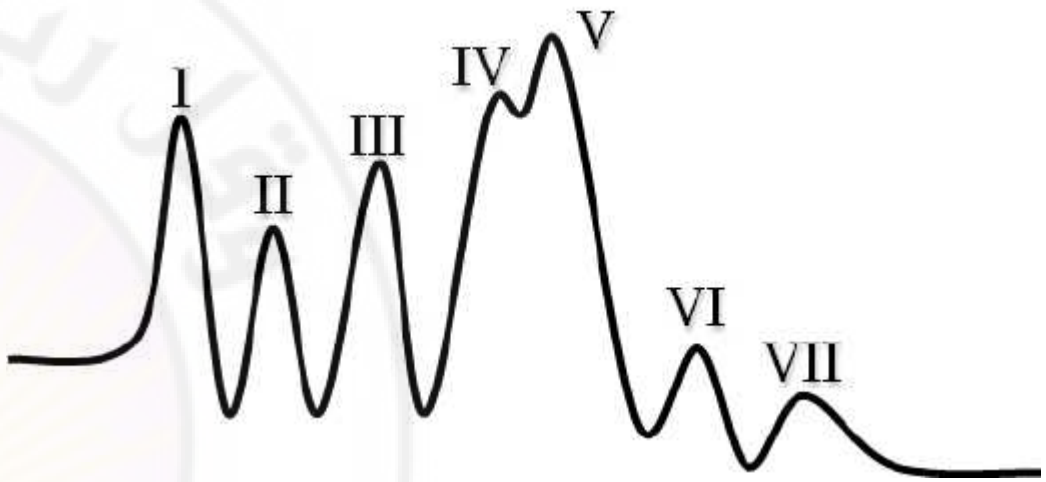
Auditory Evoked Responses

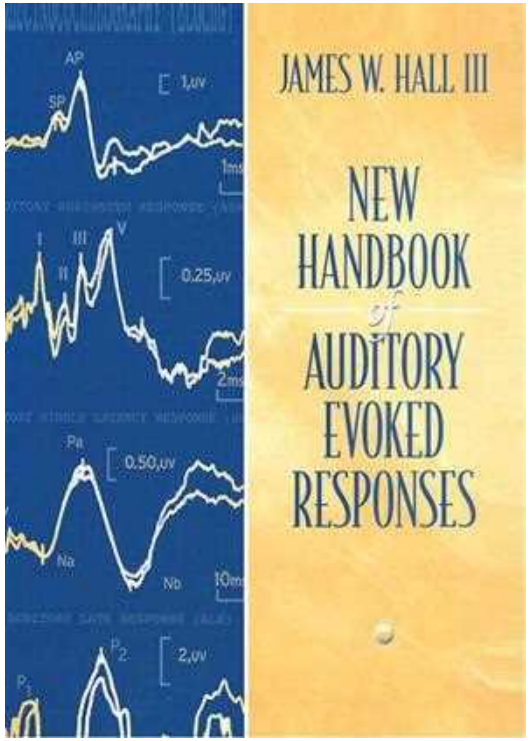
Mohsen Ahadi, Ph.D.
Associate Professor of Audiology
Iran University of Medical Sciences
Rehabilitation Research Center
ahadi.m@iums.ac.ir

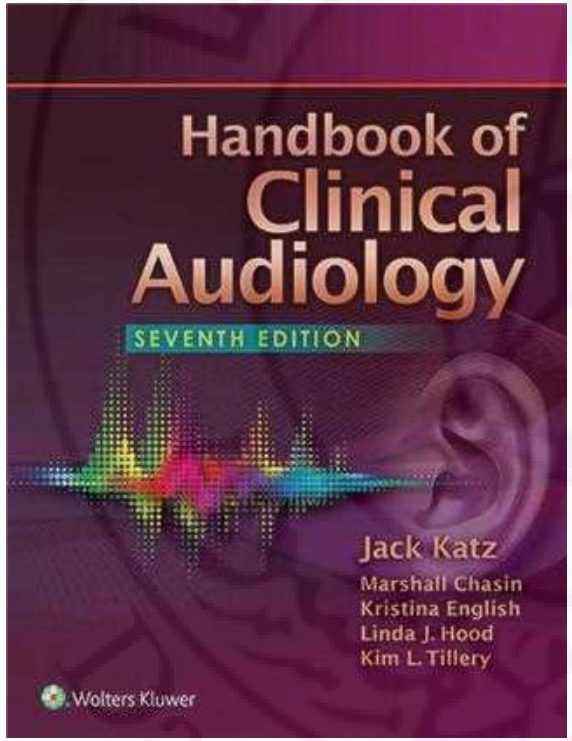
Main Topics

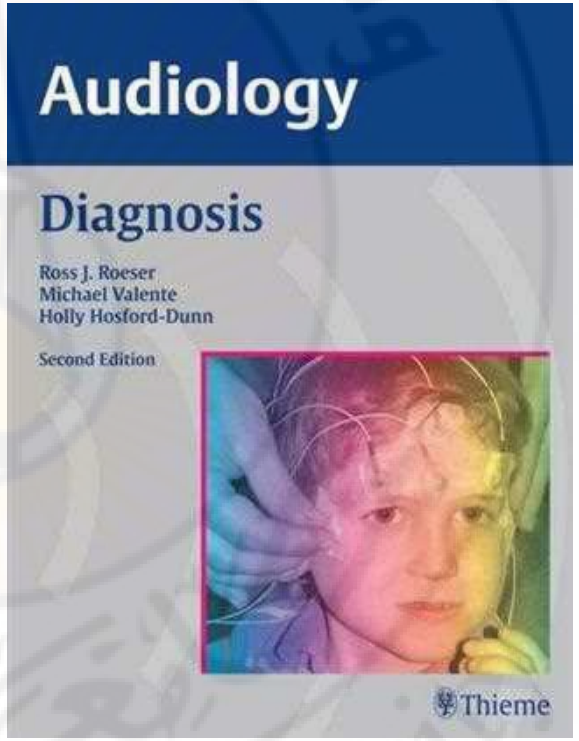
- Introduction to AERs
- Review of the anatomy of auditory system
- Factors in Measurement of Auditory Evoked Responses
- Introduction to Auditory Brainstem Response
- Auditory Brainstem Response: Stimulus Parameters
- Auditory Brainstem Response: Acquisition Parameters and Test Protocols
- Auditory Brainstem Response: Analysis and Trouble Shooting
- Auditory Brainstem Response: Clinical Applications and Patient Populations
- Auditory Steady State Response (ASSR)
- Event related potentials (ERPs)

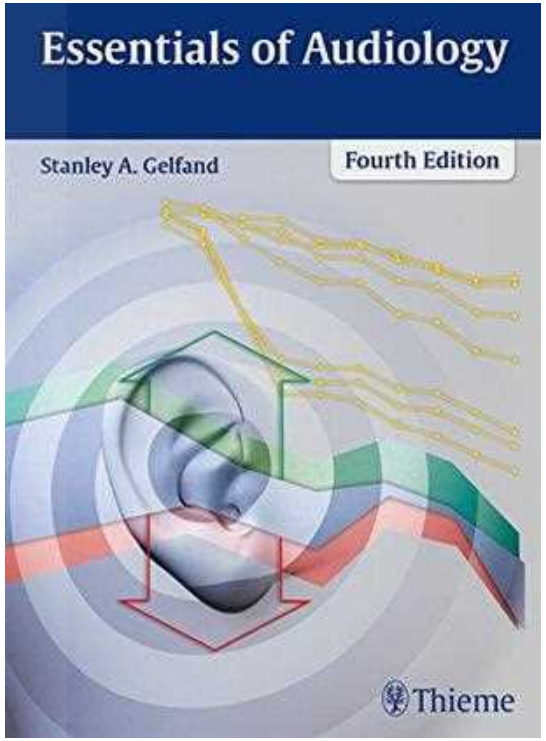


References


JAMES W. HALL III
NEW HANDBOOK of AUDITORY EVOKED RESPONSES


Handbook of Clinical Audiology
SEVENTH EDITION
Jack Katz
Marshall Chasin
Kristina English
Linda J. Hood
Kim L. Tillery
Wolters Kluwer


Audiology
Diagnosis
Ross J. Roeser
Michael Valente
Holly Hosford-Dunn
Second Edition
Thieme


Essentials of Audiology
Stanley A. Gelfand
Fourth Edition
Thieme

E. references

audiologyonline.com

asha.org

audiology.org

thebsa.org.uk



Assessment

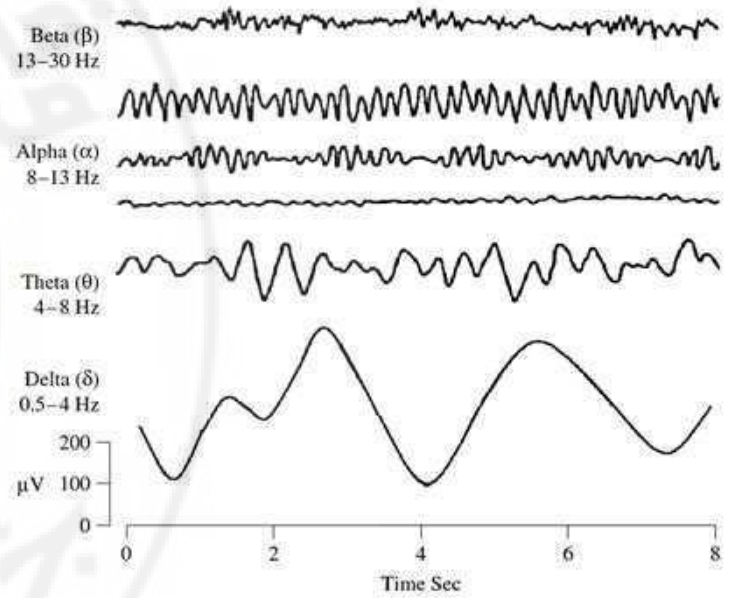
- Active participation in the class
- Final exam
  - Multiple choice questions
  - fill-in-the-blank questions
  - short answer questions

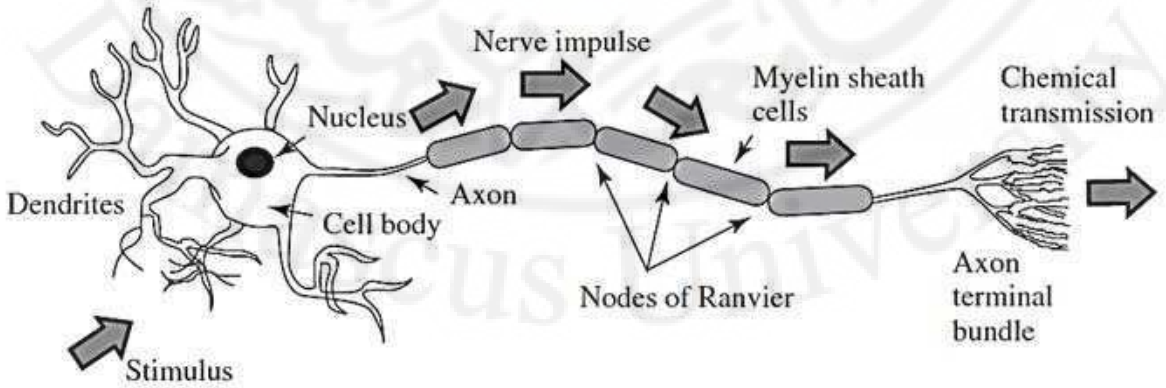


1. Introduction to AERs

Introduction to AERs: EEG

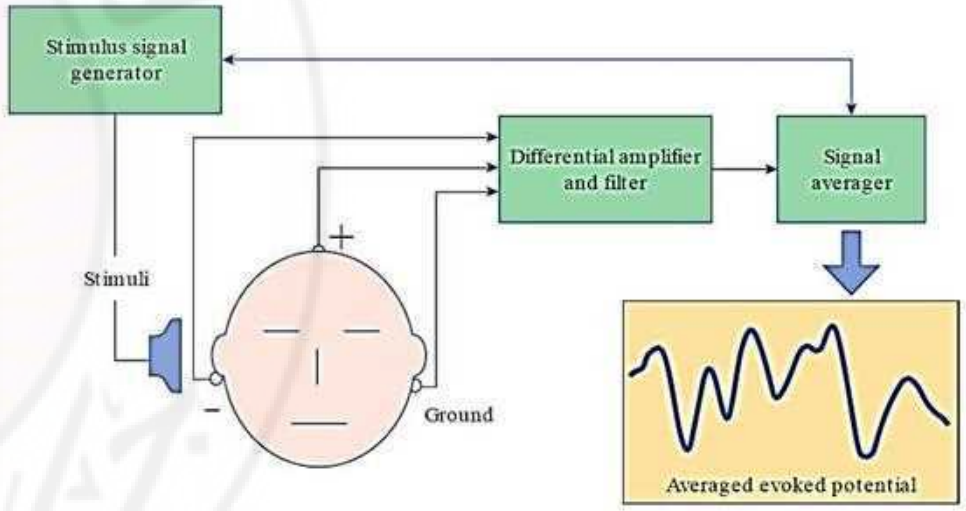
- The activity of the nervous system produces electrical signals that can be picked up by electrodes placed on the head, and can then be displayed on the screen of a recording device and/or plotted on paper. the term **EEG** is use to denote electrical neural activity of the brain.





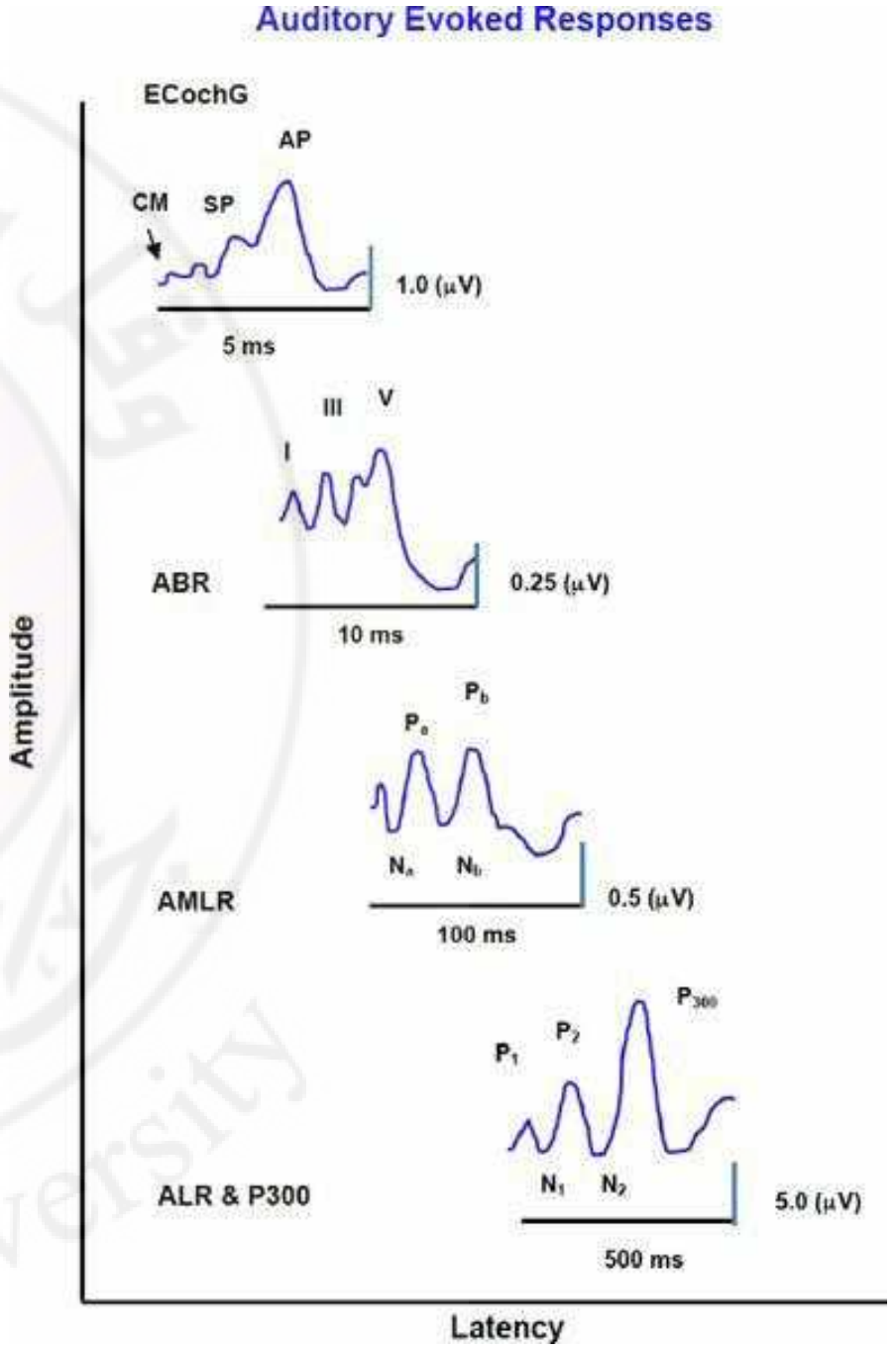
Introduction to AERs: Evoked Potentials

- A change in the activity of the nervous system occurs when it reacts to a stimulus (such as a sound). This change in neural activity also produces a change in the electrical signals picked up by the electrodes.
- As a result, the nervous system's reaction to a stimulus can be seen as a change in the electrical signals that are displayed on the recording device. These electrical responses of the nervous system that are elicited by a stimulus are called **evoked potentials**.
- When the stimulus is sound, they are called **auditory evoked potentials (AEPs)** or **auditory evoked responses (AERs).**



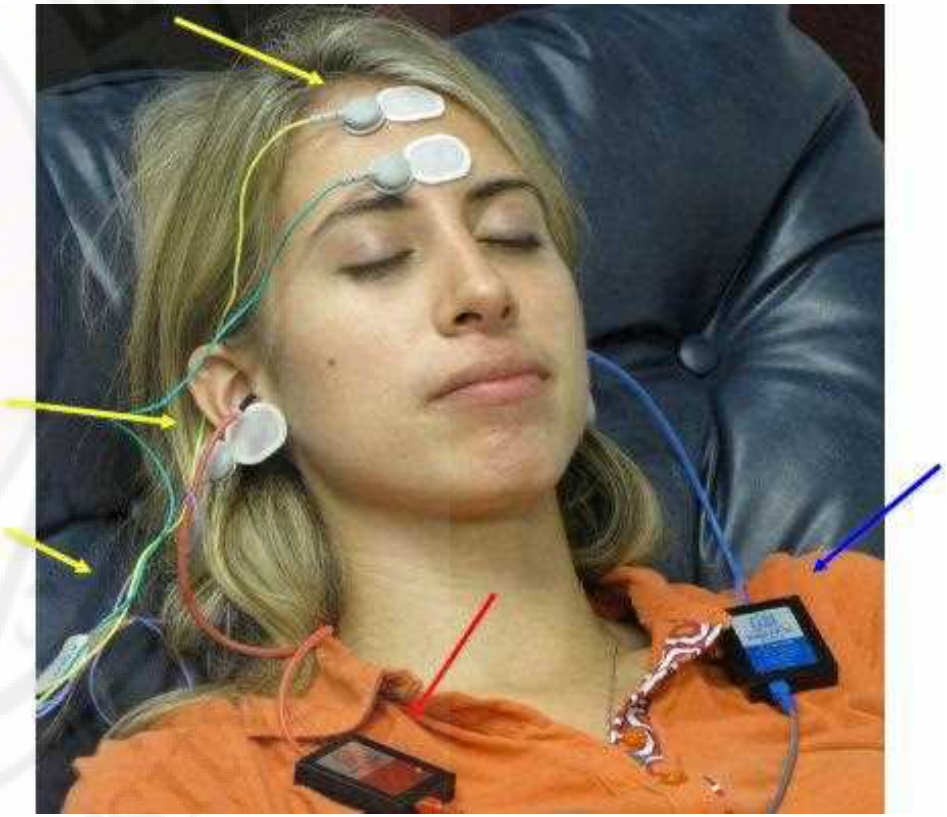
Introduction to AERs

- Auditory evoked responses represent activity within the auditory system that is stimulated or evoked by sounds.
- With the proper acoustical stimuli, auditory evoked responses can be recorded from the inner ear, the auditory nerve, or auditory regions of the brain.
- Auditory evoked responses contribute importantly and in many ways to the early detection and accurate diagnosis of auditory dysfunction, and to effective intervention for hearing loss and other types of auditory disorders.



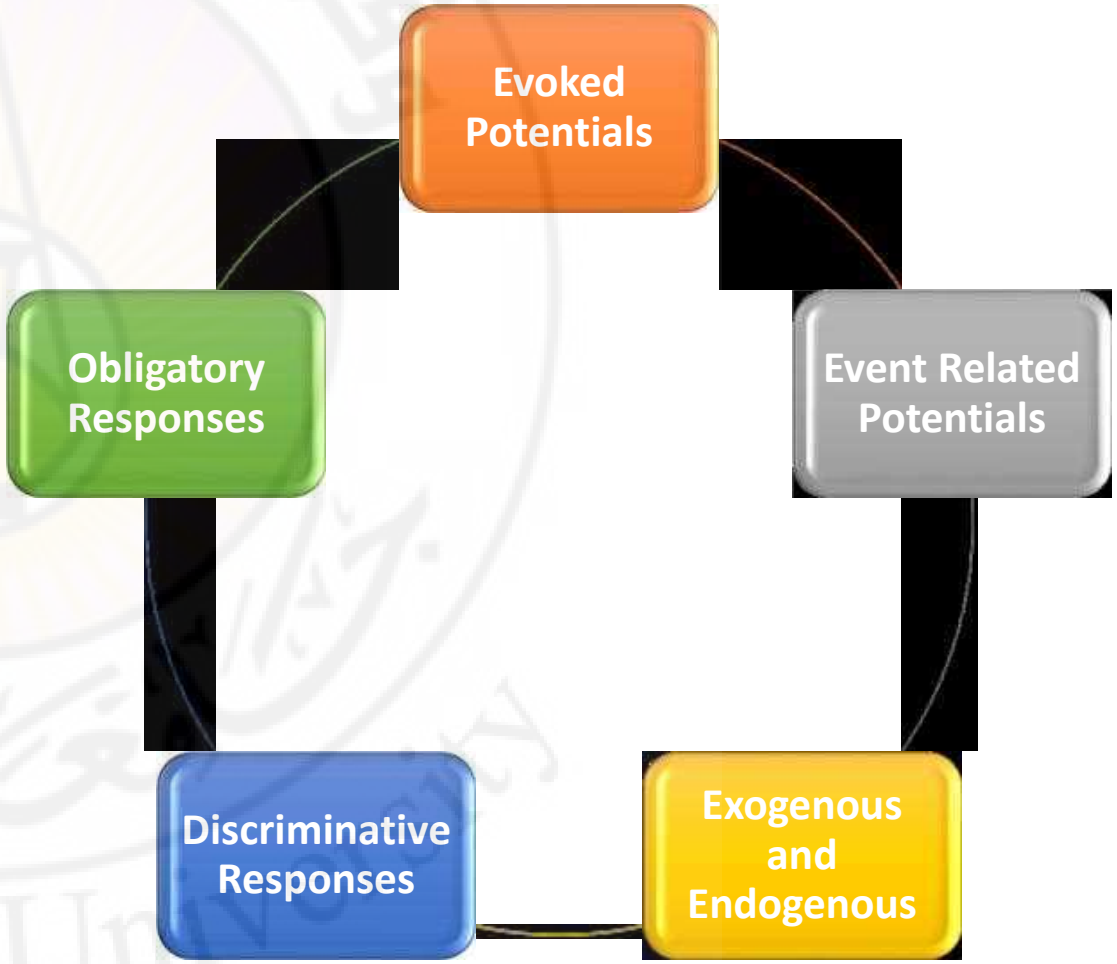
Introduction to AERs

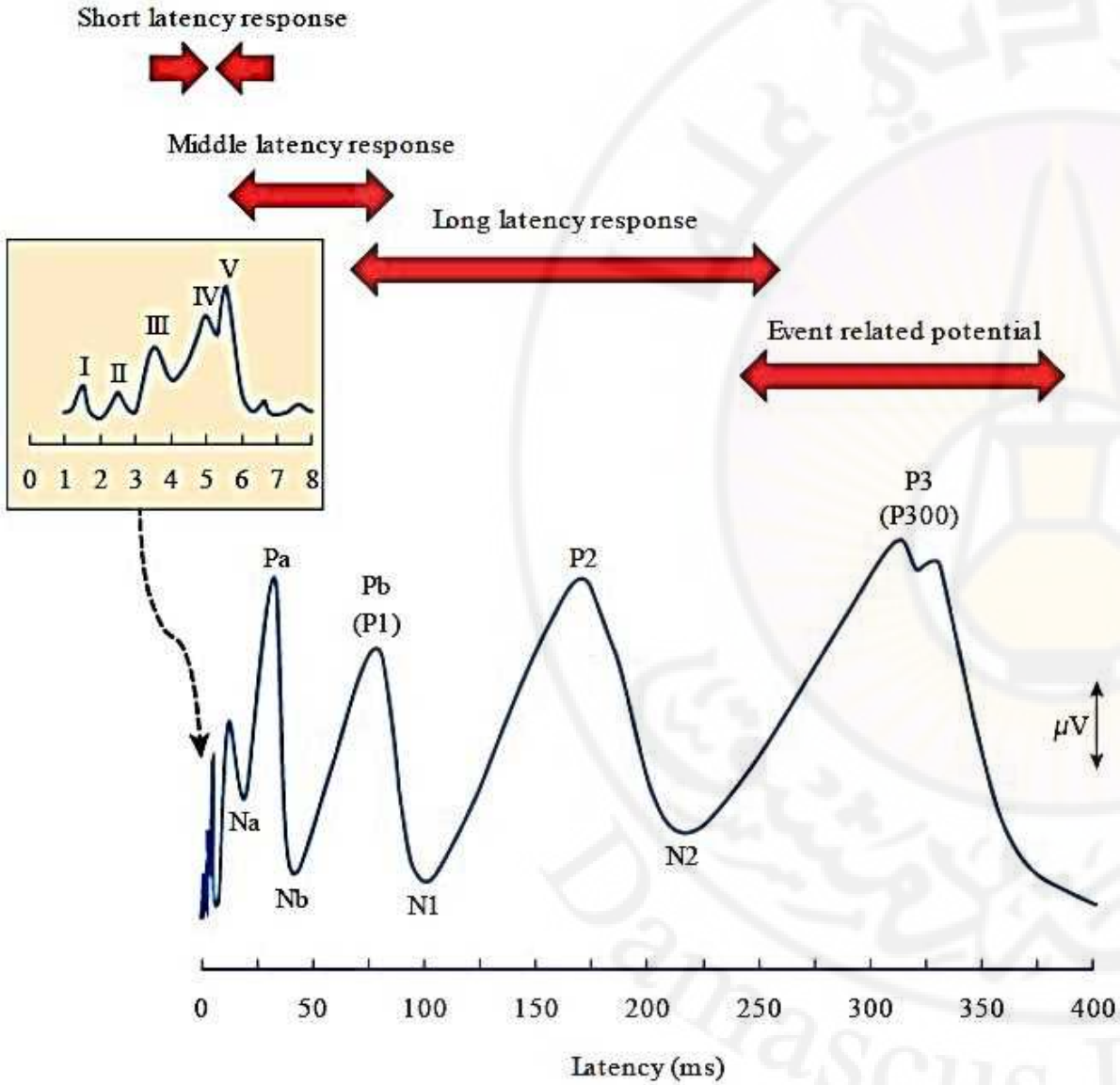
- Multiple brain regions would be activated at the same time. However, it would be true that, the more caudal structures in the auditory nervous system would have shorter onset latencies than the more rostral structures.
- This latency increase for more rostral structures is the result of the finite action potential conduction velocity and the delay as the activity passes through chemical synapses.
- Although we have no noninvasive way of recording from these various auditory nuclei directly, it is possible to record a series of responses from the scalp (using noninvasive surface electrodes) which have latencies ranging from one one-thousandth to several tenths of a second.

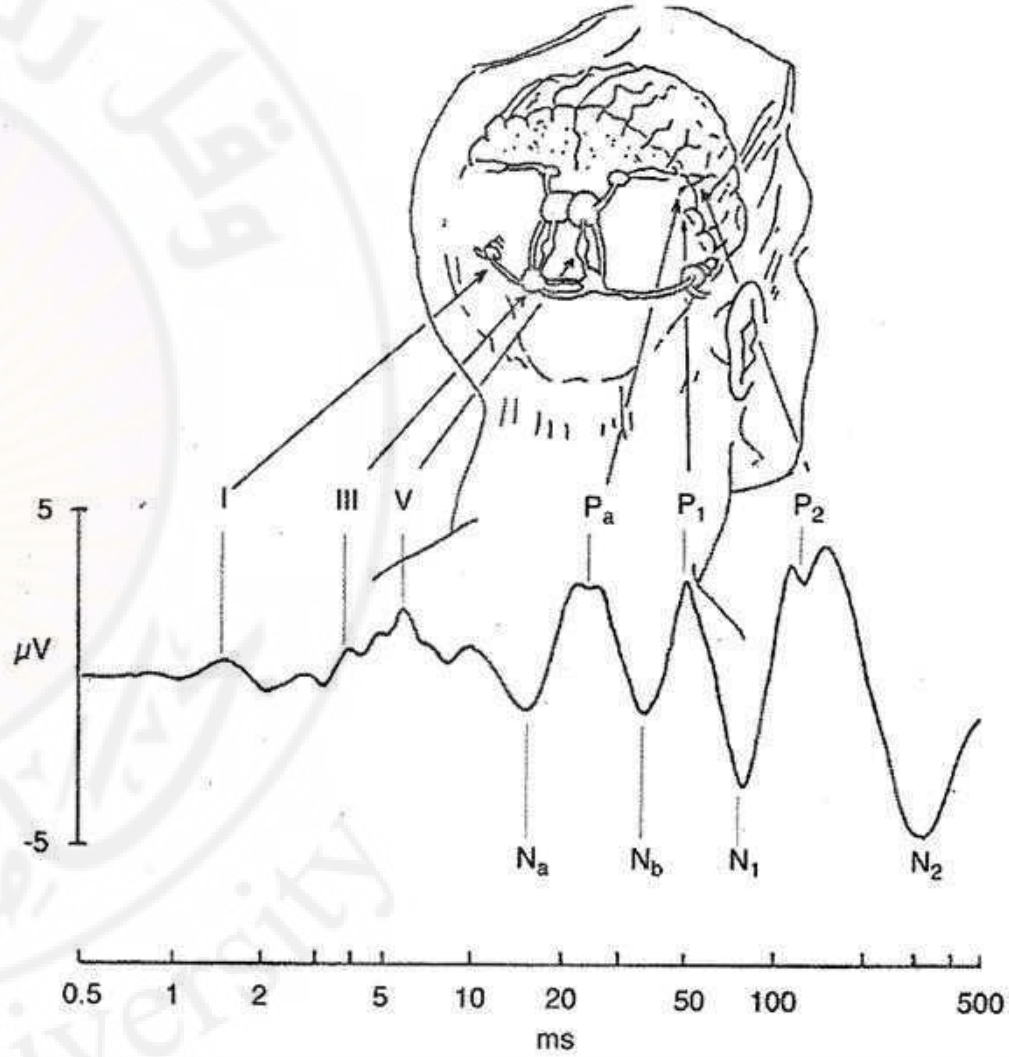


Classification of auditory evoked potentials

- Because of the progressive latency increase of responses from more rostral auditory structures, it is popular to classify AEPs by their response time following the onset of a transient stimulus.
- EcochG
- ABR
- Middle latency response: MLR
- Slow vertex potential: SVP or ALR
- Event-related potential: ERP

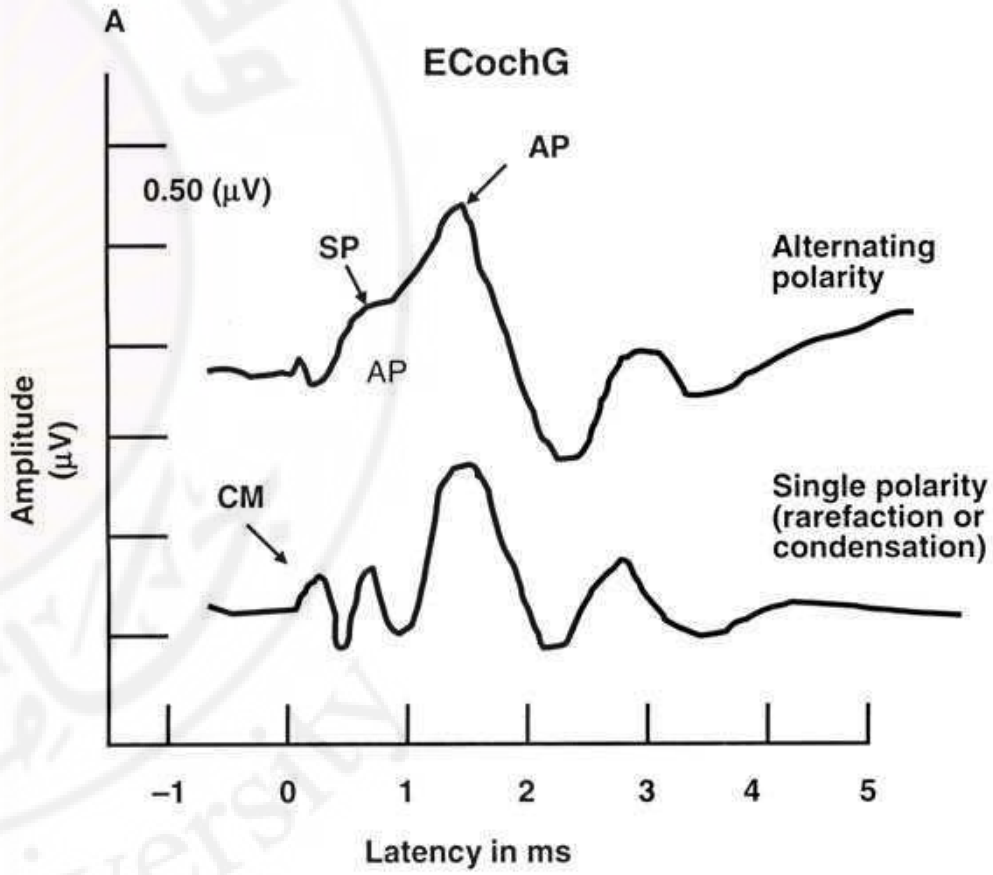



Short latency response
Middle latency response
Long latency response
Event related potential
I
II
III
IV
V
0 1 2 3 4 5 6 7 8
Pa
Pb
(P1)
P2
P3
(P300)
Na
Nb
N1
N2
μV
0 50 100 150 200 250 300 350 400
Latency (ms)


I
III
V
Pa
P1
P2
5
μV
-5
Na
Nb
N1
N2
0.5 1 2 5 10 20 50 100 500
ms

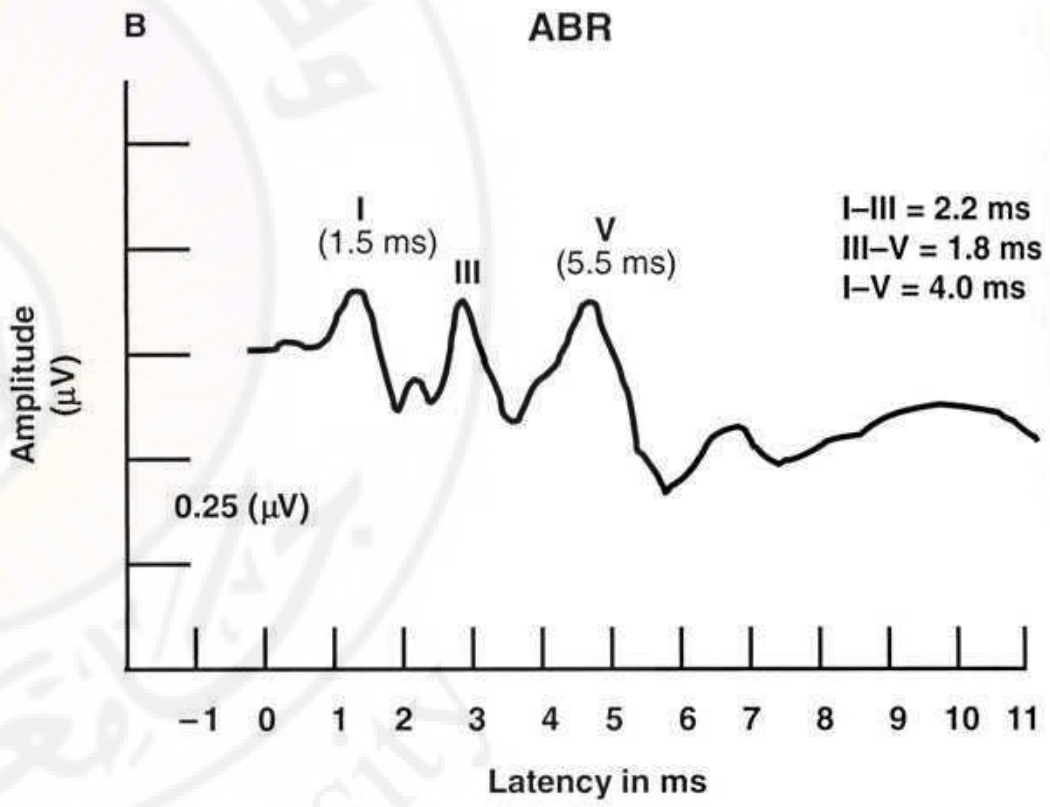
EcochG

- EcochG refers to the responses from the cochlea and auditory nerve, using a recording electrode located in close proximity to the inner ear.
- Two responses arise from the hair cells: the cochlear microphonic (CM) and the summating potential (SP).
- Each has a very short latency (1 ms or so), which is basically the delay from stimulus onset to hair cell excitation.
- The response from the acoustic portion of the eighth cranial nerve is called either the whole-nerve action potential (WNAP) or the compound action potential (CAP).



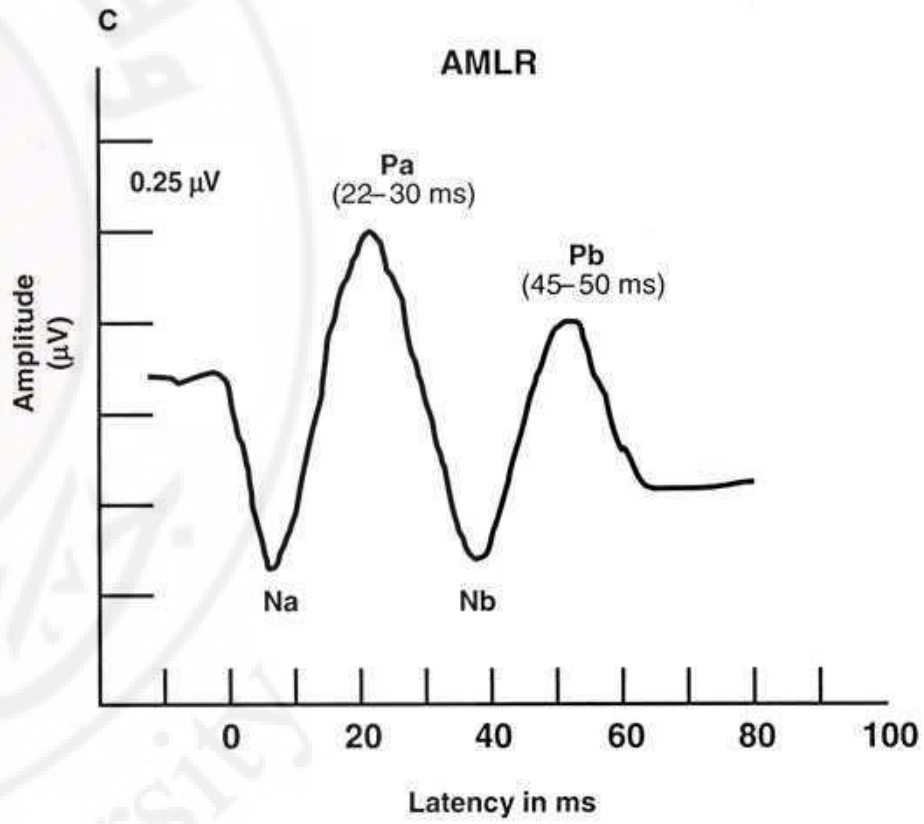
ABR

- The ABR includes a series of five to seven peaks arising from auditory nerve and brainstem structures, occurring within 10 ms of the onset of a moderate intensity click stimulus in otologically, audiologically, and neurologically intact adults.
- The ABR is, without question, the most clinically useful AEP at the present time.
- It can be used for estimating hearing threshold and differential diagnosis of peripheral and central abnormalities and for intraoperative monitoring.



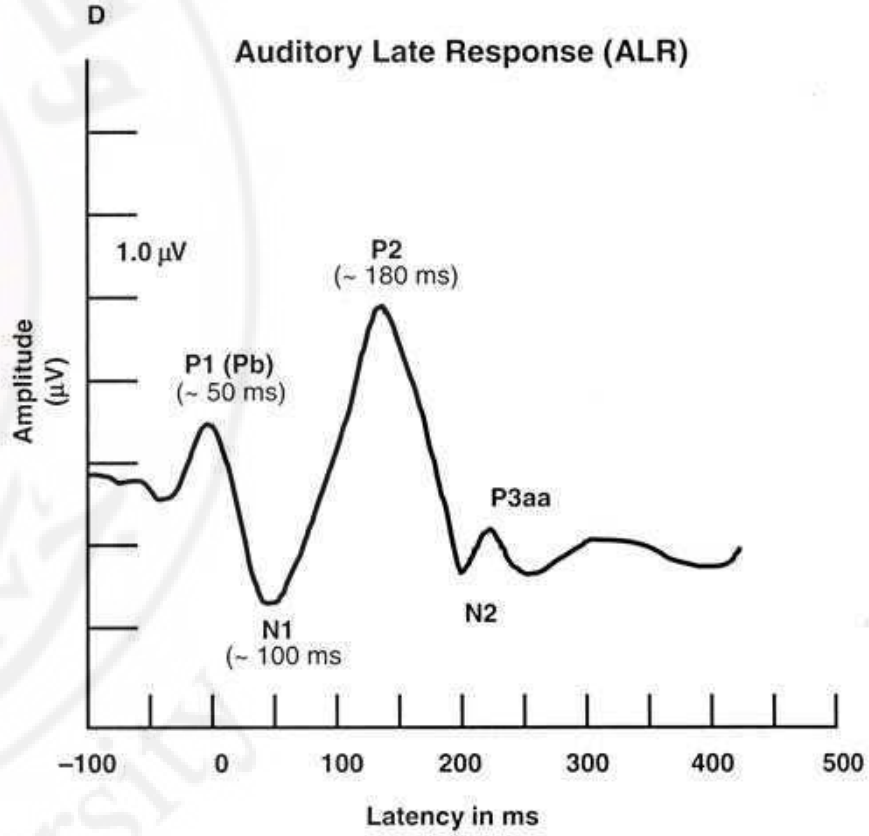
MLR or AMLR

- MLRs are typically recorded over a time window of 80 to 100 ms.
- Generators are thought to include thalamus and auditory cortex.
- Unlike EcochG and ABR, the MLR appears to be affected by subject variables such as attention and arousal.
- Peak-labeling nomenclature varies somewhat with investigator, but the polarity of the peak is typically indicated by a capital P or N (positive or negative), subscripted by small case early letters of the alphabet (e.g., Pa and Nb).



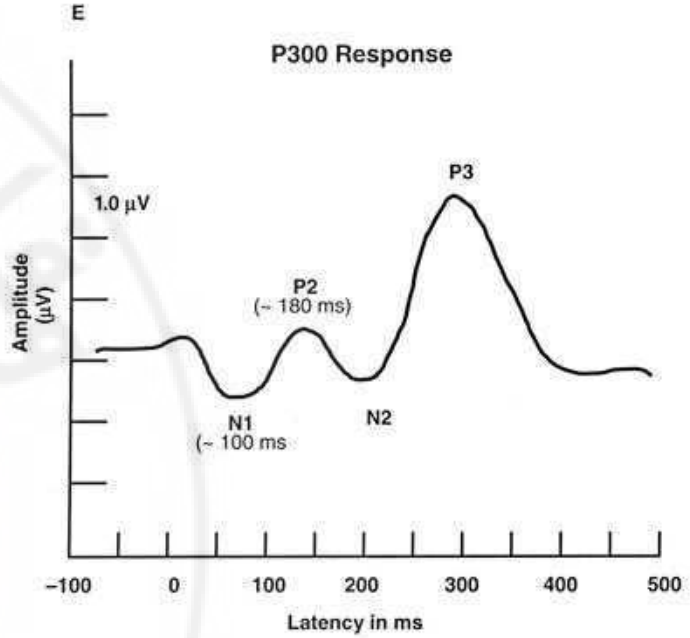
ALR (LLR) or SVP

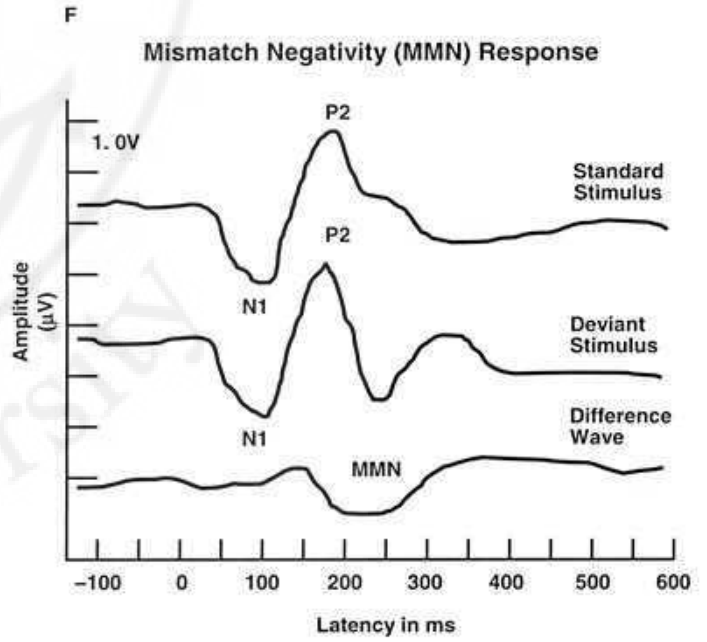
- AEP responses occurring beyond ~75 ms are collectively called the SVP or late component responses.
- These responses are most commonly labeled with a capital N or P, to indicate peak polarity and subscripted with an Arabic number indicating which SVP peak of that polarity it is (e.g., P1 is the first positive SVP peak).
- Alternatively, an Arabic number indicating average peak latency may be used as a subscript. For example, N200 would be the negative peak with a mean latency of approximately 200 ms.



Event-related potential (ERP)

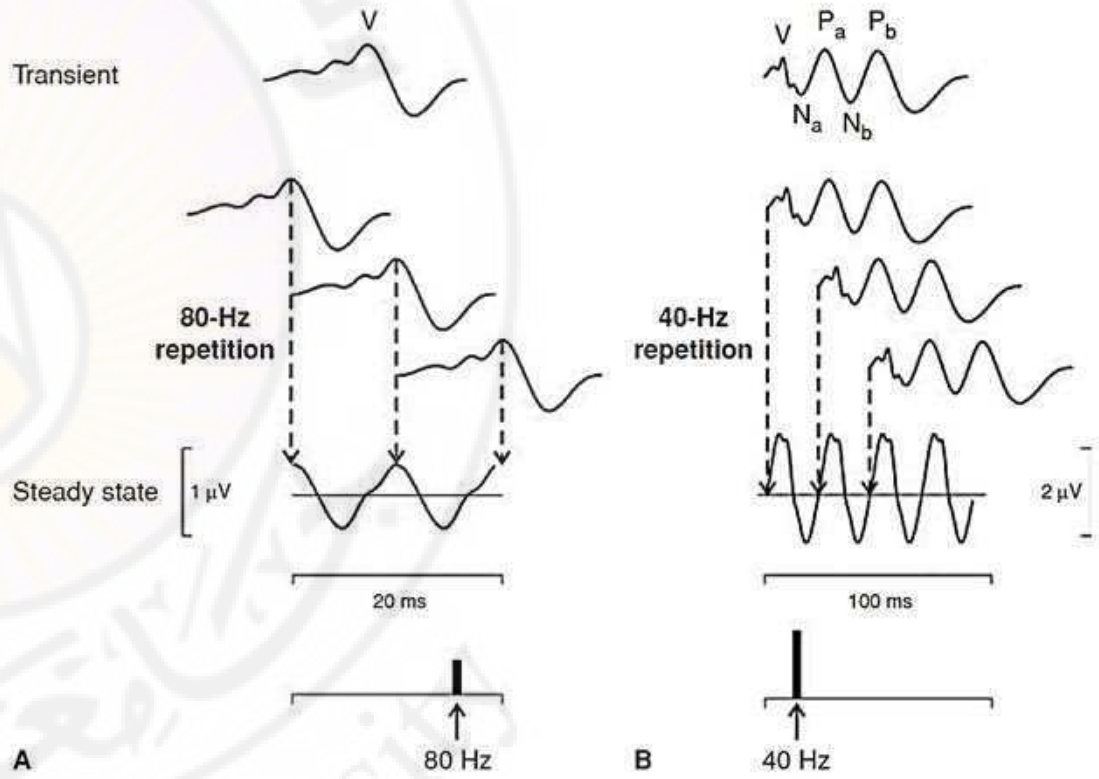
- The term event-related potential (ERP) is used when referring to long-latency responses that are strongly dependent on the attention and arousal of the subject.
- P300
- MMN





Auditory steady-state response (ASSR)

- A relative newcomer to the family of AEP responses is the auditory steady-state response (ASSR).
- This response represents a sustained response and can be elicited by trains of clicks, noisebursts, or tonebursts, as well as amplitude modulated (AM) and/or frequency-modulated (FM) stimuli.



Clinical Applications of AEPs

- Hearing screening
- Estimation of hearing thresholds of difficult-to-test populations.
- Site-of-lesion testing
- Intraoperative monitoring
- Mapping of cochlear implants in the pediatric population
- Diagnosis and perhaps in the efficacy of treatment of such complex clinical entities as central auditory processing disorder.



For threshold estimation, it is not very important to know the generators of a particular AEP peak. In contrast, for such clinical applications as site-of-lesion testing or intraoperative monitoring, knowledge of the generators of a particular peak can be invaluable.

2. Review of the anatomy of auditory system

The human auditory system can be divided anatomically into two subsystems:

Peripheral auditory system

Central auditory system

It can be further subdivided *anatomically* into four divisions:

Outer ear

Middle ear

Inner ear

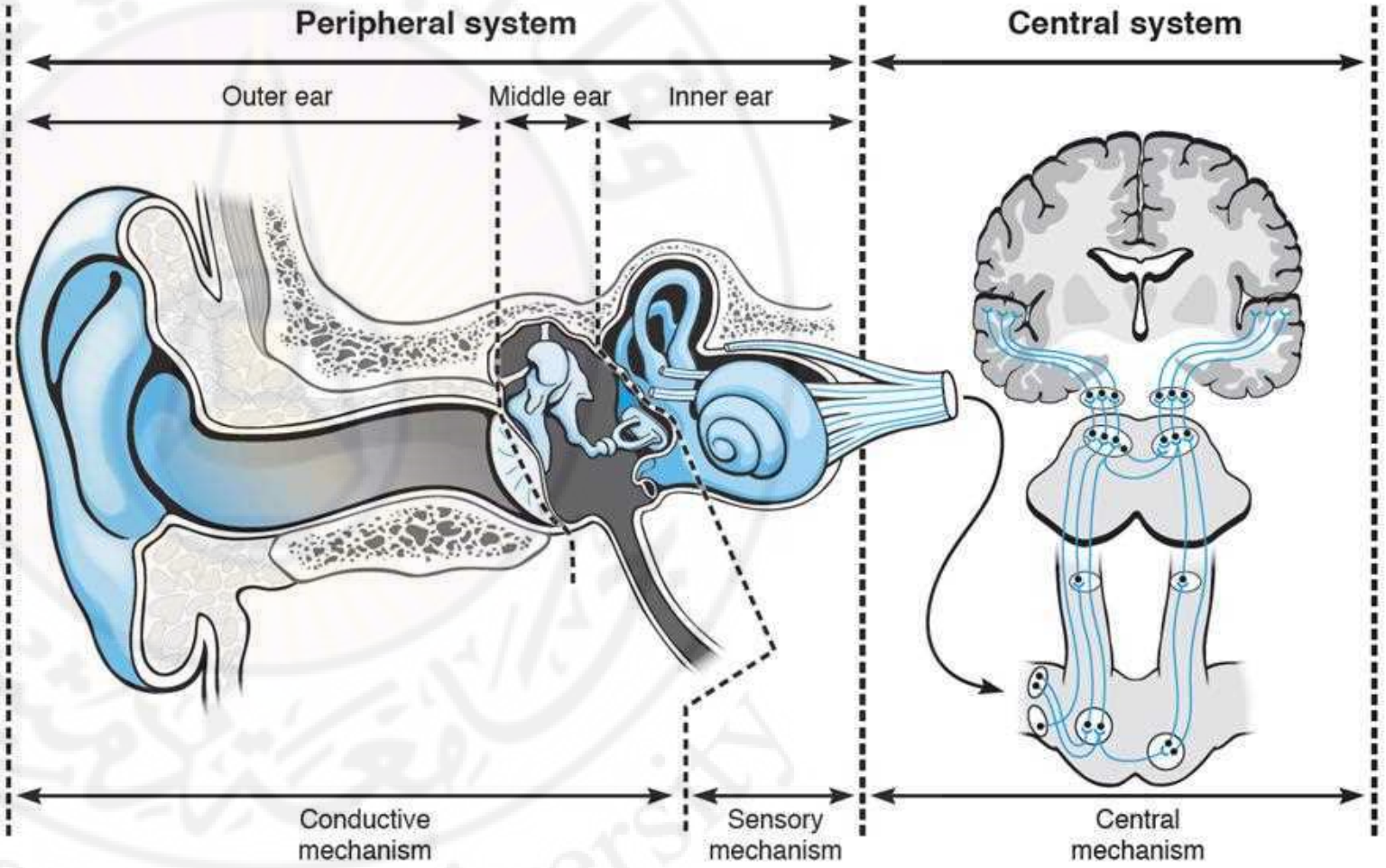
Central auditory system

Functionally, the auditory system is comprised of three components:

The conductive mechanism

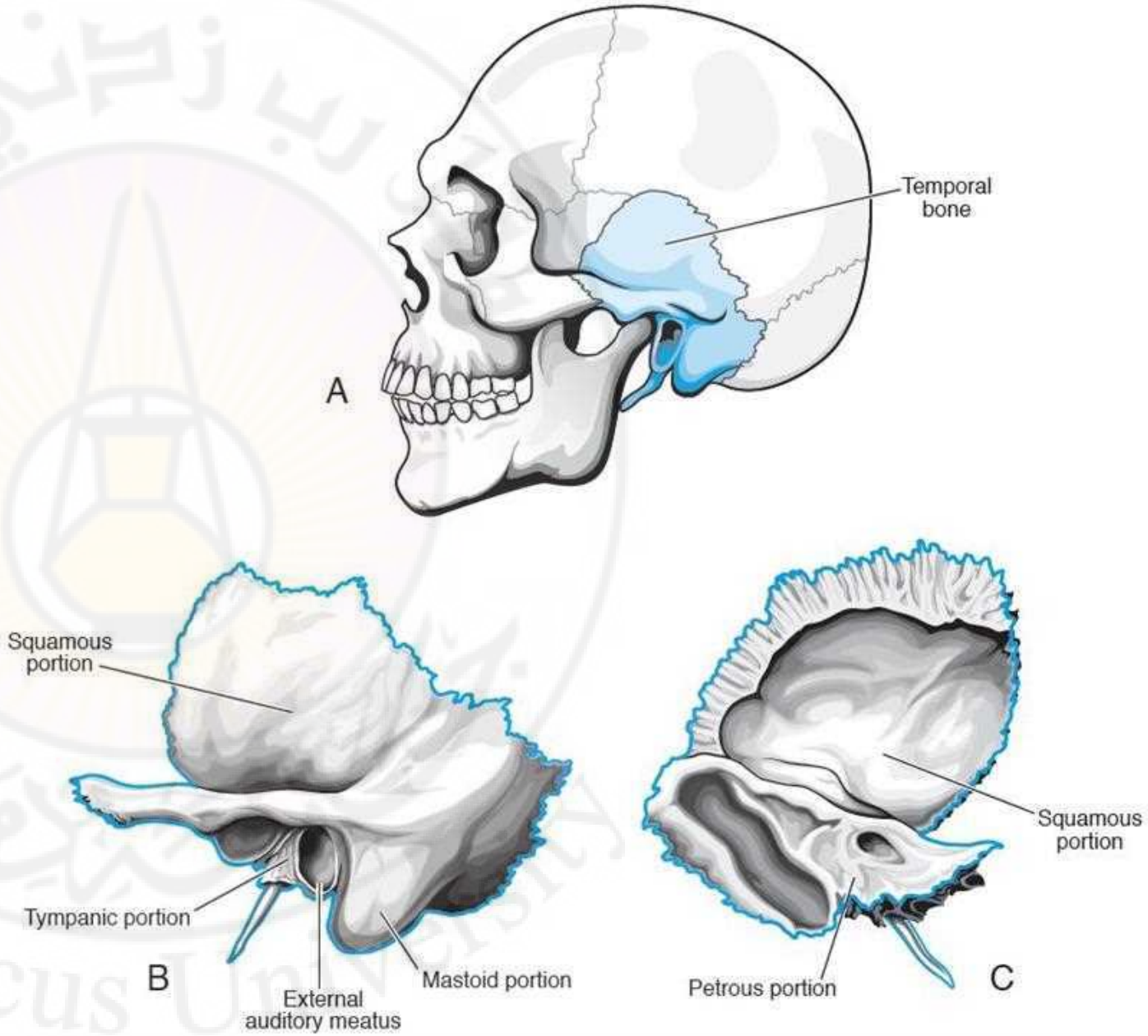
The sensory mechanism

The central mechanism

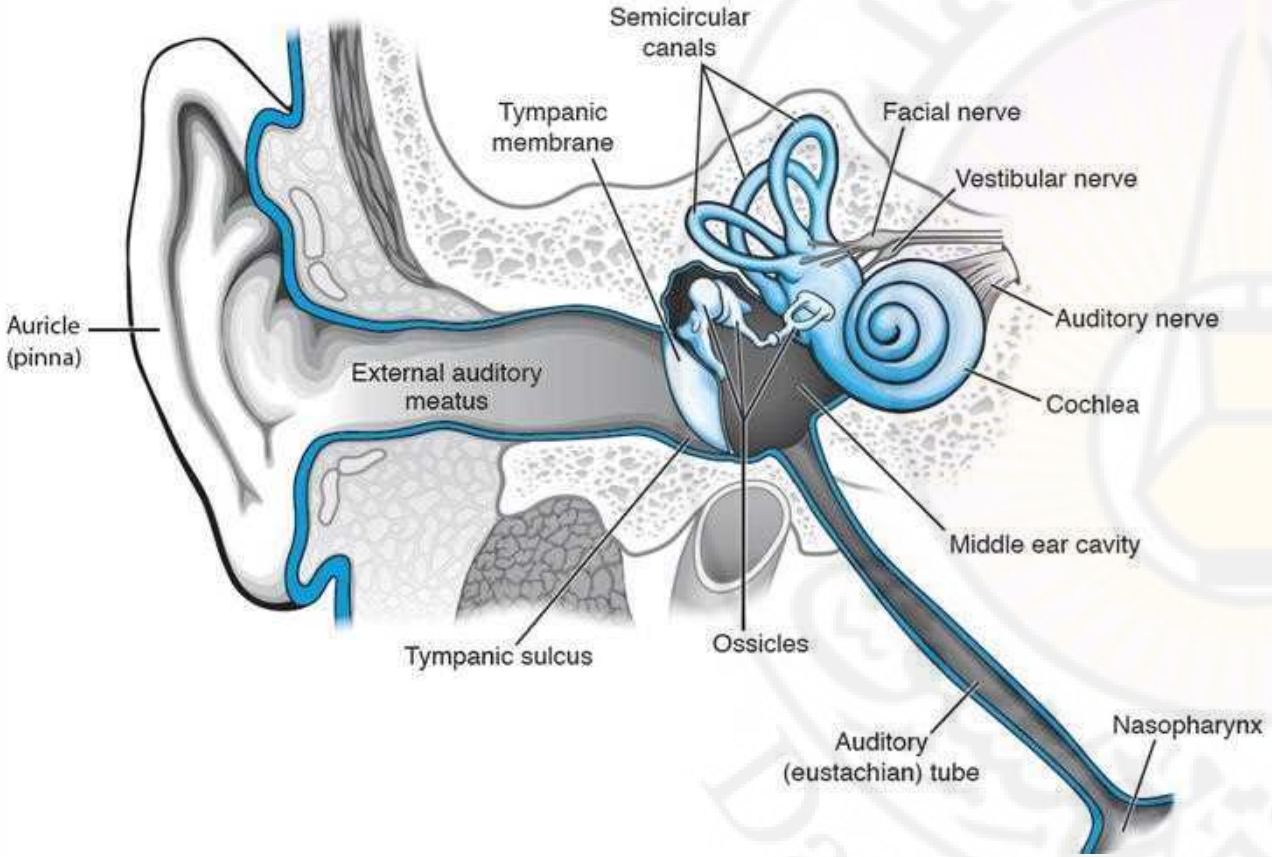


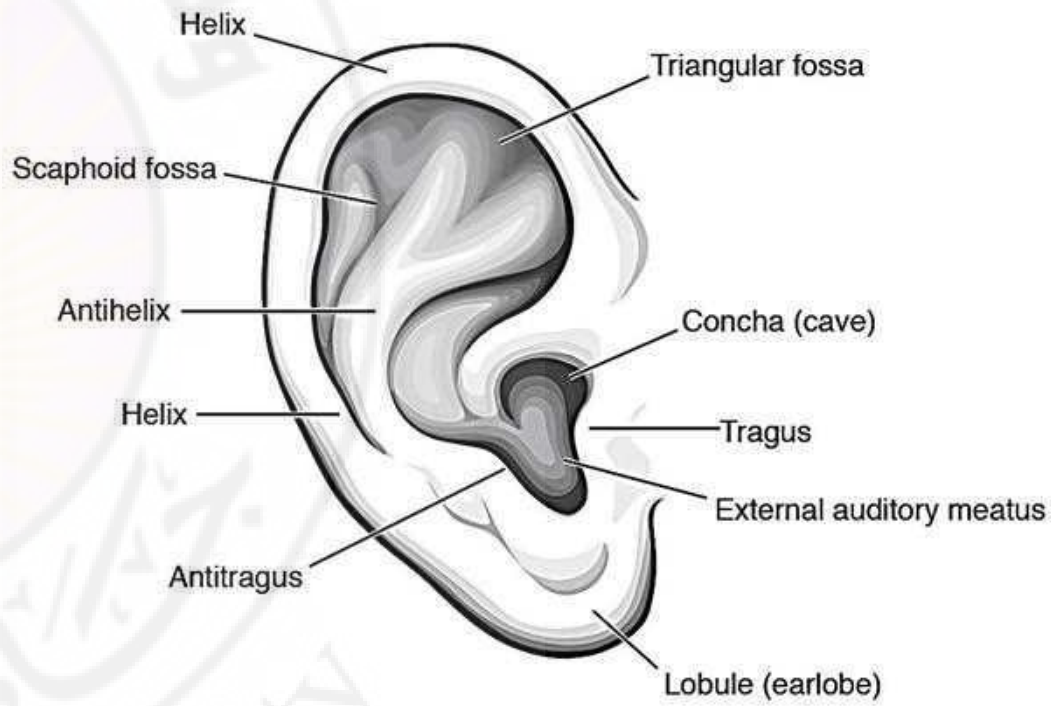
Human temporal bone

Almost all of the **peripheral auditory mechanism** is located in the **temporal bone**, a paired cranial bone of the skull that comprises the major portion of the lateral base and sides of the braincase



Structures of the outer ear



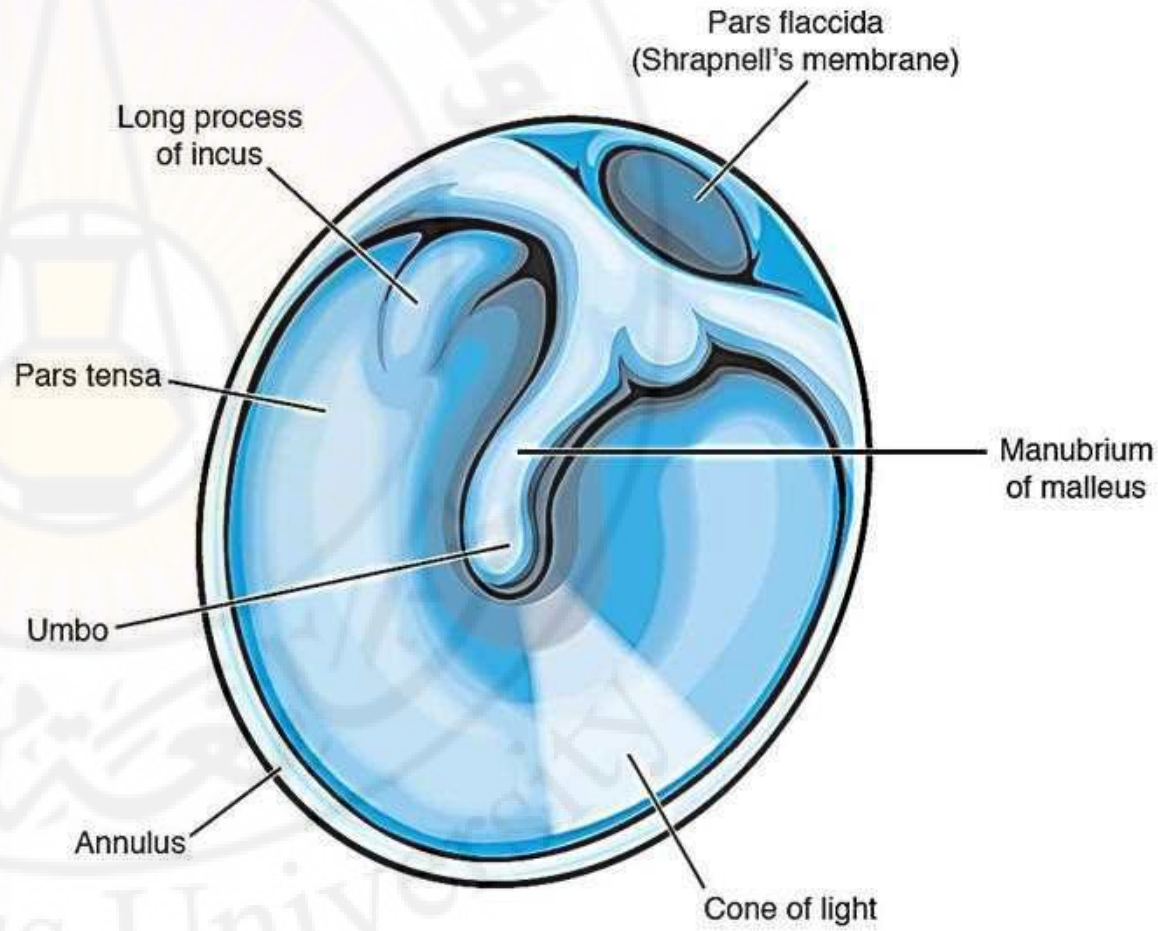


The outer ear represents the outermost portion of the auditory system and consists of the **auricle** (or **pinna**) and the **external auditory meatus** (or **outer ear canal**).

Tympanic membrane (eardrum)

Tympanic membrane is an elastic structure that separates the outer ear from the middle ear cavity.

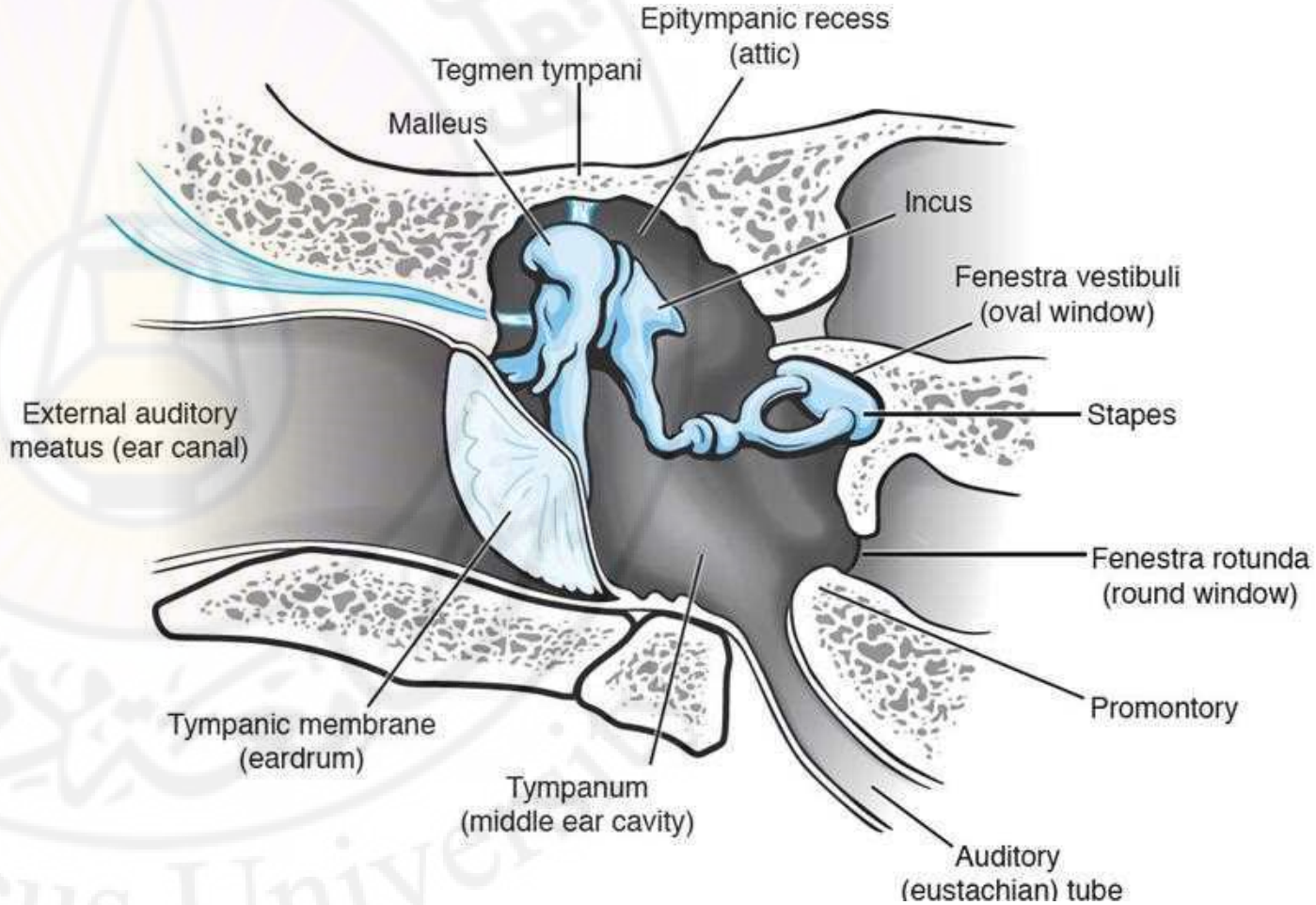
It is surrounded by fibrous tissue called the **annulus**, which fits tightly into the **tympanic sulcus**, a groove in the bony wall of the external auditory meatus.



The middle ear space

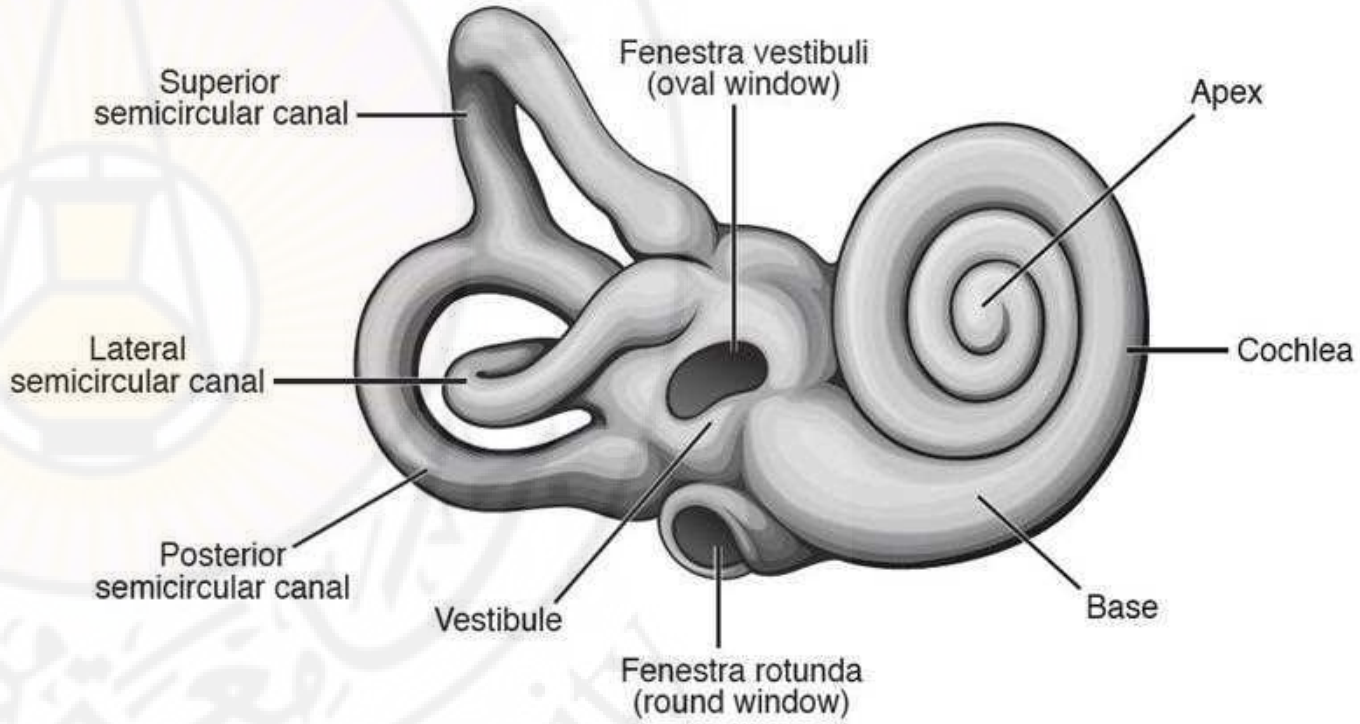
Airborne sound is transduced to mechanical energy as a result of the collection of sound energy by the tympanic membrane and subsequent movement of the three tiny ossicles within the middle ear.

The adult middle ear is a hollow, air-filled cavity approximately 0.5 inches (1.5 cm) high and wide and about 0.25 inches (0.5 cm) in depth (lateral to medial) located behind the tympanic membrane.

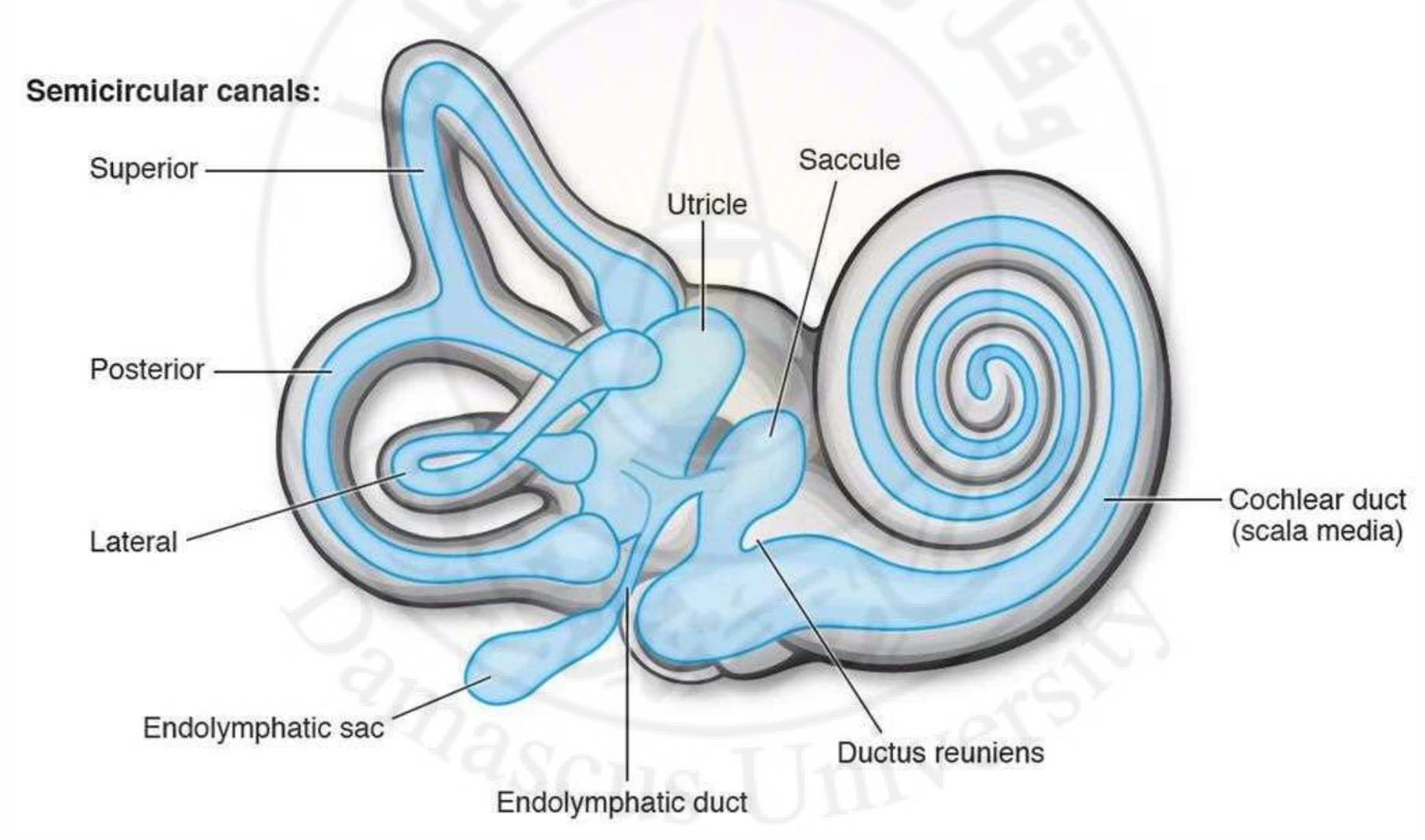


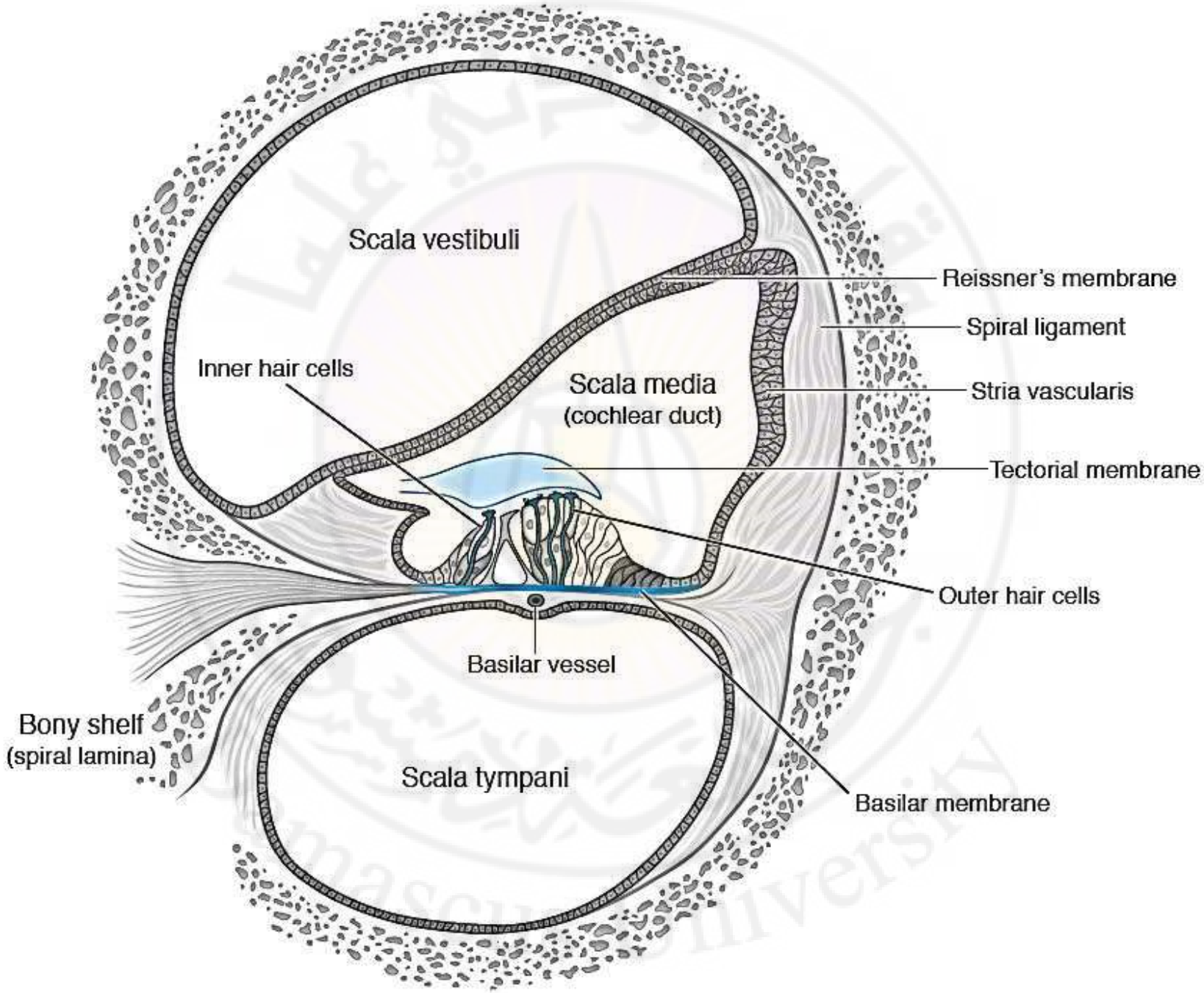
Inner Ear

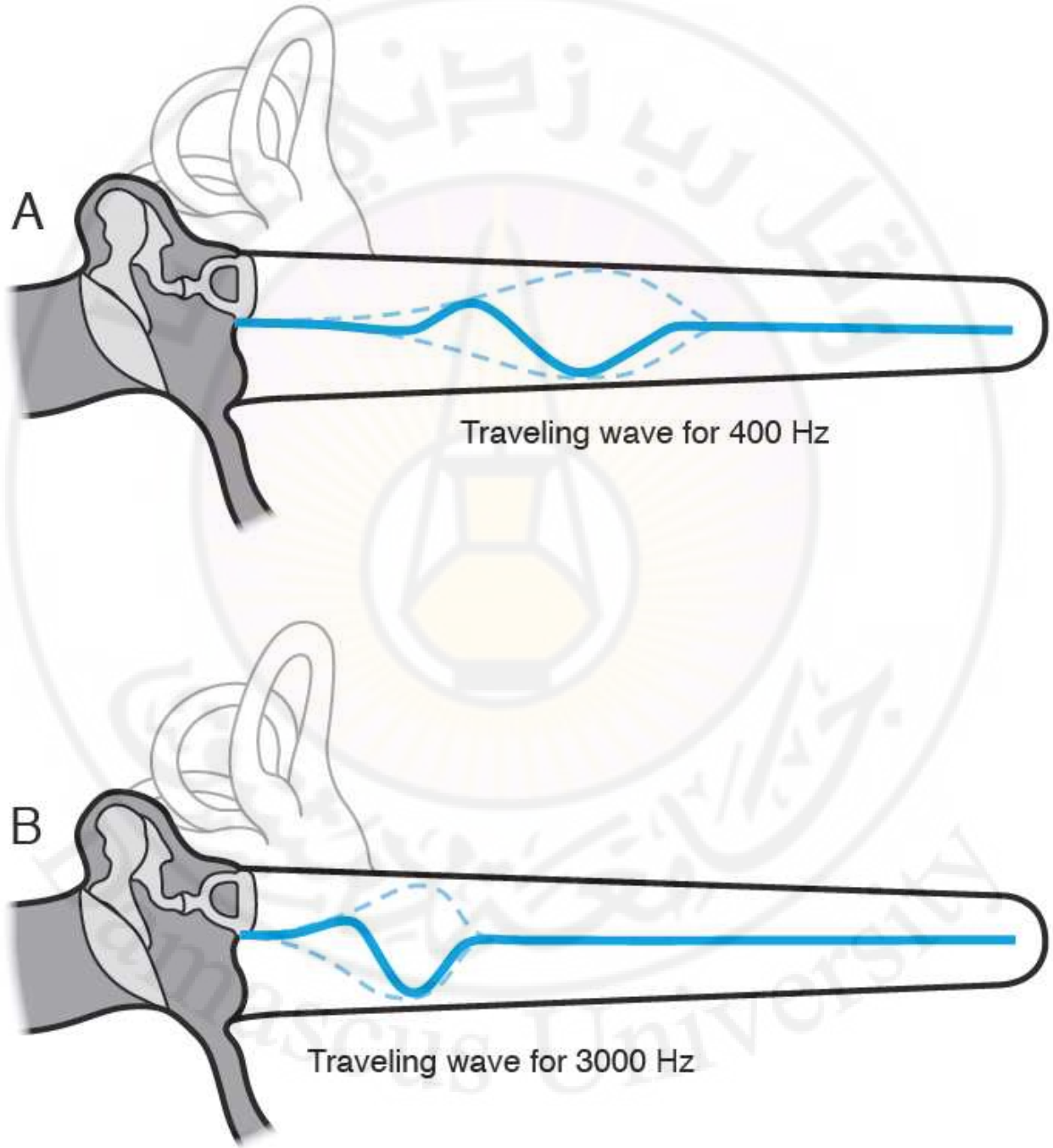
- The inner ear is a fluid-filled series of canals that lie medial to the middle ear cavity in the petrous portion of the temporal bone. It is referred to as the **Labyrinth.**
- The labyrinth consists of two separate parts, with one part (the **membranous labyrinth**) contained within the other (the **bony** [or **osseous**] **labyrinth**).
- The bony labyrinth, the outer portion of the labyrinth, is filled with fluid called **perilymph** (composed of high sodium and low potassium levels similar to cerebrospinal fluid) and contains the **cochlea**, the three **semicircular canals**, and the **vestibule**.

