

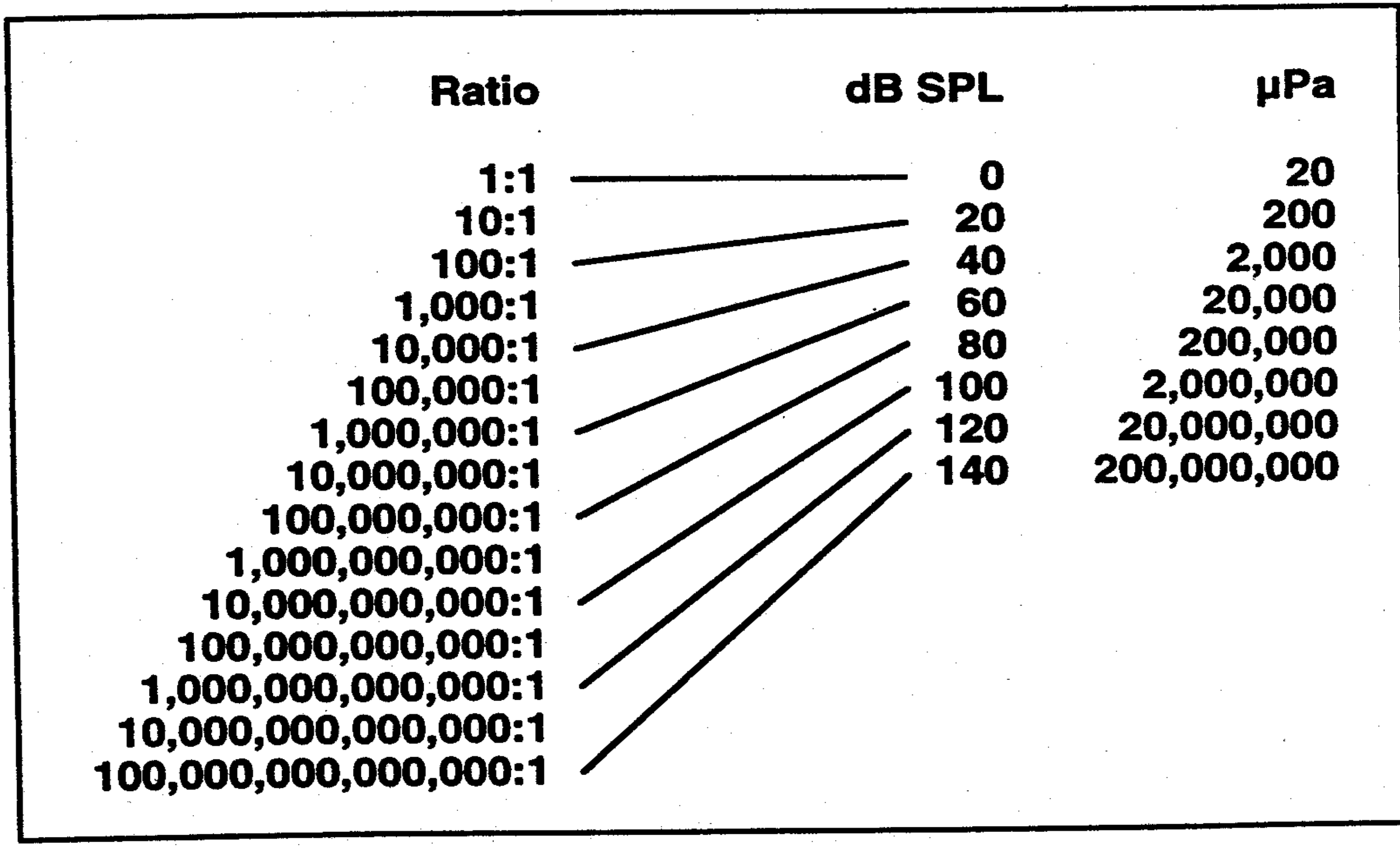


Figure 2-7. The relationship of the ratio of sound magnitude to the range of sound intensity expressed in sound pressure level. Sound ranges from barely audible at 20 μPa to painful at 200,000,000 μPa.

B. A. Stach (1998). Clinical Audiology: An Introduction. San Diego: Singular Publishing Group, Inc.

Hearing loss prevention

- Noise controls, hearing protectors
  - Primary prevention ➔ reduction or elimination of HL
- Screening neonates, school age, elderly, industrial
  - Secondary prevention ➔ early identification to reduce negative effect of HL
- Audiology services (hearing aids, rehab)
  - Tertiary prevention ➔ services to deal with adverse effects of HL

Types of Tests

BEHAVIOURAL

- reliable & consistent response to sound
- Developmental age
- not used in newborn screening

OBJECTIVE

- no voluntary response
- infants and young children
- non compliant subjects
- people with developmental level that doesn't allow other testing.

Age based hearing assessment

BEHAVIOURAL

OBJECTIVE

SCHOOL-AGED +

TODDLER

BIRTH

PURE TONE AUDIOMETRY

PLAY AUDIOMETRY

VROA

BOA

Measure responses

Need to consider individual's functional age

Overview

- Behavioral audiometry
- Tympanometry
- Acoustic reflex measurements
- ECochG
- Auditory Brainstem Response (ABR)
- Otoacoustic Emissions

Behavioural Observation Audiometry (BOA)

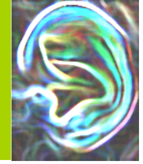
<u>Observing changes in behaviour in response to sounds</u>

Who?

Very young babies (under 6mths corrected) or with similar functional age.

Test sounds & materials

- Calibrated (known frequency and intensity) noisemakers
- Audiologist records sound level (from sound level meter), sound type & observed response- observer determines whether response is present/absent

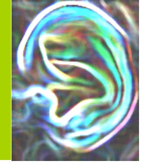


Infants 7 months-3 years

- Aim: to detect hearing impairment greater than 20-30 dB HL
- Typically use behavioural techiques
  - **Visual Reinforcement Orientation Audiometry** (VROA) for 6-18 months
  - **Play audiometry**
- May incorporate objective testing if non-compliant or very difficult to test

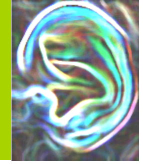
Visual Reinforcement Oreintation Audiometry (VROA)

– Uses operant conditioned response and visual reinforcement
  - Response typically head turn. Eye turn also possible
  - Complex visual reinforcement usually lighted puppet theatre- colour movement and light are important



Play audiometry 3-9 years

- Before testing
  - Subjective check of audiometer
  - Check test environment, audibility of tones
  - Avoid visual clues
  - Instruct client, demonstrate procedure
  - Position headphones
  - Present orienting tone (40dBHL) and check client's response. Re-instruct if necessary



Screening with Play Audiometry

- use peg board, blocks etc.
  - if very young get parents to train child at home
- headphones on desk present 100dB tone
- train child without headphones- Stimulus - Response
- introduce headphones
- present 40dB HL tone with headphones on. Repeat
- decrease tone to 20dB HL for screen

Pure Tone Audiometry

- Most common test
- Threshold of audibility
- Activation of auditory system
- Energy formatted into neural code
- Air conduction assesses entire system
- Bone conduction assesses cochlea onwards

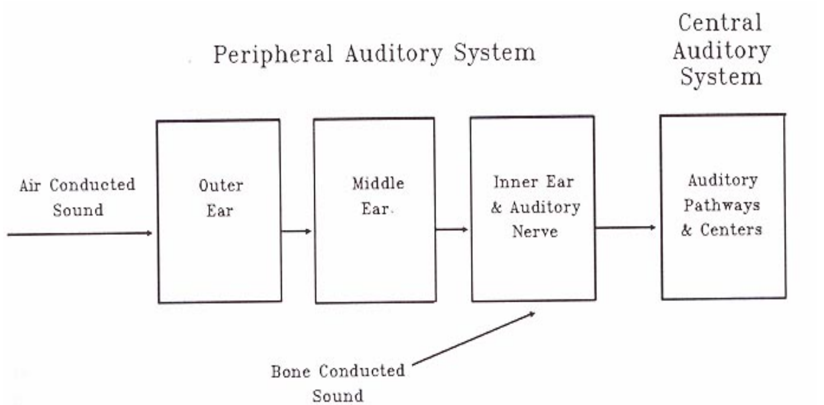
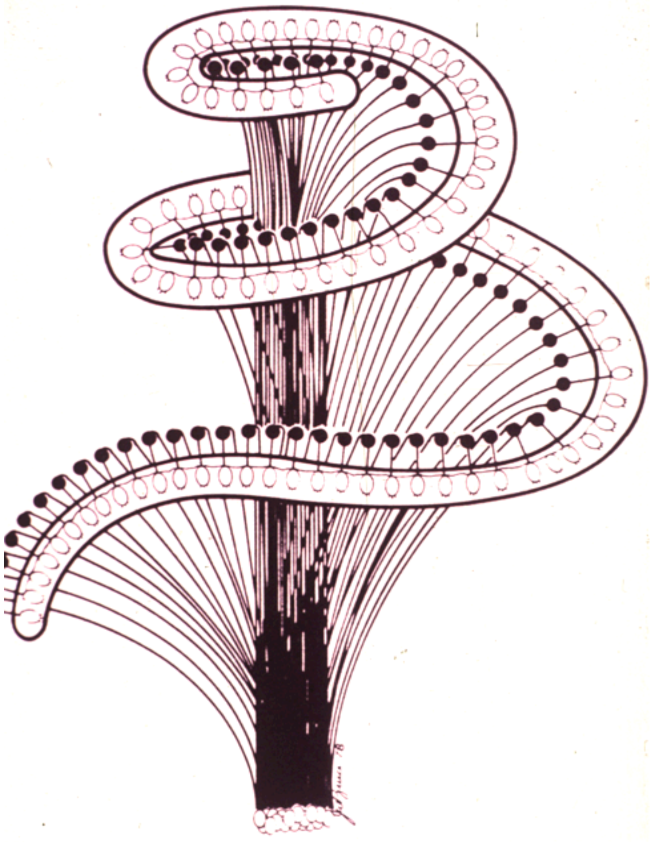
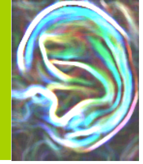


Figure 1. Schematicized pathways for air- and bone-conducted sound.

Pure Tones

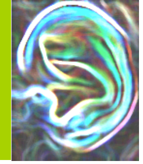
- Auditory acuity
- Spectrally specific
- High frequency tones stimulate basal turn of the cochlea
- Low frequency tones stimulate apical turn of the cochlea



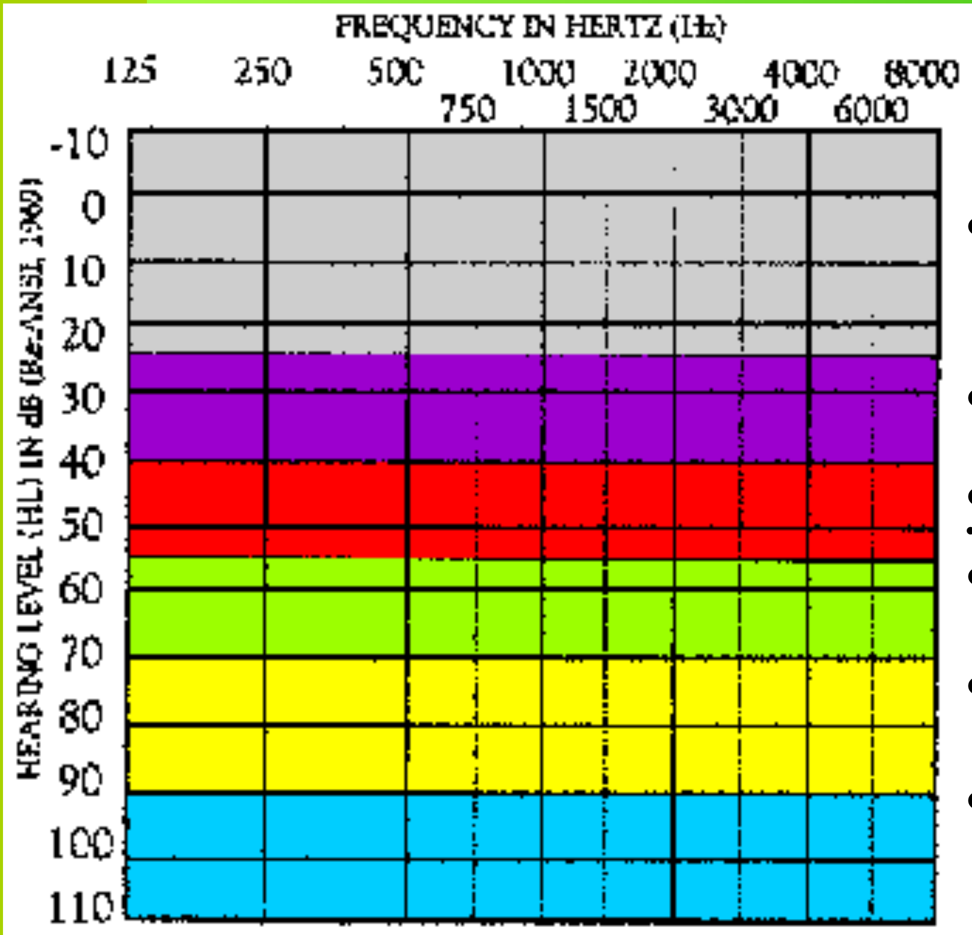


Assessment of thresholds

- Octave frequencies tested
- Bone conduction thresholds
- Mastoid or forehead used
- Mastoid preferred because less intensity required
- Occlusion effect
- Ascending series of tone presentations

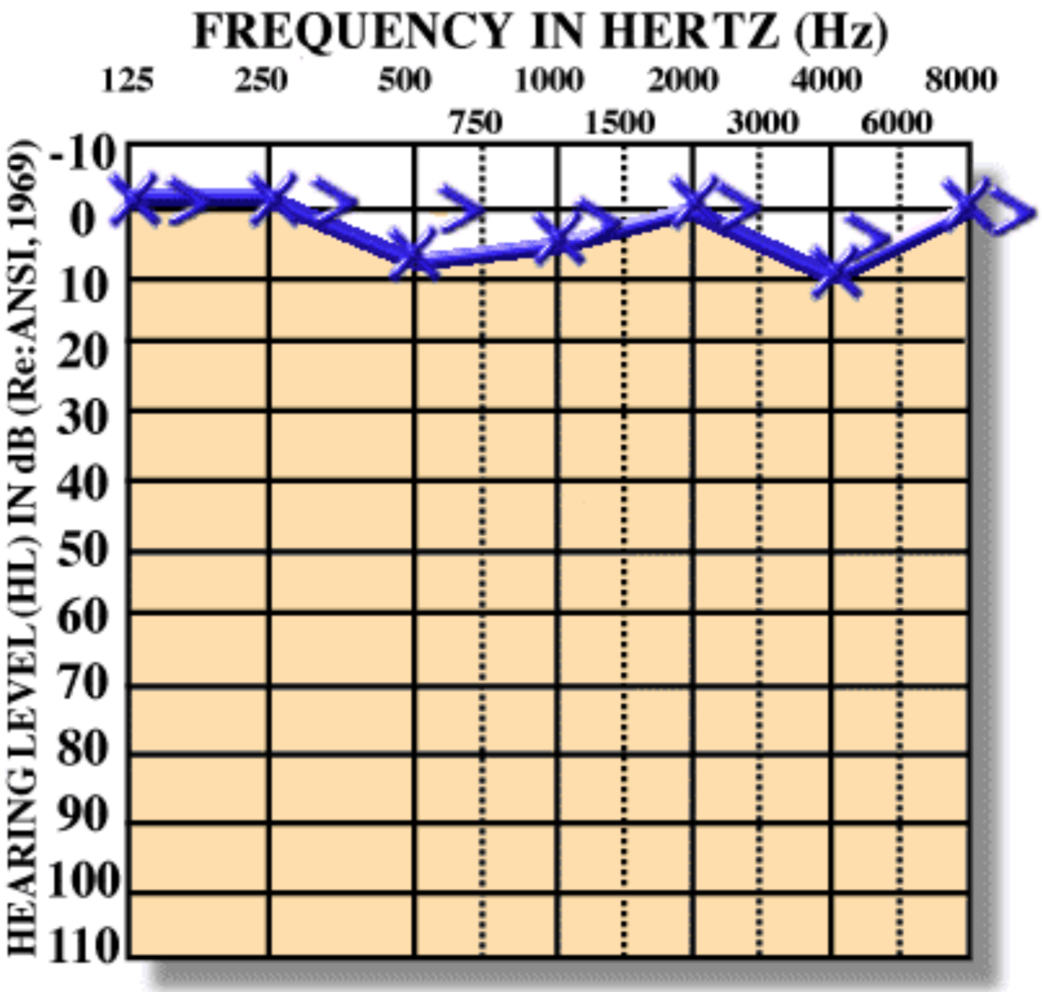


Ranges of Hearing Loss

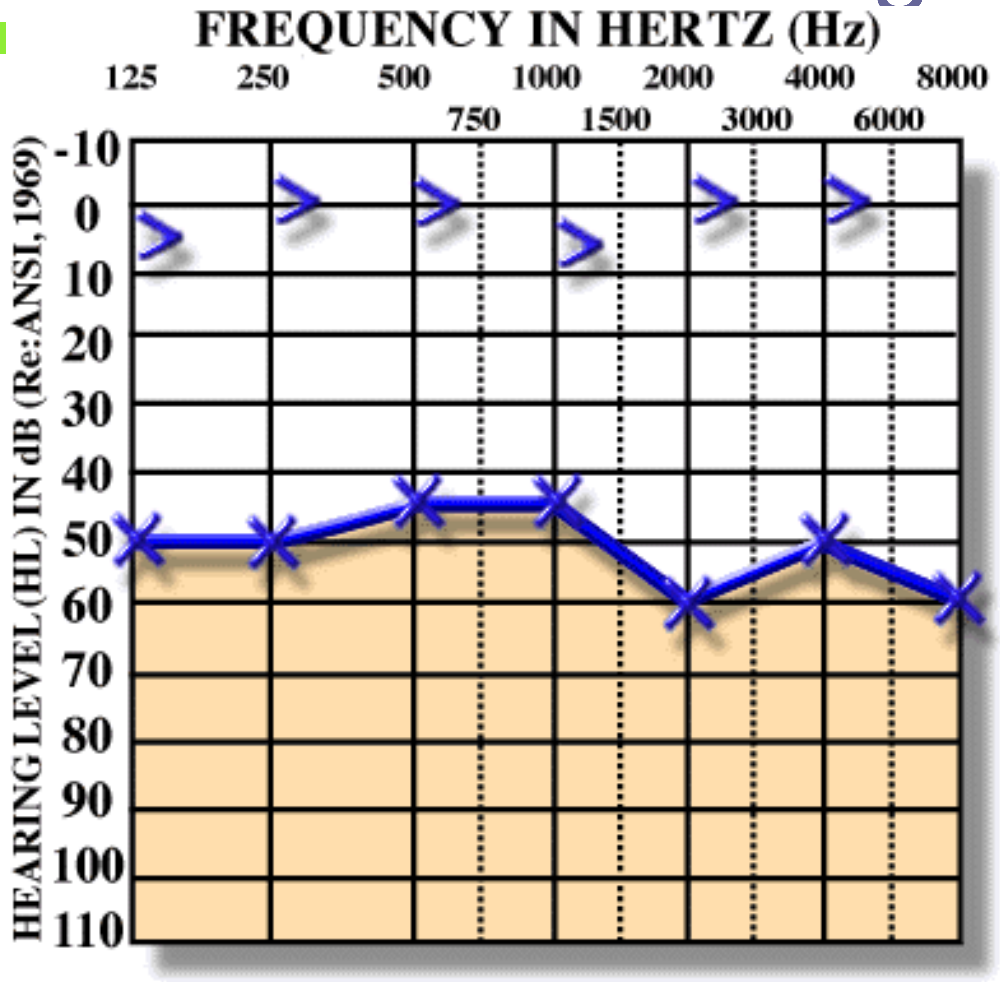


- -10 – 25 dB HL = Normal range
- 26 – 40 dB HL = Mild hearing loss
- 41 – 55 dB HL = Moderate
- 56 – 70 dB HL = Moderately Severe
- 71 – 90 dB HL= Severe
- Greater than 90 dB HL = Profound

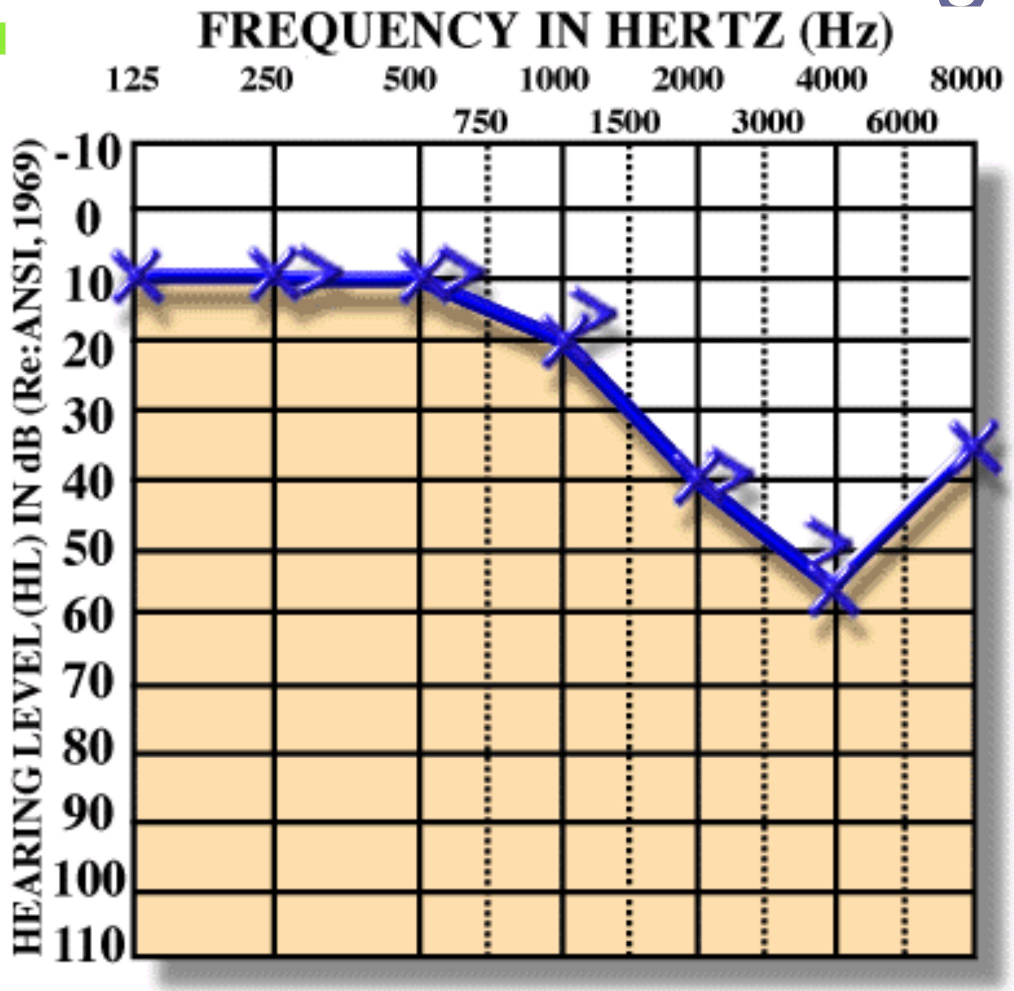
Normal Hearing



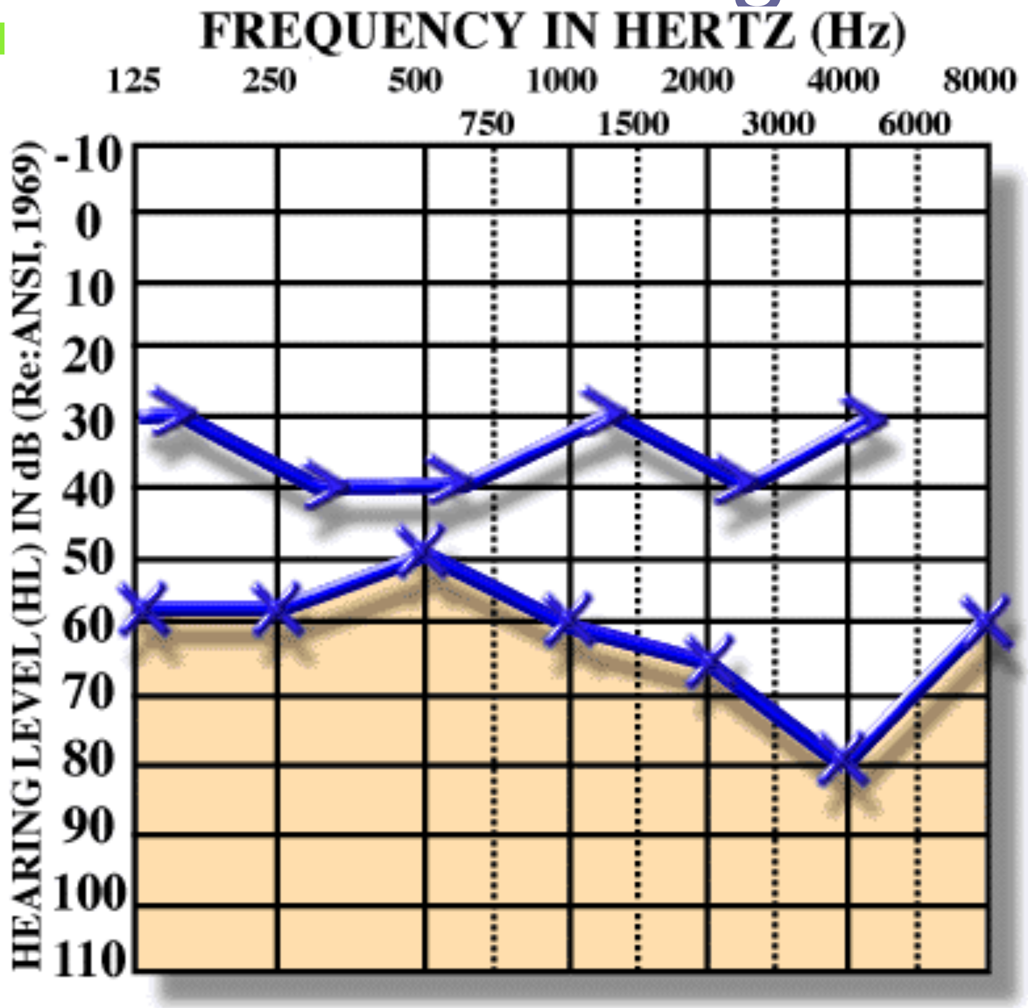
Conductive Hearing Loss



Sensorineural Hearing Loss



Mixed Hearing Loss



Speech Audiometry

- Speech Reception Threshold using spondaic words
- Standardized word lists
- Familiarization with spondees
- Ascending series of presentation
- Excellent speech discrimination in conductive hearing loss patients
- Poor speech discrimination in cochlear hearing loss patients
- Poorest speech discrimination in retrocochlear hearing loss patients

Clinical Masking

- Nontest ear can influence thresholds of test ear
- Shadow curve apparent without masking
- Interaural attenuation varies from 40 to 80 dB with air conduction
- Interaural attenuation is about 0 dB with bone conduction

Shadow Curve

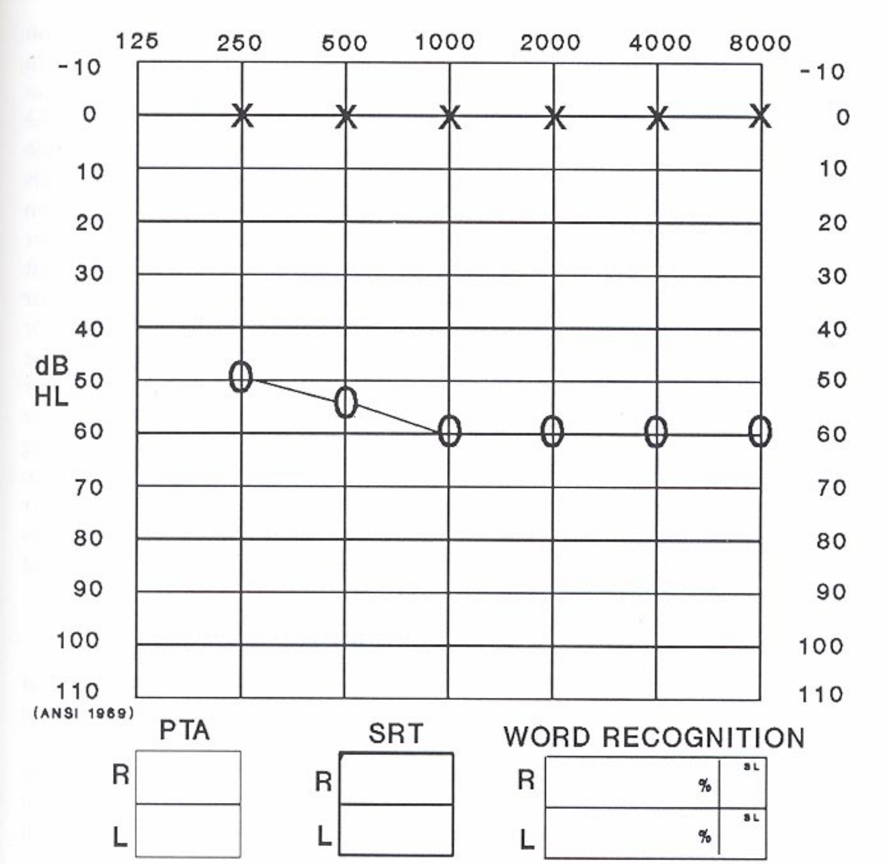


Figure 2. Pure tone audiometric example of air-conduction shadow curve for right ear caused by crossover hearing of test tone in left ear.

Clinical Masking cont.

- Compare bone conduction threshold of nontest ear with air conduction threshold of test ear to determine whether masking is necessary

Plateau method

- Mask nontest ear with progressively greater amounts of sound until threshold does not rise.
- Masking Dilemma

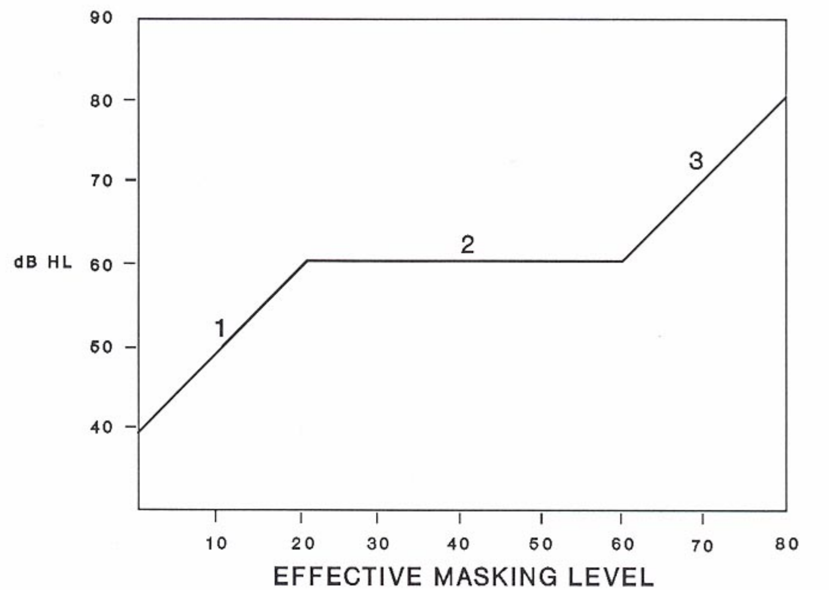
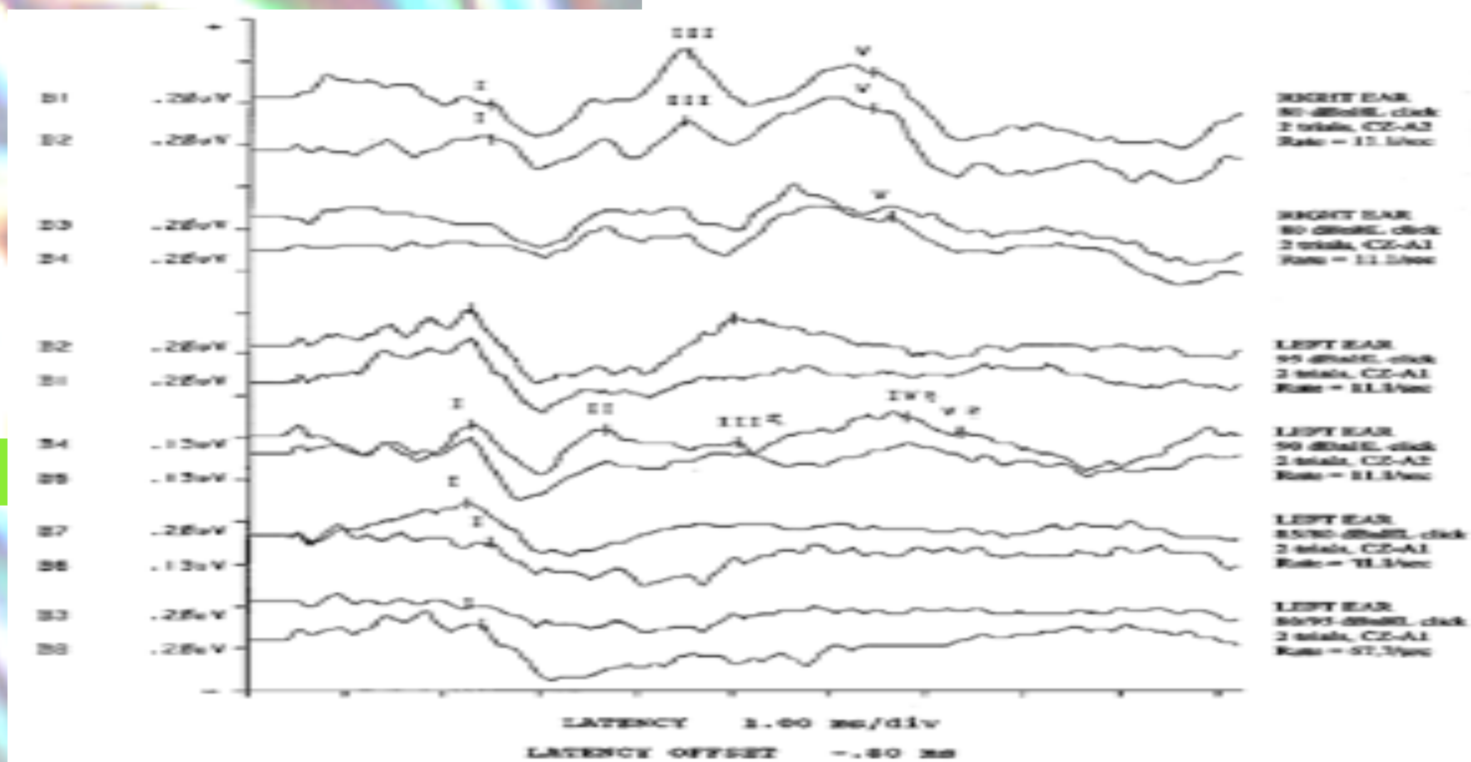
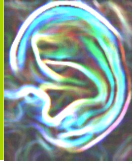


Figure 5. Function illustrating the masking plateau.