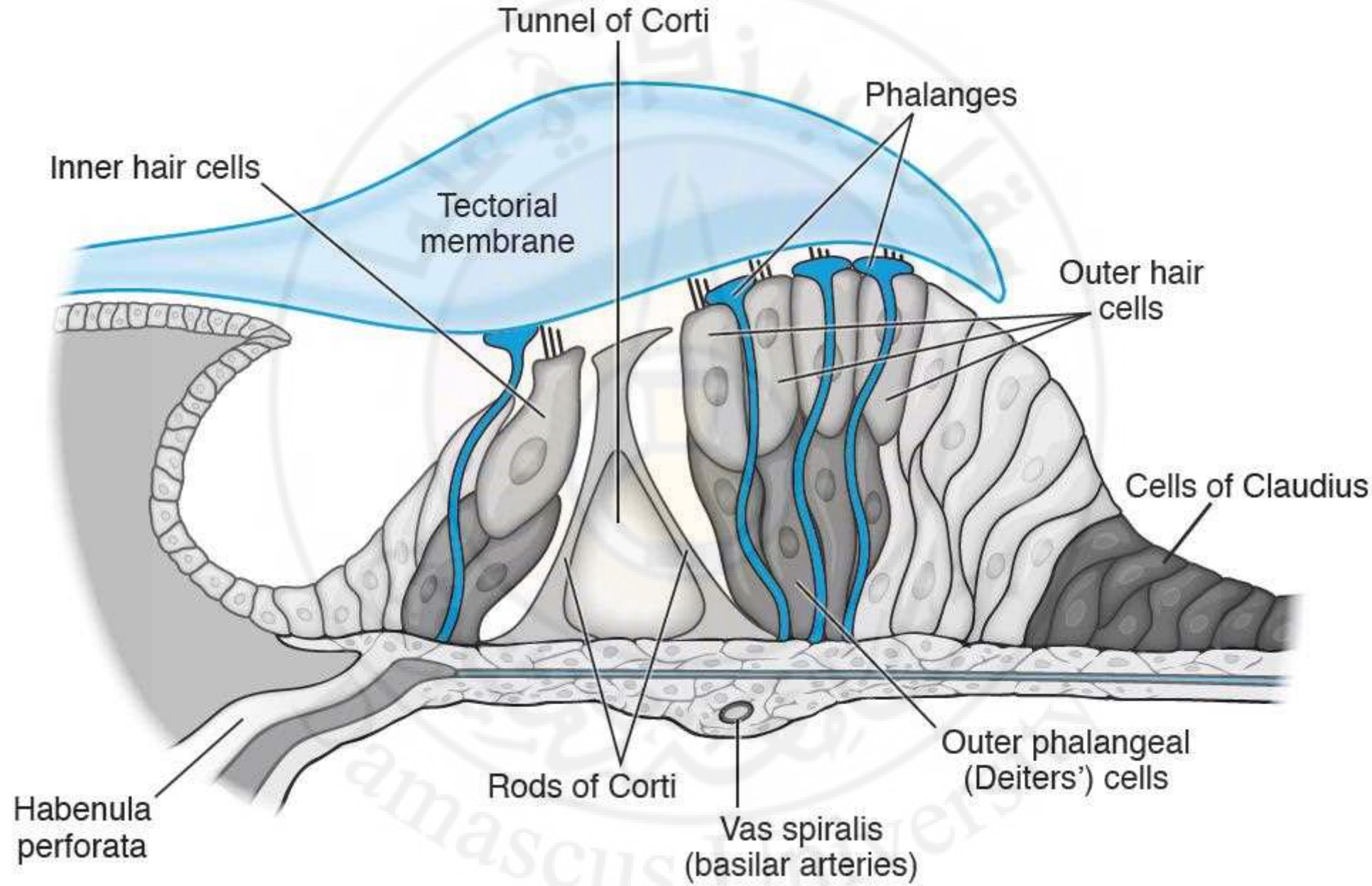


The membranous labyrinth

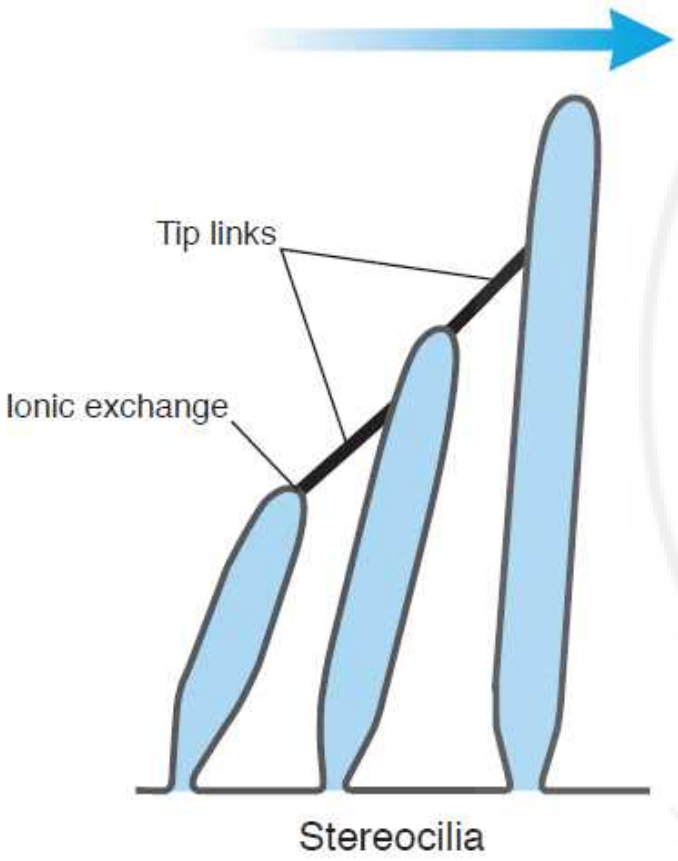


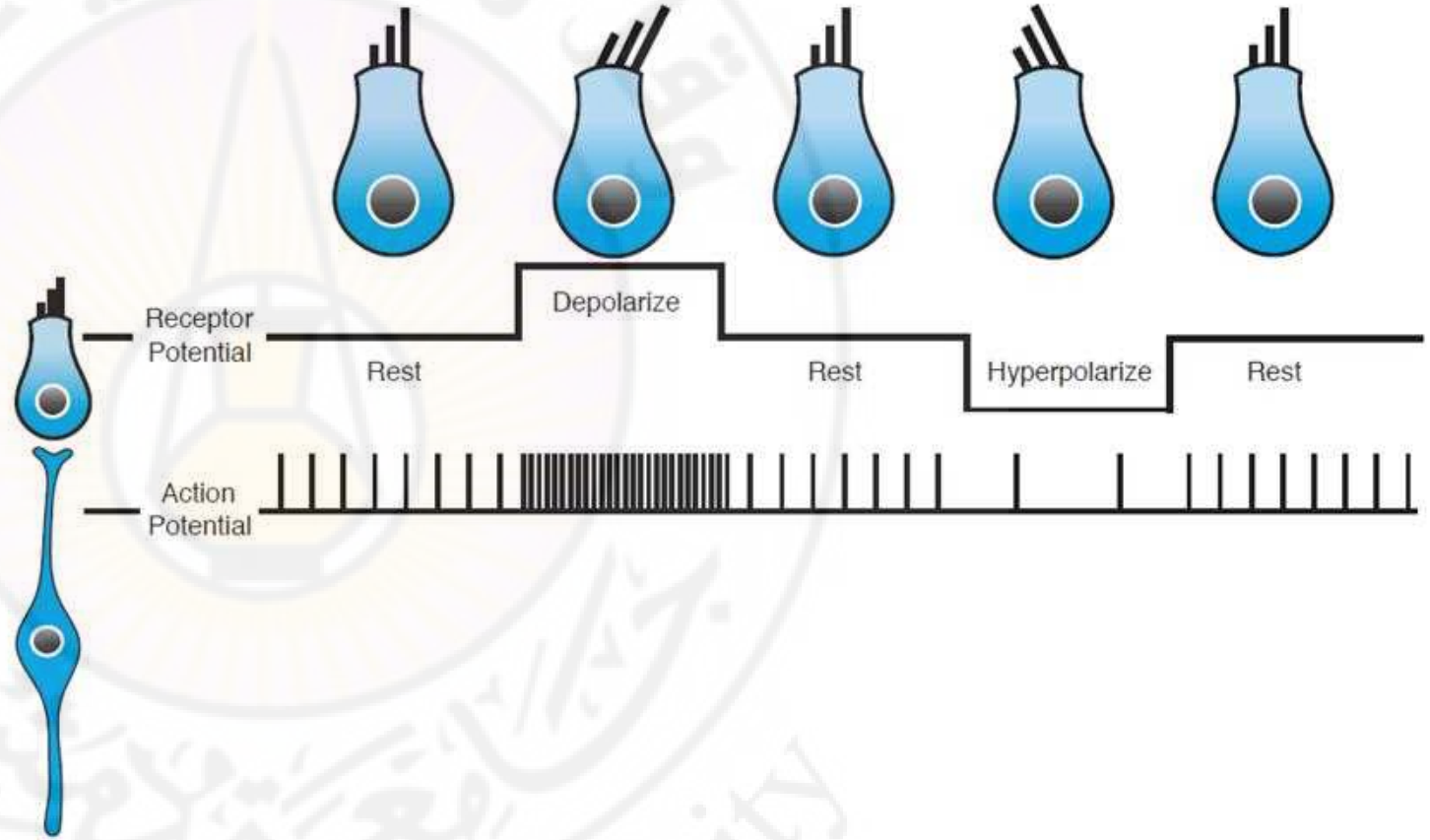

Scala vestibuli
Reissner's membrane
Spiral ligament
Inner hair cells
Scala media
(cochlear duct)
Stria vascularis
Tectorial membrane
Outer hair cells
Basilar vessel
Bony shelf
(spiral lamina)
Scala tympani
Basilar membrane


A
Traveling wave for 400 Hz
B
Traveling wave for 3000 Hz

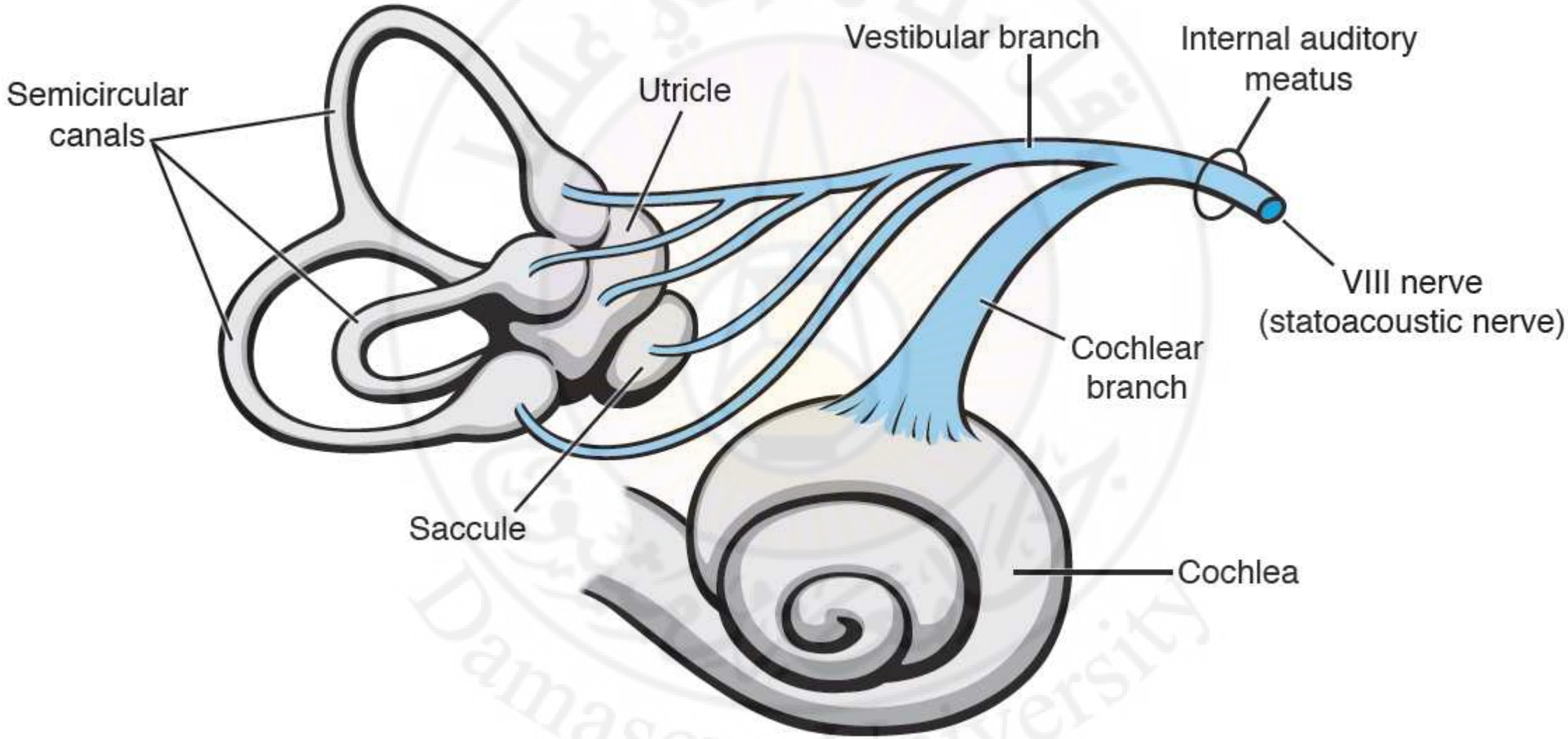

Tunnel of Corti
Phalanges
Inner hair cells
Tectorial membrane
Outer hair cells
Cells of Claudius
Outer phalangeal (Deiters') cells
Rods of Corti
Habenula perforata
Vas spiralis (basilar arteries)

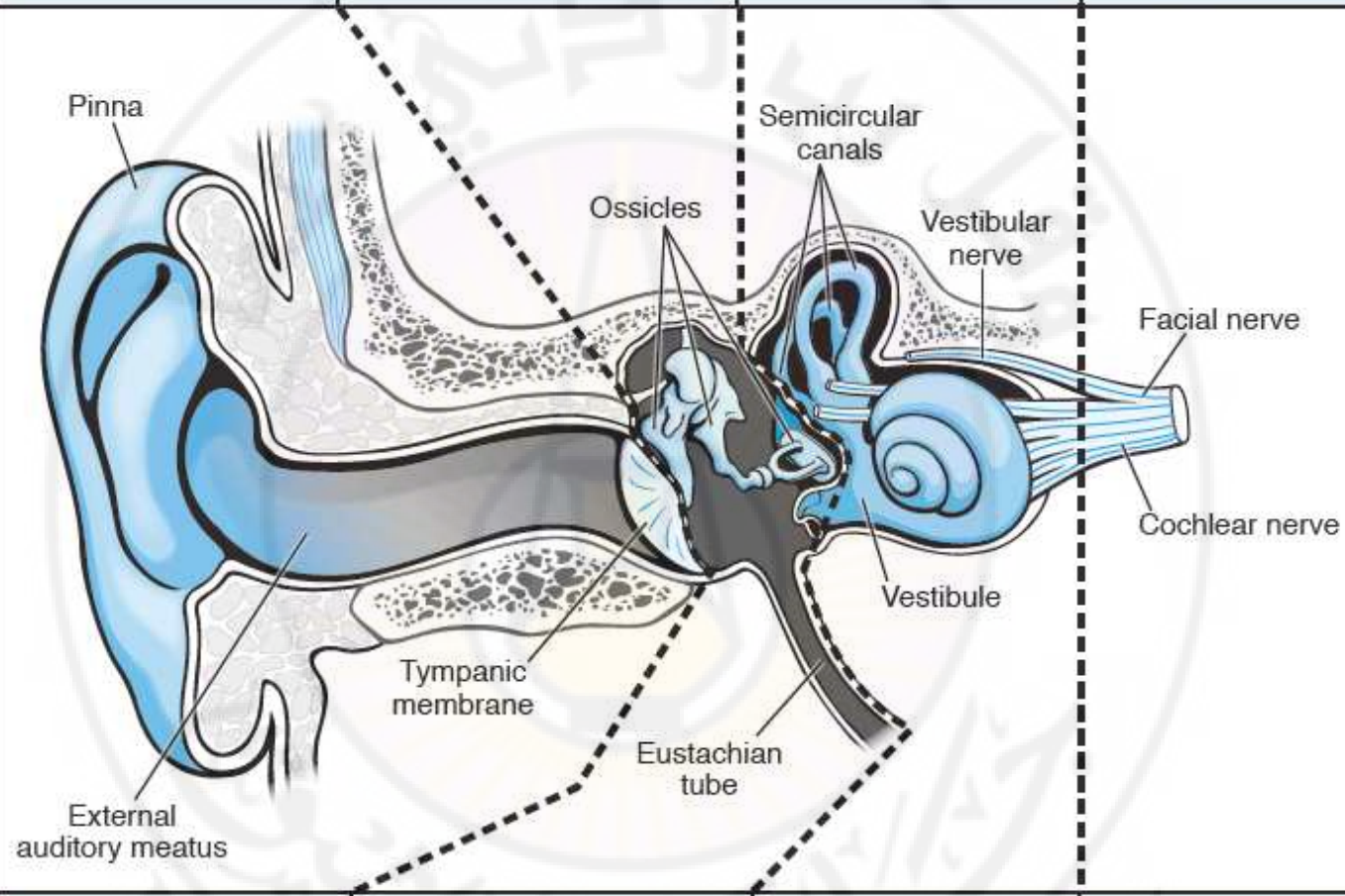
Comparison of Outer Hair Cells Versus Inner Hair Cells		
Attribute	***Outer Hair Cells***	***Inner Hair Cells***
Shape	Cylindrical	Flask shape
Number (per ear)	9,000 to 12,000	3,000 to 3,500
Rows	3	1
Mechanics	Active	Passive
Function	Electromotility	Primarily afferent
Effects of Damage	Reduced sensitivity to low-level auditory inputs	Reduced processing of speech and complex sounds



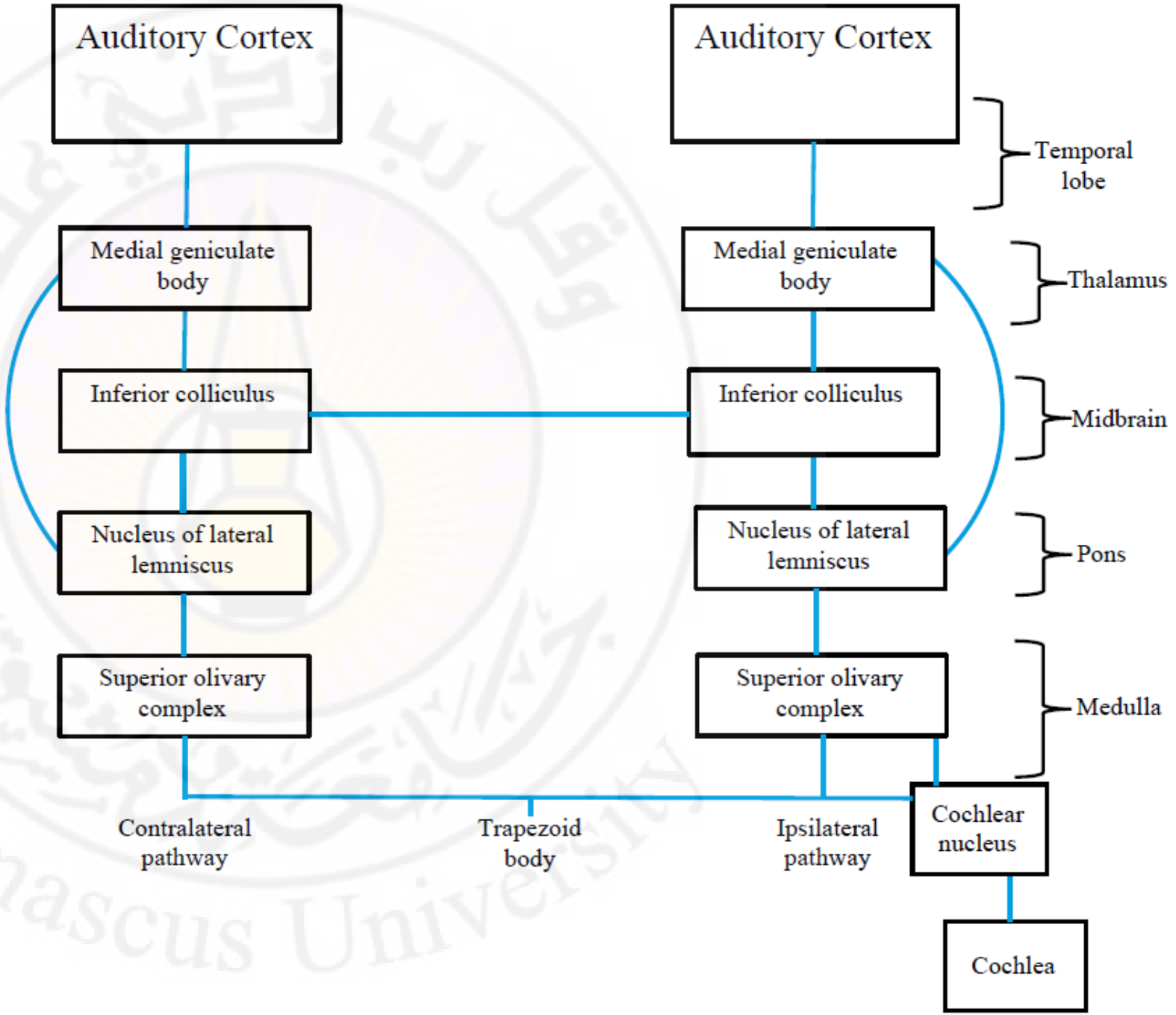


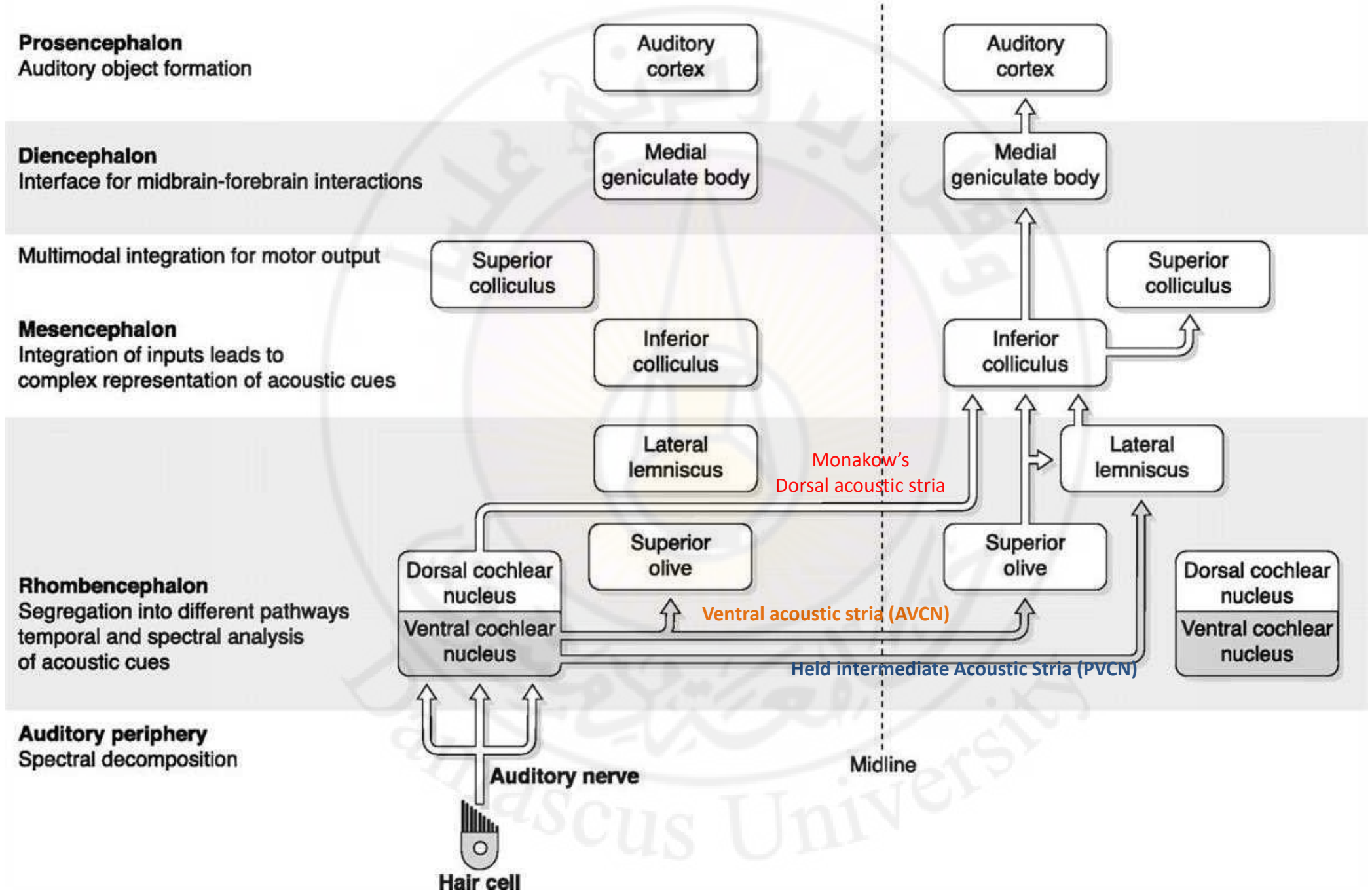
Damascus University

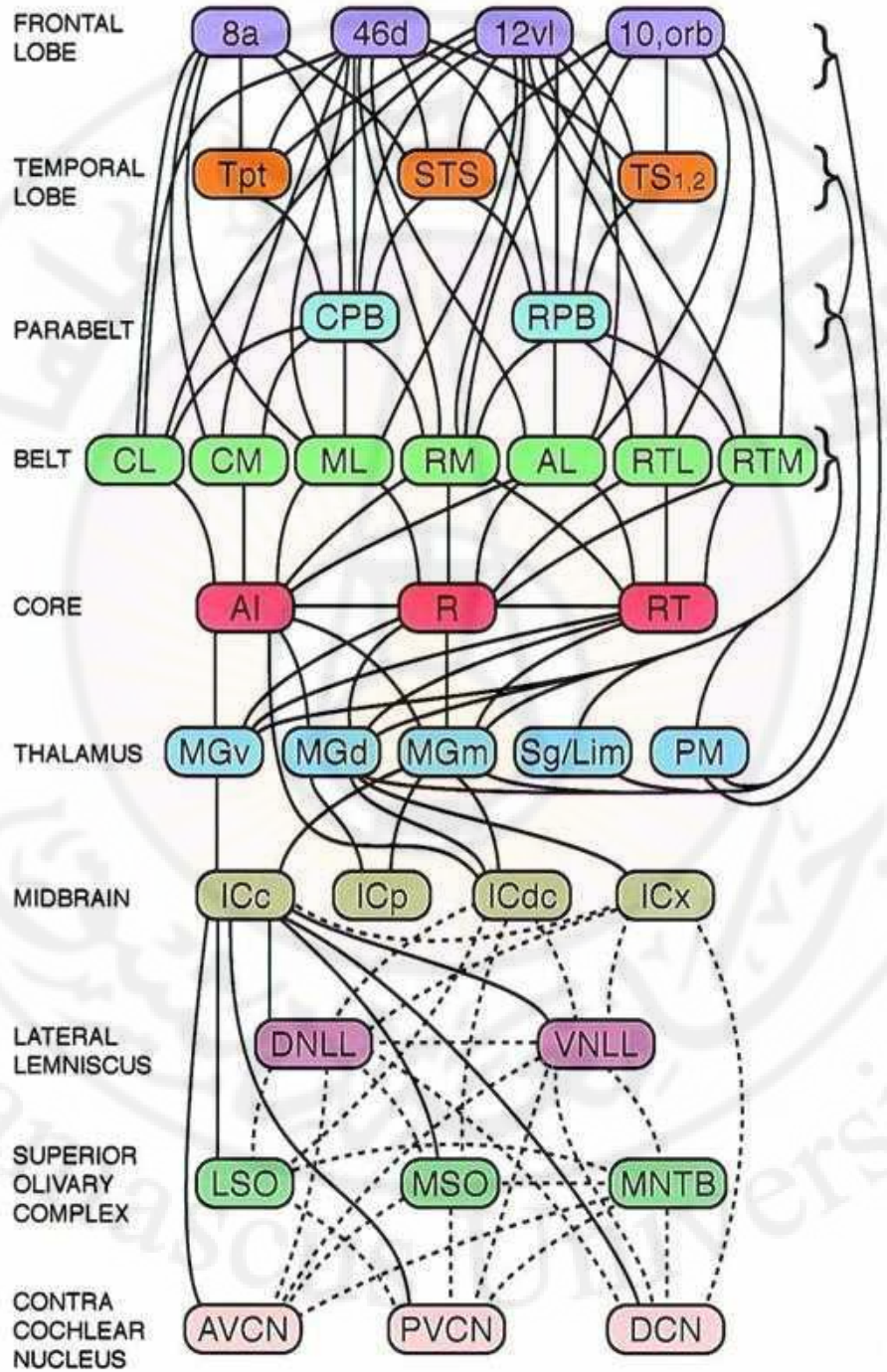

Semicircular canals
Utricle
Vestibular branch
Internal auditory meatus
VIII nerve (statoacoustic nerve)
Cochlear branch
Saccule
Cochlea

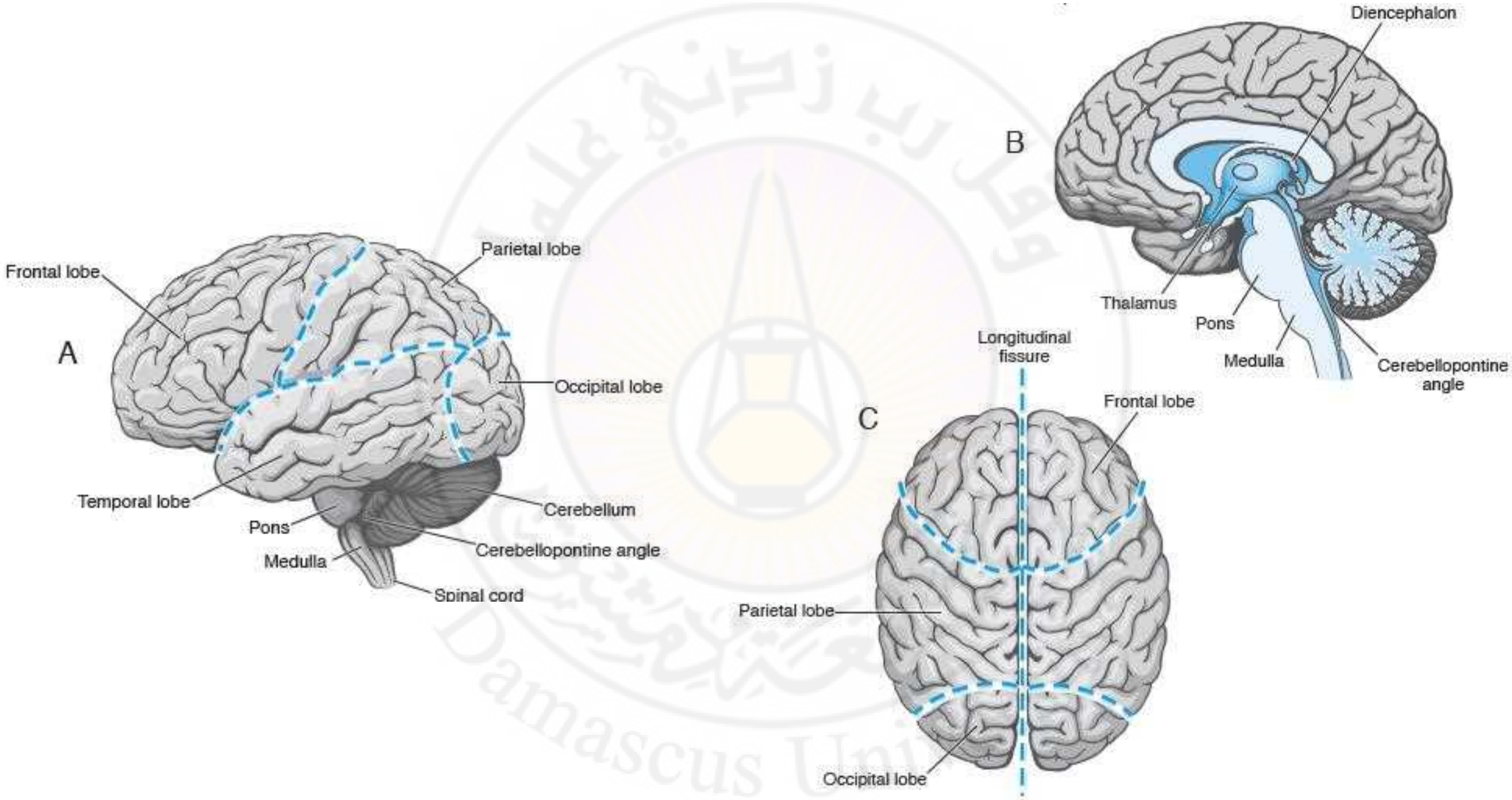
Gross division	Outer ear	Middle ear	Inner ear	Central auditory nervous system
Anatomy				
Mode of operation	Air vibration	Mechanical vibration	Mechanical Hydrodynamic Electrochemical	Electrochemical
Function	Protection Amplification Localization	Impedance matching Selective oval window simulation Pressure equalization	Filtering distribution Transduction	Information processing

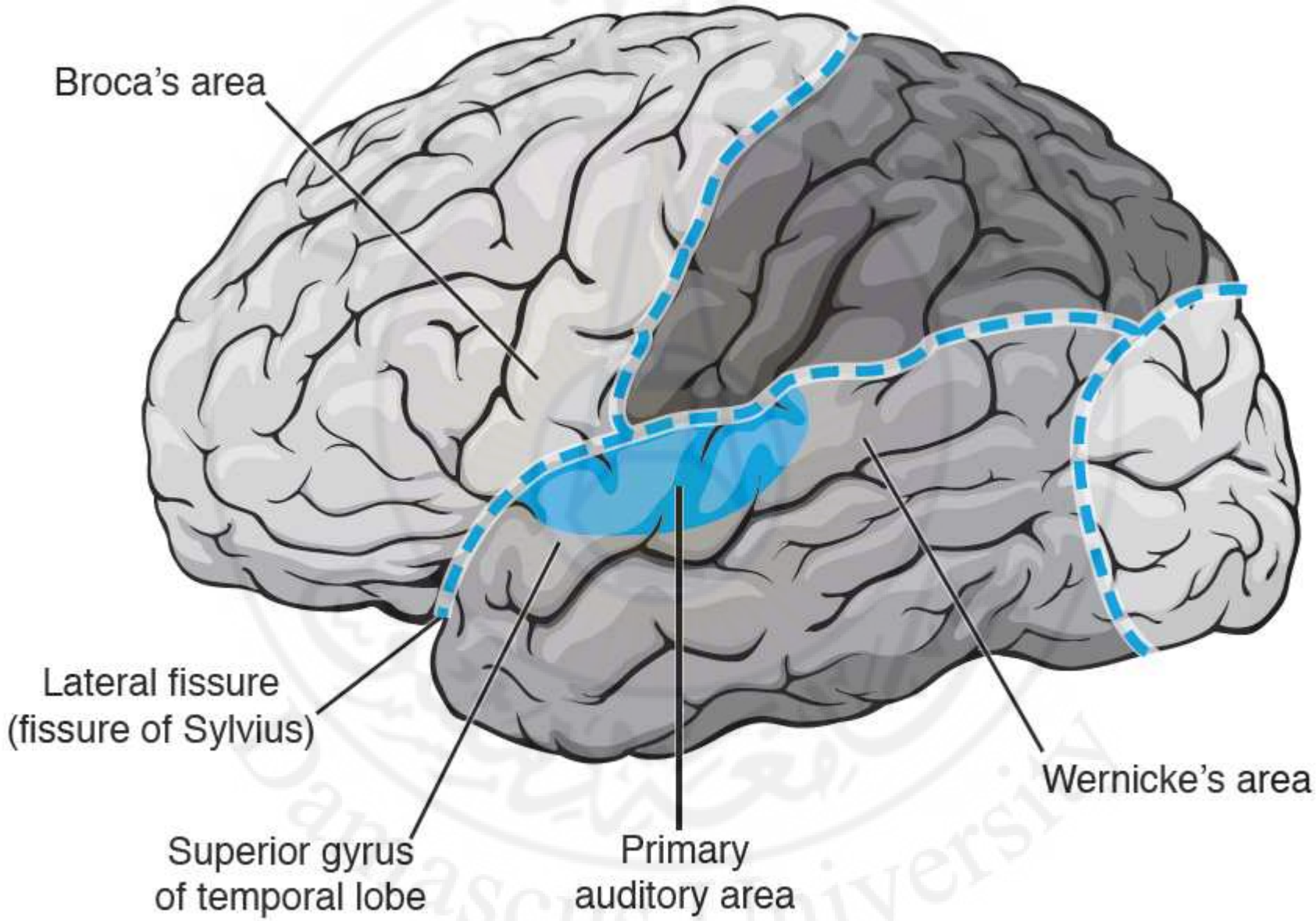
Structures of the central auditory nervous system (CANS).



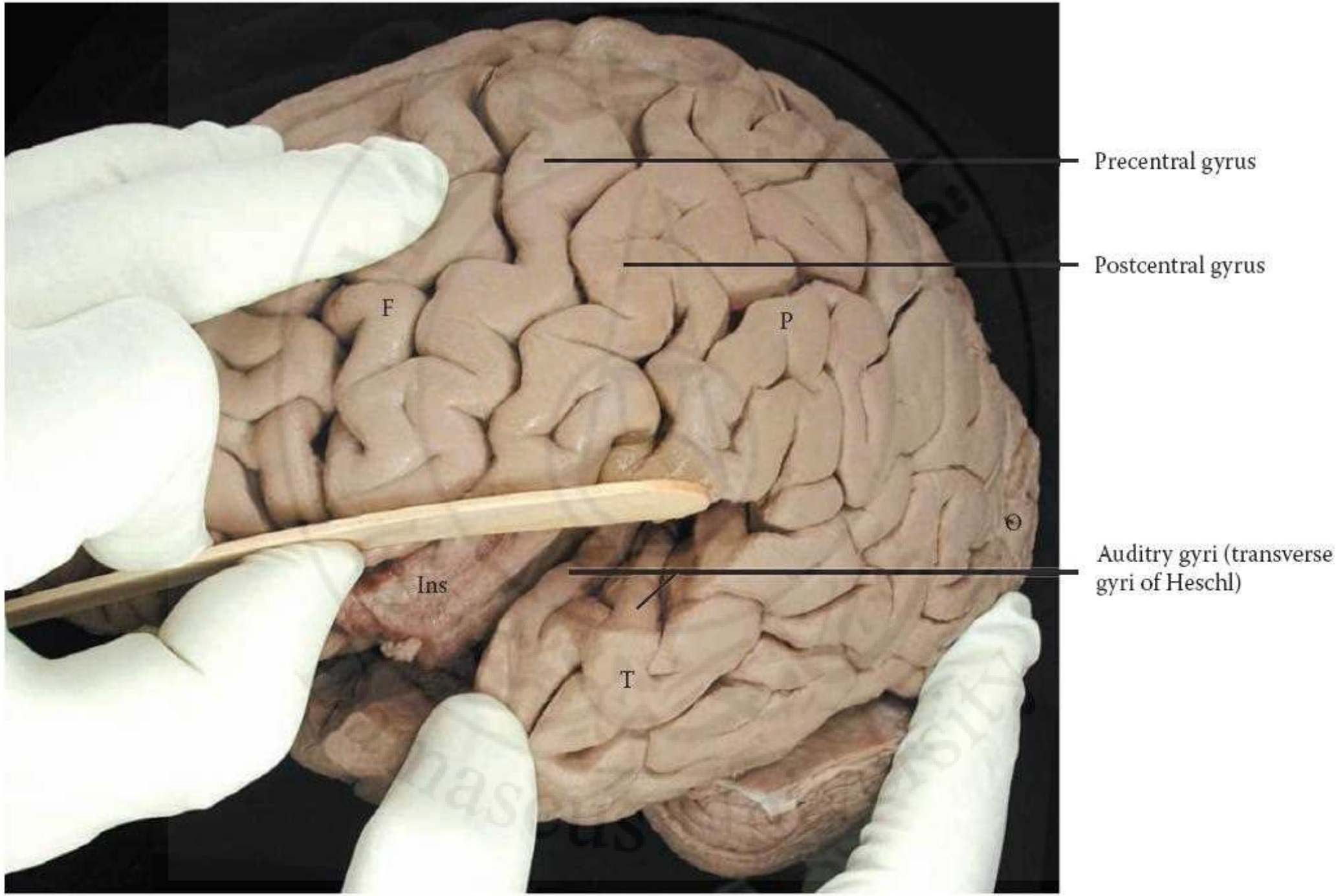

Prosencephalon
Auditory object formation
Diencephalon
Interface for midbrain-forebrain interactions
Multimodal integration for motor output
Mesencephalon
Integration of inputs leads to complex representation of acoustic cues
Rhombencephalon
Segregation into different pathways temporal and spectral analysis of acoustic cues
Auditory periphery
Spectral decomposition
Auditory cortex
Medial geniculate body
Superior colliculus
Inferior colliculus
Lateral lemniscus
Superior olive
Dorsal cochlear nucleus
Ventral cochlear nucleus
Auditory nerve
Hair cell
Midline
Monakow's
Dorsal acoustic stria
Ventral acoustic stria (AVCN)
Held intermediate Acoustic Stria (PVCN)

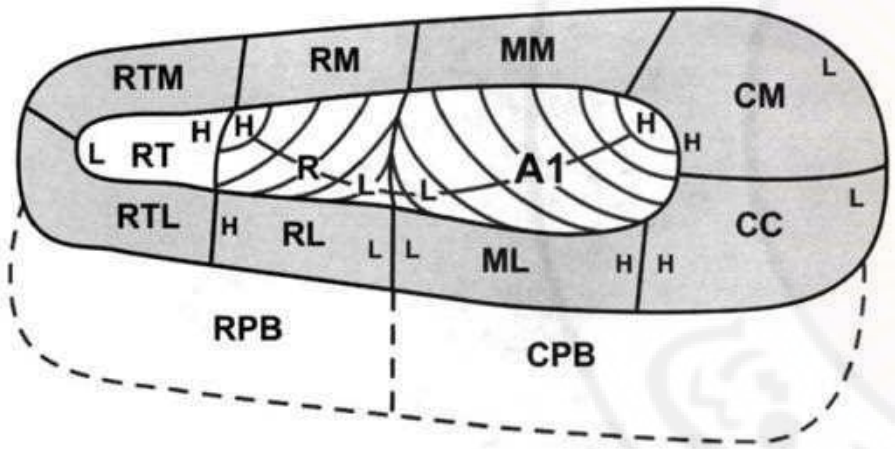

FRONTAL LOBE
8a
46d
12vl
10,orb
TEMPORAL LOBE
Tpt
STS
TS1,2
PARABELT
CPB
RPB
BELT
CL
CM
ML
RM
AL
RTL
RTM
CORE
AI
R
RT
THALAMUS
MGv
MGd
MGm
Sg/Lim
PM
MIDBRAIN
ICc
ICp
ICdc
ICx
LATERAL LEMNISCUS
DNLL
VNLL
SUPERIOR OLIVARY COMPLEX
LSO
MSO
MNTB
CONTRA COCHLEAR NUCLEUS
AVCN
PVCN
DCN

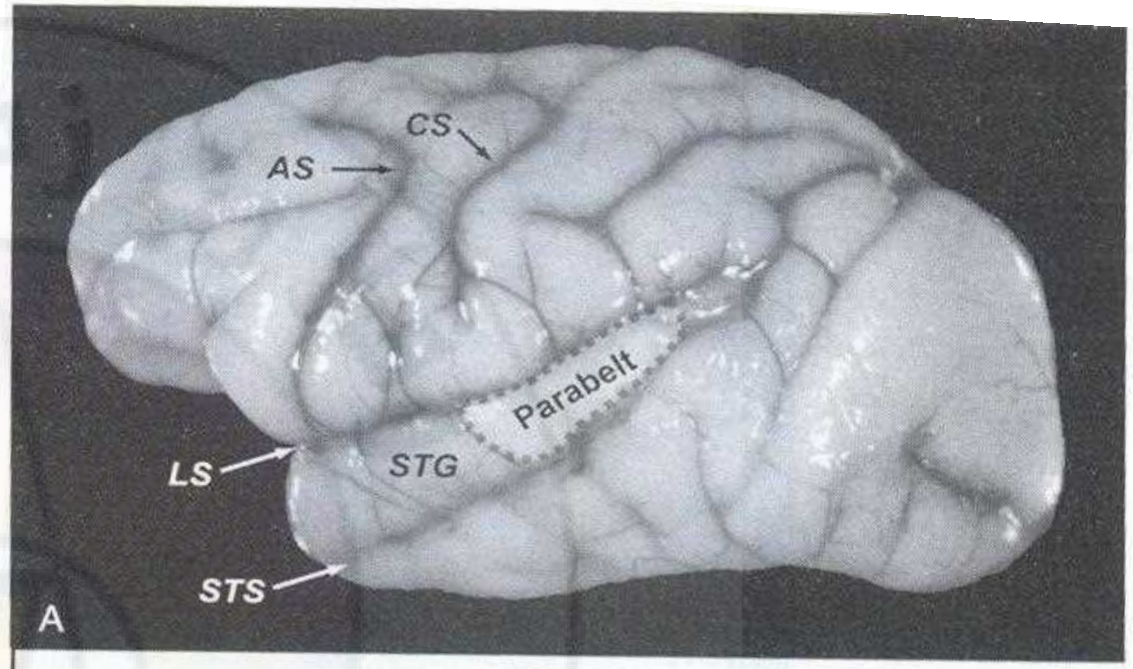

A
Frontal lobe
Parietal lobe
Occipital lobe
Temporal lobe
Cerebellum
Pons
Cerebellopontine angle
Medulla
Spinal cord
B
Diencephalon
Thalamus
Pons
Medulla
Cerebellopontine angle
C
Longitudinal fissure
Frontal lobe
Parietal lobe
Occipital lobe

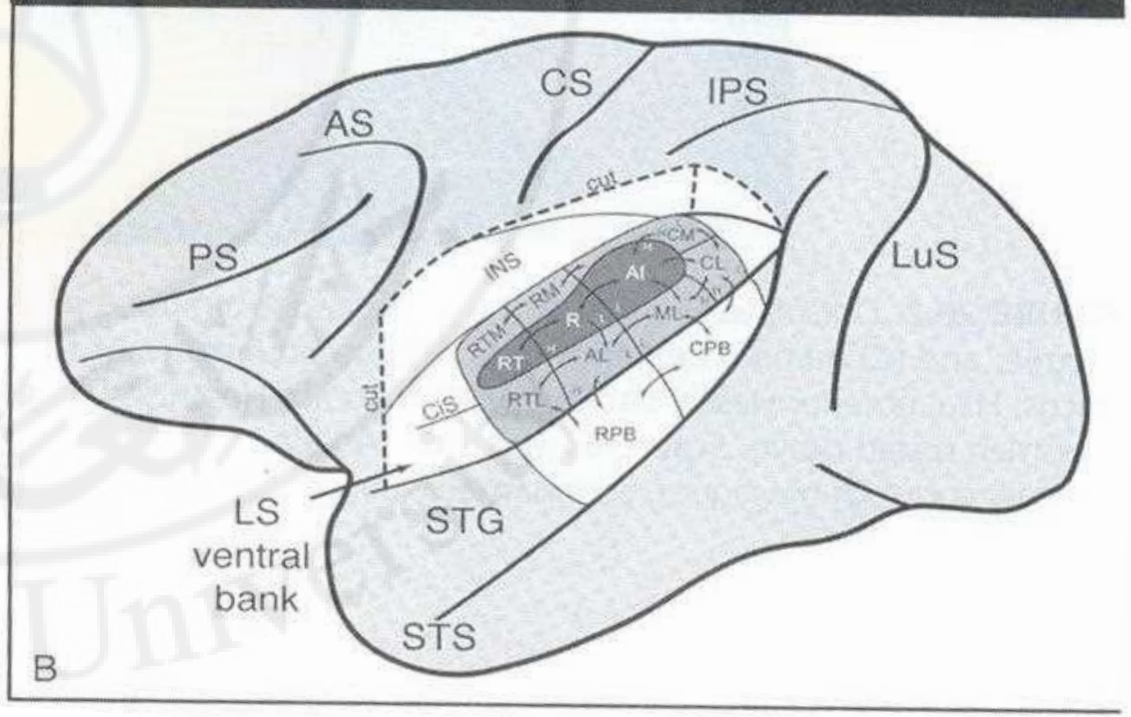

Broca's area
Lateral fissure
(fissure of Sylvius)
Superior gyrus
of temporal lobe
Primary
auditory area
Wernicke's area


Central fissure
Auditory gyri (transverse gyri of Heschl)
Insula
Lateral fissure (opened)
TW


Precentral gyrus
Postcentral gyrus
F
P
O
Auditry gyri (transverse gyri of Heschl)
Ins
T

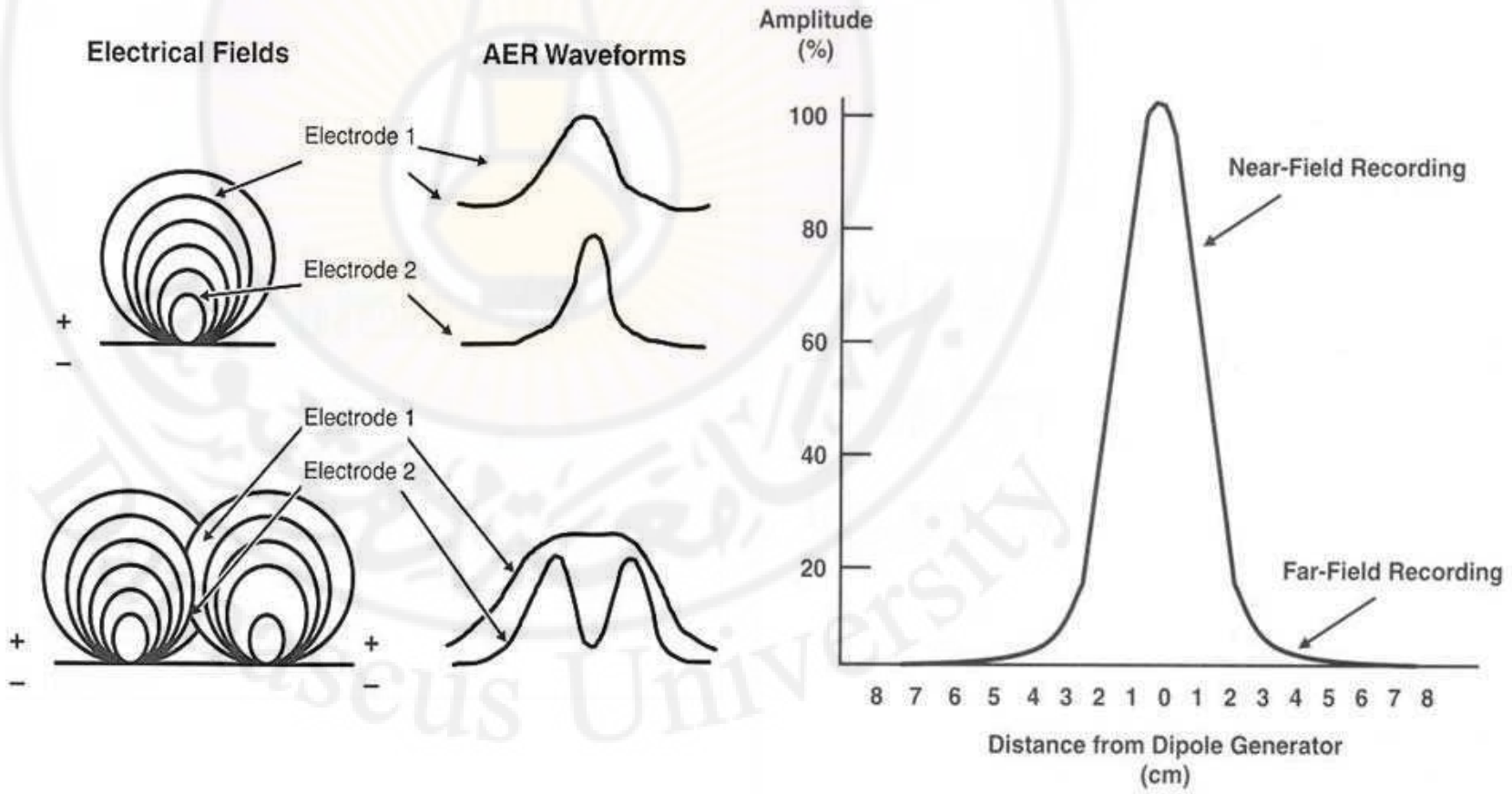

RTM
RM
MM
CM
L
H
L RT
R
A1
RTL
RL
ML
CC
RPB
CPB


CS
AS
Parabelt
LS
STG
STS
A


CS
IPS
AS
cut
PS
INS
LuS
CM
CL
AI
RM
R
ML
RTM
RT
AL
CPB
CiS
RTL
RPB
LS
ventral
bank
STG
STS
B

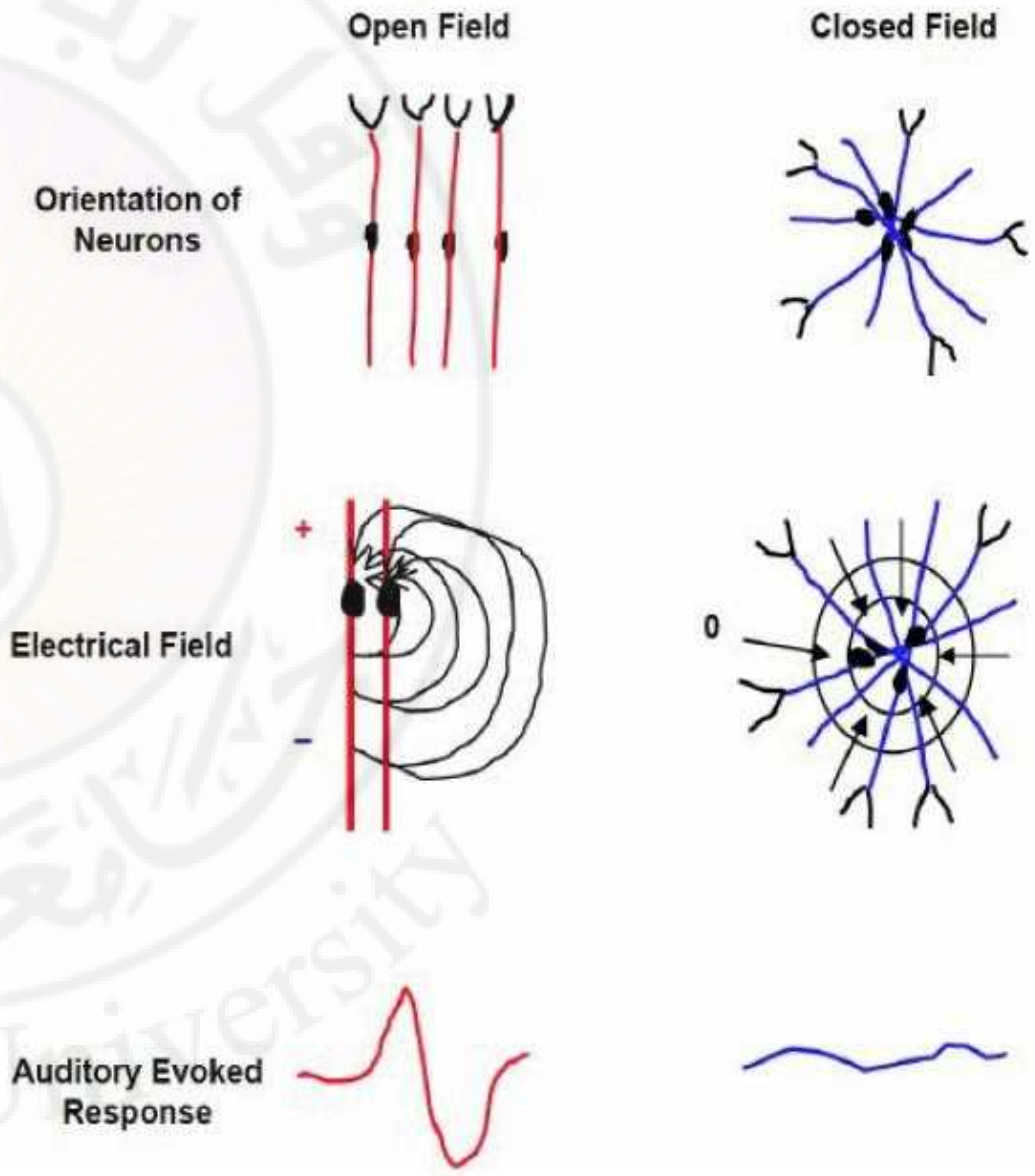
Neurophysiologic Principles in AEP recording

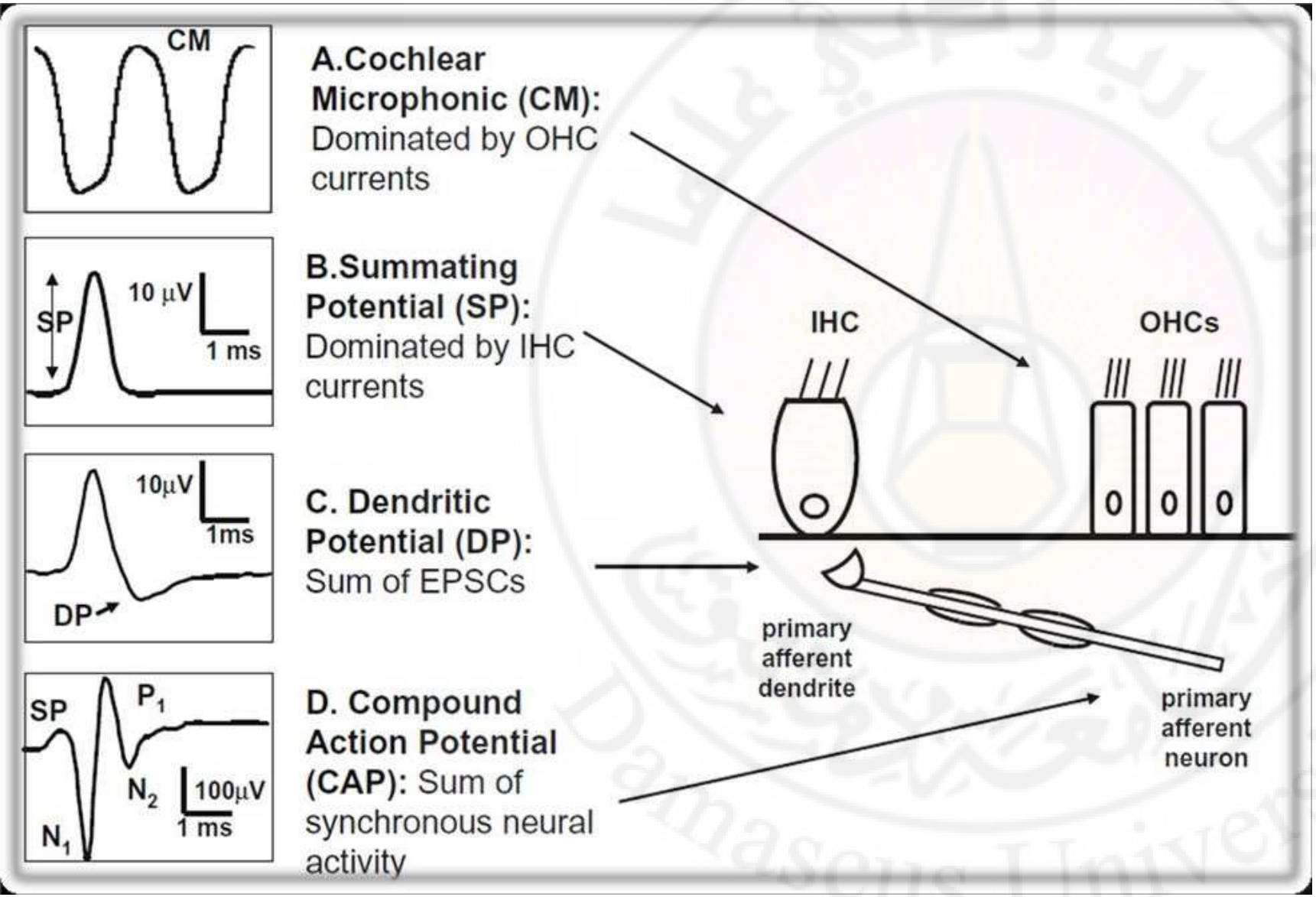
- 1. Electrode distance from dipole generator:
  - Far-field and near-field recording

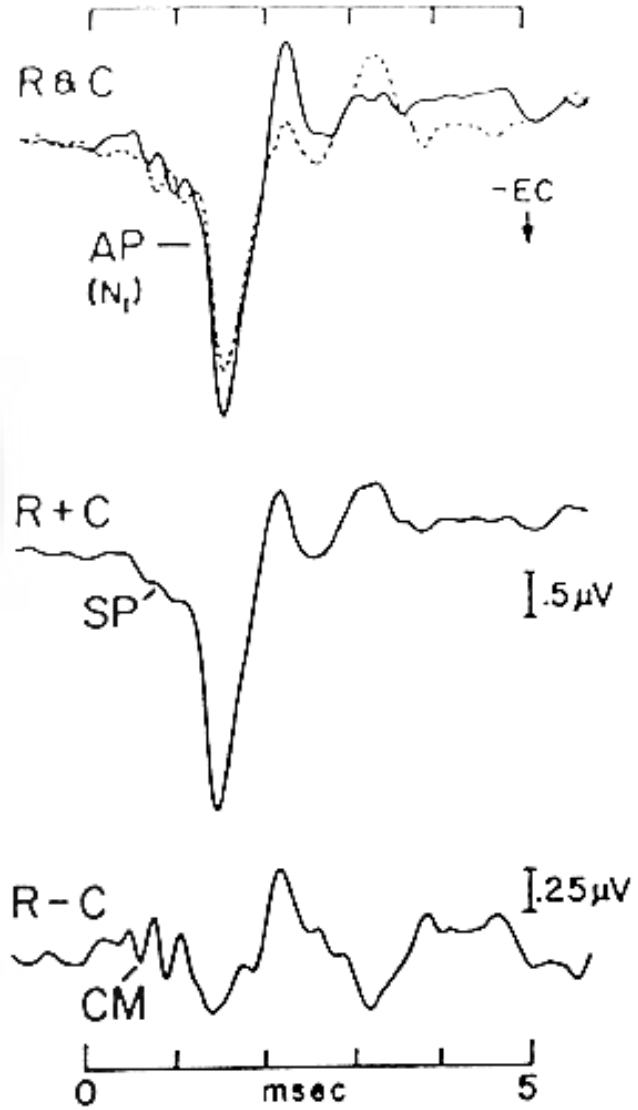


Neurophysiologic Principles in AEP recording

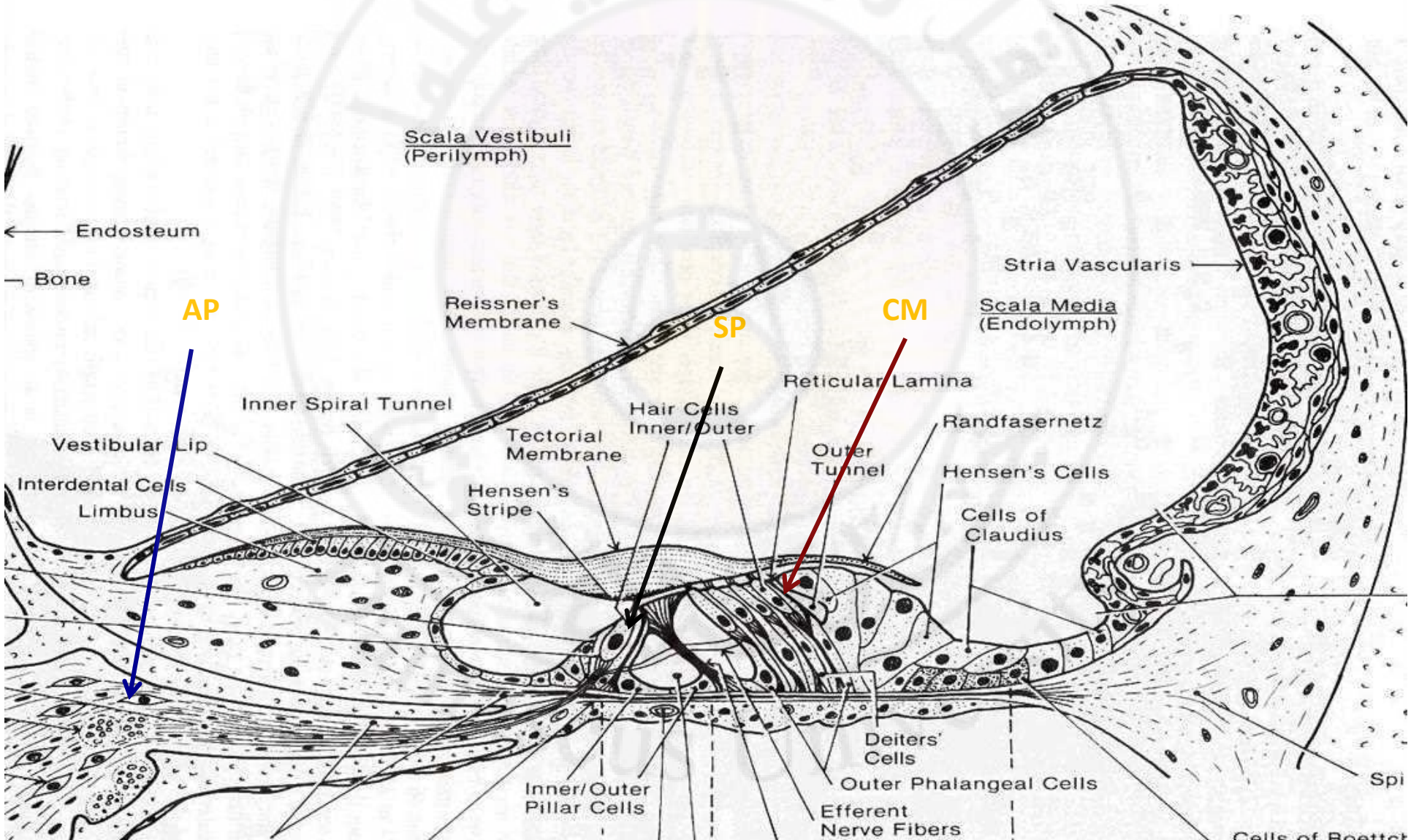
- 2. Electrical fields of neurons
  - Open or closed field?

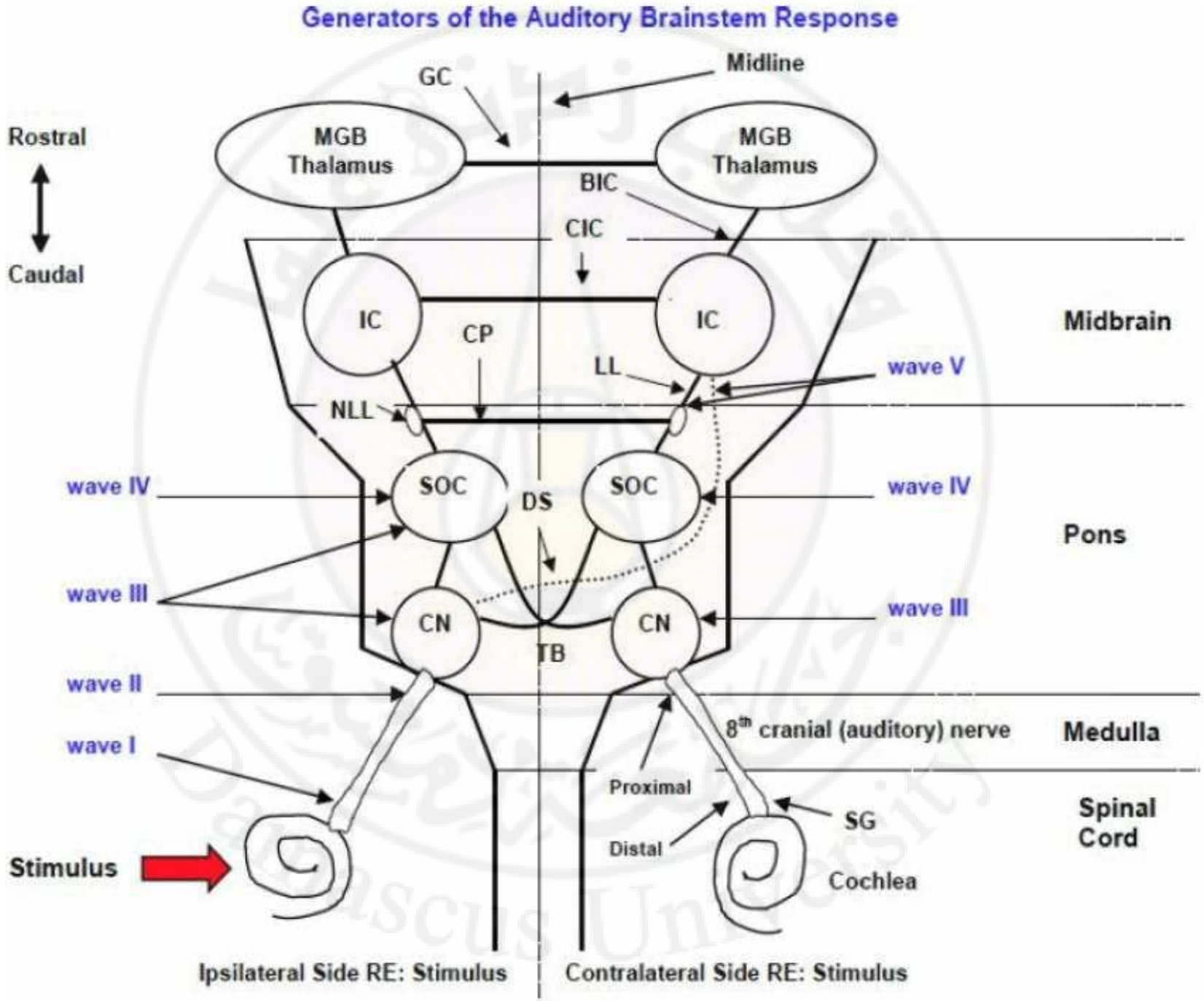



CM
A.Cochlear Microphonic (CM): Dominated by OHC currents
SP
10 μV
1 ms
B.Summating Potential (SP): Dominated by IHC currents
10μV
1ms
DP
C. Dendritic Potential (DP): Sum of EPSCs
SP
P1
N2
N1
100μV
1 ms
D. Compound Action Potential (CAP): Sum of synchronous neural activity
IHC
OHCs
primary afferent dendrite
primary afferent neuron

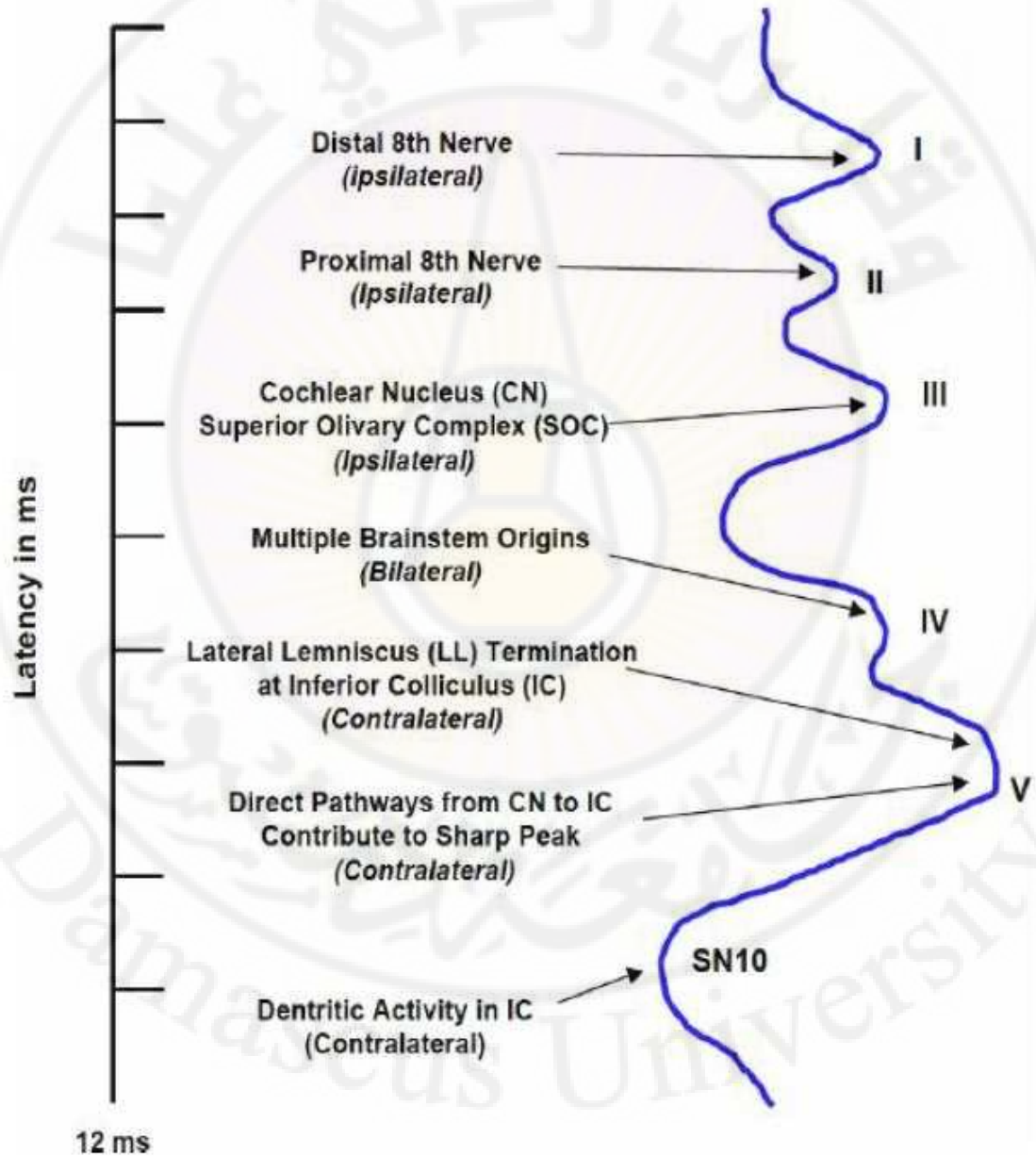

R&C
-EC
AP
(N1)
R+C
SP
.5μV
R-C
.25μV
CM
0
msec
5

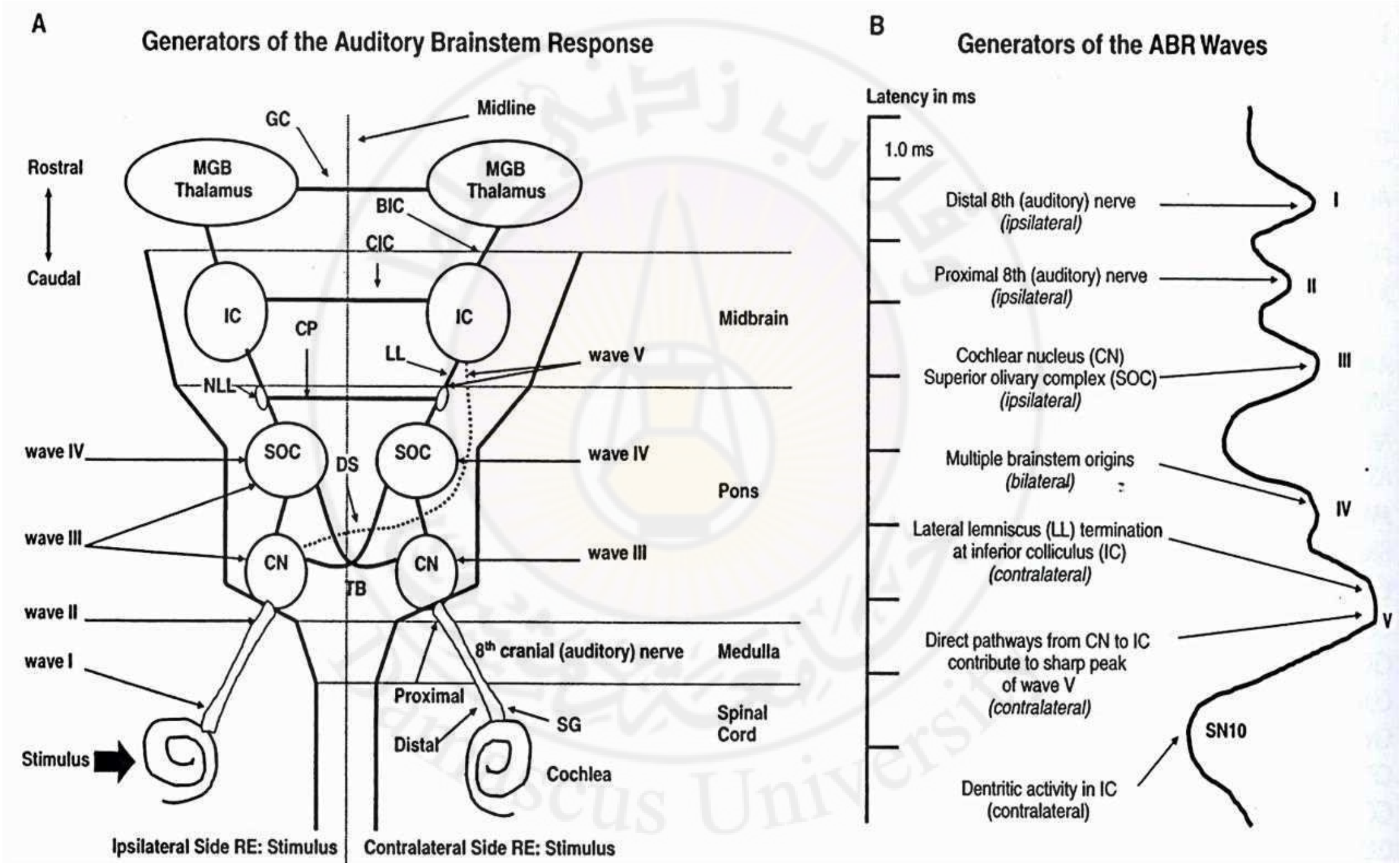
EcochG


Scala Vestibuli
(Perilymph)
Endosteum
Bone
AP
Reissner's
Membrane
SP
CM
Scala Media
(Endolymph)
Stria Vascularis
Reticular Lamina
Inner Spiral Tunnel
Hair Cells
Inner/Outer
Randfasernetz
Tectorial
Membrane
Outer
Tunnel
Vestibular Lip
Hensen's Cells
Interdental Cells
Hensen's
Stripe
Limbus
Cells of
Claudius
Deiters'
Cells
Outer Phalangeal Cells
Inner/Outer
Pillar Cells
Efferent
Nerve Fibers


Generators of the Auditory Brainstem Response
GC
Midline
Rostral
Caudal
MGB Thalamus
MGB Thalamus
BIC
CIC
IC
IC
CP
LL
wave V
NLL
Midbrain
wave IV
SOC
DS
SOC
wave IV
Pons
wave III
CN
CN
wave III
TB
wave II
wave I
8th cranial (auditory) nerve
Medulla
Proximal
Distal
SG
Cochlea
Spinal Cord
Stimulus
Ipsilateral Side RE: Stimulus
Contralateral Side RE: Stimulus

Generators of ABR Waves



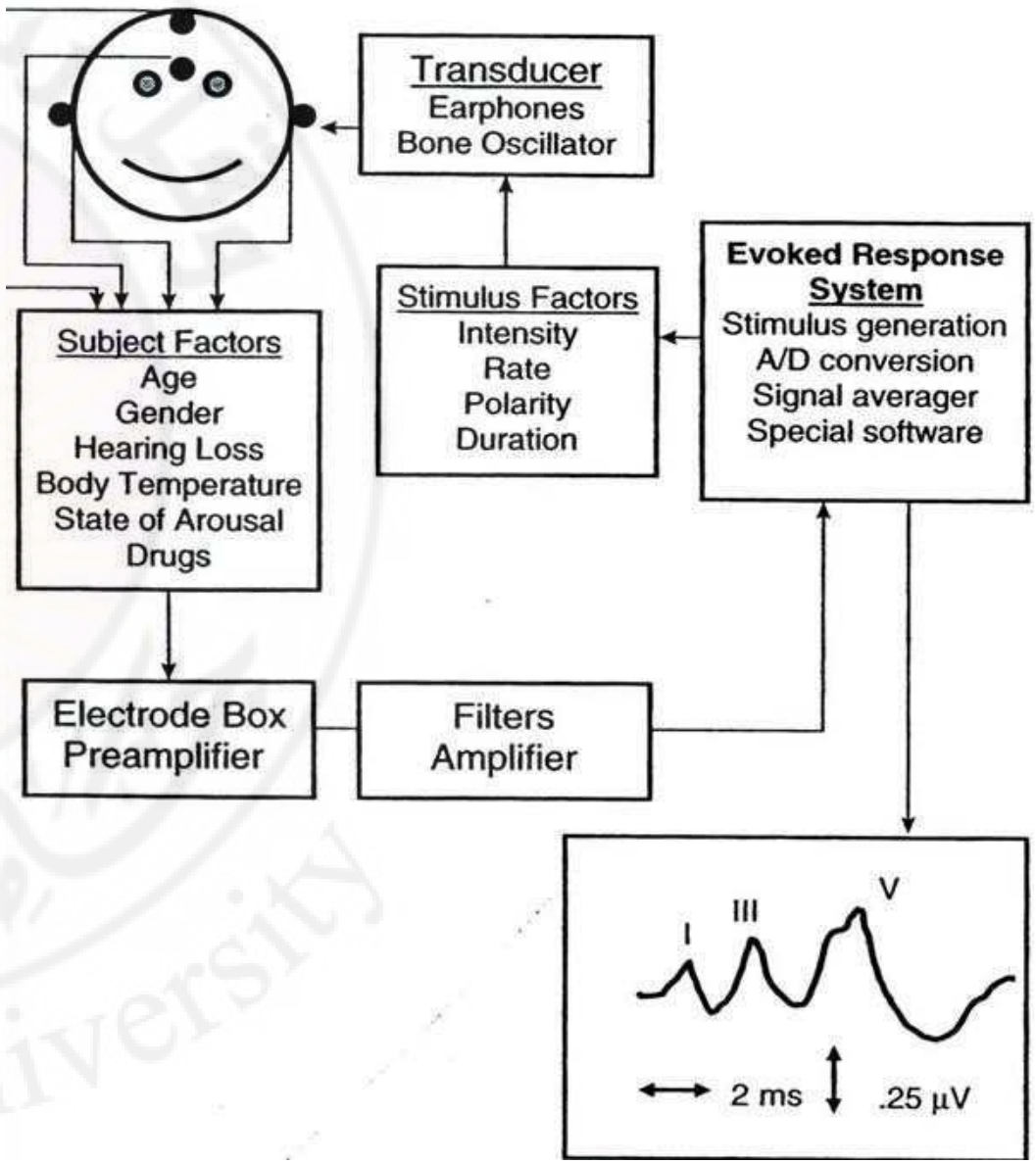

A
Generators of the Auditory Brainstem Response
GC
Midline
Rostral
Caudal
MGB Thalamus
MGB Thalamus
BIC
CIC
IC
IC
CP
LL
wave V
NLL
Midbrain
wave IV
SOC
DS
SOC
wave IV
Pons
wave III
CN
CN
wave III
TB
wave II
8th cranial (auditory) nerve
Medulla
wave I
Proximal
SG
Spinal Cord
Distal
Stimulus
Cochlea
Ipsilateral Side RE: Stimulus
Contralateral Side RE: Stimulus
B
Generators of the ABR Waves
Latency in ms
1.0 ms
Distal 8th (auditory) nerve (ipsilateral)
I
Proximal 8th (auditory) nerve (ipsilateral)
II
Cochlear nucleus (CN) Superior olivary complex (SOC) (ipsilateral)
III
Multiple brainstem origins (bilateral)
IV
Lateral lemniscus (LL) termination at inferior colliculus (IC) (contralateral)
V
Direct pathways from CN to IC contribute to sharp peak of wave V (contralateral)
SN10
Dentritic activity in IC (contralateral)

3. Factors in Measurement of Auditory Evoked Responses

Important factors influencing AERs

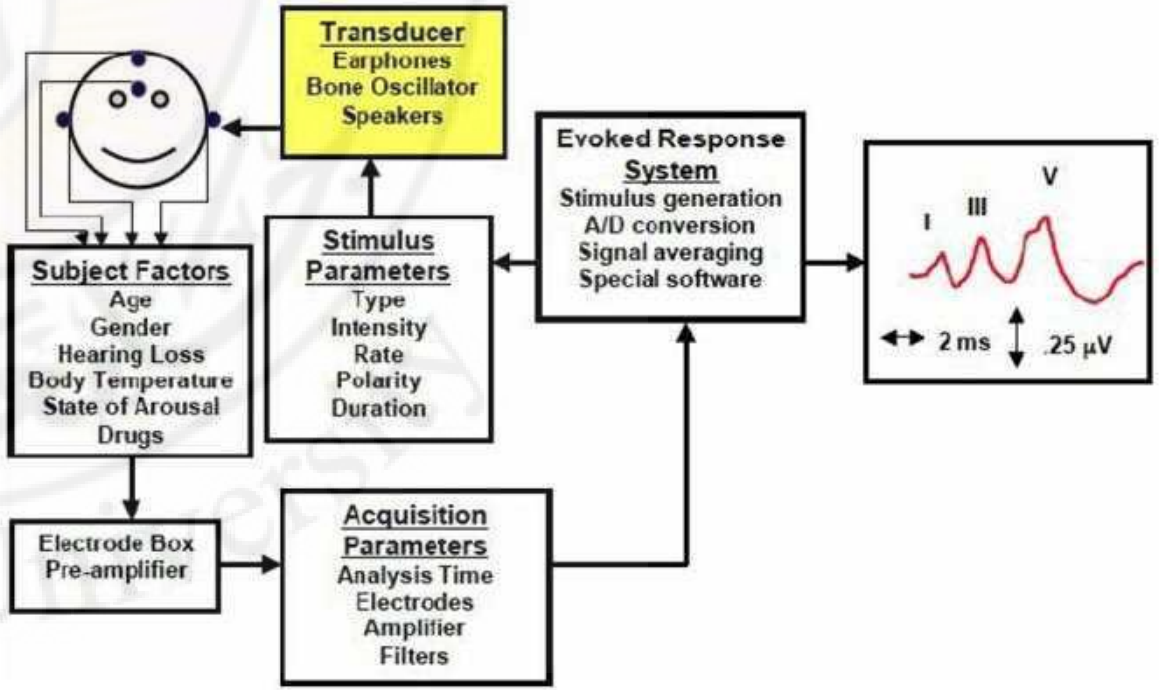
- **Stimulus Parameters**
- **Acquisition Parameters**
- **Subject factors**
  - Non-Pathological
  - Pathological
- **Examiner(s) Factors**

- Accurate, reliable, and clinically meaningful auditory evoked response measurement depends on an appreciation and understanding of how the above mentioned factors affect each type of response.



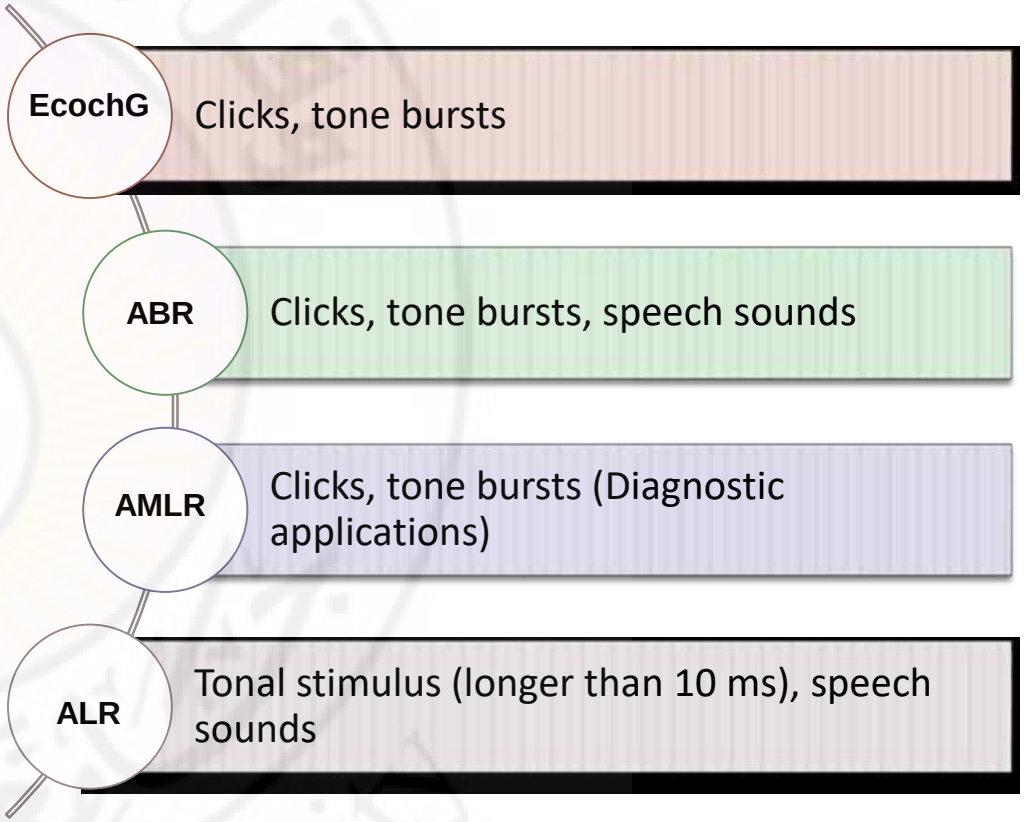
Stimulus Parameters

- Major Stimulus parameters in measurement of auditory evoked responses are:
- **Type and frequency of stimulus**
- **Duration**
- **Intensity**
- **Rate of presentation**
- **Inter-stimulus intervals (ISI)**
- **Polarity**
- **Transducer**
- **Masking**



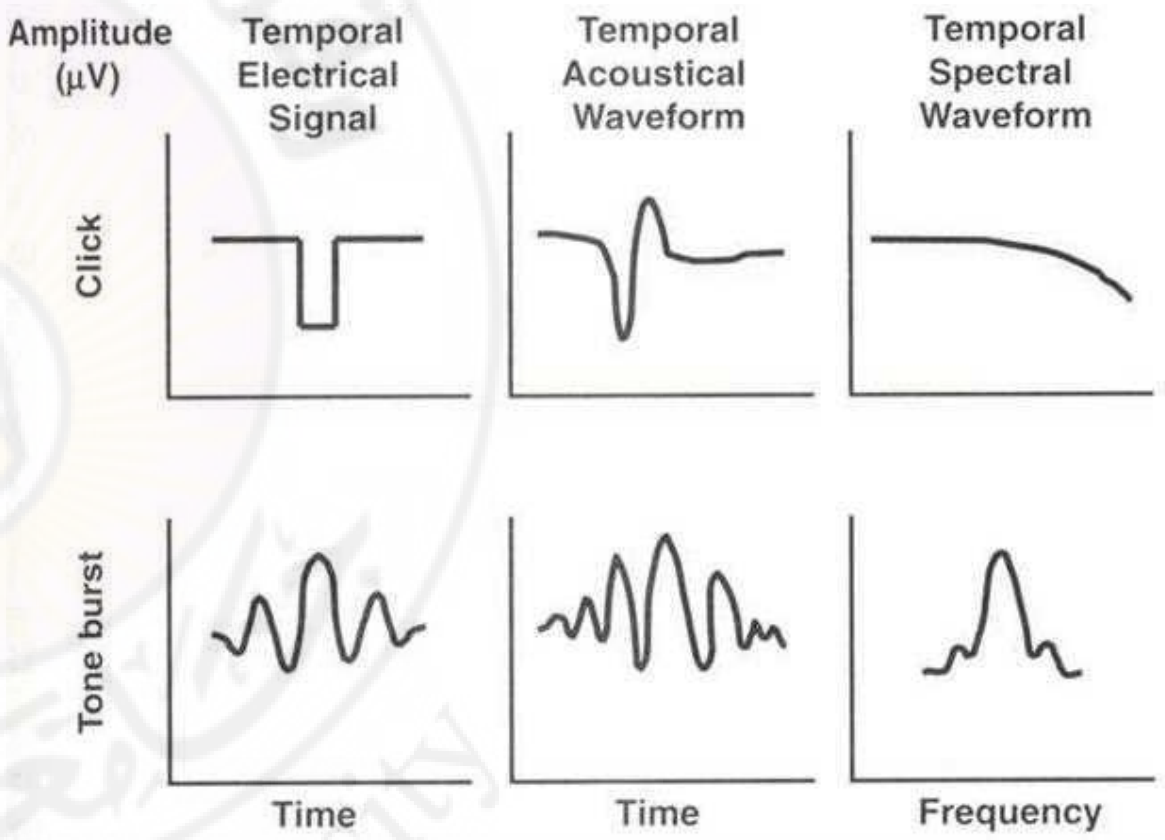
1. Type and frequency of stimulus

- For neurophysiological reasons, early latency auditory evoked responses such as the ABR are recorded optimally with very brief transient stimuli having an almost instantaneous onset.
- In fact, the rapid onset of the transient stimulus is important in producing the synchronous firing of numerous auditory neurons that underlies these responses.



1. Type and frequency of stimulus

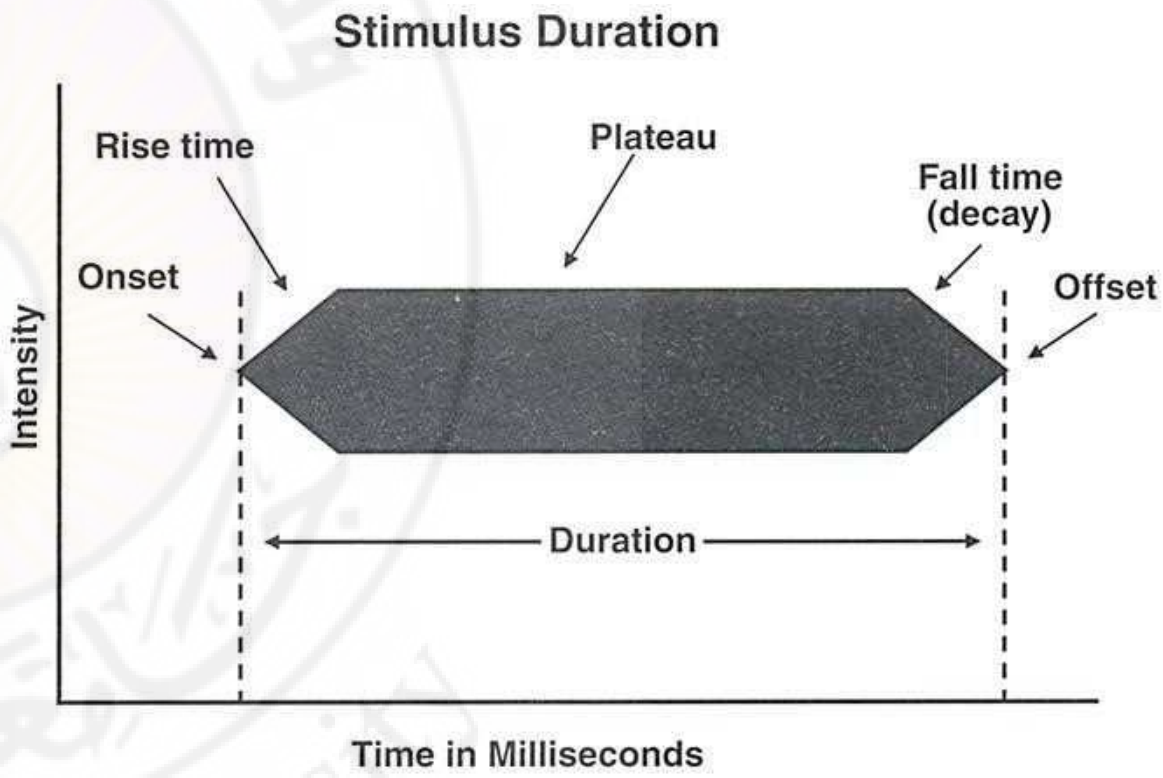
- ***Click* stimuli** have a very abrupt almost instantaneous onset and a brief duration of 0.1-ms. Keep in mind that 0.1-ms is the same as 100 microseconds, abbreviated µsec. Clicks are often referred to as transient stimuli. Click stimuli are commonly used in the measurement of ECochG or ABRs.
- ***Tone bursts*** consist of 4 or 5 cycles of pure tone signals.
- ***Speech stimuli*** are typically consonant-vowel combinations like /da/ with a duration of less than 50-ms.
- ***Chirp stimuli***



- Temporal and spectral characteristics of these types of stimuli differ considerably.

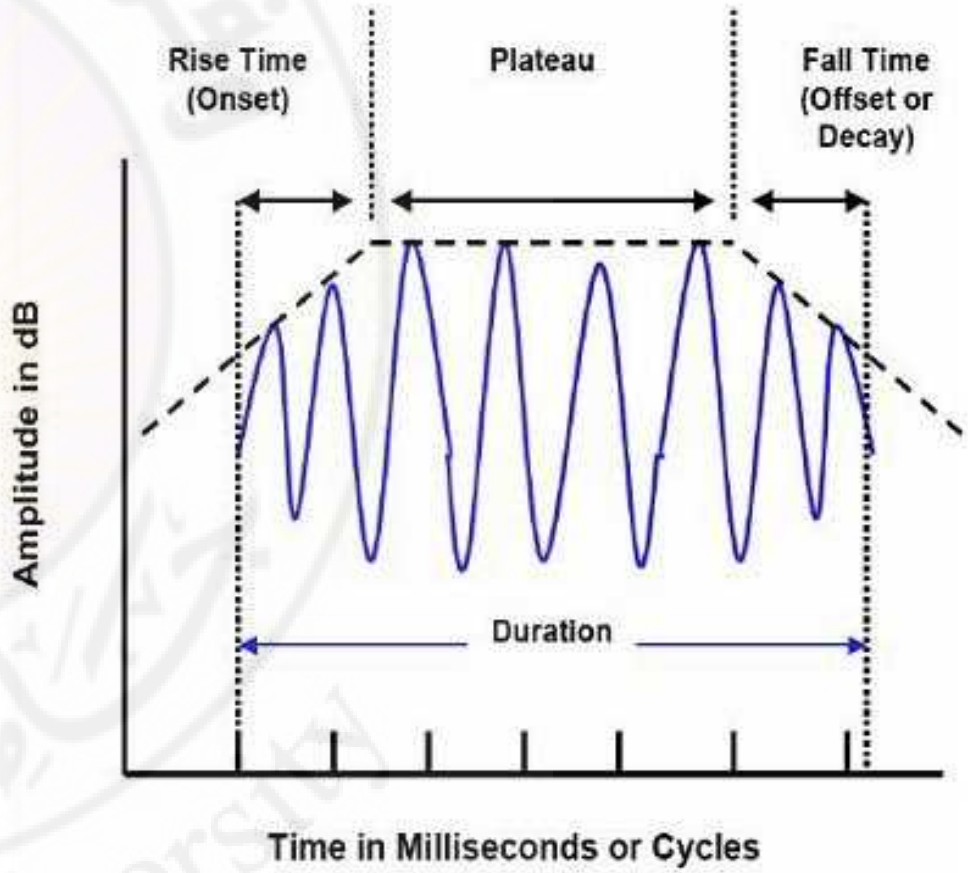
2. Stimulus Duration

- Duration is the length of the acoustic stimulus from beginning (Onset) to end (Offset).
- It's usually described in **milliseconds**.
- Stimulus duration is the sum of the rise time, plateau time, and fall time.
- Duration for the **electric waveform** used in generating the stimulus can be determined with an oscilloscope.
- Duration of the **acoustic waveform** of the stimulus also can be measured with an oscilloscope, along with a standard coupler and a sound level meter (SLM).



2. Stimulus Duration

- tone-burst duration usually define on the basis of a constant number of cycles.
- 2-1-2 toneburst means 2-sycle rise time, 1 cycle plateau, 2 cycle fall time
- For a 1000 Hz tone there are 1000 cycles per second (cps). Duration of a single cycle for a 1000 Hz tone is 1-ms. Following the 2-1-2 rule, a 1000 Hz tone burst has rise/fall times of 2-ms and a plateau of 1-ms (5 ms in total).
- What about 500 Hz?
- And 2000 Hz?