Objective Audiological Tests



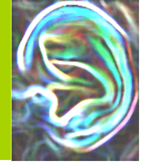


Electrophysiological Tests

- Immittance
- Evoked Potential
- Otoacoustic Emissions

Immittance

- Ear Canal Volume
- Tympanometry
- Static Compliance
- Acoustic Reflex, Decay, & Latency

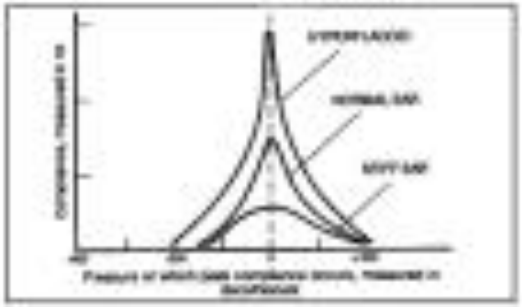


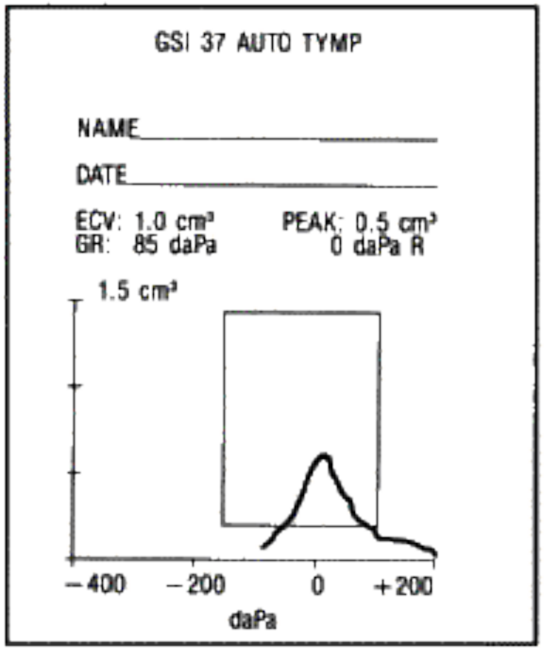
Ear Canal Volume

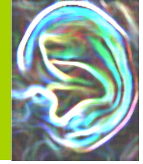
- Measure at +200 mmH20
- Provides measure of volume of external ear canal
- Volumes based on age
- Volumes greater than 2.5 suggest:
  - Perforation or
  - Patent V. tube

Tympanometry

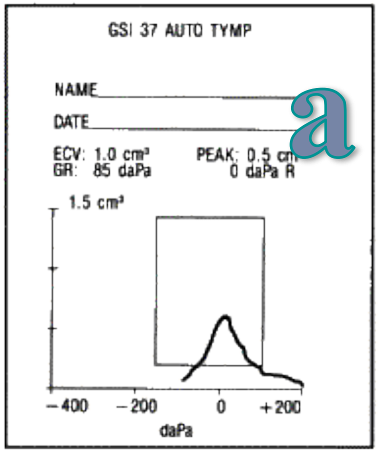
- Objective measure of the function of the TM and middle ear
- 5 or 6 basic shapes

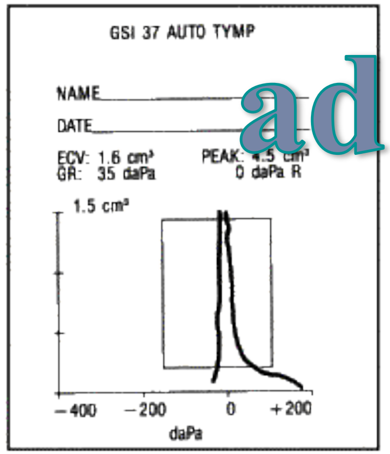


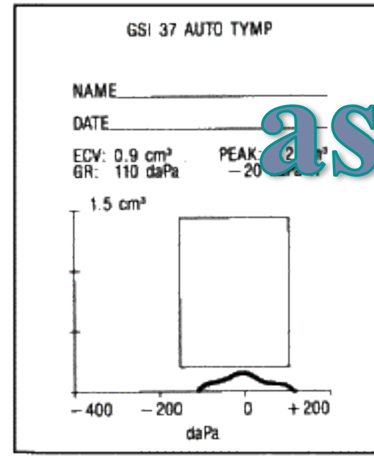


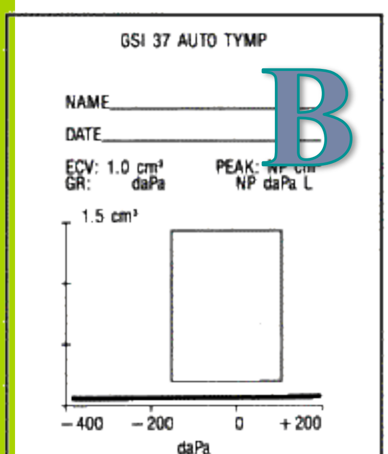


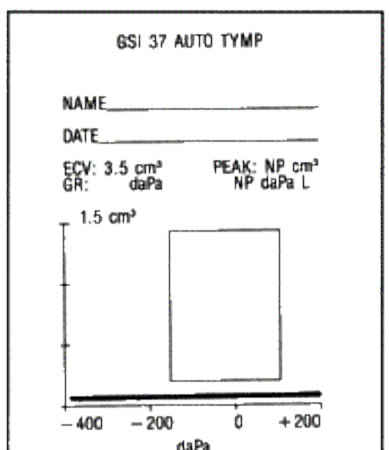
Tympanogram Types

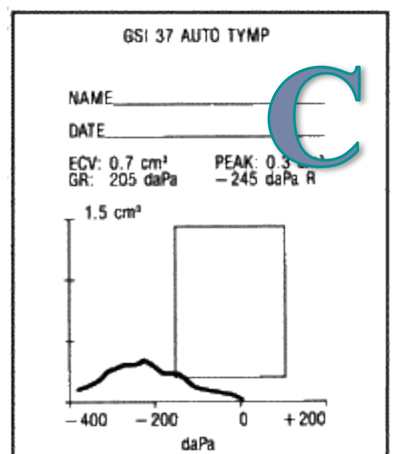


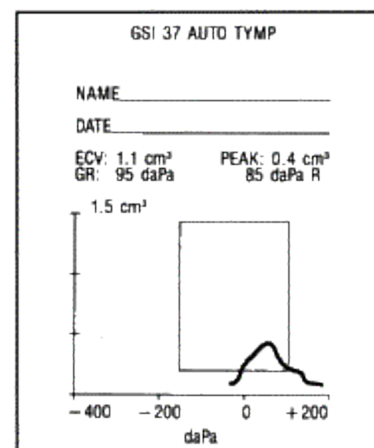








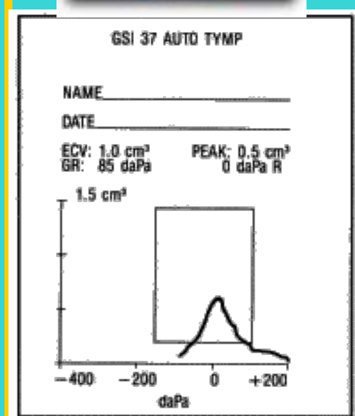




Type A Tympanogram

OE	ME	IE	AN	CNS

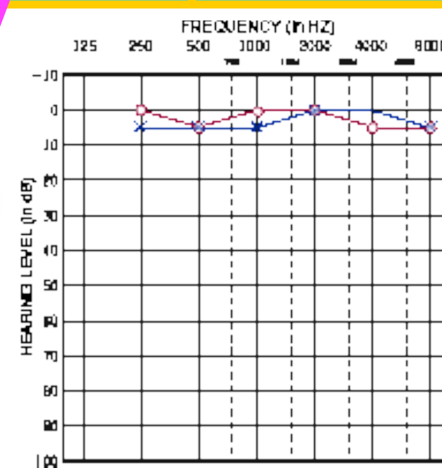
AC

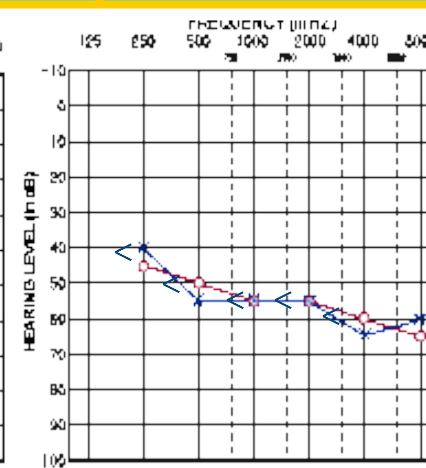


BC

A

Normal or SN

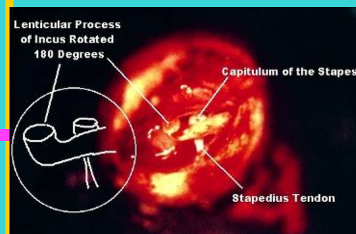


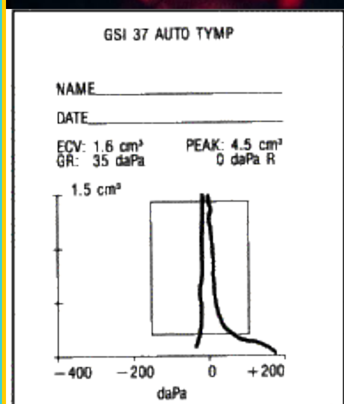


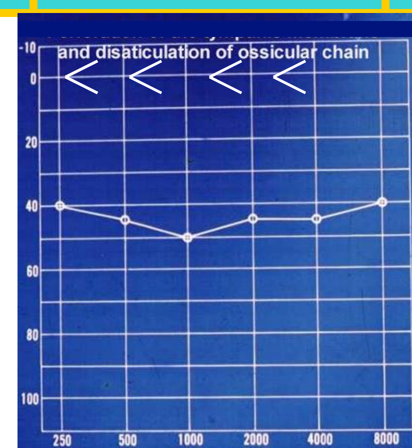
Type AD Tympanogram

OE	ME	IE	AN	CNS

AC







AD

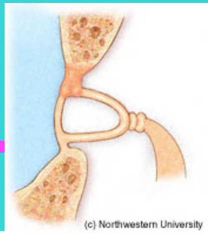
BC

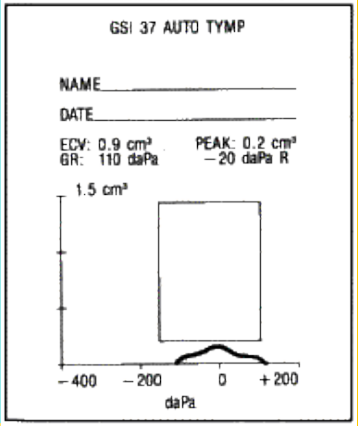
Disarticulation

Type As Tympanogram

OE	ME	IE	AN	CNS

AC



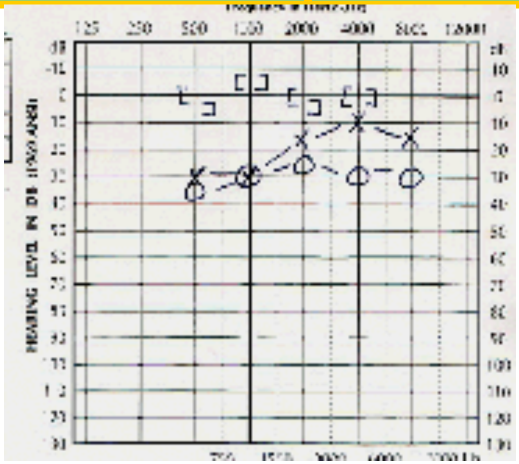

GSI 37 AUTO TYMP

NAME

DATE

ECV: 0.9 cm³ GR: 110 daPa

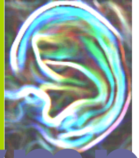
PEAK: 0.2 cm³ −20 daPa R



BC

As

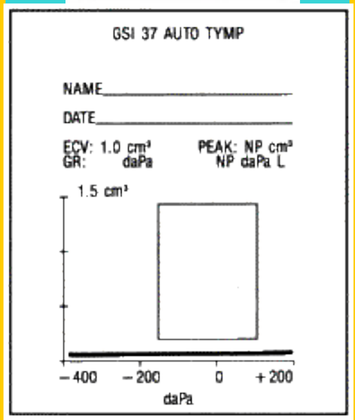
Otosclerosis



Type BLow Tympanogram

OE	ME	IE	AN	CNS

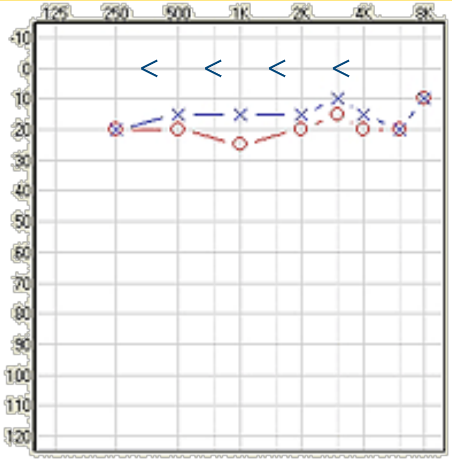
AC



BC

BLow

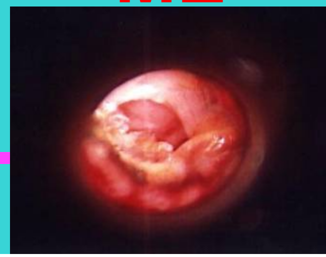
OME

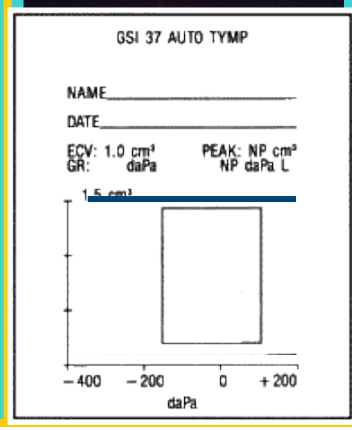


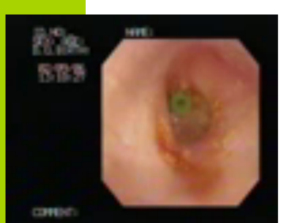
Type BHi Tympanogram

OE	ME	IE	AN	CNS

AC



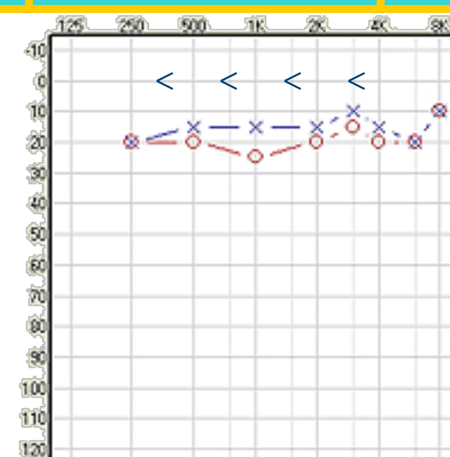




BHi

Perforation

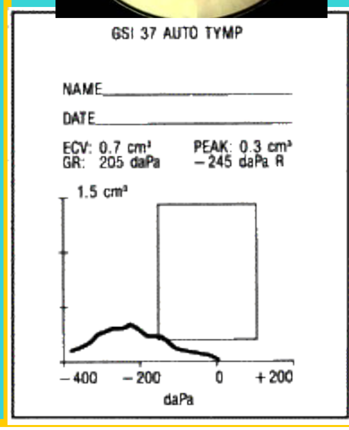
BC



Type C Tympanogram

OE	ME	IE	AN	CNS

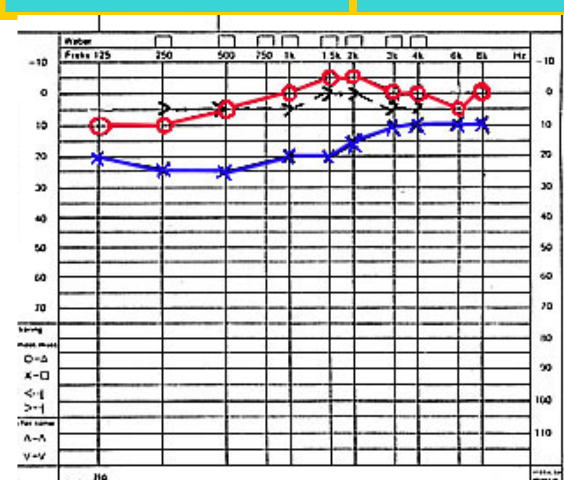
AC



C

BC

Eustachian Tube Dysfunction



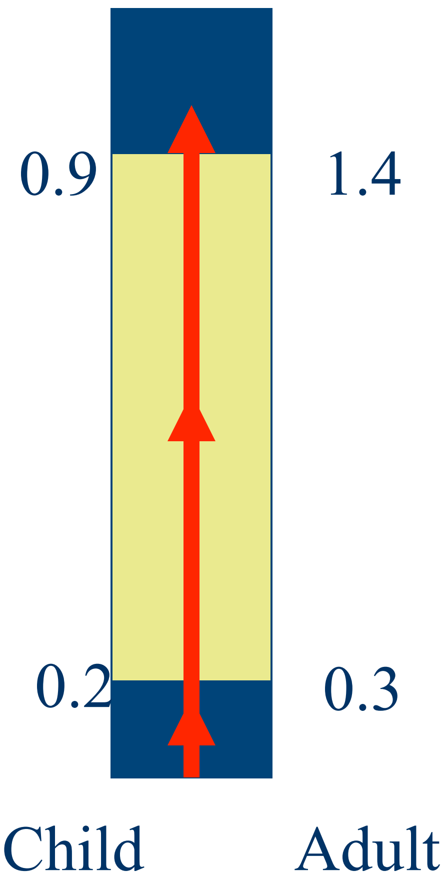
Static Compliance (Peak Compliance)

Acceptable Range by Age

	Peak Compliance (mmho or cc)	Ear Canal Volume (cc)
Mean	0.5	0.7
90% range	0.2 to 0.9	0.4 to 1.0

Adults

	Peak Compliance (mmho or cc)	Ear Canal Volume (cc)
Mean	0.8	1.1
90% range	0.3 to 1.4	0.6 to 1.5

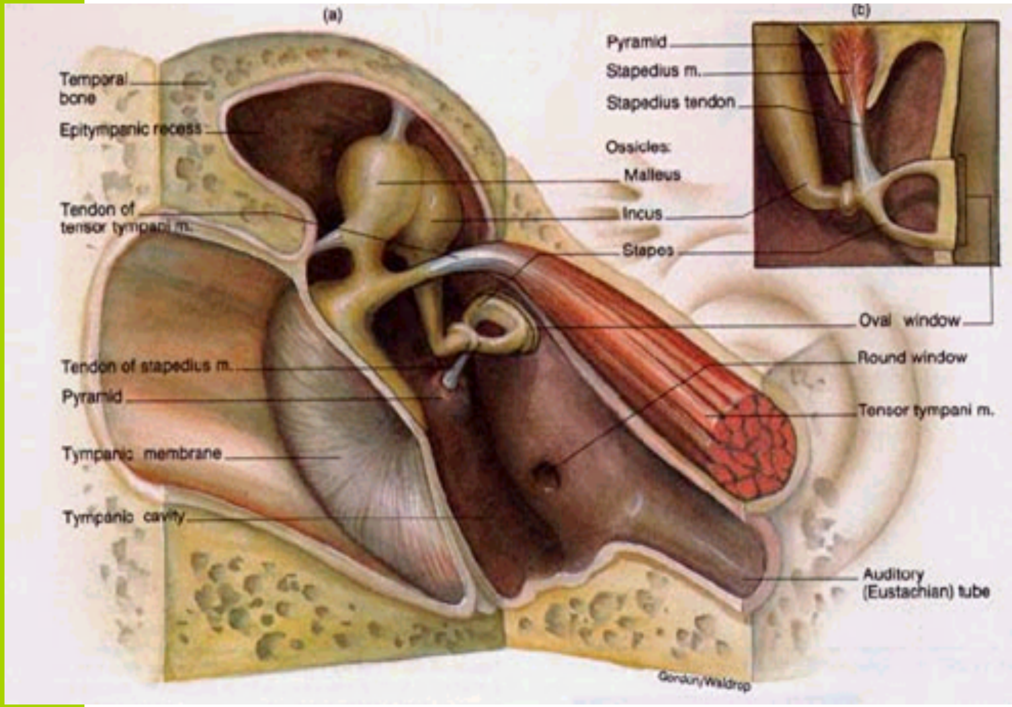


Flaccid: disarticulation, flaccid TM, etc.

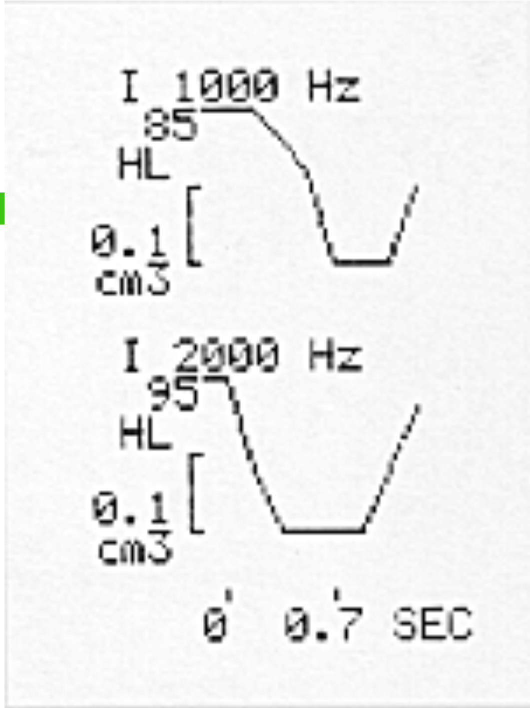
Normal mobility

Stiff: otosclerosis fluid, tympanosclerosis, etc.

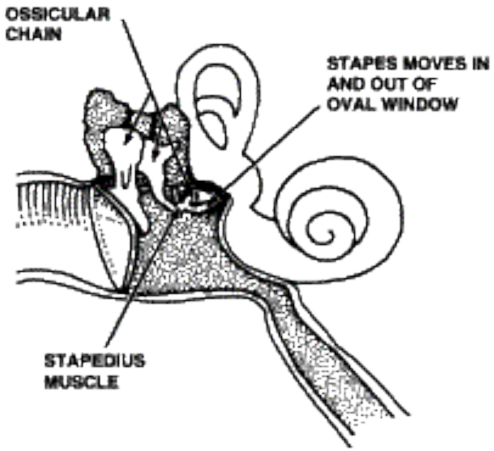
ART



(a)
(b)
Temporal bone
Epitympanic recess
Tendon of tensor tympani m.
Tendon of stapedius m.
Pyramid
Tympanic membrane
Tympanic cavity
Pyramid
Stapedius m.
Stapedius tendon
Ossicles:
Malleus
Incus
Stapes
Oval window
Round window
Tensor tympani m.
Auditory (Eustachian) tube



I 1000 Hz
85
HL
0.1
cm3
I 2000 Hz
95
HL
0.1
cm3
0 0.7 SEC



OSSICULAR CHAIN
STAPES MOVES IN AND OUT OF OVAL WINDOW
STAPEDIUS MUSCLE

Acoustic Reflex Threshold

- Stapedial muscle contraction
- Temporary increase in middle impedance
- Bilateral Stimulation
- Adaptation
- Neural network in lower brainstem

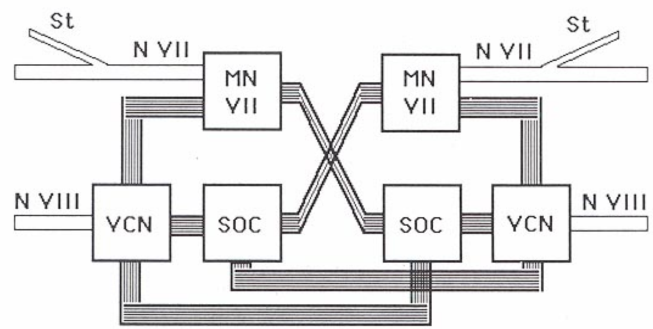
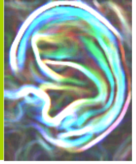


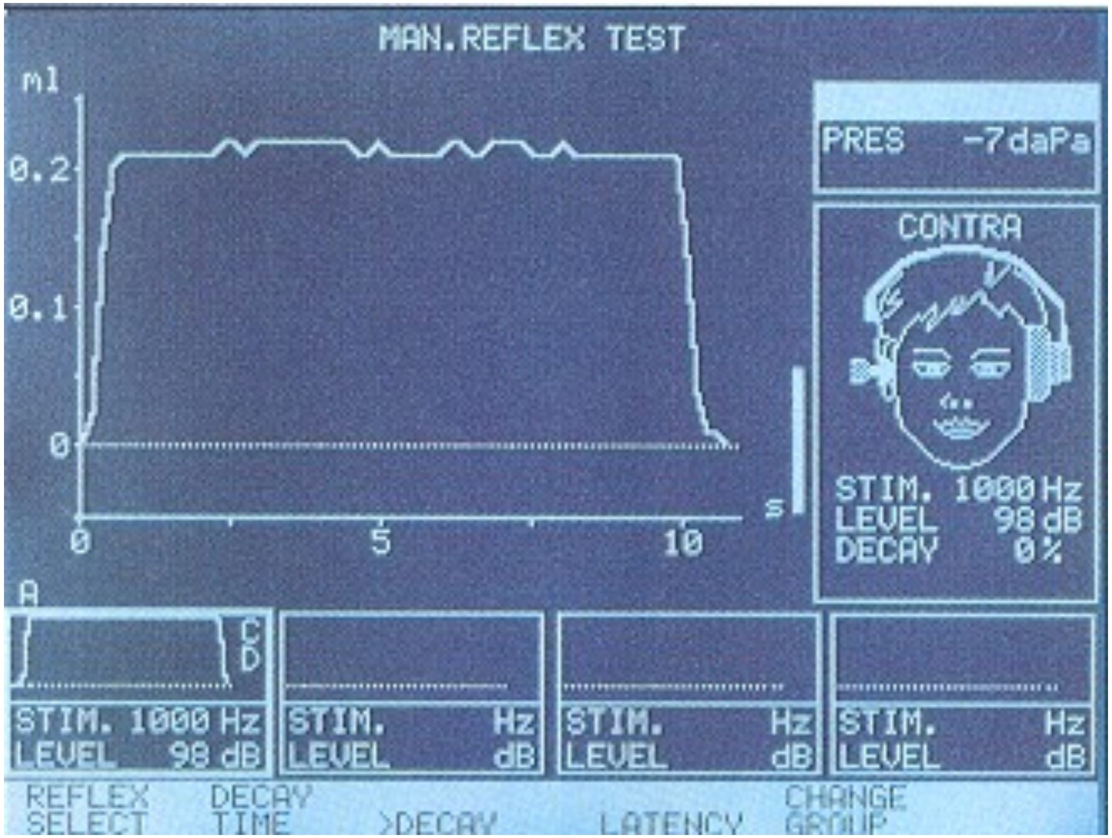
Figure 1. Acoustic-stapedius reflex (ASR) pathways. The afferent input to the ASR arc is the eighth cranial (auditory) nerve (N VIII). The central projections of N VIII synapse with dendrites in the ventral cochlear nucleus (VCN). The VCN sends projections to the ipsilateral and contralateral superior olivary complex (SOC) and to a region near the ipsilateral medial nucleus of the seventh cranial (facial) nerve (MN VII). The motoneurons of the stapedius muscle originate near MN VII and project via N VII to the stapedial nerve (St), which innervates the stapedius muscle in its bony canal in the posterior wall of the middle ear.



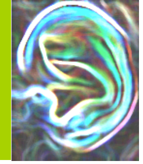
Clinical application of ASR

- Middle Ear Disease
- Otosclerosis
- Cochlear hearing loss and loudness recruitment
- Retrocochlear lesions may abolish the ASR
- Brainstem lesions may abolish the contralateral reflexes
- Determination of site of a seventh nerve lesion
- Acoustic Reflex Decay

Reflex Decay



otoacoustic emissions

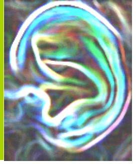


Background

The presence of cochlear emissions was hypothesized in the 1940's on the basis of mathematical models of cochlear nonlinearity.

However, OAEs could not be measured until the late 1970s, when technology created the extremely sensitive low-noise microphones needed to record these responses.

David Kemp first discovered Otoacoustic emissions in 1978.

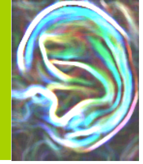


Otoacoustic Emissions

- Otoacoustic emissions are sounds that are produced by healthy ears in response to acoustic stimulation.
- OAE's arise because our ears have evolved a special mechanism to give us extra hearing sensitivity and frequency responsiveness. The mechanism is known as the cochlear amplifier and it depends on a specialized type of cell called "outer hair cells."
- It's the job of the cochlea to receive the sound energy collected by the outer and middle ear and to prepare it for neural transmission.

Purpose of OAE's

- The primary purpose of otoacoustic emission (OAE) tests is to determine cochlear status, specifically hair cell function. This information can be used to
- (1) screen hearing
- (2) partially estimate hearing sensitivity within a limited range
- (3) differentiate between the sensory and neural components of sensorineural hearing loss
- (4) test for functional hearing loss.

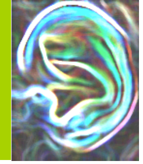


Types of OAE’s

- Types
  - Spontaneous OAE’s (SPOAE’s)
  - Distortion Product OAE’s (DPOAE’s)
  - Transient Evoked OAE’s (TEOAE’s)

Spontaneous OAE's

- Occurs in the absence of any intentional stimulation of the ear.
- Prevalence is in about 40-60% of normal hearing people.
- When you record SOAE's, you average the number of samples of sounds in the ear and perform a spectral analysis.
- The presence of SOAE's is usually considered to be a sign of cochlear health, but the absence of SOAE's is not necessarily a sign of abnormality.



Distortion Product OAE's

- Result from the interaction of two simultaneously presented pure tones.
- Stimuli consist of 2 pure tones at 2 frequencies (ie, f1, f2 [f2>f1]) and 2 intensity levels (ie, L1, L2). The relationship between L1-L2 and f1-f2 dictates the frequency response.
- DPOAEs allow for a greater frequency specificity and can be used to record at higher frequencies than TOAE's. Therefore, DPOAE's may be useful for early detection of cochlear damage as they are for ototoxicity and noise-induced damage.
- DPOAEs often can be recorded in individuals with mild-to-moderate

  hearing losses for whom TOAE's are absent.