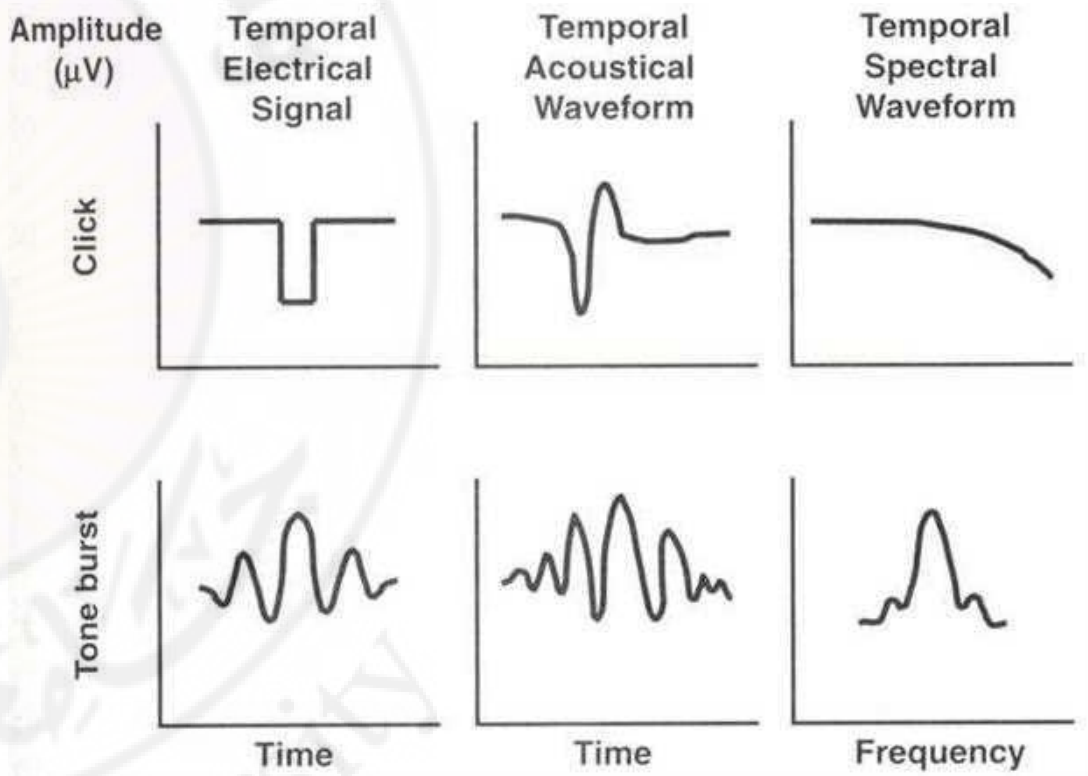


2. Stimulus Duration

- There is a complex interaction between **duration** and ***frequency***, ***ISI***, and ***rate*** of stimulus presentation in a given time.

- The concentration of energy in a specific **frequency** region is indirectly related to duration.

- With very brief stimuli, energy tends to be distributed over more frequencies whereas stimuli with longer durations are more spectrally constrained.

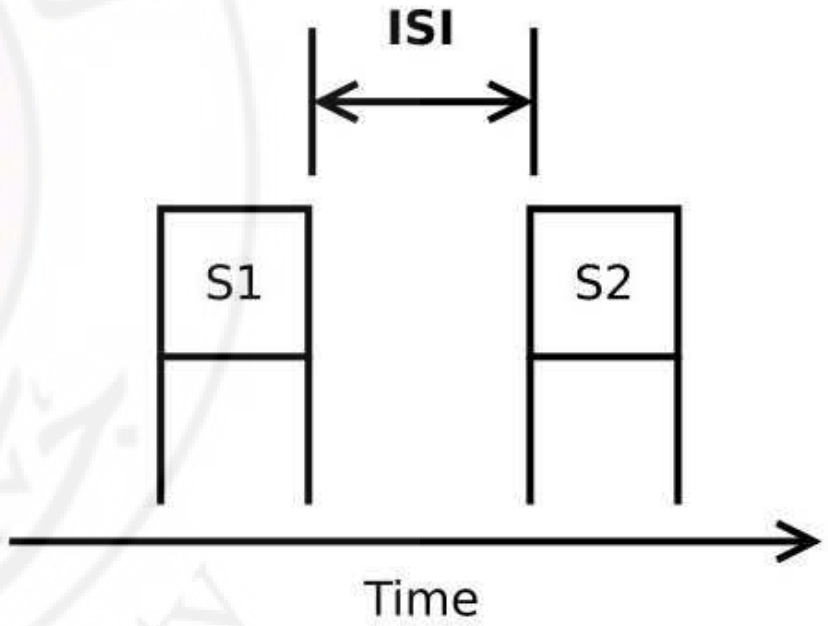


2. Stimulus Duration

- The connection between stimulus duration, stimulus rate, and inter-stimulus interval can be understood intuitively.

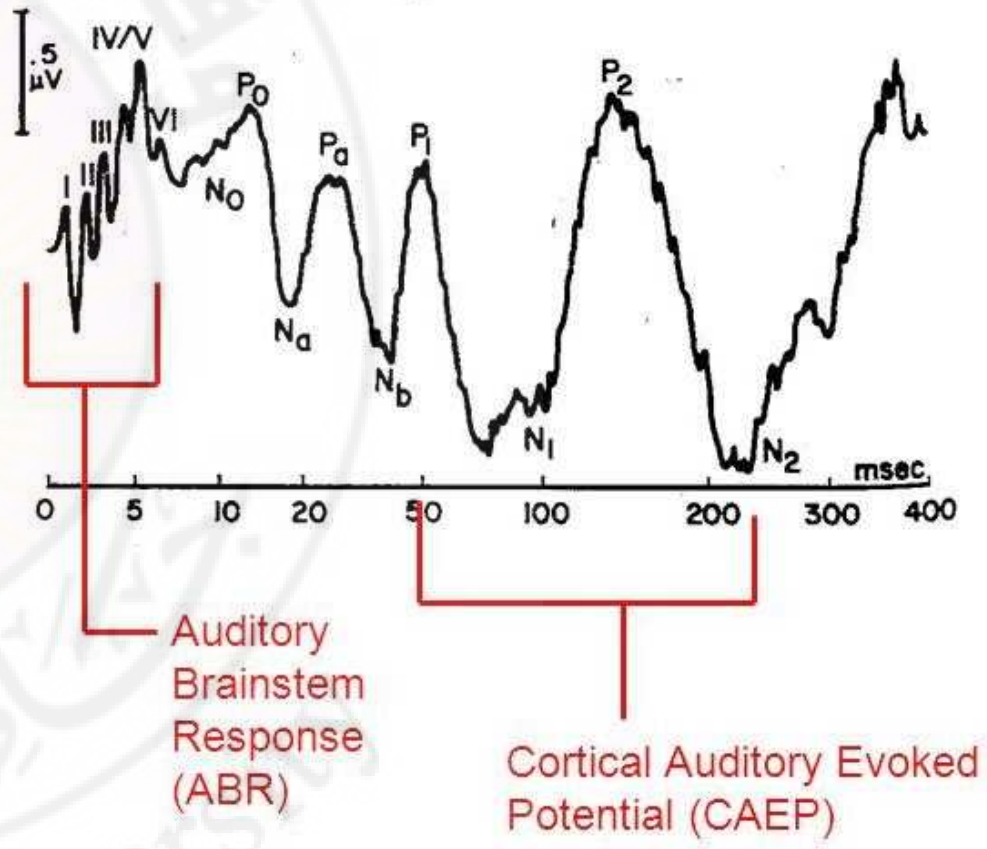
- If a certain number of stimuli are presented within a specific amount of time, such as 20/second, then increasing the duration of each stimulus while keeping the number constant results in decreased **inter-stimulus intervals**.

- Alternatively, increasing the number of stimuli presented within 1 second will, of course, increase the **rate** and decrease the inter-stimulus intervals.



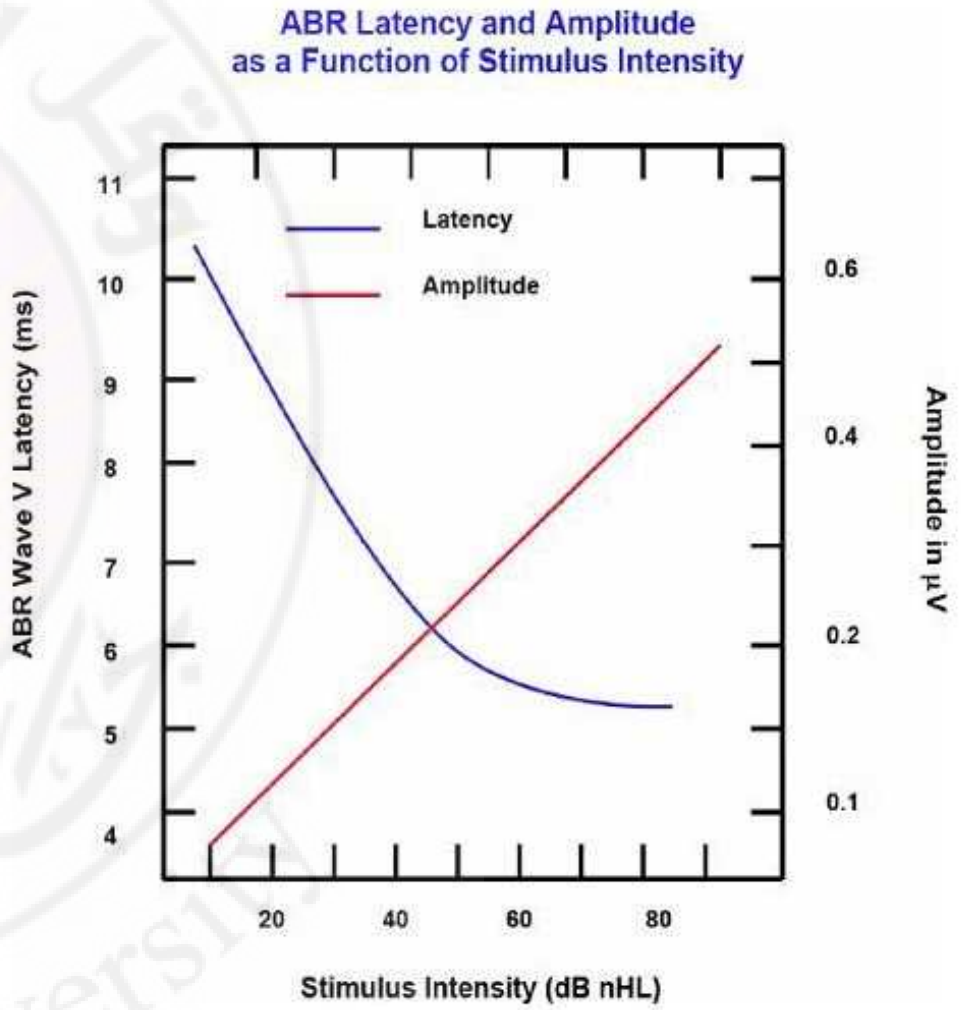
2. Stimulus Duration

- Finally, there is typically a direct relationship between duration of the response and duration of the stimulus.
- That is, slower responses with longer latencies, like cortical auditory evoked responses, are optimally activated with stimuli of longer duration that are presented at slower rates.
- In contrast, faster shorter latency responses such as the ABR can be recorded with stimuli of shorter onset and duration that are presented at faster rates.

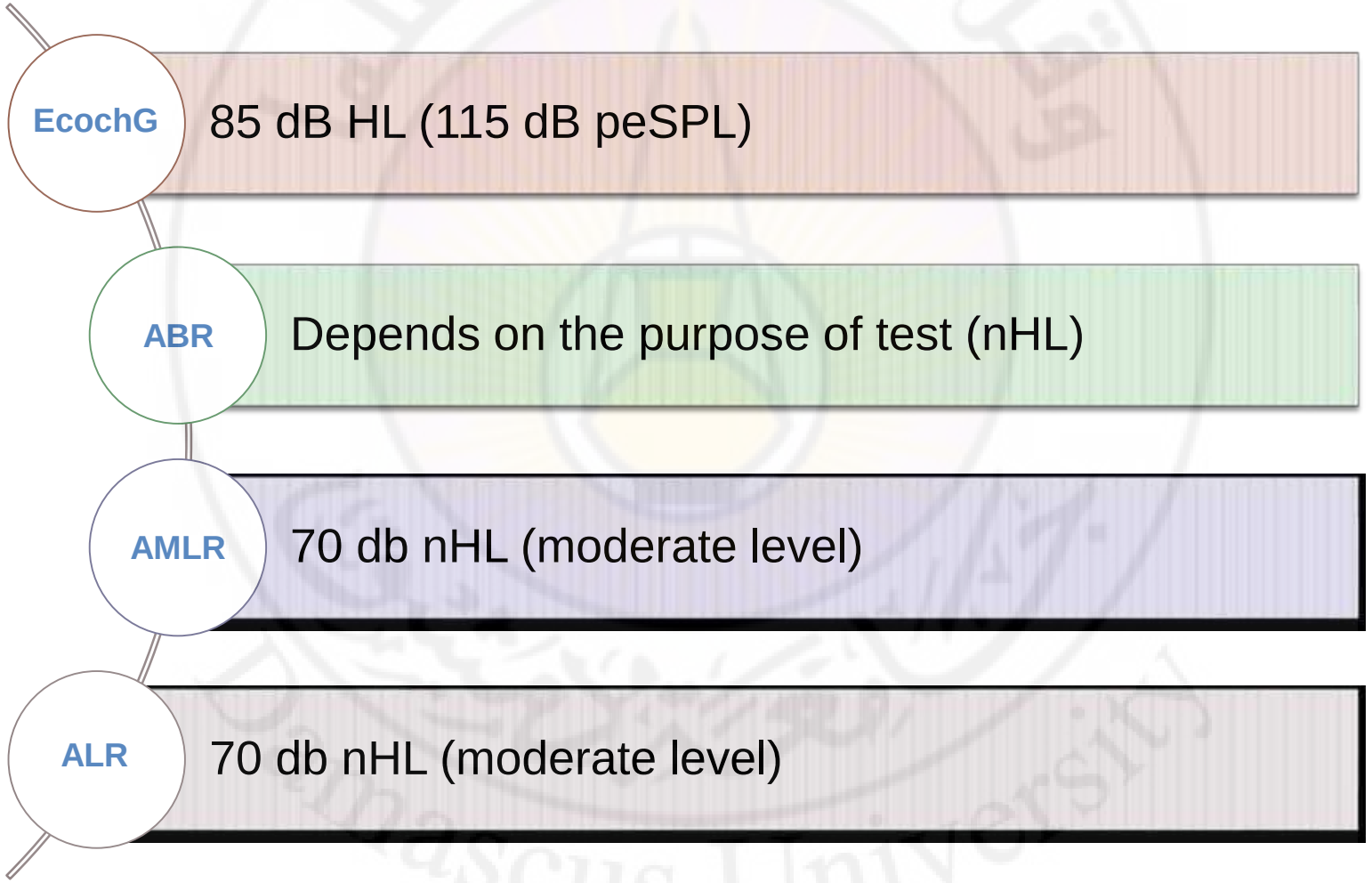


3. Stimulus Intensity

- **Generally, auditory evoked response latency decreases, and amplitude increases with greater stimulus intensity.**
- The unit of measure for intensity is the dB (decibel).
  - 1) dB sound pressure level (dB SPL)
  - 2) dB peak-equivalent SPL (peSPL)
  - 3) dB hearing level (dB HL)
  - 4) dB sensation level (dB SL)
  - 5) dB normal hearing level (dB nHL).



3. Stimulus Intensity



4. Stimulus Presentation Rate

- In the hands of an experienced clinician, stimulus rate can be manipulated as needed to optimize auditory evoked response measurement, thus contributing to the fastest data collection in the least amount of **time**.
- The manipulations of stimulus presentation rate save test time and often permit a thorough assessment in the time available.
- With pediatric applications of auditory evoked responses, test time is often a very important factor particularly for young children who are sleeping naturally, without sedation, during the assessment.
- **Diagnostic protocols vs. Threshold estimation protocols**



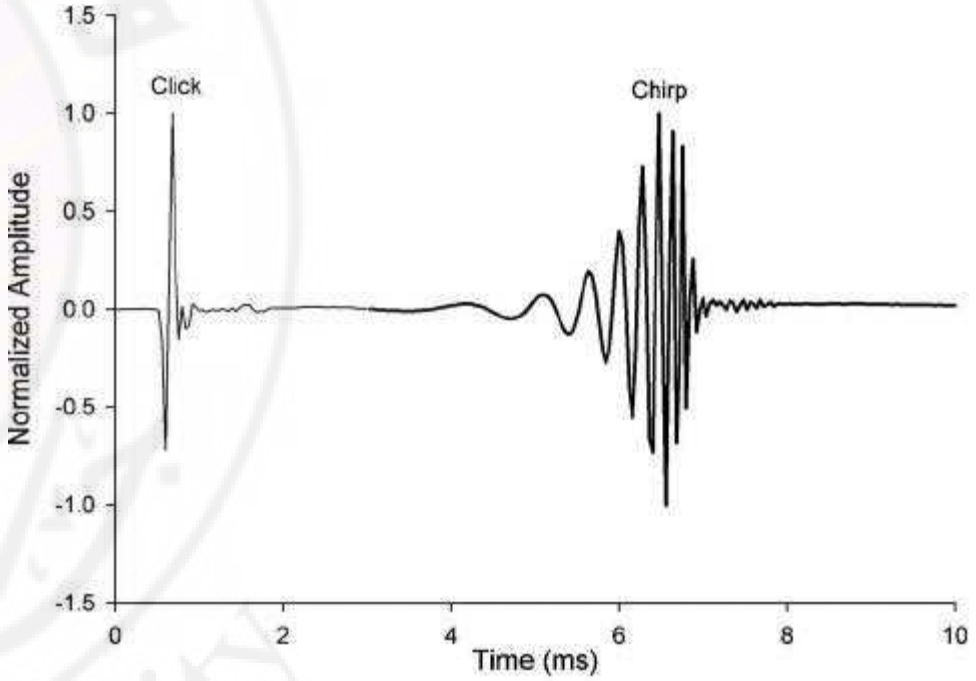
4. Stimulus Presentation Rate

- No single correct stimulus rate is appropriate for all patients under all test circumstances. The effects of stimulus rate are distinct for different auditory evoked responses.
- The contrasts in influence of rate are greatest for the shorter-latency responses like ECochG or ABR versus longer cortical evoked responses.
- For each type of auditory evoked response, the effects of stimulus presentation rate are a product of the interactions among the rate, various other stimulus parameters such as intensity and duration, and a variety of subject characteristics like age, body temperature, and drugs.
- Finally, stimulus presentation rate appears to be a factor in the diagnostic power of auditory evoked responses. That is, stimulus rate may interact also with patient neuropathology



5. Inter-stimulus intervals (ISI)

- For **transient stimuli (Clicks)**, the interval between successive stimuli can be determined by dividing a discrete time period by the number of stimuli presented within that period (i.e., 1 second/rate = ISI).
- If a transient stimulus, for example, is presented at a rate of 20/second, the accumulated time of the actual stimulus presentation is negligible. A total of 1000-ms divided by 20 results in an ISI of 50-ms.
- The ISI is 100-ms for a stimulus rate of 10/second and the ISI for a rate of 100 stimuli per second is only 10-ms.

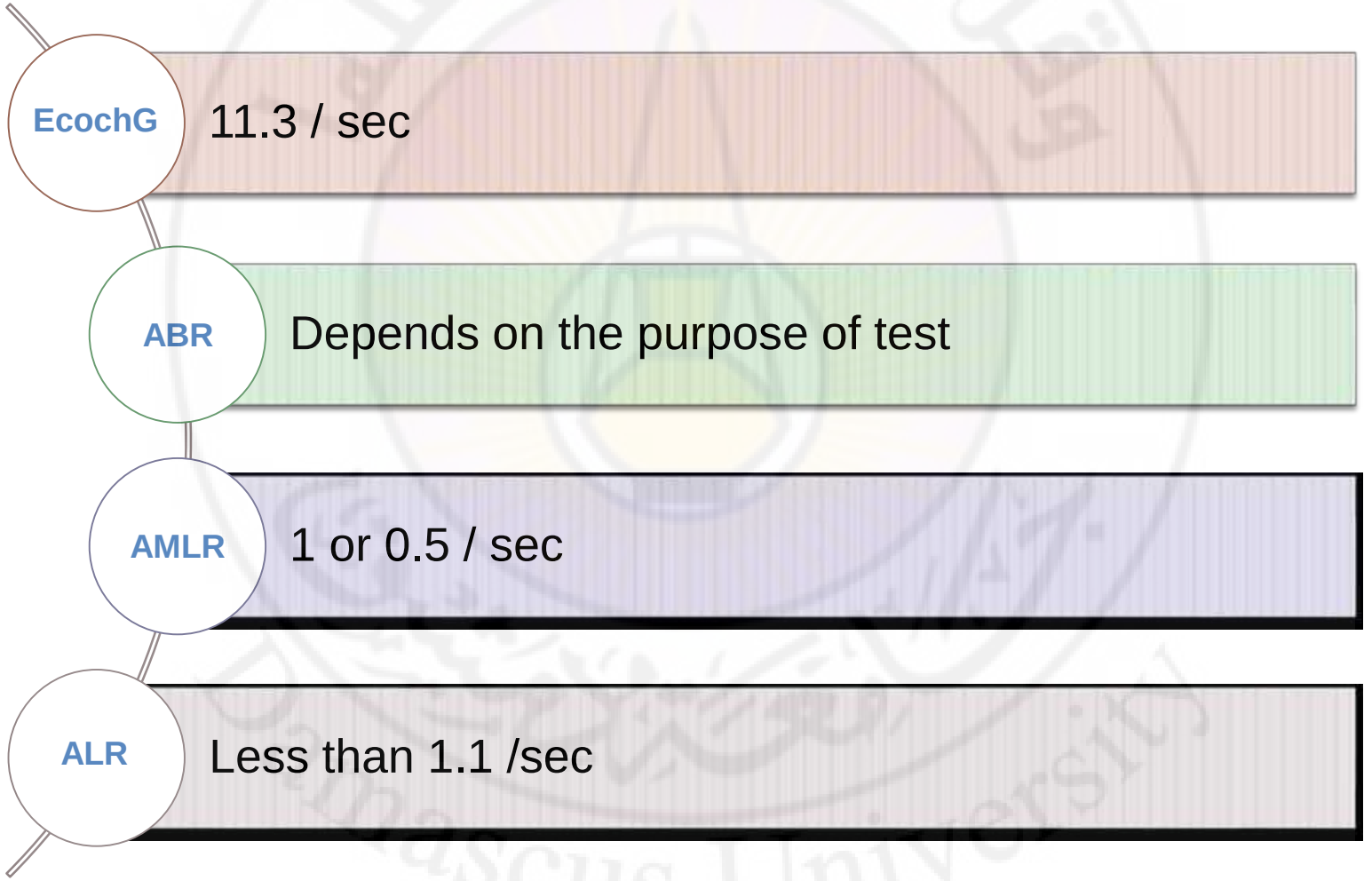


5. Inter-stimulus intervals (ISI)

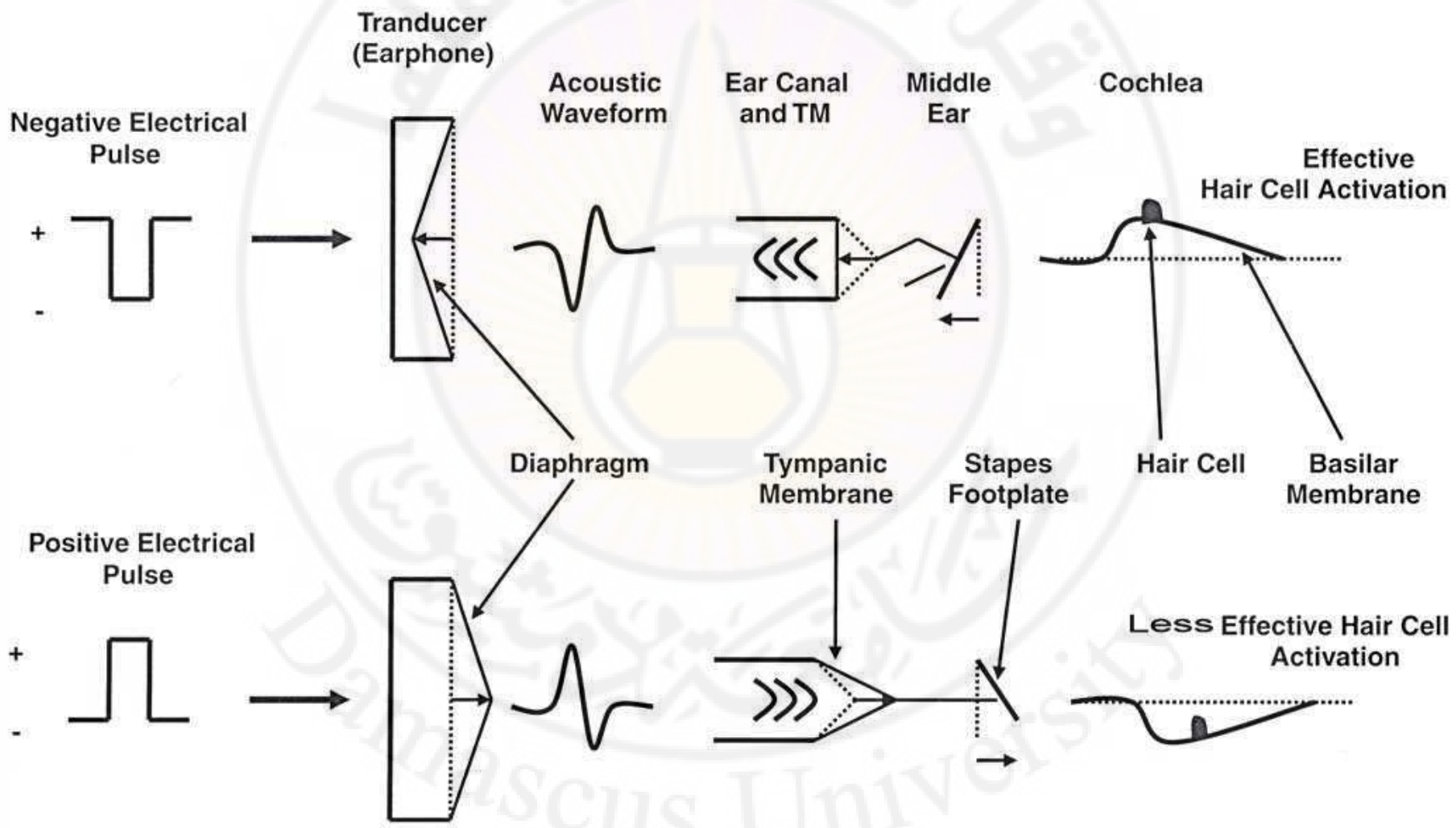
- Calculation of ISI is not as straightforward for longer duration tone burst or speech stimuli because duration times for each individual stimulus accumulate and consume some of the overall presentation time.
- If total duration of each stimulus is 5-ms, then the accumulated stimulus time for a rate of 20 stimuli/second is 100-ms (20 stimuli at 5-ms each).
- Within a 1 sec (1000-ms) time frame, therefore, only 900-ms are available for the ISIs. Thus, 900-ms/20 yields an ISI of 45-ms.

- Analysis time can't be greater than this without including the response from the subsequent stimulus presentation within the same time period. If stimuli are presented at such a rapid rate that they occur within the analysis period, they will not contribute to the response and can actually degrade the averaged response.

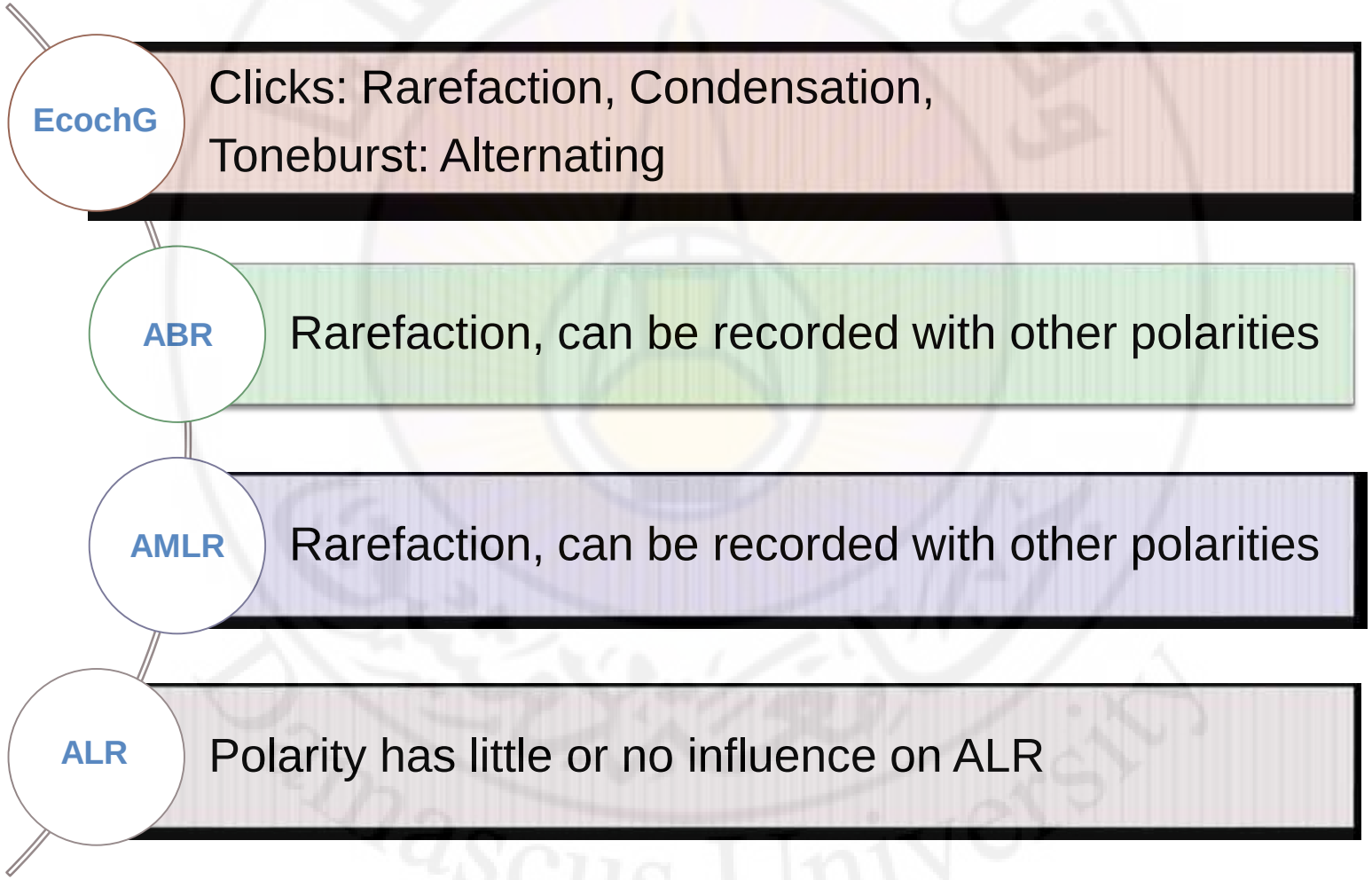
5. Inter-stimulus intervals (ISI)



6. Stimulus Polarity

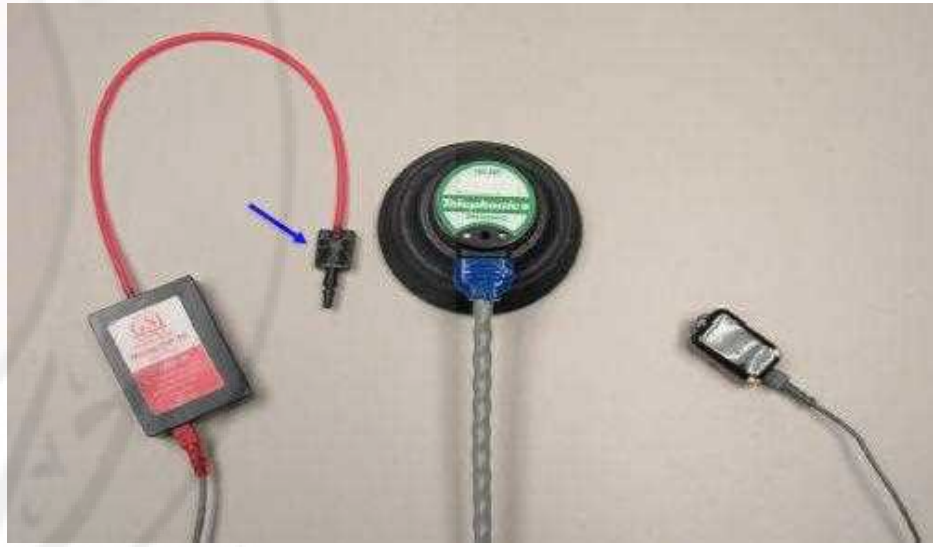


6. Stimulus Polarity



7. Transducers

- Transducers used in auditory evoked response measurement receive an electrical signal and produce a sound that is often presented as an air-conduction stimulus.
- For most auditory evoked response applications, the stimulus is acoustic and the transducer is an earphone but there are exceptions to this statement.
  - **Earphone & Insert Earphones**
  - **Bone Vibrator**
  - **Loudspeakers**
  - **Cochlear implant for Electrical responses**



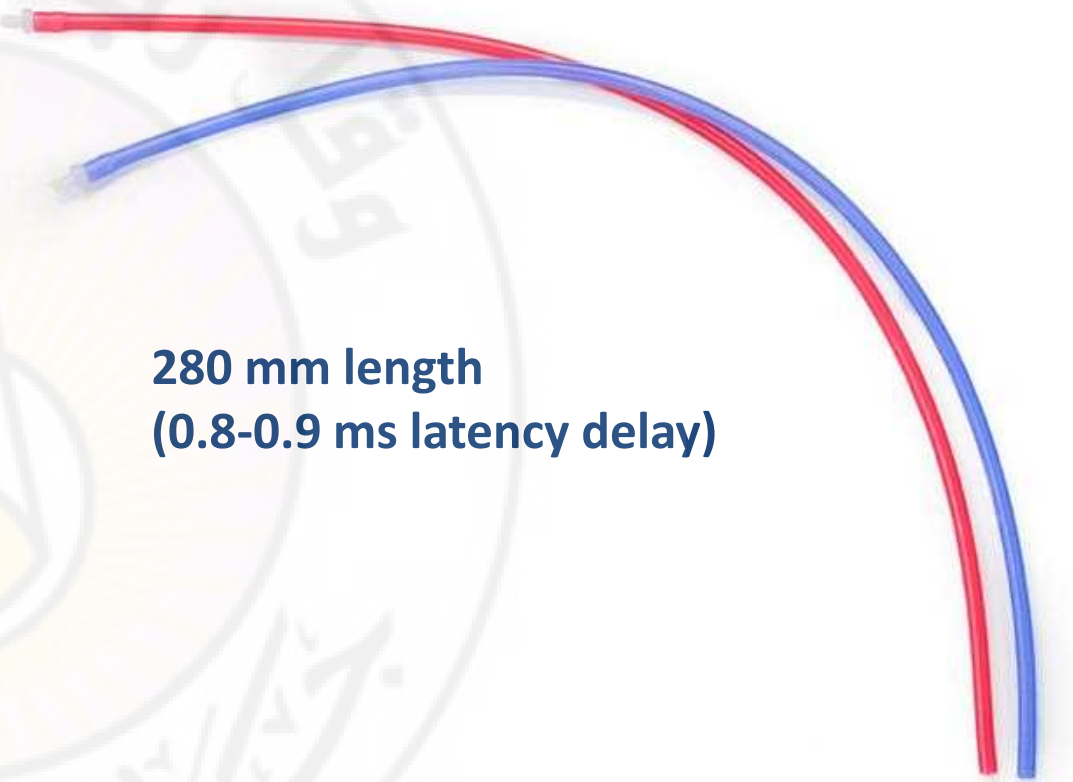


TDH-39

Stimulus artifacts at high levels

Less reliability in children





280 mm length
(0.8-0.9 ms latency delay)


ICS Chartr EP 200









Ear Tip Adaptor

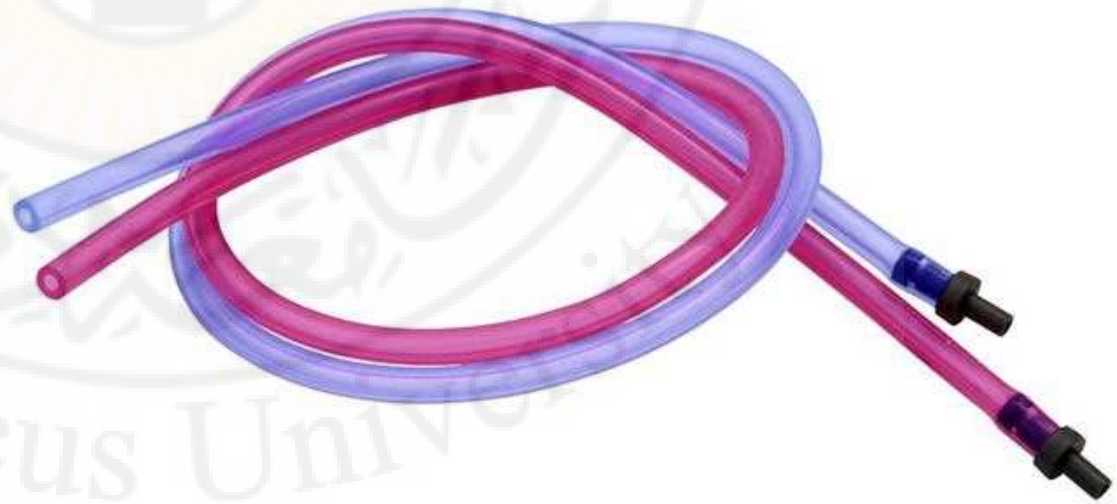












Sound tube nippel









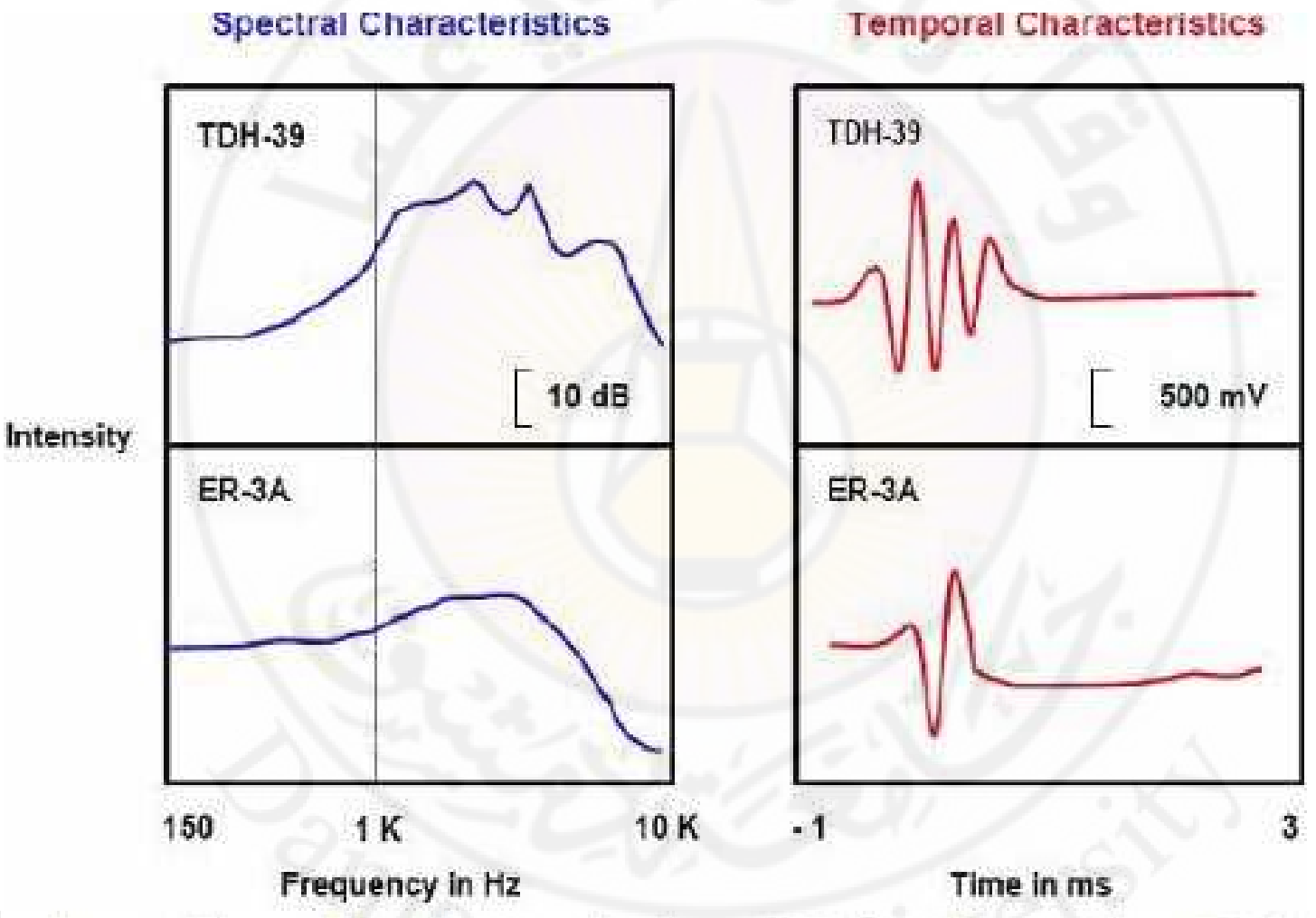


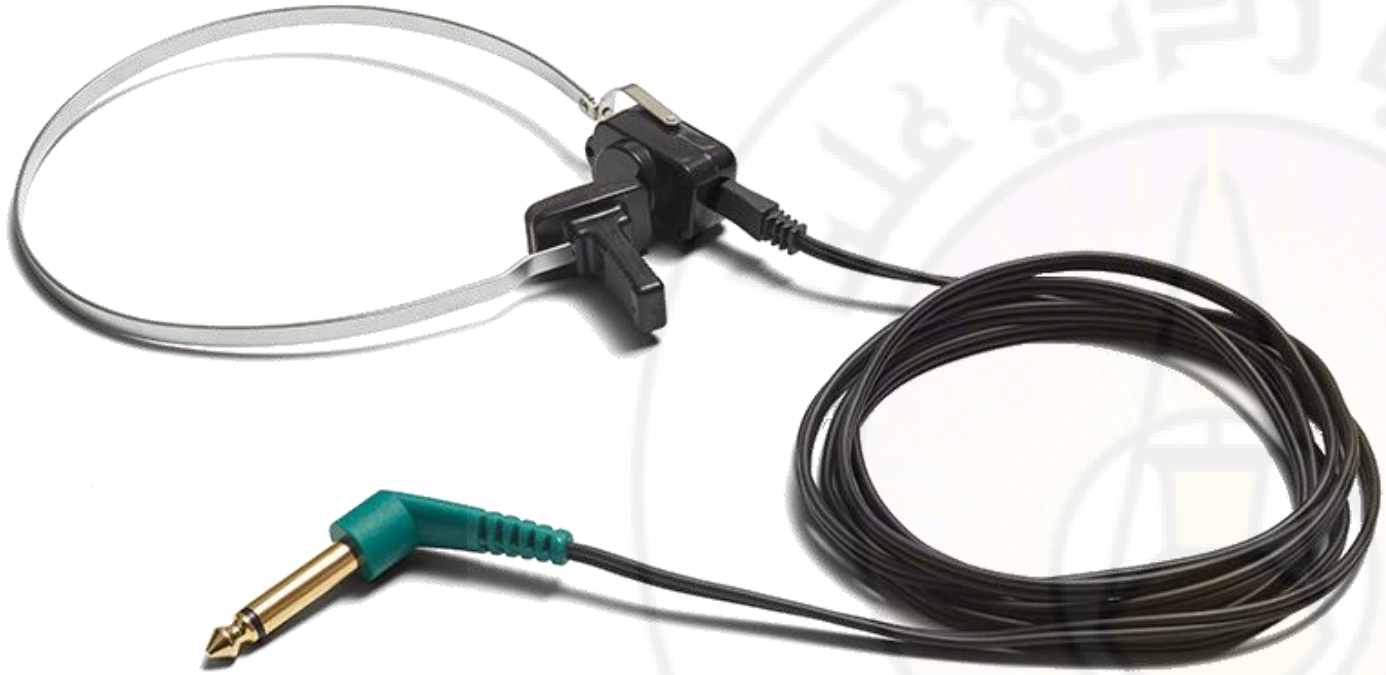


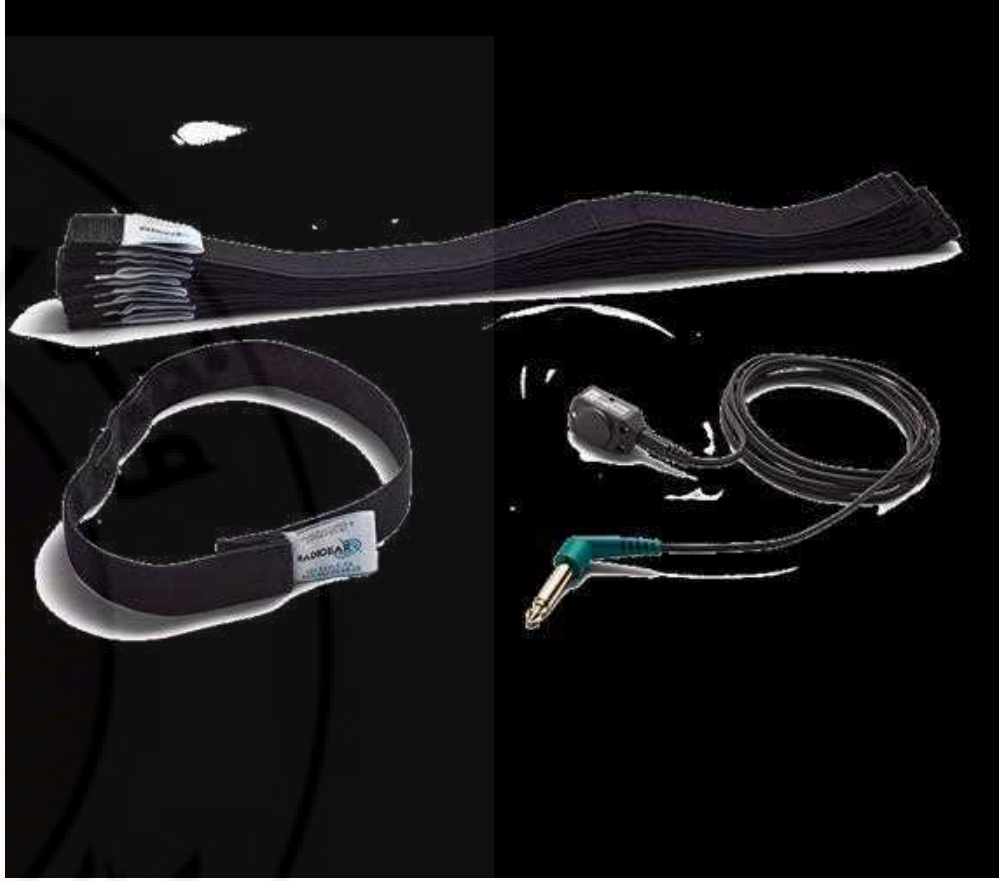
Insert phone benefits:



1. Increased inter-aural attenuation for the stimulus with less chance that the stimulus will cross over to the non-test ear
2. Increased ambient noise reduction. The patient is essentially wearing sound-attenuating ear protection.
3. Elimination of the possibility of collapsing ear canals in infants
4. Increased patient comfort
5. More precise placement in infants with small and soft ear tips, versus hand-held imprecise placement with supra-aural earphones
6. Aural hygiene and infection control because insert cushions are discarded after single patient use
7. Insert earphones can be used as TIPtrode electrodes to enhance the amplitude of the ABR wave I.
8. The insert cushion and tubing can be sterilized for intra-operative use.
9. The non-sterile portion of the earphone can be placed outside surgical field.
10. Flatter frequency response versus supra-aural earphones
11. Reduced transducer ringing with transient acoustical signals
12. Reduced stimulus artifact with separation of the transducer box and the electrode by extending the acoustical tube from ear and locating the insert transducer box away from any electrode wires


Spectral Characteristics
Temporal Characteristics
TDH-39
10 dB
TDH-39
500 mV
Intensity
ER-3A
ER-3A
150
1 K
10 K
-1
3
Frequency in Hz
Time in ms





Radioear B-71

B71



B81



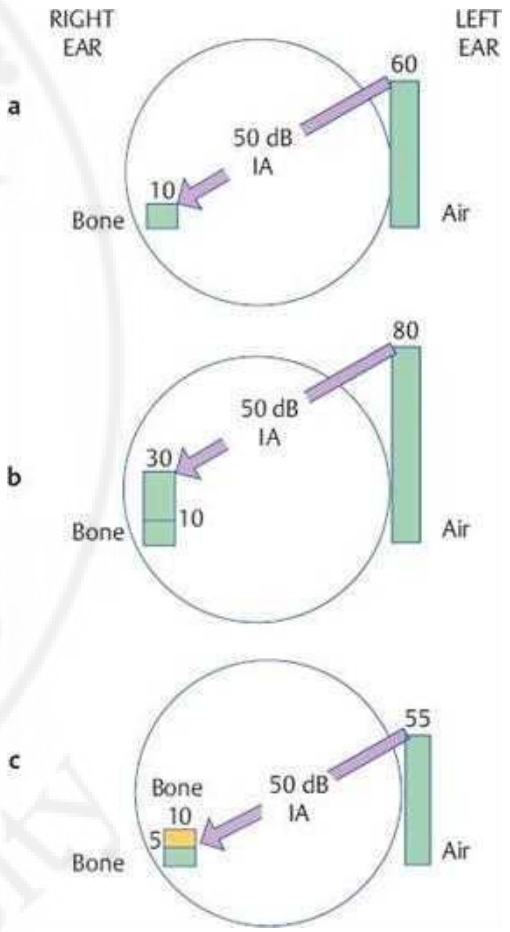
Output limitation: 50-55 dB nHL

8. Masking

- Effective masking of the non-test ear with an appropriate type and level of noise is often necessary in order to verify that test results are ear specific.

- Masking does not play as important a role in auditory evoked response measurement as it does in traditional behavioral hearing testing.

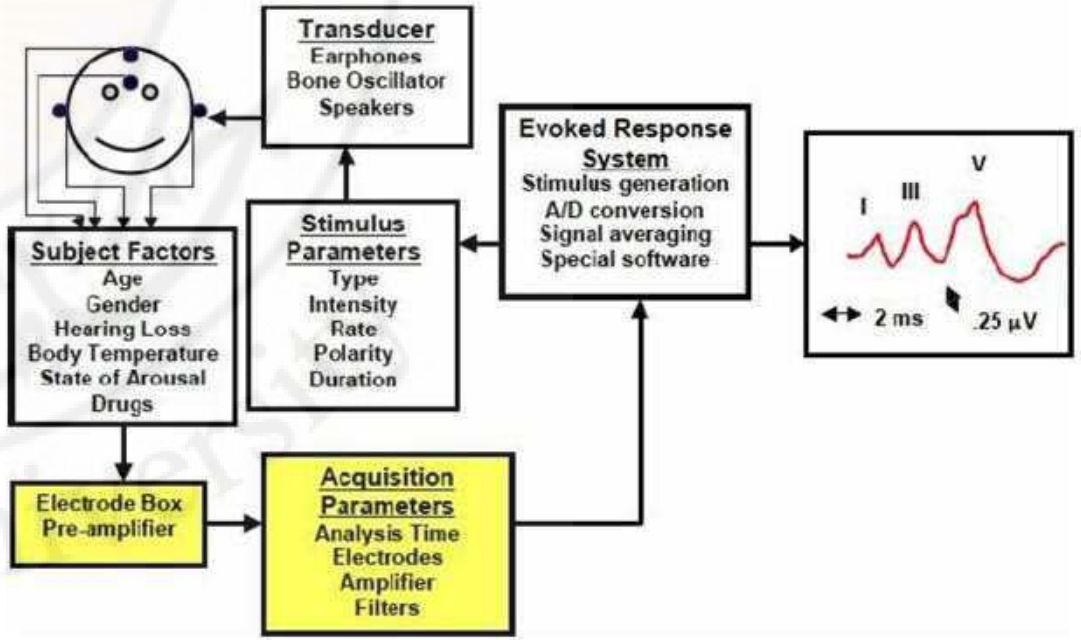
- Masking is occasionally needed in recording the ABR, but only under certain test conditions and with selected patients.



Parameter	Selection	Rationale
Transducer	ER-3A inserts	Numerous infant advantages
	B71 or B81	Bone oscillator as needed
Type	Clicks	Rule out ANSD
	Tone bursts	Available on all systems
	Chirp stimuli	Topic of part 2 course
Mode of Presentation	Air conduction	Always
	Bone conduction	As indicated
Polarity	Rarefaction	Condensation as needed
Ramping (window)	Blackman	Less spectral splatter; more frequency-specific
Rate	Click: 21.1/sec	Record wave I in less time
	Tone Burst: 37.7/sec	Record wave V in less time
Frequencies	500 Hz, 1 kHz, 2 kHz, 4 kHz	Sequence varies clinically
Duration	2-0-2 cycles	Equal intensities; < splatter
Intensity	dB nHL	Calibration in peRETSPL
		plus normal behavioral thresholds
		for each stimulus

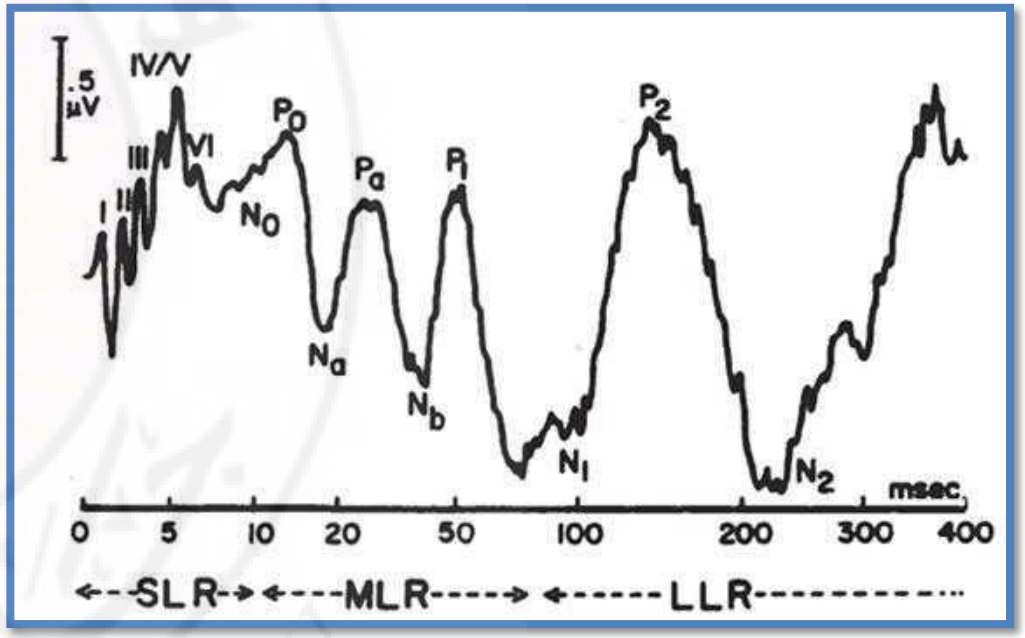
Acquisition Parameters

- Major Acquisition parameters in measurement of auditory evoked responses are:
- **Analysis time**
- **Electrode type**
- **Electrode location**
- **Processing of signals**
  - **Filter settings**
  - **Amplification**
  - **Averaging (Sweeps or number of stimuli presented)**



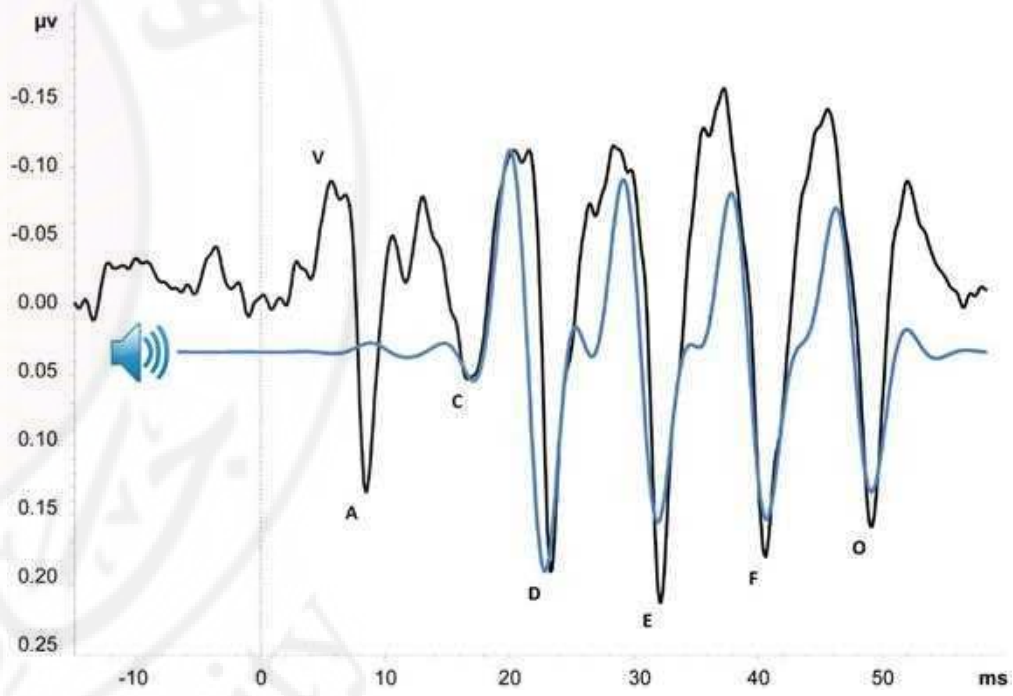
1. Analysis time (Epoch)

- Analysis time or *epoch* is the time period after presentation of each stimulus during which auditory evoked response data are collected.
- Although they vary considerably from one auditory evoked response to the next, analysis times are always quite short, ranging from 5- ms or 5/1000 of a second for ECochG to more than one-half of a second (600-ms) for cortical auditory evoked responses.
- Analysis time in measurement of auditory evoked responses must be long enough to encompass the response of interest under all test conditions.



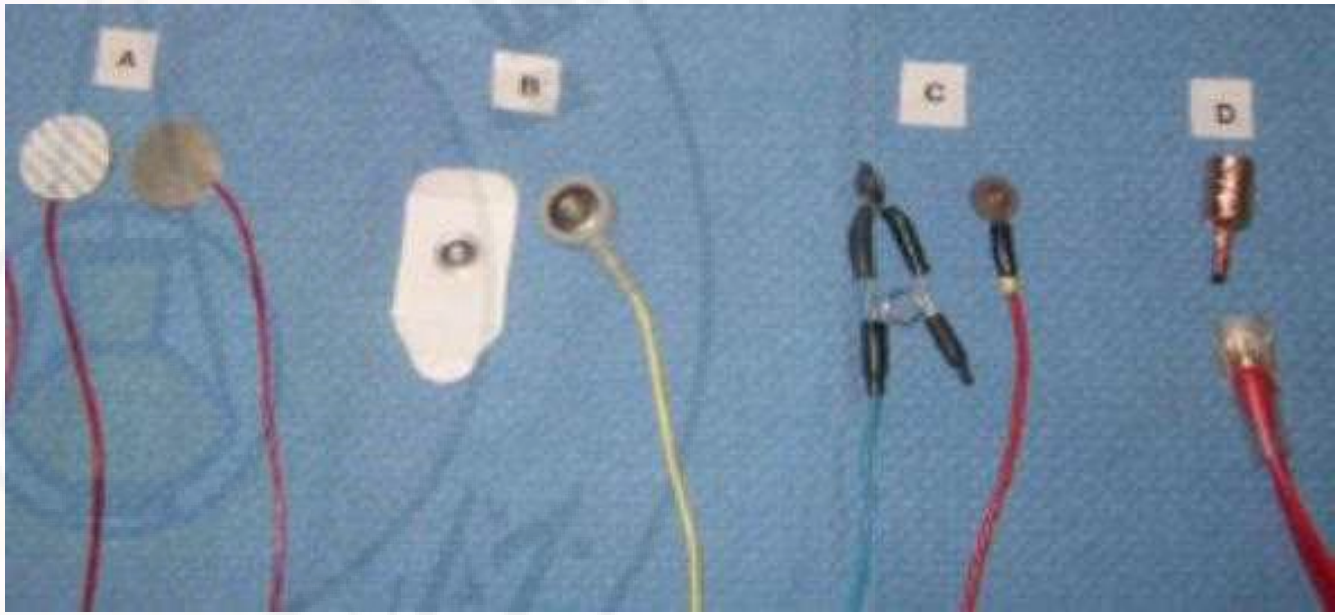
1. Analysis time (Epoch)

- A **pre-stimulus baseline**, usually 10% of the entire analysis period, is useful to assess the amount of non-response noise in the waveform for any auditory evoked response.
- The pre-stimulus averaging period can be selected from the collection parameters or configuration page when an auditory evoked response test protocol is first developed.
- For the ABR, a pre-stimulus baseline period of 1 or 2-ms (actually –1 or – 2-ms) is appropriate



2. Electrode type

- **Disc Electrodes**
- **Ear Clip Electrodes**
- **Disposable Electrodes**
- **Ear Canal Electrodes**

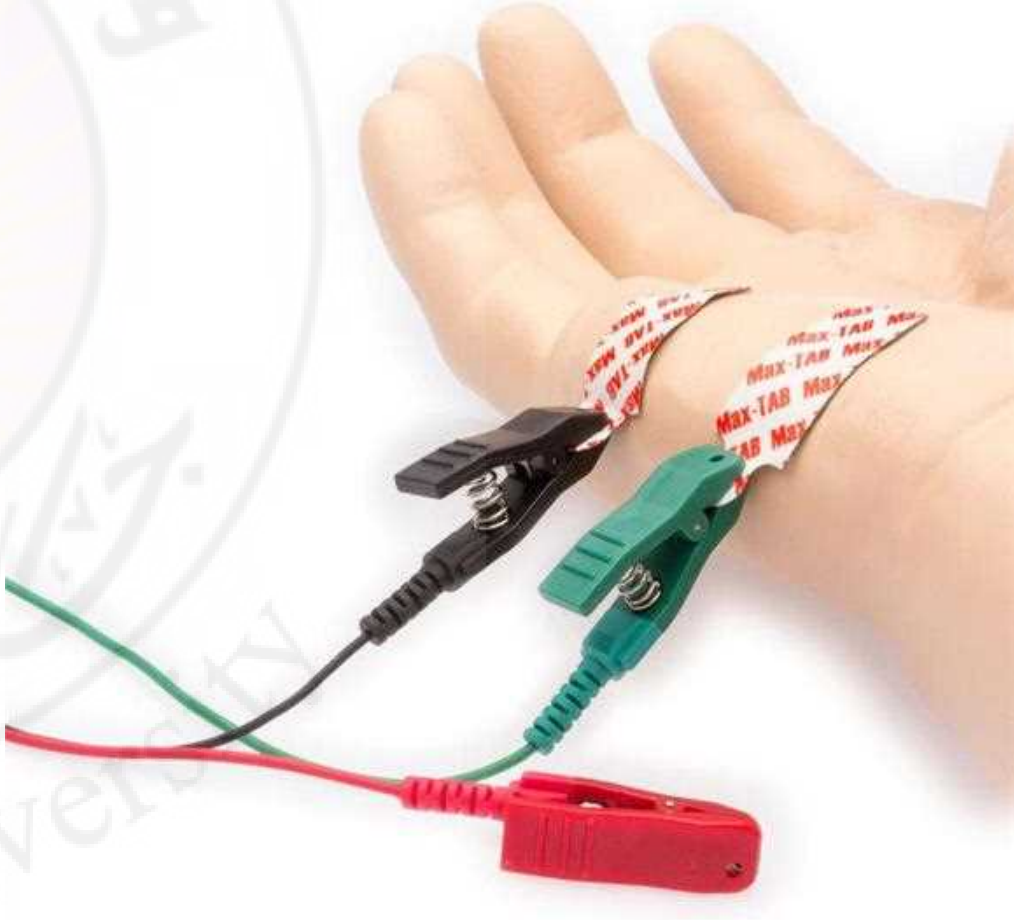


Alligator clip electrode cable









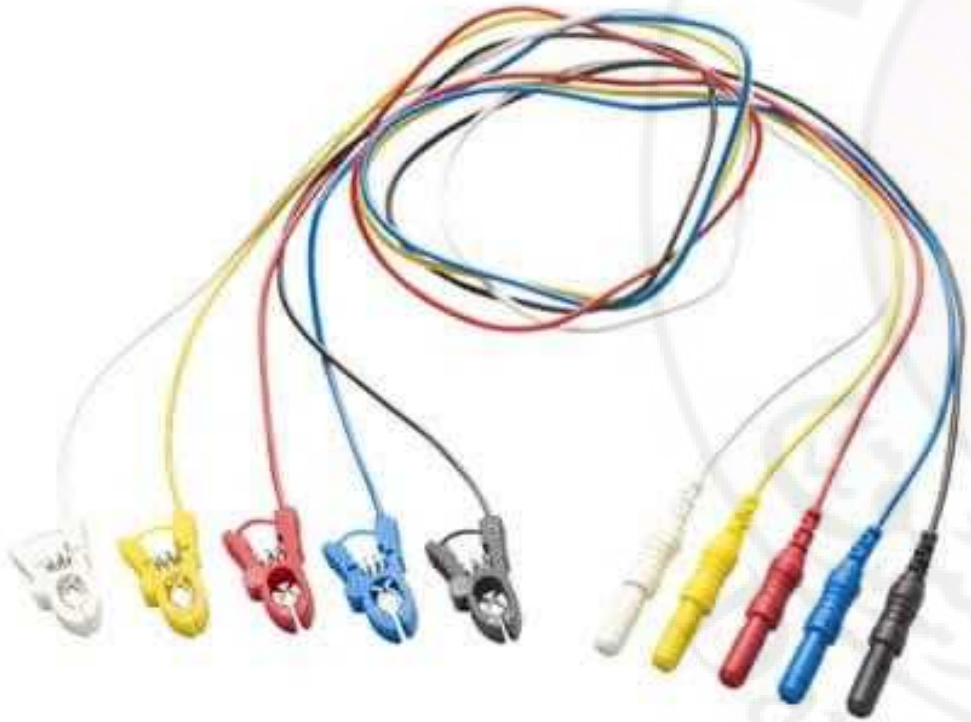
Button electrode cable







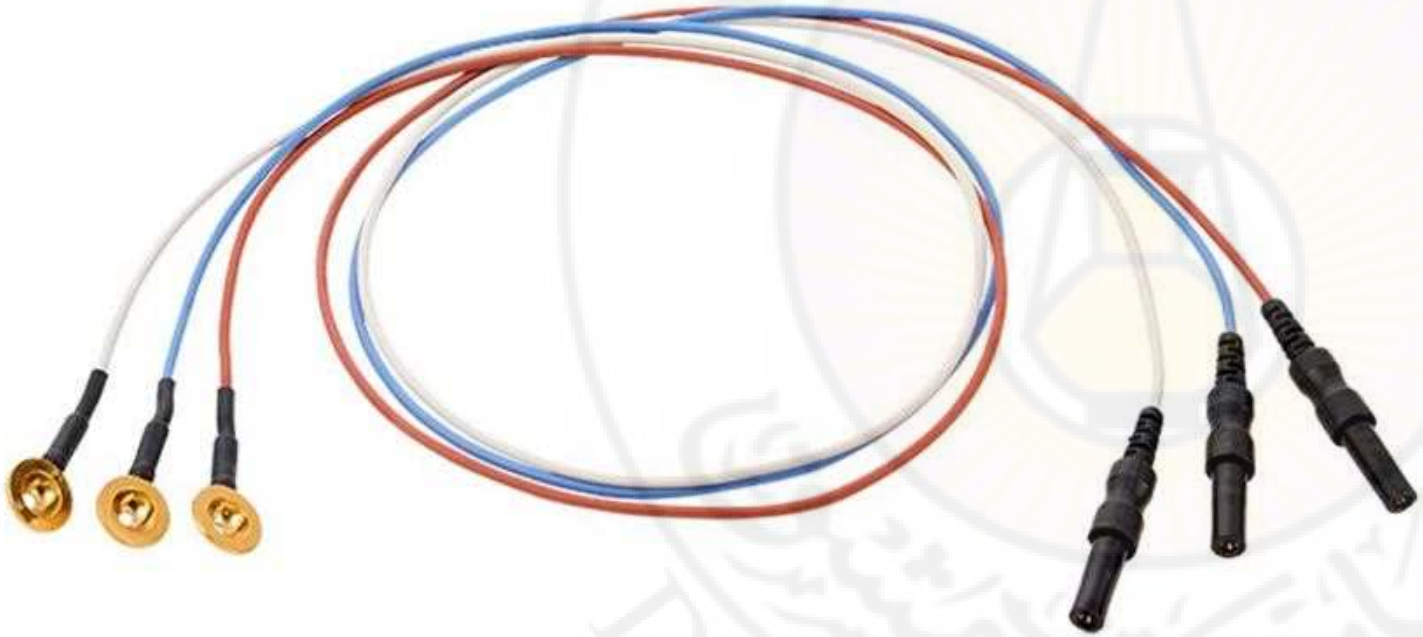
Pinch clip electrode cable







Gold-plated cup electrodes





RE-usable disc electrodes







Universal electrode cable

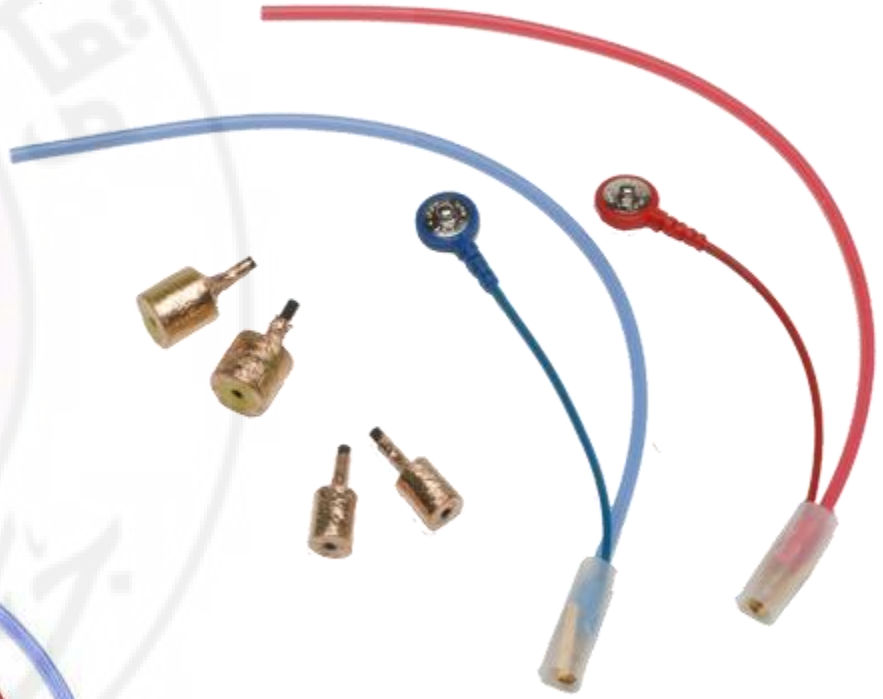


Electrode cable for tiptrodes





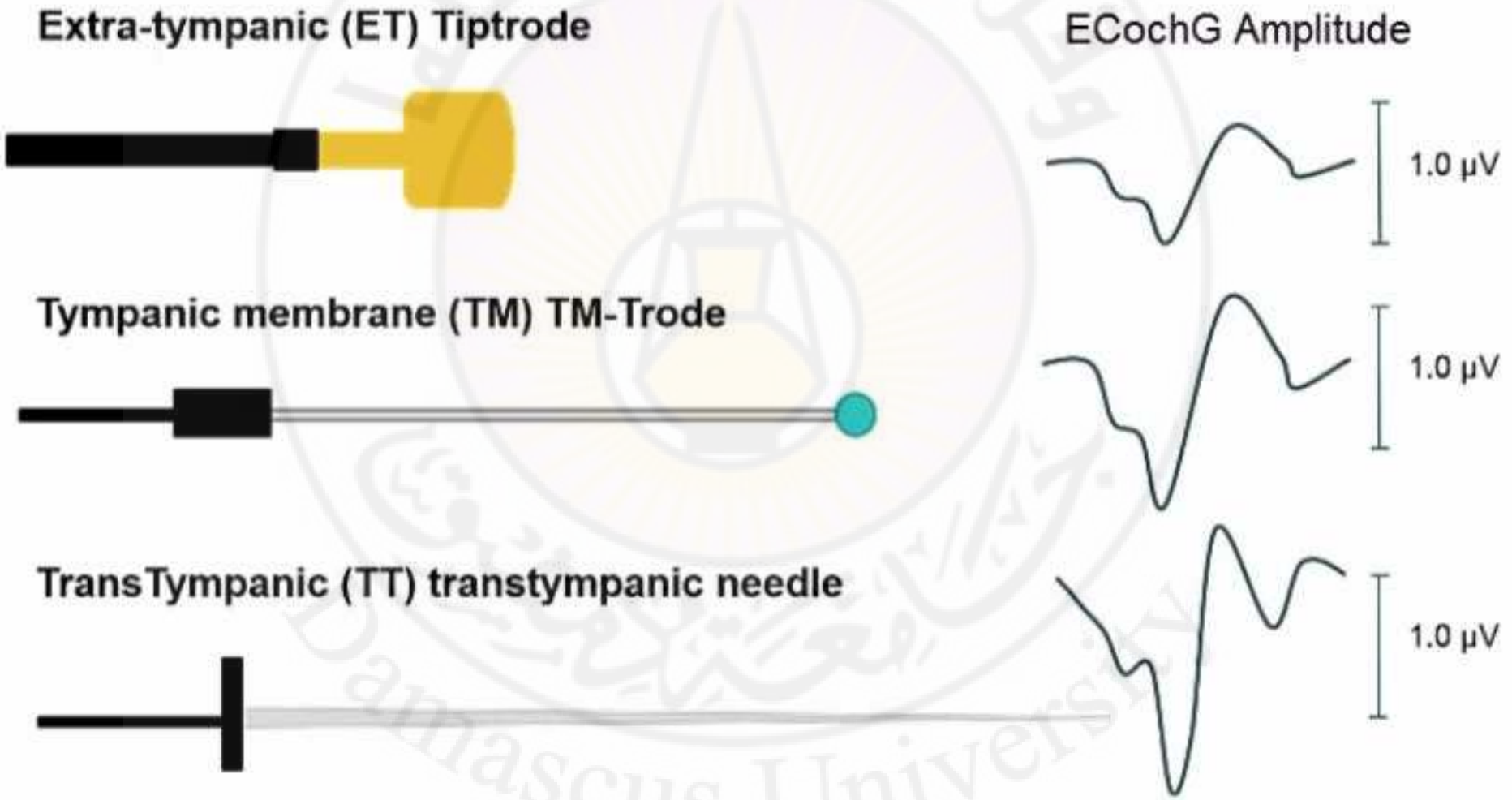




Cable for TM electrode (ECochG)



EcochG Electrodes



ECG/EKG Leads



EP electrode jumper cable



Ambu® Blue Sensor



Disposable tab electrodes










IP30
ABR


IP30
ABR
IP30
ABR



Alcohol pads



Electrode Gel



conductive EEG paste



NuPrep™ abrasive gel



conductive EEG paste

Electrode placement

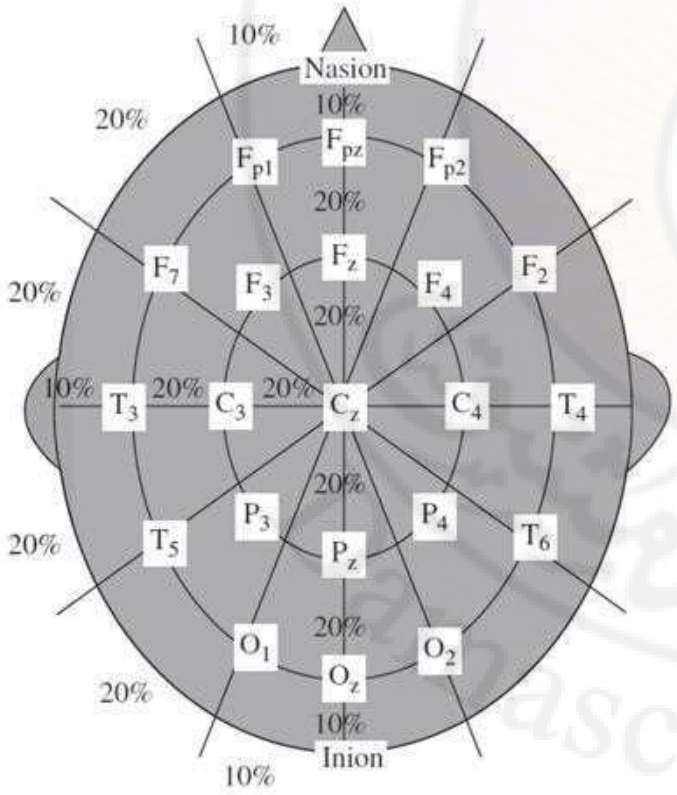
1) Consistent placement among subjects,
2) Anatomically accurate placement,
3) Low inter-electrode impedance (less than 5000 ohms),
4) Balanced inter-electrode impedance with a difference between electrodes of less than 2000 ohms,
5) Secure and consistent attachment throughout the test session,
6) Minimal discomfort and no risk to the subject

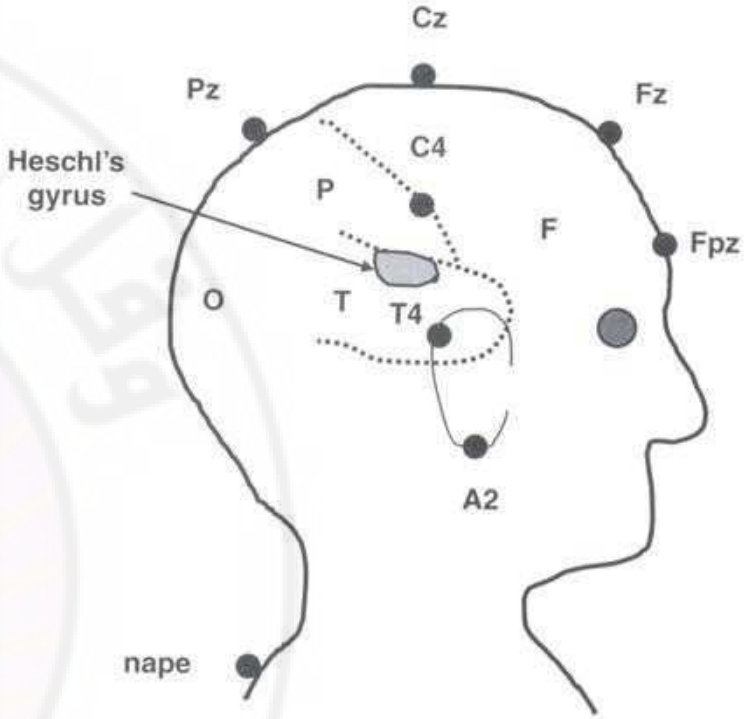


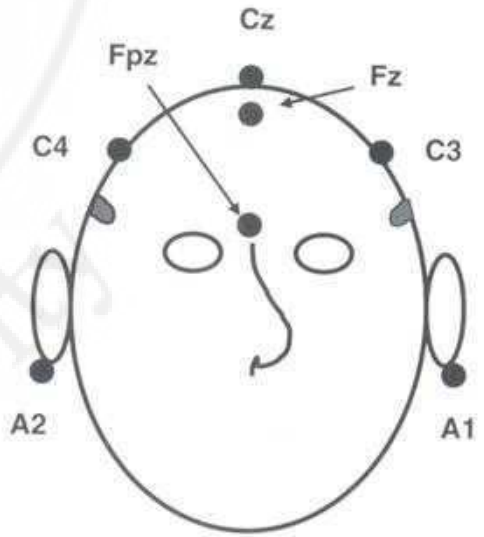
Interacoustics
Academy

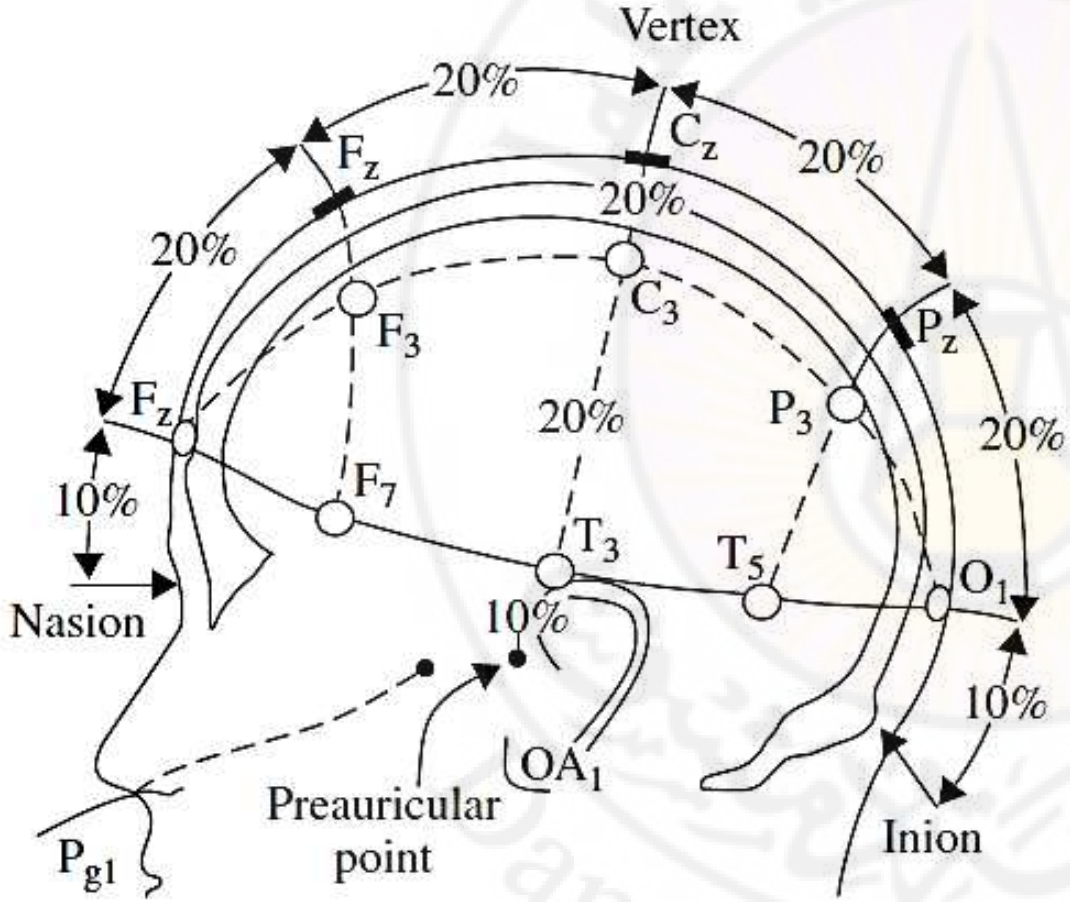
3. Electrode location

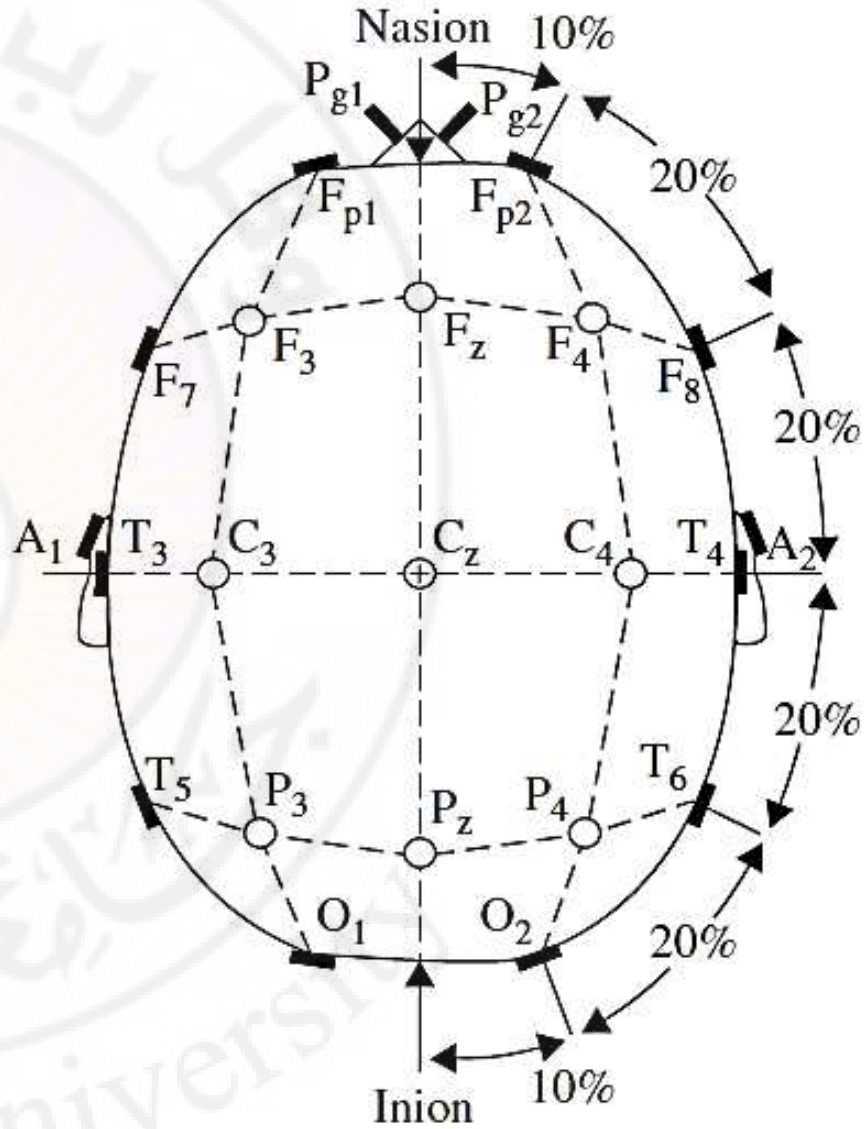
10-20 international system







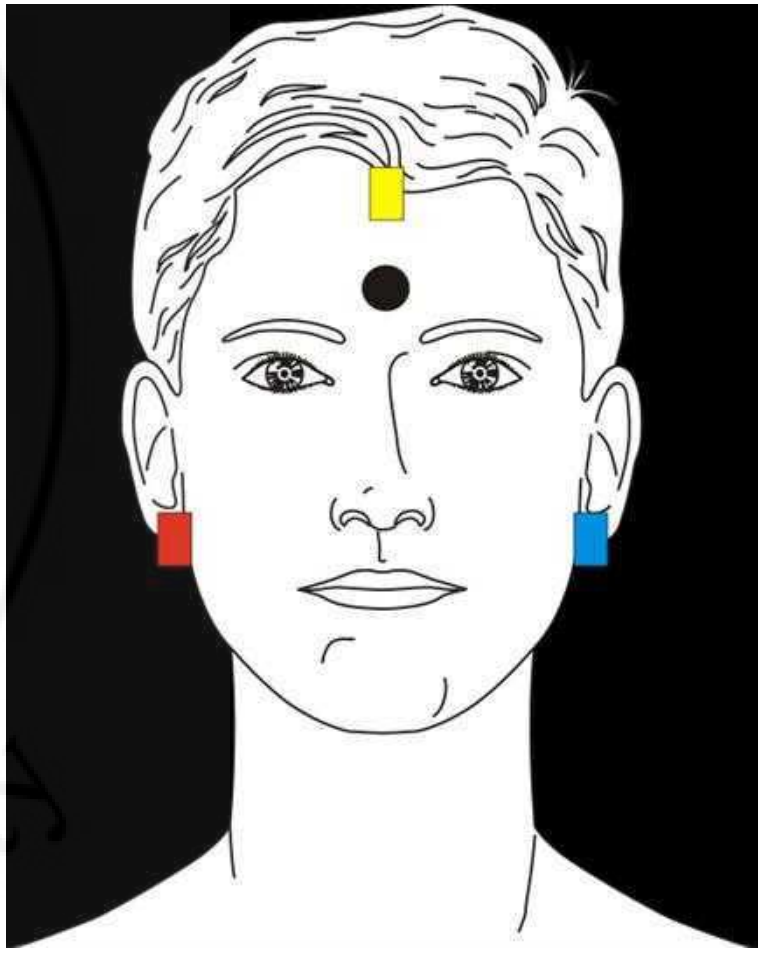

Vertex
20%
20%
20%
20%
20%
20%
20%
F_z
C_z
F_3
C_3
P_z
F_z
P_3
F_7
T_3
T_5
O_1
10%
Nasion
10%
10%
OA_1
P_{g1}
Preauricular point
Inion


Nasion
10%
P_{g1}
P_{g2}
20%
F_{p1}
F_{p2}
F_7
F_3
F_z
F_4
F_8
20%
A_1
T_3
C_3
C_z
C_4
T_4
A_2
20%
T_5
P_3
P_z
P_4
T_6
O_1
O_2
20%
Inion
10%



Electrode Terminology

- ***Non-inverting electrode*** is the proper term for the electrode located at the Cz or Fz location, whereas the other electrode near the ear is the ***inverting electrode***.
- Activity recorded with a set of two electrodes is conveyed with the electrode wires to an **amplifier** within the evoked response system. The amplifier has one input for each electrode.
- The non-inverting electrode is so called because the electrical activity recorded with the electrode is not inverted when it is plugged into a receptacle and enters the amplifier for the evoked response system. Electrical activity for the inverting electrode is inverted … turned upside down … when it enters the amplifier. Then, the sum of the two inputs is amplified before it is undergoes further processing in the evoked response system.



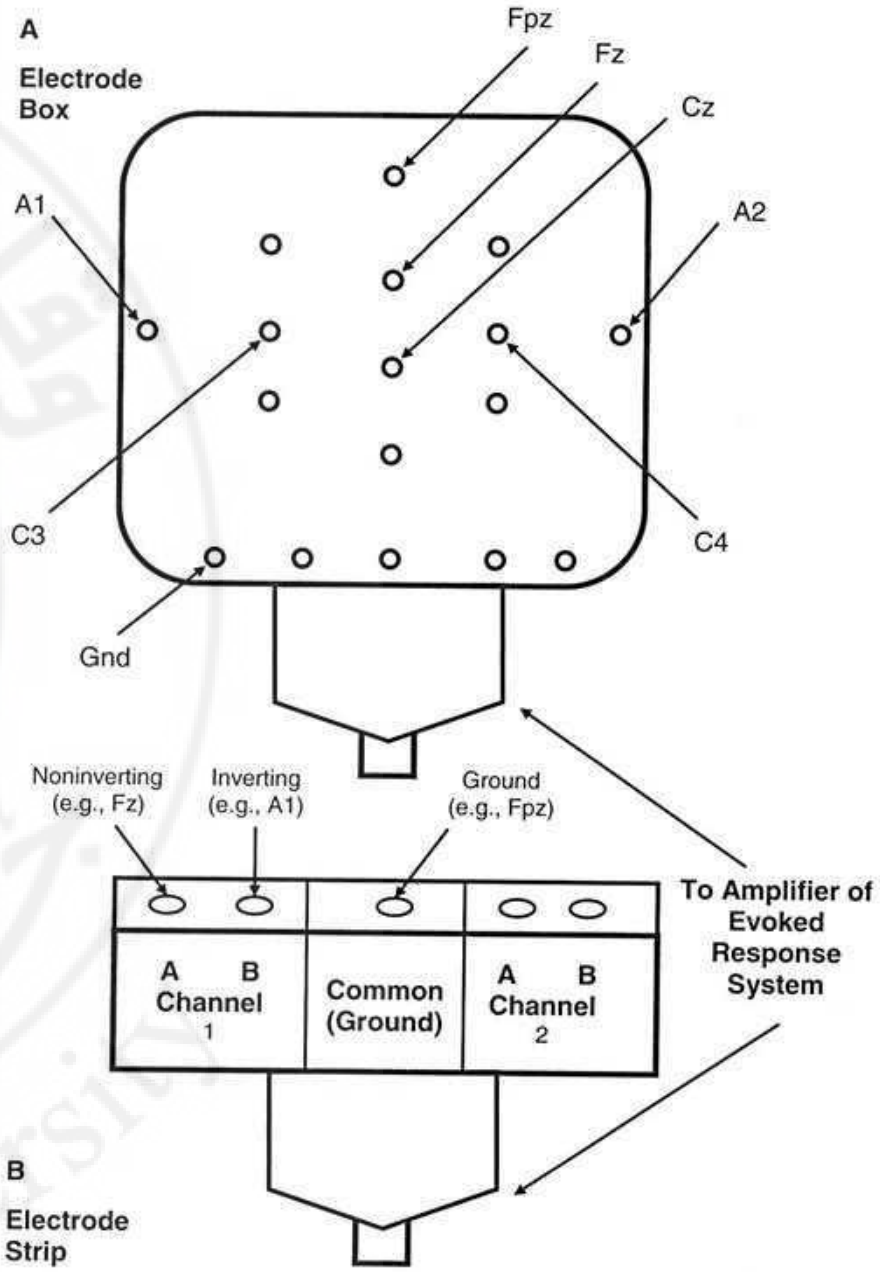
Electrode Terminology

- The terms **“active”** rather than non-inverting and **“reference”** instead of inverting are often used incorrectly to describe the two electrodes in measurement of the ABR.
- These terms imply that only the electrode at the Cz or Fz site is really recording the response and the second electrode near the ear is inactive, neutral, and detecting auditory evoked activity during ABR recording.
- ***electrode array or*** **electrode** ***montage*** *is the* combination of two recording electrodes.
- ***Non-cephalic*** electrode location



Connecting Electrode to AEP System

- Electrodes connect the patient to the evoked response system.
- Electrode wires lead to an **electrode strip, box, or pre-amplifier**.
- That device is usually connected to the evoked response system with an electrical cable, but *Bluetooth* technology is now also an option



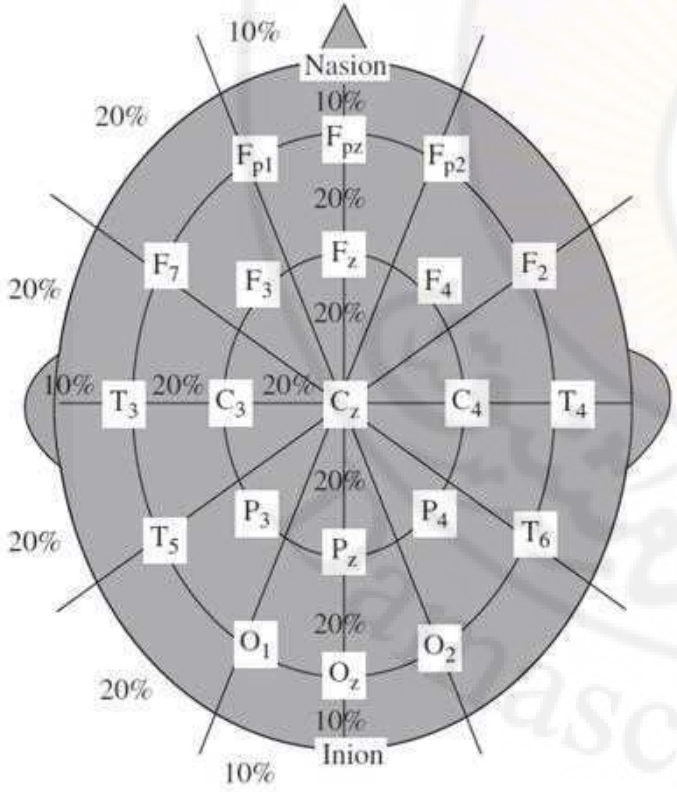

1
2
3

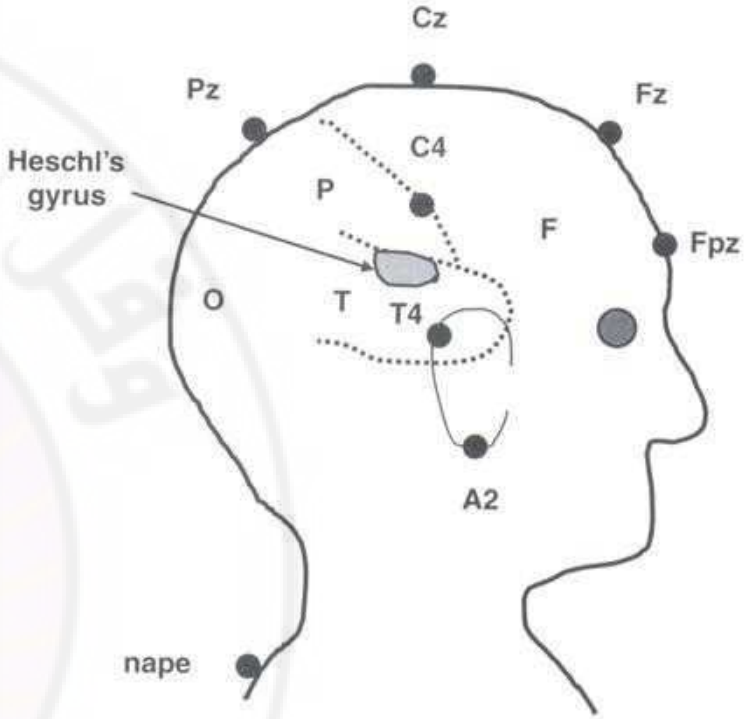

Titan

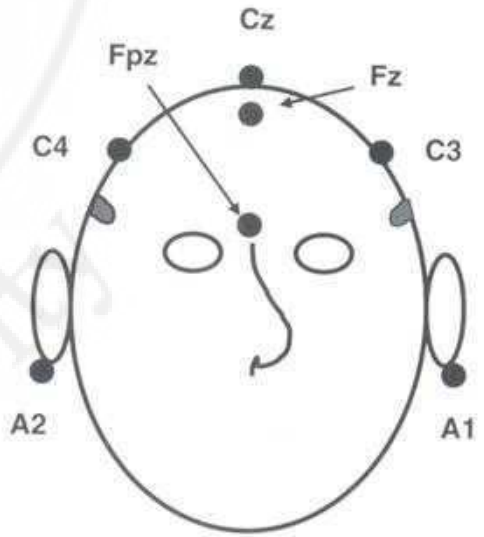

IP30
IP30
MAICO

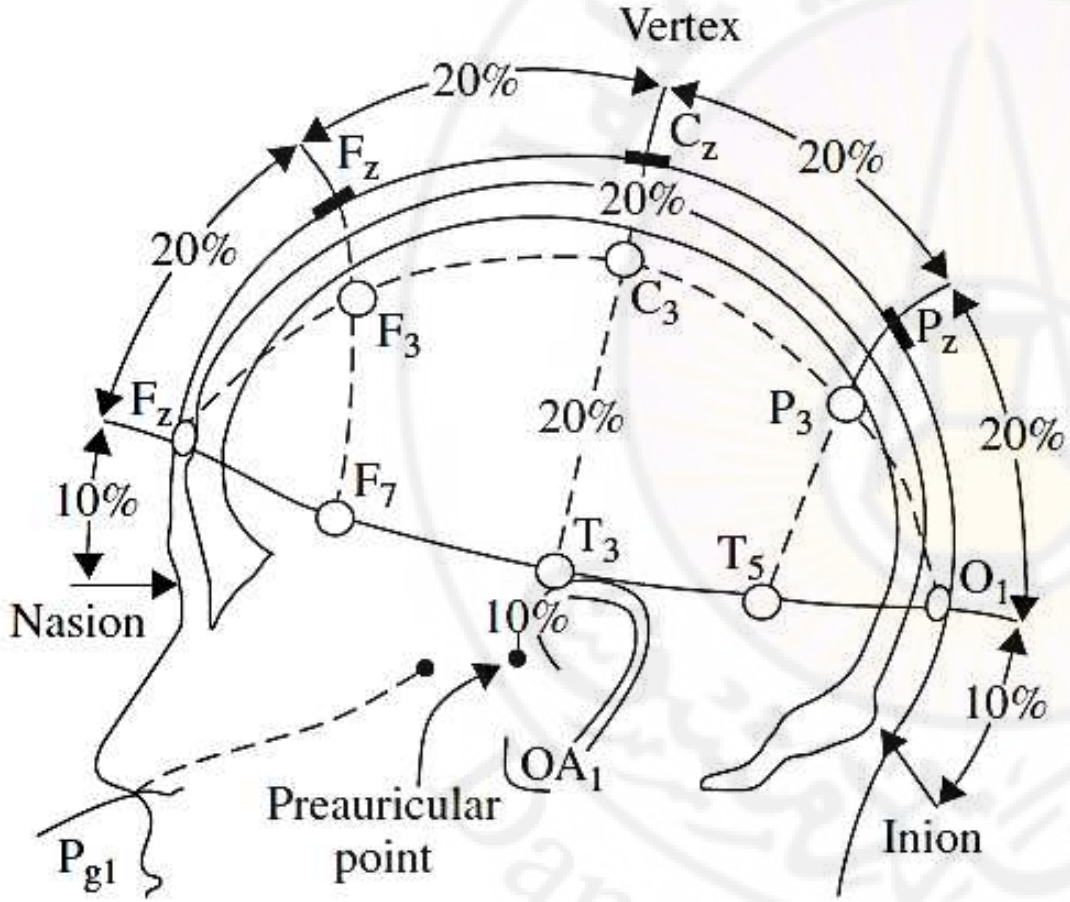
Electrode location

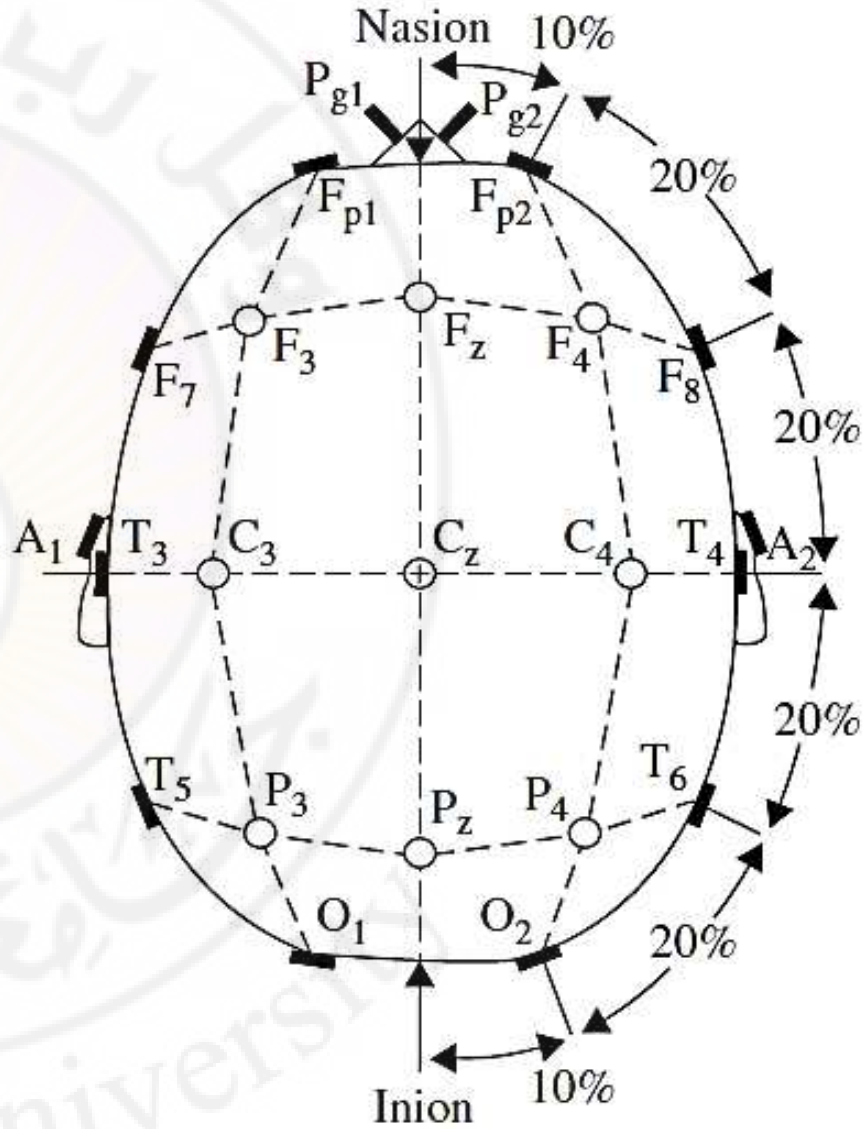
10-20 international system







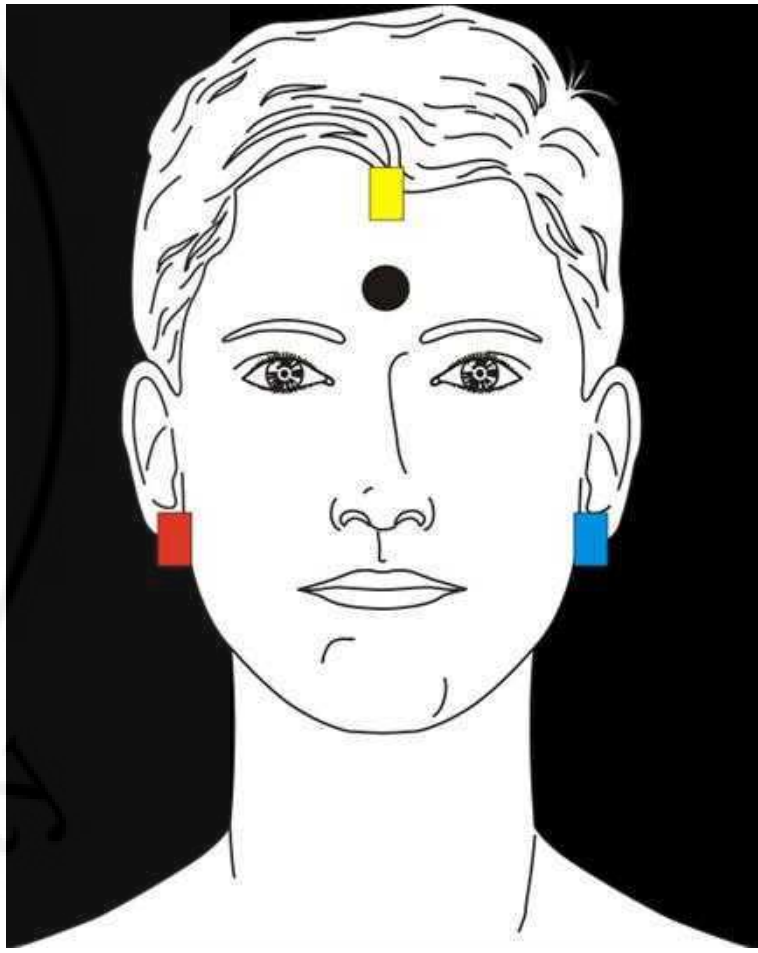

Vertex
20%
20%
20%
20%
20%
20%
20%
F_z
C_z
F_3
C_3
P_z
F_z
P_3
F_7
T_3
T_5
O_1
10%
Nasion
10%
10%
OA_1
P_{g1}
Preauricular point
Inion


Nasion
10%
P_{g1}
P_{g2}
20%
F_{p1}
F_{p2}
F_7
F_3
F_z
F_4
F_8
20%
A_1
T_3
C_3
C_z
C_4
T_4
A_2
20%
T_5
P_3
P_z
P_4
T_6
O_1
O_2
20%
Inion
10%



Electrode Terminology

- ***Non-inverting electrode*** is the proper term for the electrode located at the Cz or Fz location, whereas the other electrode near the ear is the ***inverting electrode*.**
- Activity recorded with a set of two electrodes is conveyed with the electrode wires to an **amplifier** within the evoked response system. The amplifier has one input for each electrode.

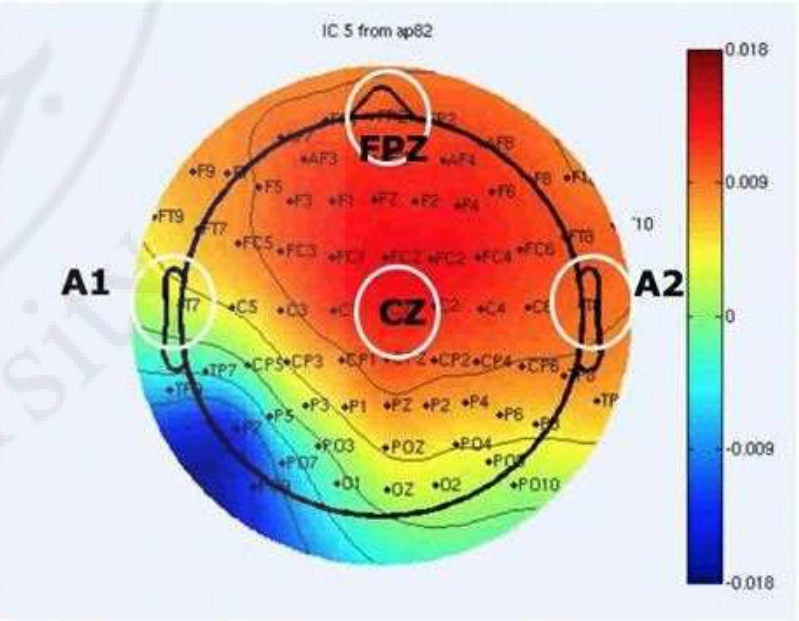


- The non-inverting electrode is so called because the electrical activity recorded with the electrode is not inverted when it is plugged into a receptacle and enters the amplifier for the evoked response system.
- Electrical activity for the inverting electrode is inverted … turned upside down … when it enters the amplifier. Then, the sum of the two inputs is amplified before it is undergoes further processing in the evoked response system.

Electrode Terminology

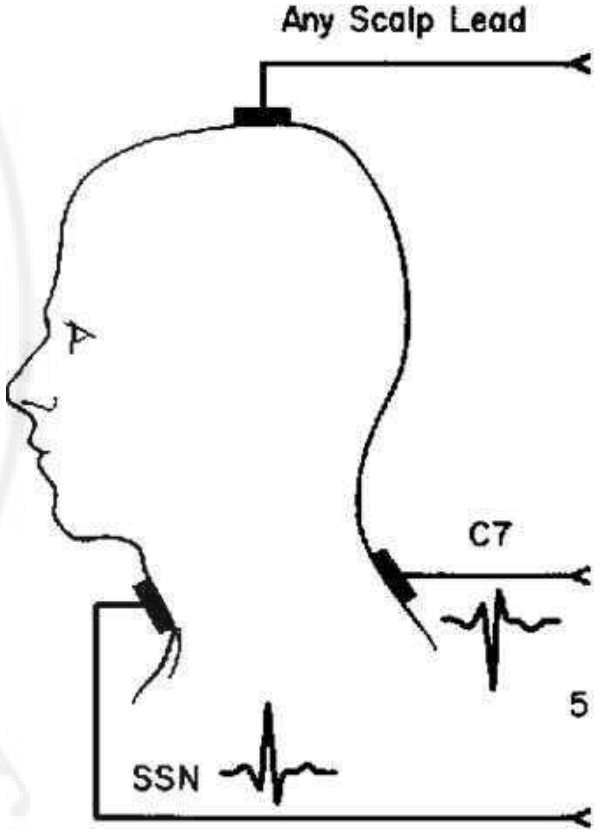
- The terms **“active”** rather than non-inverting and **“reference”** instead of inverting are often used **incorrectly** to describe the two electrodes in measurement of the ABR.
- These terms imply that only the electrode at the Cz or Fz site is really recording the response and the second electrode near the ear is inactive, neutral, and detecting auditory evoked activity during ABR recording.
- ***electrode array or*** **electrode** ***montage*** *is the* combination of two recording electrodes.
- ***Non-cephalic*** electrode location





Non-cephalic electrode location

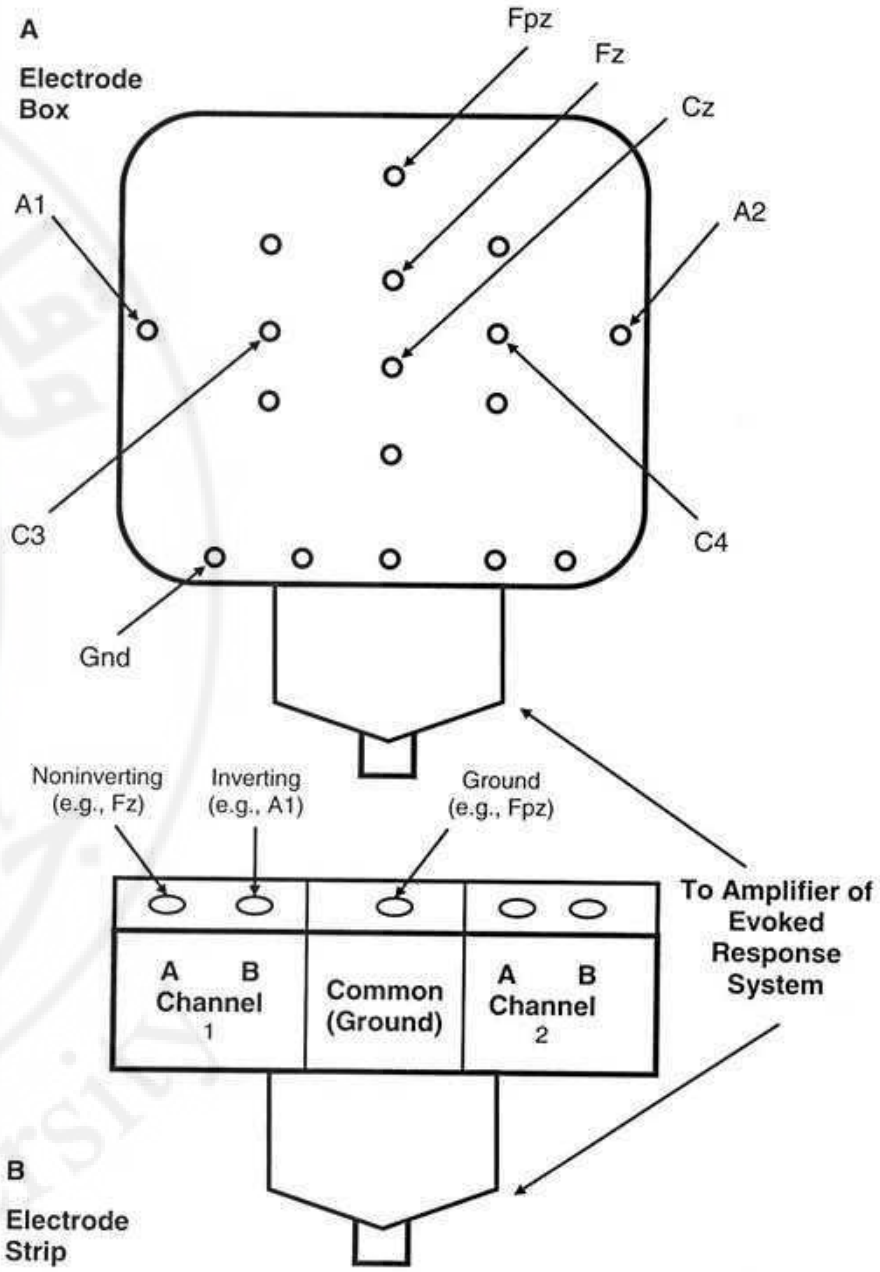
- An inverting electrode in a *non-cephalic* electrode location is truly a **"reference“** electrode since it doesn’t detect any activity from the ear or auditory pathways. With an electrode array employing a non-cephalic site for the inverting electrode, the non-inverting Fz electrode alone detects the response.
- The non-cephalic electrode array offers two possible advantages in ABR measurement.
- The wave V component is usually larger than for a conventional electrode array (Fz to Ai). Also, the wave V component may be more clearly differentiated from other components when an ABR is recorded with a non-cephalic inverting electrode.




Interacoustics
ABRIS440 binaural testing

Connecting Electrode to AEP System

- Electrodes connect the patient to the evoked response system.
- Electrode wires lead to an **electrode strip, box, or pre-amplifier**.
- That device is usually connected to the evoked response system with an electrical cable, but *Bluetooth* technology is now also an option

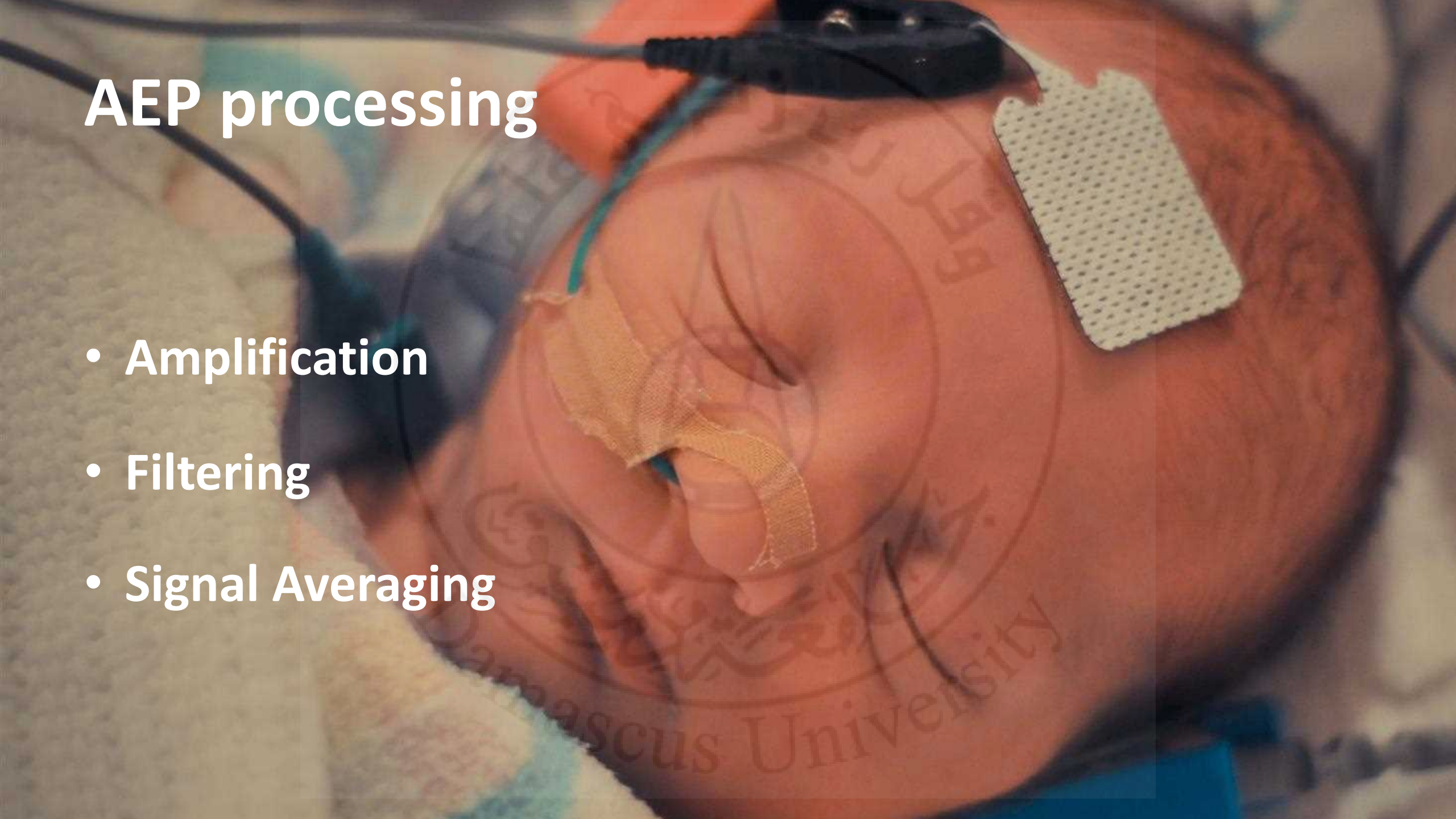



1
2
3


Titan


IP30
IP30
MAICO

AEP processing

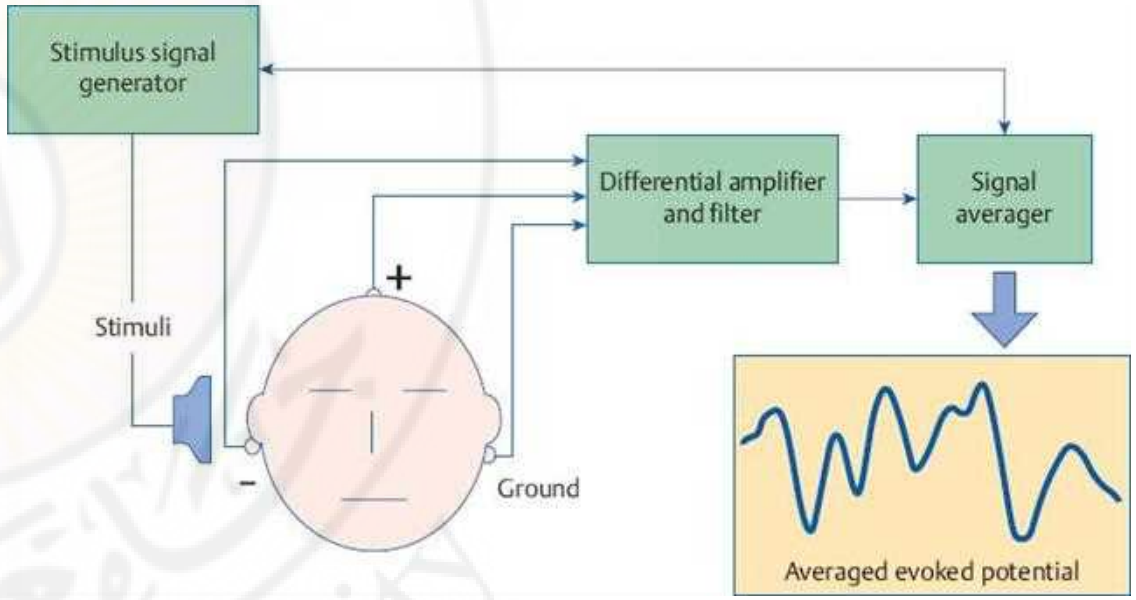


- Amplification
- Filtering
- Signal Averaging

Damascus University

Amplification

- *Amplification* is one important step in processing a response.
- An **amplifier** is a device that increases the strength of an electrical signal or acoustical signal.
- A simple example is found in every radio, **Increasing the gain or amplification** makes music or talking louder.
- **Gain** is technically defined as the ratio of the voltage of the signal at the output of the amplifier after amplification to the voltage delivered to the input.



Amplification

- An **amplifier** is a crucial component of an evoked response system because auditory evoked responses are very small in amplitude.
- Often a smaller **pre-amplifier** device where electrodes are plugged in increases the size of recorded electrical activity before it is sent on to another amplifier within the evoked response system.
- Auditory evoked response amplitude is very small even in comparison to the ongoing brain activity, referred to as electroencephalography (EEG). Amplitude of the normal EEG is up to 100 times larger than amplitude of even the biggest auditory evoked response.



Amplification

- Amplitude of a cortical auditory evoked response recorded under ideal conditions from a person with normal ears and a normal brain is only about 10 microvolts (10 µV).
- The average normal amplitude for ABR wave V is much smaller, usually is about 0.5 µV, or one-half of one-millionth of a volt, Take a moment to process that statement.
- Auditory evoked responses must be amplified substantially before they can be processed with an evoked response system computer and displayed on a computer screen.
- An ABR recording is typically amplified 100,000 times before it is displayed and analyzed.
- **Amplifier Gain= 10^5**



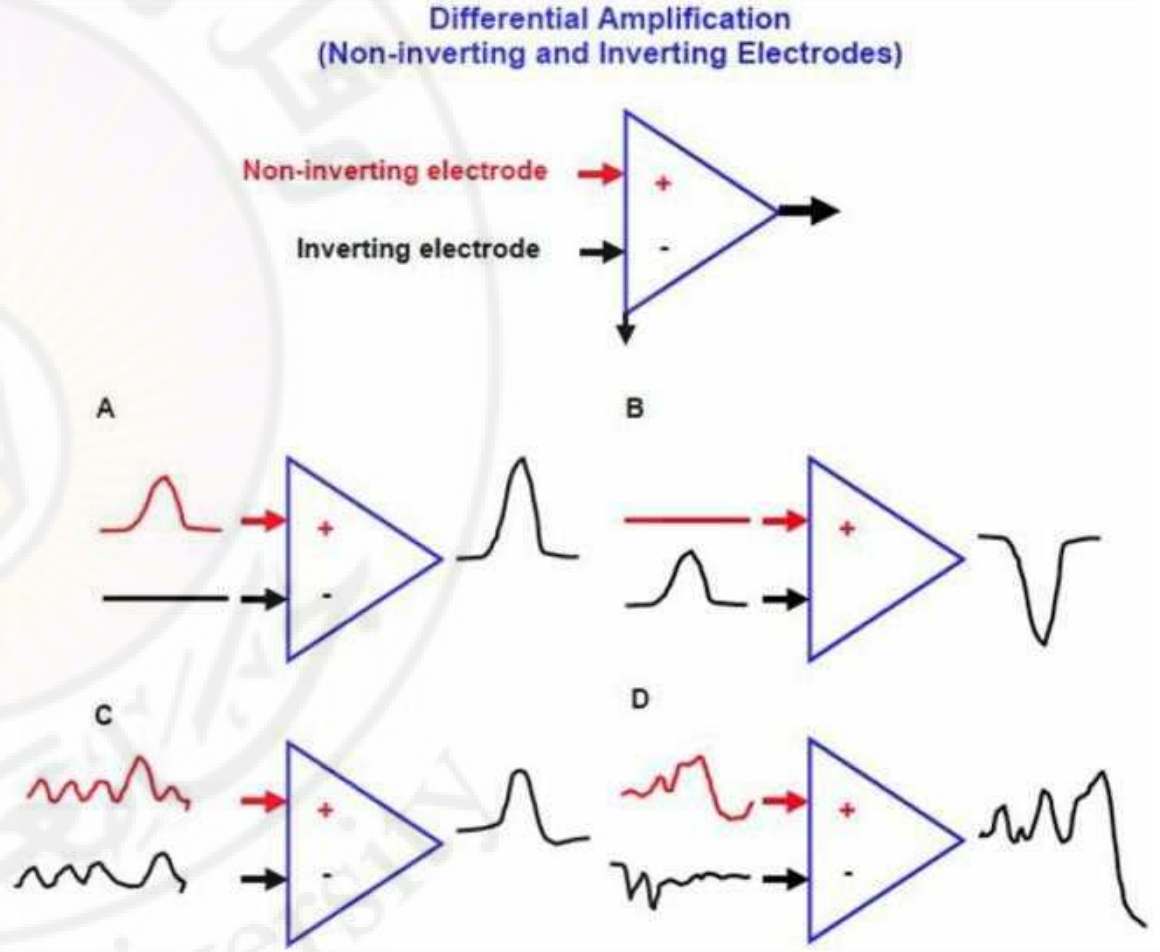
Input Impedance of Amplifier

- Input impedance is a characteristic of any amplifier that has a direct influence on successful auditory evoked response recording.
- Input impedance is simply defined as **opposition to** alternating current flow and, specifically, impedance across the amplifier inputs.
- Optimally, input impedance of the amplifier is comparable to or higher than the electrode impedances in auditory evoked response recordings.
- A serious problem develops when there is an imbalance in electrode impedance, with one electrode having higher impedance than another.



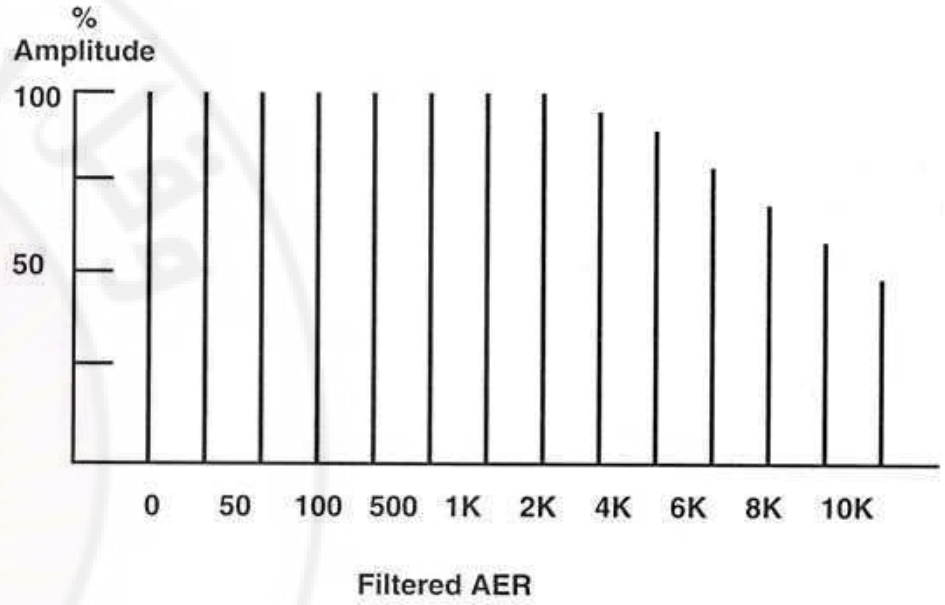
Common Mode Rejection (CMR)

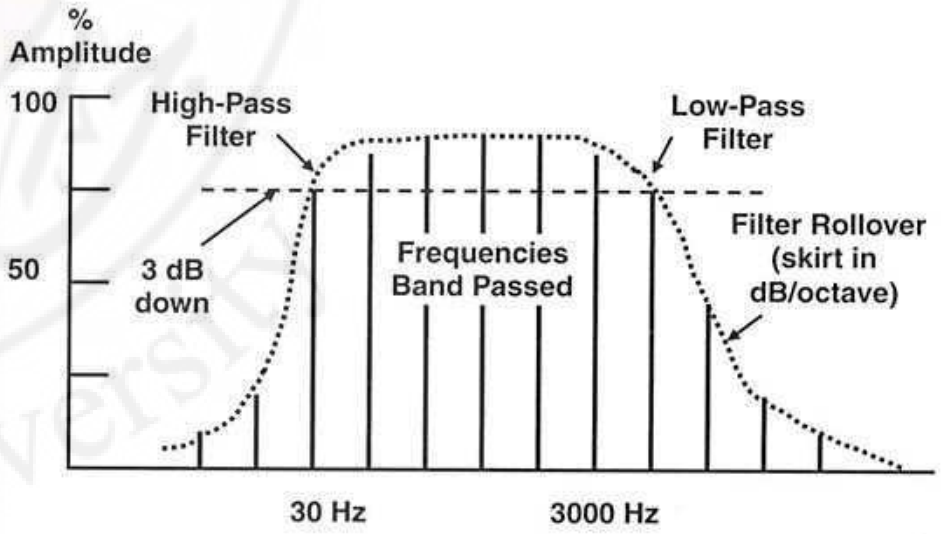
- Two electrodes placed at different locations on the head presumably each detect the same amount of electrical interference or activity **(NOISE)** in the region of the head that does not include the response.
- A **differential preamplifier**, a component of most evoked response systems, reverses polarity of inverting electrode input voltage. That is, positive voltage input is reversed to negative voltage and vice versa. The pre-amplifier then combines the inverted electrode input with the non-inverting electrode input. The differential amplifier in effect performs a subtraction process. As a result of this processing, electrical activity that is the same as detected with each electrode is eliminated or rejected.



Filtering

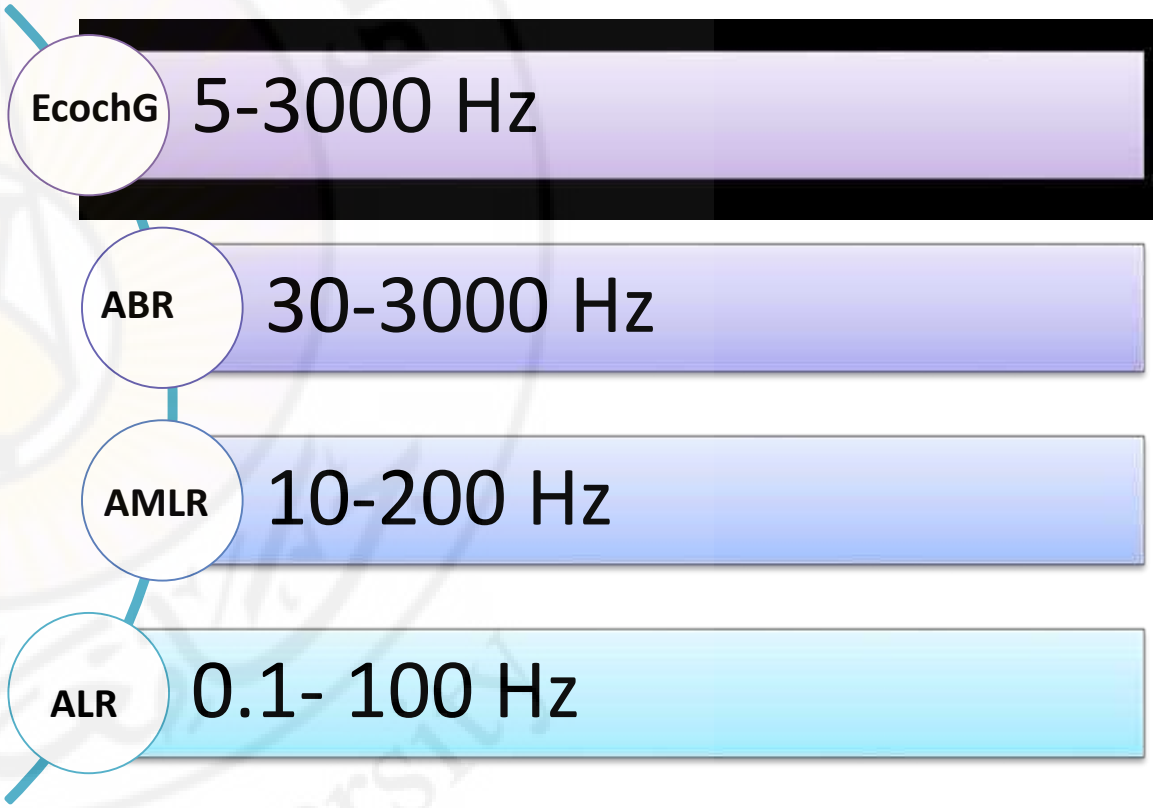
- **Filter settings** are chosen to eliminate unwanted non-response activity, mostly electrical artifact and muscle interference, while preserving the actual response.
- In measurement of auditory evoked responses, filters reject electrical energy at certain frequencies and pass energy at other frequencies.
- Two filter settings are generally selected in recording auditory evoked responses. The ***high pass filter*** setting removes lower frequencies from the recording, whereas the ***low pass filter*** setting removes higher frequencies.
- In combination these two filter settings result in a band of frequencies (a ***band pass filter***) that encompasses the spectrum of the response being recorded while filtering out lower and higher frequencies.





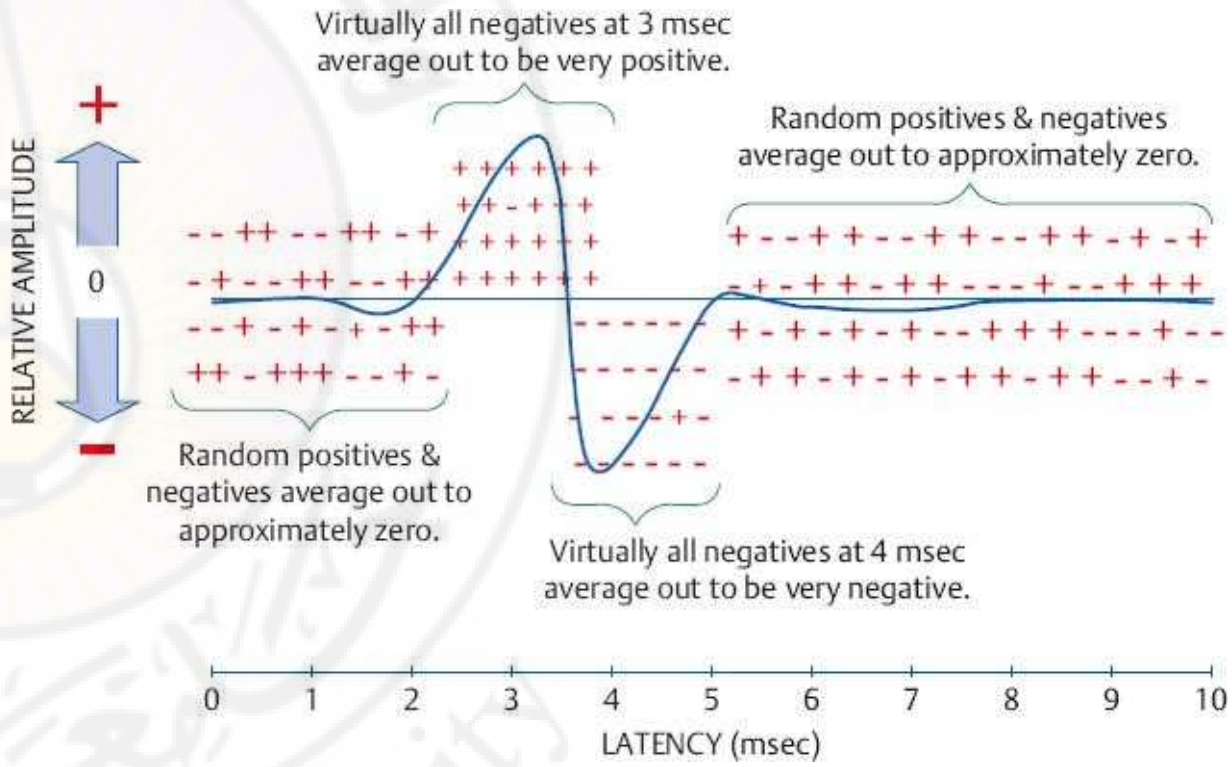
Filter setting

60 Hz (Cycle) Notch Filtering. Most evoked response systems provide the option for narrow band rejection or filtering of electrical activity in the region of 60 Hz. The objective is to selectively eliminate from the auditory evoked response 60 Hz power line interference without removing other frequencies from the response.



Signal Averaging

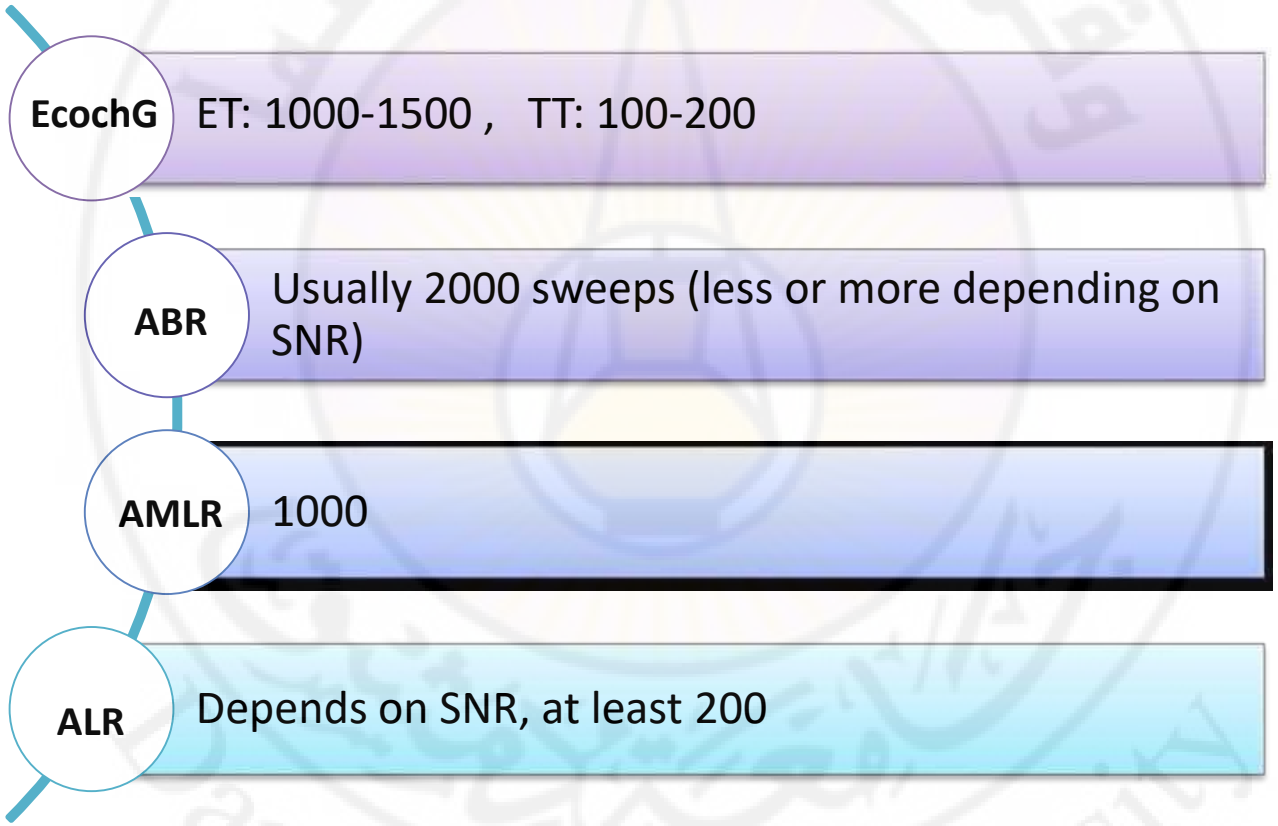
- The responses we are looking for are tiny signals embedded in all kinds of noise. A great deal of noise still remains after filtering and differential amplification.
- **Averaging** is a technique that allows the responses (evoked potentials) to be extracted from the noise, and is a central principle of many physiological methods.
- Averaging relies on a few fundamental notions. The first principle is that the evoked potential responses are ***time-locked* to (or *synchronized* with) the stimulus**. This means that the response will consistently appear in a certain way at the same latency, or point in time after the stimulus.
- On the other hand, **noise is *random***.
- **Averaging the responses to a large number of stimuli (sweeps) results in a appropriate waveform.**



How many Sweeps do we need to present?

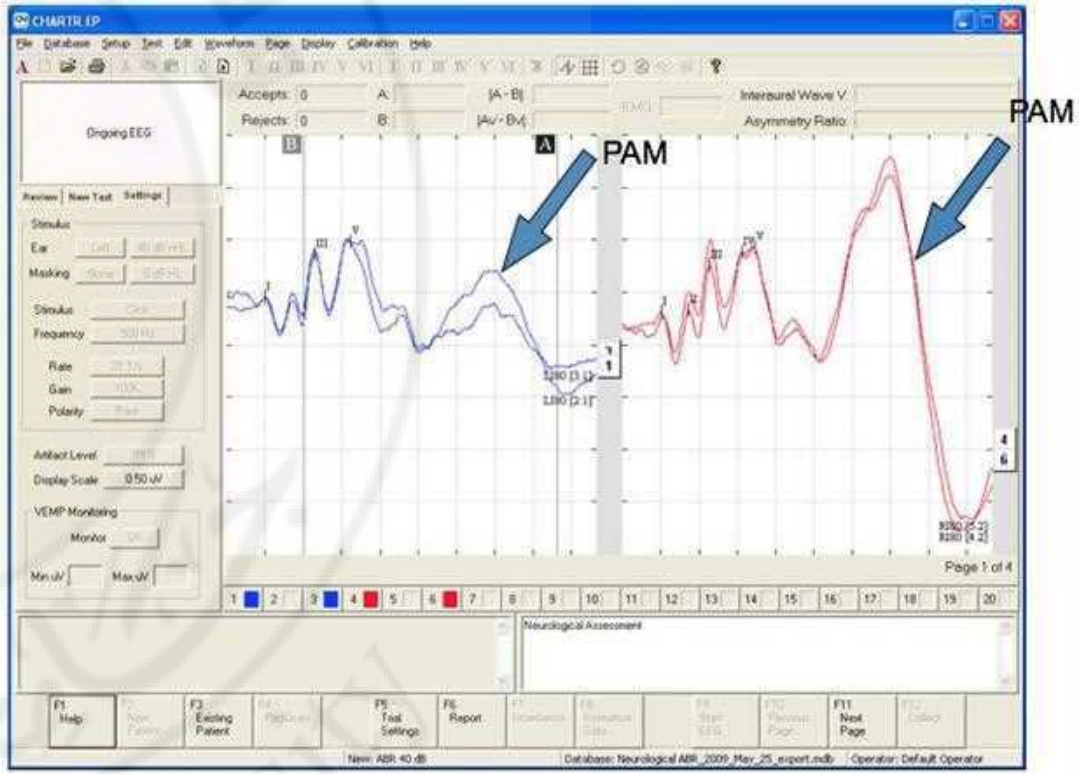
- We want to produce a response that's twice as big as background noise; we want a **3:1 signal-to-noise ratio (SNR) or better**.
- When testing a quiet child using a high intensity click stimulus, you might reach a 3:1 SNR after 500 stimuli. When you are testing a child with a hearing loss near threshold using a tone burst stimulus, it might take a lot more stimuli before you reach that SNR.
- Factors contributing to the **signal** include the **intensity, the patient's hearing status, and the type of stimulus** (such as use of a chirp, which we cover in part two of this course). Factors contributing to the *noise* include *muscle and electrical activity.*
- One way we can improve test efficiency is by only presenting as many stimuli as we need depending the testing conditions.

Averaged Sweeps



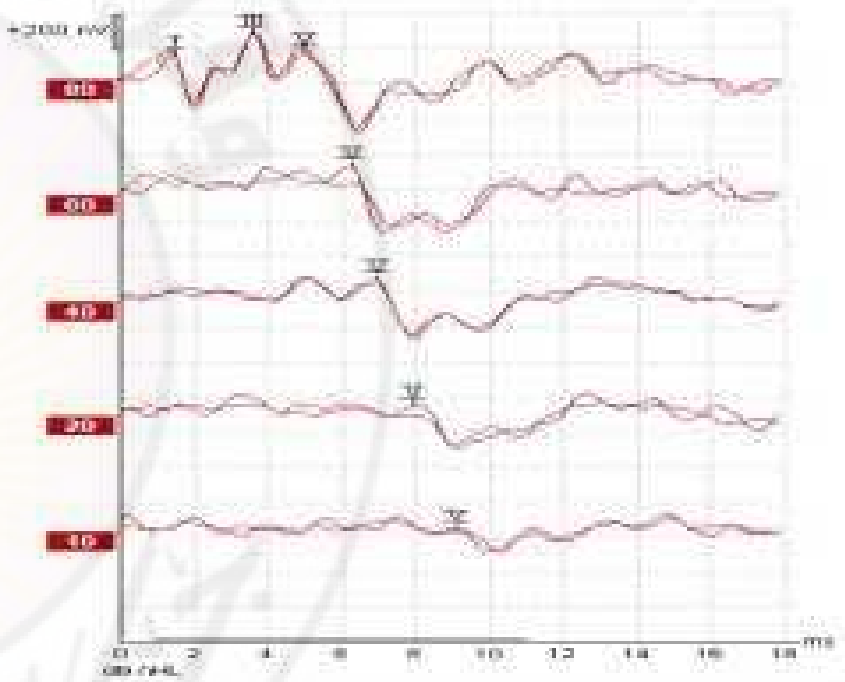
Artifact Rejection

- EEG contaminated by general patient movement, neuromuscular artifact, electrical interference at 60 Hz or another discrete frequency, or high frequency electrical interference.
- The artifact rejection indicator may alert the clinician to the presence of interference but visual inspection of the raw incoming signal is a more effective approach for determining the type and sometimes the source of interference. This information can then guide attempts at reducing or eliminating the problem.
- So the recommendation is to keep the artifact reject **"On"** in most cases.



Reliability (Reproducibility)

- When we're making our final measurements at low intensities that are going to be used to estimate the child's behavioral threshold, we need more than one run.
- If the response repeats, there's really a response there.
- If the waves do not repeat, your test is not complete.
- As we like to say, “If the waves do not replicate, you must investigate”.

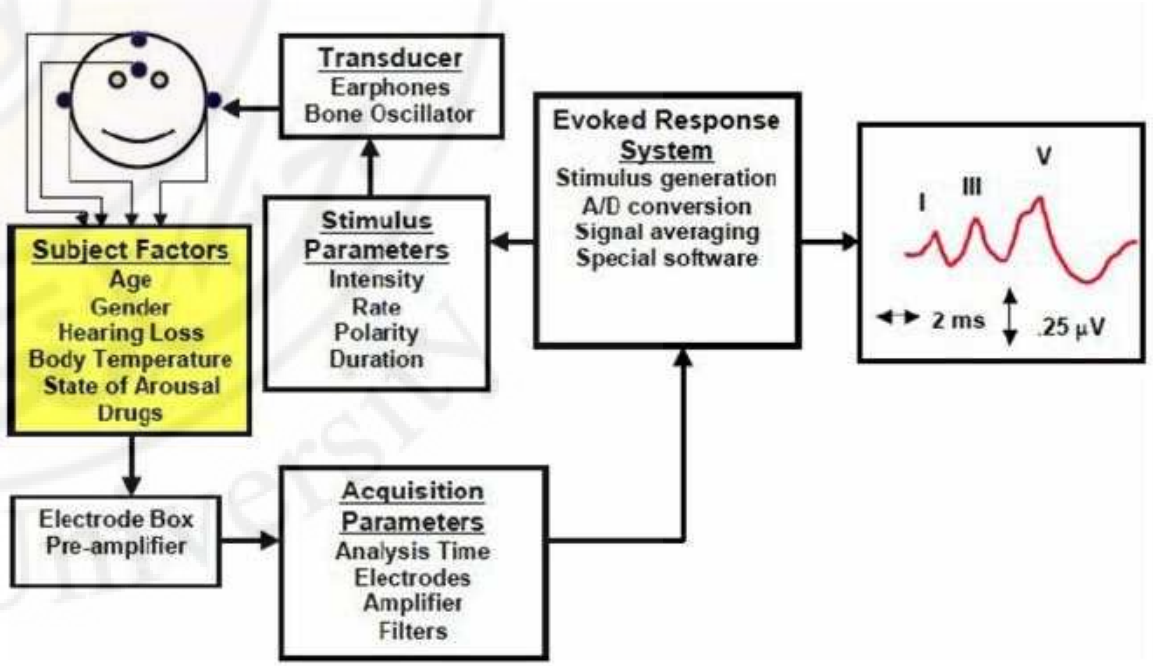




Parameter	Selection	Rationale
Artifact reject	On	Minimize muscle artifact
Analysis time	15-ms	Click, 4000 Hz, 2000 Hz
	20-ms	1000 Hz, 500 Hz
		Encompass delayed wave V and SN10 after wave V
Sweeps	Variable	To produce SNR of > 3:1
		To increase test efficiency
Reliability	2 or 3 runs	"If the waves don't replicate, you must investigate!"
Electrode type	Disc & ear clip	Disposable = <infection
	or disposable	
Electrode location	Fz - Ai	Optimal infant response
	Fpz ground	Good for BC stimulus
		Permits ipsi/contra measurement
Filter settings	30 - 3000 Hz	Encompass infant spectrum
	No notch filter	

Subject factors: Non-Pathological

- Major non-pathological factors related to subject in measurement of auditory evoked responses are:
- **Age**
- **Gender**
- **Body temperature**
- **State of arousal**
- **Drugs**
- **Myogenic artifacts**



Age

- ABR peak latencies, interwave intervals (IWIs), and amplitudes have been shown to vary with the age of a subject.
- Young age in children affects the ABR mostly *from birth to 18 months.*
- **Infant** peak latencies and IWIs are longer than those seen in adults.
- **Older adult** subjects have ABRs that are typically reported to be longer in latency and smaller in amplitude, as compared to younger adult subjects. However, many of these older subjects have a hearing loss, which makes it difficult to separate the changes in the ABR that occur as a result of advancing age from the changes that can occur from a hearing loss.

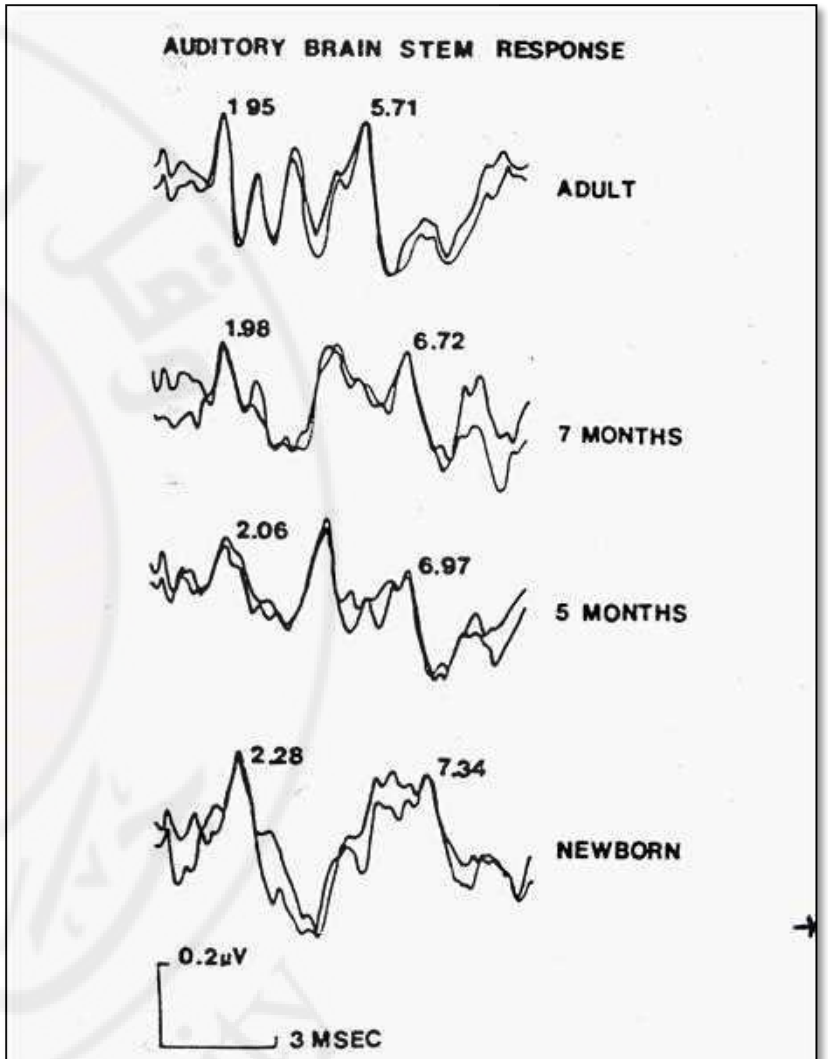
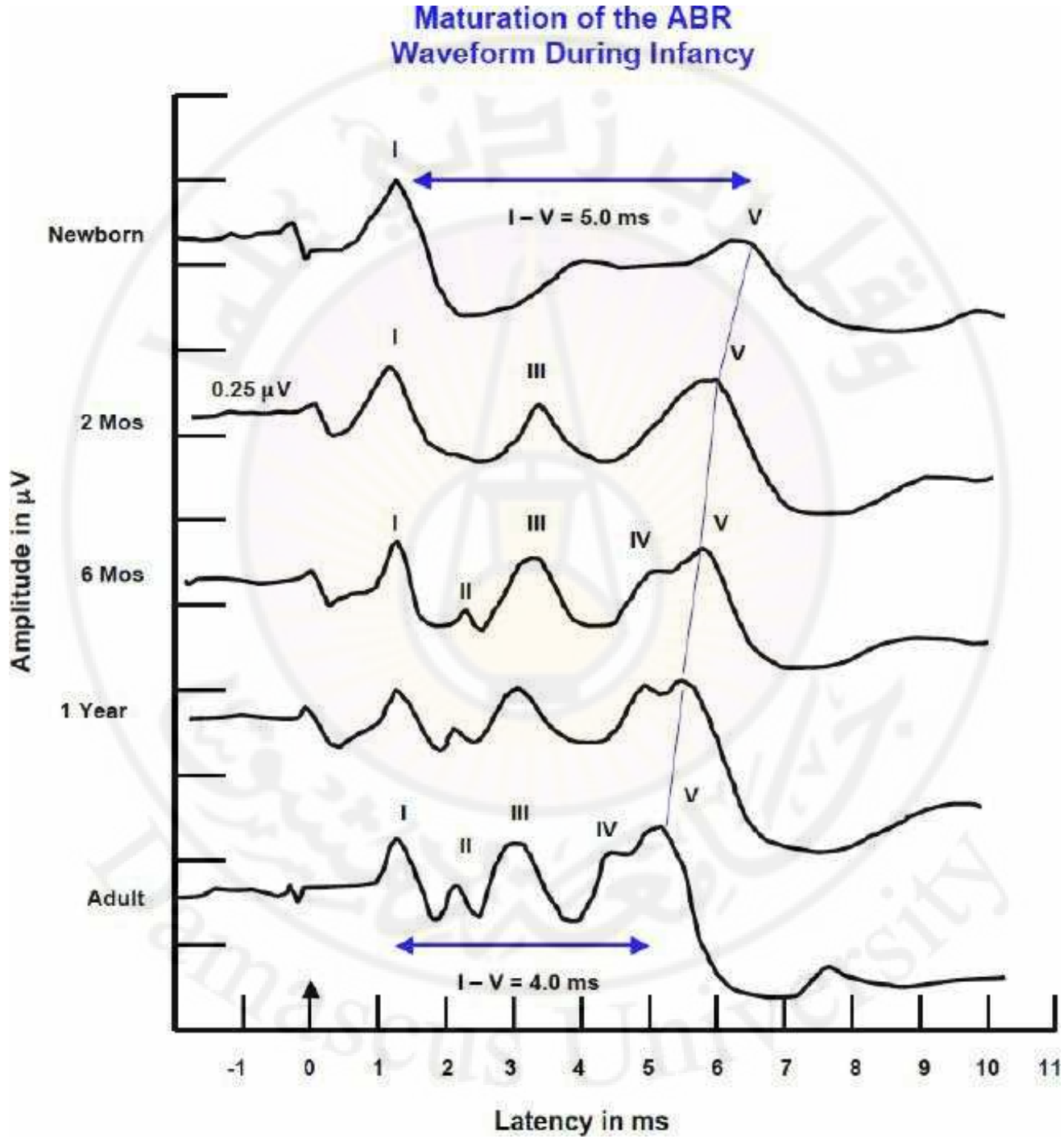


Figure 19–13 ABR waveforms showing maturation of the response from newborn to adult. In each example, the latencies of waves I and V are indicated. Over time, the progressive emergence of waveform components, decrease in latencies, and change in amplitude ratio can be observed. (From Jacobson & Hall [1994], with permission.)


Maturation of the ABR
Waveform During Infancy
Newborn
I
I – V = 5.0 ms
V
2 Mos
0.25 µV
I
III
V
6 Mos
I
II
III
IV
V
1 Year
Adult
I
II
III
IV
V
I – V = 4.0 ms
Amplitude in µV
-1
0
1
2
3
4
5
6
7
8
9
10
11
Latency in ms

Gender

- Females generally show shorter response latencies and IWIs, as well as larger response amplitudes, than males.
- These sex differences cannot be explained by differences in head size alone, but rather appear to be attributable, at least in part, to differences in cochlear length.
- Human females have shorter cochleae than their male counterparts.
- Don et al. (1993), reported that shorter cochlear length results in greater traveling-wave velocity, which is believed to account for some of the gender-related differences noted above.



Body temperature

- A decrease in core temperature **(hypothermia)** results in an increase in ABR peak latencies, an increase in interwave intervals (IWIs), and a decrease in peak amplitudes.
- Latency values decrease with higher than normal body temperature **(hyperthermia).**
- It is important to monitor core temperature during intraoperative monitoring. This is because a patient's core temperature may be outside of the normal range during, for example, heart surgery, and core temperature changes can have an influence on the interpretation of the results.



State of arousal

- The ABR is not substantially influenced by attention or sleep state, which makes it optimal for evaluating patients who are unable or unwilling to cooperate, such as infants or young children.
- **ABR testing in uncooperative subjects is usually perform under sedation.**




C8383-100G
Chloral hydrate
sigmaaldrich.com


120 ml (Approx)
Cedate
(Chloral hydrate USP)
Syrup
XENON PHARMACEUTICALS
Cedate



Drugs

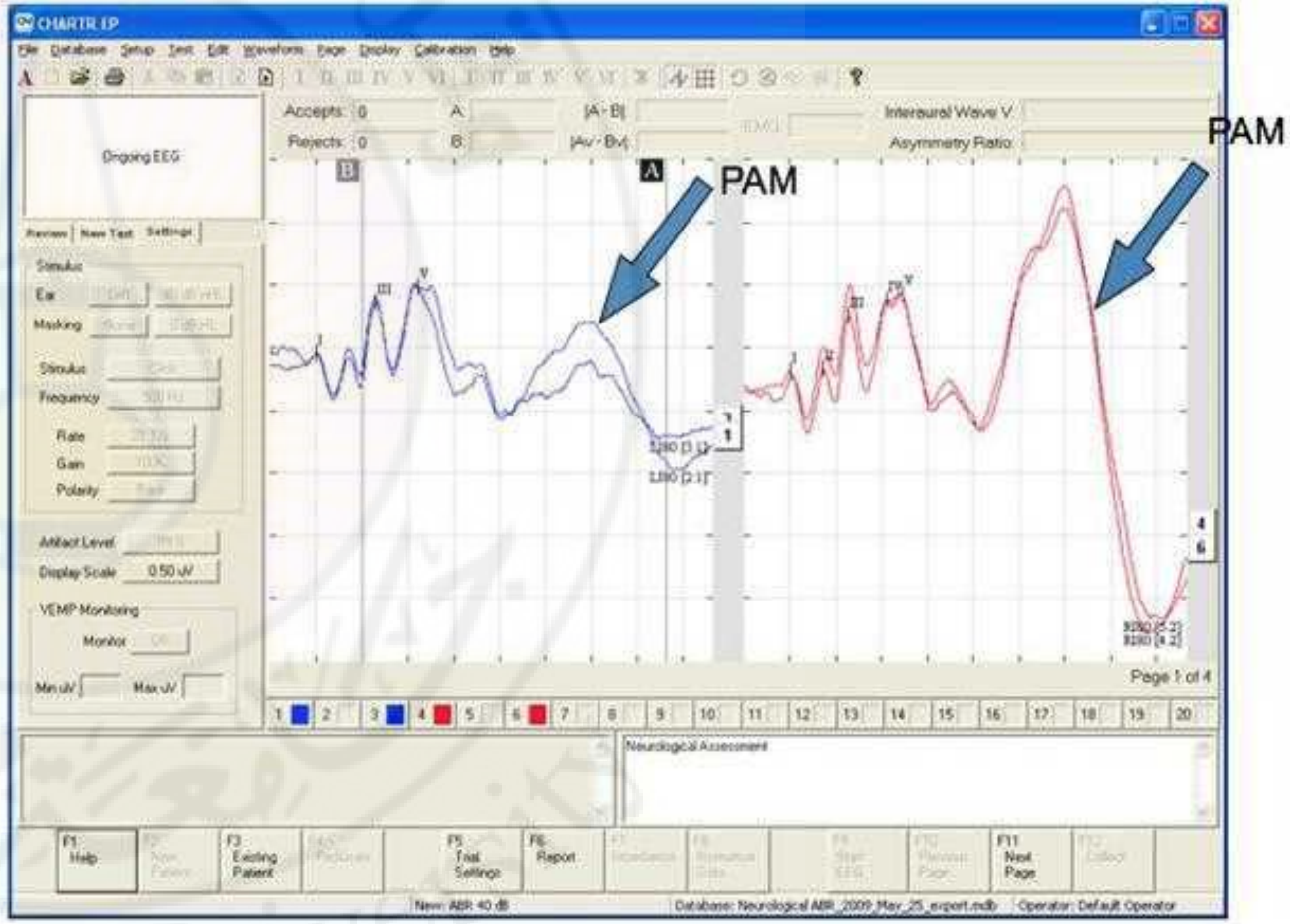
- Sedative and anesthetic drugs generally have no significant effect on ABR although slight latency delays are associated with certain anesthetic agents.

- **General anesthesia with Enflurane!**



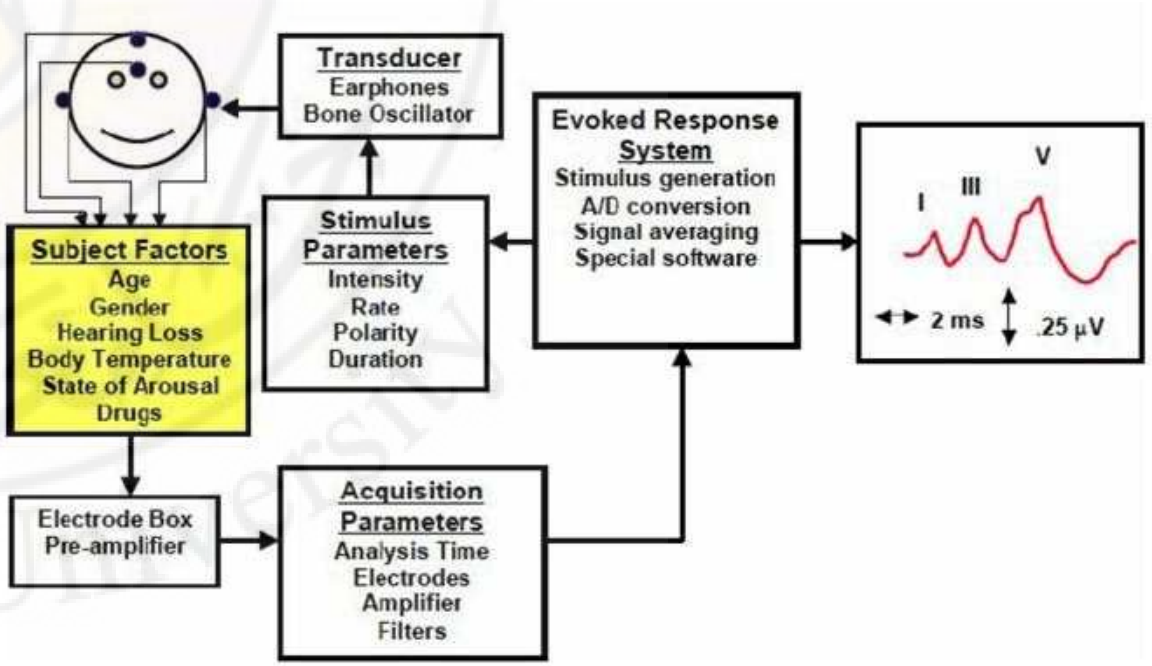
Myogenic artifacts

- Movement and muscle interference may have a pronounced effect on the ABR.



Subject factors: Pathological

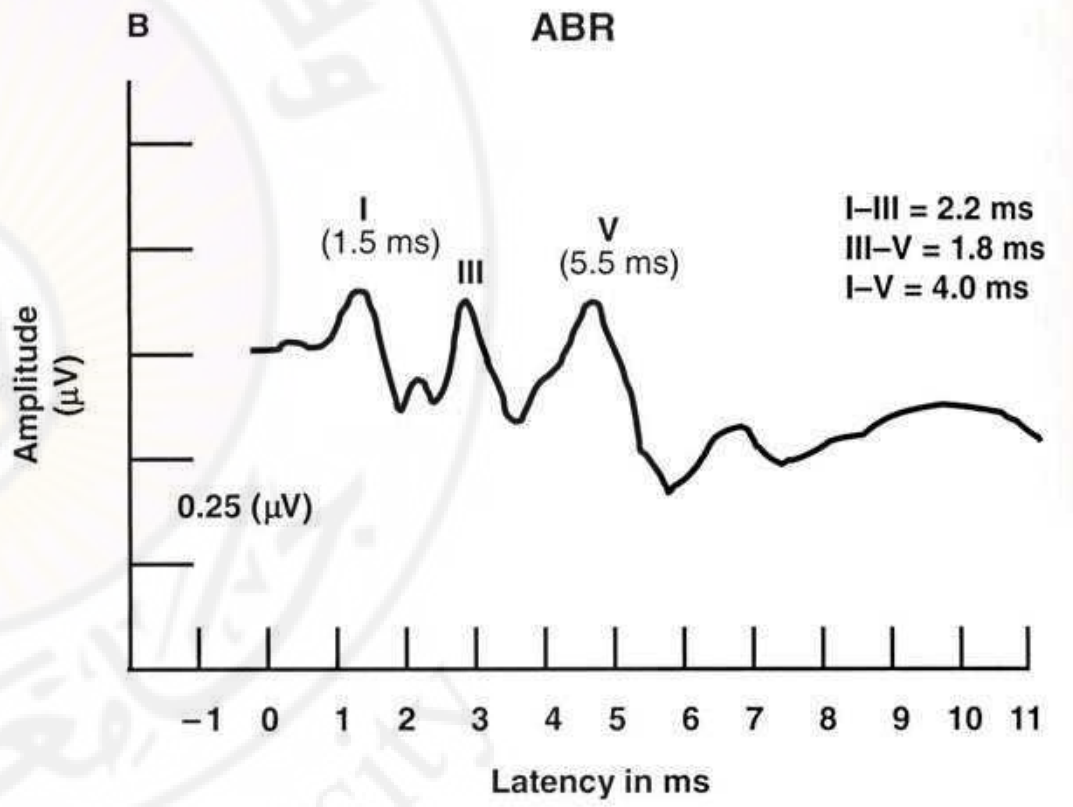
- Major pathological factors related to subject in measurement of auditory evoked responses are:
- **Conductive Hearing loss**
- **Cochlear hearing loss**
- **Auditory Nerve Involvement**
- **Brainstem Involvement**



4. Introduction to Auditory Brainstem Response

Auditory Brainstem Response (ABR)

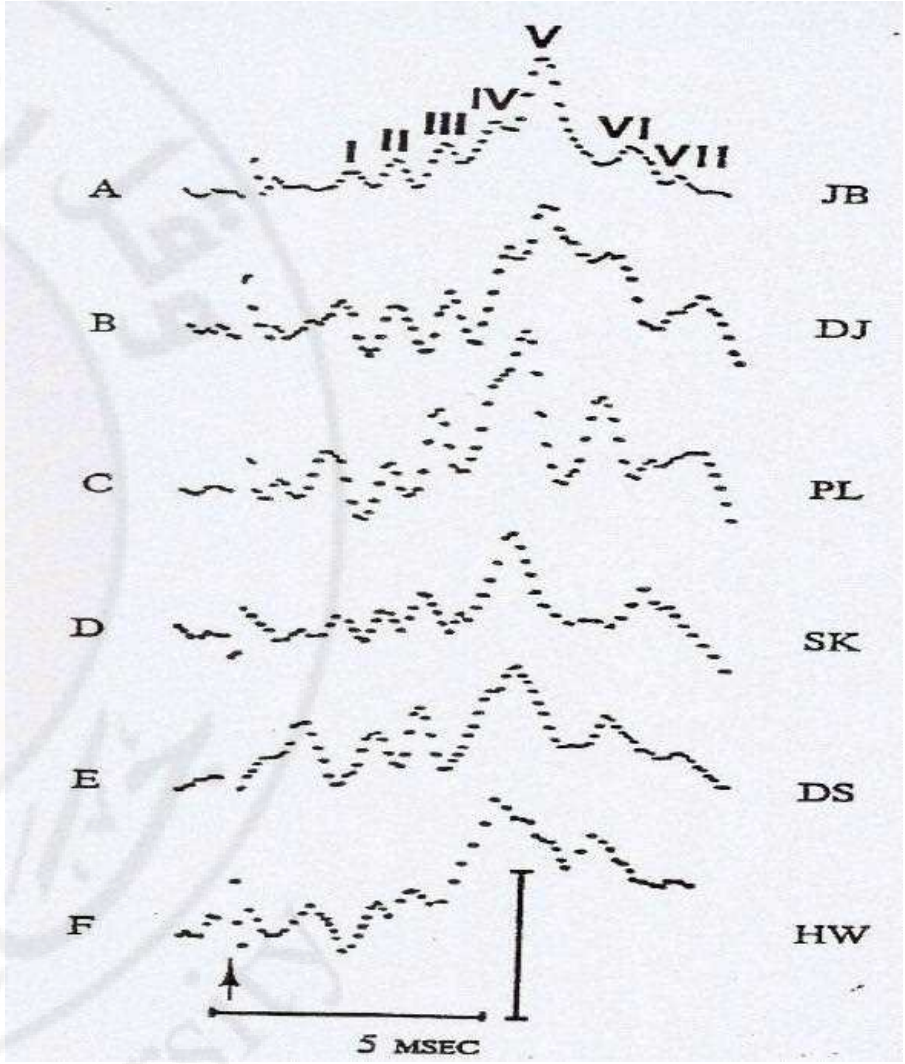
- The ABR includes a series of **five to seven peaks** arising from auditory nerve and brainstem structures, occurring within 10 ms of the onset of a moderate intensity click stimulus in otologically, audiologically, and neurologically intact adults.
- The ABR is, without question, the most clinically useful AEP at the present time.
- It can be used for estimating hearing threshold and differential diagnosis of peripheral and central abnormalities and for intraoperative monitoring.



Brief History

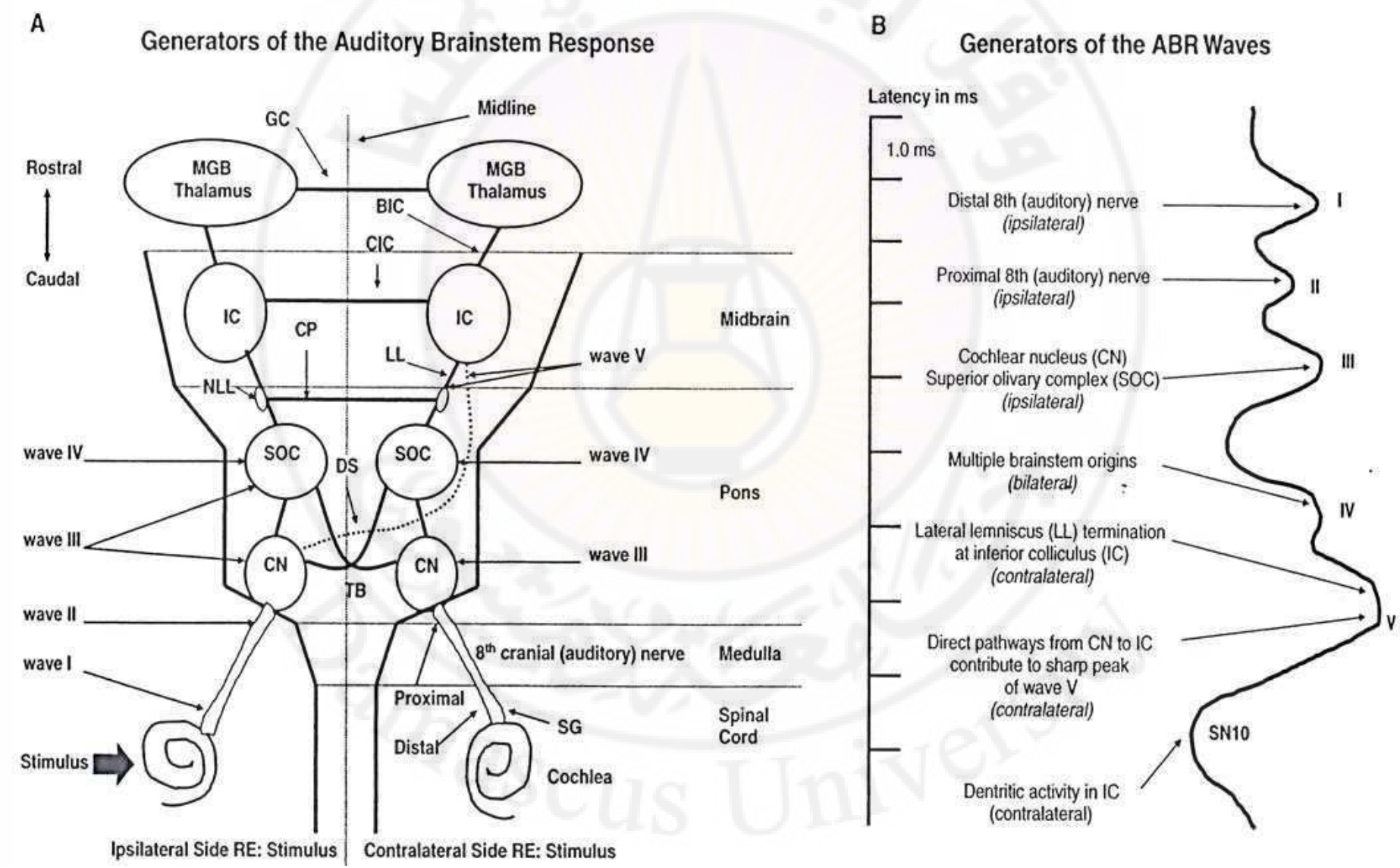
- 1970: Jewett described ABR in animal model
- **1970: Jewett, Romano & Williston first describe ABR in humans**
- 1971: Jewett & Williston systematic study ABR in humans
- 1971: Moore completed unpublished PhD project revealing ABR
- 1973: Terkildsen, Osterhammel and colleagues conducted a series of studies on stimulus and acquisition parameters
- 1974: Hecox & Galambos described ABR in infants and children
- 1975: Schulman-Galambos & Galambos described ABR in premature infants
- **1975: Starr described ABR in patients with varied CNS pathologies**

- The clinical research in the 1970s showed the reliability and dependability of the ABR—which remains a key to its continued use.

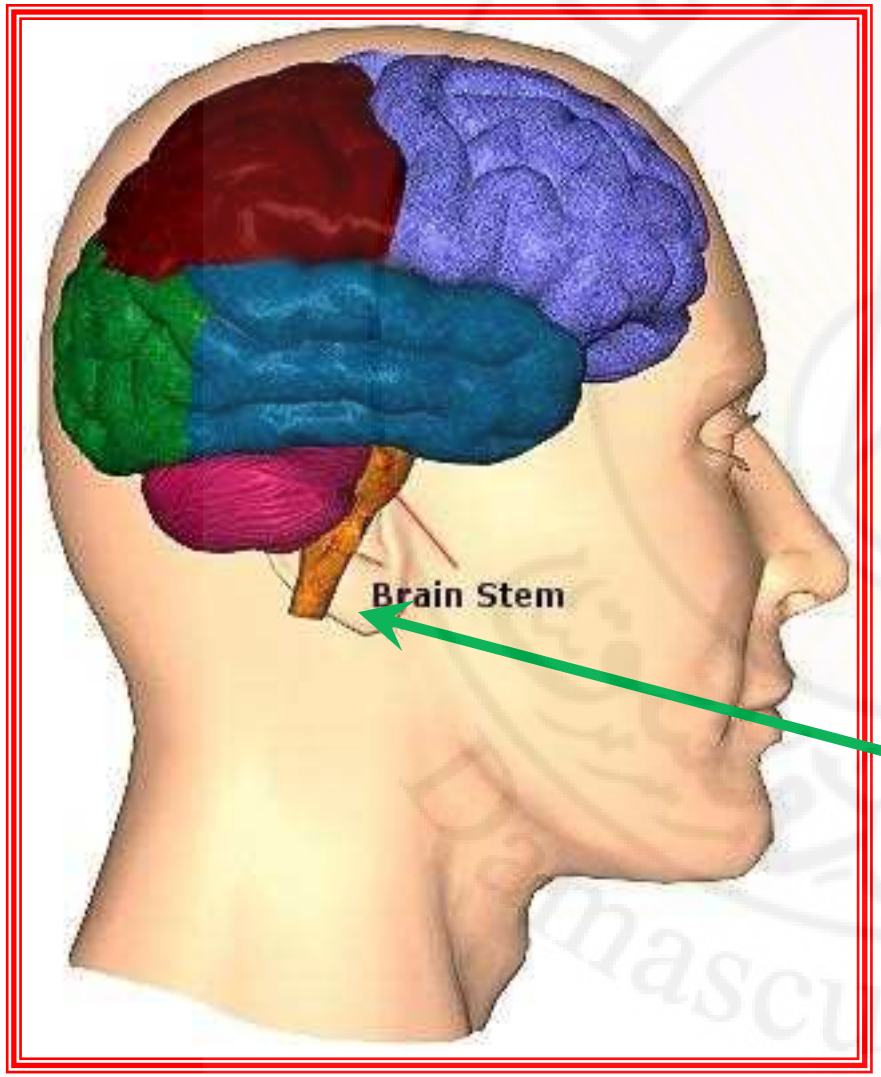


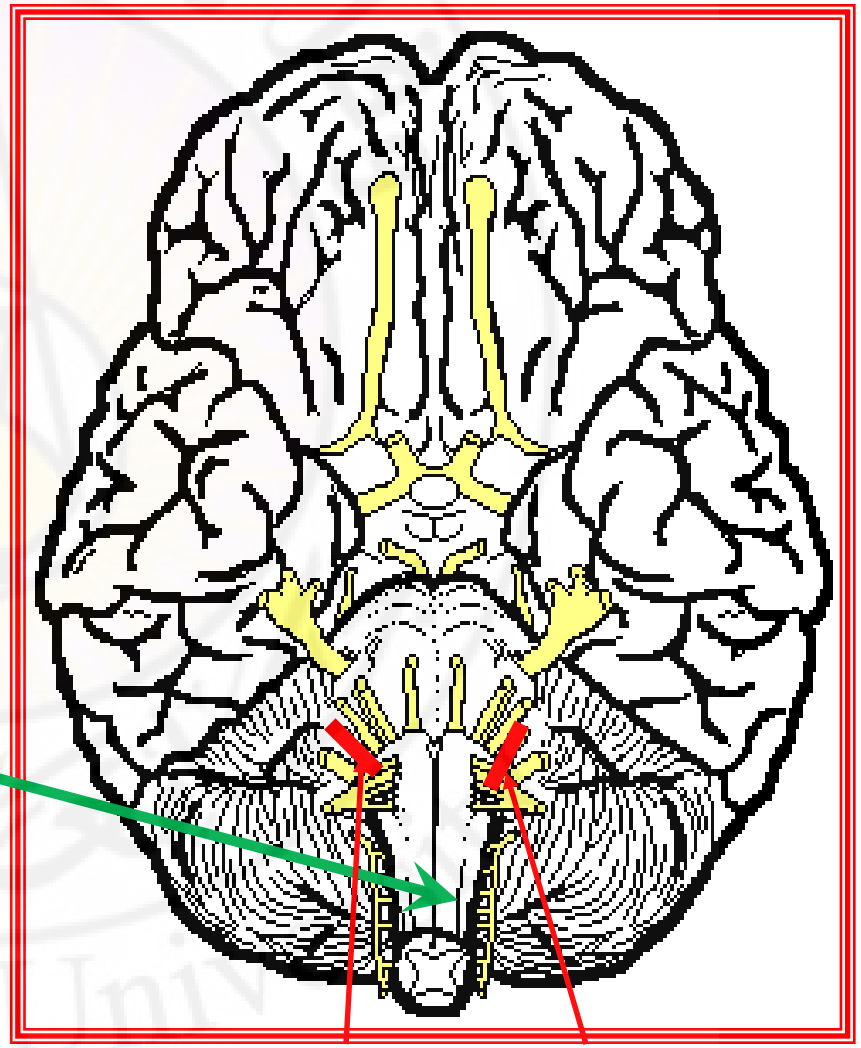
Waveforms from the Jewett & Willston (1971) article illustrating the high level of inter-subject consistency characterizing the ABR.

Overview Of Generator Sites



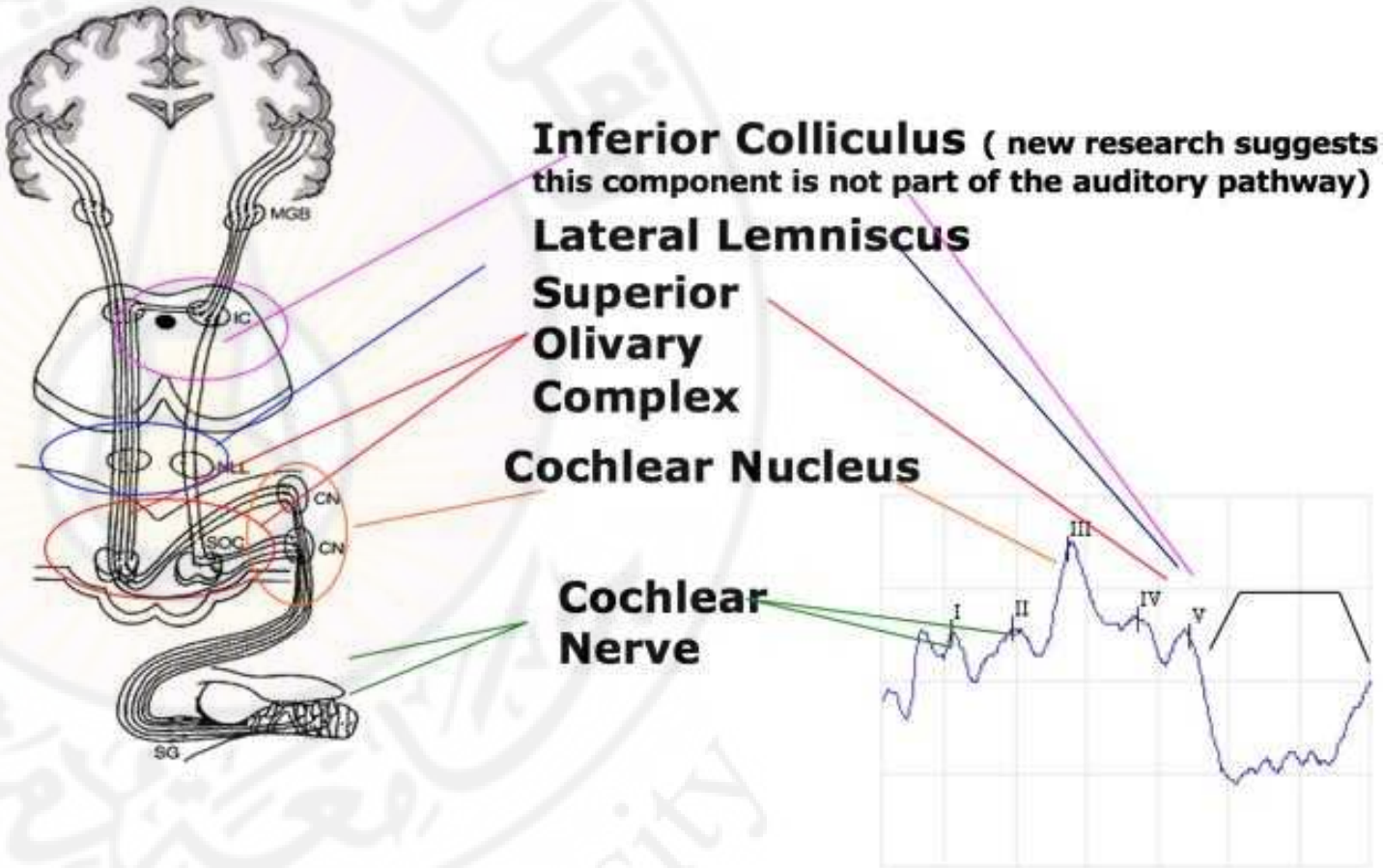
Brainstem and the Cranial Nerves





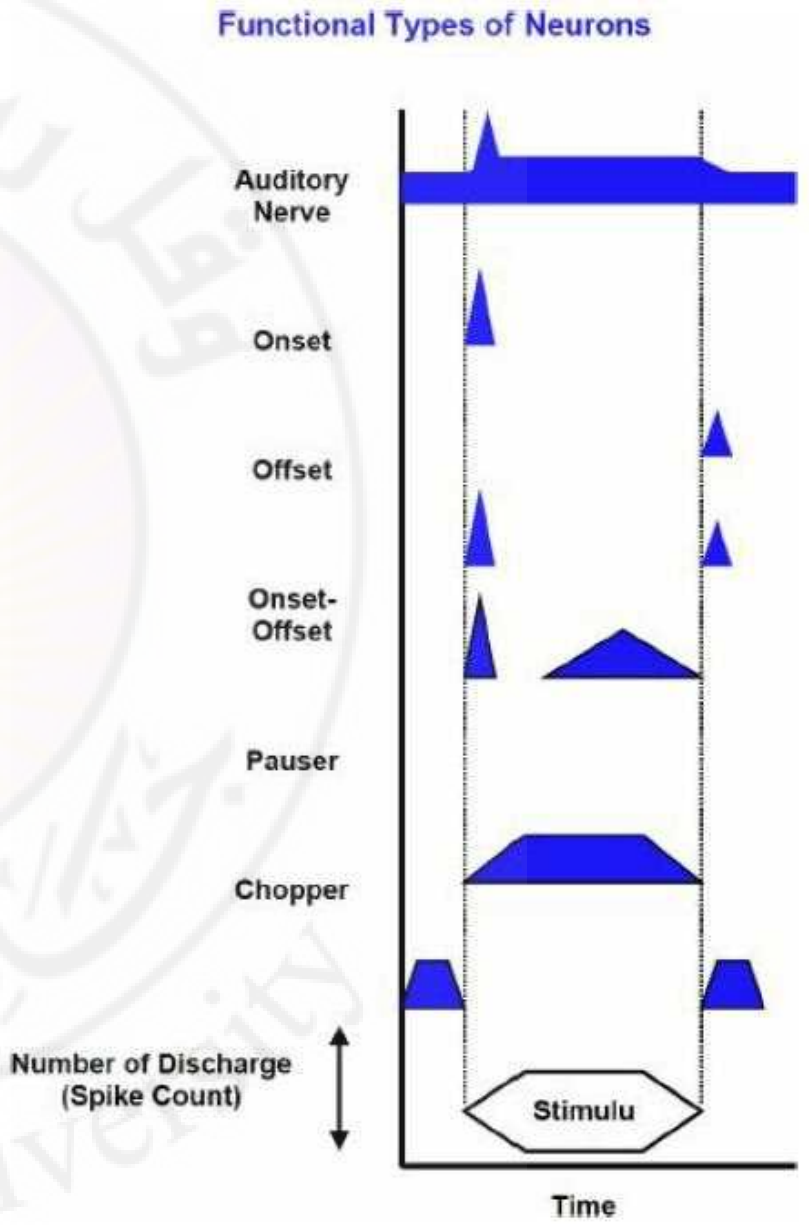
XIIIth Cranial Nerve

While it does appear that the first two peaks are produced by the auditory nerve, the subsequent peaks actually have **multiple generators**, meaning that they are due to the combined electrical activity of several nuclei in the auditory brainstem.