  *DPOAE's do not occur in the frequency

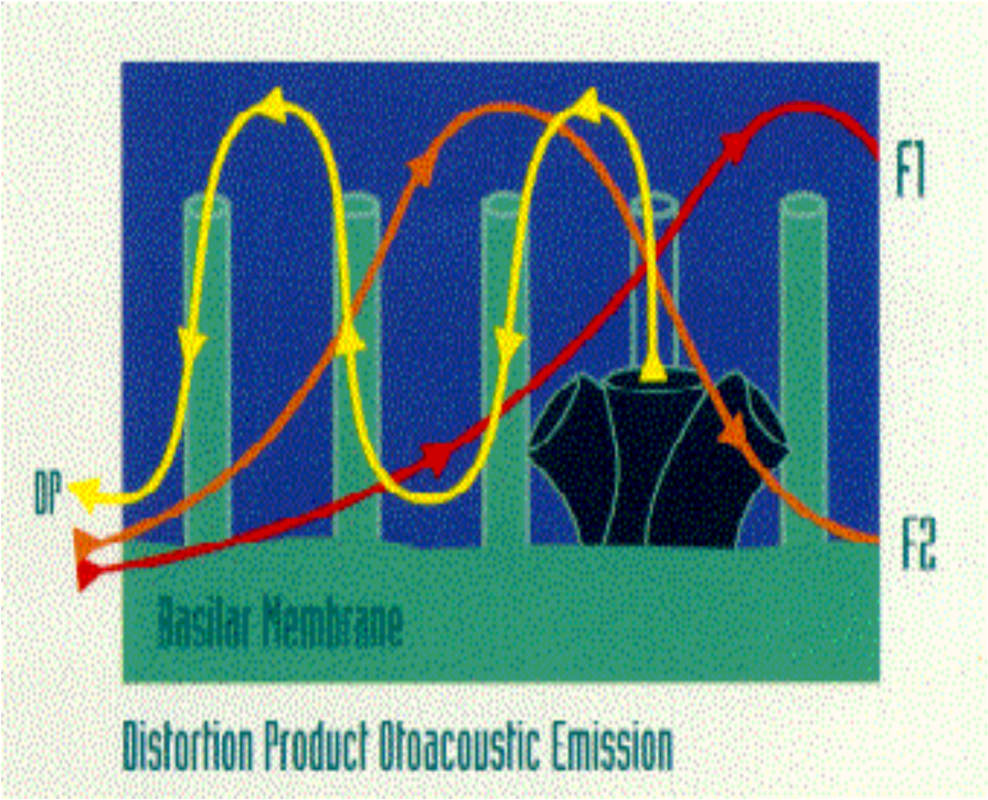
  regions with more than 50-55dB Hearing loss.

  * DPOAE's can be elicited from ears that

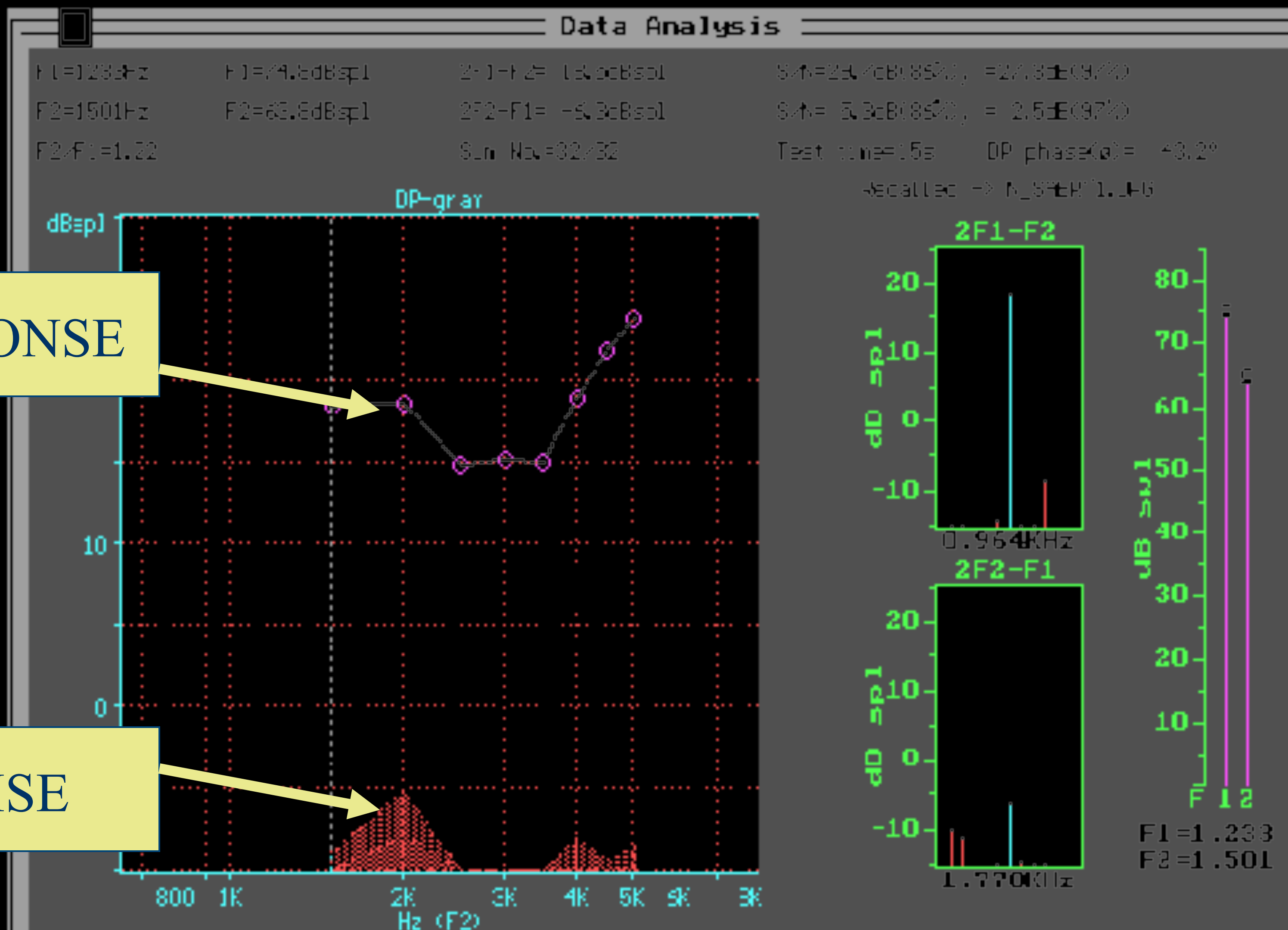
  have a greater hearing loss than TEOAE's.

DPOAEs

- 2 tone stimuli (F1 and F2)
- Cochlea hair cells generate a resonance

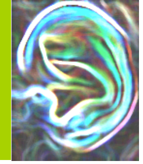


DPOAE data from a normal subject: High level protocol 75 -65



RESPONSE

NOISE



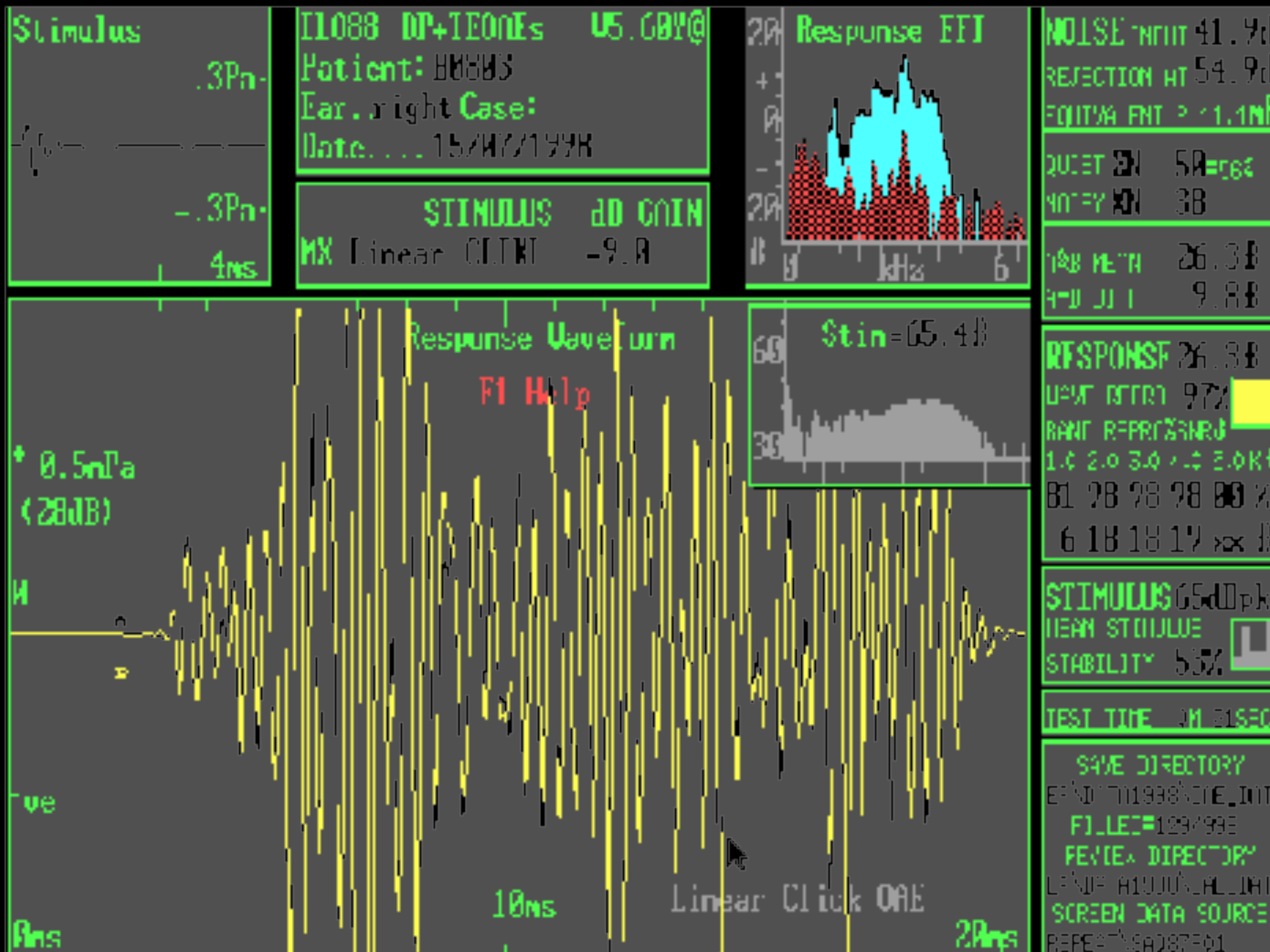
Transient Evoked OAE

- TEOAE's are frequency responses that follow
  a brief acoustic stimulus, such as a click or tone burst.
- The evoked response from this type of stimulus covers the frequency range up to around 4 kHz.
- In normal adult ears, the click-elicited TEOAE typically falls off for frequencies more than 2 kHz, and is rarely present over 4 kHz, because of both technical limitations in the ear-speaker at higher frequencies and the physical features of adult ear canals so that is why DPOAE's would be more efficacious.
- For newborns and older infants, the TEOAE is much more robust by about 10 dB and typically can be measured out to about 6 kHz indicating that smaller ear canals influence the acoustic characteristics of standard click stimuli much differently than do adult ears.
- TEOAE's do not occur in people with a hearing loss greater than 30dB.

TEOAEs

Stimulus

TEOAE response

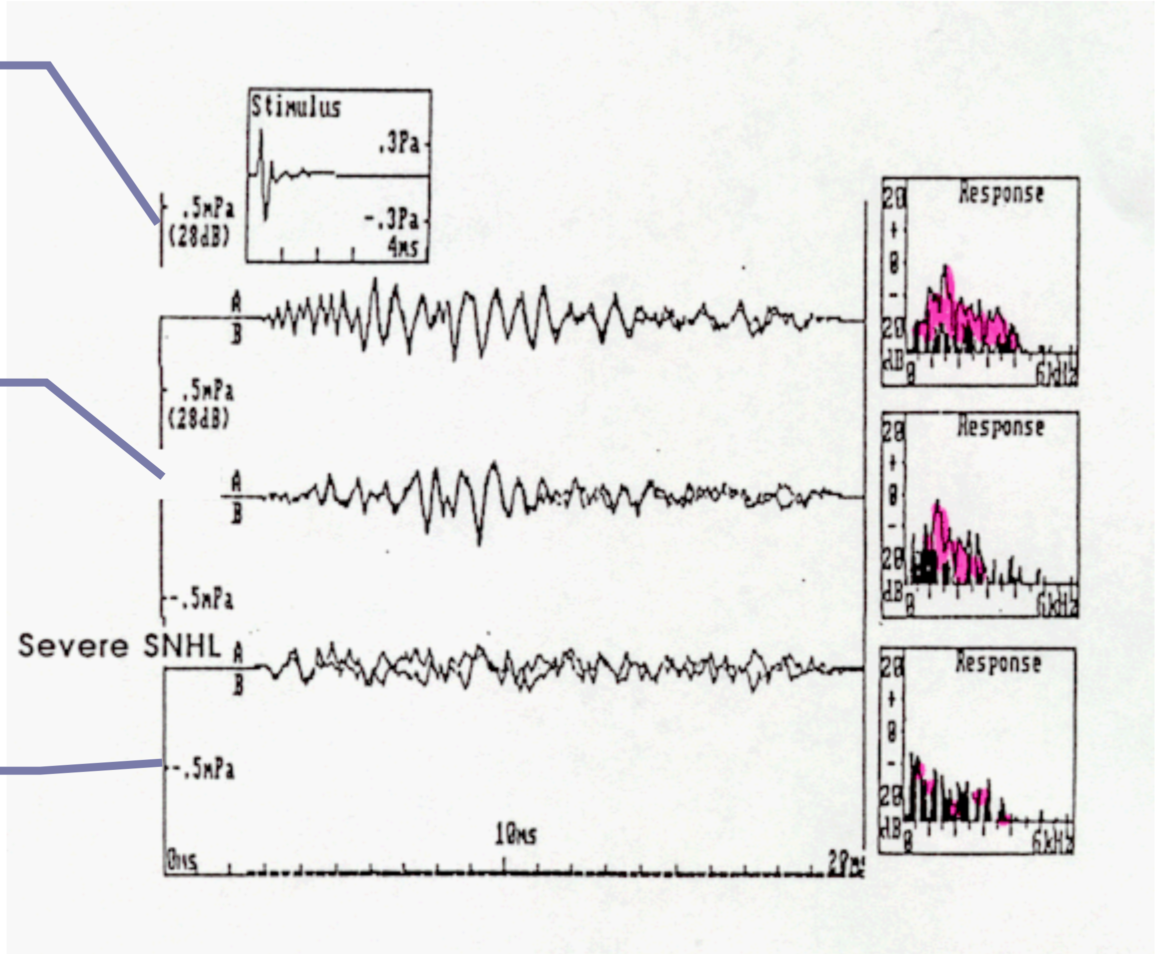


TEOAE results

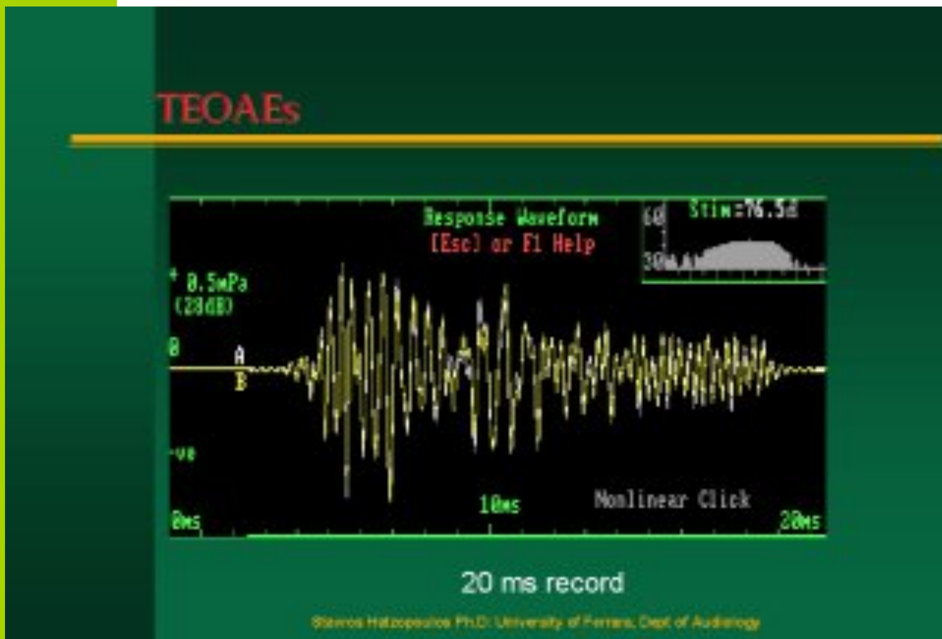
Normal hearing

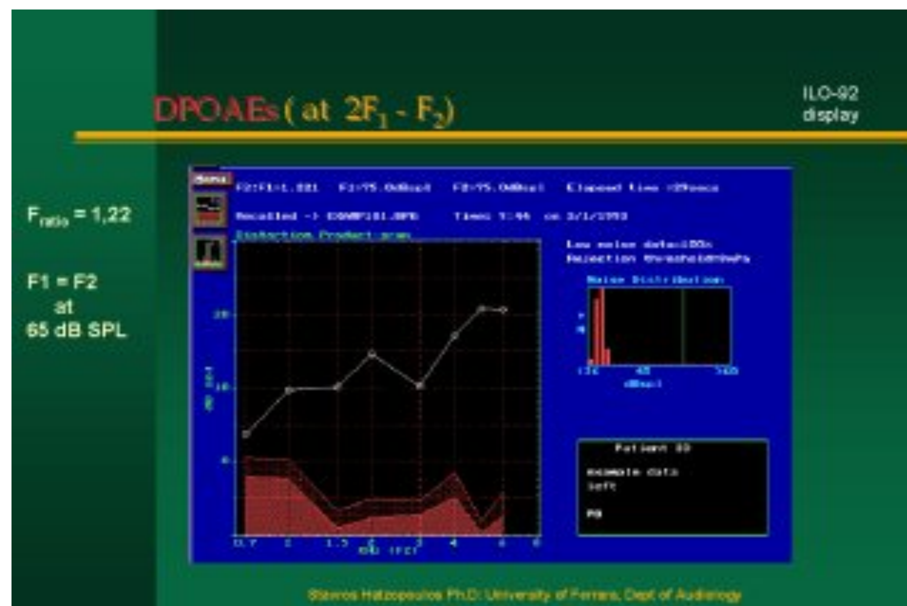
High frequency HL

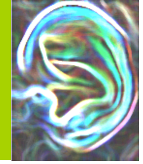
Severe SN HL



TEOAE & DPOAE


TEOAEs
Response Waveform
[Esc] or F1 Help
0.5mPa
(28dB)
A
B
10ms
Nonlinear Click
0ms
20ms
20 ms record
Stavros Hatzopoulos Ph.D: University of Ferrara, Dept of Audiology