ABR is an Onset Response

- Neurons are differentiated on the basis of structure and function. There are several types of neurons in the auditory system, each with its own distinctive appearance and its own firing response pattern.
- The structural types of shapes of neurons include **octopus, pyramidal, globular, stellate, spherical, and bushy cells**.
- ABR evoked with transient stimuli like clicks and tone bursts appears to be elicited with activation of **onset neurons** represented structurally as octopus cells.



Waveform Terminology

- Auditory brainstem response (ABR)
- Brainstem auditory evoked response (BSER)
- brain stem evoked response (BSER)
- Brainstem auditory evoked potential (BAEP)
- Brainstem auditory evoked response (BAER)

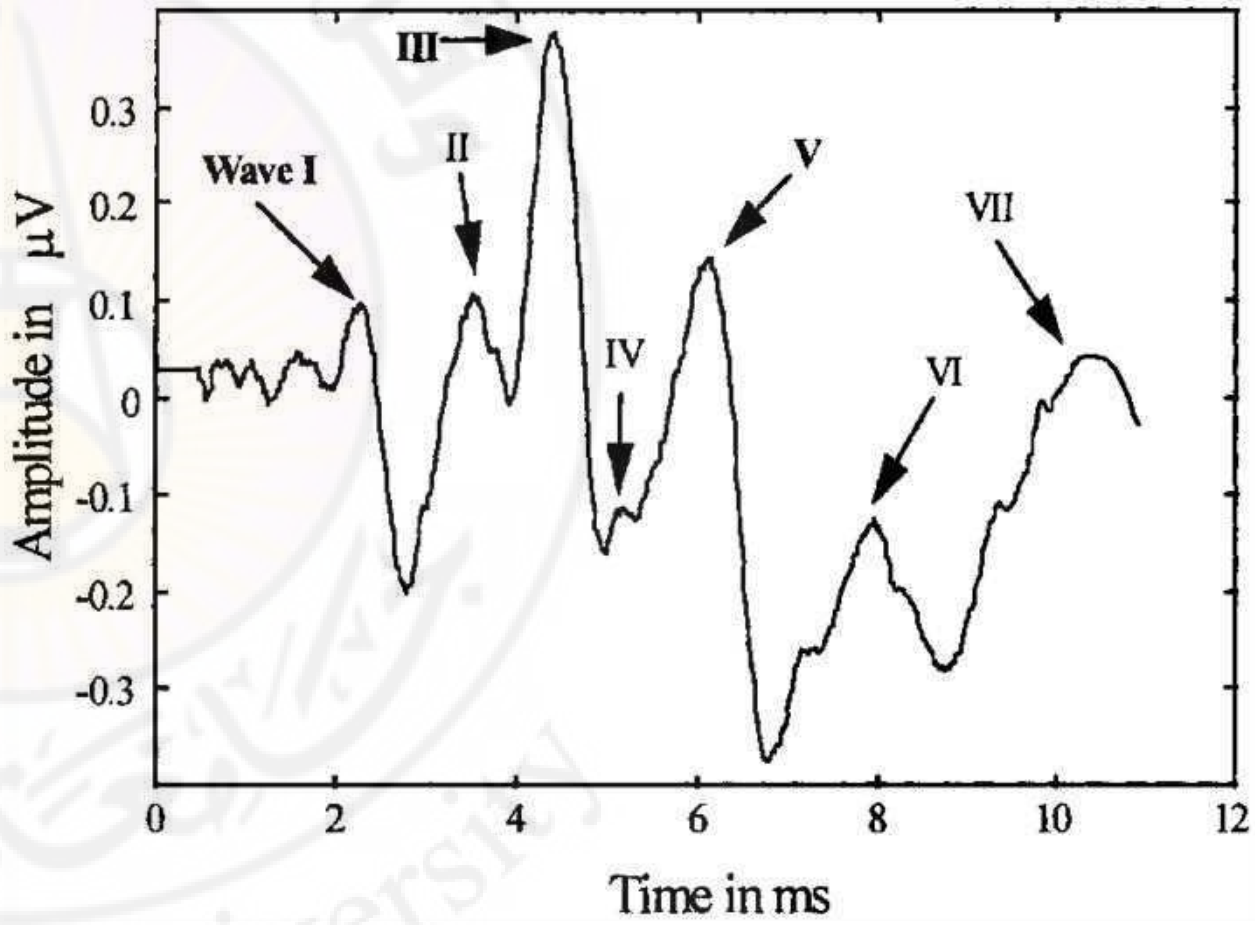
- **The term "Response" is used interchangeably with "Potential".**



ABR labeling system

- Roman numeral labeling system for ABR with vertex positive waves plotted **upward** is usually use around the world.

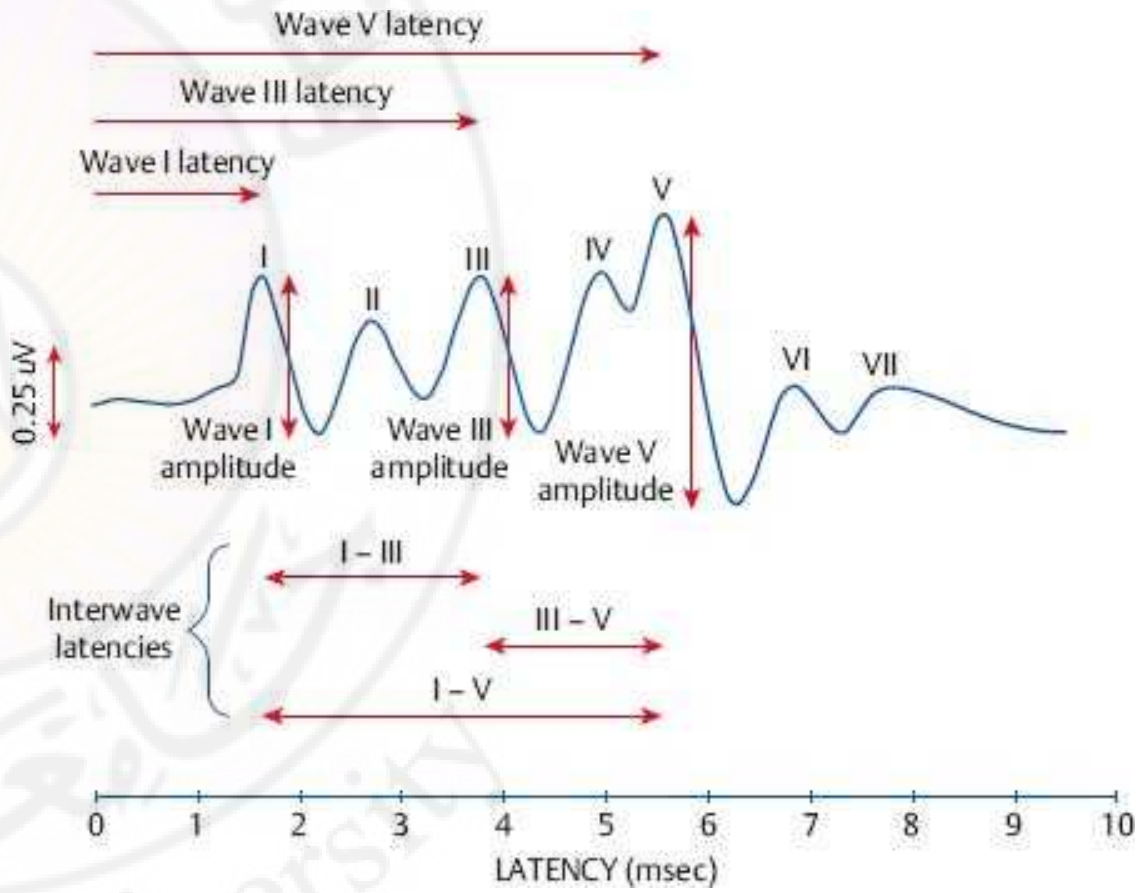
- Notice that only one curve is shown. In actual practice, two sets of tracings would be done because evoked potentials must be ***replicated*** to confirm that the results obtained are real.



Normal ABR components

- **Clinical ABR** measurements are concerned with the first five peaks (I to V), and concentrate on peaks I, III, and V.

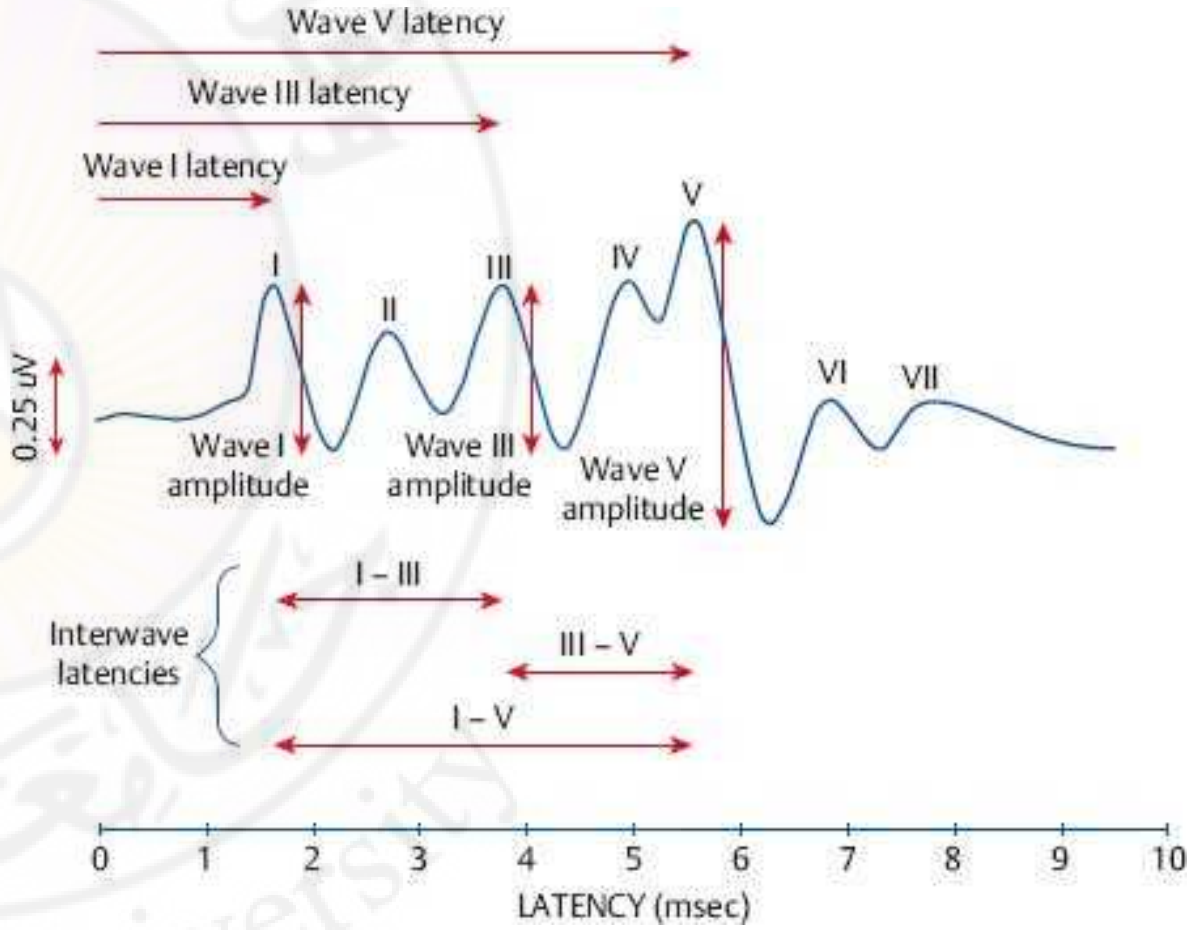
- At relatively high stimulus intensity levels of about 70 dB HL and above and with click stimulation, the ABR wave I component normally appears approximately 1.5-ms after the stimulus. Subsequent waves occur at approximately 1.0-ms intervals with wave II in the latency region of 2.5 ms, wave III at about 3.5-ms, wave IV at about 4.5-ms, and wave V at about 5.5-ms.



Normal ABR components

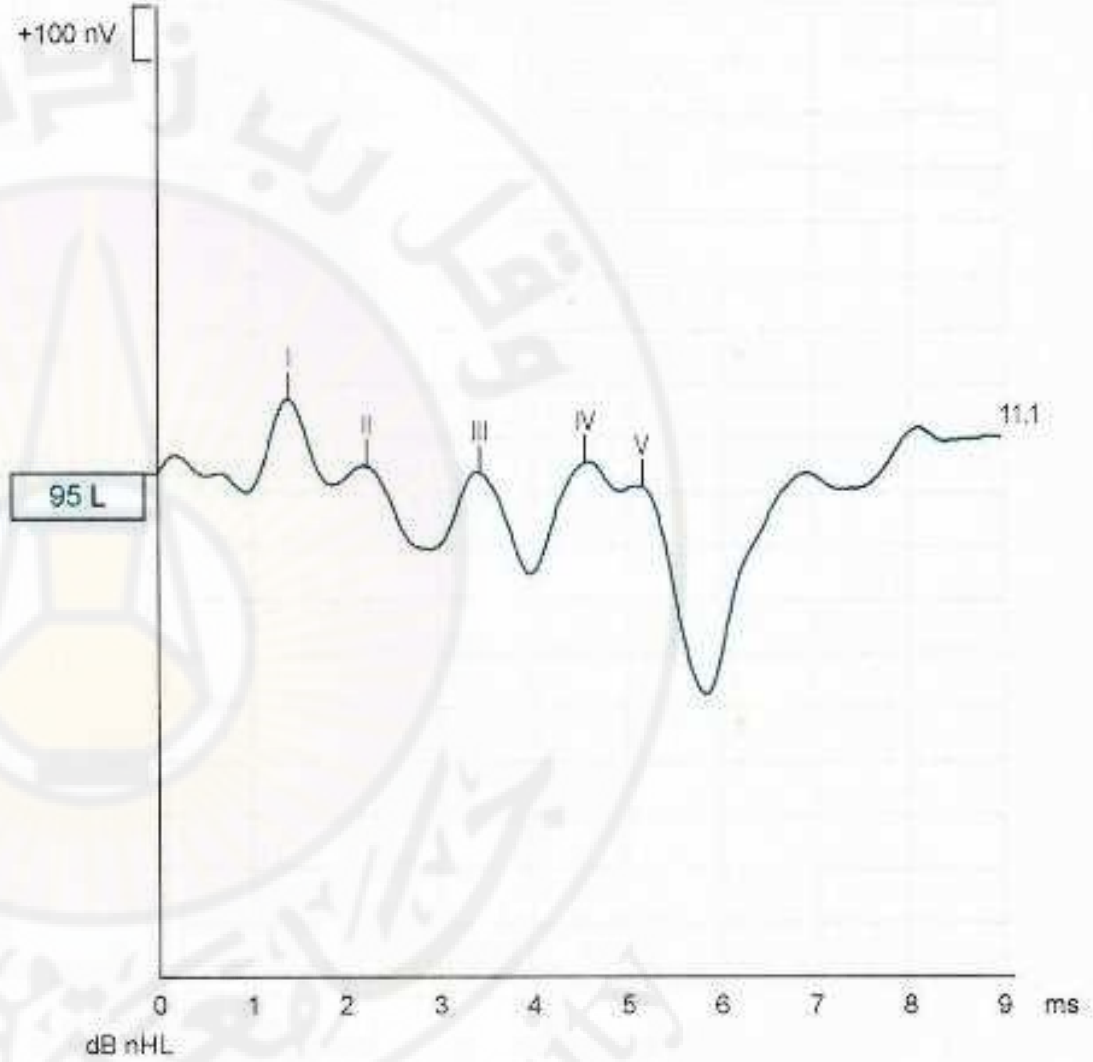
- Estimation of average **inter-wave intervals** is also rather simple, again since there is usually about 1.0-ms between each wave.

- The average normal ABR inter-wave intervals are estimated with addition of the intervals (1.0-ms) between each of the intervening waves for wave I-II, wave II-III, wave III-V, and wave IV-V). For example, the wave I-V latency interval of 4.0-ms is calculated with the addition of 1-ms for each of the waves from wave I to wave V.



ABR waveform

- The ABR waveform is usually described and interpreted in terms of the **latencies (ms)** and **amplitudes (microvolts)** of these peaks, as well as by its **morphology**, or the overall configuration and appearance of the waveform.



Curve	Latencies (ms)								Interlatencies diff. R/L			
	I	II	III	IV	V	I-III	III-V	I-V	I-III	III-V	I-V	V-V
95 L	1.40	2.23	3.43	4.57	5.17	2.03	1.73	3.77		0.50		0.90

ABR Measurement system





How to perform ABR testing?

- Preparing the test environment
- Patient preparation
- Electrode placement
- Setting up the device
- Performing the test
- Analyzing the results
- Reporting



Preparing the test environment

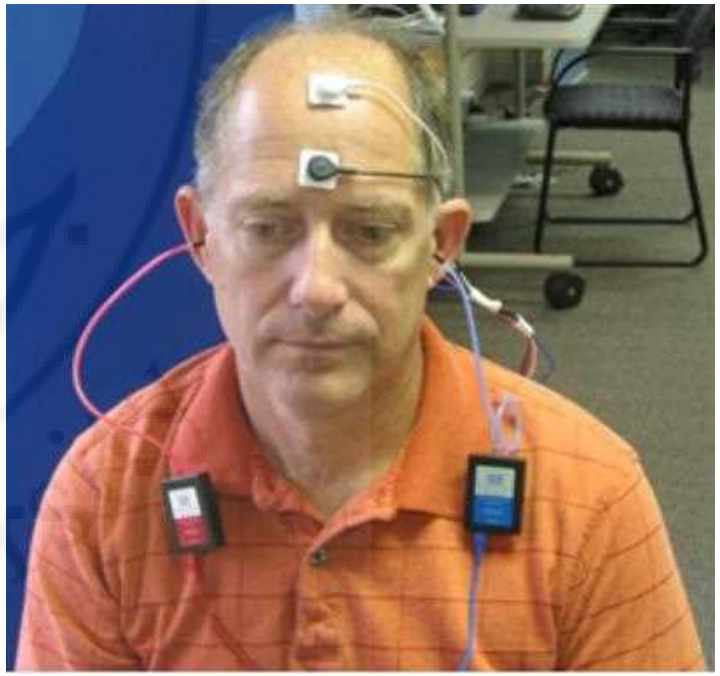
- When we are prepping for any evoked potential, a critical element we need to look at is the testing environment. Frequently, issues are related to **noise** with an evoked potential. Here are some tips to help you cut back on the amount of noise:
  1. The preamp should not be near the isolation transformer, monitor, etc.
  2. Turn off unnecessary computer monitors.
  3. Do not have the preamp in front of the monitor.
  4. If possible use a designated outlet.
  5. If the patient is in a chair that plugs in – unplug it.
  6. Assure wall outlet is grounded.
  7. Do not use cellular phones during testing.
  8. Turn off fluorescent light(s).



Patient preparation

- The patient should be relaxed or sleeping in a quiet environment.
- It is preferable that the patient lie down during the procedure to facilitate a calm and comfortable environment.
- The electrode sites must be prepared and cleaned in order to obtain acceptably low skin impedance.
- It is recommended to have impedance values be 5kΩ or lower.
- The impedance values between one another should be balanced or similar in value (Less than 2kΩ).





Instruct the patient so that:

- They are relaxed and calm.
- Their eyes are closed and that their face and jaw muscles are relaxed.
- They are lying down on a comfortable bed or reclining in a comfortable chair. The duration of an ABR test can be long, so ensure that the patient is as comfortable as possible (use pillows and blankets as needed). An upright sitting position should be avoided due to contracted neck/head muscles.
- Turn off lights in the test room to avoid electrical interference and to help the patient to relax/go to sleep. Sleeping during recording will provide the lowest noise from the patient, so a sleeping state is preferred if possible.
- Test infants and children during sleep is recommended as they cannot be instructed to or find it difficult to relax for the entire test duration.
- It is important to try and use the same test conditions and parameters for each test when comparing results.


C8383-100G
Chloral hydrate
sigmaaldrich.com

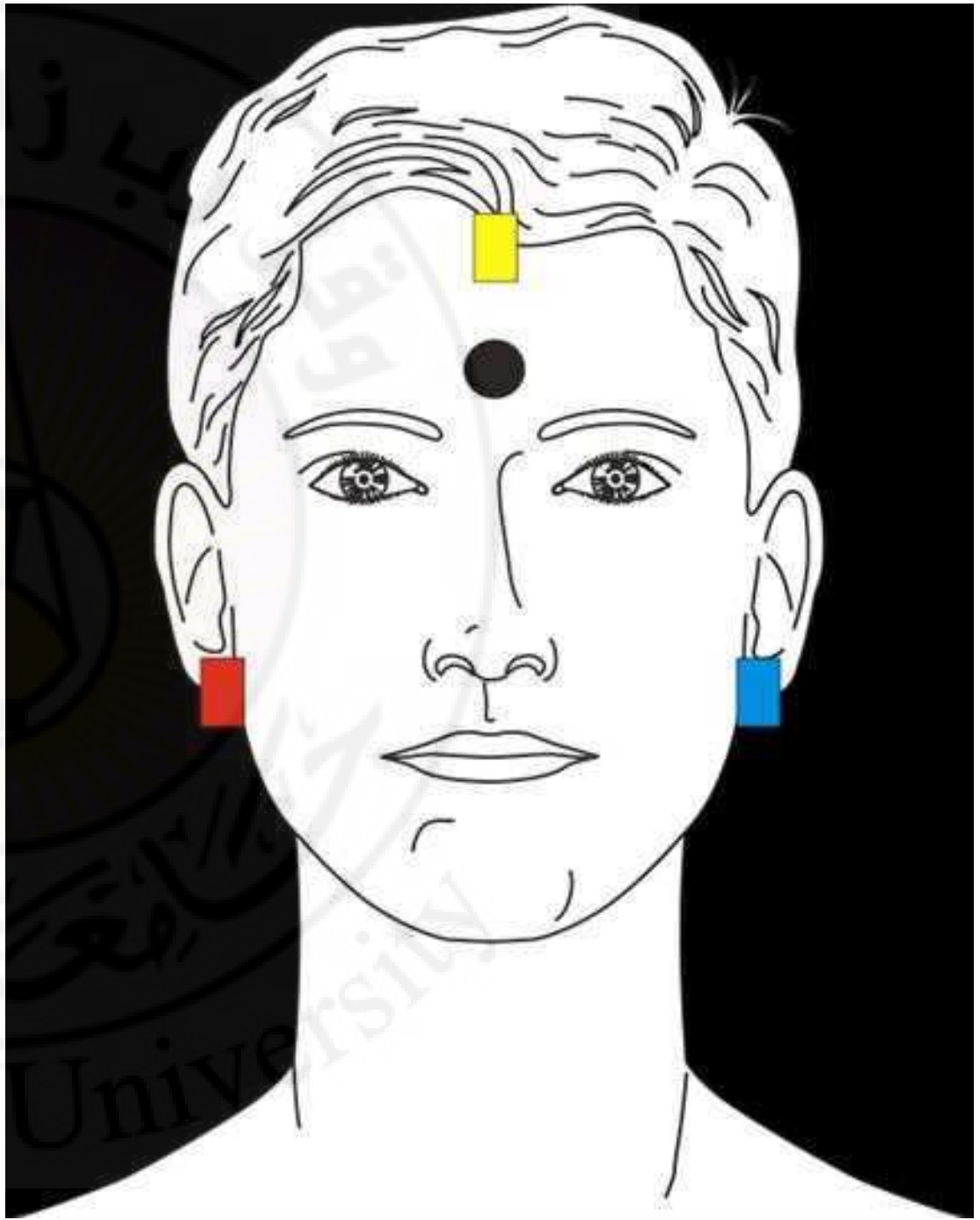

120 ml (Approx)
Cedate
(Chloral hydrate USP)
Syrup
XENON PHARMACEUTICALS
Cedate

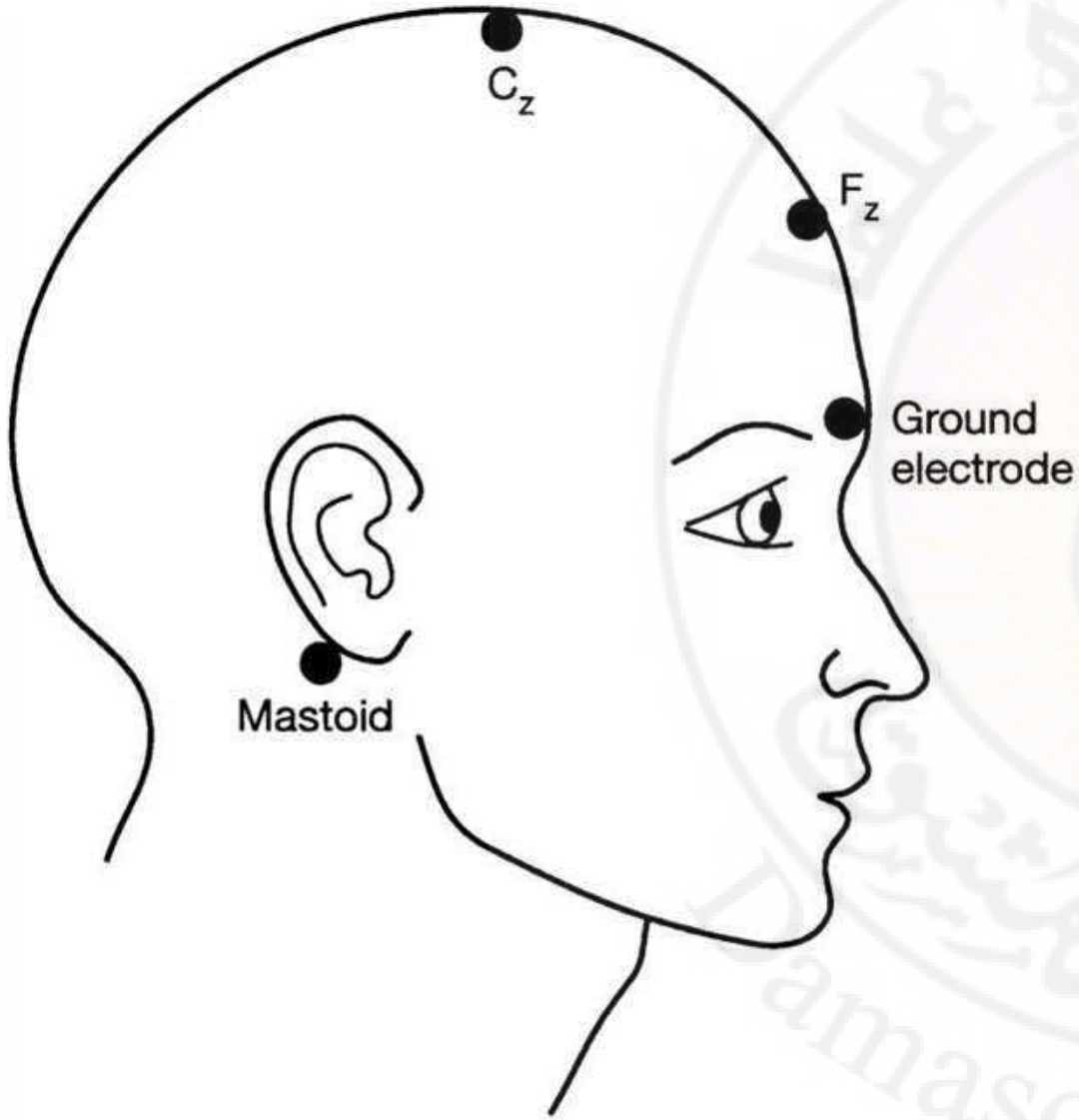


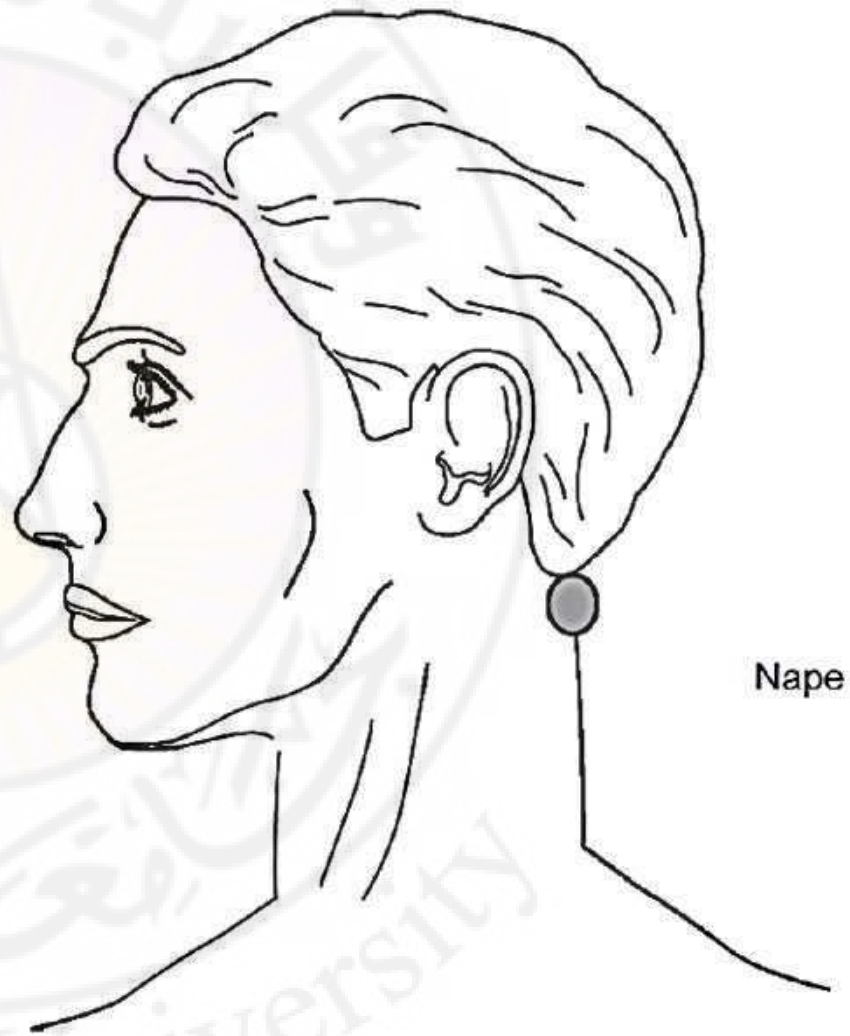
Electrode placement

- The electrodes must be placed as indicated in the picture. There must be a few centimeters between each electrode.

- Check the impedance on the preamplifier and place the transducers.
- Make sure the patient is relaxed prior to starting the test. You can monitor this by watching the EEG Window on your device screen.







Ch 2 REF
Nape of the neck or inion

Setting up the device

- Make sure that your system is calibrated! Routinely check the intensity of the stimulus and have your system **calibrated** annually.
- The AEP devices comes with **pre-programmed protocols** so the system is ready to use immediately. Protocols can be created or modified easily to fit your clinical needs.
- When you set up a new patient record, you must enter the **birthday** and **gender** to obtain *normative data*. The software will take the birthdate into account, This is an important feature for any pre-term babies when you are performing ABRs.
- Check the **impedance** within the software. The goal is to have low electrode readings of <5KOhms each with no more than <2KOhms difference between electrodes. Inter-electrode impedance is the most important (common mode rejection does not work well if inter-electrode impedance varies).
- Select a desired Protocol to start the test.

5. Auditory Brainstem Response: Stimulus Parameters

ABR Transducers

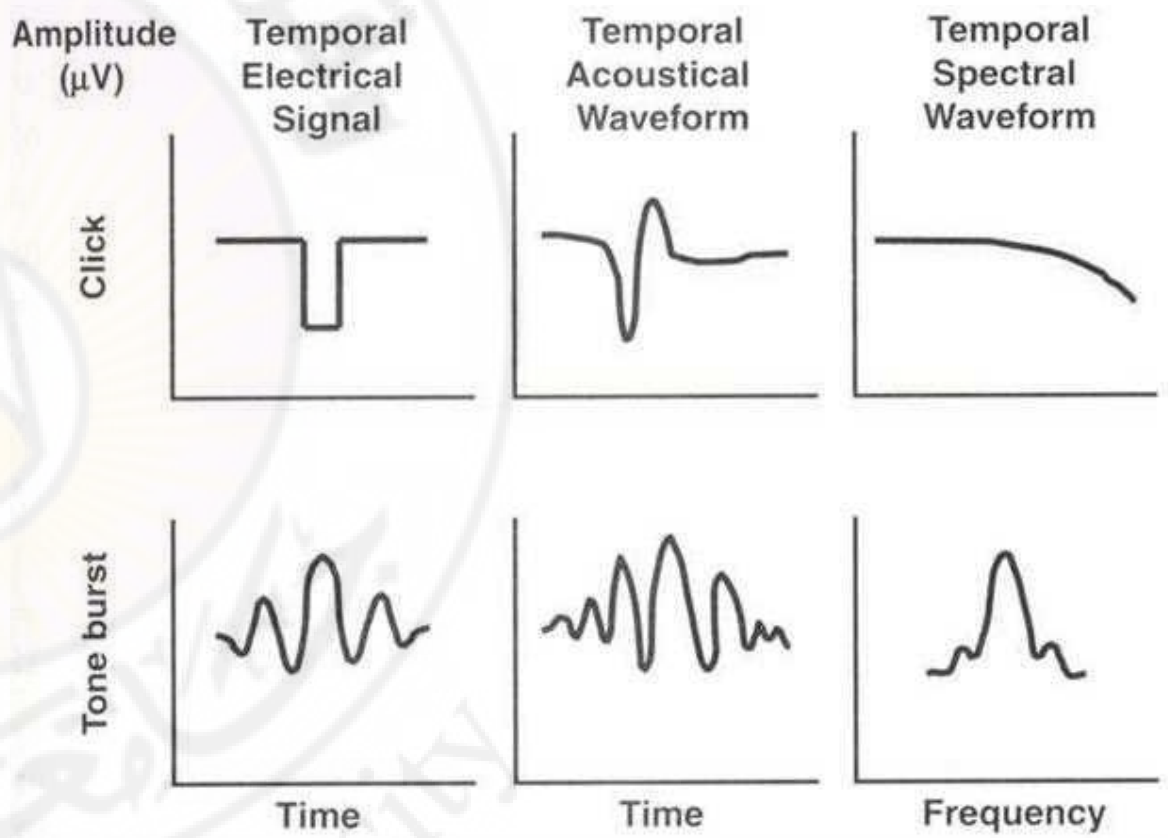
- Insert earphones
- Supra-aural earphones
- Bone vibrators

- Loudspeakers: rarely used for recording ABR.



ABR Stimulus Types

- Stimuli used to evoke the ABR include **clicks**, **tone bursts**, and less often **speech stimuli**. Also, **chirp** versions of click and tone burst stimuli are now available from some manufacturers of auditory evoked response systems.
- **Chirp stimuli** offer some distinct clinical advantages in comparison to conventional click and tone burst stimuli

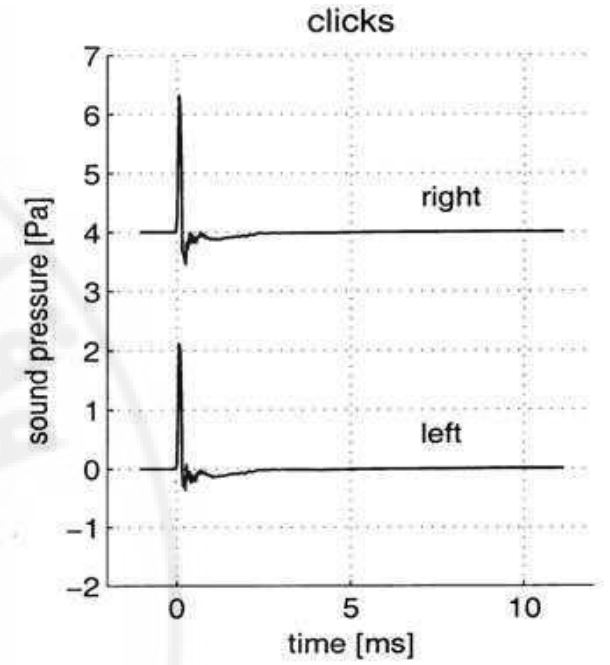


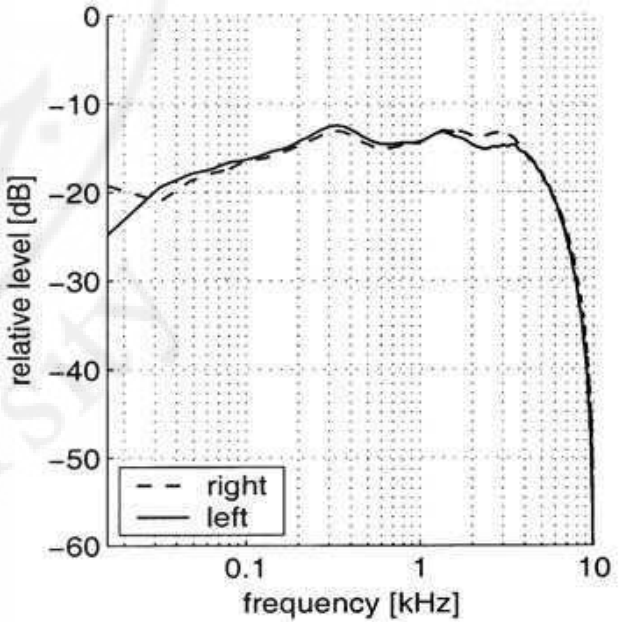
Damascus University

Click Stimuli

- Click stimuli with their almost instantaneous onset are well suited for generating **synchronous firing of neurons** in the auditory system, beginning with the 8th nerve fibers.
- The highly transient acoustic click stimulus is a ***broadband stimulus***. That is, the click is characterized by a broad spectrum of energy extending essentially across the frequency response of an earphone or bone oscillator.

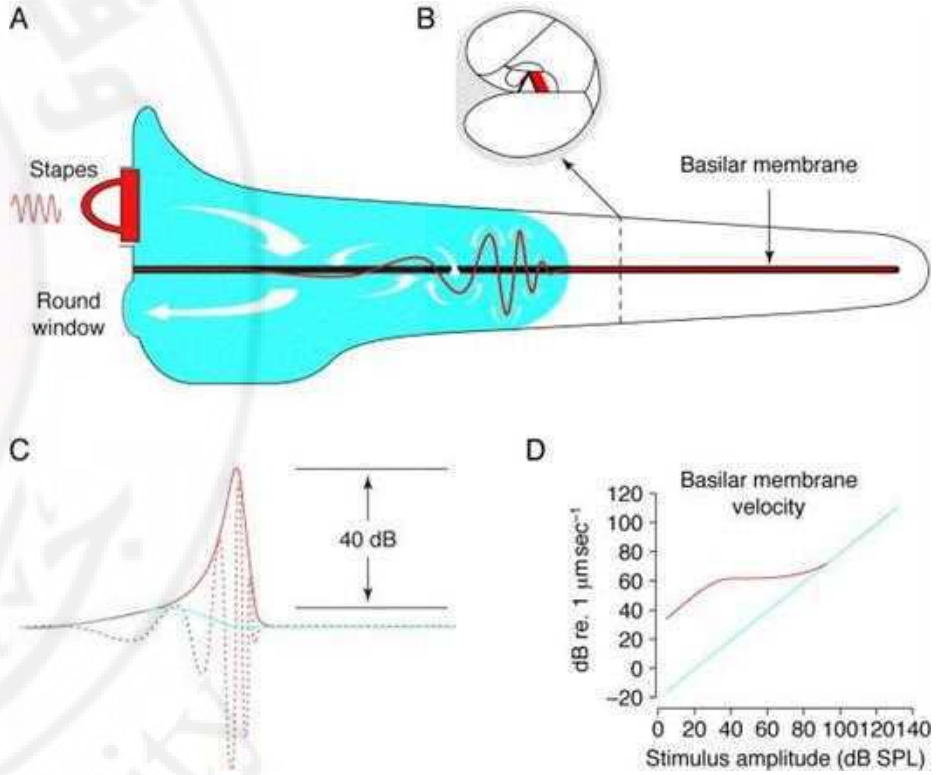
- **Lack of frequency specificity!**





Click Stimuli: Air Conduction

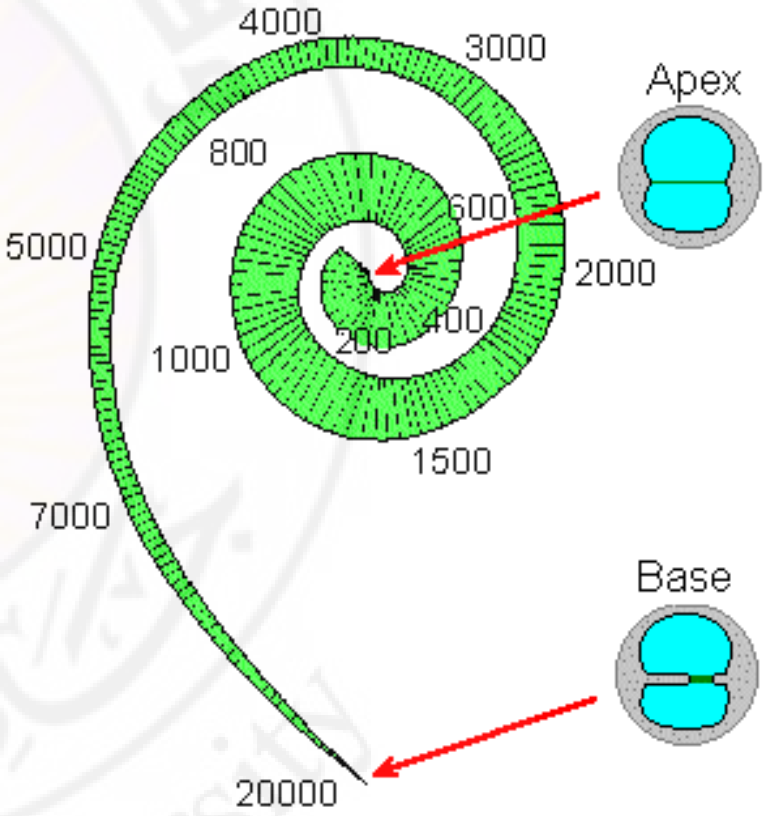
- All regions of the cochlea are activated with conventional click stimulation.
- Conventional click stimuli produce a traveling wave that travels the length of the cochlea from base to apex.
- There are two differences in click-related activation of basal versus apical regions of the cochlea.
- Neural activity is more ***synchronized*** in the base and more dispersed as the travel wave approaches apical regions.
- Also, ***velocity*** of the traveling wave is fastest in the base of the cochlea where the ABR is generated. Velocity gradually slows as the traveling wave moves apically.
- The term **"temporal dispersion"** describes the decreased synchrony and overall delay as the traveling wave moves toward the apical region of the cochlea



Click Stimuli: Air Conduction

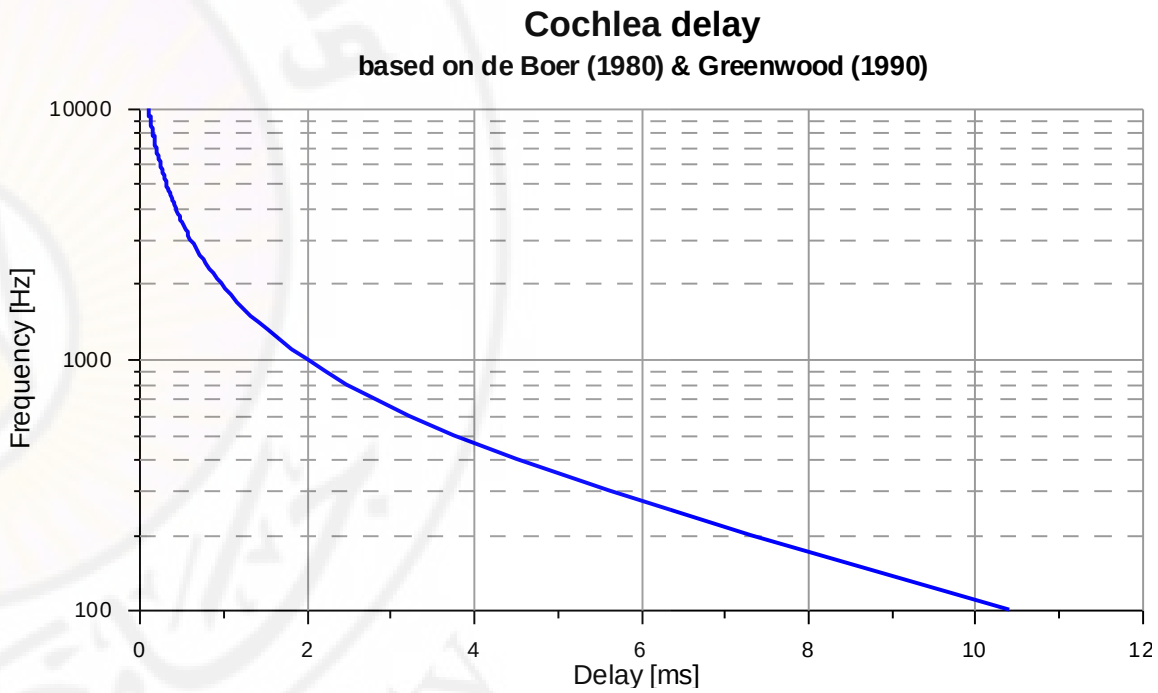
- Consequently, an ABR elicited with a conventional 0.1-ms click stimulus of moderate to high intensity in a subject with normal hearing sensitivity using insert earphones is generated mostly with activation of high frequency portions of the cochlea.

- Clinical experience suggests that thresholds for ABRs elicited with click stimuli are most closely correlated with pure tone hearing thresholds in the region of **2000 Hz to 4000 Hz**.

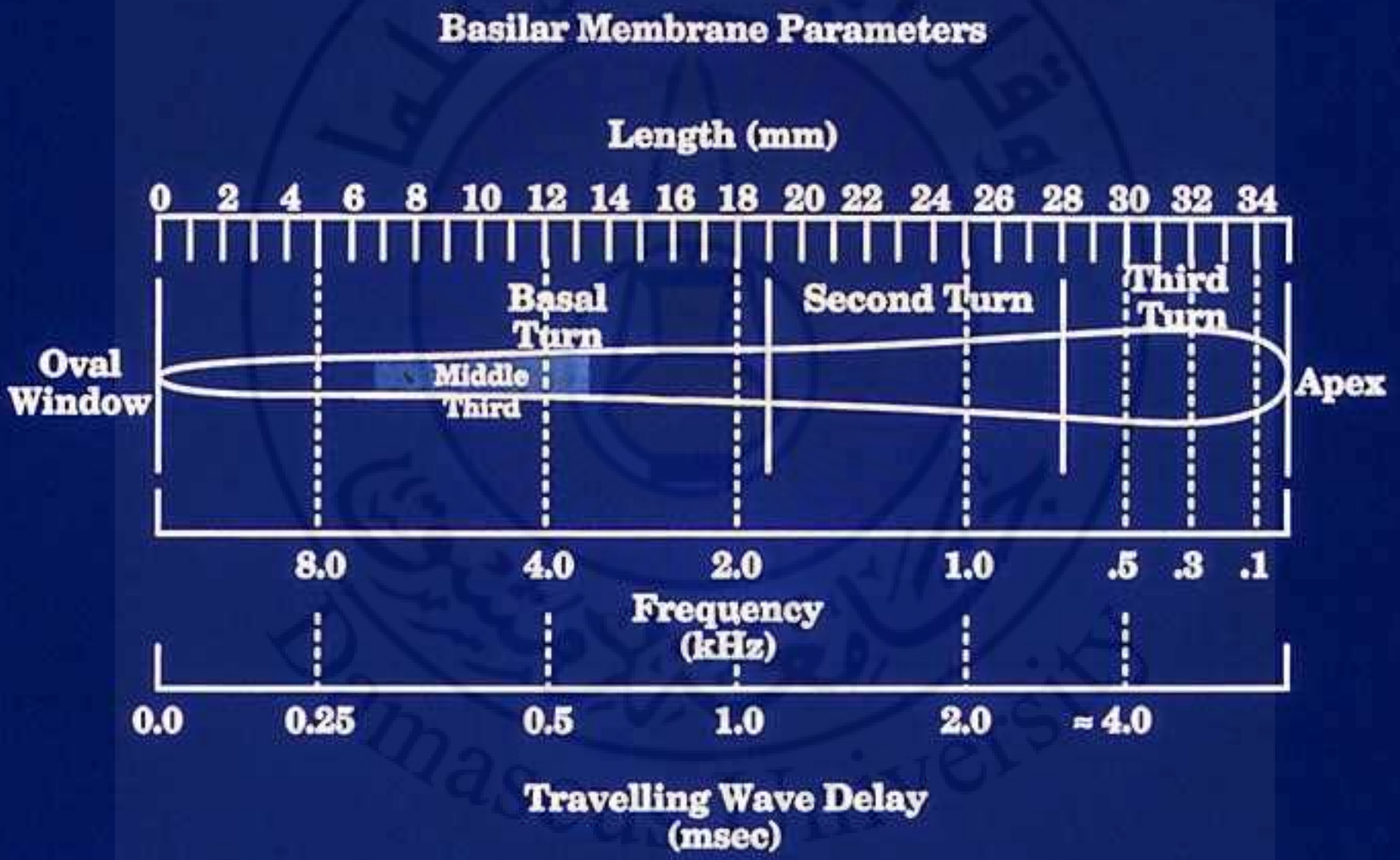


Click Stimuli: Air Conduction

- The ABR is not necessarily a product of high frequency activation of the cochlea in persons with **hearing loss.**
- A person with high frequency hearing loss but normal hearing for mid- and lower frequencies may show an ABR with abnormally **delayed latencies**.
- The prolongation in ABR latencies reflects time required for the traveling wave to reach the better hearing region of the cochlea where hair cell function is adequate to produce firing of 8th nerve fibers.

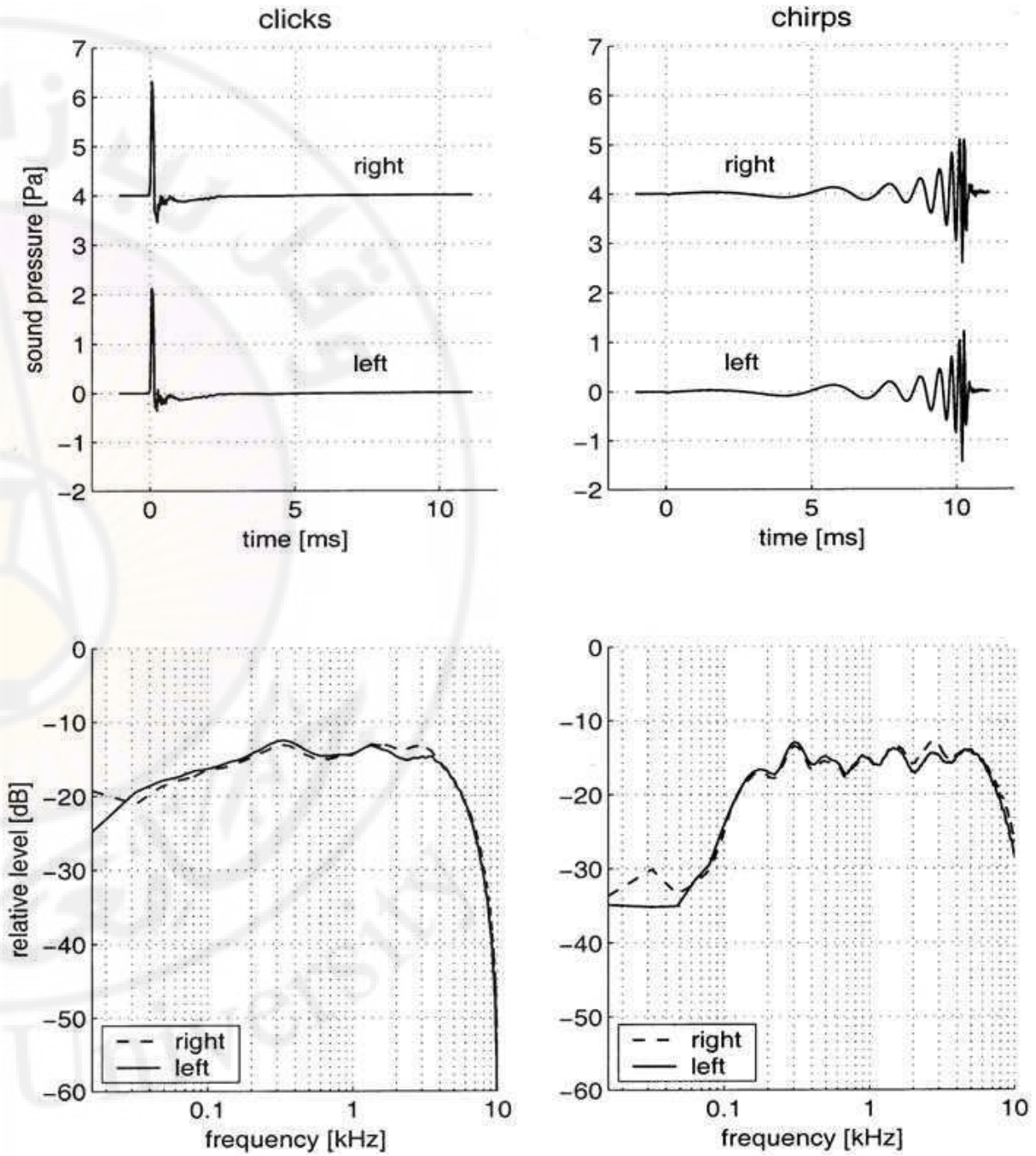


Curtis Ponton estimates delay to 500 Hz as 4 ms



Chirp Stimuli

- As just noted, there is consensus that the ABR evoked with conventional click stimulation is dominated by activation of the basal region of the cochlea.
- Attempts to enhance the contribution of other regions of the cochlea to ABR generation include the creation of rather unique types of stimuli called **"chirps".** *Chirps are sounds that sweep rapidly from low-to-high frequencies.*
- The *chirp stimulus* is designed mathematically "to produce simultaneous displacement maxima along the cochlear partition by compensating for frequency-dependent traveling-time differences"

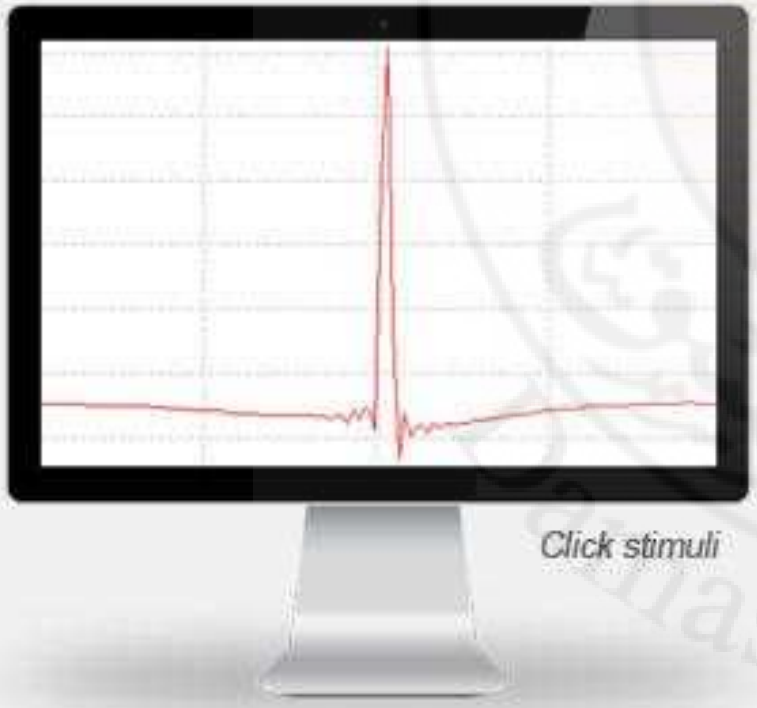


The CE-Chirp®

The Claus Elberling-Chirp®

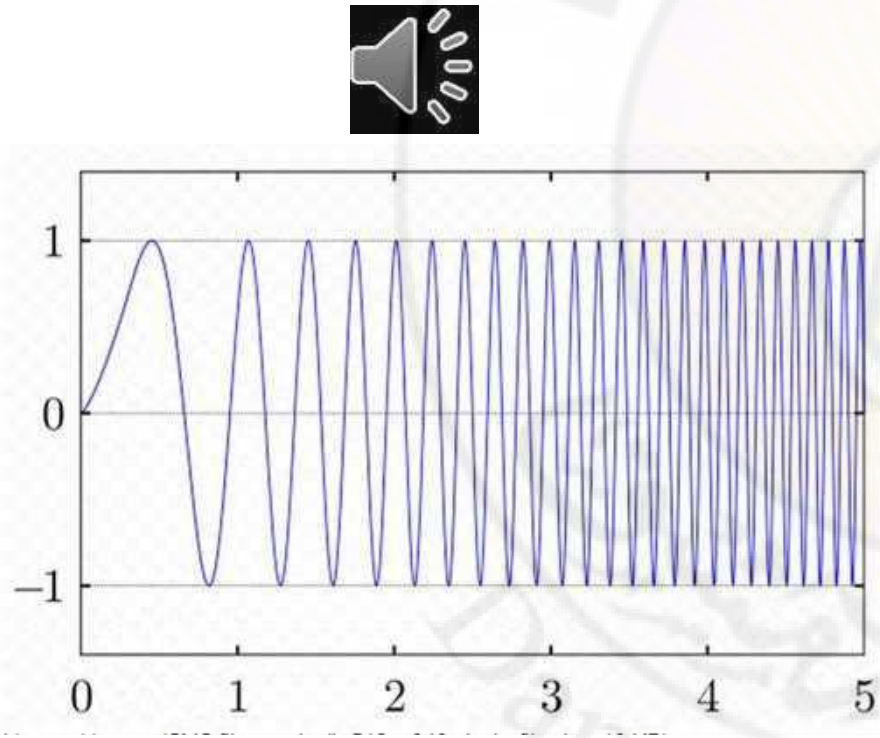


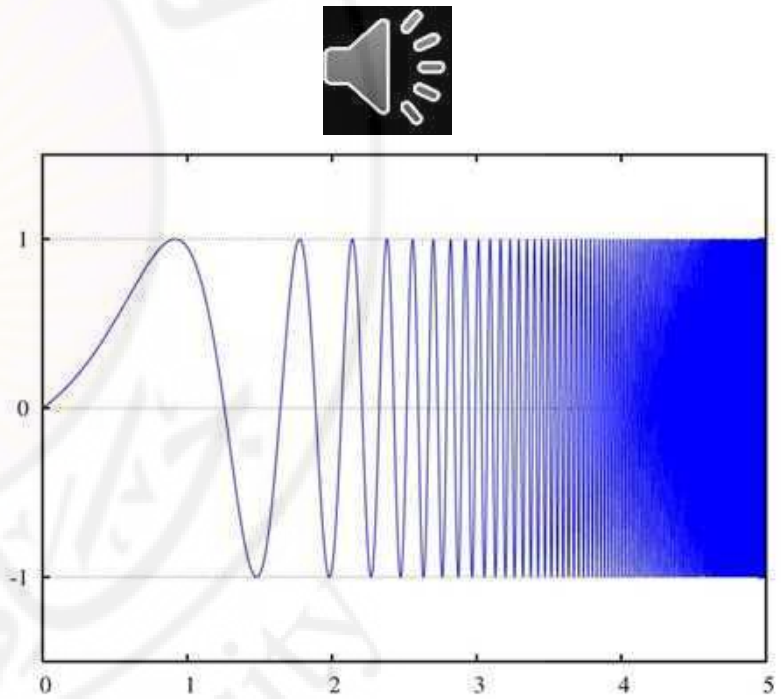
- A rising frequency or “low-frequency leading” stimulus that compensates for the cochlear traveling wave delay!





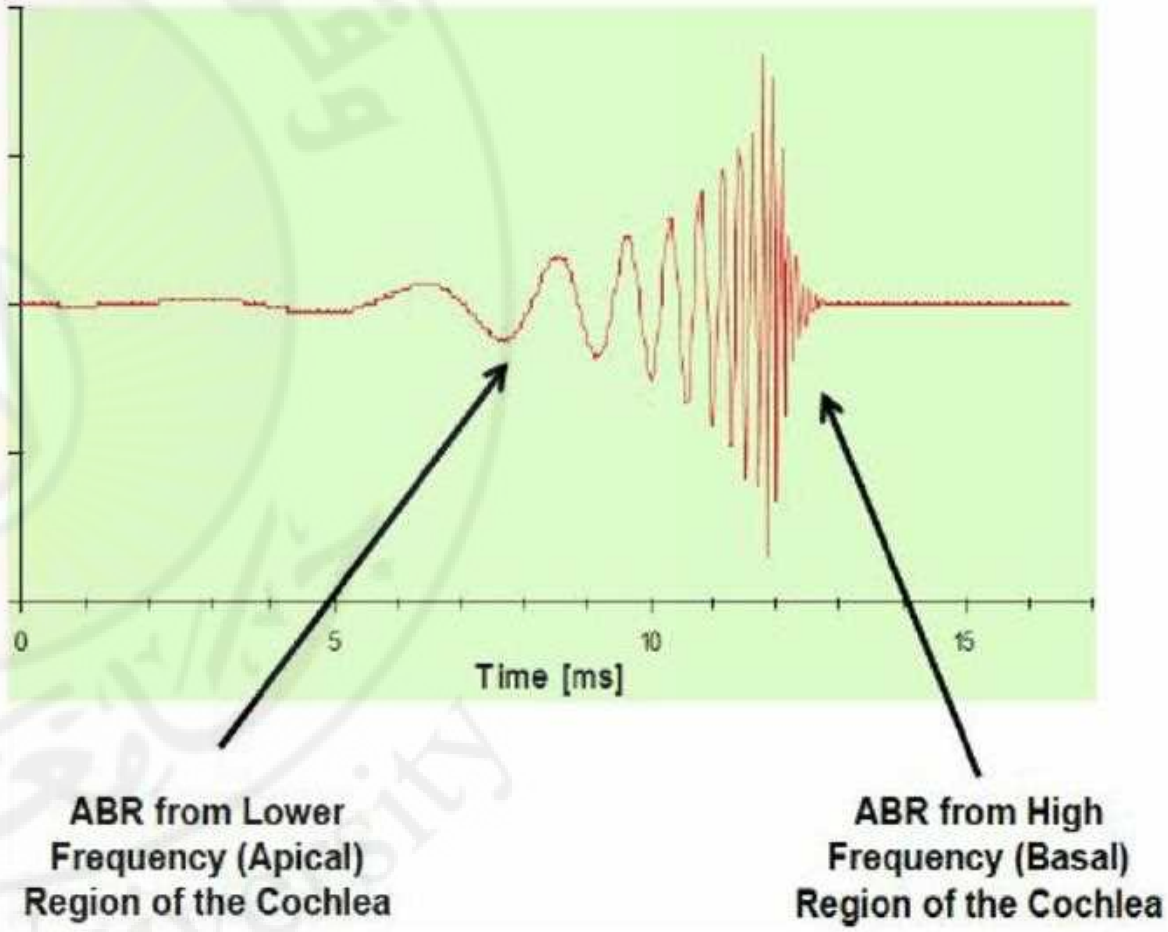
The term **chirp** is derived from the sound that birds and some other animals produce

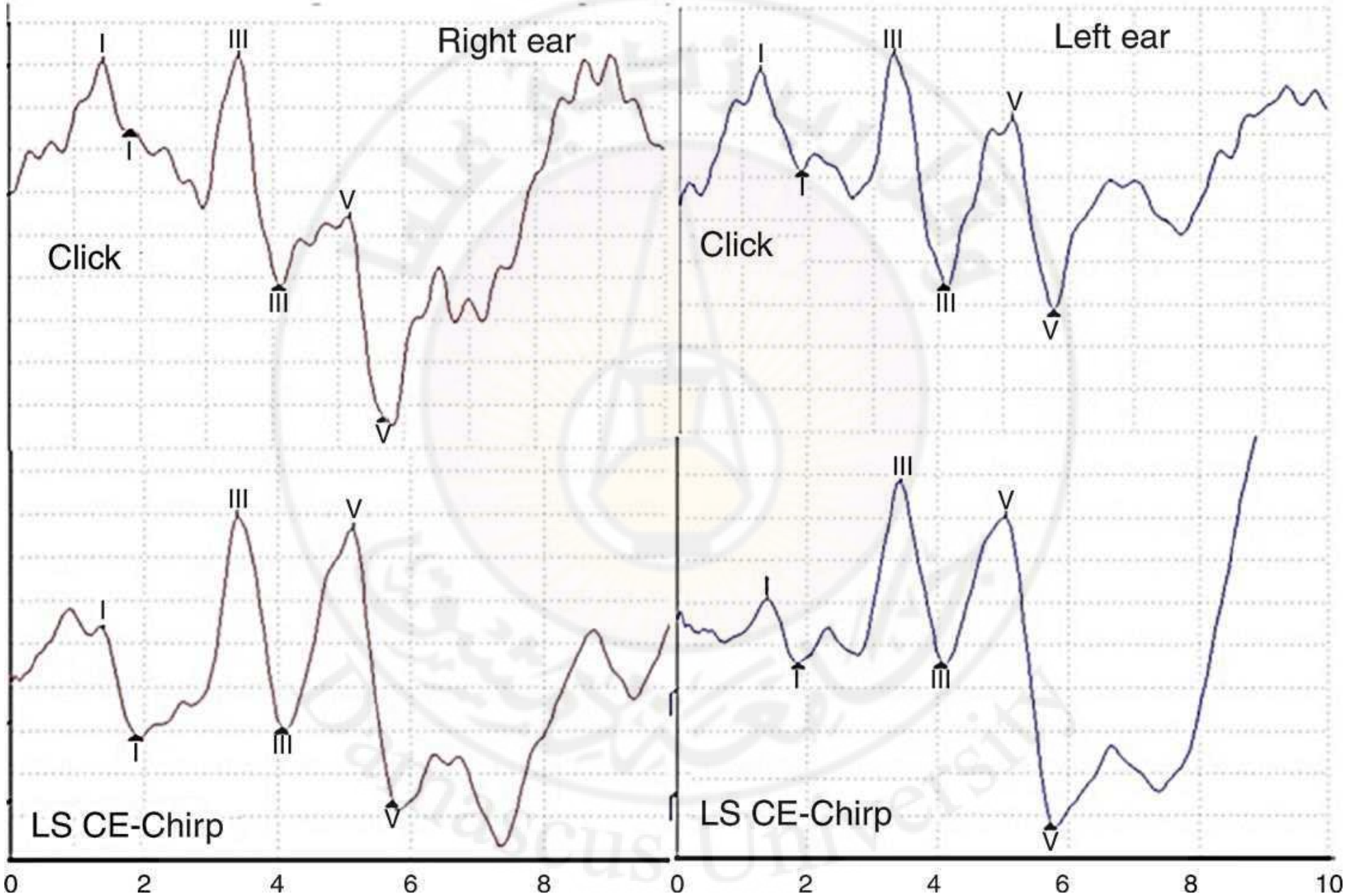




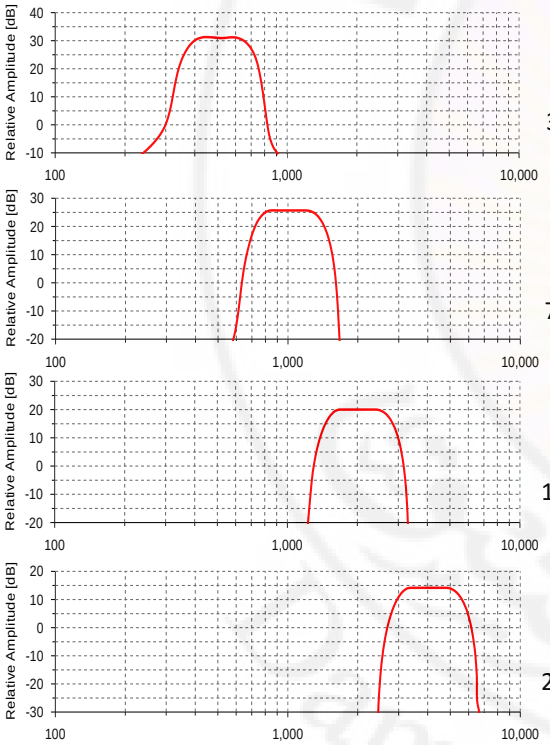
Why Use the Chirp Stimuli?

- Increasing the amplitude of the ABR
- Shorter test time
- More robust responses in different test situations
- Narrow band chirp (increased frequency specificity)
- Level-specific (LS) chirps




Right ear
Left ear
Click
Click
LS CE-Chirp
LS CE-Chirp
I
III
V
0
2
4
6
8
10

Frequency Specific NB-Chirps



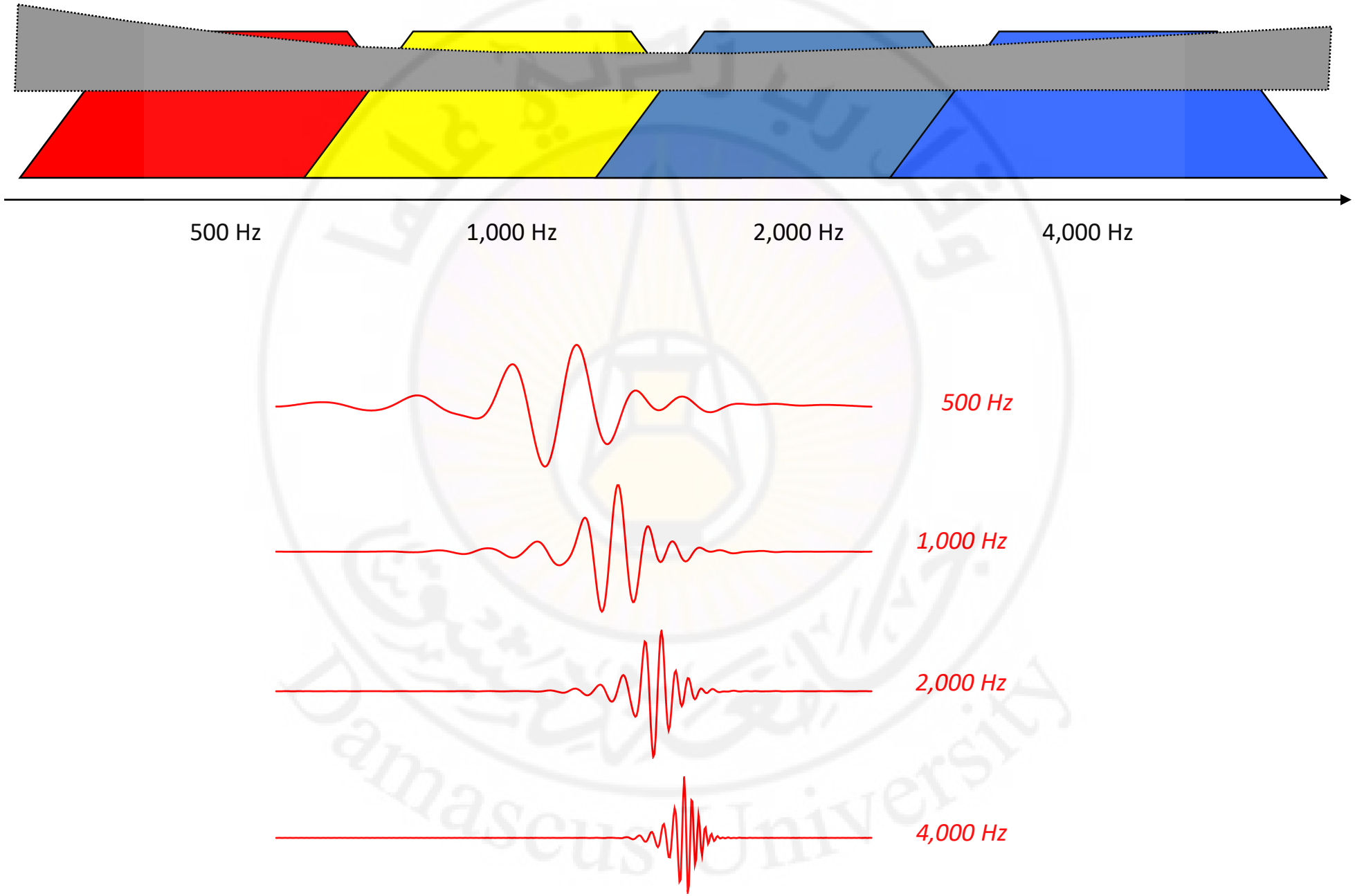
500 Hz
360 - 720

1,000 Hz
720 – 1,440

2,000 Hz
1,440 – 2,880

4,000 Hz
2,880 – 5,760




500 Hz
1,000 Hz
2,000 Hz
4,000 Hz
500 Hz
1,000 Hz
2,000 Hz
4,000 Hz

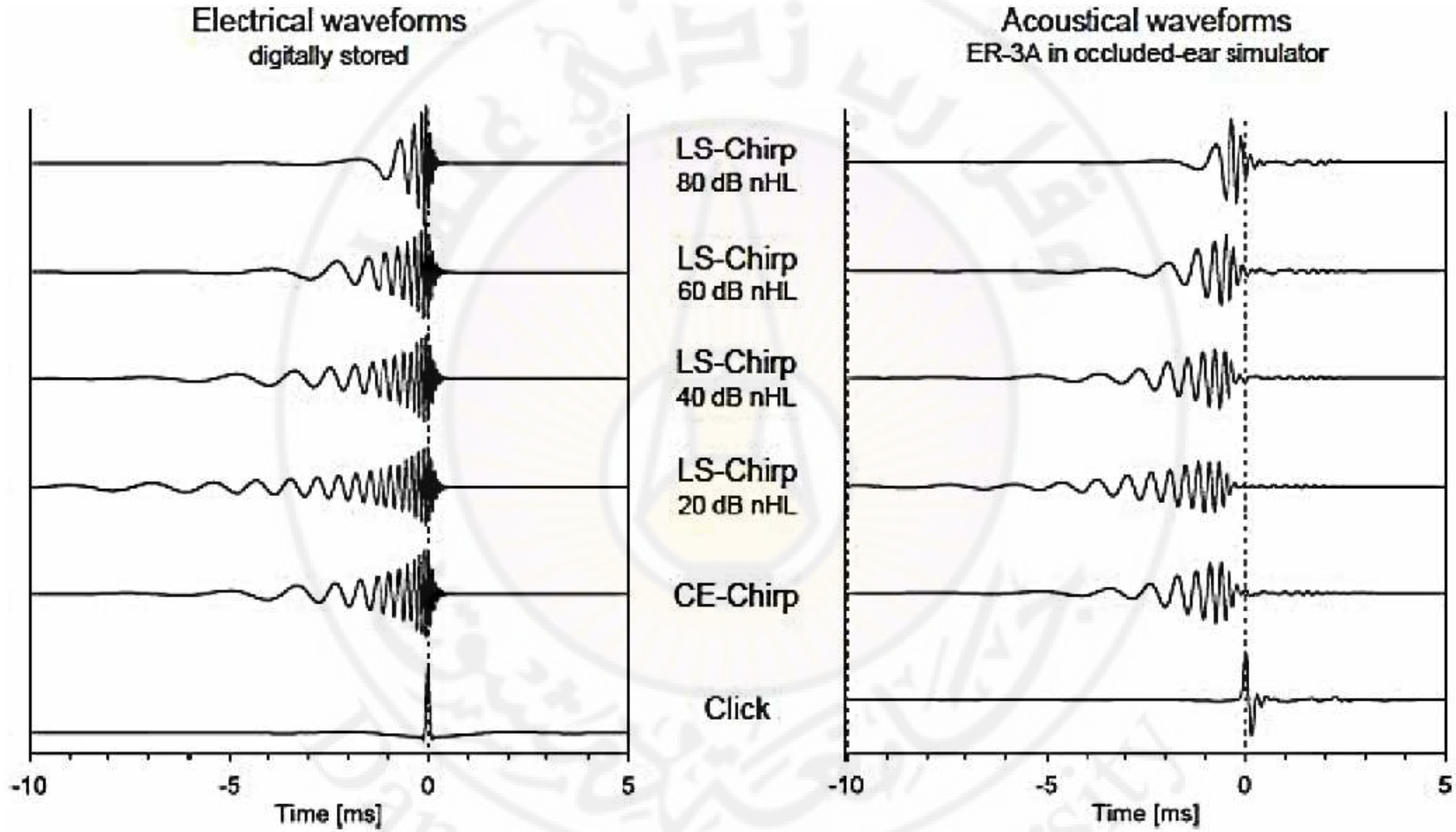
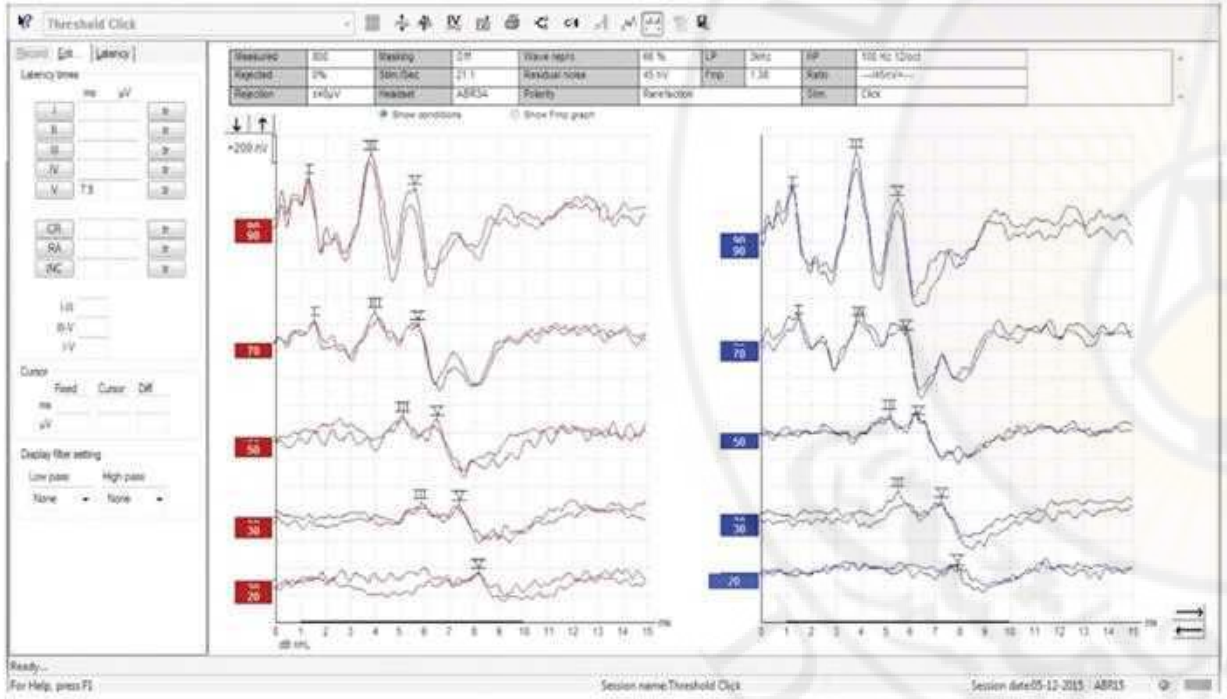
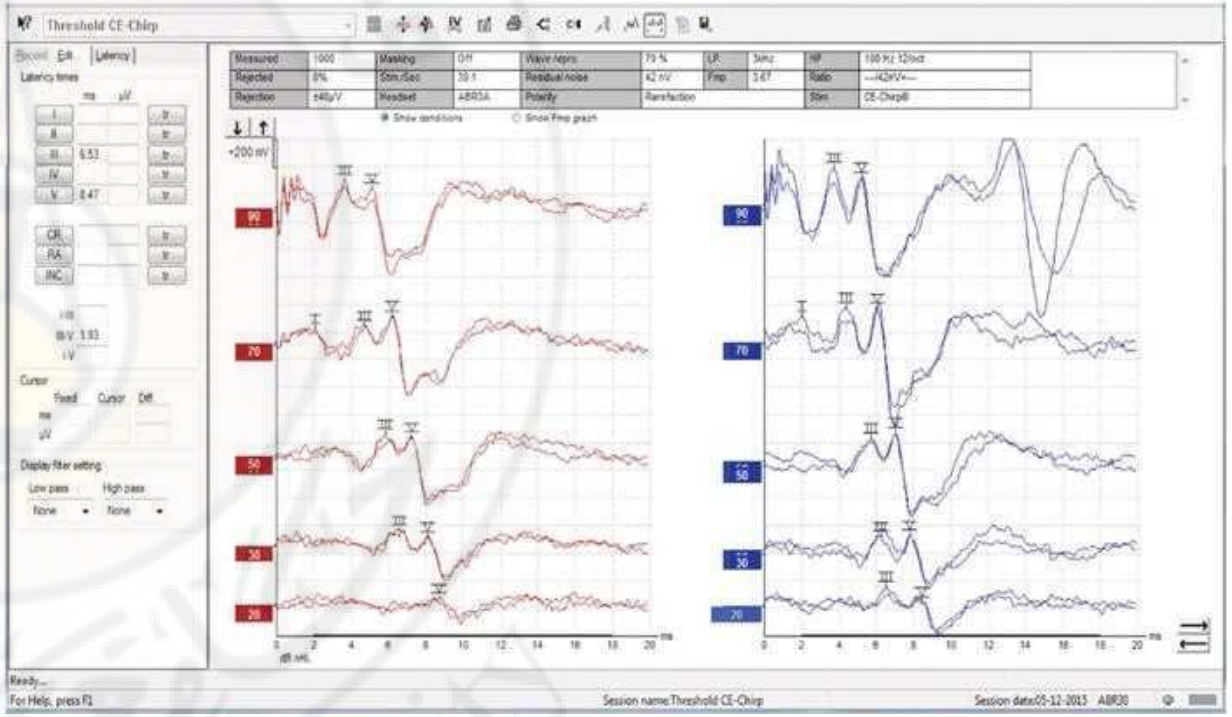


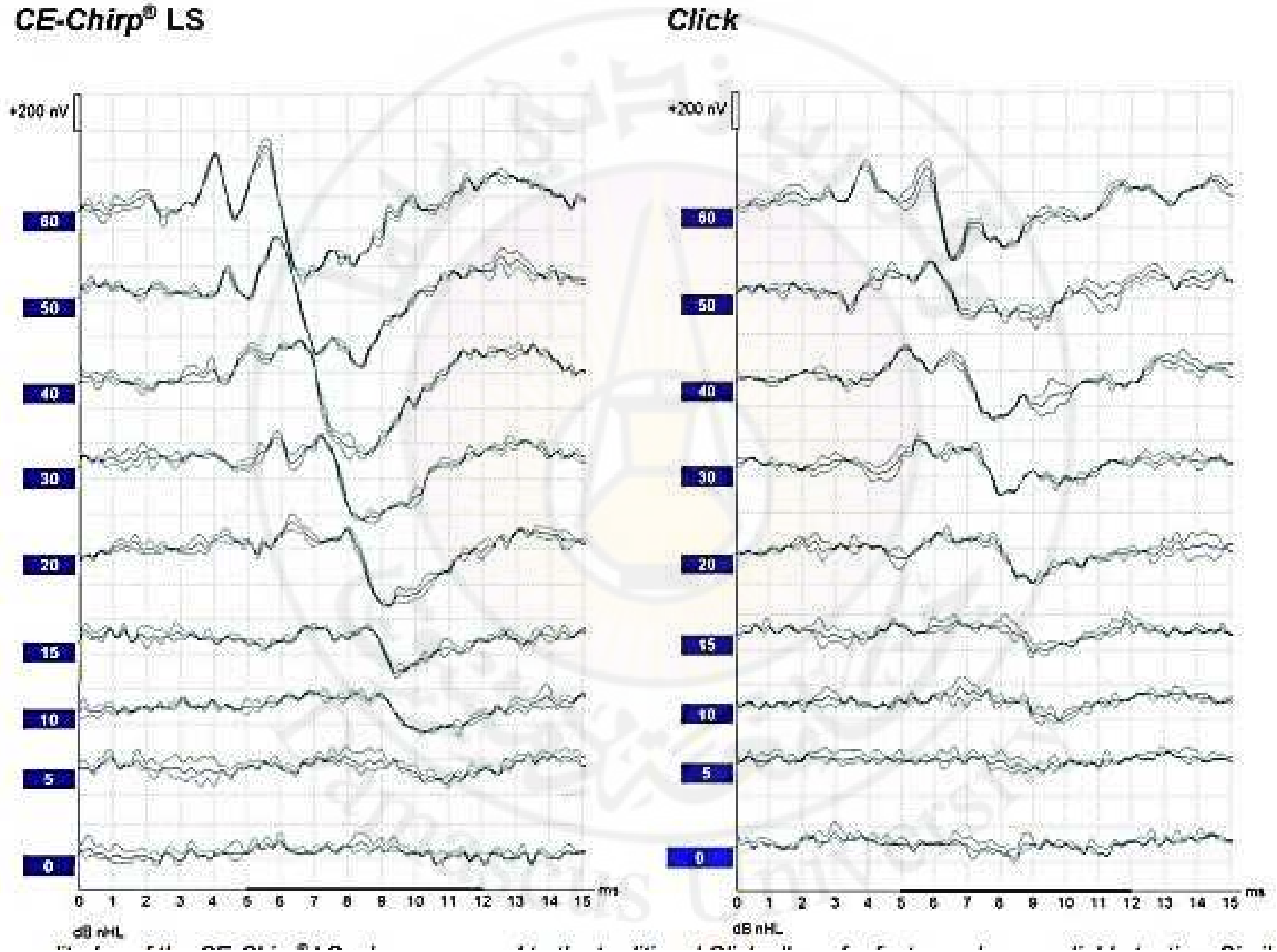
Figure 5.4. Electrical waveforms (left) and acoustical waveforms (right) of the LS-Chirp corresponding to 80, 60, 40, and 20 dB nHL of the CE-Chirp and of the Click. The 10-kHz component in the Chirps has the same temporal location as the click (0 ms). *(Courtesy of Claus Elberling)*

Click



Chirp




CE-Chirp® LS
Click
+200 nV
60
50
40
30
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ms
dB nHL

Tone Burst Stimuli

- Tone bursts are regularly used in clinical ABR measurement for estimation of auditory sensitivity for discrete frequency regions, especially in infants and young children.

- Tone burst stimuli with appropriate envelopes and onset ramping resulted in adequate **frequency-specificity** for estimation of hearing sensitivity with ABR.

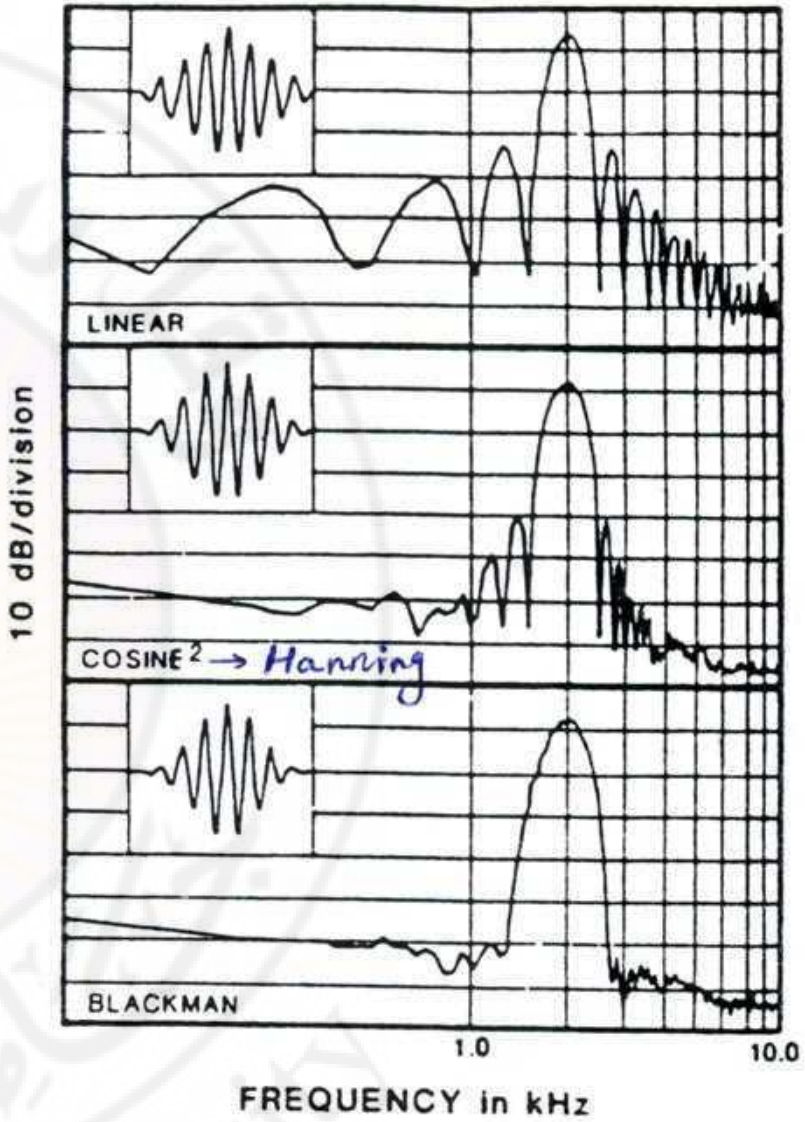
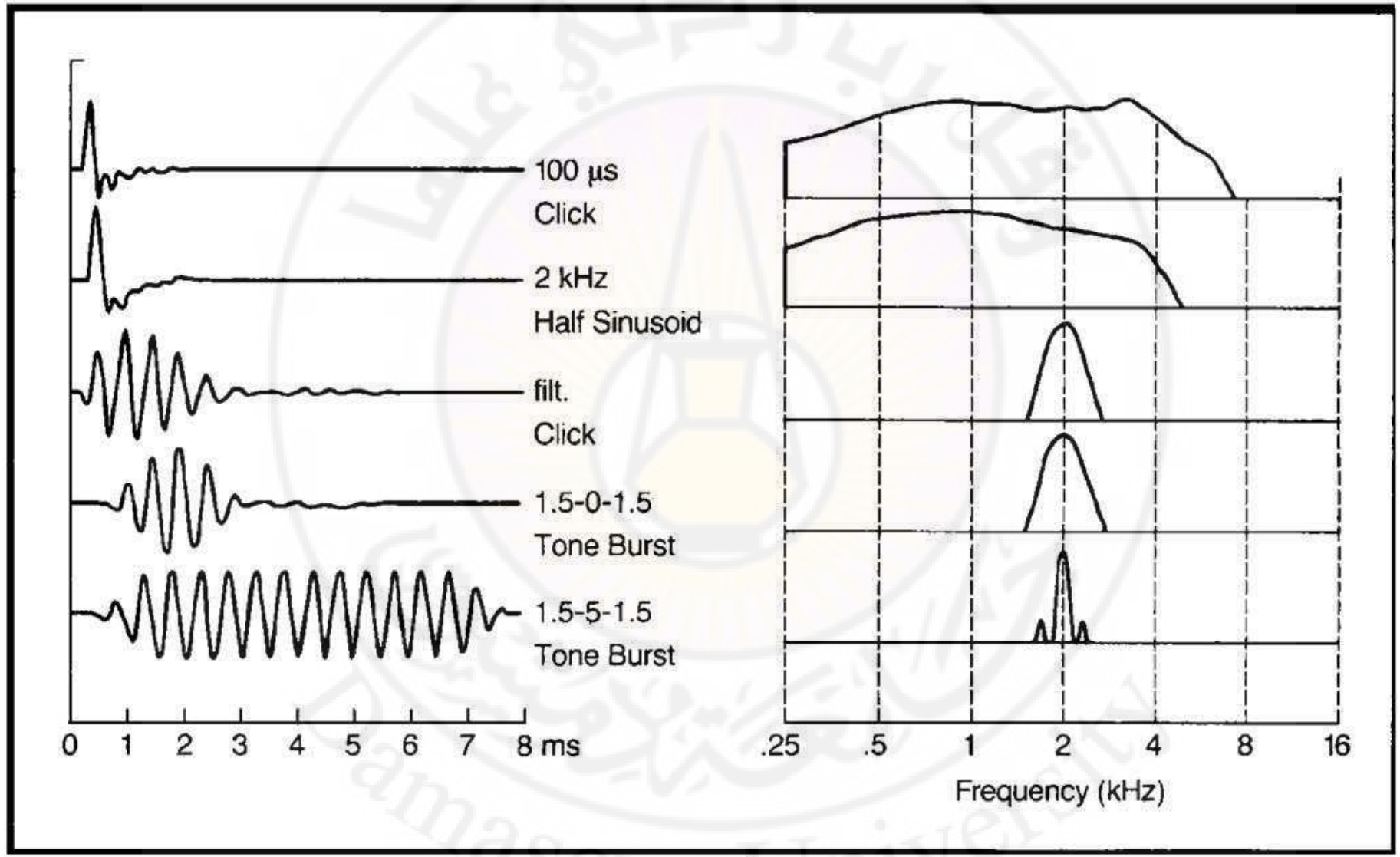
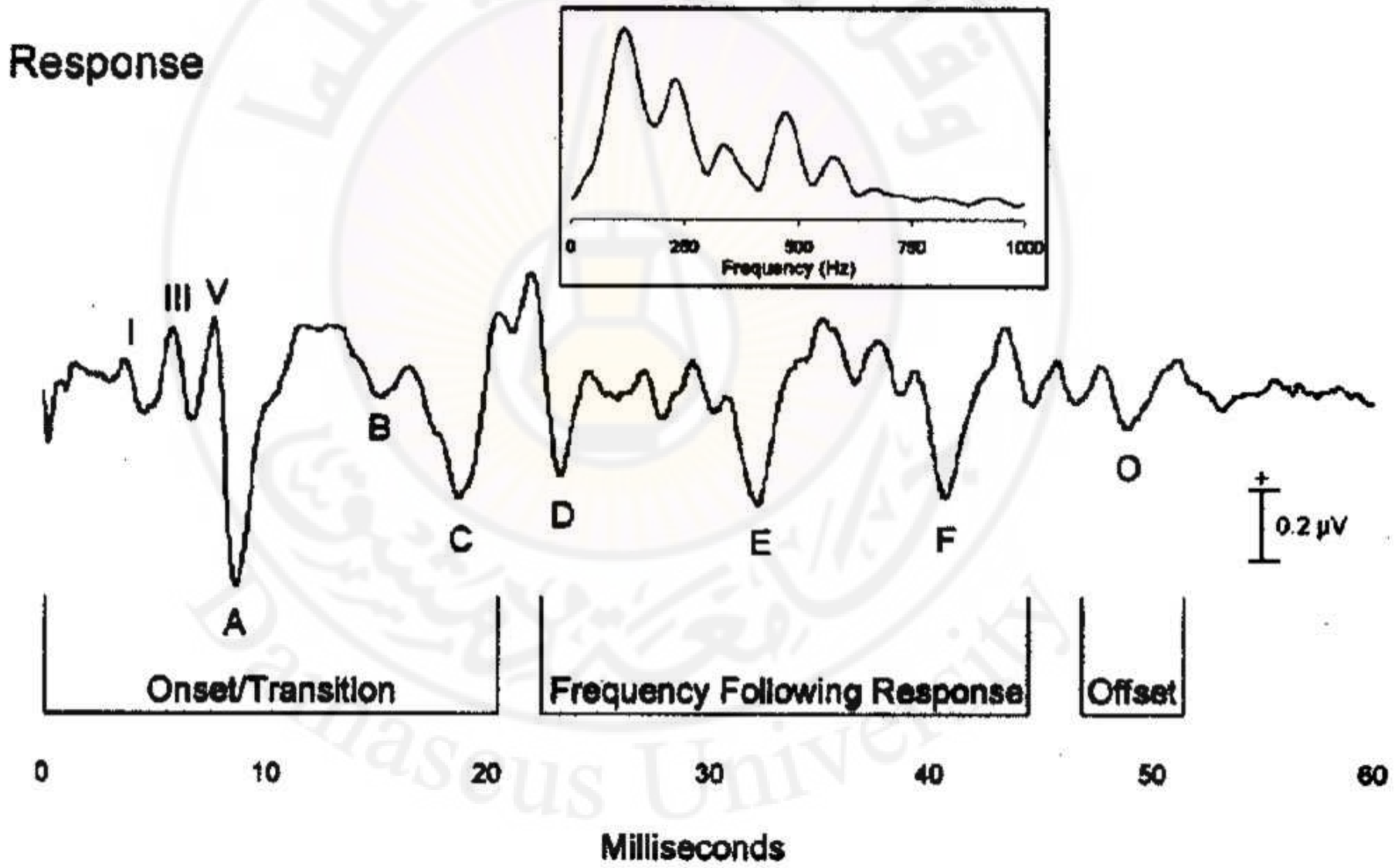


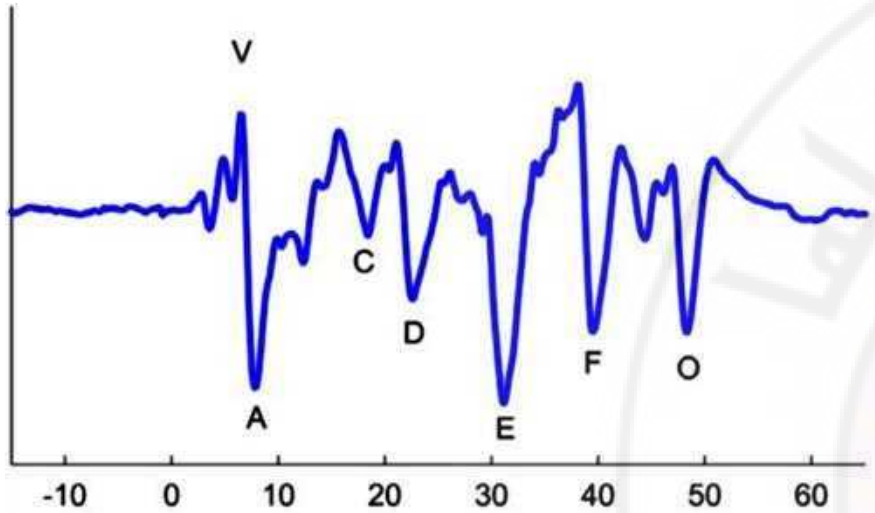
Figure 19–3 Examples of spectra of 2000 Hz tone bursts, shaped with linear, cosine squared, and Blackman windows. Each tone burst has a 2 ms rise/fall time with no plateau. The insets show the time waveform for each stimulus. (From Gorga & Thornton [1989], with permission.)


100 µs
Click
2 kHz
Half Sinusoid
filt.
Click
1.5-0-1.5
Tone Burst
1.5-5-1.5
Tone Burst
0 1 2 3 4 5 6 7 8 ms
.25 .5 1 2 4 8 16
Frequency (kHz)

Speech stimulus

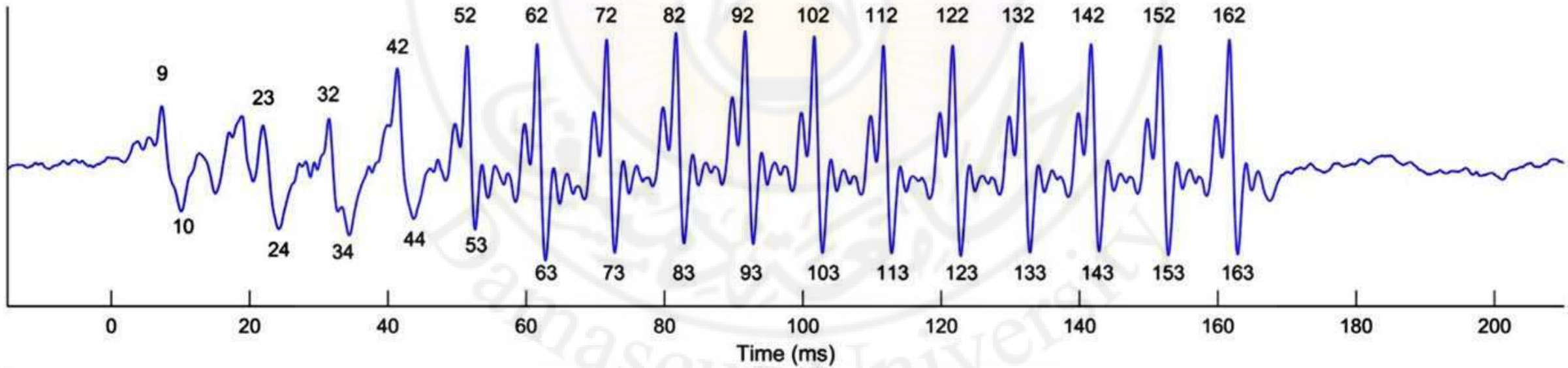






Shorter Stimuli: Manual

Longer Stimuli: Automatic peak-detection algorithm



Duration

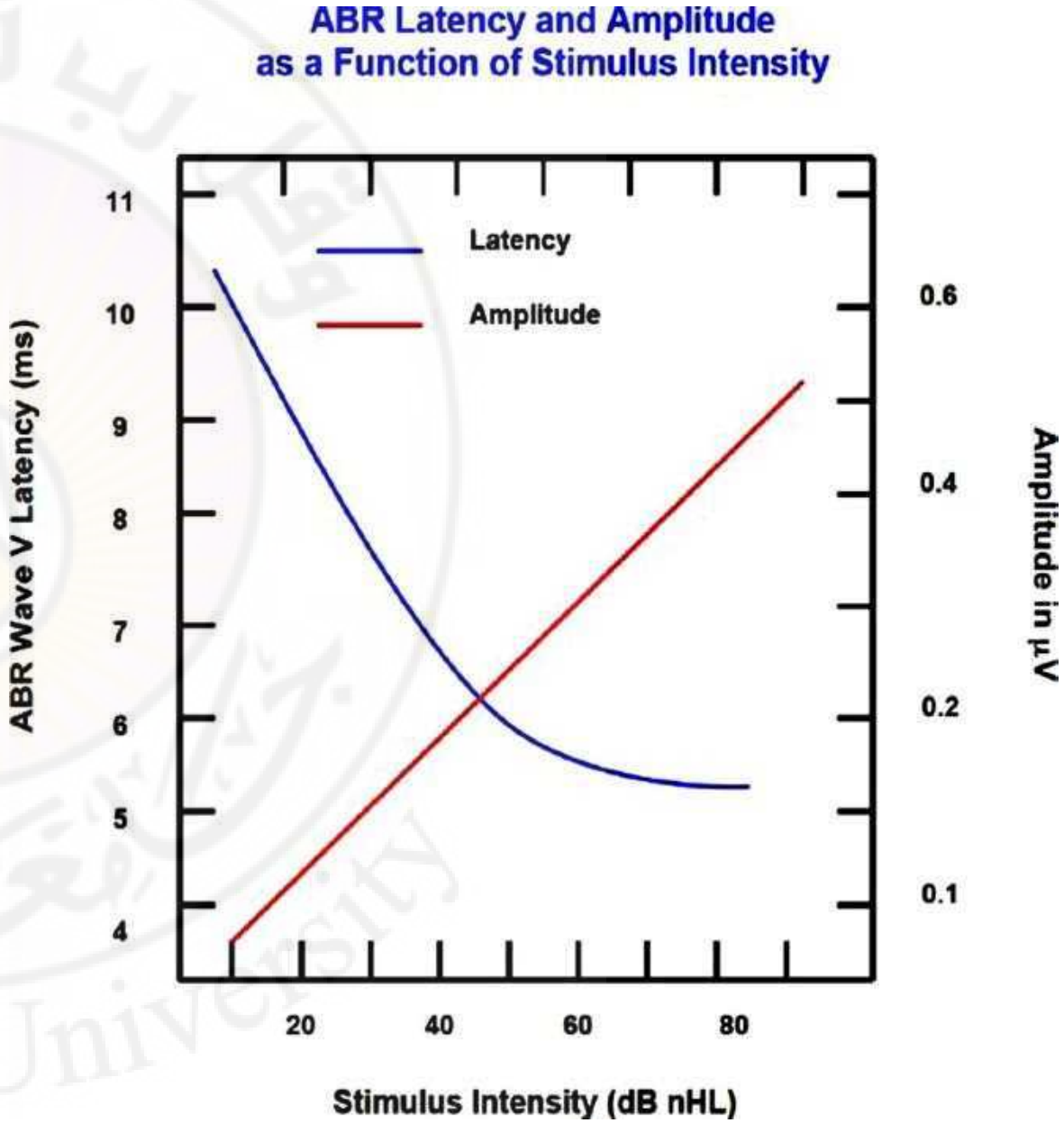
- Synchronous firing of many neurons, which is a general physiologic underpinning of the ABR, is very dependent on an **abrupt stimulus onset**.
- Click duration does not have a marked influence on ABR latency or amplitude.

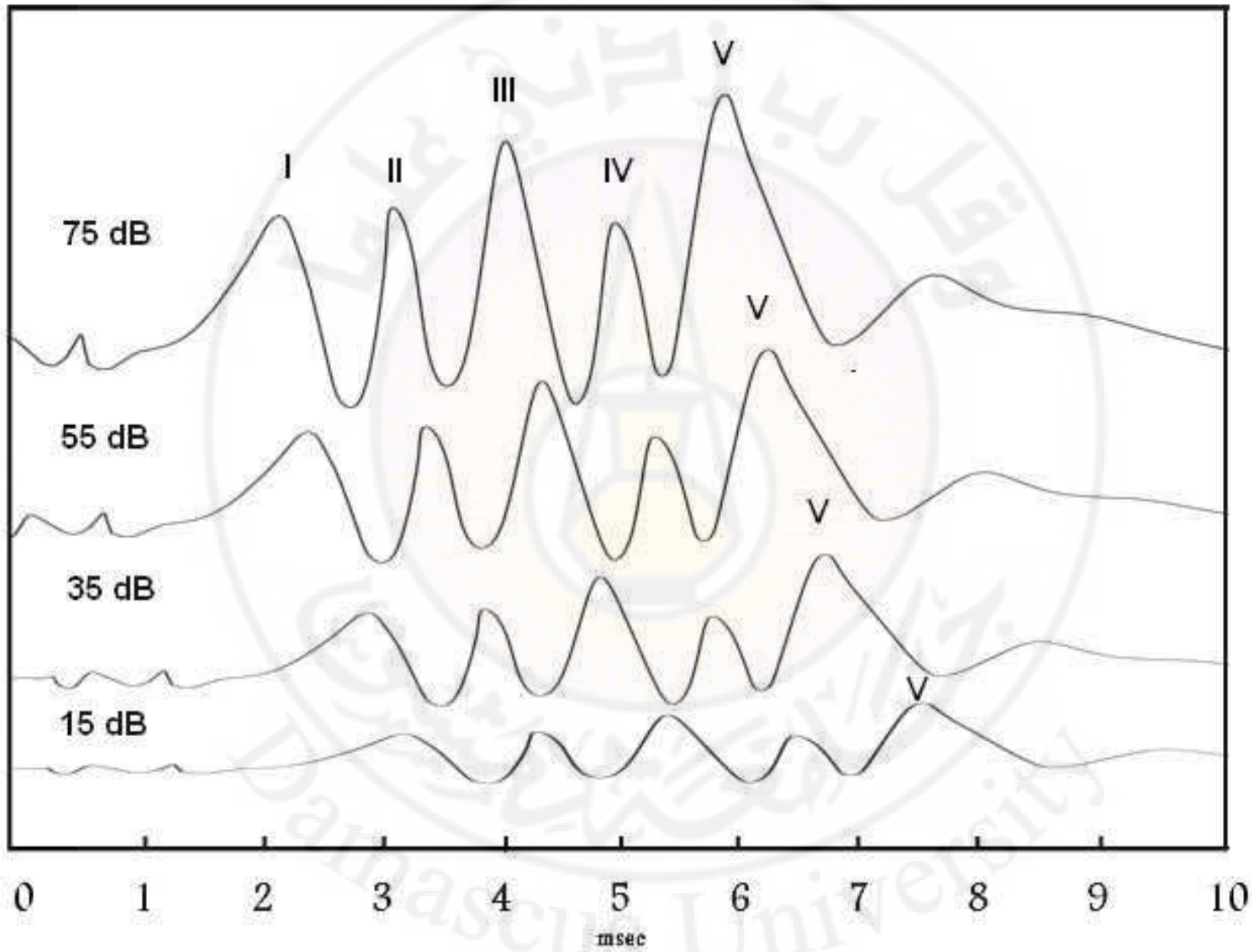
Tone Burst Frequency	Duration in Milliseconds			
	Rise	Plateau	Fall	Total
500 Hz	4	0	4	8
1000 Hz	2	0	2	4
2000 Hz	1	0	1	2
4000 Hz	0.5	0.5	0.5	1.5

Intensity

- In any given ABR assessment of an infant or young child, stimulus intensity is constantly manipulated and carefully increased or decreased to optimize quality of the response and to estimate auditory **threshold**.

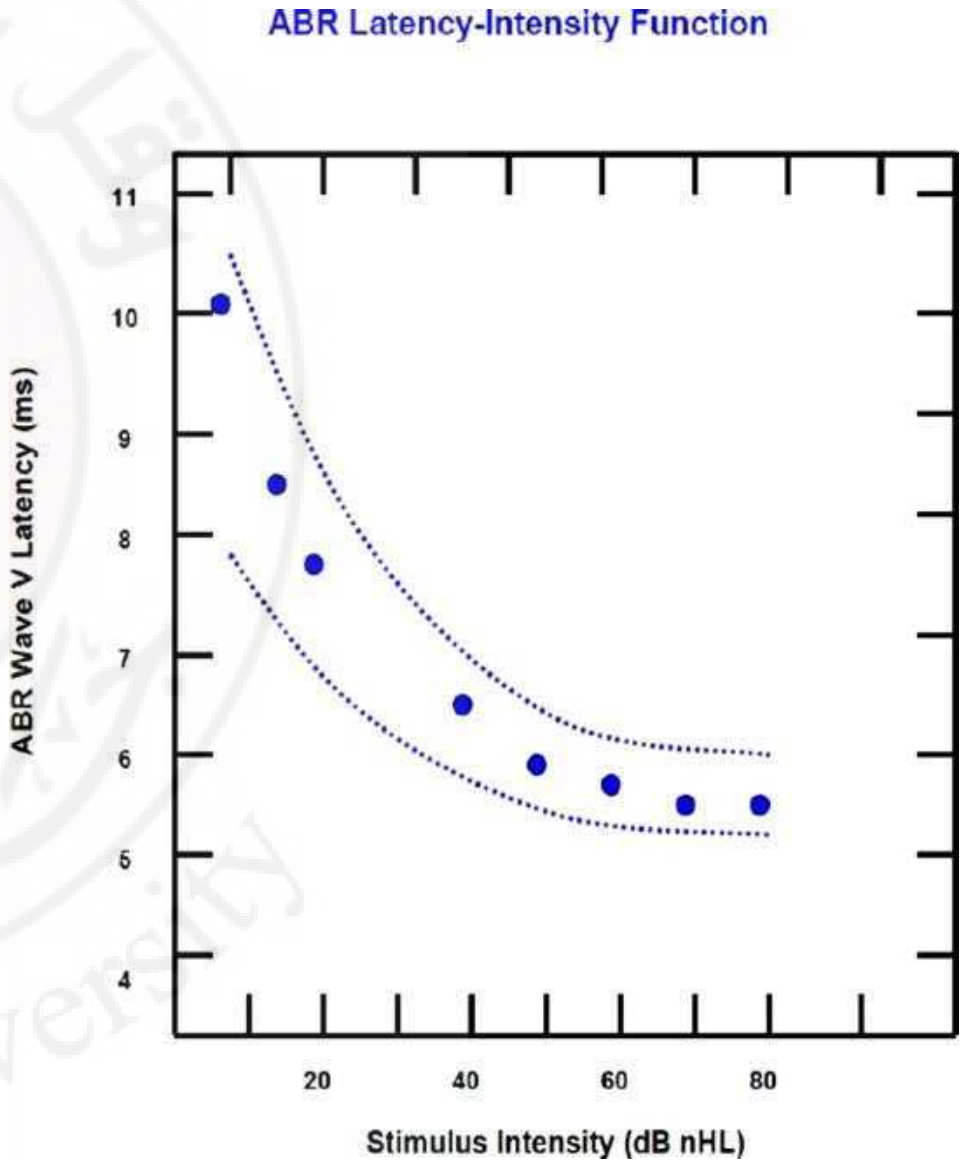
- Latencies of ABR waves decrease and amplitudes increase as stimulus intensity increases.

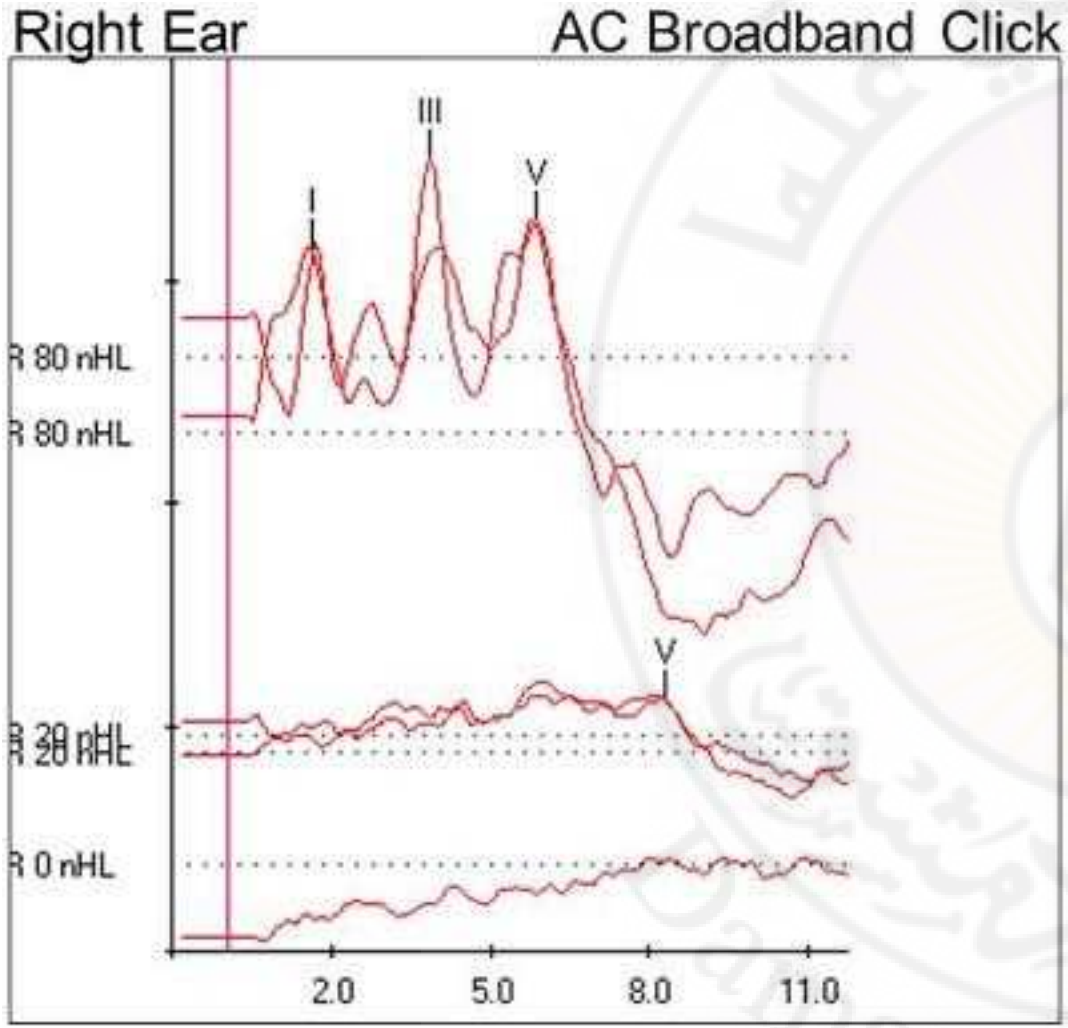


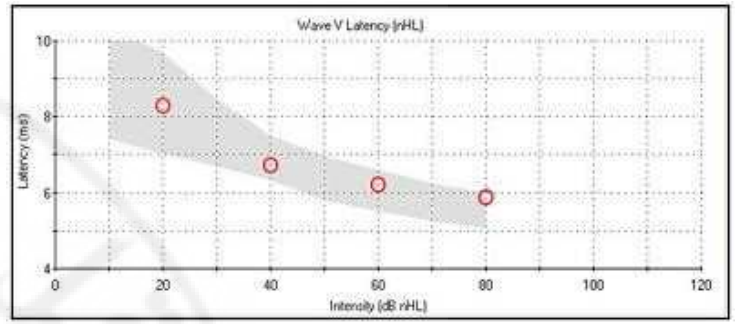

I
II
III
IV
V
75 dB
V
55 dB
V
35 dB
V
15 dB
0
1
2
3
4
5
6
7
8
9
10
msec

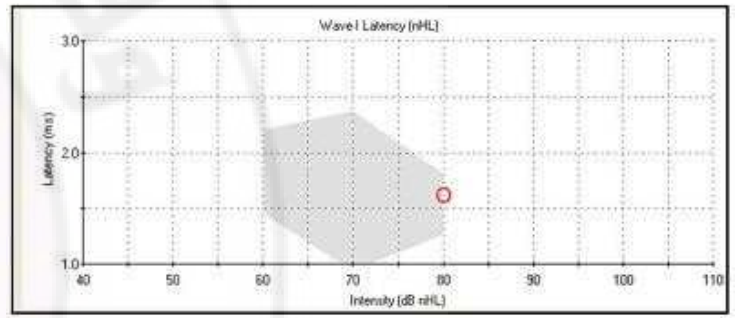
Wave V Latency-Intensity Function

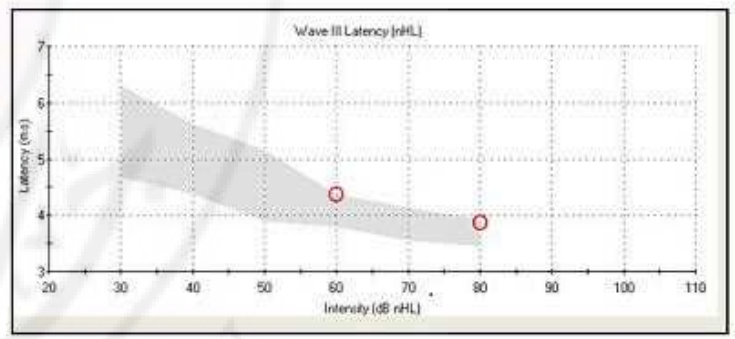
- The latency-intensity function for wave V is the most common graphic display of clinical ABR data.
- For low to moderate intensity levels, there is normally a systematic and rather abrupt shortening of latency values up to 0.5 or 0.6-ms of latency per 10 dB of intensity or 0.06-ms/dB) for wave V up to approximately 60 dB nHL.
- A wave V is generally not detected visually at intensity levels below 10 dB nHL, even in normal hearers. At these apparent ABR threshold levels, normal wave V latency is 7.5 to 8.0-ms or greater.
- For intensities from 60 to 95 dB nHL, the slope of the latency-intensity function is more gradual with a rate of change of only about 0.1 to 0.2-ms/10 dB.

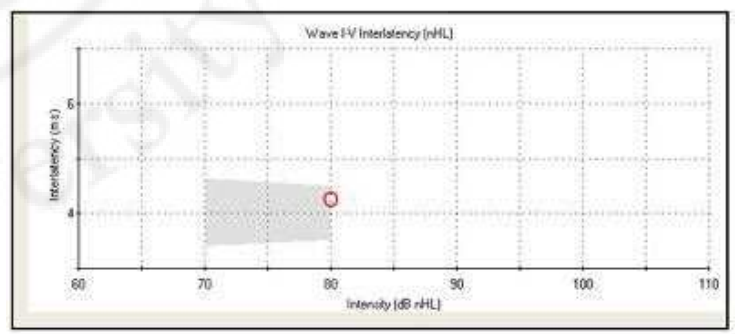



Right Ear
AC Broadband Click
I
III
V
V
R 80 nHL
R 80 nHL
R 0 nHL
2.0
5.0
8.0
11.0


Wave V Latency (nHL)
Latency (ms)
Intensity (dB nHL)


Wave I Latency (nHL)
Latency (ms)
Intensity (dB nHL)

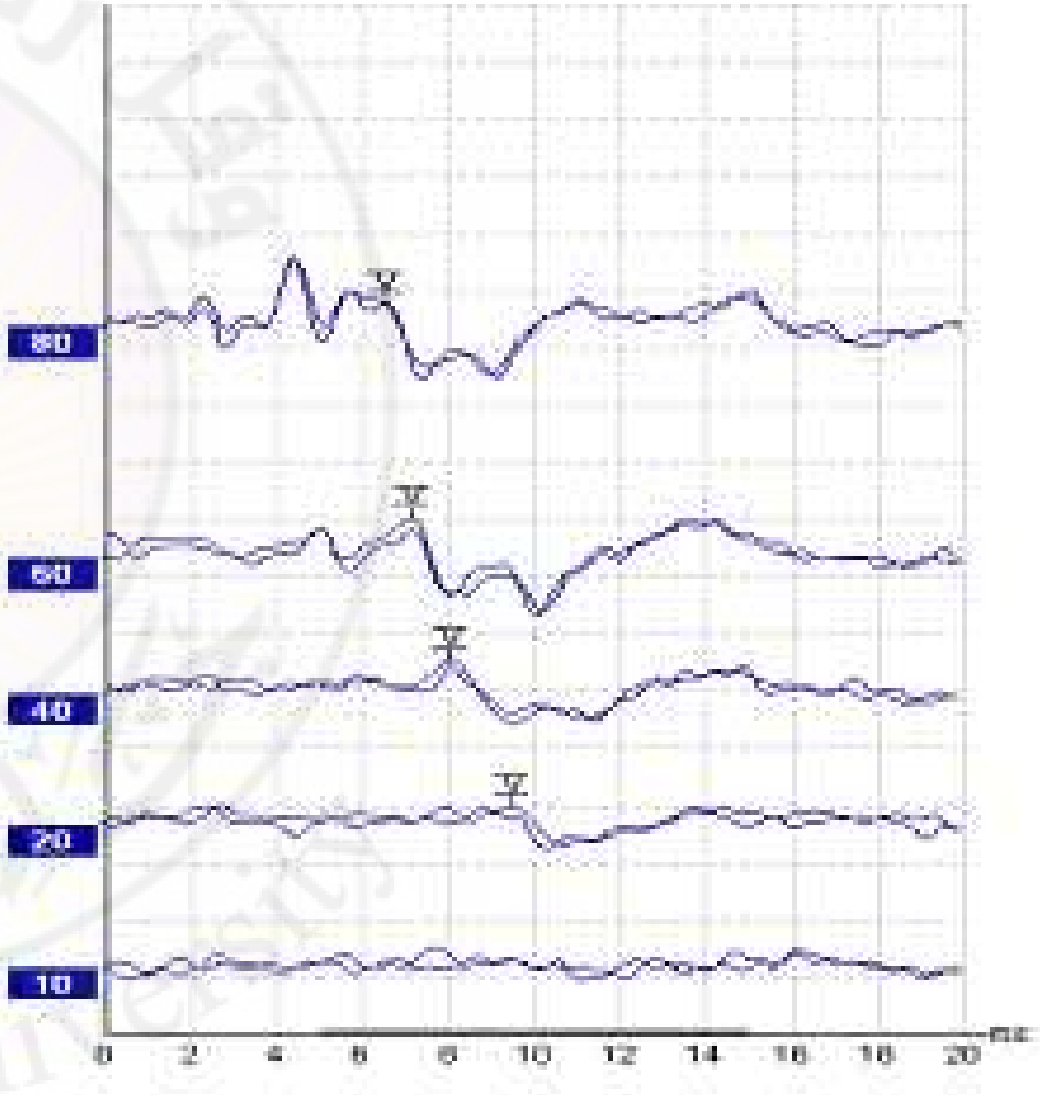

Wave III Latency (nHL)
Latency (ms)
Intensity (dB nHL)


Wave I-V Interlatency (nHL)
Interlatency (ms)
Intensity (dB nHL)

Rate Of Stimulus Presentation

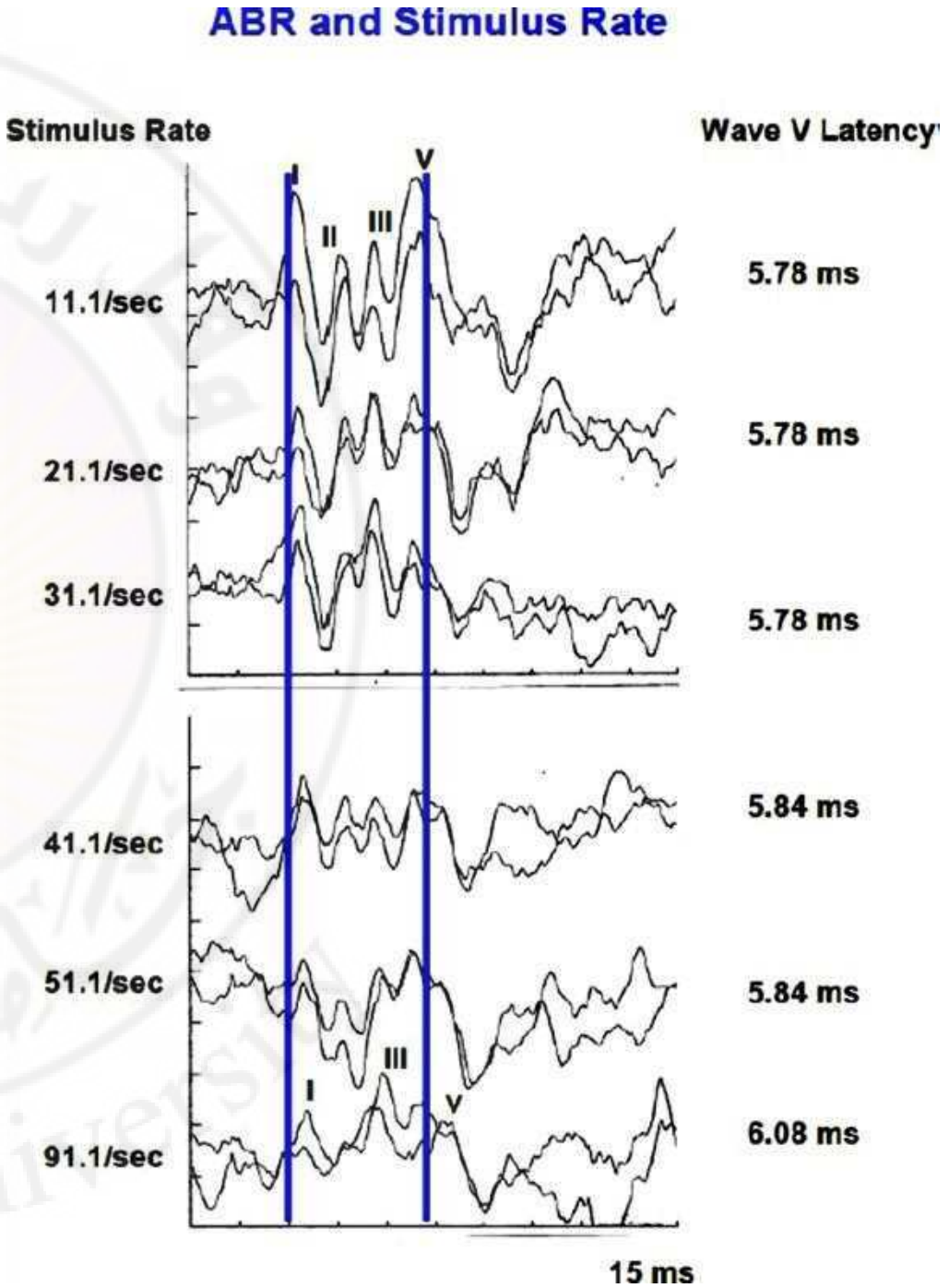
- Factors contributing to decisions about the most appropriate rate of stimulus presentation include:
  1) The clinical objective for ABR recording, such as hearing screening versus diagnostic assessment,
  2) Click versus tone burst stimulation,
  3) Interference from electrical artifact, and
  4) Developmental age of pediatric patients.

- ABR can be successfully recorded with a wide range of stimulus rates. One clinical principle guides selection of the most appropriate rate of stimulation. Rate of stimulation should be as fast as possible while still preserving optimal ABR quality.



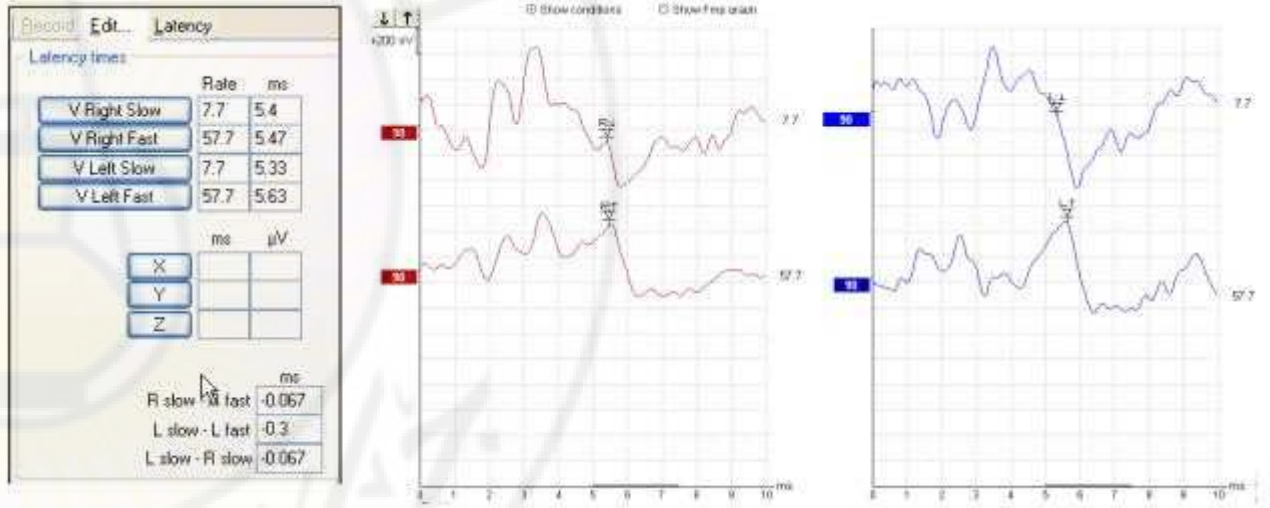
Rate of Stimulus Presentation

- An increase in rate increases the latency and decreases the amplitude.
- Always use an odd number for the clicks per second so that the rate is not a multiple of the main power supply (i.e.,50 or 60 Hz). Otherwise, you could get a 60 Hz cycle running through the waveform. This looks at the increased rate effect on latency and morphology.



Rate Study Protocol

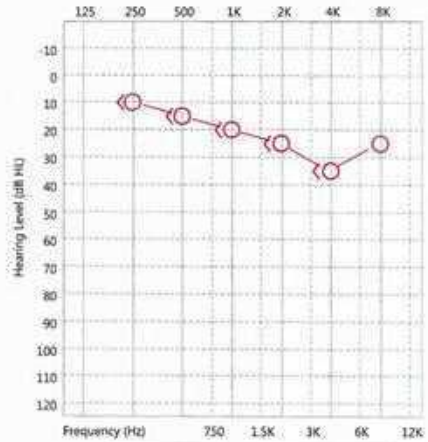
- Rate Study test is designed to evaluate the integrity of the auditory nerve and look for retrocochlear lesion abnormalities. Changes in response latency between fast stimulation rates and slow stimulation rates are recorded and compared.
- An interaural wave V latency difference greater than **0.2 to 0.4ms** is generally considered abnormal



First Name
Last Name
Age 56 years
Gender Male

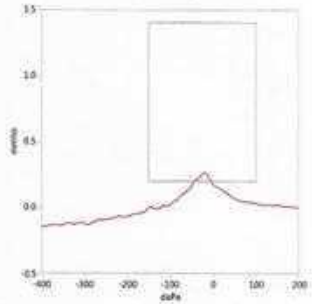
10/29/2022 6:03 PM

Right Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
R	SRT		20	
R	MCL		50	
R	WRS	100	50	

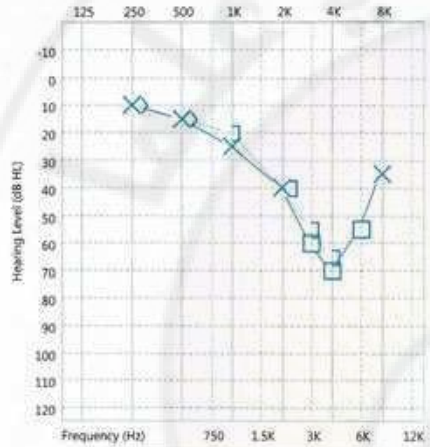
Right 226 Hz



Tymp			Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1	←	Y	1.1	-20	0.27	80	

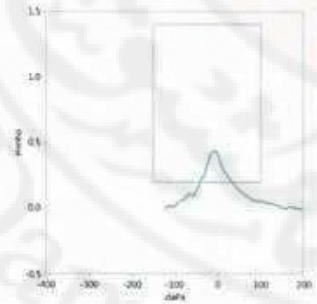
Ipsilateral / Contralateral
1000 500 2000 4000 500 1000 2000 4000
dB HL
NR
105

Left Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
L	SRT		25	
L	MCL		55	
L	WRS	100	55	
L	WRS	88	55	45

Left 226 Hz



Tymp			Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1	←	Y	1.0	-7	0.44	65	

Ipsilateral / Contralateral
1000 500 2000 4000 500 1000 2000 4000
dB HL
NR
105

Address: Day Medical Tower Unit C, 9th Floor, IranTehran

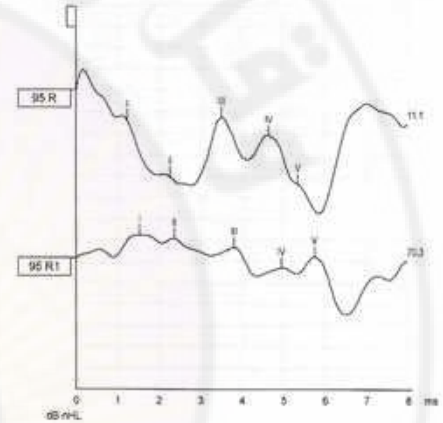
Tel: 021-88205806 Fax: 021-88202934 E-Mail: @tehranearclinic

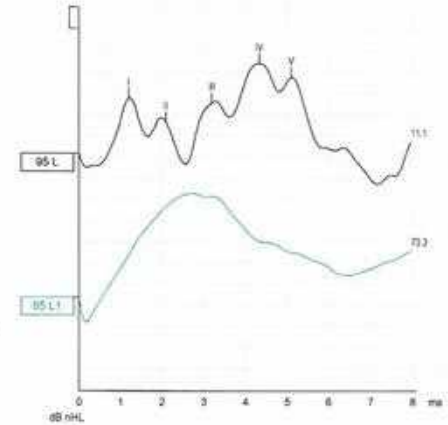
Last name:
First name(s):
Address:

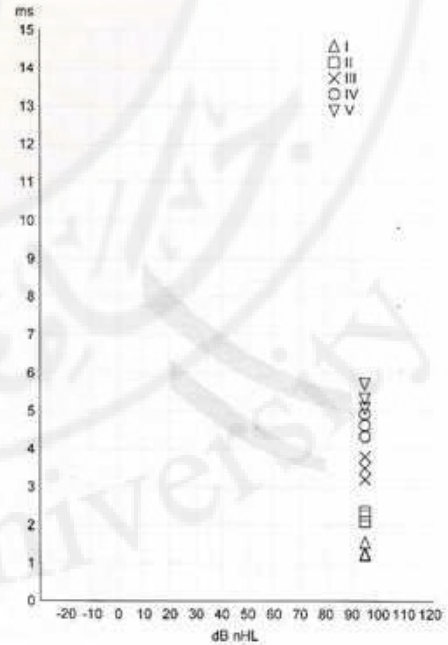
Sex: M
Age: 56 years
ID no: 4010856
Date of test: 10-29-2022
Day of birth: 08-10-1966

Tel:
E-Mail:

Examiner: ADM







Curve	Latencies (ms) I	II	III	IV	V	I-III	III-V	I-V	Interlatencies diff. R/L I-III	III-V	I-V	V-V
95 R	1.23	2.27	3.50	4.63	5.33	2.27	1.83	4.10	0.27	0.07	0.20	0.2
95 L	1.20	2.10	3.20	4.33	5.10	2.00	1.90	3.90	0.27	0.07	0.20	0.2
95 L1												
95 R1	1.53	2.37	3.80	4.93	5.73	2.27	1.93	4.20	0.27	0.03	0.30	0.6

گاندی
بیمارستان

تاریخ:
شماره:
پیوست:

شماره پرونده: ----
شماره سریال: -
شماره پذیرش: [redacted]
تاریخ پذیرش: 07/08/1401
نام بیمار: [redacted]
سن : 57

همکار محترم [redacted]

Brain and CPA MRI (with and without contrast):

Multiplanar, Multislice and multisequence images findings:

- *Cerebral hemispheres: normal size and grey and white matter structures and signal intensity.*
- *No hydrocephalus, mass or midline structural shift.*
- *Brain stem: normal*
- *Cerebellum: normal*
- *IAC and CP angles:* ***6.5 x 4 mm enhancing mass in left internal acoustic canal is seen infavor of acoustic schwannoma.***
- ***Fluid signal in bilateral mastoid air cells suggestive of mild mastoiditis.***
- *Sella turcica and pituitary gland: normal*

Best regards
[redacted] MD
Radiologist

No.130, South Gandhi St., Tehran - IRAN
Tel:+98(21)42624 - 42603000 / Fax:+98(21) 88651208

خیابان گاندی جنوبی، نبش کوچه ترابنده، شماره ۱۳۰
تلفن: ۴۲۶۲۴ - ۴۲۶۰۳۰۰۰ / فکس: ۸۸۶۵۱۲۰۸

WWW.GANDIHOSPITAL.IR

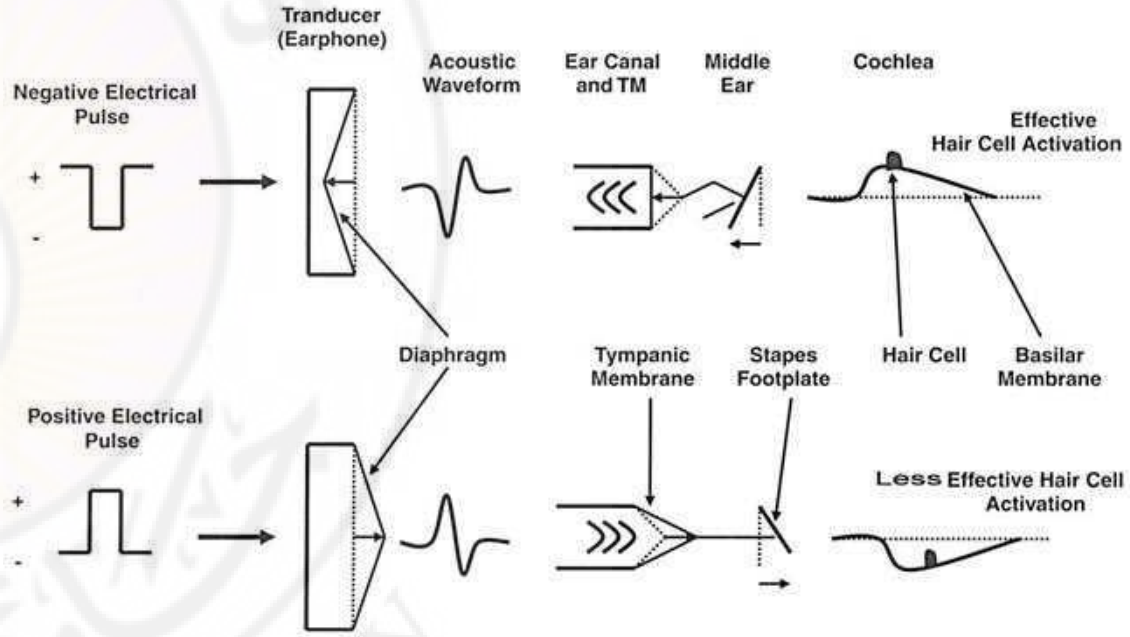
Stimulus Rate in Infants and Young Children

- There is a clear relationship between **maturity** of the central nervous system and the effect of rate on ABR.
- Stimulus rate has a more pronounced influence on ABR latency for premature than term neonates, for younger children under age 18 months than for older children, and for older children up to age 13 years than adults.



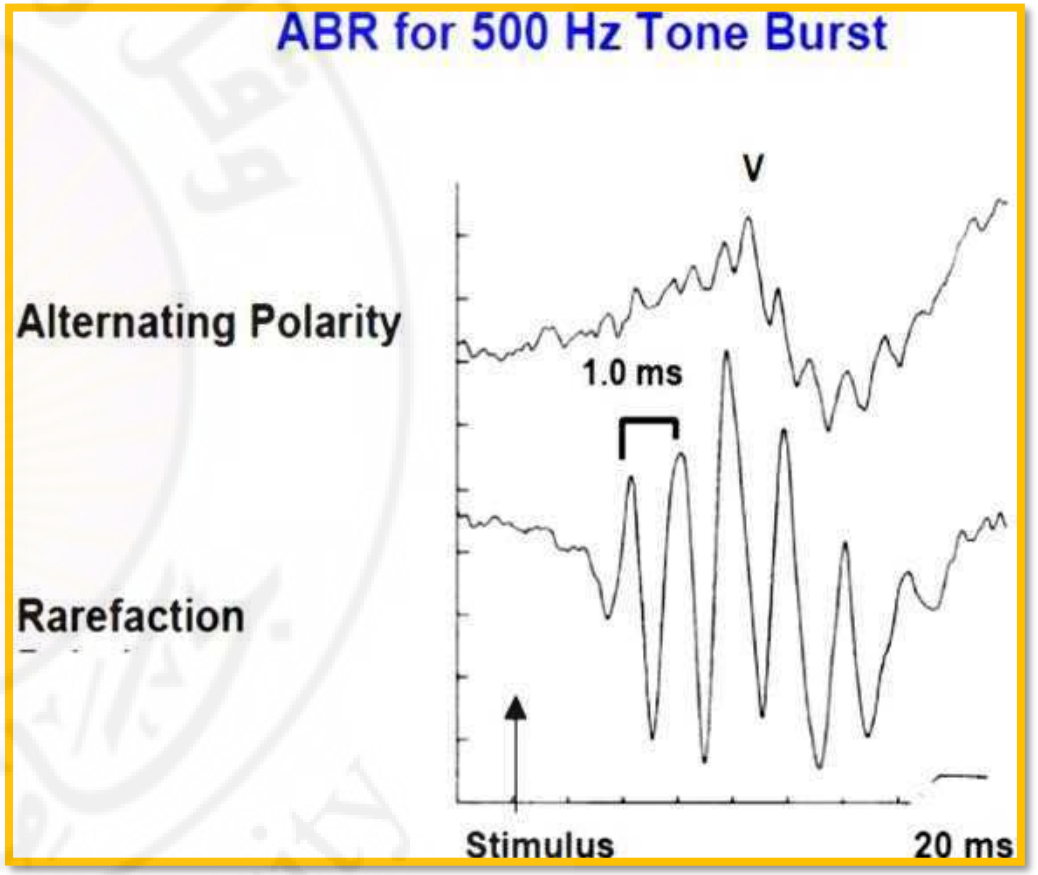
Polarity

- Polarity of an acoustic stimulus depends on whether the diaphragm of the transducer moves outward or inward in producing the sound.
- From a cochlear physiology perspective, rarefaction polarity stimuli are recommended for recording click-evoked ABRs.
- Amplitude is enhanced with rarefaction versus condensation polarity stimulation.
- Alternating polarity clicks are not recommended for ABRs evoked with air-conduction stimulation.
- However, the use of alternating polarity stimulation in ABR measurement with bone conduction helps to minimize interference from stimulus-related artifact.



Polarity

- One of the most consistent polarity-related ABR findings is shorter latency and larger amplitude for ABRs evoked with rarefaction versus condensation clicks.
- On the average, wave I latency is about 0.07-ms shorter for normal hearing adult subjects.
- Rarefaction is the polarity used for infant ABR testing, and it is important to consider changing polarity if the response you are trying to record is not optimal.
- A condensation click advantage may on rare occasions occur in patients with sensory hearing loss, but it is not a typical normal finding.

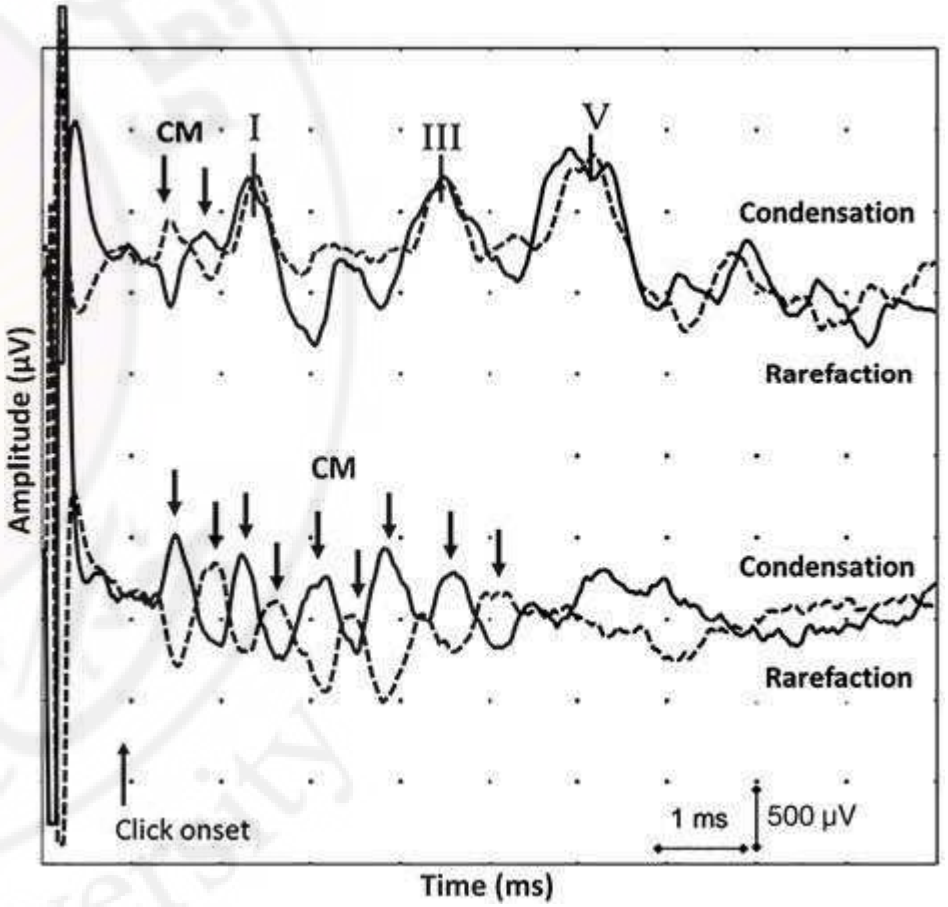


The periodic waveform in an ABR evoked with single polarity 500 Hz tone burst stimulation is sometimes referred to as “ringing”

Polarity and diagnosis of auditory neuropathy (ANSD)

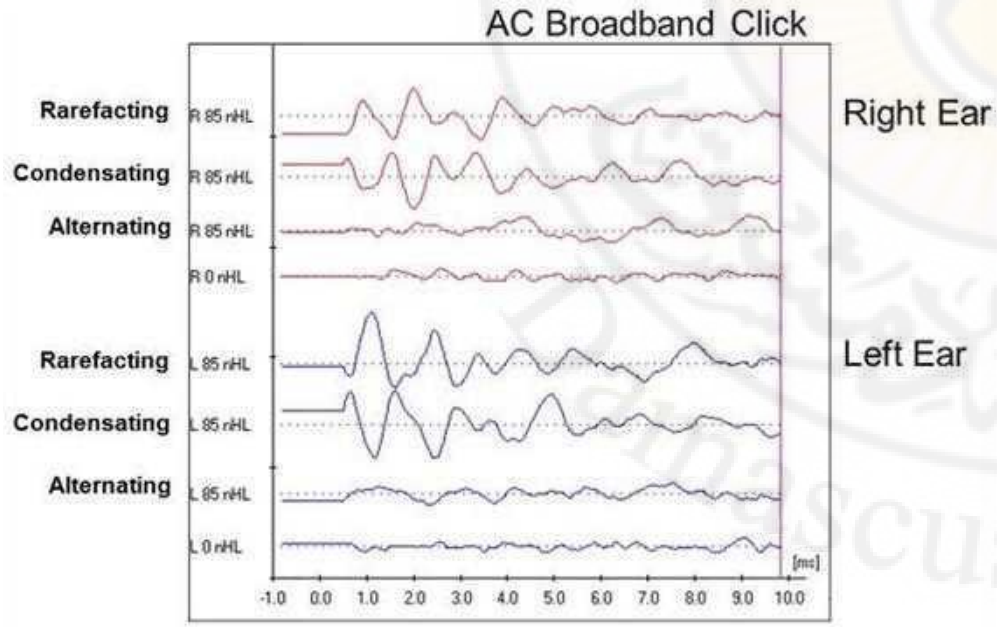
- If you first record with rarefaction stimuli and then condensation stimuli, and you get the same wave with both, then it is a real ABR.
- If you use rarefaction and then condensation, and the result is a totally opposite polarity response, then that is not an ABR.

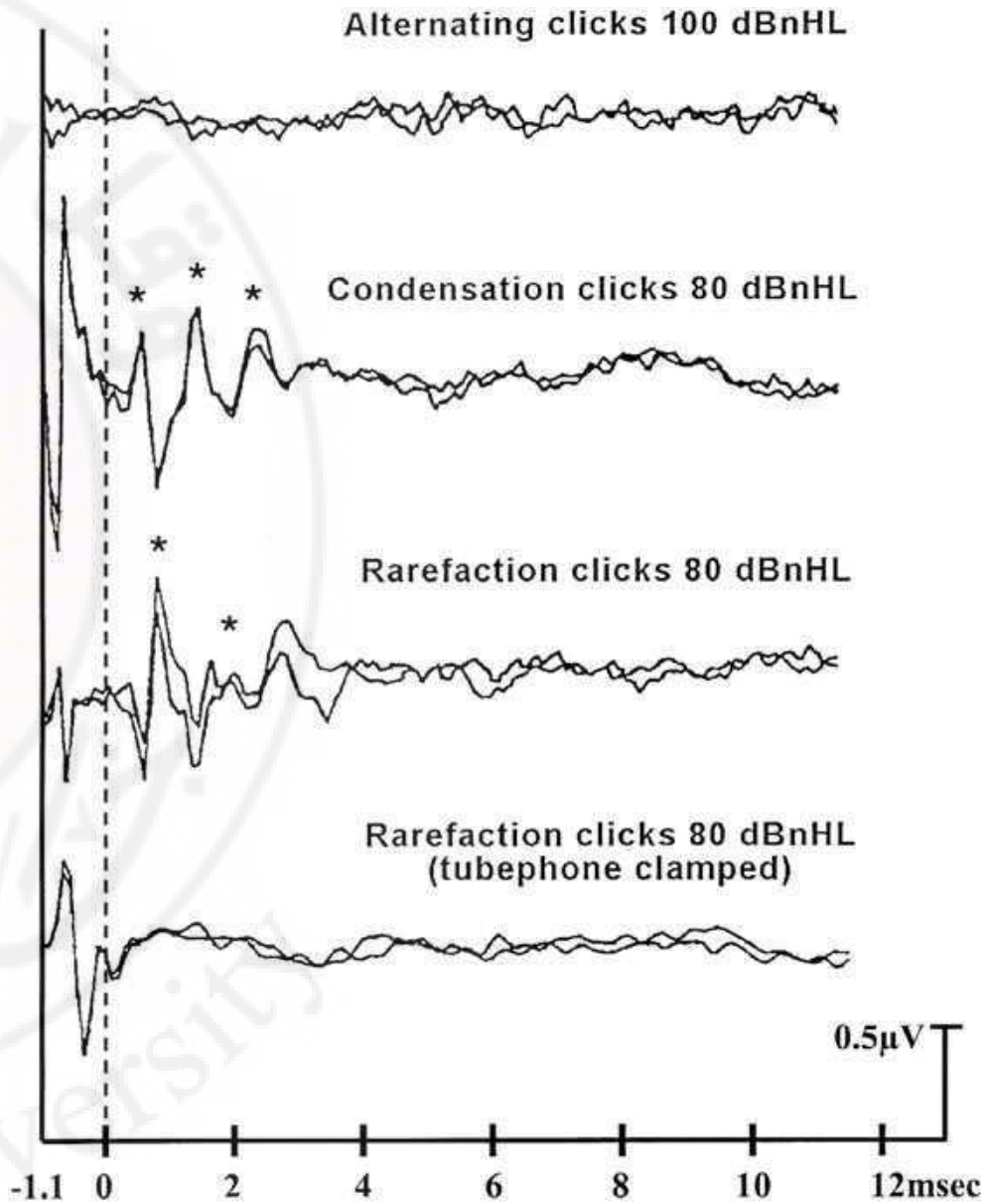
- **That is purely a cochlear microphonic.**
- You could get a cochlear microphonic followed by the typical ABR waves, and this would not be ANSD. But, if you only record a cochlear microphonic, then that's an ANSD pattern. That's why you always should use rarefaction and condensation polarity clicks to start off the ABR.

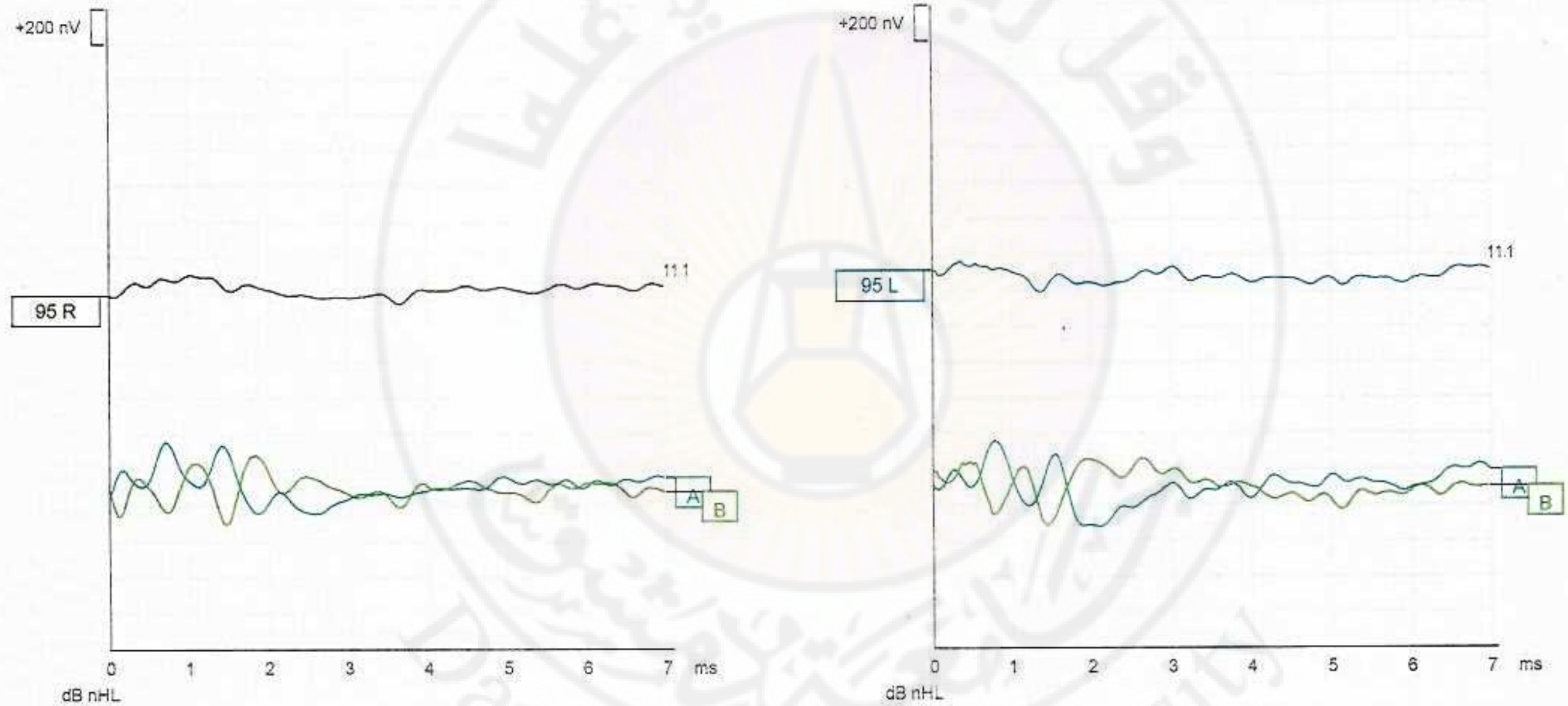


Polarity and diagnosis of auditory neuropathy (ANSD)

- Reliance on alternating polarity stimulation is not advisable as it presents some serious clinical disadvantages in recording ABR and particularly in the early identification of ANSD.

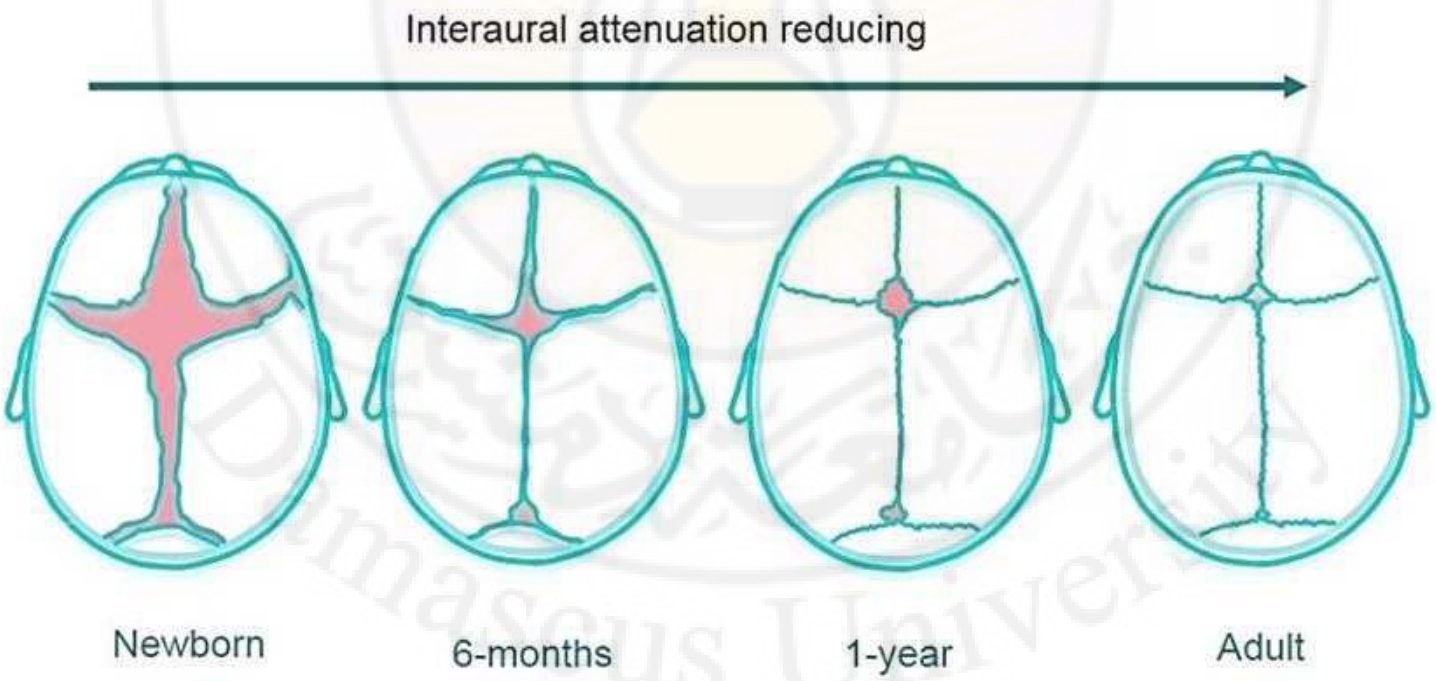





+200 nV
11.1
95 R
A
B
0 1 2 3 4 5 6 7 ms
dB nHL
+200 nV
11.1
95 L
A
B
0 1 2 3 4 5 6 7 ms
dB nHL

Masking in ABR

- Contralateral masking of the non-test ear is sometimes but not always required in recording auditory evoked responses. When its indicated, masking noise is presented to the non-test or non-stimulus ear in an attempt to ensure that it does not contribute to the response.



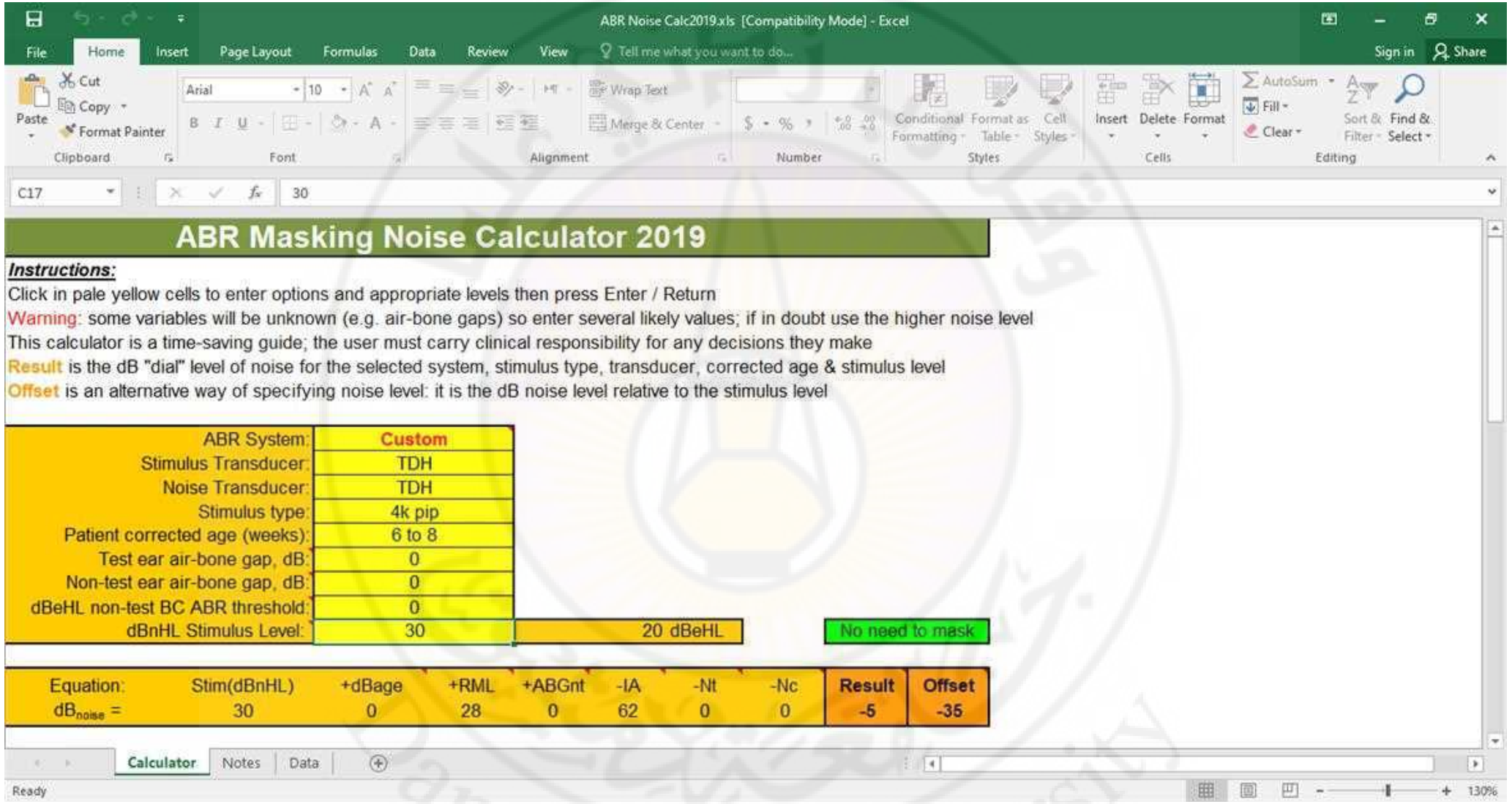
Masking in ABR

- The easiest way to determine when to mask during ABR testing, is to examine the collected ABR.
- For **air conduction**, if the absolute latencies of waves I and V are normal, there is no need to mask. This is because the crossover of the stimulus to the non-test ear takes time. This time delay would in turn delay the absolute latencies of the waveforms.
- The latencies would also be delayed due to the inter-aural attenuation (IA) of the stimulus. (The IA of the click is 65dB.)
- Therefore, a normal ABR can only be elicited from the stimulated ear. If, however, the latencies are abnormal, masking may needed.



Masking in ABR

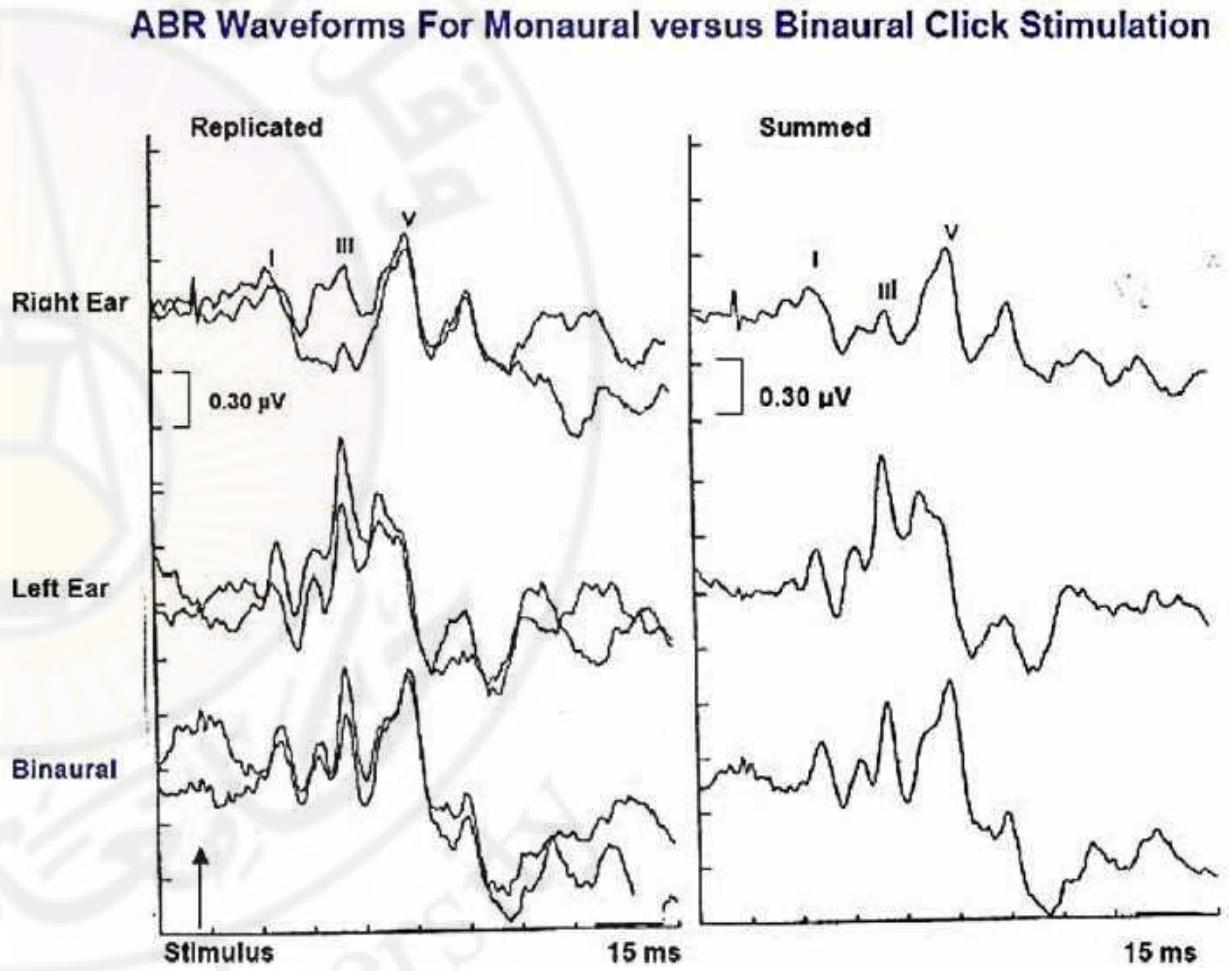
- For **bone conduction**, masking is not required if **wave I** is present at normal latencies. This is because wave I is a near-field potential and a normal wave I can only be recorded from the electrode near the stimulated ear. If, however, wave I is absent or delayed for bone conduction, masking is needed.
- Most ABR systems offer **white noise** as a masker which is an appropriate choice because the click is a broadband stimulus.
- The amount of masking noise needed would be enough to elevate the hearing threshold in the non-test ear so cross over is prevented.
- For example, if a click is presented at 95 dB nHL via insert earphones and the IA is 65 dB, the signal will be reaching the non-test ear at 30 dB. Enough masking noise (without over-masking) that elevates the threshold in that ear above 30 dB would be adequate—approximately 40-50 dB.
- Masking noise does not affect the latency or amplitude of the response.



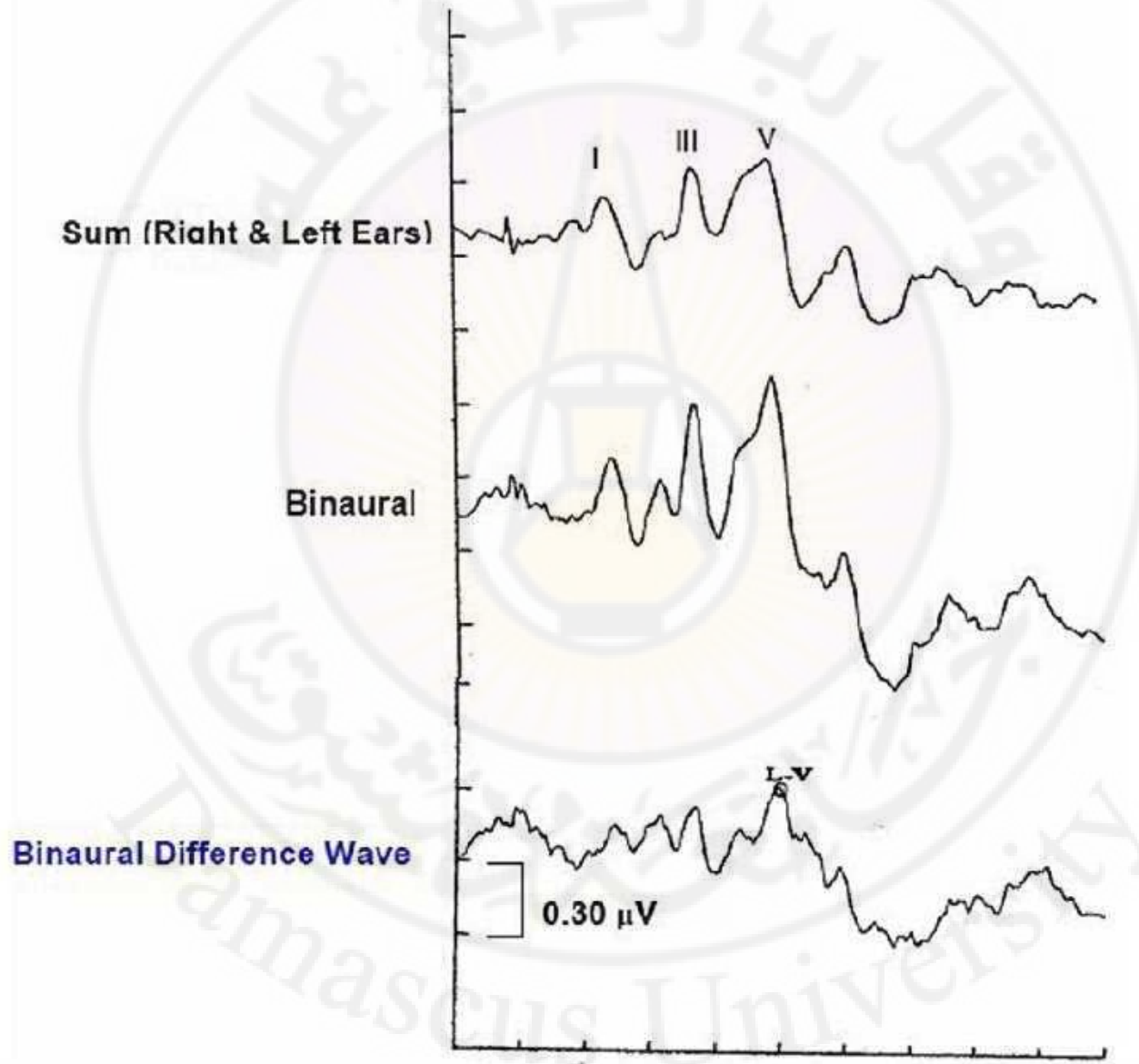
https://eratraining.co.uk/onewebmedia/ABR%20Noise%20Calc2019.xls

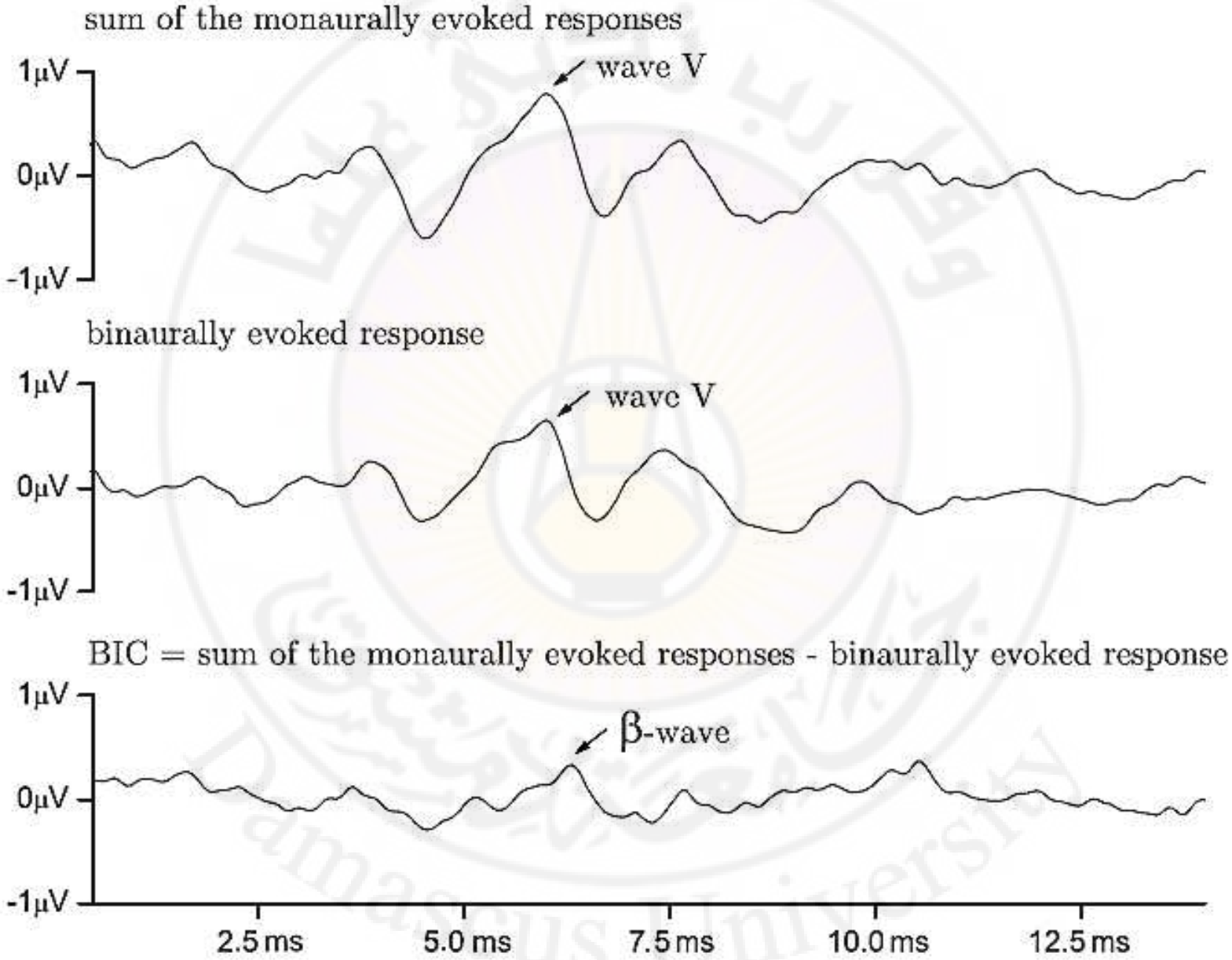
Binaural Stimulation

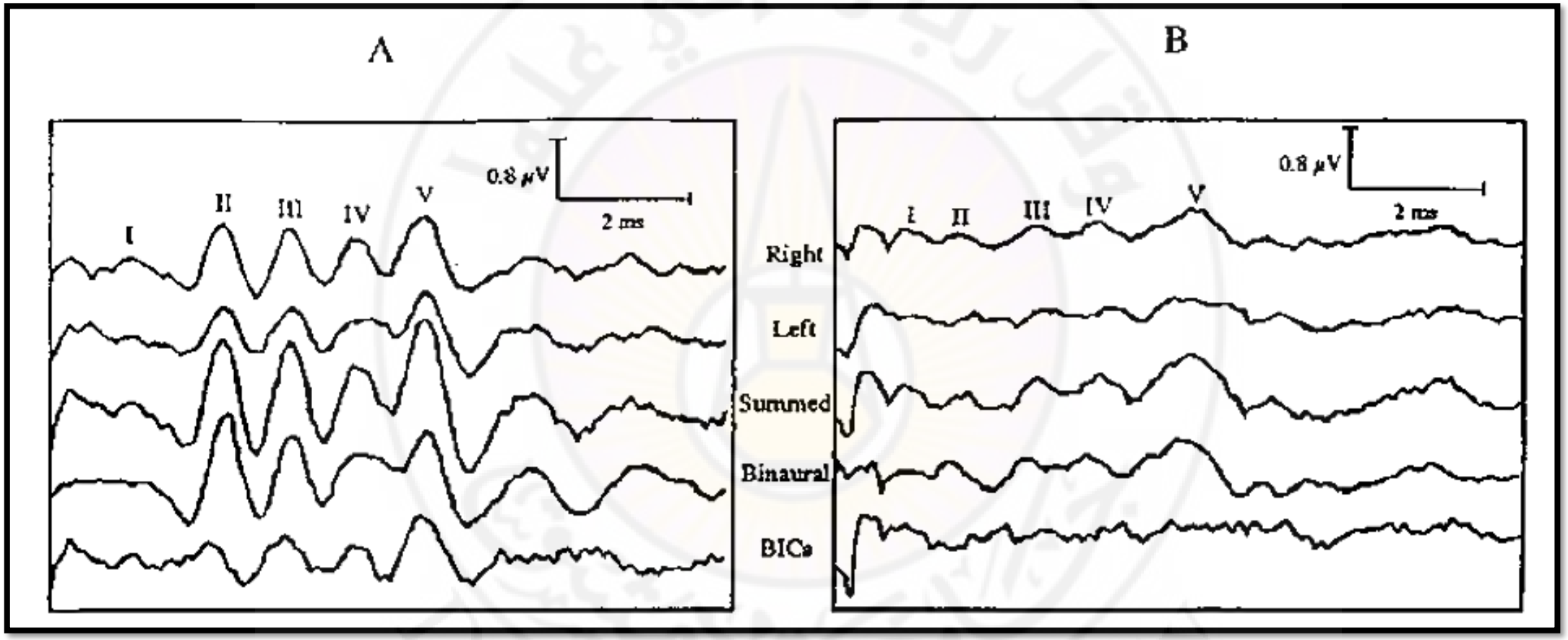
- Binaural stimulation and analysis of binaurally evoked ABRs is rarely performed in clinical settings.
- The persistent interest in the **binaural interaction component (BIC)** of the ABR is probably a reflection of the importance of binaural phenomena in auditory processing.
- the binaural wave V amplitude is up to twice the monaural amplitude, resulting in a typical binaural-to-monaural wave V amplitude ratio of around 1.5 to 2.0.



ABR Binaural Difference Wave




sum of the monaurally evoked responses
1μV
0μV
-1μV
wave V
binaurally evoked response
1μV
0μV
-1μV
wave V
BIC = sum of the monaurally evoked responses - binaurally evoked response
1μV
0μV
-1μV
β-wave
2.5 ms
5.0 ms
7.5 ms
10.0 ms
12.5 ms



Normal

APD

Endogenous Evoked Potentials

Dr. Samer Mohsen

December 2022

مقدمة

- كلما ارتفعنا بمستوى الكمونات السمعية المحرضة باتجاه المهاد والقشر تحصل العديد من التبدلات الهامة:
  - في كل مرحلة جديدة تتدخل مناطق مختلفة في توليد الكمونات.
  - يمكن لهذه المناطق أن تتنبه بفعل منبهات مختلفة ومتنوعة (سمعية، بصرية، ولمسية).
  - الأمواج ذات أزمنة اكلمون الطويلة تمتاز بانها لاتتعلق إلى حد كبير بنوع المنبه وخصائصه.
- الكمونات المرتبطة بالحدث: [illegible]
- هي مجموعة من الاستجابات التي تنشأ من تدخل فاعل للفرد المفحوص في تعامله مع المنبه وليس من خصائص المنبه ذاته.
- التدخل الفاعل قد يكون: الانتباه للمنبه، تنفيذ مهمة معينه تزامنا مع المنبه، أو الانتباه للتغيرات التي تطرأ على المنبه.
- الاستجابات داخلية التوليد [illegible]: هي الاستجابات التي تنشأ عادة من العمليات المعرفية والانتباه أثناء تسجيل الكمونات المحرضة.

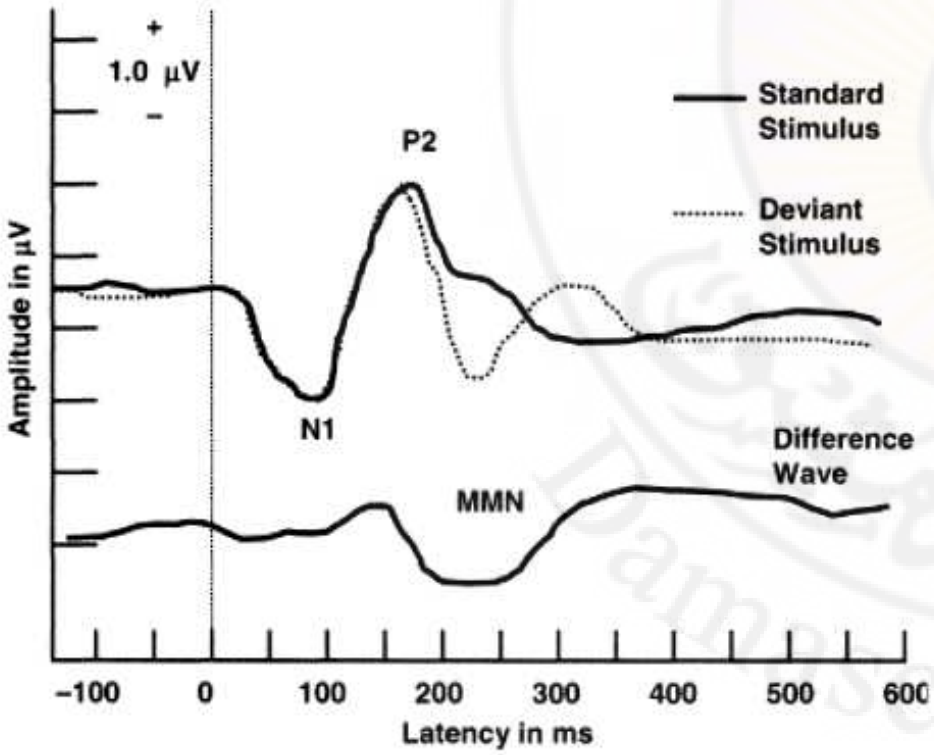
مقدمة

- تتشكل مجموعة من الاستجابات كنتيجة للتغيير في المنبه وللحصول على هذه الاستجابات نقوم بتقديم منبه متشابه بشكل سلسلة منبهات تسمى المنبه النموذجي (العادي) [illegible] ويقدم كذلك منبه يختلف عنها بشكل عشوائي وقليل الحدوث وغير متوقع يسمى المنبه المنحرف أو النادر [illegible] ويسمى هذا البروتوكول في تقديم المنبهات بال [illegible]
- تستطيع الجملة العصبية إضافة للاستجابة للمنبه النموذجي أن تستجيب أيضا للمنبه النادر أو المنحرف.



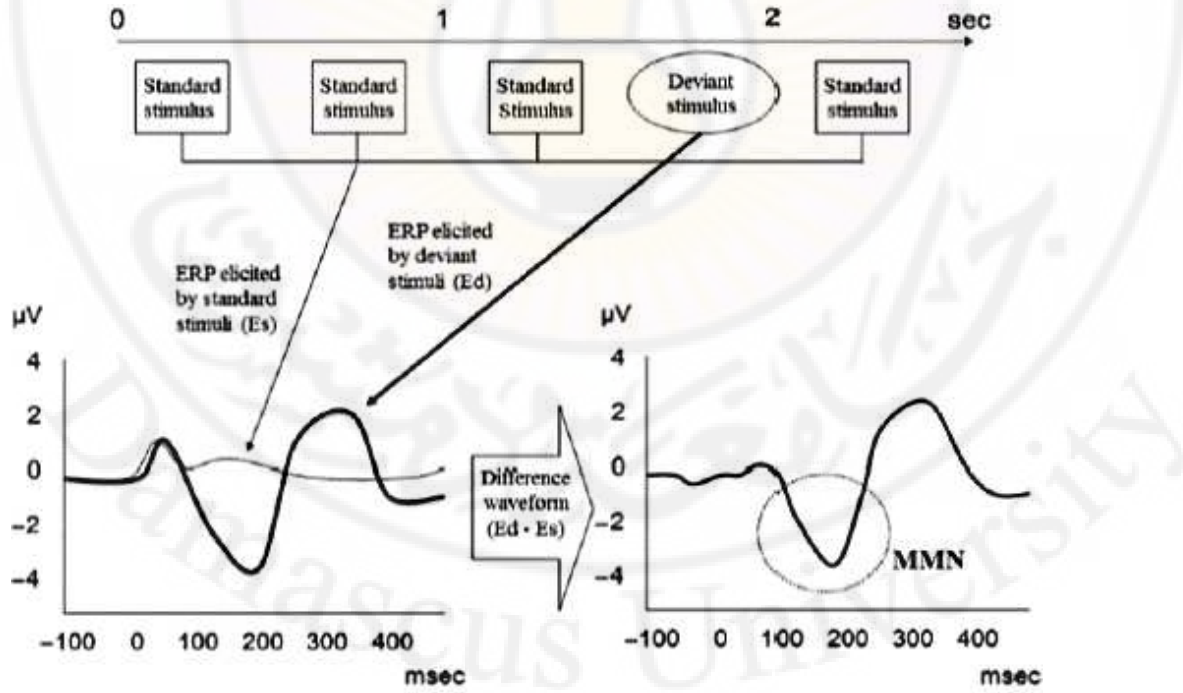
Mismatch Negativity (MMN)

- تم تسجيل ووصف هذه الاستجابة لأول مرة من قبل [illegible] و [illegible] في جامعة هليسنكي.
- ثم تابع طلابه وزملاءه الدراسات حول ال[illegible]



تعريف

- استجابة هي عبارة عن موجة سلبية واسعة ضمن مجال زمن الكمون من 100-300 وبمطال يقدر بحدود 1µ تنتج هذه الموجة عن التفاضل مابين الاستجابة الناجمة عن المنبه الستاندارد والاستجابة الناجمة عن المنبه النادر.