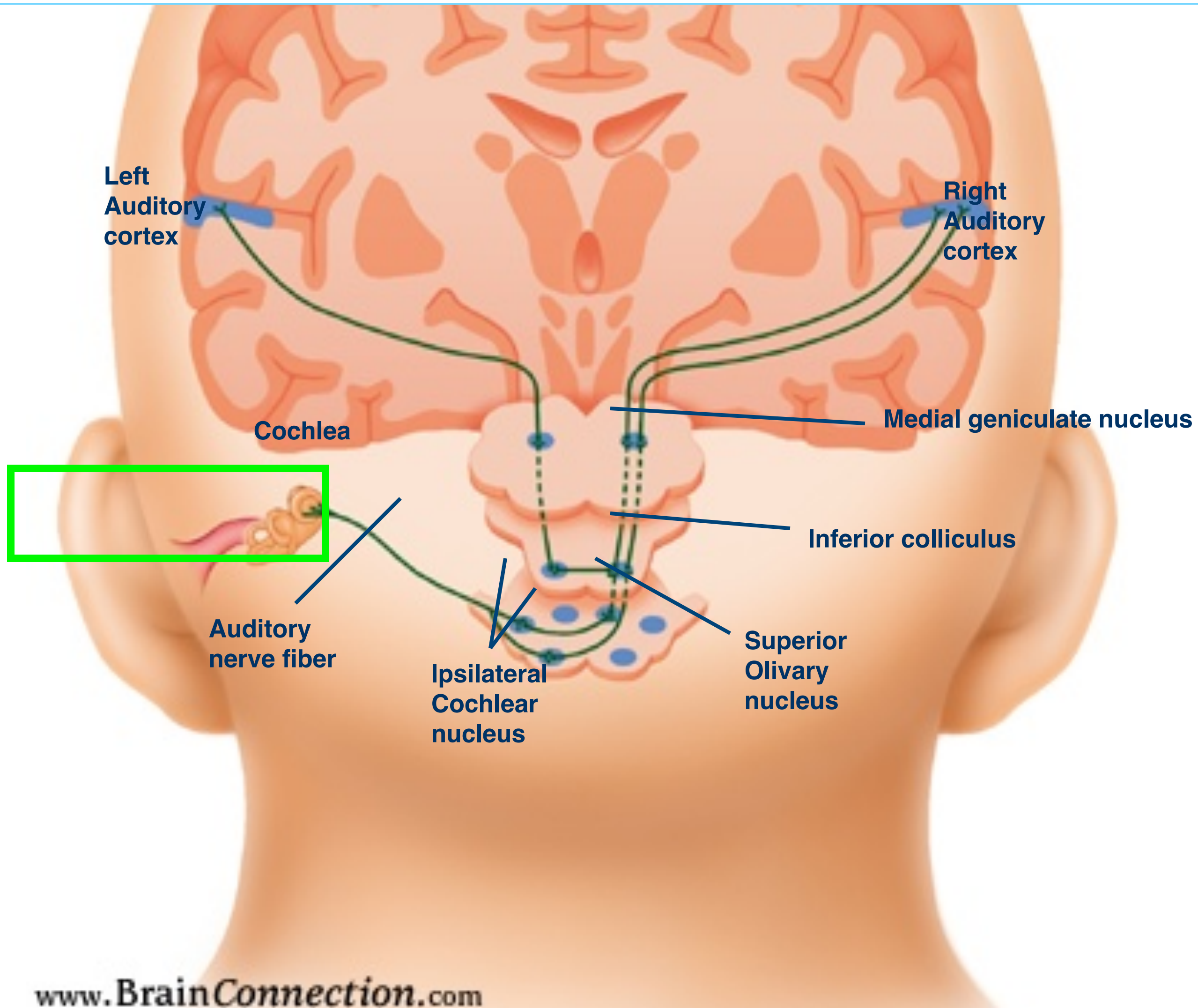

DPOAEs (at 2F1 - F2)
ILO-92
display
Fratio = 1,22
F1 = F2
at
65 dB SPL
Stavros Hatzopoulos Ph.D: University of Ferrara, Dept of Audiology



Recording OAE’s

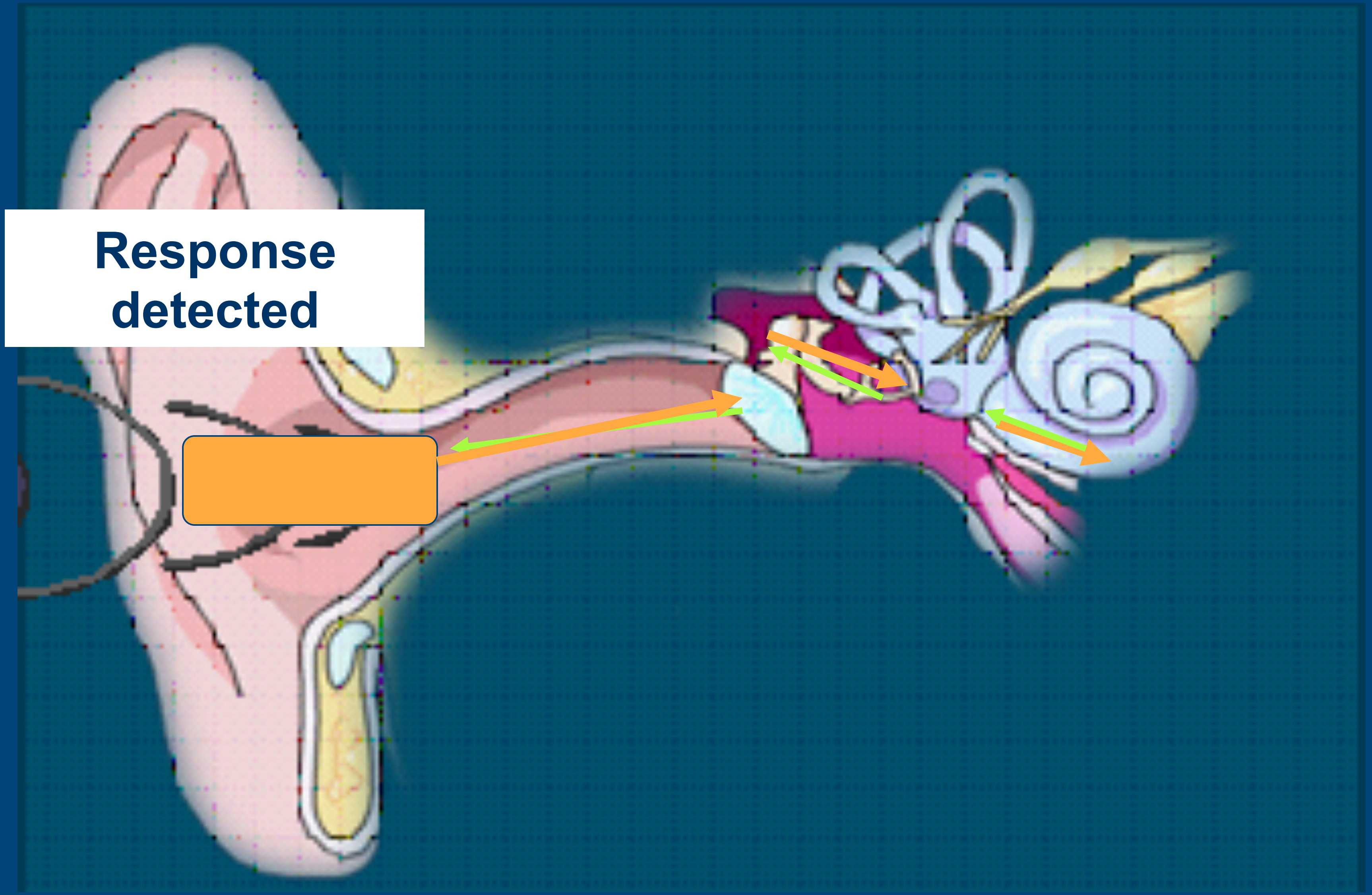
- OAEs are measured by presenting a series of very brief acoustic stimuli, clicks, to the ear through a probe that is inserted in the outer third of the ear canal. The probe contains a loudspeaker that generates clicks and a microphone that measures the resulting OAE’s that are produced in the cochlea and are then reflected back through the middle ear into the outer ear canal.
- The resulting sound that is picked up by the microphone is digitized and processed by specially designed hardware and software. The very low-level OAEs are separated by the software from both the background noise and from the contamination of the evoking clicks.

anatomy



Left Auditory cortex
Right Auditory cortex
Medial geniculate nucleus
Cochlea
Inferior colliculus
Auditory nerve fiber
Ipsilateral Cochlear nucleus
Superior Olivary nucleus
www.BrainConnection.com

SOUND IN EAR CANAL → TRAVEL THRU ME → FWD COCHLEA → BWD COCHLEA → TRAVEL THRU ME → SOUND IN EAR CANAL



OAEs

- Otoacoustic emissions
- “Echo”-like response of outer hair cells of the cochlea
- Can only indicate functioning outer hair cells and good middle ear function.

Types of OAEs

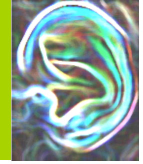
- Spontaneous
  - 20-60% of population, related to age
  - Not clinically useful
  - Not related to tinnitus
- Evoked
  - Present in normal ears
  - Not present in ears with SNHL greater than 25-30 dB
  - Absent in presence of conductive hearing loss. WHY?

Evoked OAEs

- Types
  - Click (transient) evoked OAE-TEOAE
    - Absent for sensori neural loss greater than 20-30dB HL
  - Distortion product OAE (DPOAE)
    - Absent in sensori neural losses greater than 45-55 dB HL

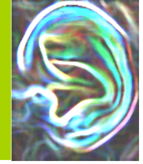
Acquisition

- Not affected by sleep but needs test subject to be still and compliant
- Very quick



clinical applications

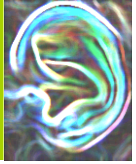
- Quick screening tool
- Good indicator of cochlear reserve- correlated with hearing
- Monitoring
- TEOAE present with hearing loss up to 30dBHL
- DPOAE present with hearing loss up to 50dB HL
- Monitoring of drug ototoxicity (can affect OAE before HL present)
- Sensory vs. neural HL



clinical limitations

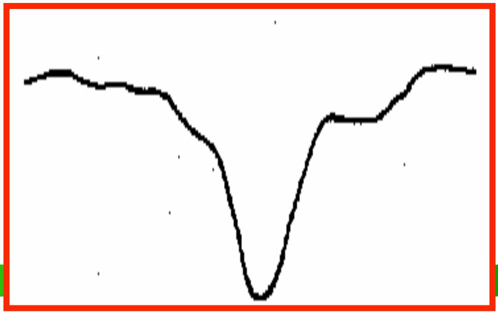
- Problems because of middle ear disease
- Not sensitive for neonates within 24 hours of birth
- Results affected by test conditions
  - Noise
  - Electrical interference
- Not a test of hearing- limited application

electrocochleography



history

- Little confusion in the literature, apart from what letters of the original appear in the abbreviation
- Animal models first discovered in 1930s
- Clinical applications started in 1960s

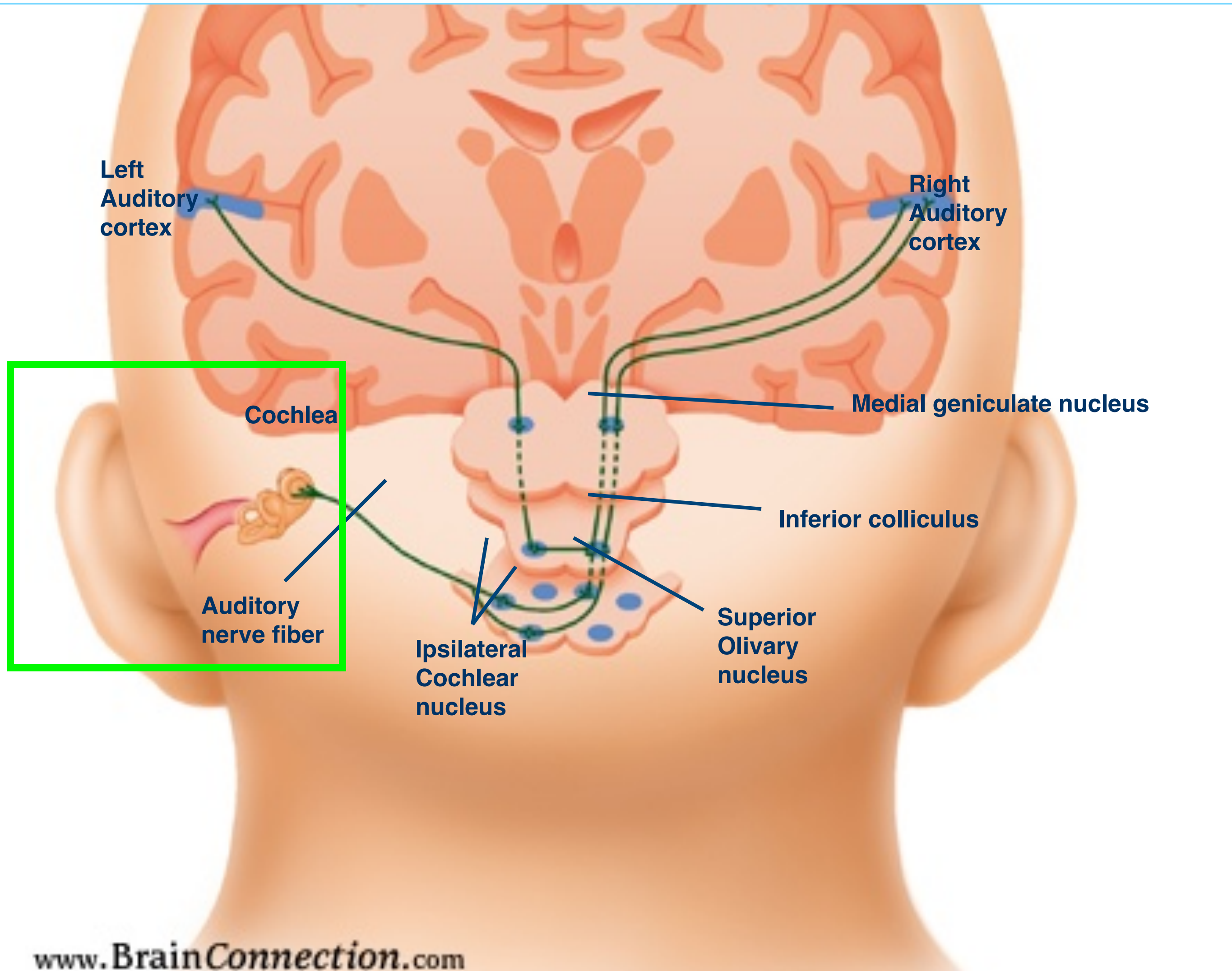


components

- Cochlear microphonic: outer hair cell response
- Summating potential: cochlear activity
- Action potential: Firing of auditory nerve (same as ABR wave 1)

- All occur within the first 1.5-2 ms after an acoustic stimulus

anatomy



Left Auditory cortex
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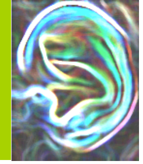
www.BrainConnection.com