آليات توليد استجابة ال MMN

- التحليل ماقبل الانتباهي لخصائص المنبه المقدم (تواتر – شدة – المدة – وخصائص الكلام).
- استخراج أو كشف التغيير في المنبه النموذجي مع تكرار المنبه.
- المقارنة اللحظية بين المنبه الاستاندارد والمنبه النادر من خلال الذاكرة الحسية السمعية.
- تشكيل الموجة التفاضلية السلبية:

  خلال تسجيل ال؟؟؟؛ يستطيع الكمبيوتر أن يشجل الاستجابة الناجمة عن المنبه العادي والاخرى الناجمة عن المنبه النادر ويقوم بطرحهما من بعض بطريقة رياضية ومن ثم رسم الموجة الناشئة عن هذه العملية والتي تمثل ال؟؟؟؟

- يمكن توليد هذه الاستجابة بمنبهات سمعية – بصرية – ولمسية وتعتبر اداة لكشف التغيير في الوارد الحسي إلى الدماغ بطريقة لحظية سريعة سابقة للانتباه.

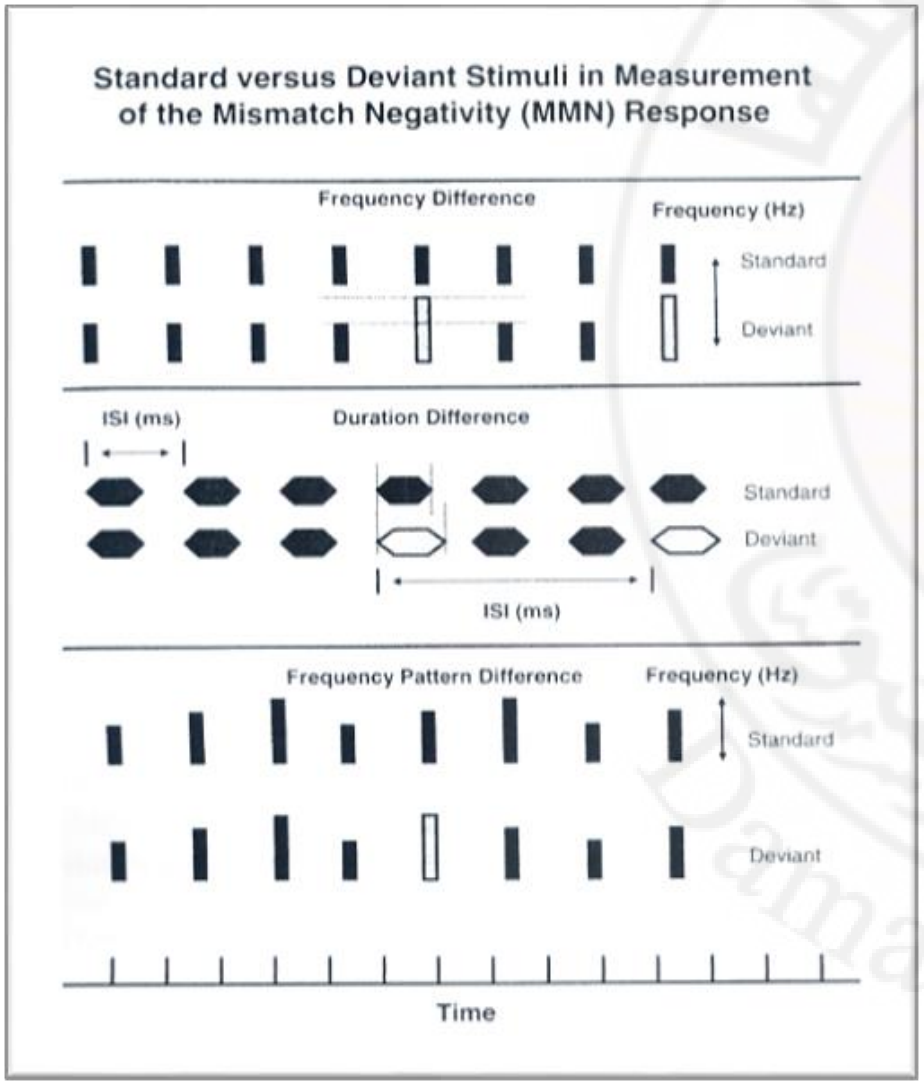
آليات توليد استجابة ال MMN

- لايتم تداخل عناصر عصبية جديدة لتوليد استجابة ال MMN وإنما هي وظيفة نفس العناصر العصبية التي تستجيب في مستوى القشر للاستجابات المتاخرة.
- يشترط لتوليد الاستجابة وجود ذاكرة حسية وظيفية تقوم بتسجيل المنبه العادي النموذجي والاحتفاظ به لمقارنته بالمنبه النادر او املنحرف.
- تكرار المنبه النموذجي يتم تسجيله في الذاكرة الحسية ضمن مايسمى تعقب الذاكرة لخصائص المنبه أو لاحدى خاصياته. ومن ثم يتم كشف التغيير من خلال المنبه المنحرف وفق آلية تسمة آلية كشف التغيير الذاتي، وهي المولد الاساسي لل MMN

مزايا ونقاط قوة استجابة ال MMN

- استجابة معرفية باكرة نسبيا .....أول استجابة معرفية تظهر عند حديثي الولادة
- الموقع التشريحي..... ذات منشأ قشري صدغي وجبهي
- لاترتبط بالانتباه..... استجابة ماقبل الانتباه
- لاترتبط بحالة الشخص..... لاتحتاج لتعاون الفرد ويمكن تسجيلها في النوم واليقظة وفقد الوعي.
- تفيد في تخمين الاختلافات في منبه الكلام.....تشخيص الحد الأدنى من الاختلاف في المنبه الكلامي .
- تستجيب لتنوع واسع من المنبهات الصوتية..... من النغمة الصافية وصولا إلى الكلمات والجمل.
- اختبار الكتروفزيولوجي موضوعي..... يفيد في تشخيص اضطراب المعالجة السمعية المركزية، اضطراب الذاكرة الحسية واضطراب الذاكرة العاملة، الضمور الدماغي – التراجع المعرفي وغيرها.

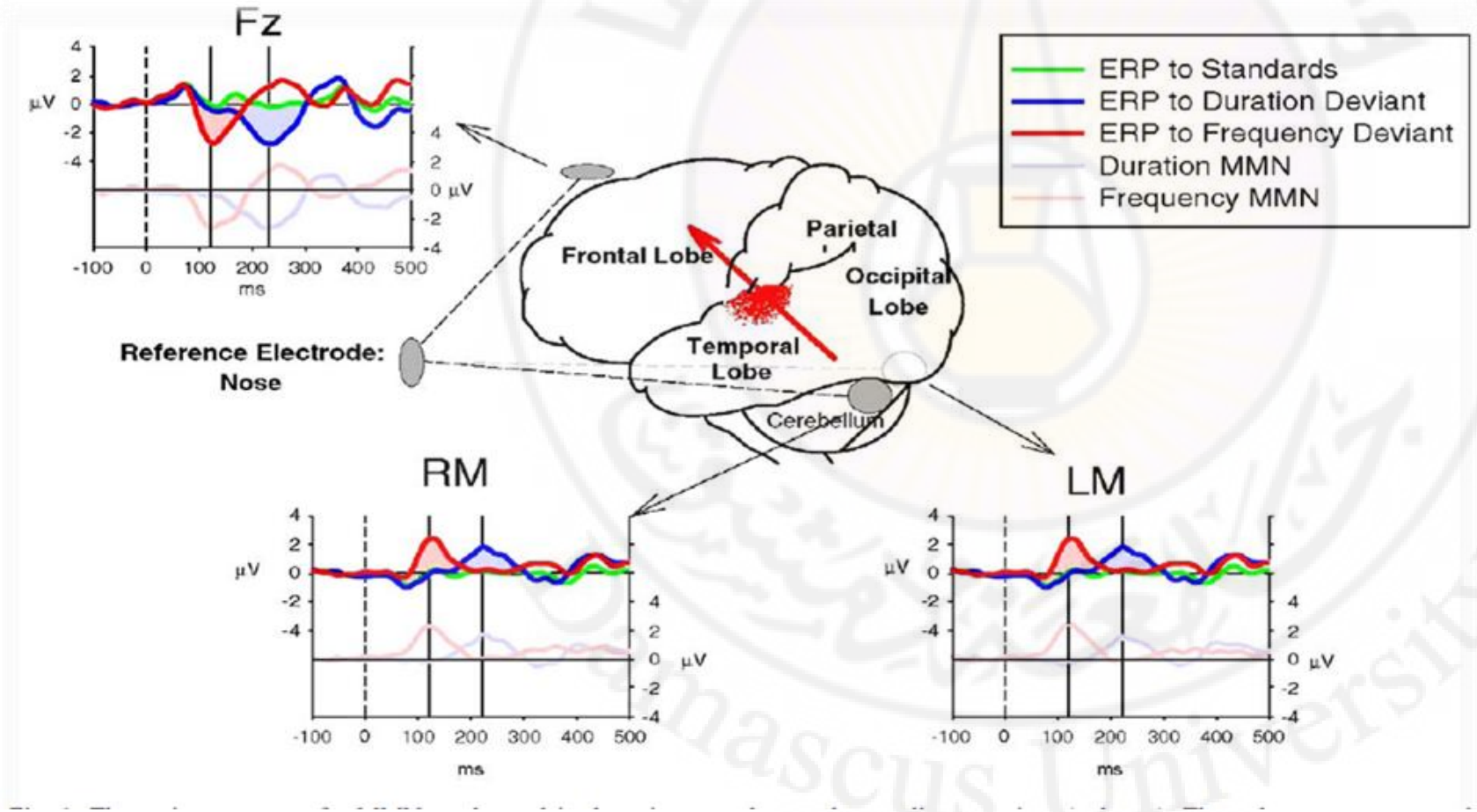
مقدار الاختلاف عن المنبه النموذجي اللازم حدوثه لتوليد MMN



- تفاوت التواتر في النغمة الصافية (استاندارد : 1000هرتز ، منحرف : 1100 هرتز)
- تفاوت الشدة بين المنبهين
- تفاوت المدة بين المنبهن
- وجود فجوة صامتة في منبه نغمة صافية او ضجيج
- اختلاف جهة أو منبع الصوت
- حذف احد المنبهات المتتالية (نمط ناقص)
- اختلاف النمط في تقديم المنبهات التكرارية (متصاعد أو نازل)
- ?????????
- تبدل الريتم
- تبدلات كلامية صغيرة مثل تبدل زمن بدء التصويت
- تبدل في المقاطع والكلمات غير ذات المعنى

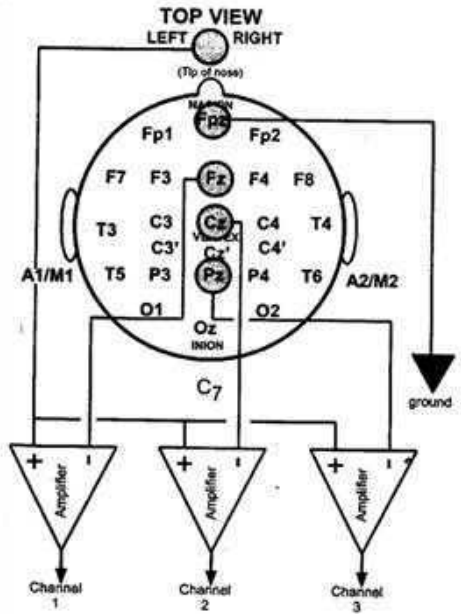
المنشأ التشريحي

- صدغي جبهي

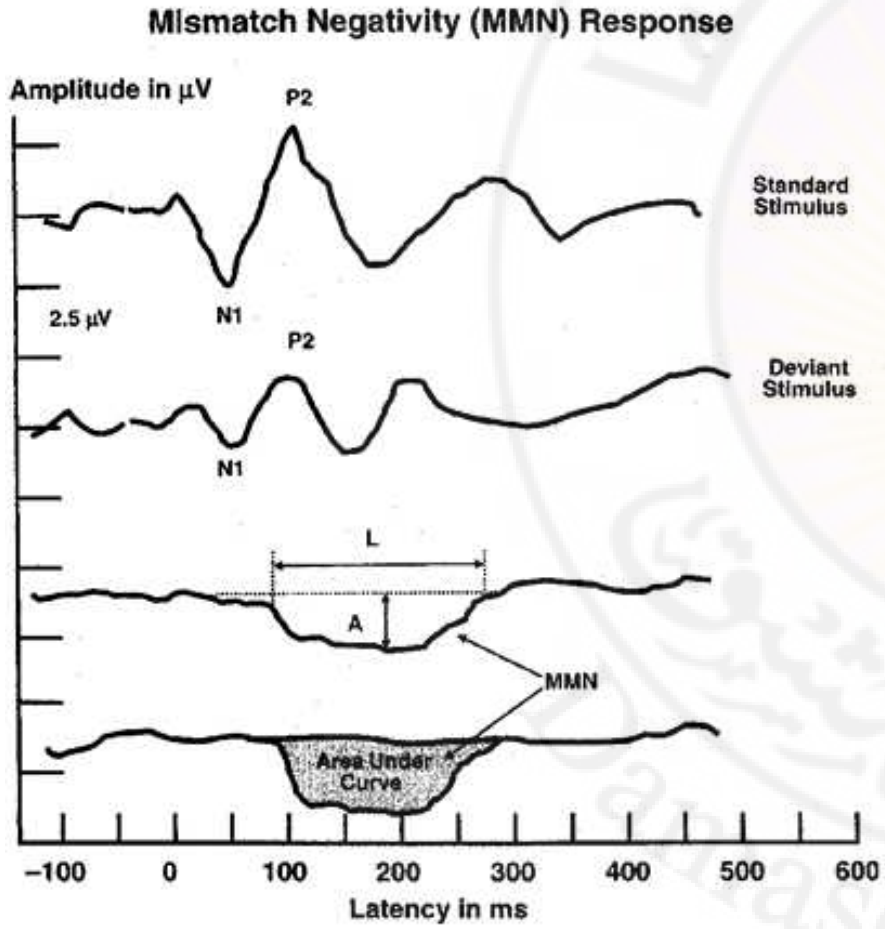


تسجيل ال MMN

- المنبه: نغمة صافية - نغمة مركبة – ضجيج – مقطع كلامي – موسيقى.
- النقطة الأهم هي طريقة توليد النمط من المنبه النموذجي بالتكرار مثلا تتالي زمني –تواتري – نغمة – او نمط يعطي للمنبه النموذجي تكراره ثم تقديم المنبه النادر أو المنحرف.
- نافذة التسجيل حتى 700 ميلي ثانية وسطيا (150 -400).
- توزيع الالكترودات: يعتمد على بروتوكول تسجيل تخطيط الدماغ ب 32 الكترود.
- الفلتر بين 0.1 إلى 30 هرتز لان الطيف التواتري للاستجابة يترواح بين 2-3 هرتز
- يمكن استخدام فلتر أضيق لرفع ال وتمييز ال عن ال .
- وجود نويز كهربائية يتطلب معدل دفعات كبير نسبيا ويمكن زيادة المنبه النموذجي ولكن يجب الحذر عند زيادة المنبه النادر كي لايتم التعود عليه وتقل ال .



تحليل وتفسير الاستجابة



- زمن الكمون: قليل الموثوقية ومتبدل بشدة كون الموج عريض وغير واضح الذروة.
- المطال: ويعتمد بشكل أساسي على تعيين الخط القاعدي.
- تسجيل المساحة تحت المنحني وقد يعتبر الحل الأكثر إنصافا لدراسة موثوقة لل [illegible]

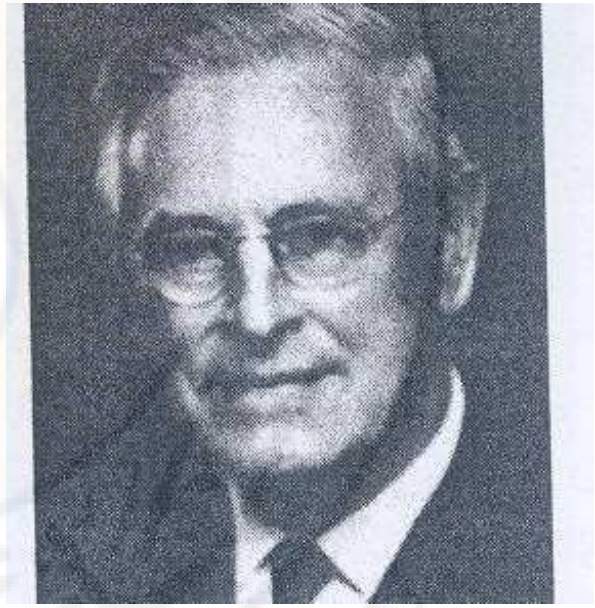
التطبيقات السريرية

- قليل الاستخدام سريريا ولازال اداة بحثية لتحري وظيفة القشر السمعي والذاكرة الحسية السمعية.
- يمكن استخدامه لتحري الفائدة على التدريب السمعي بعد استخدام السماعة أو زرع الحلزون.
- في نقص السمع تنقص السعة ويزداد زمن الكمون.
- يمكن استخدامه في دراسة اضطراب المعالجة السمعية المركزية.
- يمكن أن يستخدم لدراسة تأثير بعض الأدوية على القشر السمعي وبعض الاضطرابات القشرية كالزهايمر وغيرها.
- يمكن استخدامه كدليل على وجود المرونة العصبية [illegible].
- والأهم هو استخدامه لتشخيص اضطرابات كشف التغيير الذاتي في بعض الاضطرابات السمعية كاضطراب المعالجة والطنين وغيرها

P300 RESPONSE

History

- First identified by Davis, Sutton et al. 1965
- Primarily described the effects of stimulus alteration in normal subjects



P300 response

- Extended ALR time
  - Within 300 ms region
  - Third positive peak
- Oddball paradigm
  - Frequent (standard)
  - Rare (oddball, target)
    - A cognitive response

Damascus University

Generators

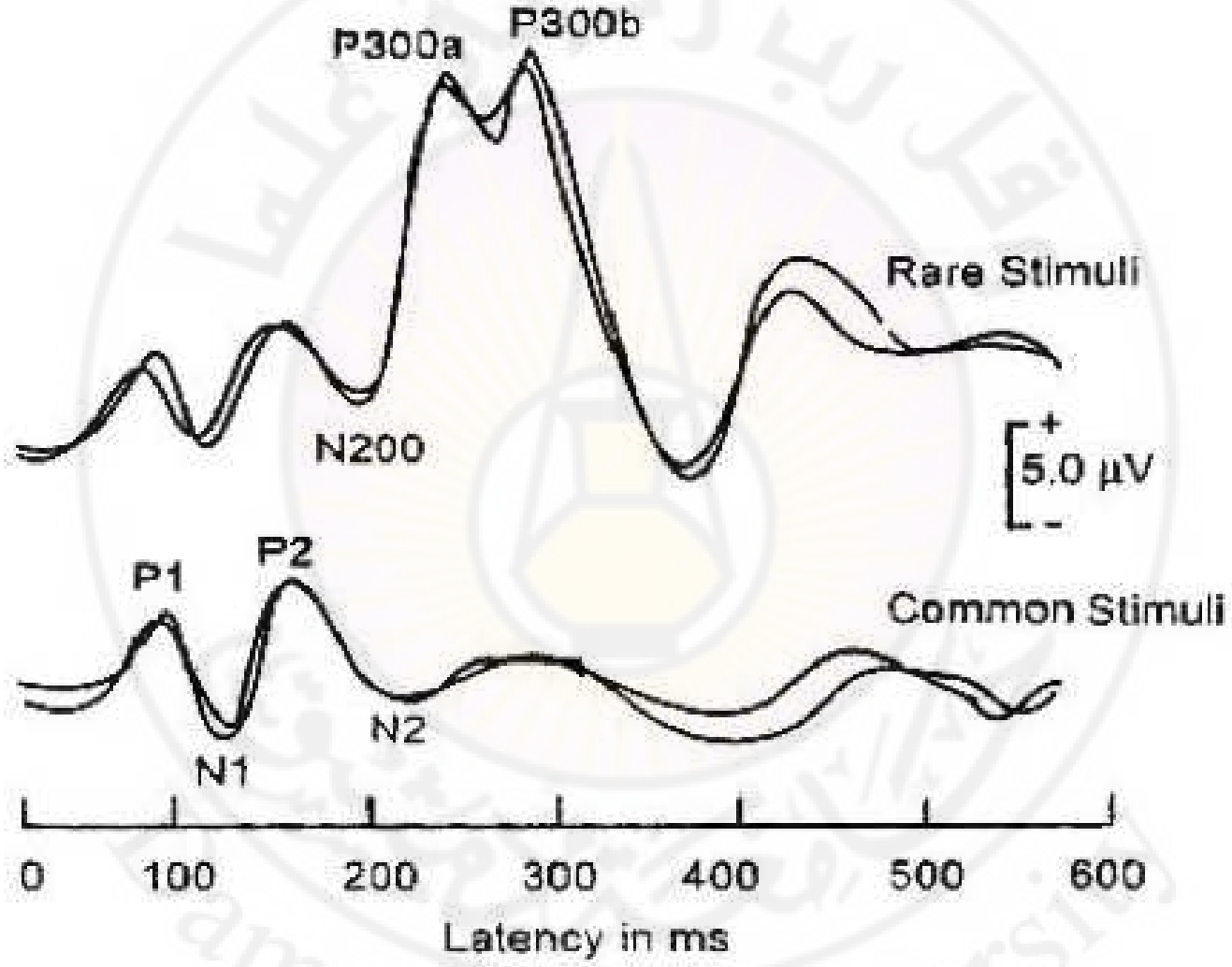
- Subcortical structures
  - Hypocampus
  - Lymbic system
  - Thalamus
- Cortical structures
  - Auditory regions
  - Frontal and Parietal lobe
- Visual and somatosensory stimulation

Oddball paradigm

- 1- **passive** (large deviance or distractor/ novel stimulus)
  - An automatic P3a
    - Smaller amplitude, shorter latency, faster habituation
    - Fronto- central location
    - An initial alerting response
    - دليل تحويل الانتباه للتغيير المنتظر حدوثه

Oddball paradigm

- 2- **active**: P3b
  - P3b
    - An conscious processing
    - Memory and more attention cooperation
    - Max amplitude in parietal region
    - Post decision evaluation
    - يطلب من المريض تنفيذ تاسك معين كعد منبه الهدف او كبس زر عند سماعه وغيرها
    - تدل على حدوث الانتباه والاستجابة الصحيحة للمنبه المطلوب



ش. ۱۰/۹ اجزاء موج P_{300}

Analysis time

- Similar to ALR
- 450 to 500 ms
- Low F energy (< 30-40 Hz)

Electrode location

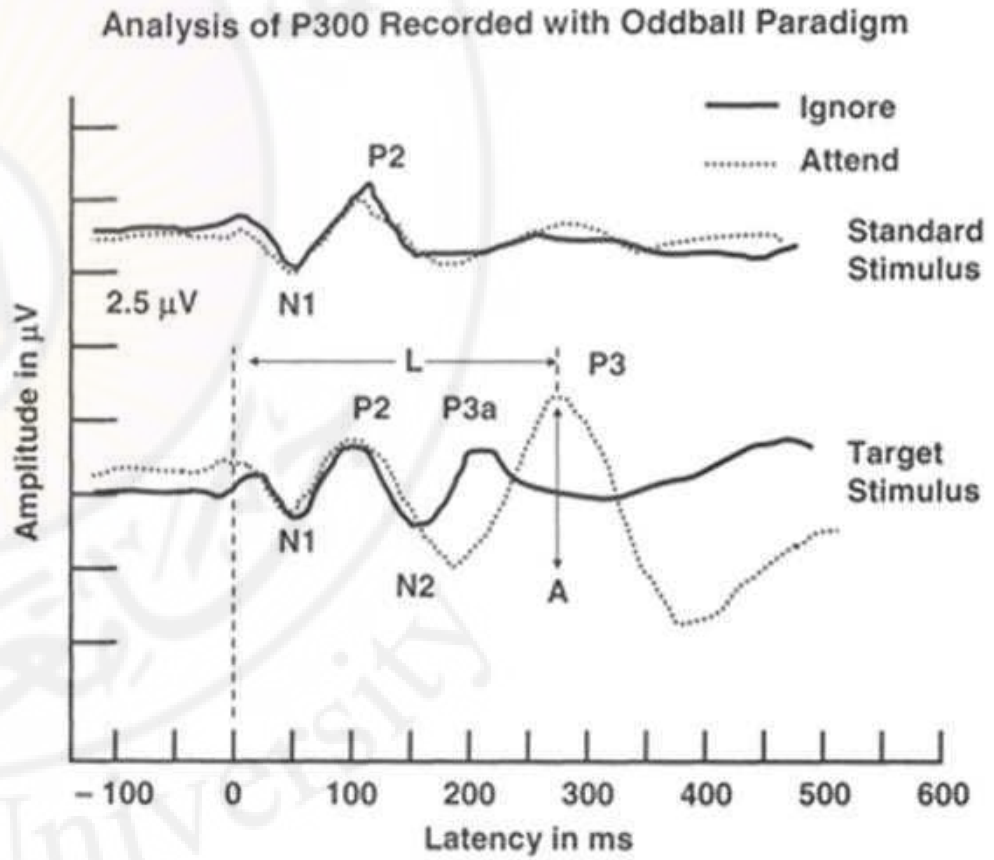
- Noninverting
  - Midline frontal; Fz, Cz, Pz
- Inverting
  - Linked or ipsilateral lobule or mastoid
- Ground
  - Frontal
- Electrodes for ocular activity detection
  - Vertical: Sub- and supra-orbital
  - Horizontal: outer canthus
  - Activities larger than 100-200mv will be rejected.

Filter setting

- 0.01-0.25 to 30-50 Hz
- Spectral power of late responses: 1-15Hz, mainly under 8Hz, max at 5Hz.

Wave Analysis

- Latency:
  - From stimulus onset to peak
  - 250-400; or 800 for special patients
  - Latency interpretation: Processing speed (difficulty, short-term memory demands)
- Amplitude:
  - The highest point: 10-20 µv
  - Reference: Previous trough (N2), baseline



Abnormal patterns
considerations

- Sudden loss of attention
- Age
- CNS abnormalities, such as, Dementia

Later Language-related Waves

المعالجة القشرية للغة

- تتم المعالجة القشرية للغة في ثلاث مستويات أساسية :
  - المعنى
  - الفونولوجيا
  - النحو
- وظيفة هذه الأمواج التأكد من كفاءة المراكز الدماغية العصبية في القيام بهذه المعالجات بالشكل الصحيح.
- يتم تسجيل هذه الاستجابات باستخدام منبهات كلامية وتمتاز بانها متأخرة جدا تصل لحدود 800 ميلي ثانية احيانا.
- تولد هذه الأمواج بنتيجة عدم التطابق بين المنبه الذي يتم معالجته وبين النماذج اللغوية المخزنة بالدماغ كالتالي:
  - عدم تطابق المعنى :
  - عدم تطابق نحوي : ، ،

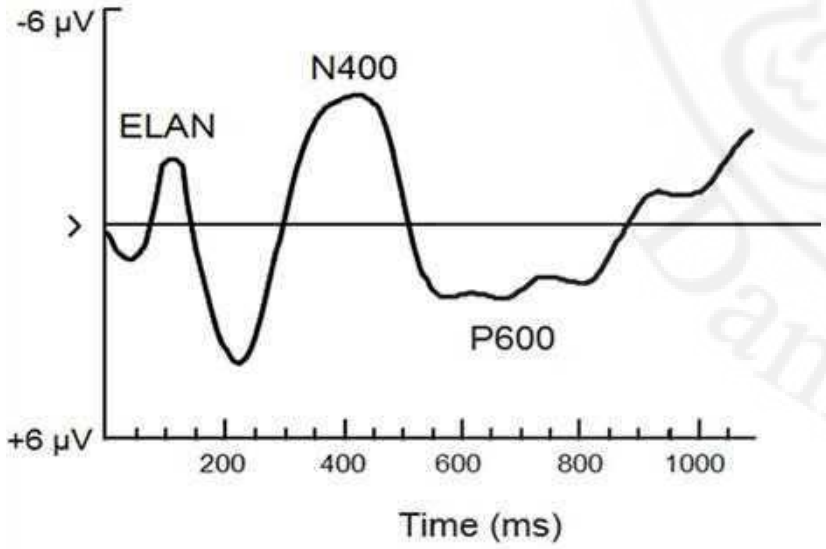
الكمونات القشرية اللغوية

الكمونات اللغوية	زمن الكمون	قطبية الموجة	نمط المعالجة
ELAN	100 - 300 ميلي ثانيه	سلبية	نحوي
LAN	300 - 500 ميلي ثانيه	سلبية	نحوي
N400	400 ميلي ثانيه	سلبية	معنى وفونولوجيا
P600	600 ميلي ثانيه	إيجابية	نحوي

Early Left Anterior Negativity
ELAN

- ❑ [illegible] له علاقة بمعرفة محل الكلمة من الإعراب: اسم، فعل، حر جر وغيرها.
- ❑ يظهر عند زمن كمون بين 120 و 200 ميلى ثانيه بعد تقديم المنبه (الكلمة)
- ❑ يتم توليده في القشر الجبهي الأمامي.
- ❑ [illegible] حساس لتغييرات [illegible] و [illegible]
- ❑ مثال:

[illegible]

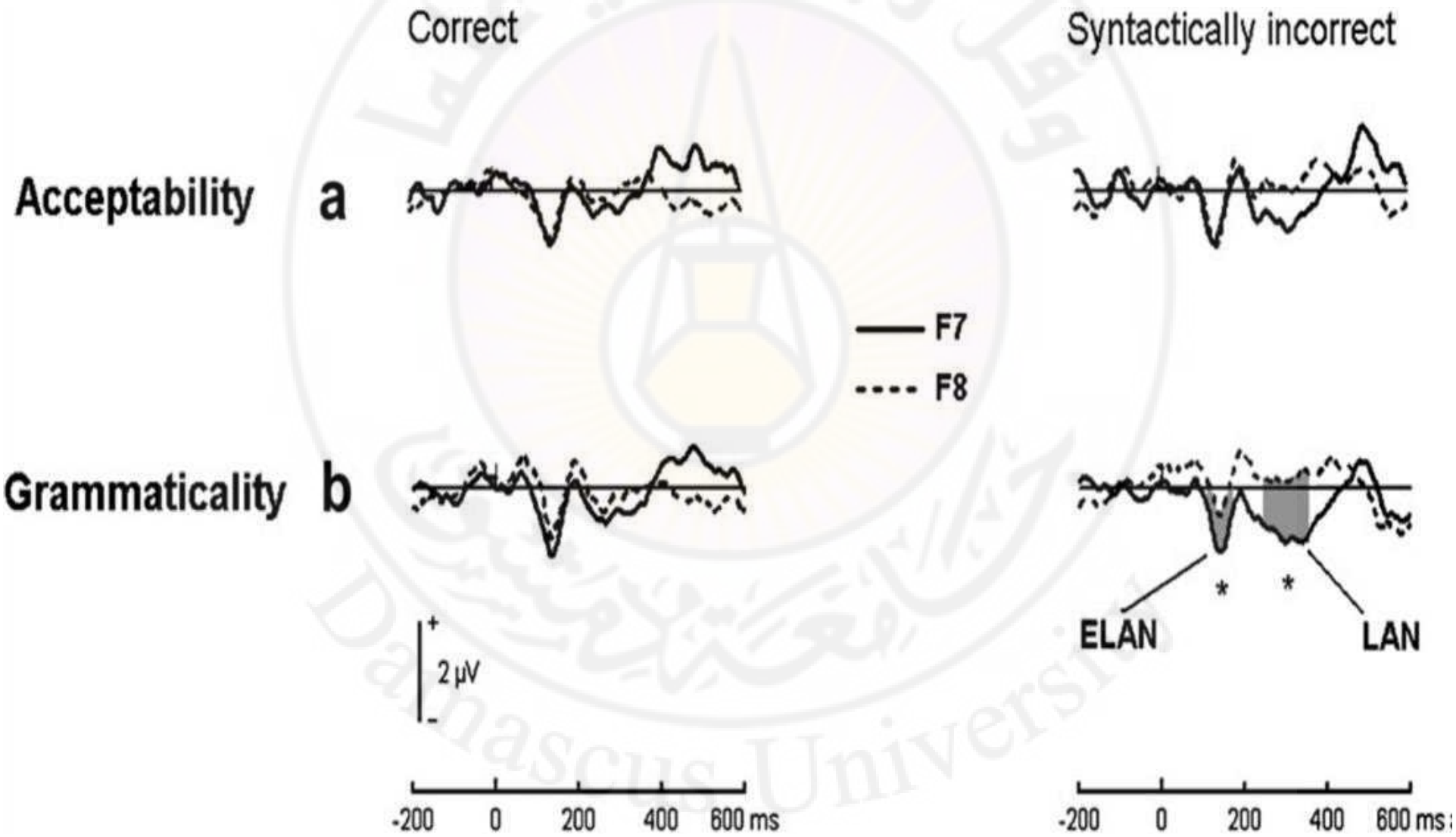


Left Anterior Negativity
LAN

- هو عبارة عن موجة سلبية تختص بمعالجة النحو عند زمن كمون 300-500 ميلى ثانيه.
- يمثل المراحل الأولى لمعالجة النحو في المراكز الدماغية.
- ينجم عن عدم التطابق بين النماذج الشكلية للنحو مثل:

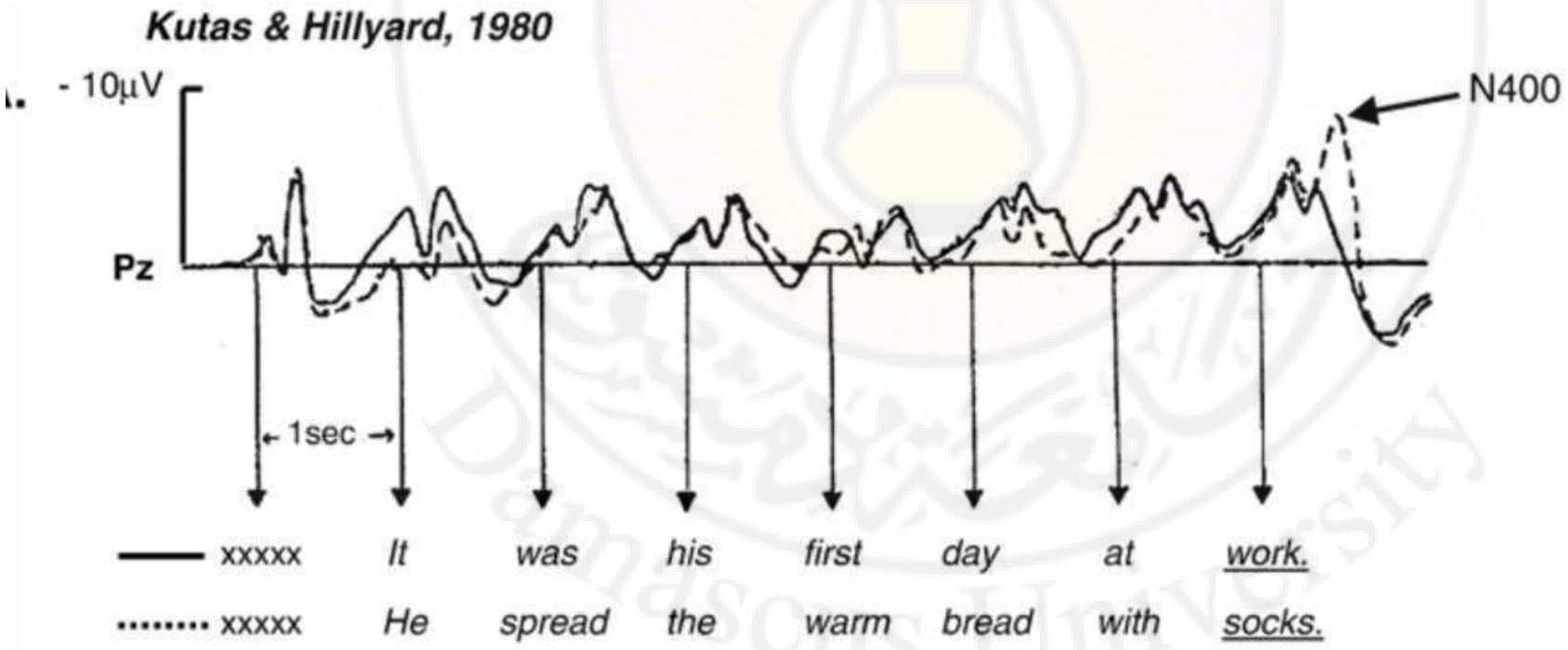
- هو استجابة سمعية بالدرجة الأولى.

Late Language Related Waves



Lexico-semantic integration:N400

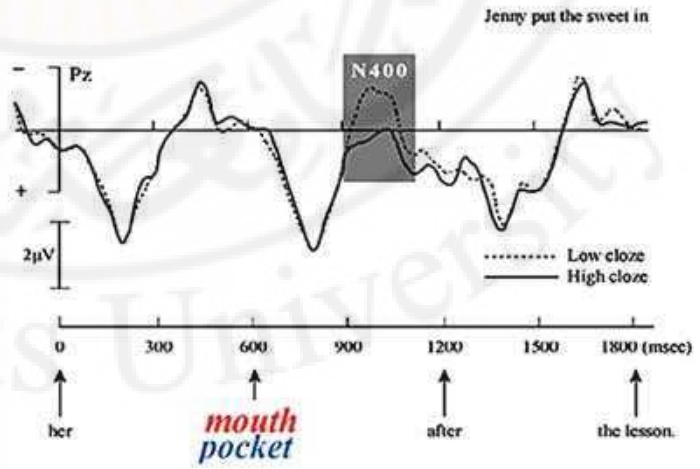
- كل كلمة في الجملة المحكية تولد موجة كدليل على إدراك المعنى ولكن عندما يحدث خلل في المعنى او عدم تطابق بين المعنى المنتظر والكلمة المسموعة يحدث ازدياد ملحوظ في مطال الموجة .
- المولد الأساسي لها هو الفص الصدغي الأيسر.



N400

- N400 عبارة عن موجة سلبية لها ذروة تقع في زمن كمون حوالي 400 ms بعد تقديم الكلمة ولكن قد تمتد ضمن المسافة 250-500ميلى ثانية.
- N400 هي عبارة عن تعبير للنشاط الدماغي الطبيعي فيما يخص معاني الكلام والمنبهات المختلفة.
- وبالتالي يمكن أن يستخدم لتوليدها العديد من المنبهات كالكلمات المنطوقة والمكتوبة، لغة الإشارة، رموز وصور وحتى ايماءات بالوجه كالابتسامة وغيرها.
- مطال هذه الموجة يصل حتى (ميلي فولط ويتم قياسه بشكل نسبي عادة لاستجابة طبيعية.

N400 عبارة عن موجة سلبية لها ذروة تقع في زمن كمون حوالي 400 ms بعد تقديم الكلمة

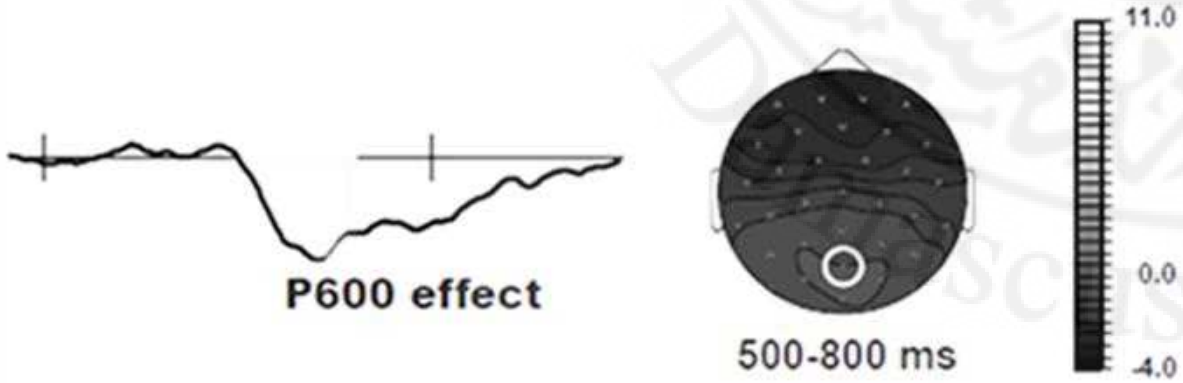


after the lesson
Jenny put the sweet in her mouth

after the lesson
Jenny put the sweet in her pocket

Syntactic positive shift: P600

- [illegible] هي عبارة عن انزياح بشكل موجة موجبة تنتج عن عدم التطابق النحوي سواء بالكلام اللفظي أو المرئي.
- يبدأ تشكلها عند حدود 500 [illegible] بعد تقديم المنبه لتبلغ ذروتها عند ال 600 [illegible] ومنها اشتقت تسميتها.
- تعتبر المراكز الجبهية مسؤولة عن توليدها ولذا أفضل توضع الكترودي هو الالكترودات المركزية.
- جميع الاخطاء النحوية تساهم في توليد الموجة كعدم التطابق بين العدد والمعدود والصفة والموصوف وزمن الفعل مع الظرف وغيرها ولكن يعتبر عدم مطابقة الفعل والفاعل المنبه الأفضل لتوليد أكبر مطال للموجة.



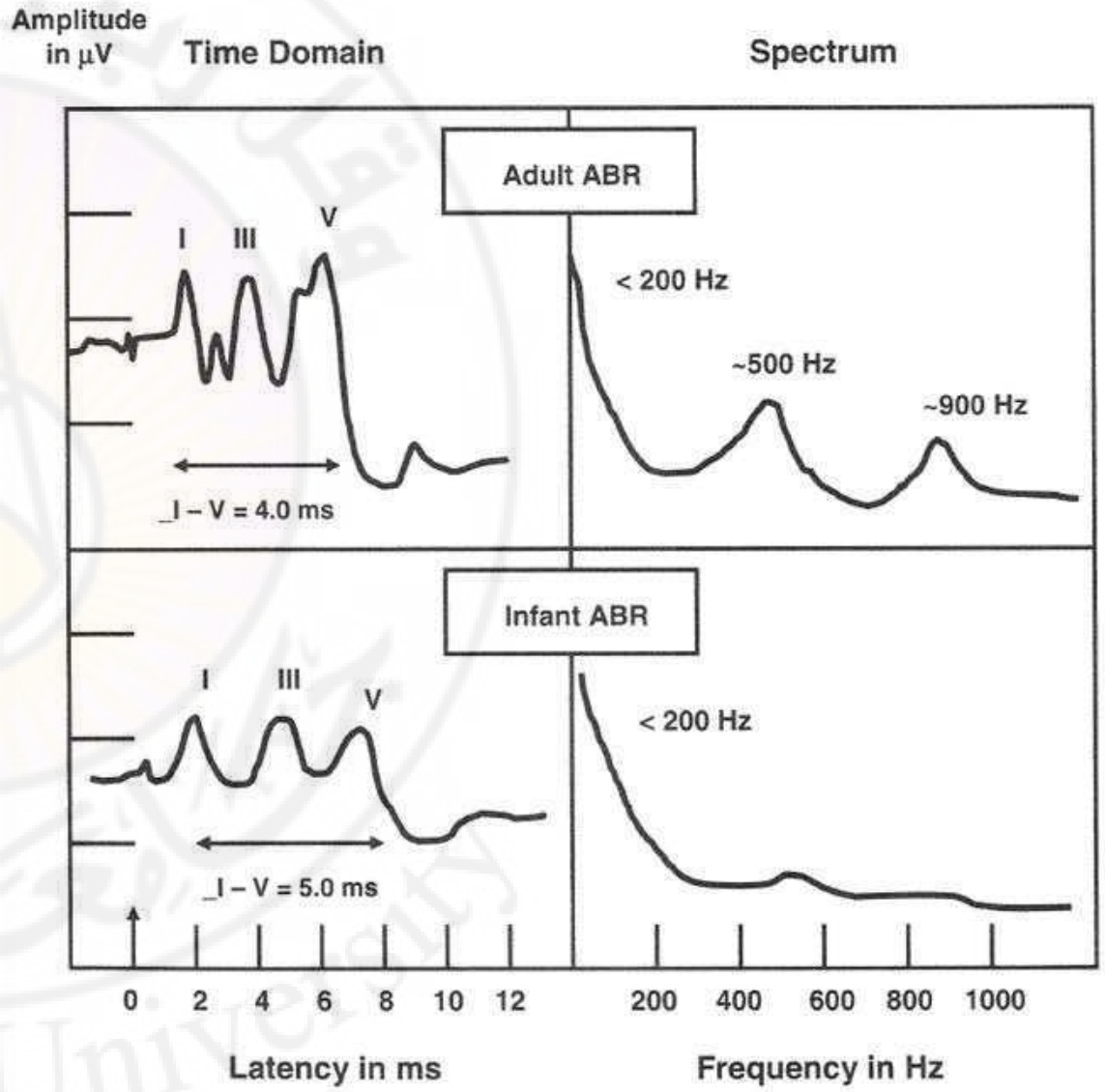
أي سؤال؟؟

7. Auditory Brainstem Response: Analysis Techniques

Plotting ABR

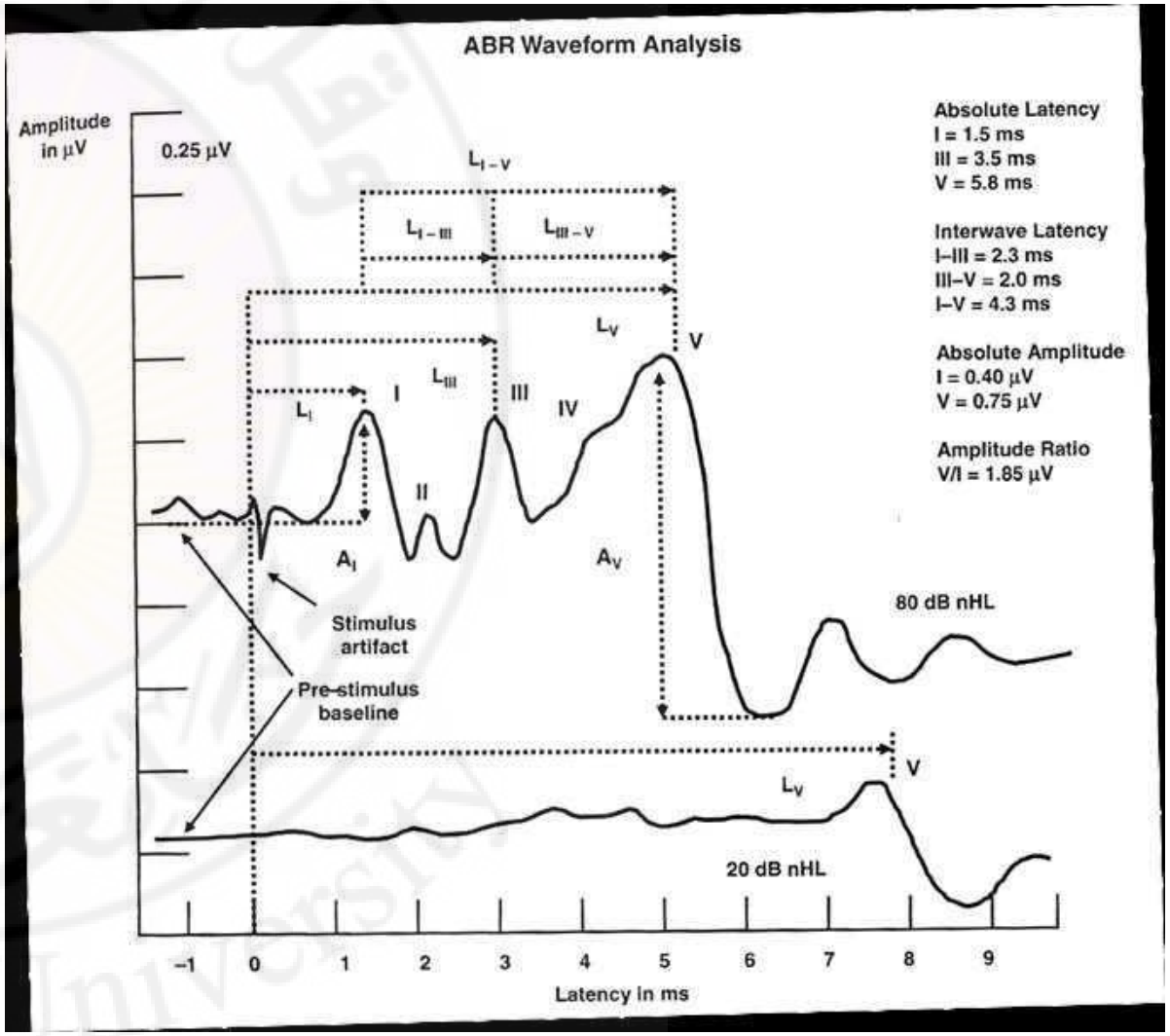
- **Time domain:** with amplitude of the ABR waveform in µvolt displayed over time in milliseconds.

- **Frequency domain:** with amplitude expressed in µvolts or phase expressed in radians or degrees displayed as a function of frequency in Hz.



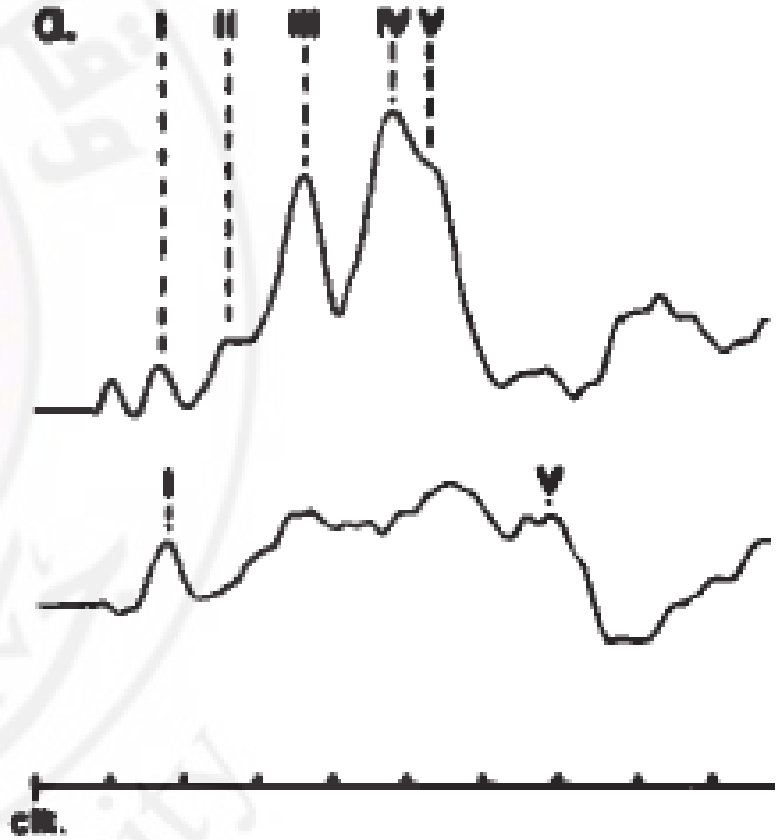
ABR Analysis parameters

- **Morphology**
- **Latency measures**
  - Absolute Latency
  - Inter-peak Latency
  - Latency-Intensity Function (LIF)
  - Interaural Wave V Latency Difference
  - Shift in Wave V Latency at High Stimulus Rates
- **Amplitude measures**
  - Absolute Amplitudes
  - Wave V/I Amplitude Ratio
- **Reproducibility**
- **Absent Waveform Components**



ABR Morphology

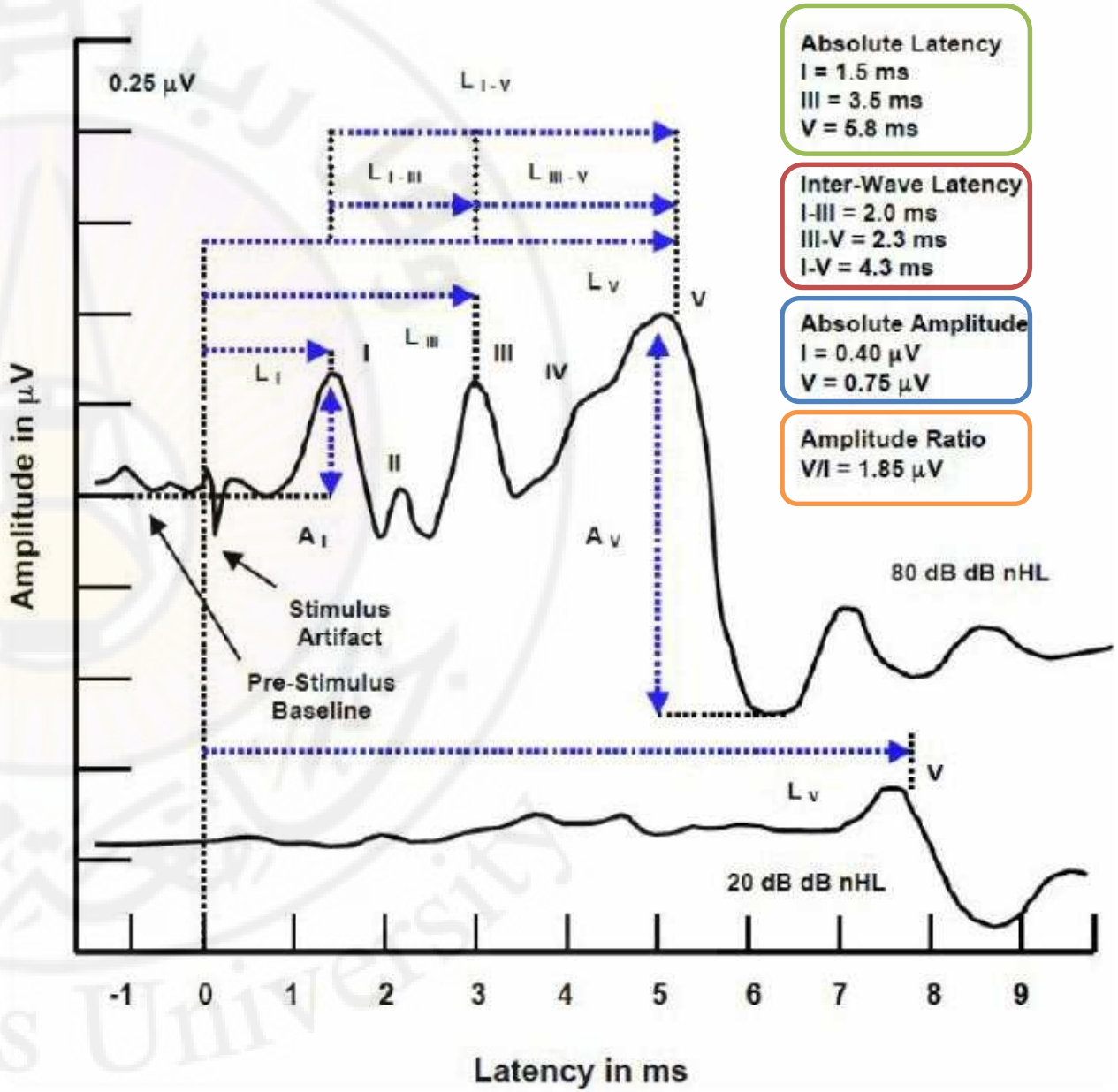
- ABR morphology is the general pattern, shape, or appearance of the waveform.
- Usually, morphology is described with reference to an expected normal appearance for a particular auditory evoked response.
- Morphology is often judged **"poor"** if an ABR waveform does not fit a clinician's expectation of normal appearance or if two ABR waveforms recorded in sequence appear different, even though latency and amplitude values of the major waves are within normal limits.
- Morphology is a rather subjective analysis parameter.



Damascus University

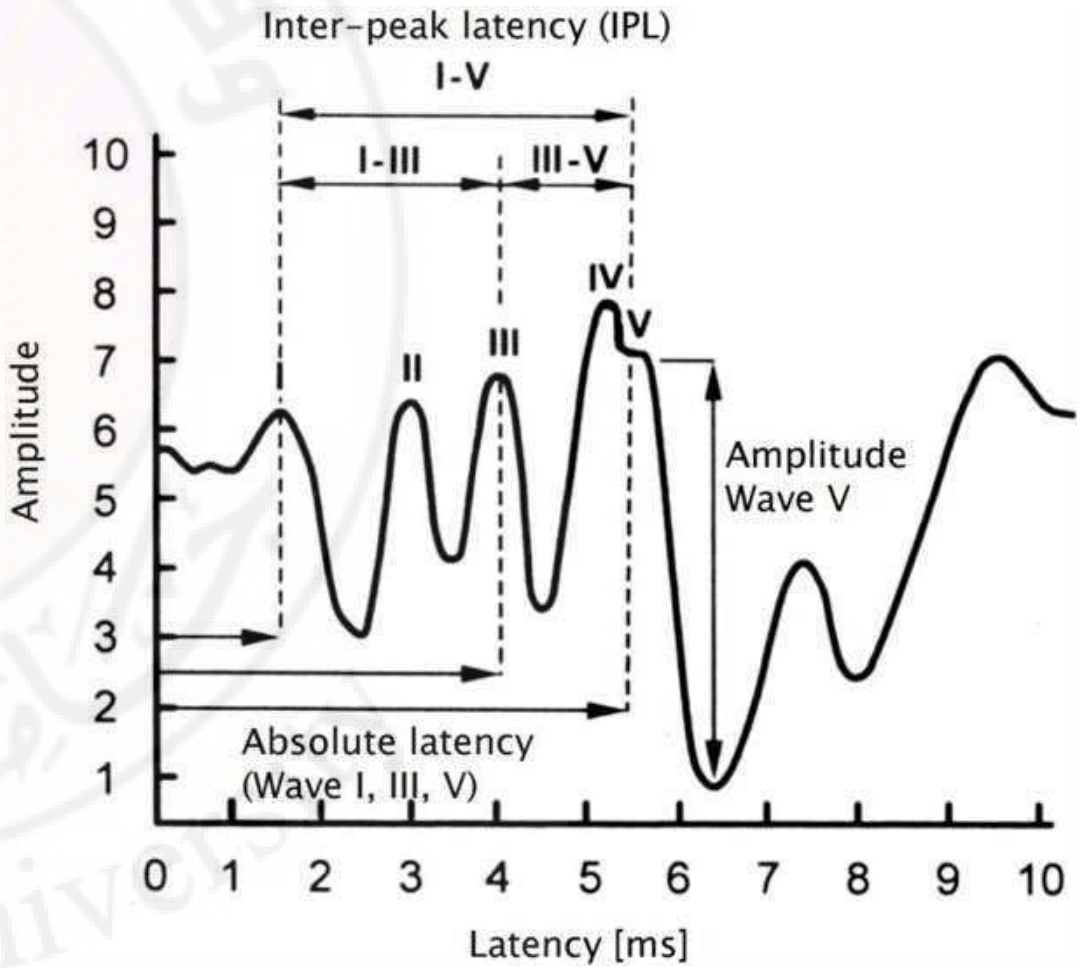
Latency Analysis

- **Absolute Latency** is the time interval between stimulus presentation, specifically the onset of a stimulus, and a positive peak in the ABR waveform, described in milliseconds (ms).
- Audiologists often calculate ABR wave V latency and amplitude from the shoulder following the peak and just preceding the subsequent trough.
- **Inter-wave latencies** are relative measures calculated as the time between two different ABR waves.



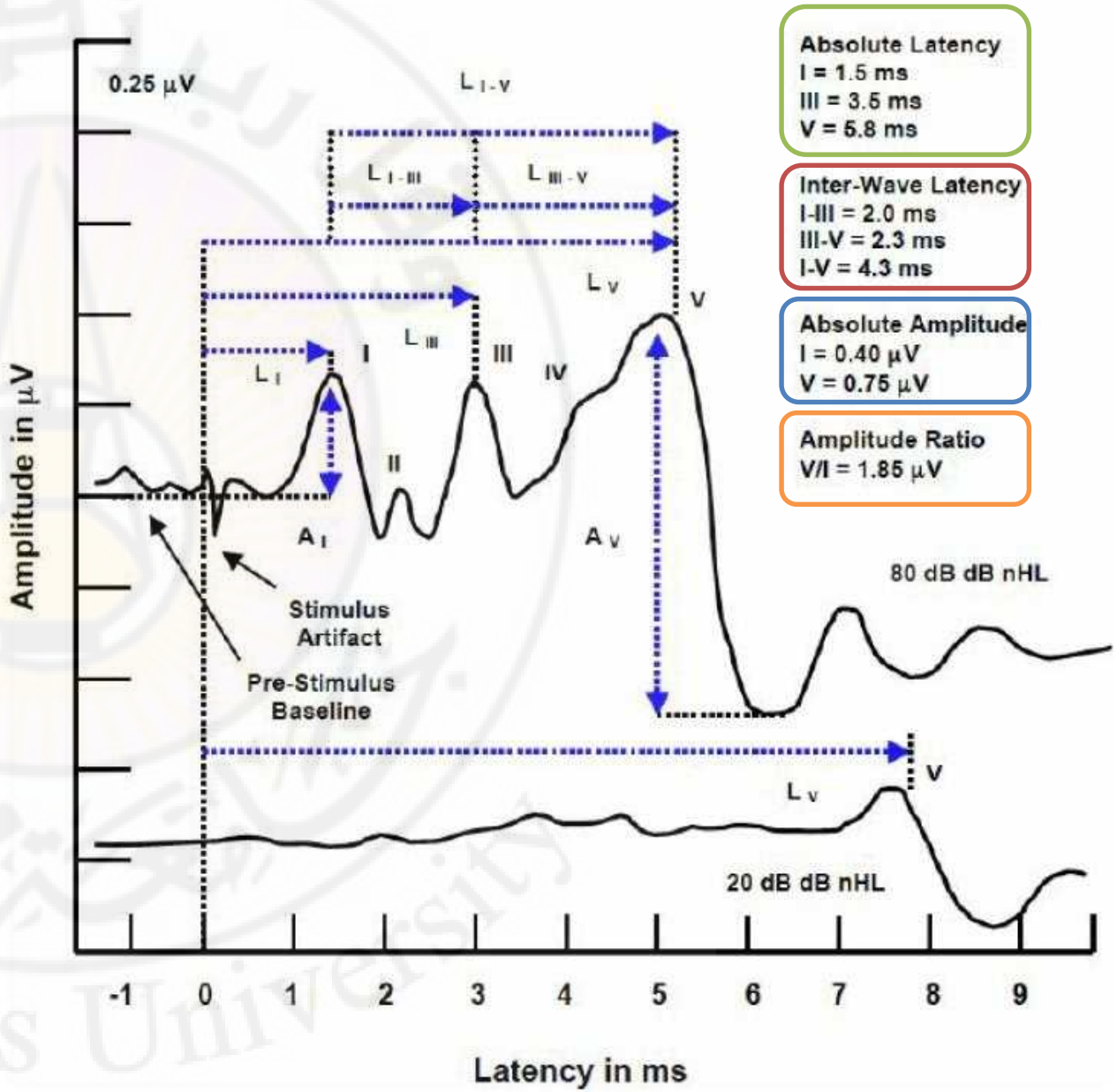
The Wave I to V Latency Interval

- Inter-wave latencies are often referred to as an index of **"brainstem transmission time " or "central conduction time".**
- Inter-wave latencies may also be described as inter-peak latencies, abbreviated **IPLs.**
- Factors influencing the wave I-V latency interval are related to stimulus and acquisition parameters and to peripheral and central auditory dysfunction. For accurate interpretation of ABR inter-wave latency data in neuro-diagnostic assessment, it is very important to consider such factors.



Amplitude Analysis

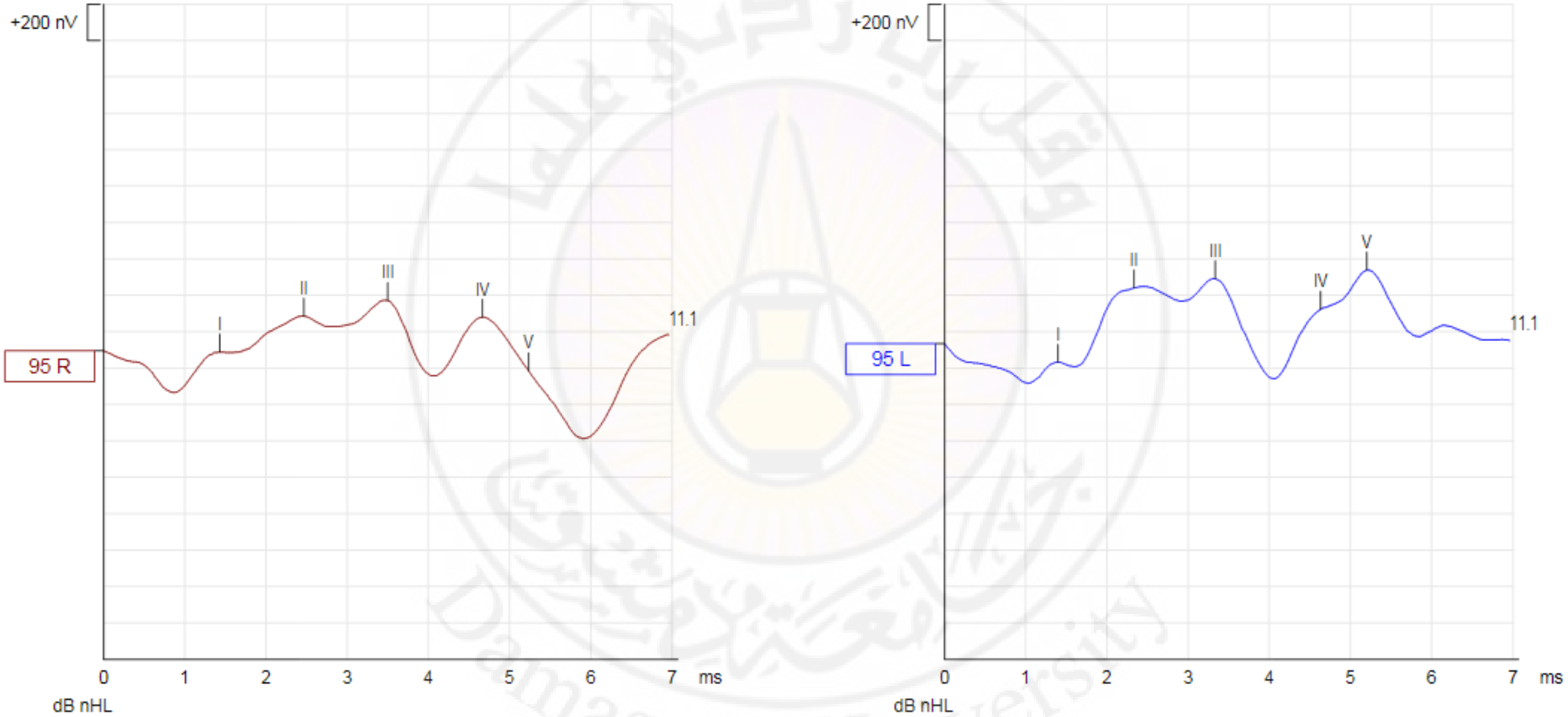
- **Amplitude** is described in µvolts, and different techniques are used for calculating amplitude for ABR waves:
- **Wave I and wave III**: Measurement of the voltage difference between the peak and the preceding trough the peak of a wave.
- **Wave V**: Calculation of the peak and following trough.
- The most commonly calculated *relative amplitude measure* in ABR analysis is the **wave V to wave I ratio**. Normally the value is at least 1.0 or considerably larger.



Normal Variations

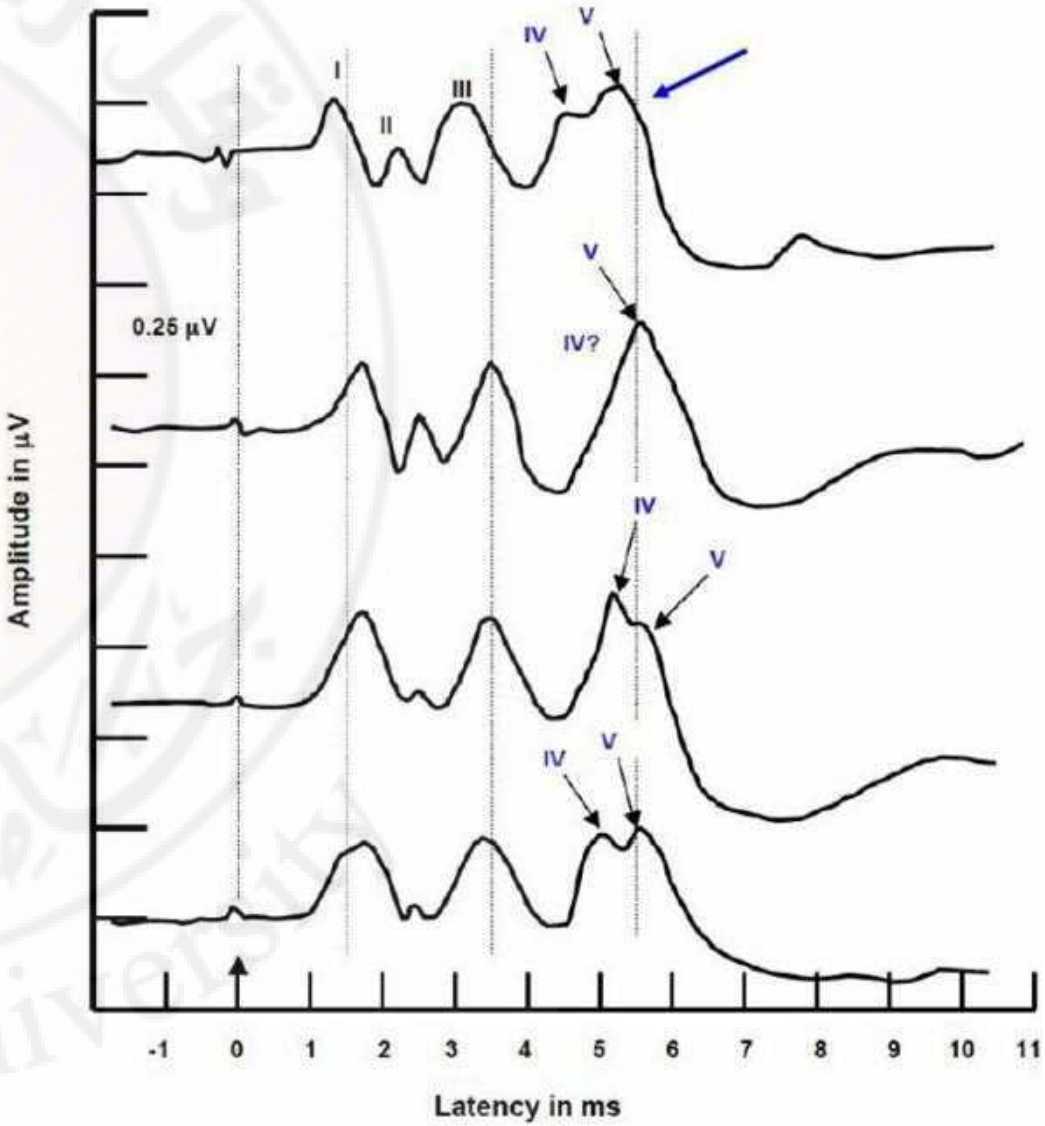
- ABR waveforms **among individuals** are quite distinctive, much like **fingerprints**. Identical ABR waveforms are rarely recorded from any two persons.
- There are even differences in ABR waveforms for stimulation of the **right versus left ears** for some entirely normal hearing persons.
- ABR waveforms in **multiple birth infants**, including twins, triplets, quadruplets, may even have distinctly unique waveforms under the same recording conditions.
- Subtle differences in waveforms among patients are not important clinically.




+200 nV
95 R
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
ms
dB nHL
+200 nV
95 L
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
ms
dB nHL

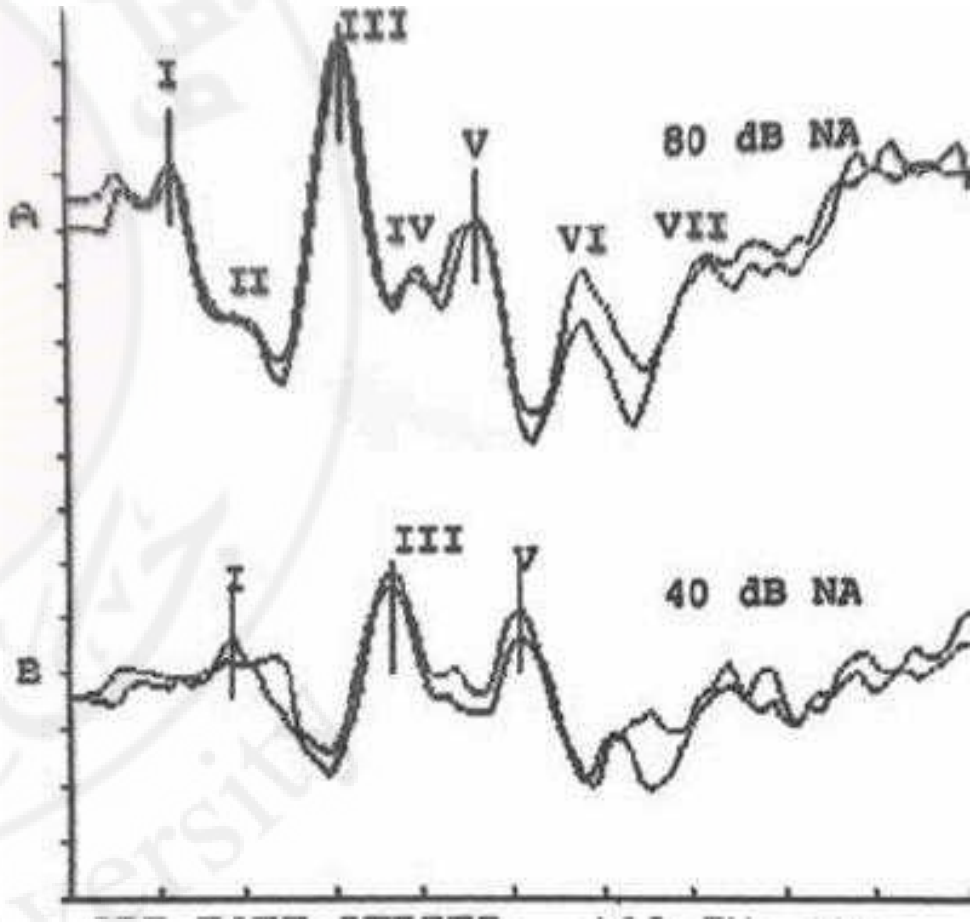
ABR Peak Picking

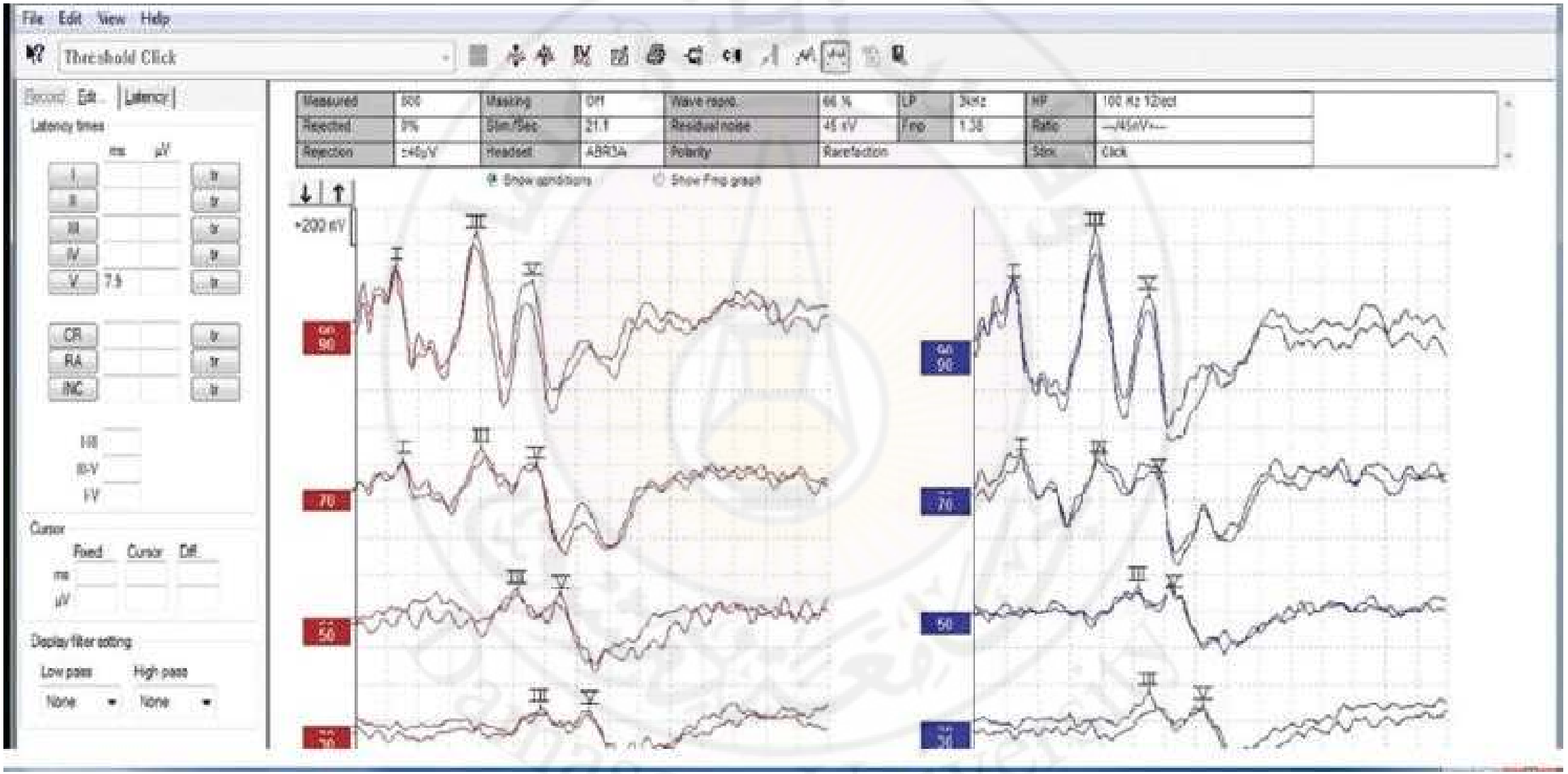
- There are two fundamental approaches for identification of ABR waves.
- In waveforms with sharply peaked components, you can select the peak at the point on the wave component that produces the greatest amplitude.
- The second fundamental "peak picking" approach is to select the final data point on the waveform before the sharply negative slope that follows the wave **(shoulder picking).** This point may be the final peak or it may be a plateau or shoulder in the downward slope.
- Optimizing waveform morphology and repeatability during ABR recording with modification of the test protocol as needed is very effective for minimizing confusion in ABR analysis.

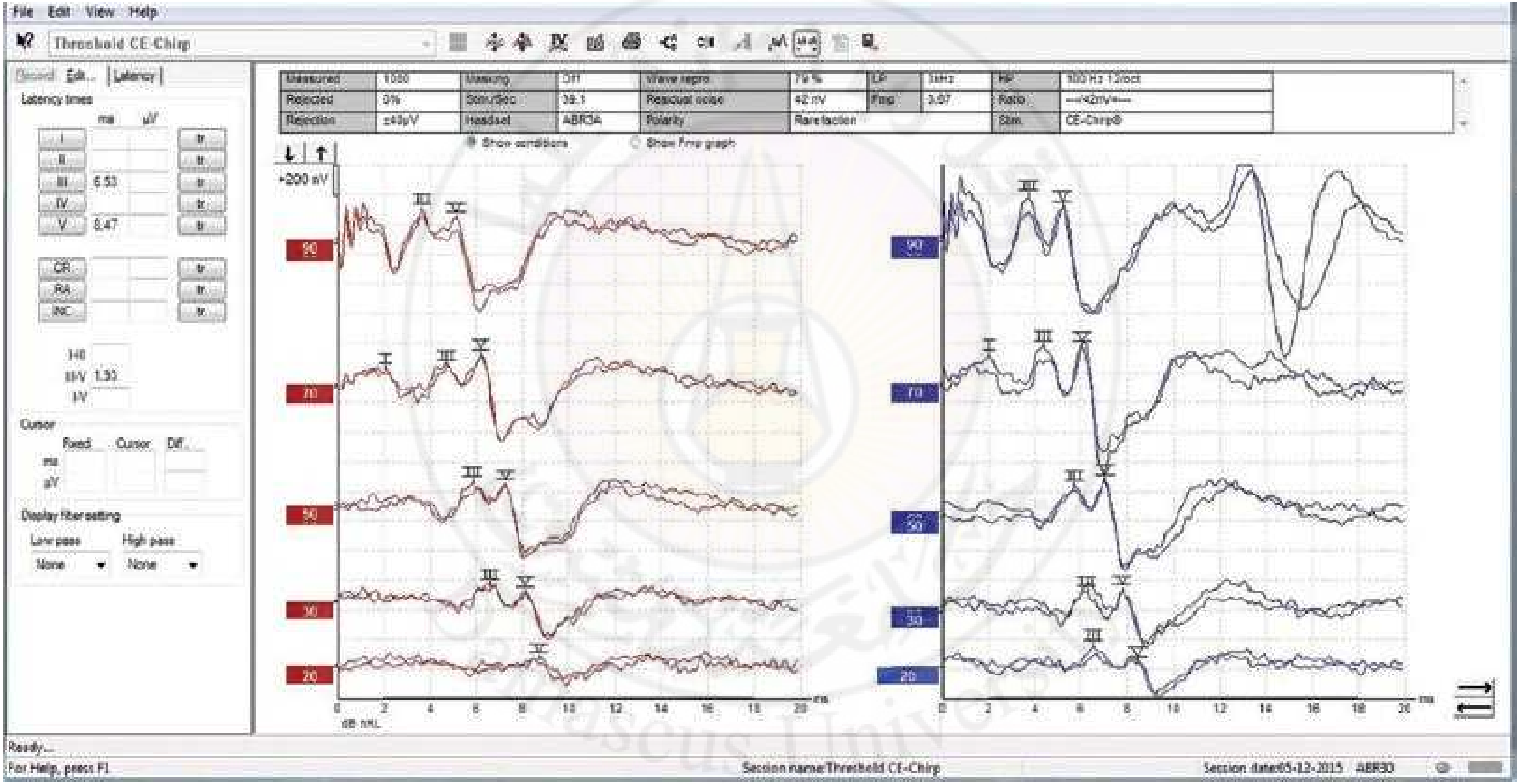


Response Reliability or Repeatability

- **Repeatability** of at least two ABR waveforms recorded in succession under the same measurement conditions is a typical prerequisite for waveform analysis.
- In fact, an ABR is not really an ABR unless it is repeatable for at least two recordings under the same test condition.
- Ideally, the two waveforms are almost indistinguishable, except for slight differences in background activity or noise.
- No single factor contributes more to confidence and accuracy in ABR analysis than waveform repeatability. Every effort should be made to manipulate measurement conditions to enhance repeatability of ABR waveforms

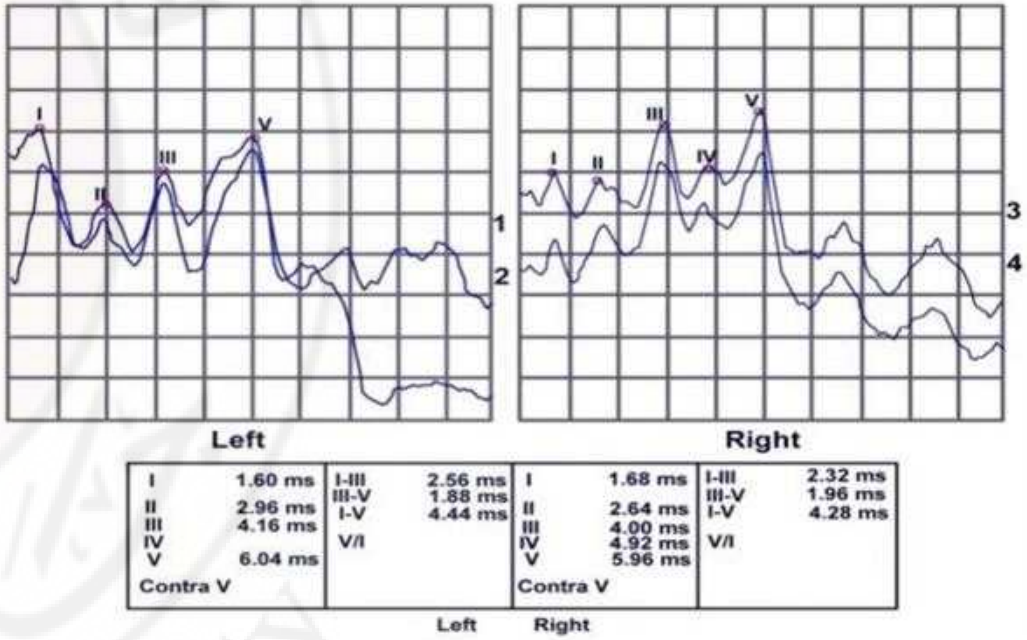



File Edit View Help
Threshold Click
Record Edit Latency
Latency times
ms µV
I
II
III
IV
V
7.5
CR
RA
INC
I-III
III-V
I-V
Cursor
Fixed Cursor Diff.
ms
µV
Display filter setting
Low pass
High pass
None
None
Measured 800 Masking Off Wave reject 66 % LP 3kHz HP 100 Hz 12dB/oct
Rejected 9% Stim/Sec 21.1 Residual noise 45 nV Freq 1.38 Ratio —/45nV—
Rejection ±45µV Headset ABR3A Polarity Rarefaction Stim Click
Show sonations
Show Freq graph
+200 nV
90
70
50
30
90
70
50
30


File Edit View Help
Threshold CE-Chirp
Record Edit... Latency
Latency times
ms µV
I
II
III 6.53
IV
V 8.47
CR
RA
RNC
I/III 1.33
III/V
I/V
Cursor
Fixed Cursor Diff.
ms
µV
Display filter setting
Low pass
High pass
None
None
Measured 1000 Missing Off Wave repro 79 % LP 1kHz HP 100 Hz 12/oct
Rejected 0% Stim/Sec 39.1 Residual noise 42 nV Freq 3.67 Ratio ---/+42nV/---
Rejection ±45µV Headset ABR3A Polarity Rarefaction Stim CE-Chirp®
Show conditions
Show Free graph
+200 nV
90
70
50
30
20
dB nHL
ms
Ready...
For Help, press F1
Session name:Threshold CE-Chirp
Session date:05-12-2015 ABR30

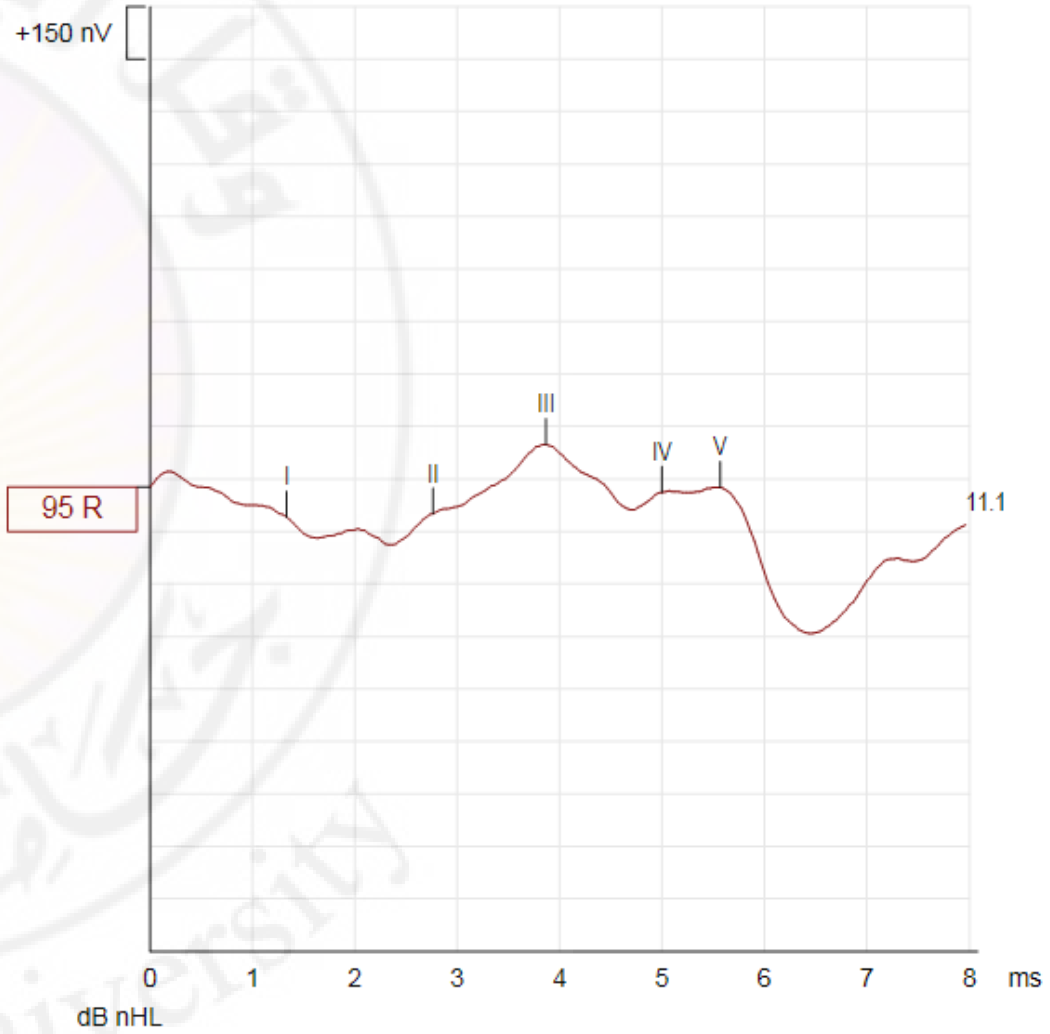
Extra Peaks

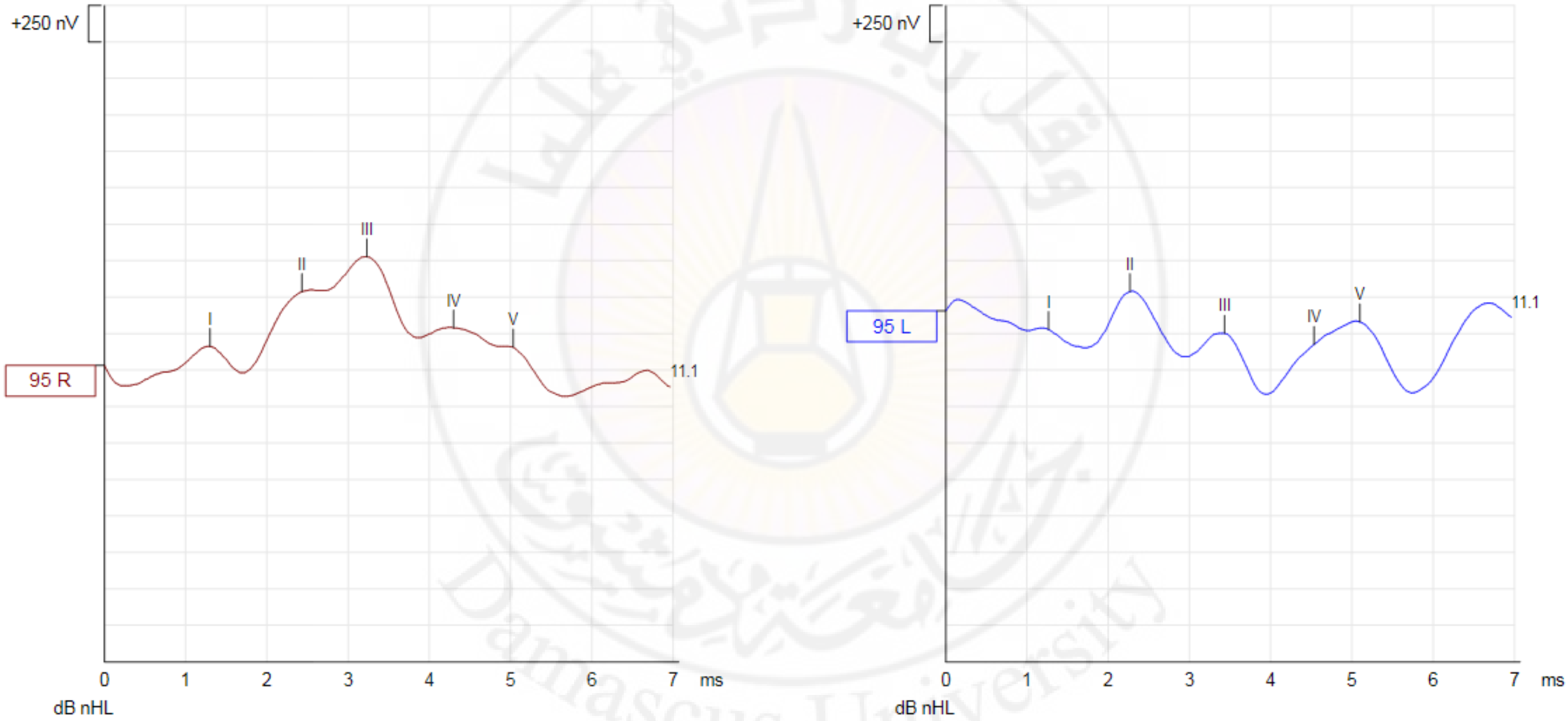
- A normal variant in auditory evoked response morphology is when multiple smaller peaks are reliably recorded along with major components in an ABR waveform; and are most prominent in ABRs recorded from **newborn infants.**
  - **A bifid wave I**
  - **Fusion of waves IV-V**
  - **Combination of a diminished wave V plus prominent wave VI**
  - **Multiply peaked wave V components**
- Sometimes, changing the electrode sites, filter setting, stimulus polarity, and other modifications in test parameters can help to overcome these issues.