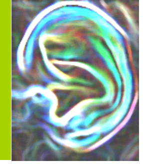


stimulus & acquisition

- Recording electrode must be as close to response as possible (transtympanic)
- Children: general anaesthetic
- Adults: may be done without anaesthetic
- resistant to effects of drugs and subject state of arousal
- Can be used in pre-implant assessment to test cochlear function

clinical applications

- Diagnosis of Meniere’s disease
- Diagnosis of cochlear hearing loss/auditory dysynchrony, sensory vs neural.
- Assessment of hearing status for difficult to test subjects



clinical limitations

- Auditory information only provided to cochlea
- Very invasive
- Results can vary up to 20dB from actual hearing
- Limited frequency specificity
- expensive

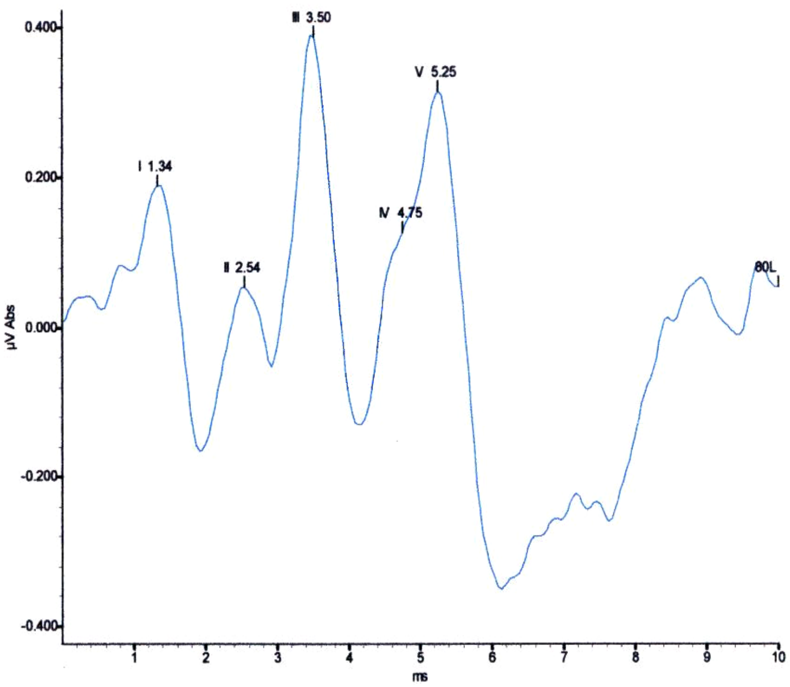
auditory brainstem response

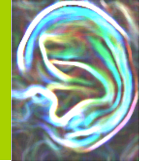
history

- First complete description in 1970s
- Response found between 1-15ms after stimulation.
- Recording has 7 peaks, peak five being the most prominent.
  - The amplitudes, latencies and relationship of those peaks can be used to diagnose certain pathological conditions.

What is an ABR?

- The Auditory Brainstem Response is the representation of electrical activity generated by the eighth cranial nerve and brainstem in response to auditory stimulation

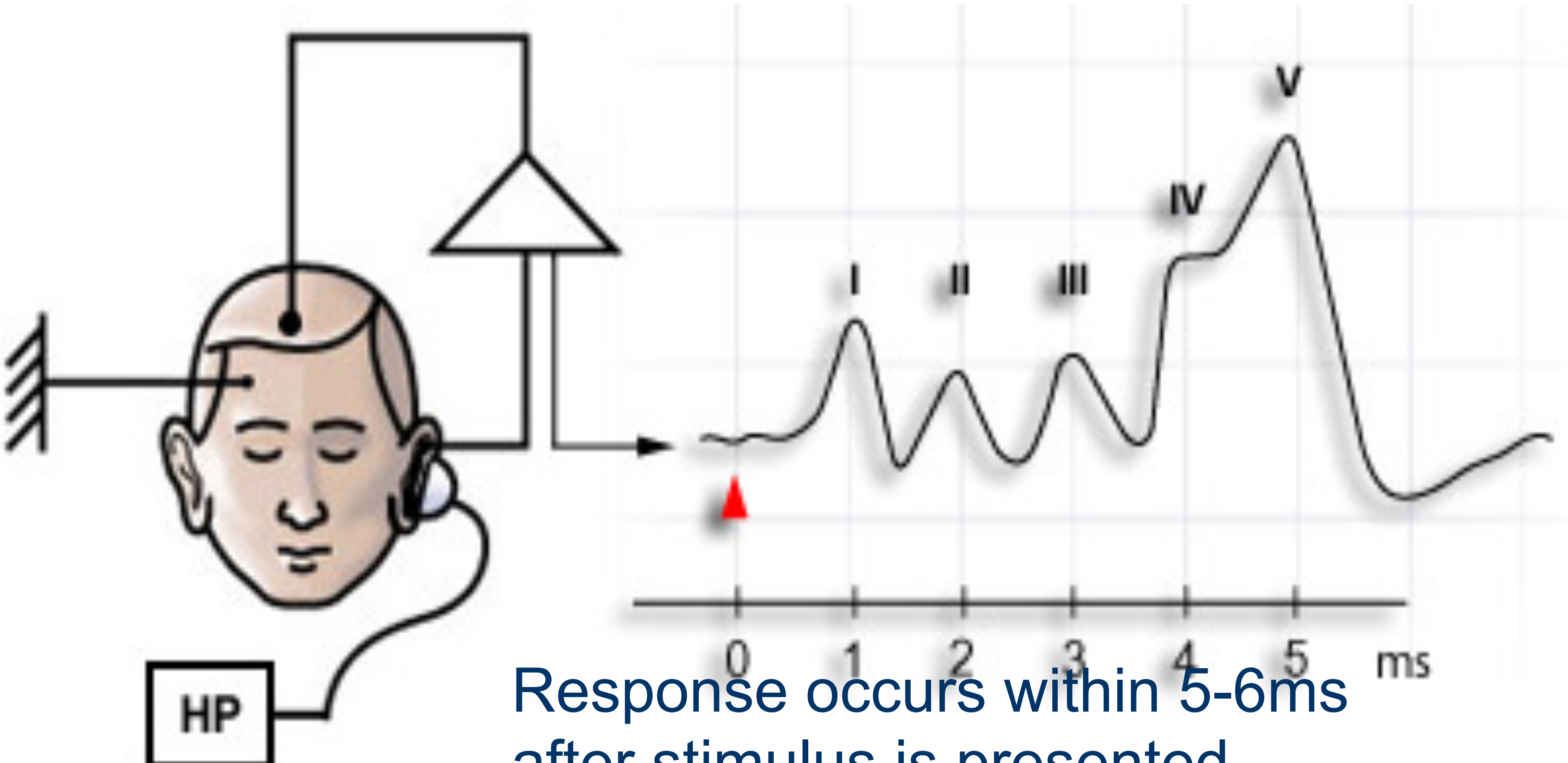




How is an ABR recorded?

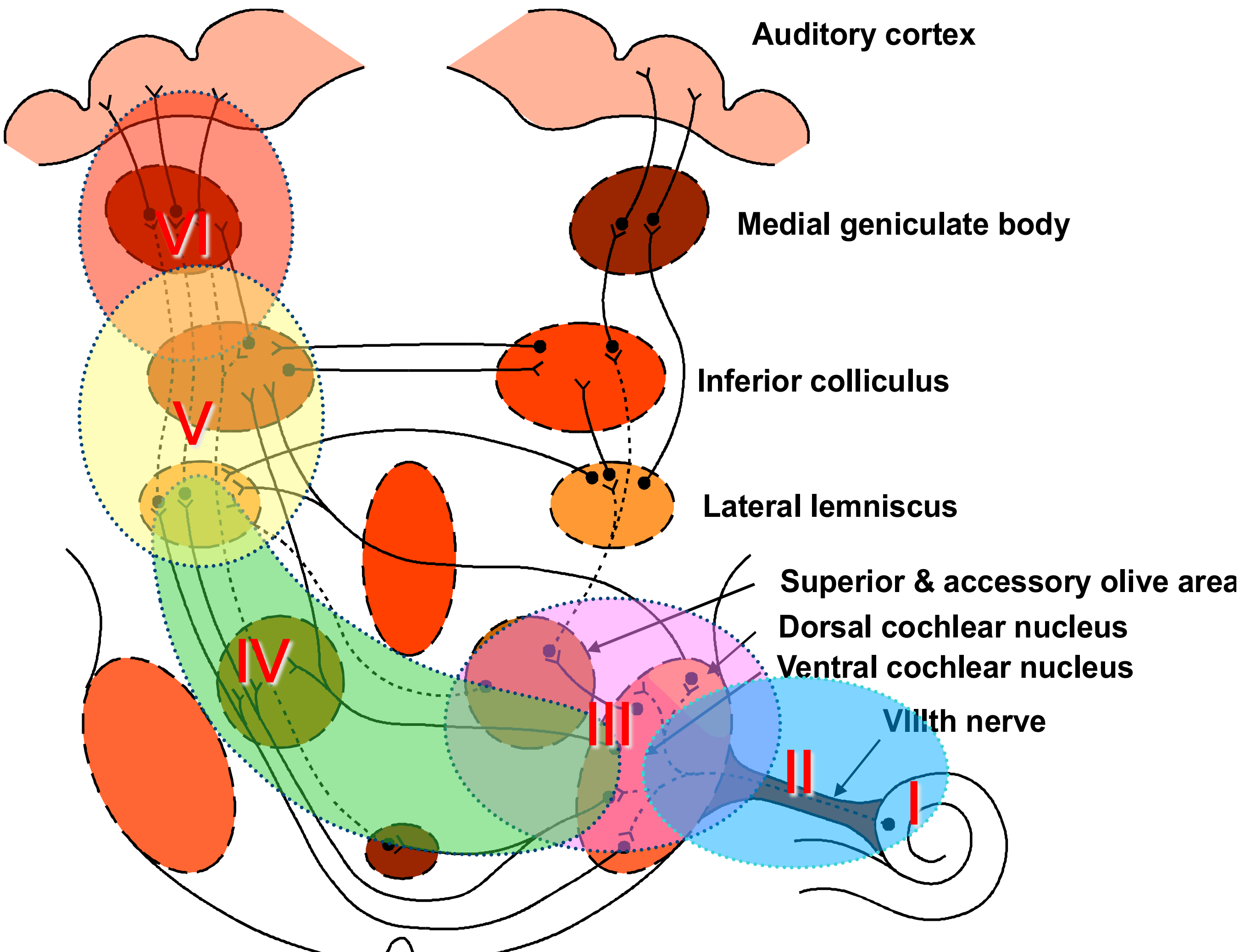
- Electrodes are placed on the scalp and coupled via leads to an amplifier and signal averager. EEG activity from the scalp is recorded while the ear(s) are stimulated via earphones with brief clicks or tones.
- A series of waveforms unique to the auditory neural structures is viewed after time-locking the EEG recording to each auditory stimulus and averaging several thousand recordings.

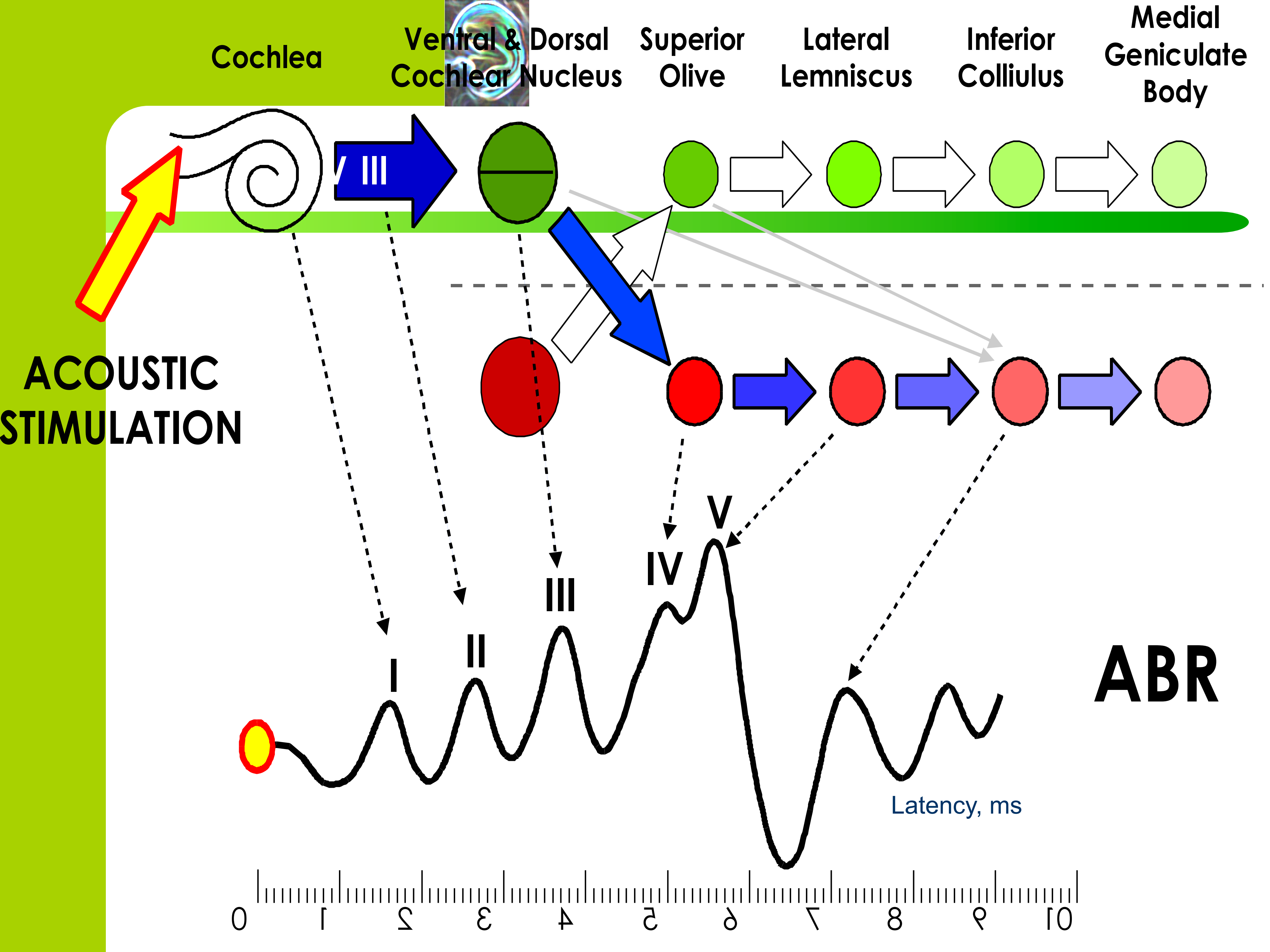
components



Response occurs within 5-6ms after stimulus is presented

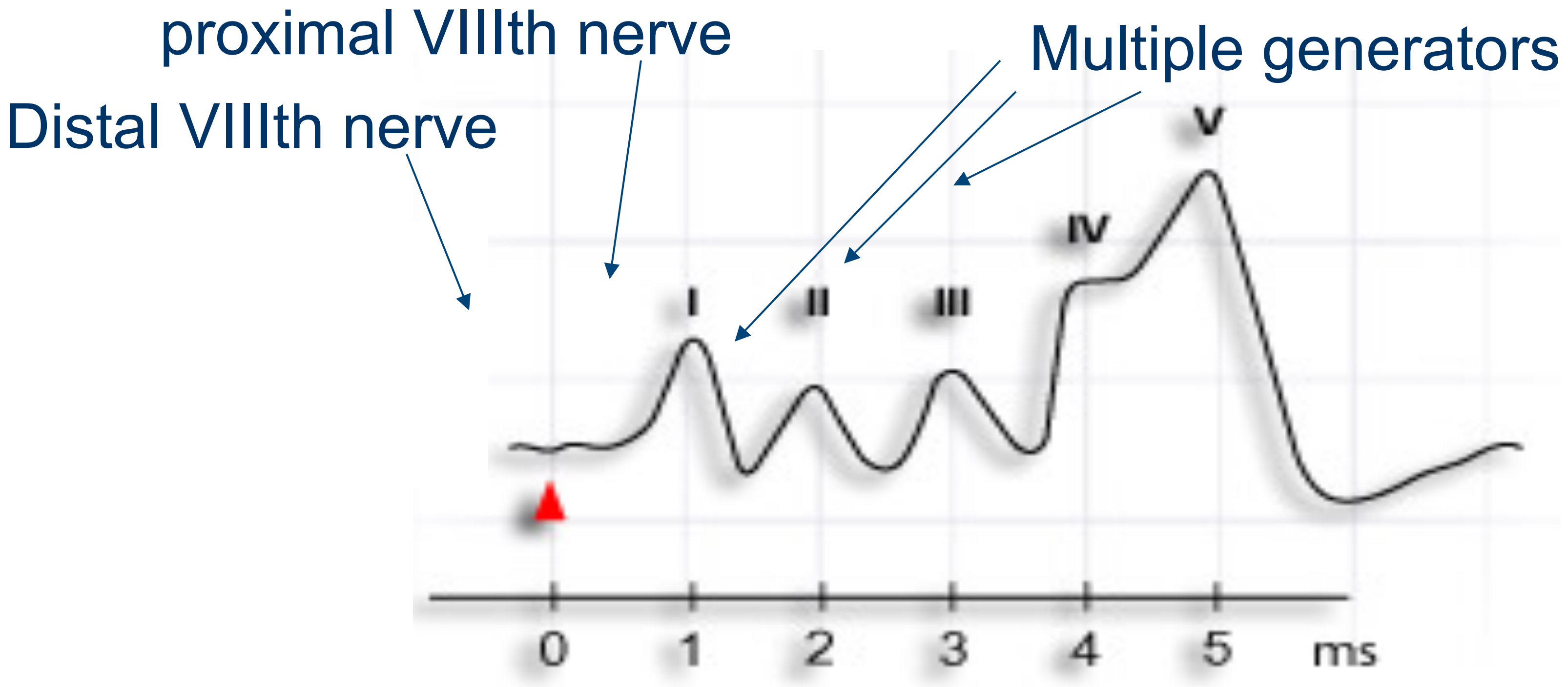
Generators of the ABR





Cochlea
Ventral & Dorsal Cochlear Nucleus
Superior Olive
Lateral Lemniscus
Inferior Colliulus
Medial Geniculate Body
ACOUSTIC STIMULATION
III
I
II
III
IV
V
ABR
Latency, ms
0
1
2
3
4
5
6
7
8
9
10

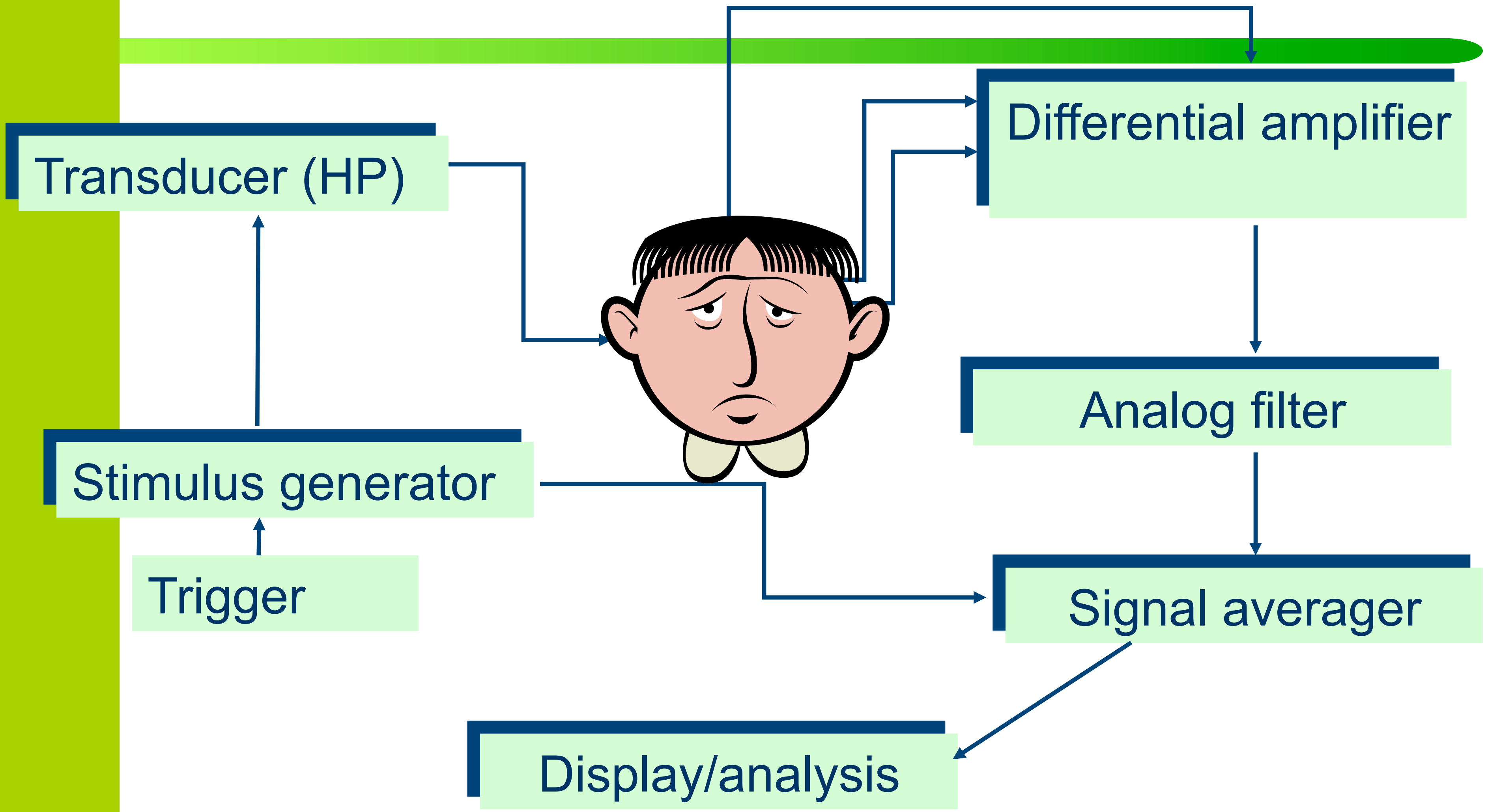
anatomy



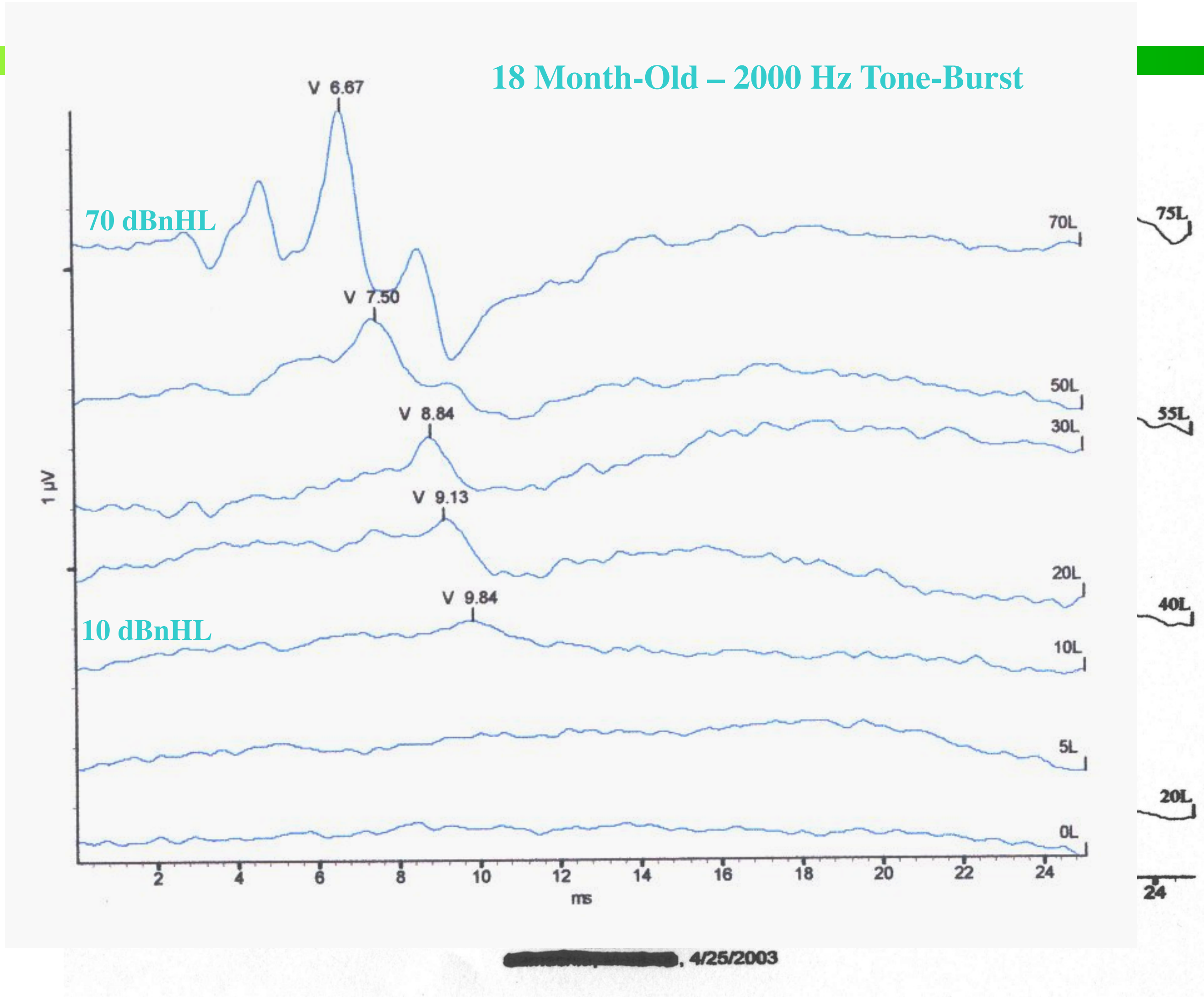
proximal VIIIth nerve
Distal VIIIth nerve
Multiple generators
I
II
III
IV
V
0
1
2
3
4
5
ms

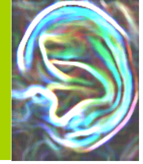
stimulus & acquisition

- Short clicks or tone bursts used
- Rate of around 20/sec or faster
- Responses can be + or – 20dB on true thresholds, mixed in with EEG
- Electrodes on head (surface electrodes)
- Can be influenced by subject characteristics (age, gender, body temperature)
- Not affected by arousal state or most drugs


Differential amplifier
Transducer (HP)
Analog filter
Stimulus generator
Signal averager
Trigger
Display/analysis

Example Normal Hearing

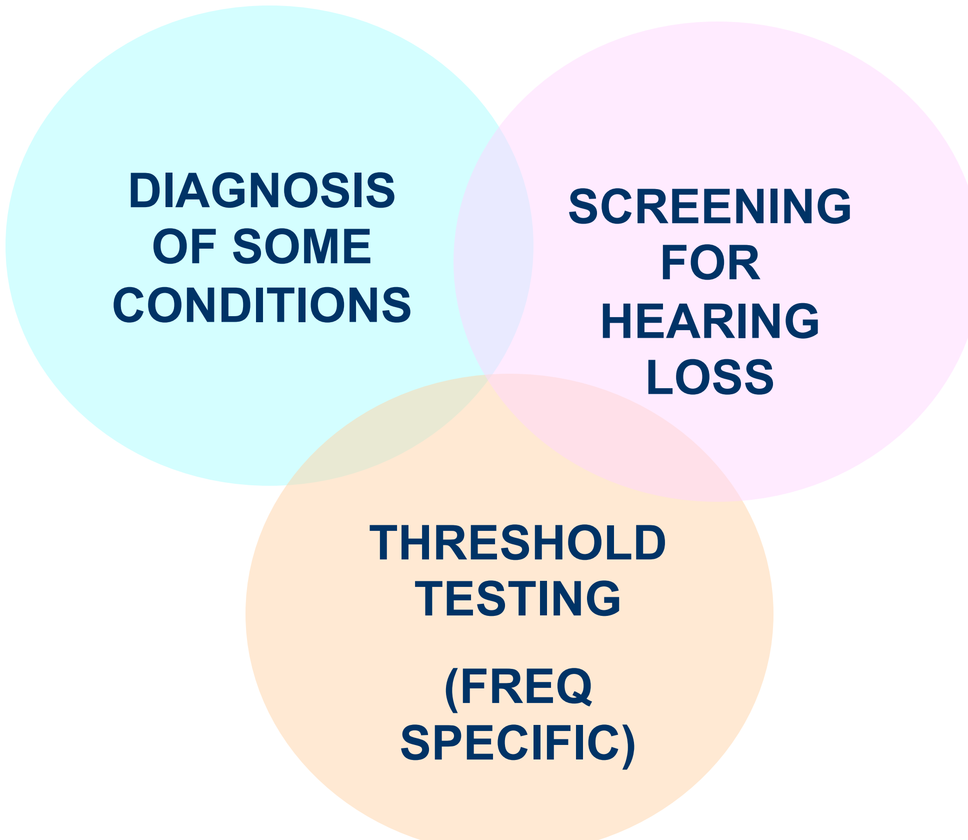


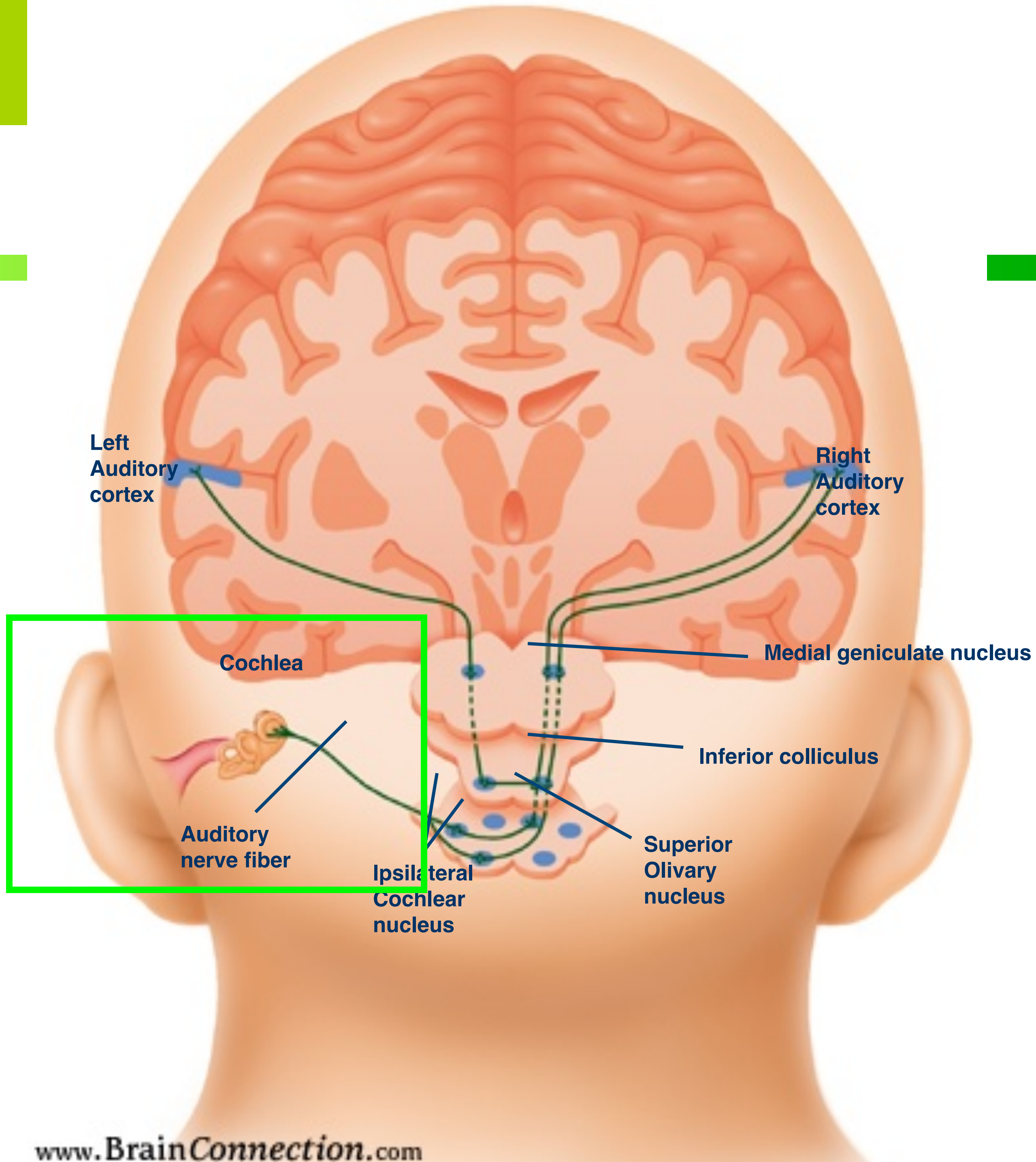


clinical applications

- Basis of Newborn screening tests: non-invasive, high success rate
- Estimation of thresholds for difficult to test people
- Neurodiagnosis of VIIIth nerve/ brainstem problems
- Intraoperative monitoring
- Cochlear implant evoked responses
- Test-retest reliability

Why use ABR testing?





Left
Auditory
cortex
Right
Auditory
cortex
Medial geniculate nucleus
Cochlea
Inferior colliculus
Auditory
nerve fiber
Superior
Olivary
nucleus
Ipsilateral
Cochlear
nucleus
www.BrainConnection.com

Retrocochlear lesion