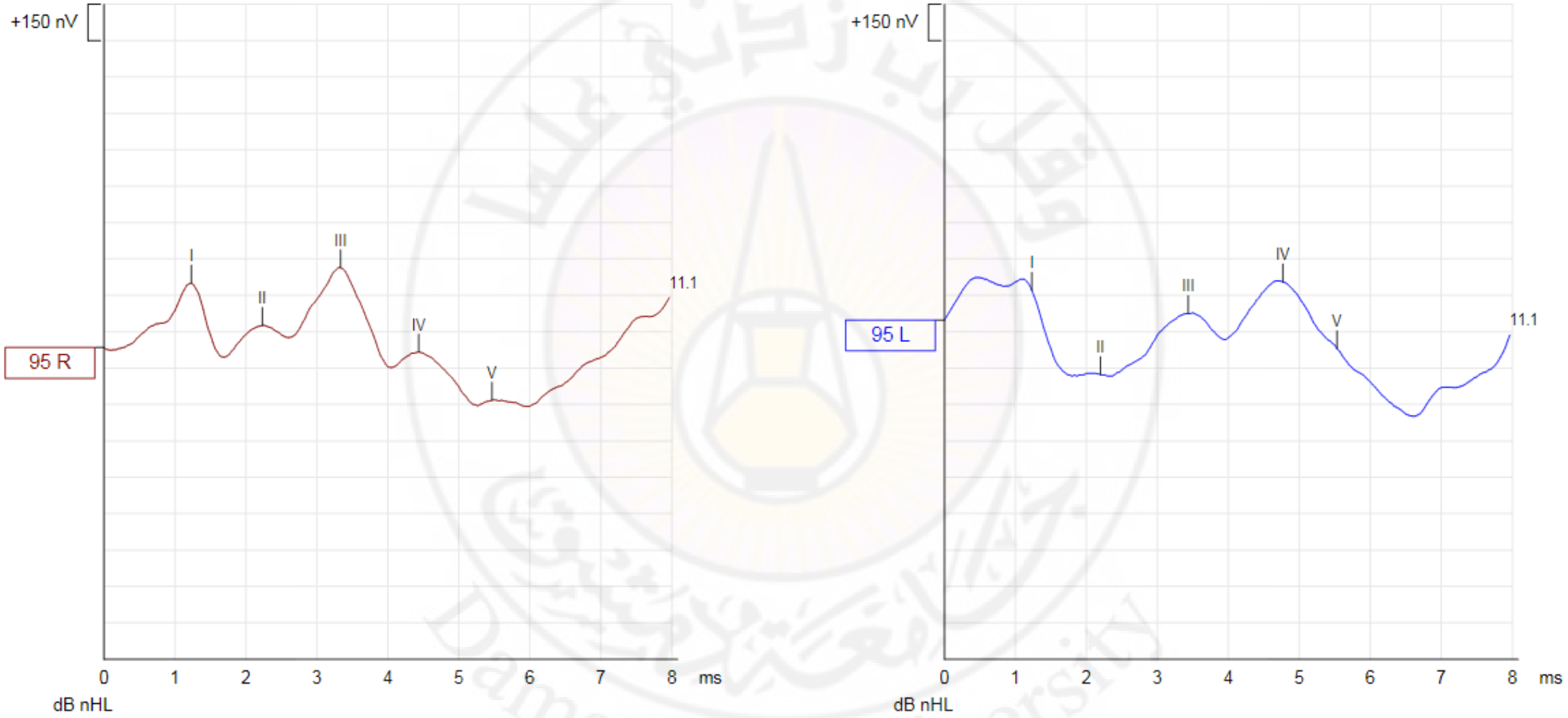


Fused Peaks

- Fused peaks are, technically, two peaks combined into a single wave complex. Both peaks are distinct yet one of the peaks usually dominates.
- The peaks most often fused in normal ABR waveforms are IV and V. In these cases, wave IV usually appears as a hump or short plateau before wave V or, conversely, wave IV is a distinct peak and is followed by a shoulder or plateau.
- If there is single peak in the expected latency region for waves IV-V, it is typically labeled as wave V and the wave IV is presumed missing.
- Fusion of waves IV and V is more likely in cochlear pathology than normal hearers.

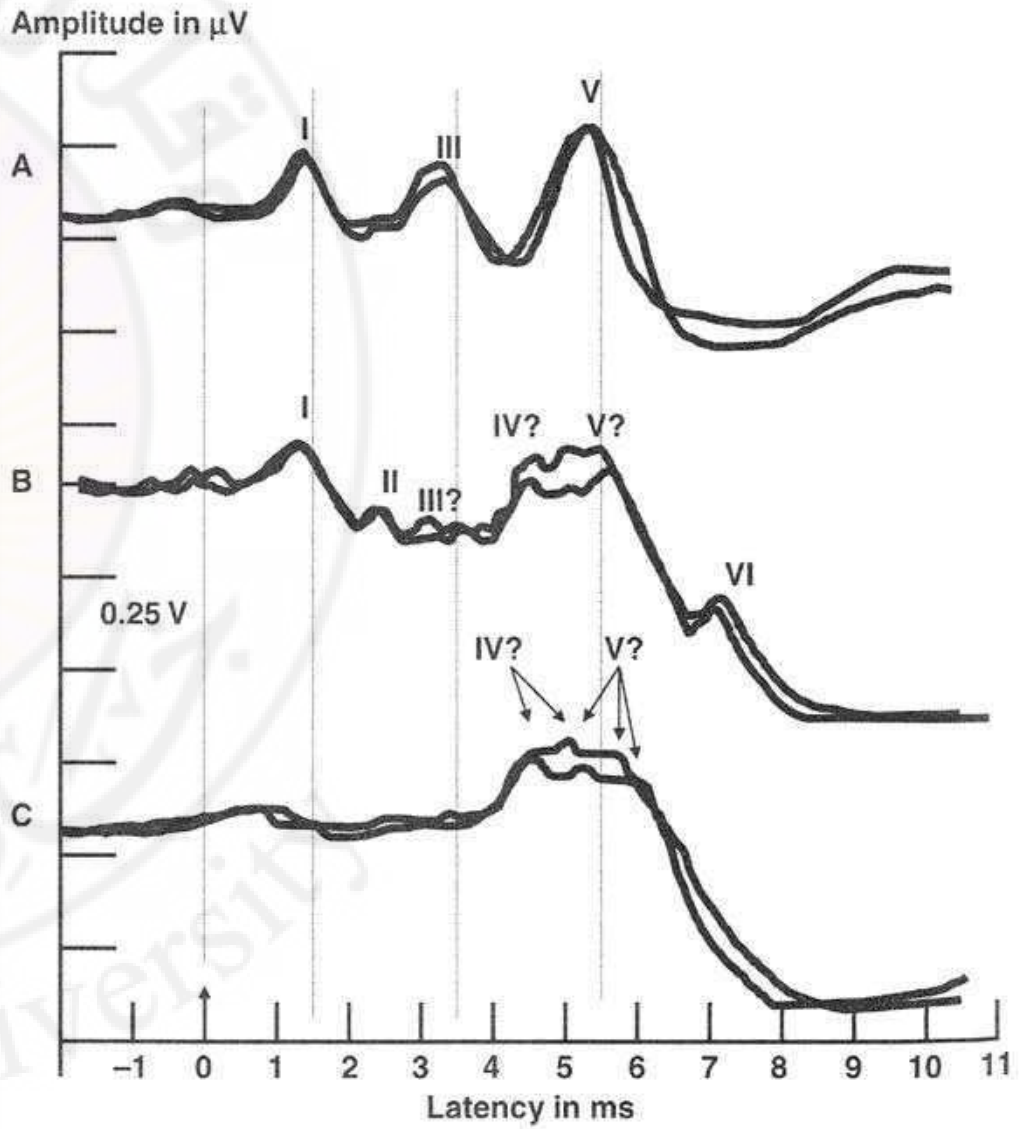


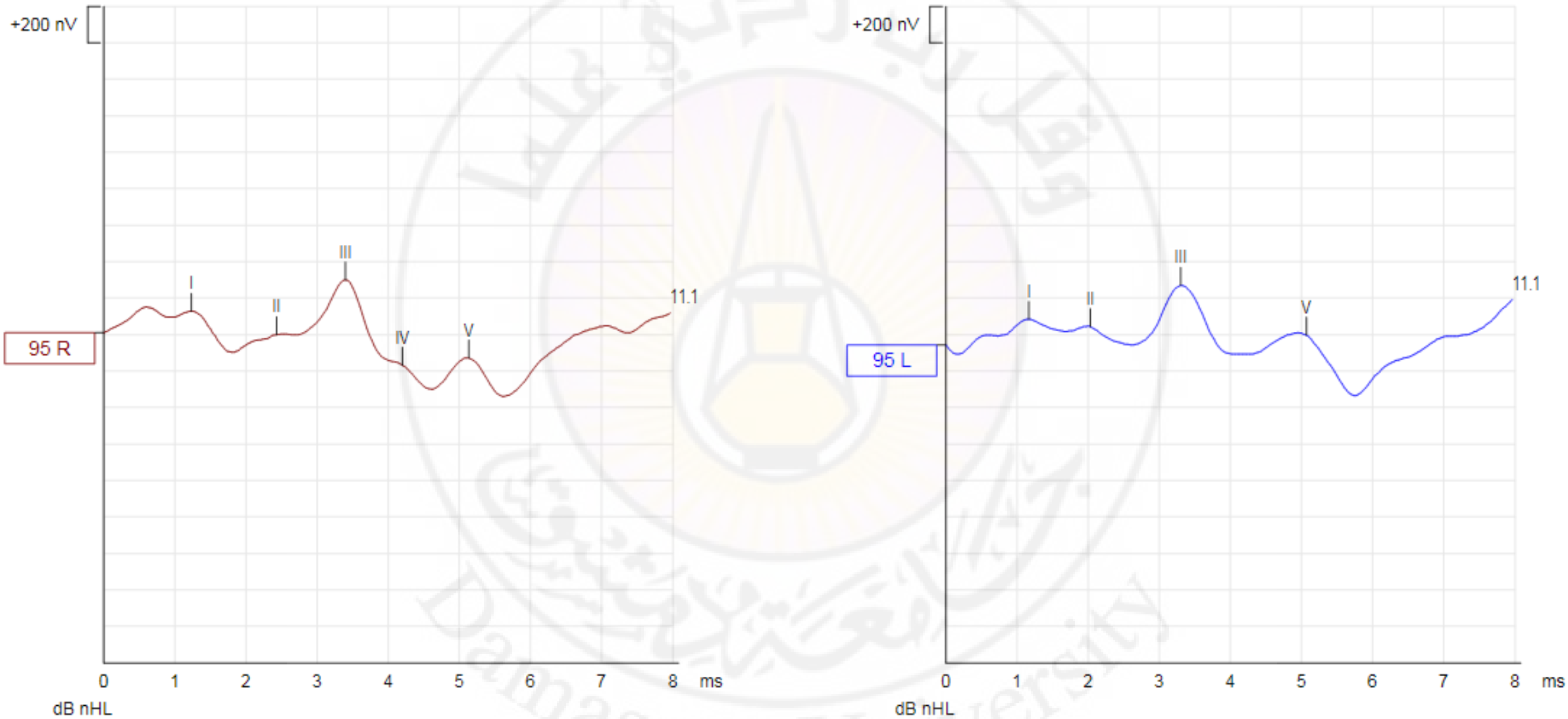

+250 nV
95 R
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
ms
dB nHL
+250 nV
95 L
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
ms
dB nHL

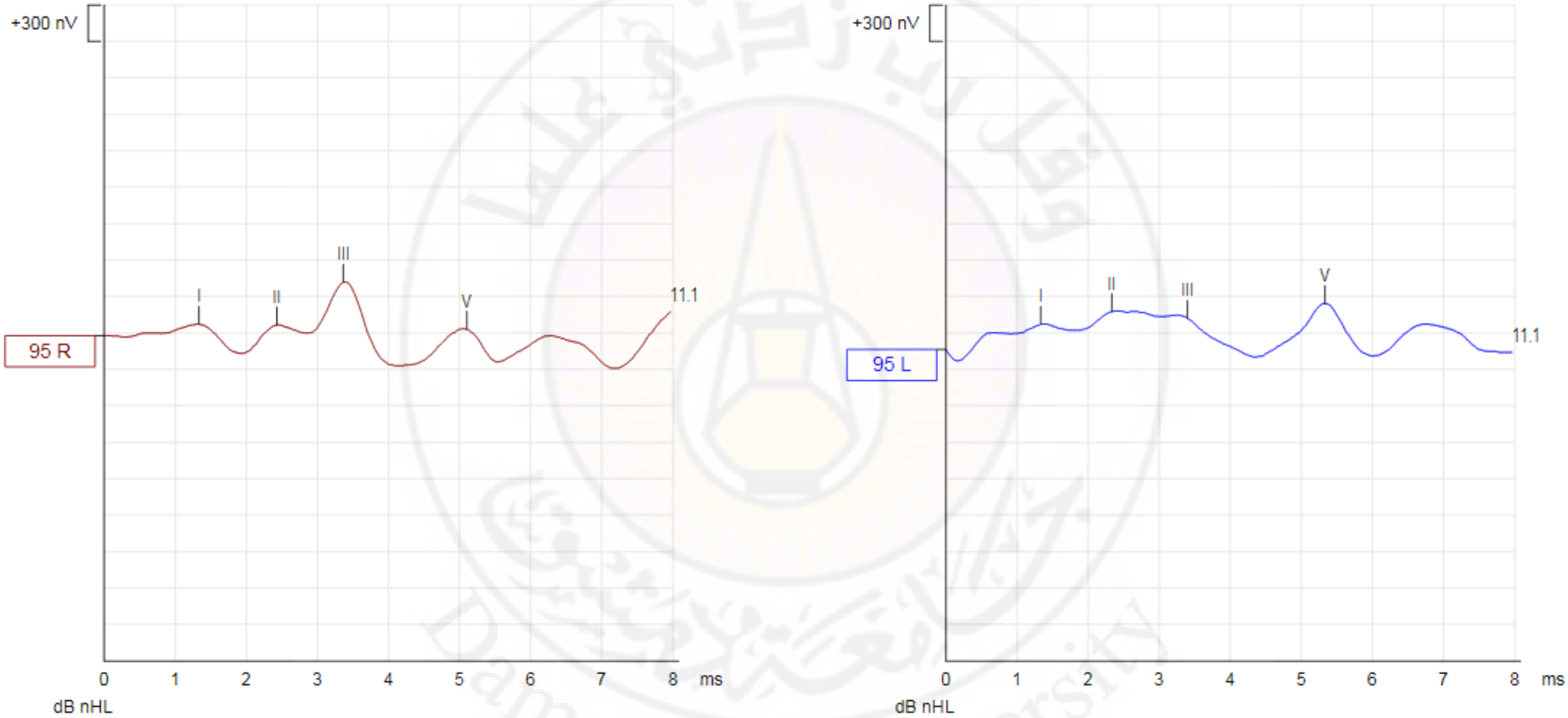

+150 nV
95 R
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL
+150 nV
95 L
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL

Missing Peaks

- Peaks often missing in normal ABR waveforms include wave IV, and waves II and VI.
- Relatively minor peripheral hearing deficits in the high frequency region, including inter-octave audiometric test frequencies of 3000 and 6000 Hz and other frequencies in that region, can influence ABR waveform morphology. Without careful audiometric assessment, this factor in ABR interpretation may go undetected.
- Missing peaks for waves II, III and IV are not unexpected in some otherwise normal subjects, such as newborn infants.




+200 nV
95 R
I
II
III
IV
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL
+200 nV
95 L
I
II
III
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL


+300 nV
95 R
I
II
III
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL
+300 nV
95 L
I
II
III
V
11.1
0
1
2
3
4
5
6
7
8
ms
dB nHL

Enhancing ABR waveform

Enhancing ABR amplitude:

- Increase stimulus intensity
- Use non-cephalic non-inverting electrode (ABR wave V)
- Use inverting electrode closer to the cochlea (ABR wave I)
- Slow stimulus presentation rate (ABR wave I)
- Change to another stimulus polarity
- Record ABR with chirp stimuli

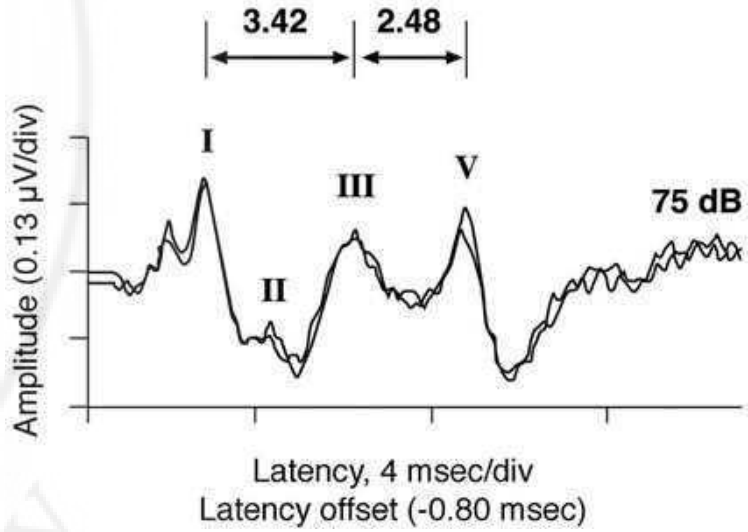
Minimizing measurement noise:

- Increase number of sweeps (signal averaging)
- Use weighted averaging option
- Sum replicated waveforms
- Alter filter settings as necessary
- Take steps to minimize patient movement and physical activity

Damascus University

ABR Outcomes

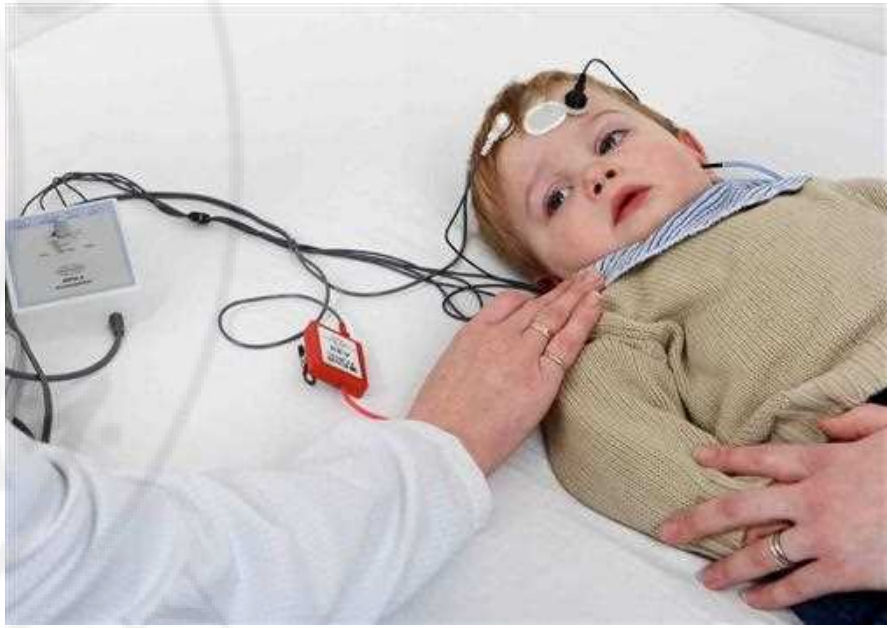
- **Clear Response (CR):** requires “a high degree of correlation between the replications and the waveforms should show the expected characteristics in terms of amplitude, latency, and morphology” and the 3:1 ratio for wave V amplitude to background noise.
- **Response Absent (RA):** waveforms must be appropriately flat, with no evidence of a response and the average difference (noise) between a pair of optimally superimposed waveforms should be less than or equal to 25nV.
- **Inconclusive (Inc):** if the waveforms do not meet criteria for either a CR or a RA.



Abnormal ABR Patterns

Abnormal ABR findings

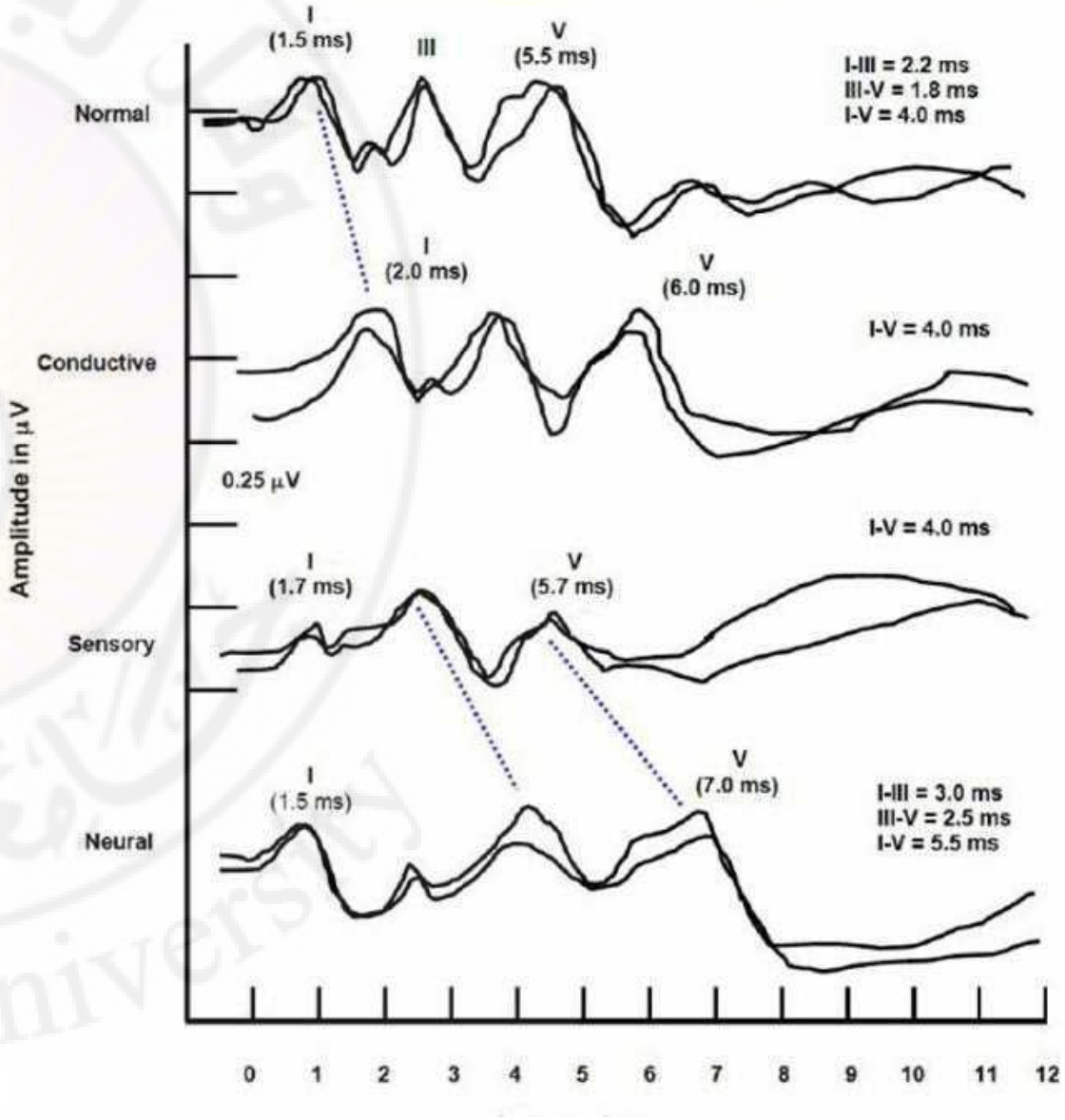
- There is virtually no limit to the ways that ABR waveforms can be altered in patients with disorders of the peripheral and/or central auditory system.
- Abnormal ABR findings range from subtle latency aberrations to total absence of a detectable response.
  - **Abnormal Absolute ABR Latency**
  - **Abnormal Inter-Wave Latency**
  - **Poor Morphology**
  - **Abnormal Amplitudes**
  - **No response!**



Abnormal Absolute ABR Latency

- **Delayed wave I**

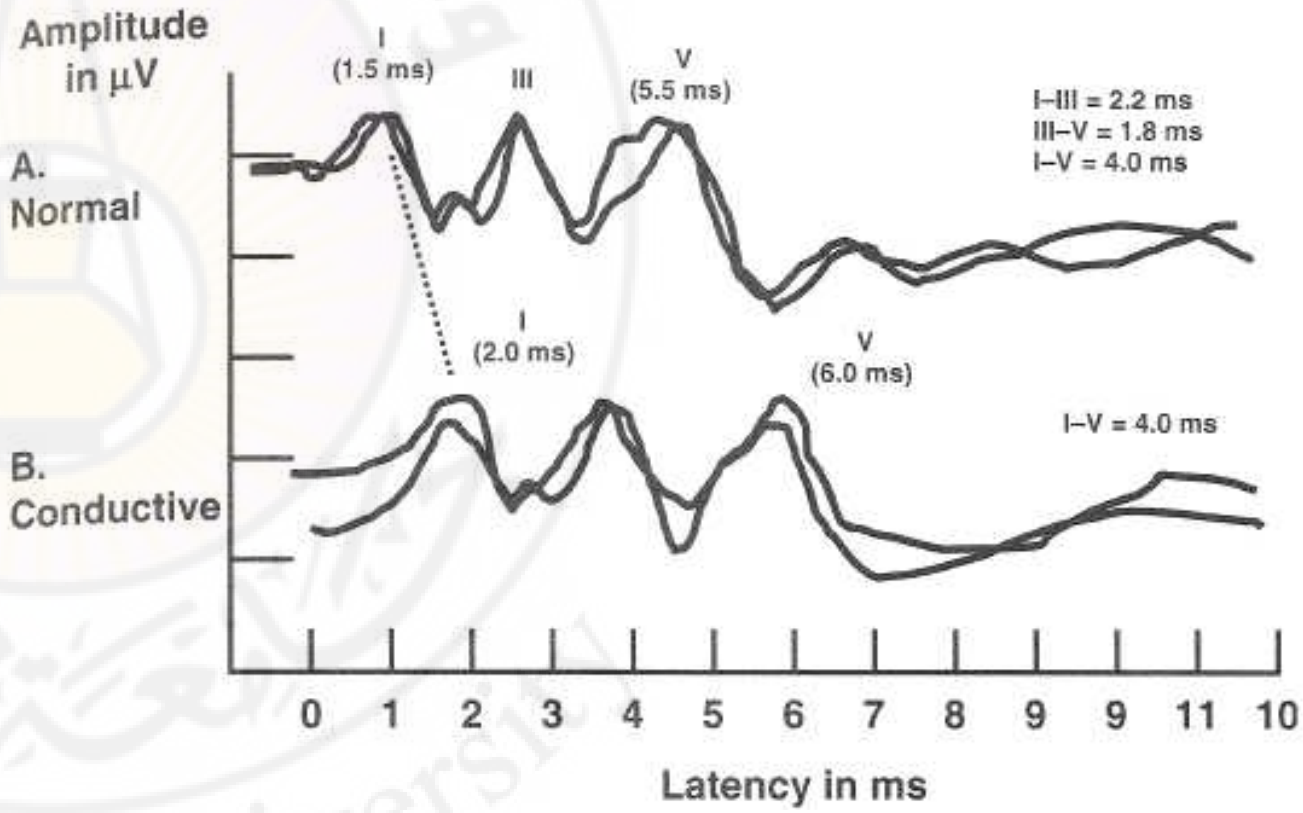
- The most common absolute latency abnormality is a delay in wave I, usually with an equivalent delay in subsequent wave components.
- This abnormal ABR pattern implies **peripheral** auditory dysfunction.
- Slightly increased wave I latency suggests a high frequency sensory (cochlear) hearing loss.
- Patients with moderate-to-severe sensory hearing loss, greater than 50 dB in the 1000 to 4000 Hz region, often have no detectable wave I for ABRs recorded with the conventional electrode array.



Abnormal Absolute ABR Latency

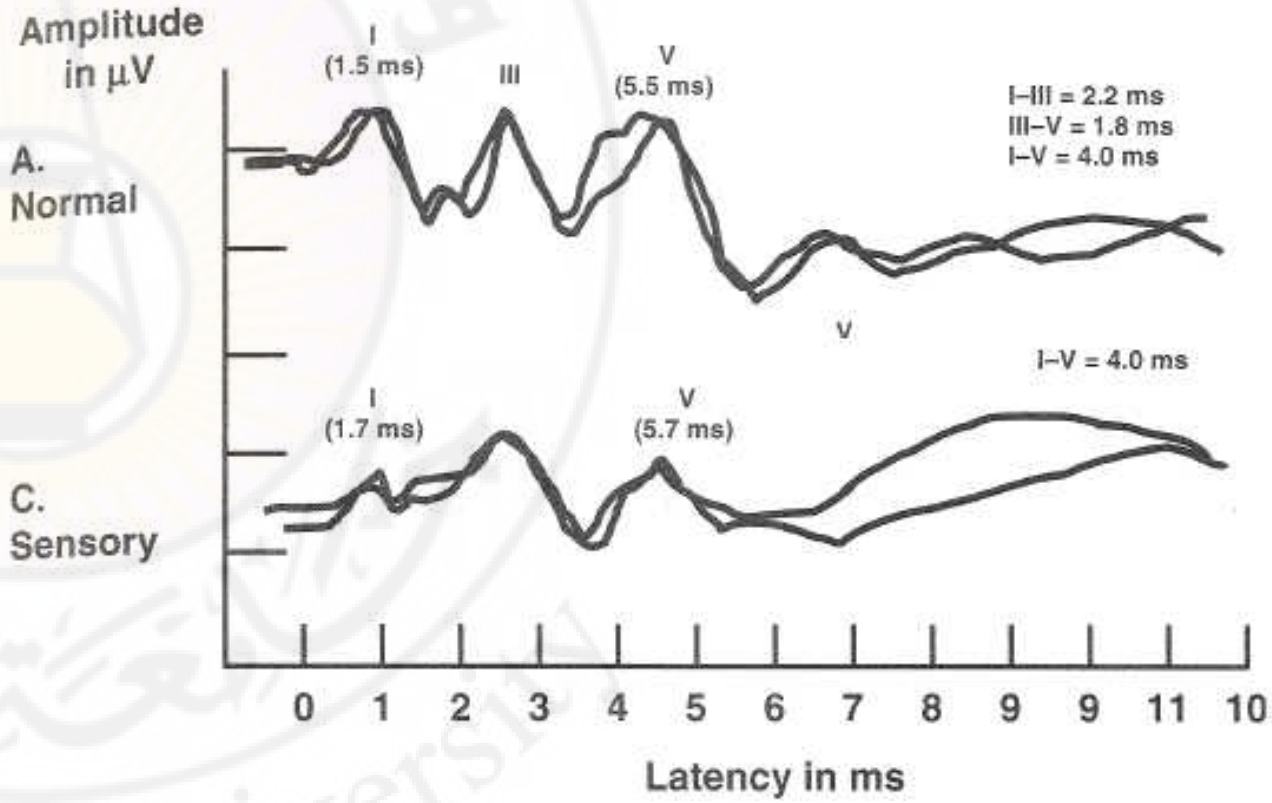
- A substantial wave I delay is a characteristic finding in **conductive** hearing loss secondary to middle ear dysfunction or mixed hearing loss due to combined middle ear and cochlear dysfunction.

- A clear and repeatable wave I may be recorded even in maximum conductive hearing losses of 60 dB or more.



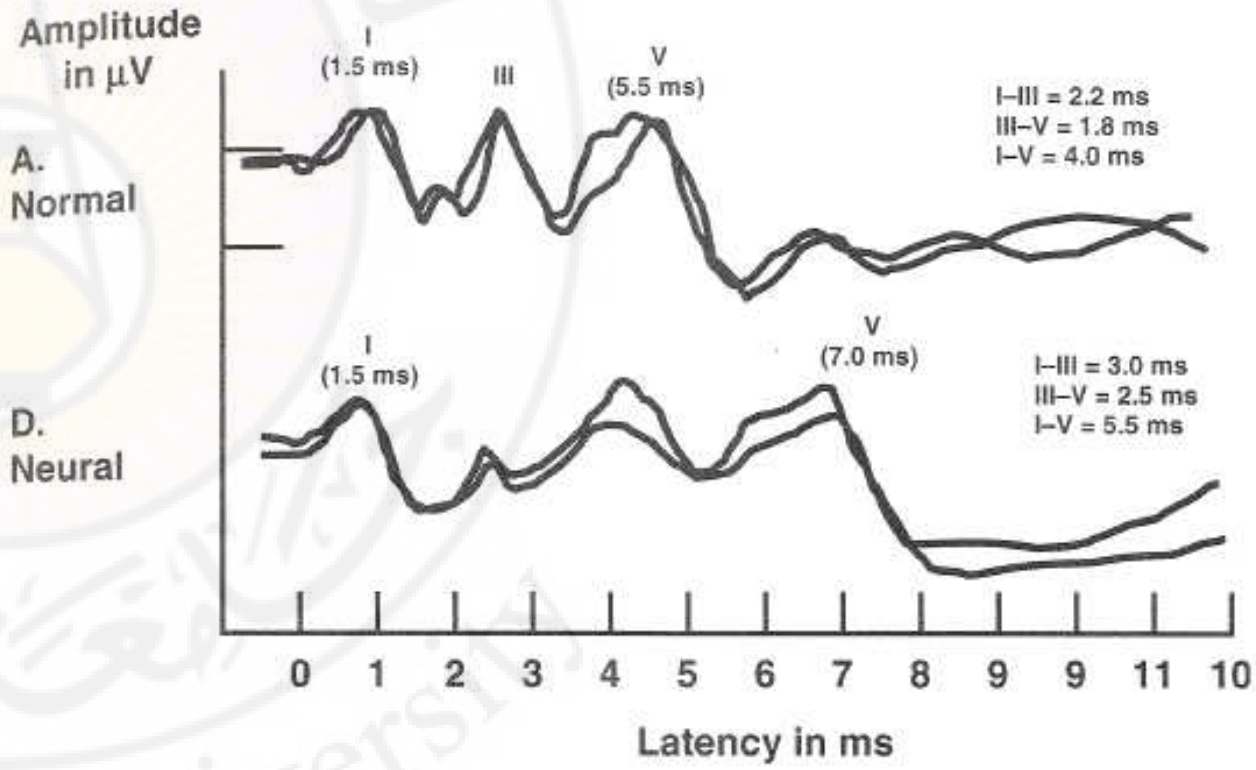
Abnormal Absolute ABR Latency

- **Sensory** hearing impairment, in contrast, has a more pronounced effect on the morphology and the amplitude for wave I of the ABR.



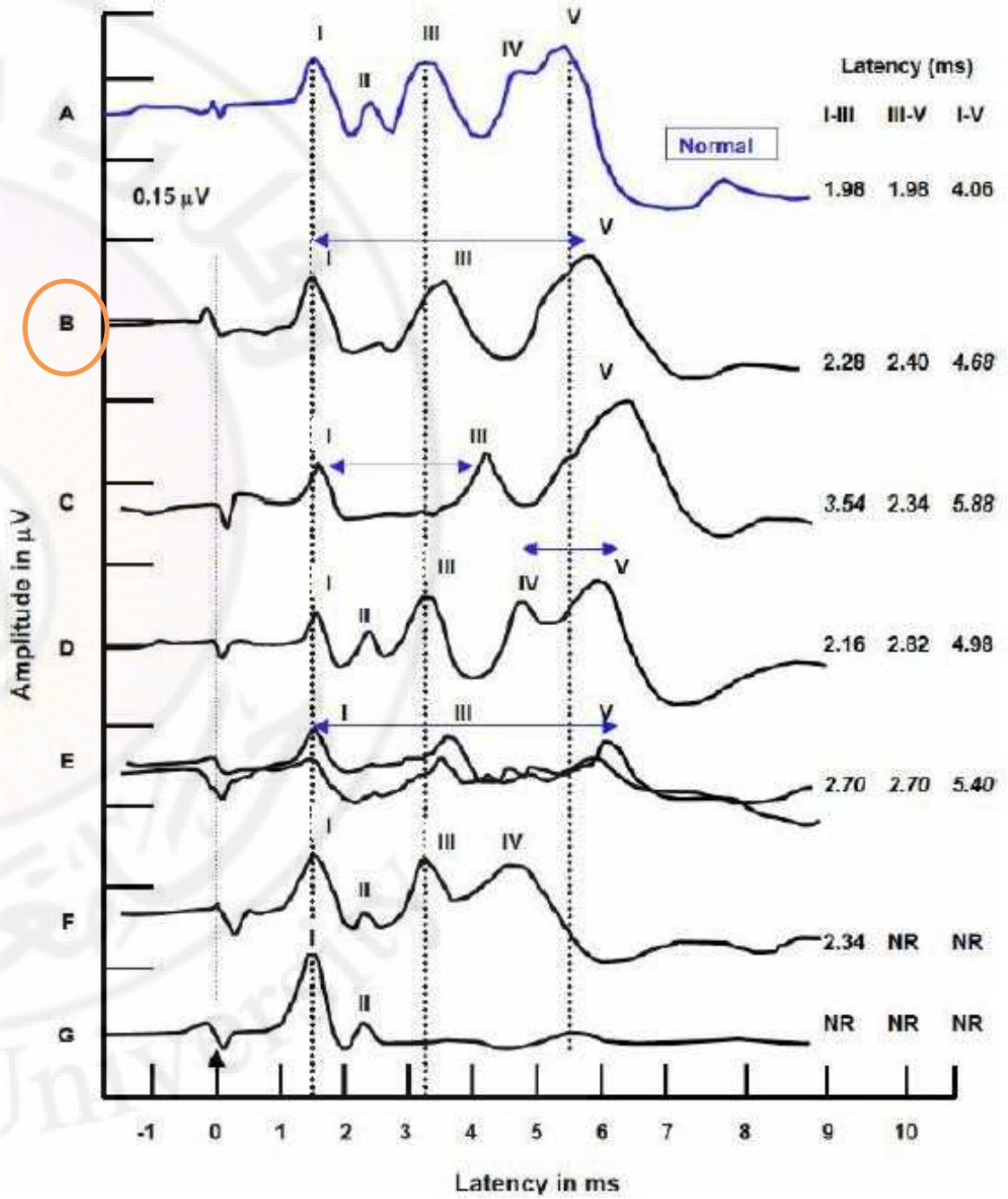
Abnormal Absolute ABR Latency

- **Neural** auditory dysfunction is associated with normal absolute latency for ABR wave I yet abnormal latency for later waves. The result is abnormally delayed inter-wave latency values.



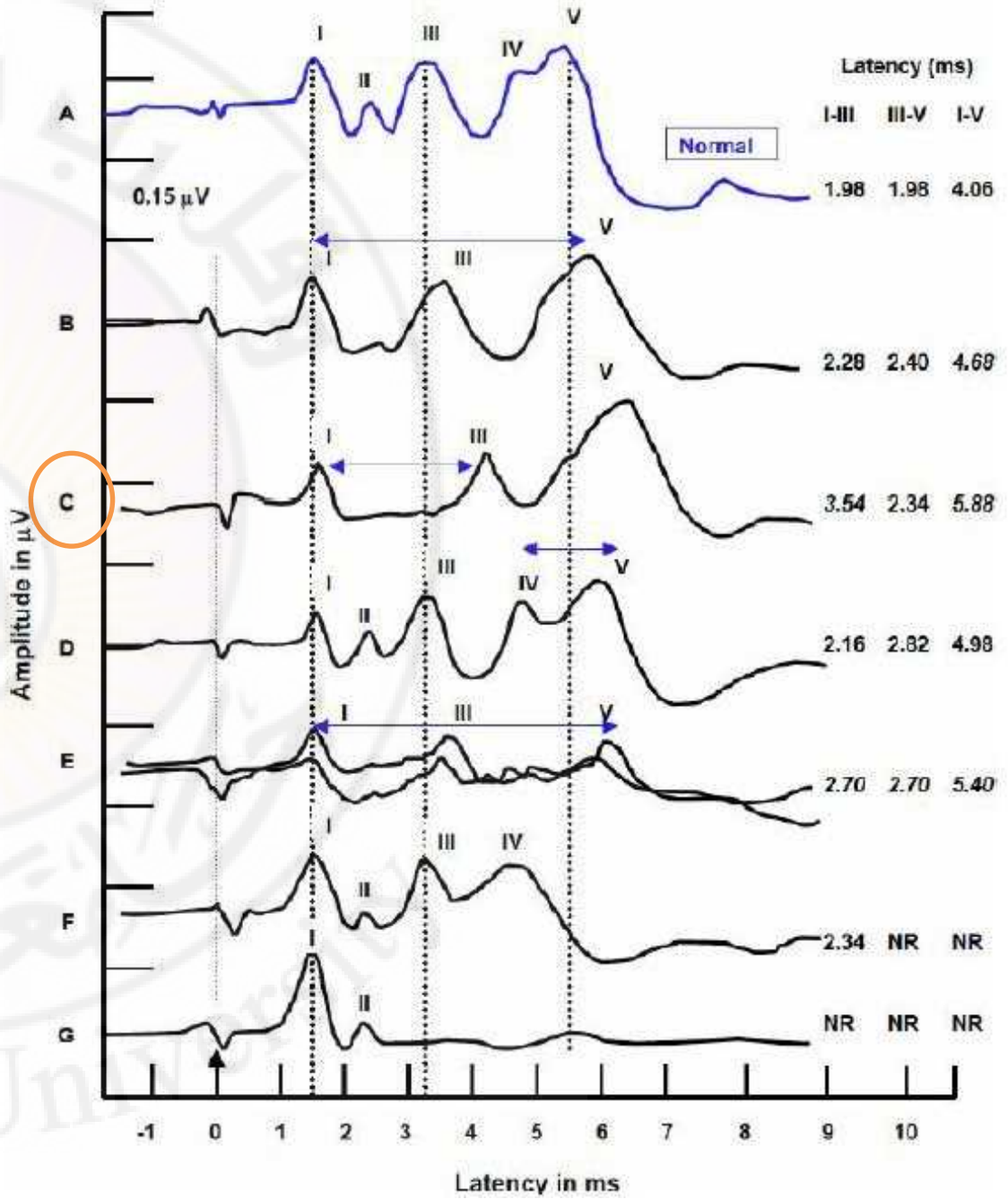
Abnormal Inter-Wave Latency

- **Slight I-V latency prolongation:**
  - Precise definition of wave peaks and calculation of wave latency values.
  - Male or female?
  - Is it bilaterally symmetric?
  - Consider the body temperature (Hypothermia).



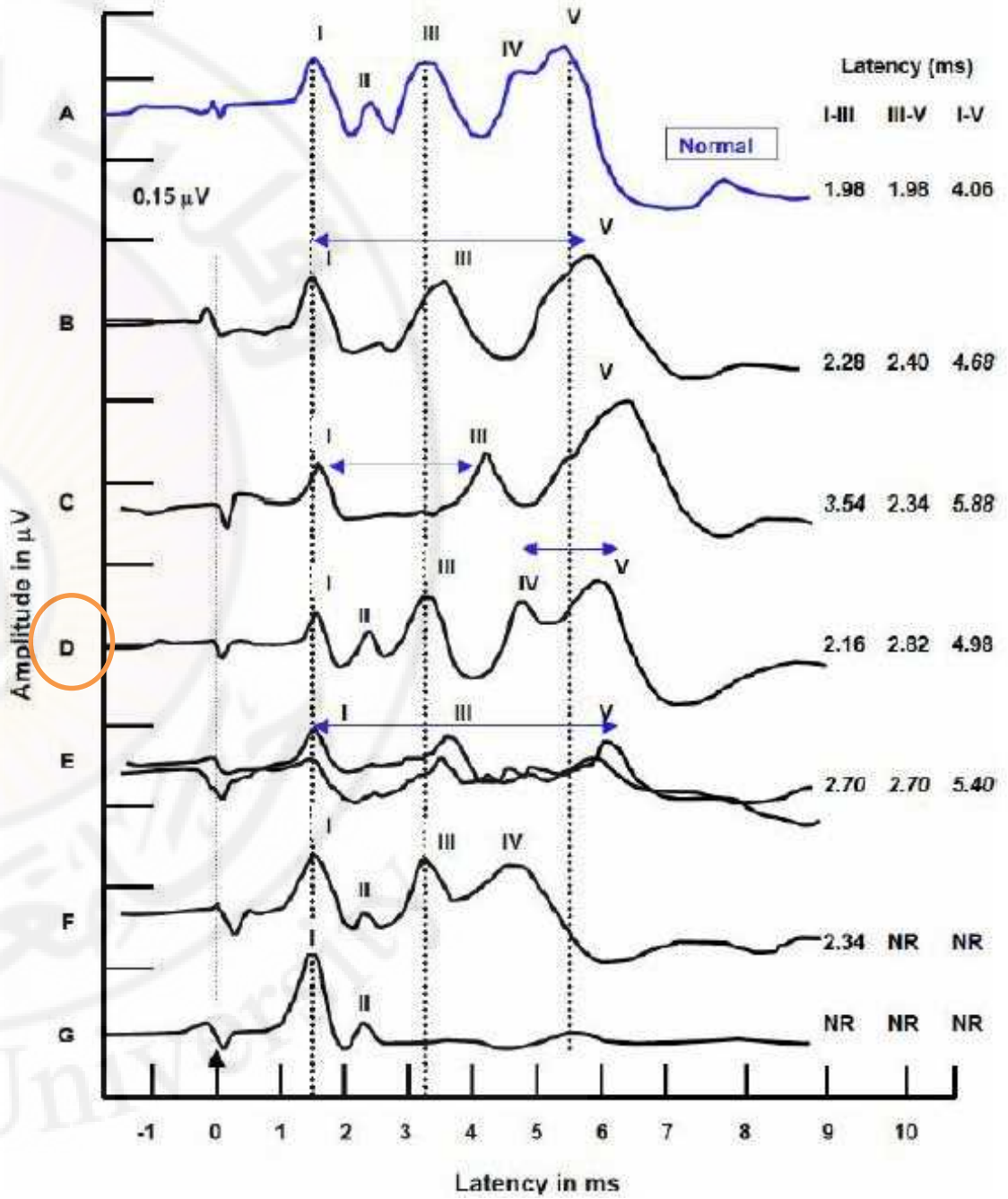
Abnormal Inter-Wave Latency

- **Waves I-III latency prolongation:**
  - Precise definition of wave peaks and calculation of wave latency values.
  - This pattern contributes to a wave I-V latency abnormality.
  - If **Unilateral**: Tumor-related auditory dysfunction in the region of the 8th cranial nerve and lower brainstem (CPA).
  - If **Bilateral**: Brainstem (pons) dysfunction; and less likely, bilateral eighth nerve dysfunction (NF2).



Abnormal Inter-Wave Latency

- **Waves III-V latency prolongation:**
  - Rostral brainstem auditory dysfunction is suggested (the prolongation is mainly due to an extended wave IV to V latency separation).
  - It is often bilateral.
  - The ABR pattern is sometimes observed in patients with hydrocephalus who have increased intra-cranial pressure or in patients with other dynamic neuropathology.
  - The ABR wave III-V delay indicates supra-tentorial compression of the upper brainstem, a very serious finding.



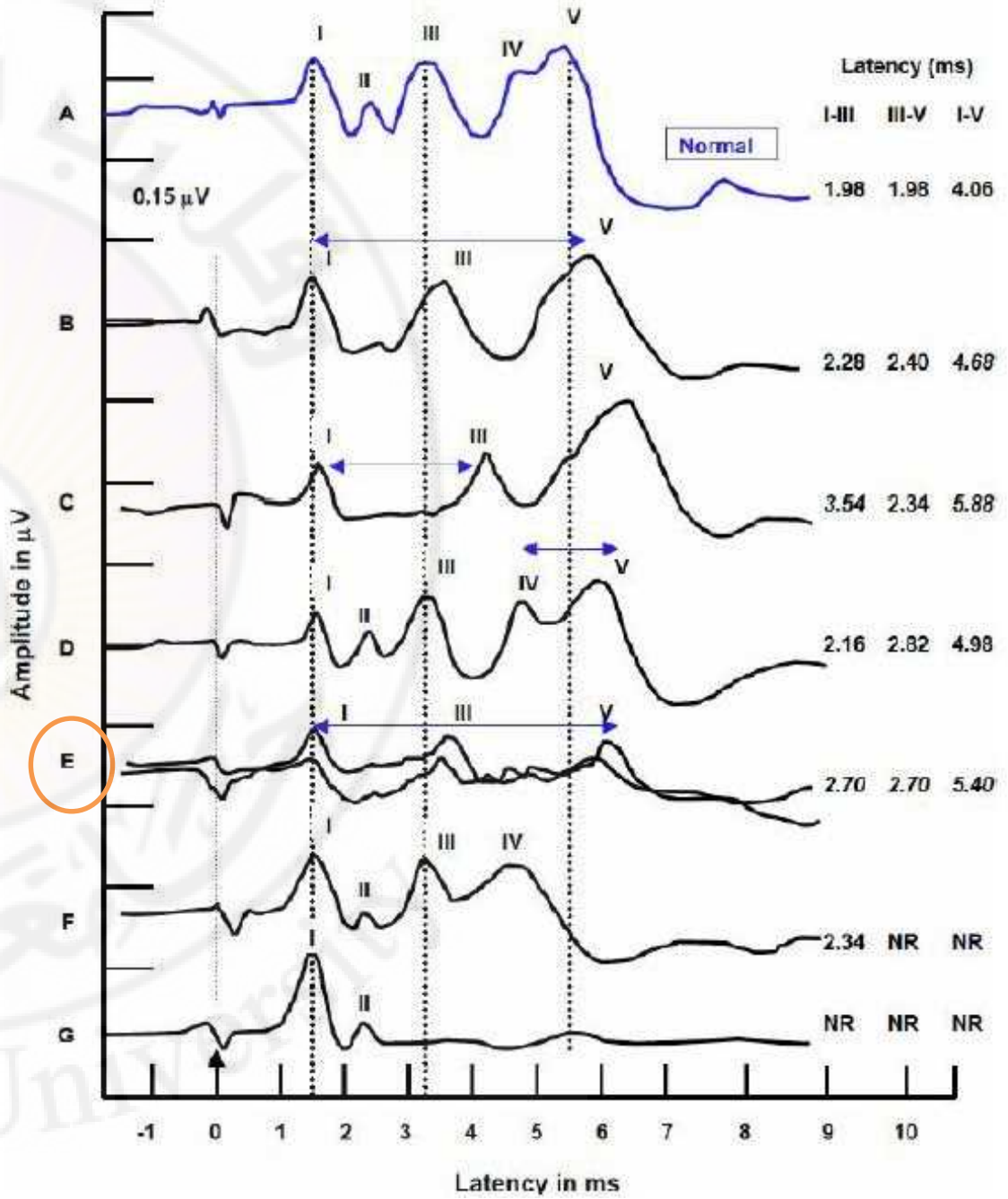
Abnormal Inter-Wave Latency

- **Overall I-V latency prolongation:**

➢ Poor repeatability & morphology often reflects asynchronous neural function and neuropathology.

➢ An overall latency delay, particularly if recorded bilaterally, confirms significant auditory brainstem dysfunction, but does not contribute to further localization of the pathology.

➢ In an apparently healthy person, multiple sclerosis would be a possible explanation for this ABR finding.

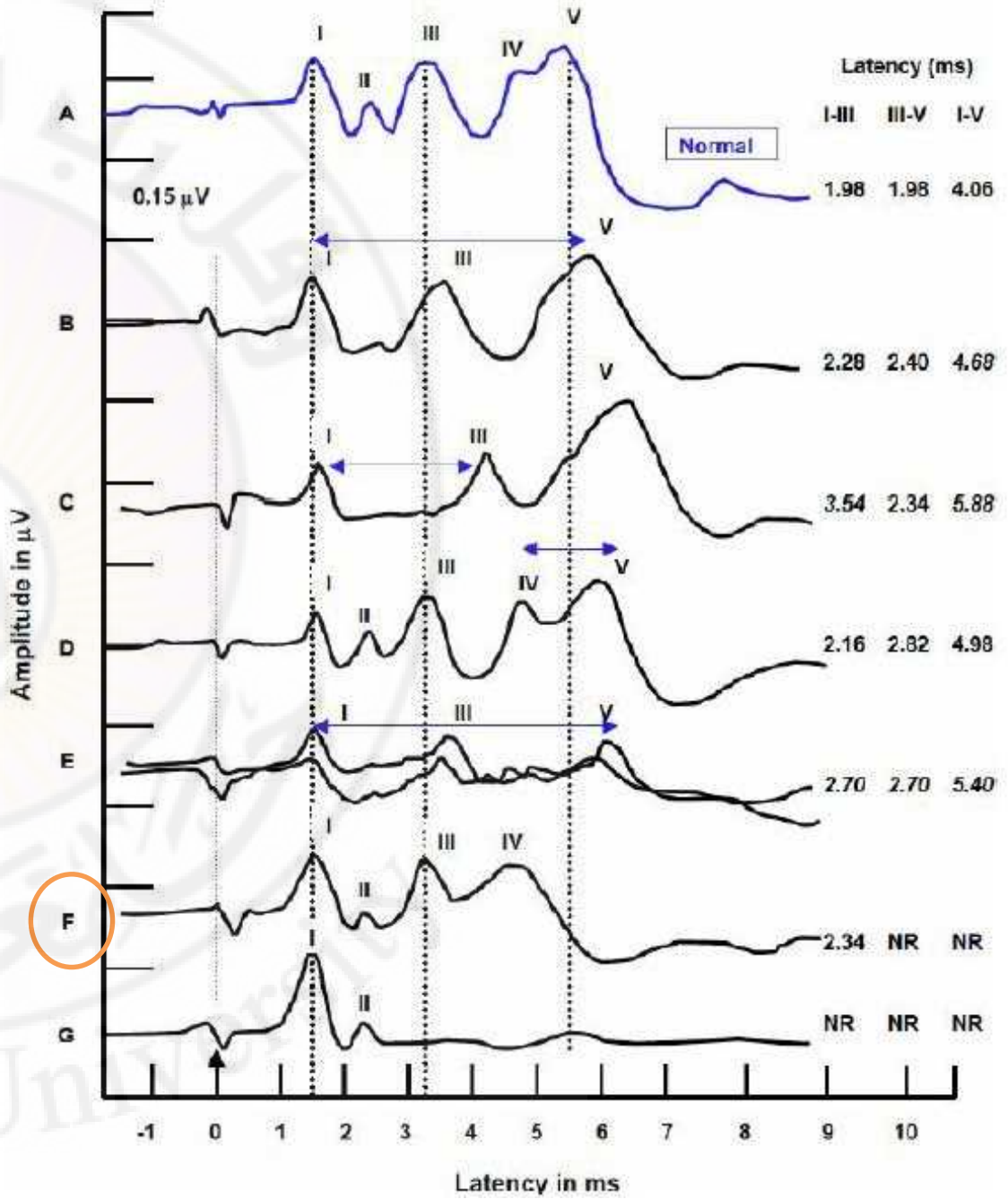


Abnormal Inter-Wave Latency

- **Missing wave V:**

➢ Information on subject characteristics is helpful for confident interpretation of the response.

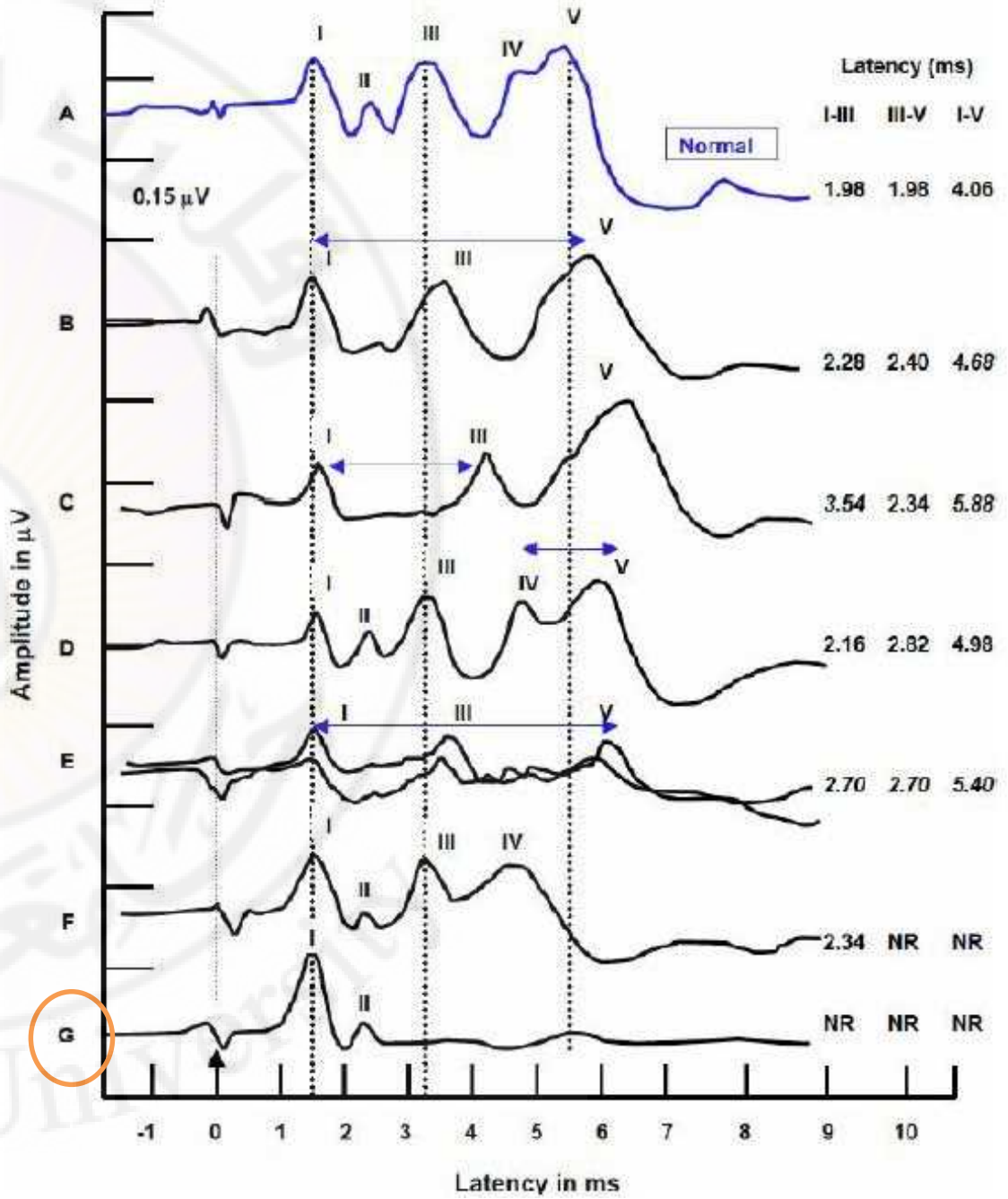
➢ This ABR pattern has been reported in patients with severe head injury and other serious neurological disorders.



Abnormal Inter-Wave Latency

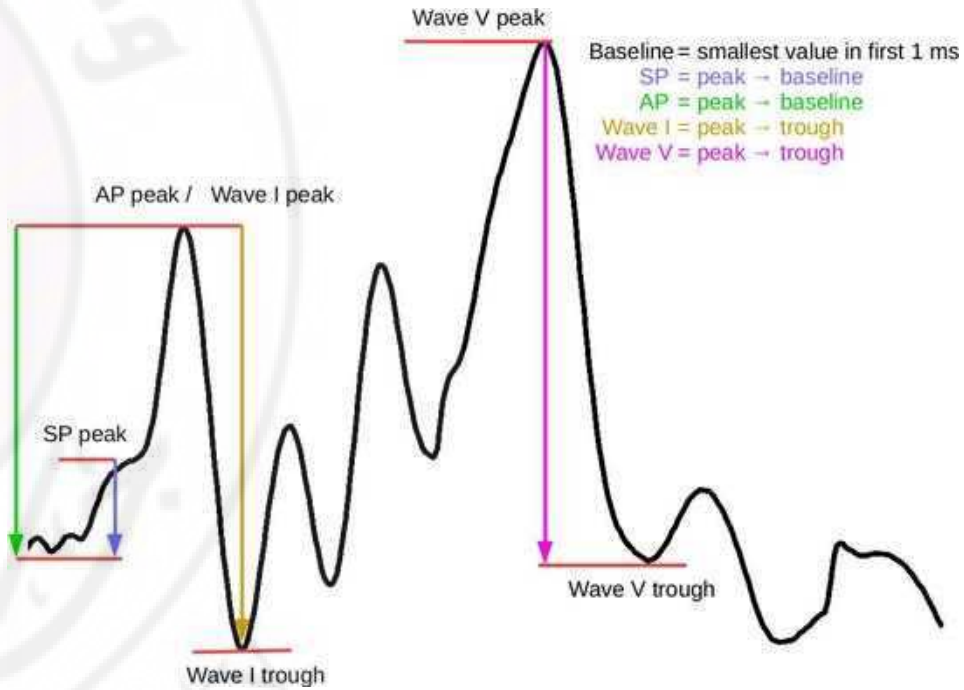
- **ABR with only wave I and II:**

- The presence of clear waves I and II rules out serious peripheral auditory deficit.
- Severe brainstem dysfunction, often found in unconscious head injured adult patients.
- If the patient is alert and orientated, a demyelinating disease like multiple sclerosis might be suspected.
- A unilateral finding with a normal response on the opposite side would suggest CPA pathology.
- The ABR pattern in an infant may reflect severe hypoxic-ischemic brain insult and is probably not consistent with brain death.



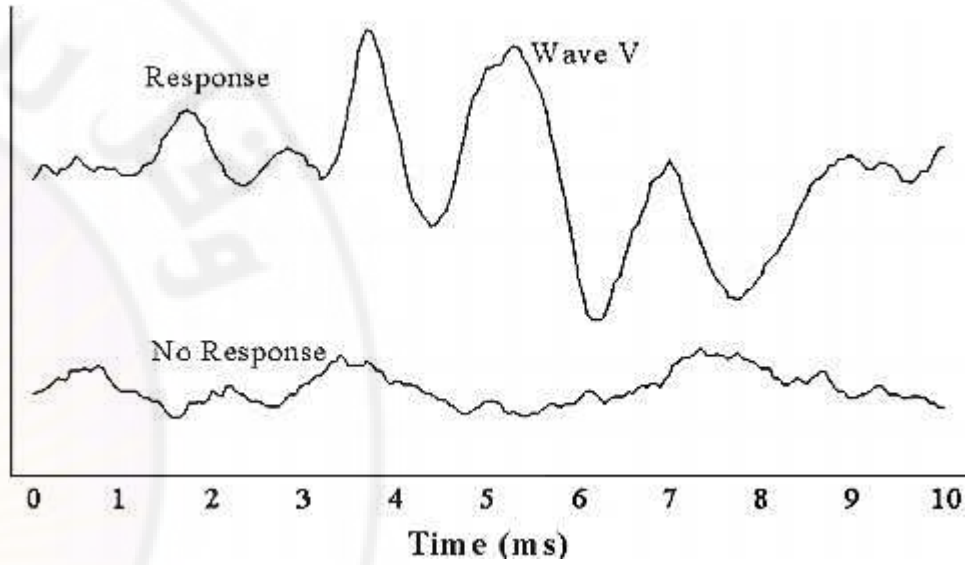
Abnormal ABR Amplitudes

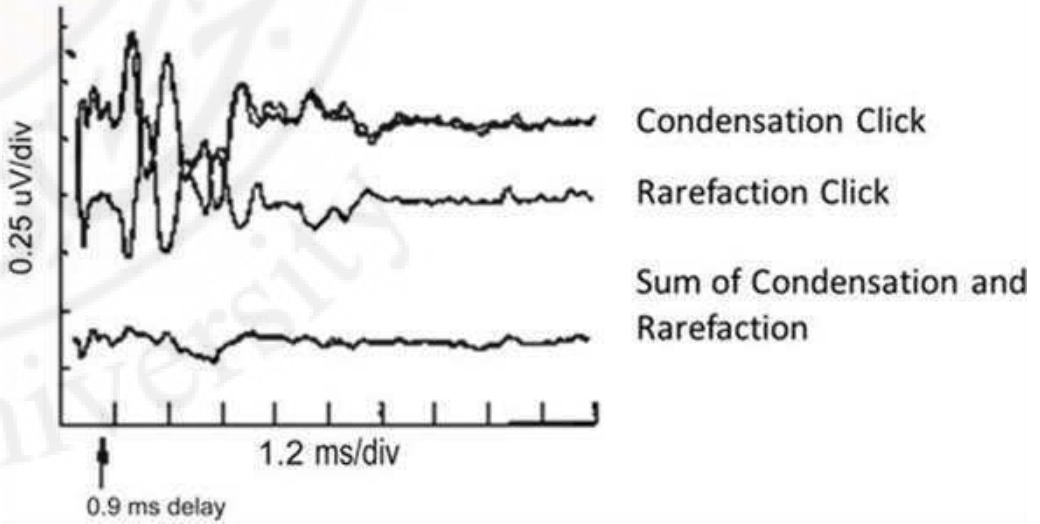
- Amplitude is highly influenced by EEG activity level and muscle artifact, as well as by measurement parameters such as stimulus intensity and filter settings.
- Calculation of a wave V to wave I **(V/I) amplitude ratio** is an attempt to limit the variability inherent in absolute amplitude measures.
- Actual criteria for abnormality vary, but a wave V/I ratio, for high intensity monaural click stimuli, of less than 0.5 is a conservative lower normal cutoff.
- A wave V/I of less than 1.00, but greater that 0.5, is found in about 10% of normal subjects.
- **This finding in isolation is not considered a strong ABR sign of auditory dysfunction.**



ABR No response

- The most obvious explanation for an absent response is a severe-to-profound hearing impairment. This conclusion can be confirmed in some patients with analysis of findings for other auditory measures such as aural impedance measurements including acoustic reflexes, otoacoustic emissions (OAEs), and behavioral audiometry.
- No detectable ABR can also be observed in ANSD patients (in the presence of normal OAEs & CM).

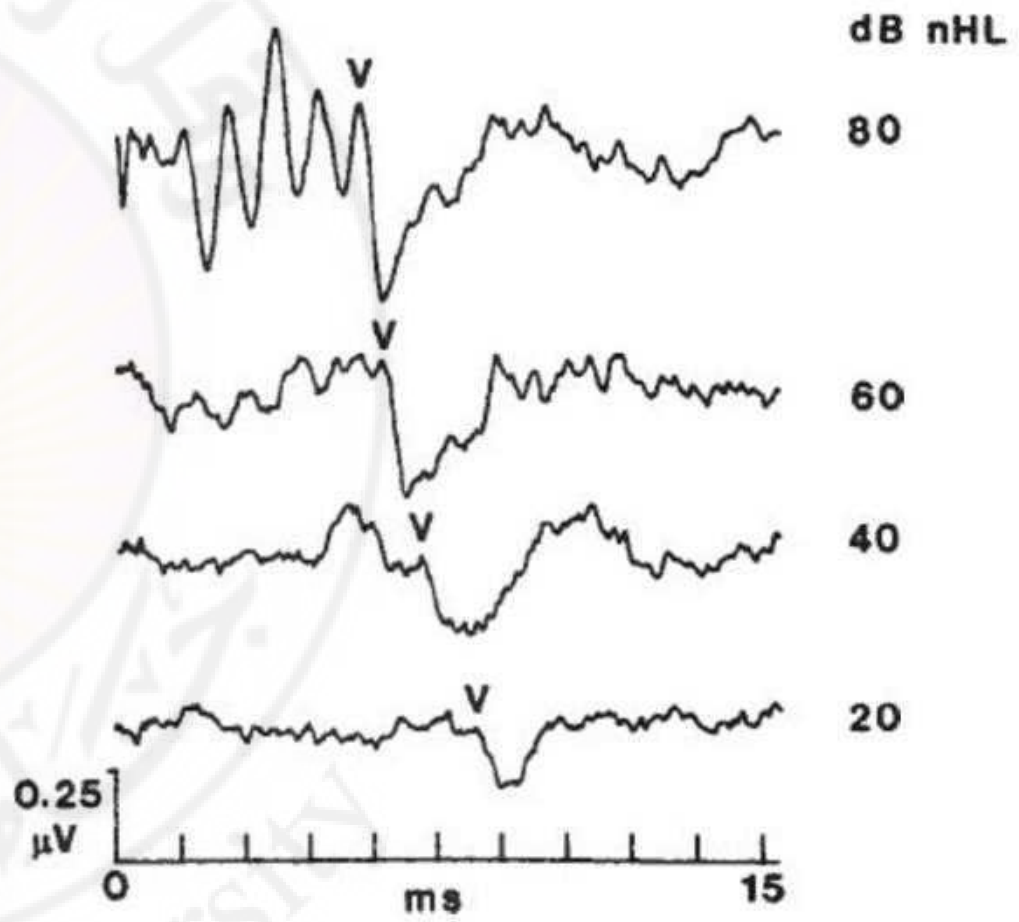




8. Auditory Brainstem Response: Estimation of Hearing Sensitivity

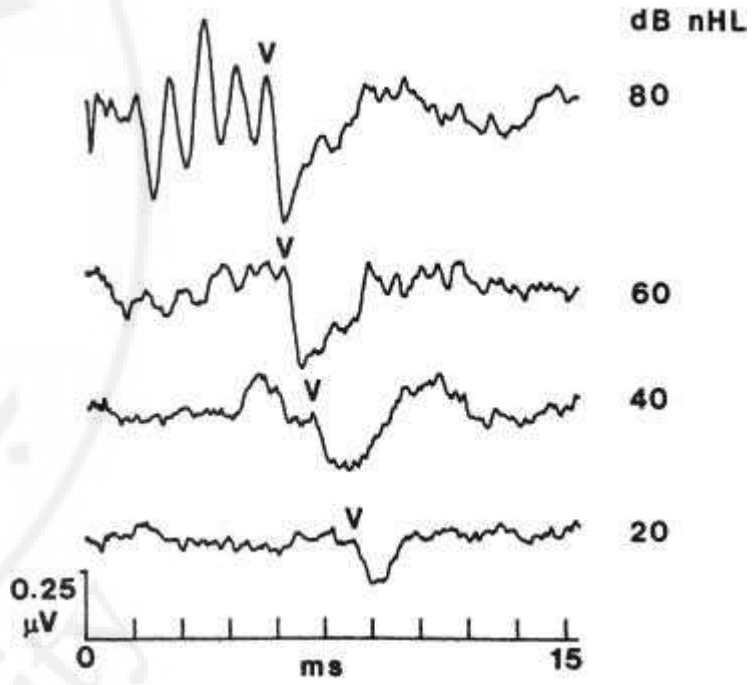
ABR is NOT a test of hearing!

- Although AEPs have proven useful in estimating hearing thresholds, it is important to remember that the ABR and other evoked potentials assess **neural synchrony**, that is, the ability of the peripheral and central nervous system to respond to external stimulation in a synchronous manner.
- For individuals who do display synchronous neural responses, we can find the lowest stimulus intensity level that yields the neural response and relate that to a threshold for hearing.
- **Limitation**: auditory neuropathy/dys-synchrony



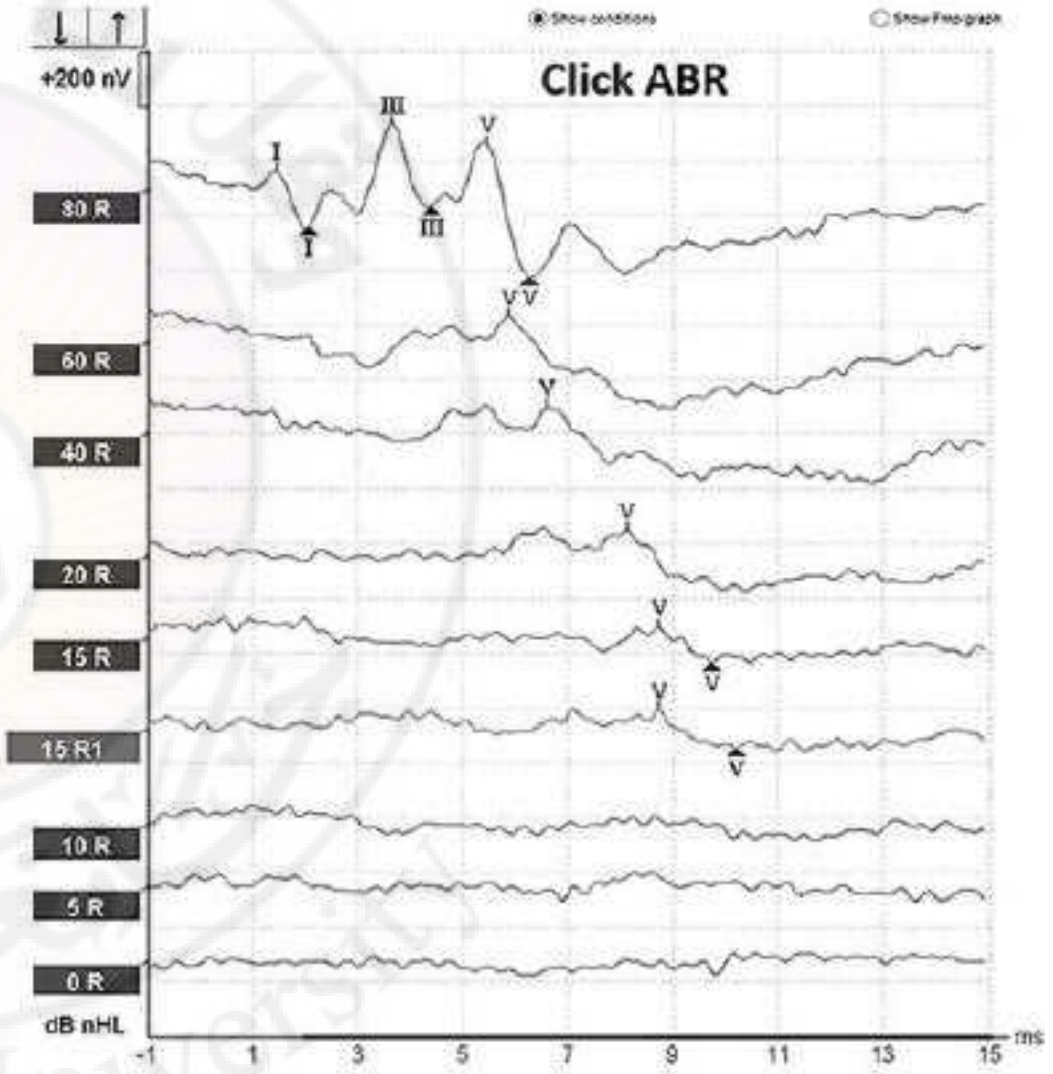
When To Use The ABR for threshold estimation?

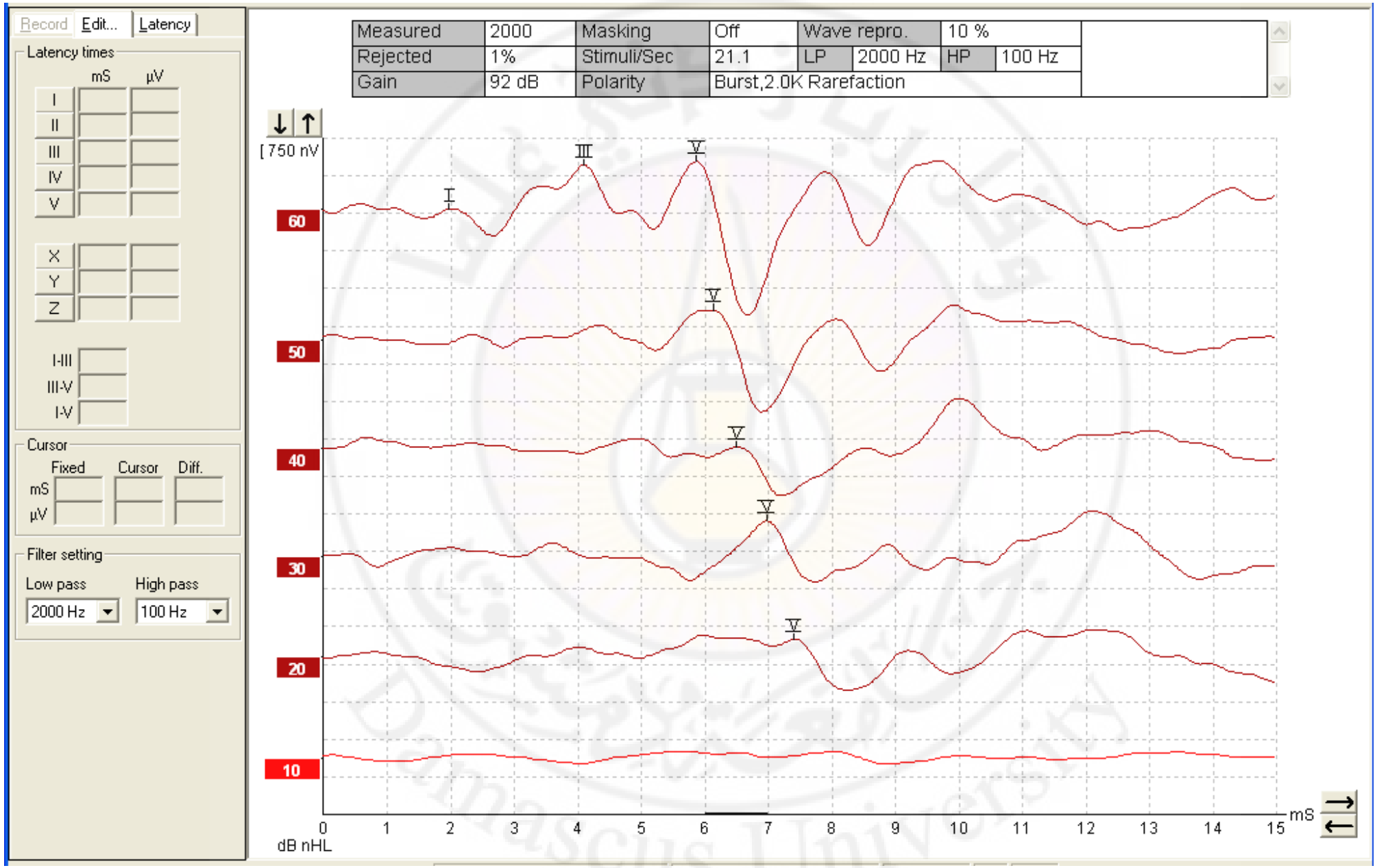
- ABR is best utilized when the clinician desires a noninvasive, objective approach to assessment of auditory function in:
  - Infants & children
  - Developmentally delayed children
  - Multiply handicapped children & adults
  - Autistic individuals
  - Person suspected of Pseudohypacusis
  - Adults who cannot participate in voluntary behavioral audiometric procedures
- ABR should not be used in lieu of a behavioral audiogram in patients who can provide reliable behavioral responses.

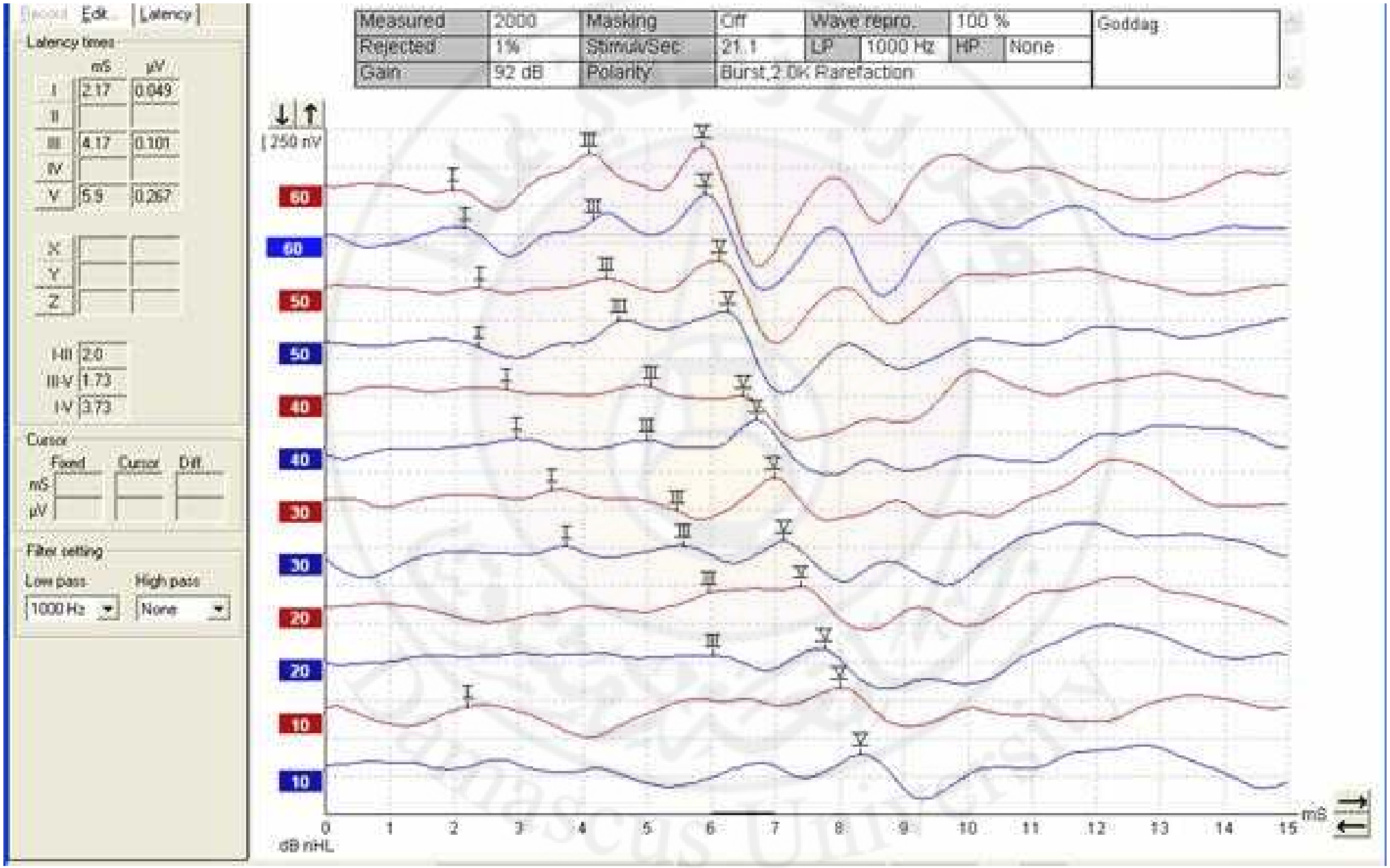


ABR threshold estimation

- For assessing the hearing sensitivity, wave V of the ABR is used, because its most robust of the waves and best correlated with behavioral thresholds.
- Wave V can be elicited at intensity levels within 5-20 dB of behavioral threshold for the click.
- If wave V is present at 20 dB nHL, this is considered normal and there is no need to test at lower intensities.

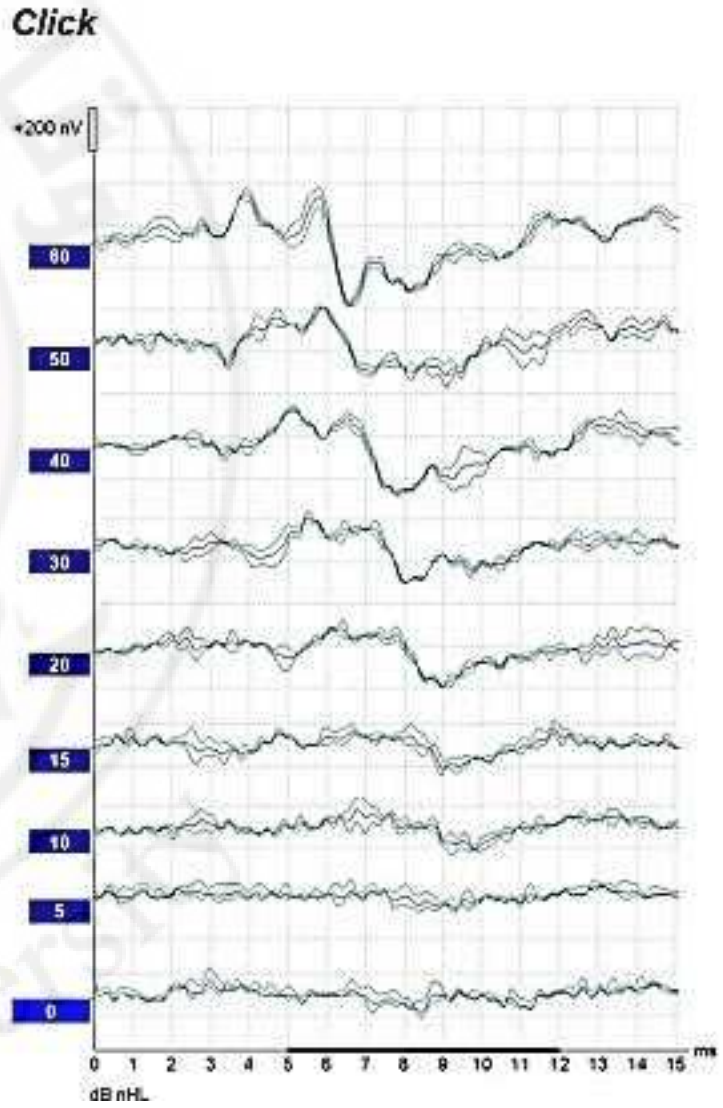



Record
Edit...
Latency
Latency times
mS
µV
I
II
III
IV
V
X
Y
Z
I-III
III-V
I-V
Cursor
Fixed
Cursor
Diff.
mS
µV
Filter setting
Low pass
High pass
2000 Hz
100 Hz
Measured
2000
Masking
Off
Wave repro.
10 %
Rejected
1%
Stimuli/Sec
21.1
LP
2000 Hz
HP
100 Hz
Gain
92 dB
Polarity
Burst,2.0K Rarefaction
[750 nV
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
mS
dB nHL


Record
Edit
Latency
Latency times
mS
µV
I
2.17
0.049
II
III
4.17
0.101
IV
V
5.9
0.267
X
Y
Z
I-III 2.0
III-V 1.73
I-V 3.73
Cursor
Fixed
Cursor
Diff.
mS
µV
Filter setting
Low pass
High pass
1000 Hz
None
Measured 2000 Masking Off Wave repro. 100 %
Rejected 1% StimuliSec 21.1 LP 1000 Hz HP None
Gain 92 dB Polarity Burst,2.0K Rarefaction
Goddag
[250 nV
60
60
50
50
40
40
30
30
20
20
10
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
mS
dB nHL

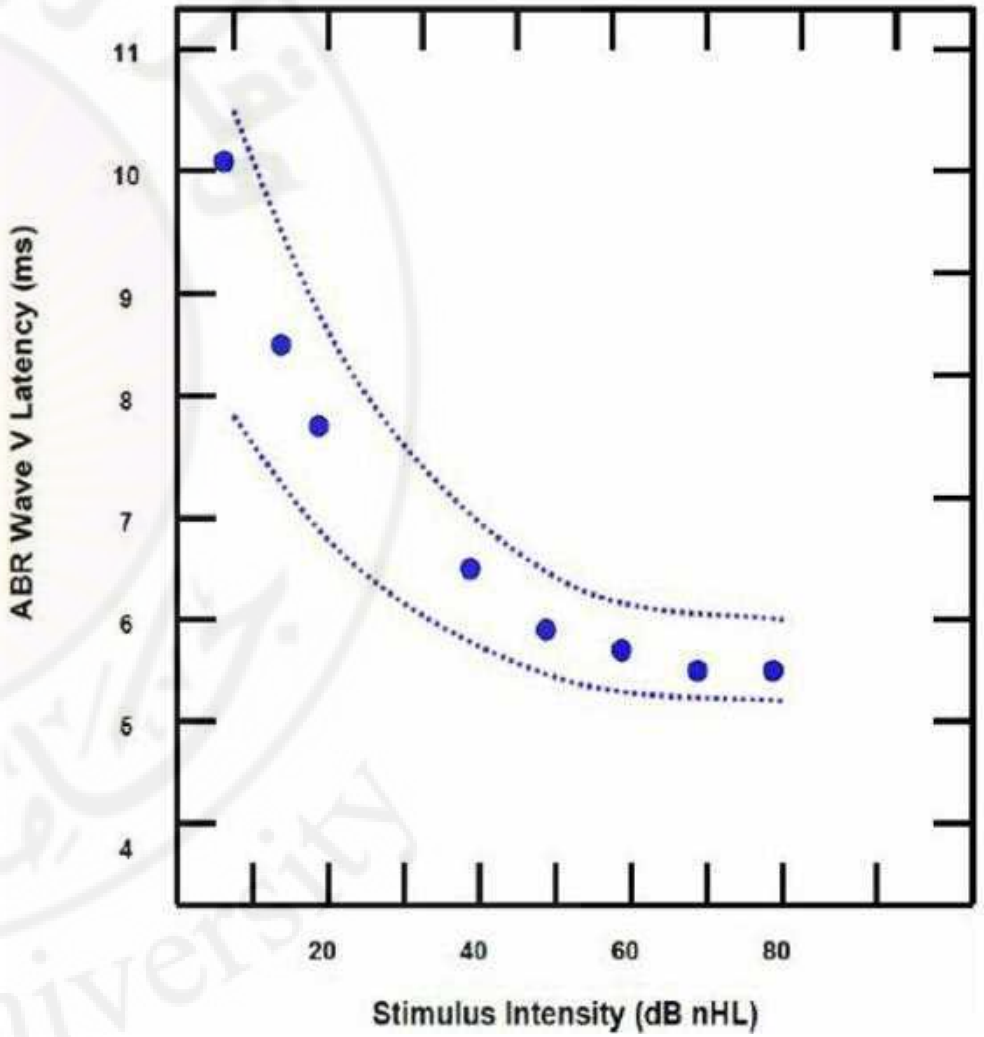
Click ABR limitations in threshold estimation

- Click threshold are **not frequency specific** and generally be 10-20 dB higher than best audiometric thresholds within the mid-to-high frequency range.
- For cochlear losses, the difference between click threshold and audiometric thresholds is often reduced (as close as 5 dB above the best behavioral threshold).
- Maximum output for clicks is limited to 90-100 dB nHL (0 dB nHL = 30 dB peSPL), and can not **differentiate between severe and profound** hearing losses.



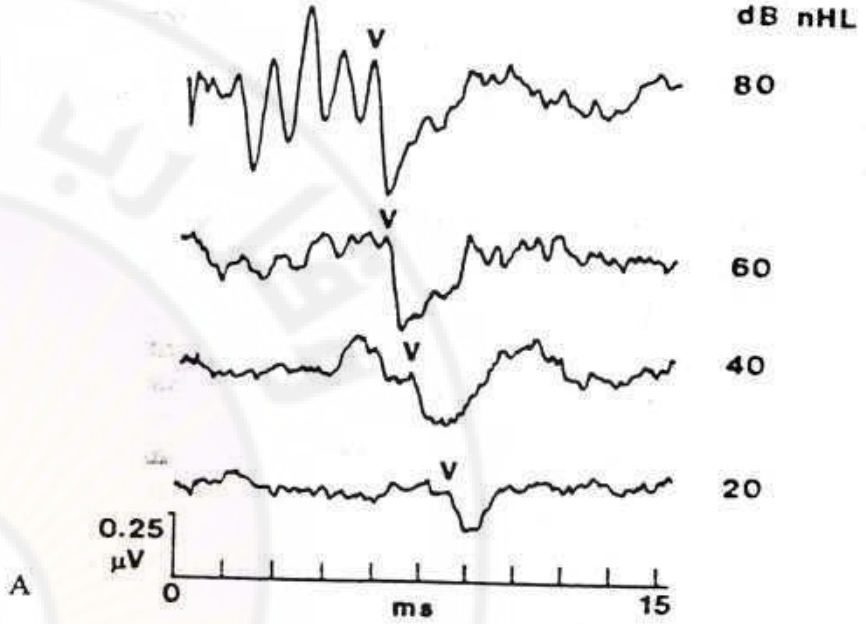
Click-ABR Latency-intensity Function (LIF)

- Wave V latency values are plotted as a function of intensity.
- At high intensity levels of 75 to 95 dB nHL, wave V latency is normally in the region of 5.5 to 6.0 ms.
- Wave V latency increases by about 2-ms over the range from high intensity levels of about 80 dB to near-threshold levels of 20 dB. That is, over this intensity range absolute latency increases from about 5.5-ms to 7.5-ms.

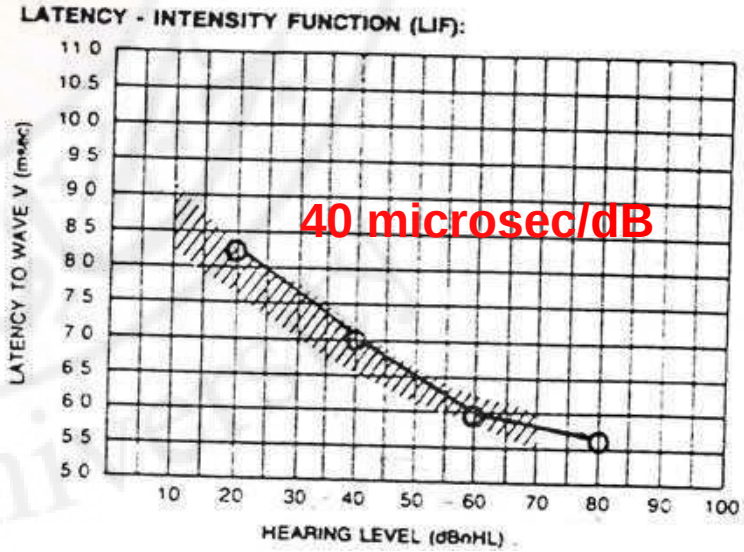


Click ABR LIF in normal hearing

- Slope of LIF for click stimuli can be used to provide some information about **type** of hearing loss, and audiometric **configuration**.



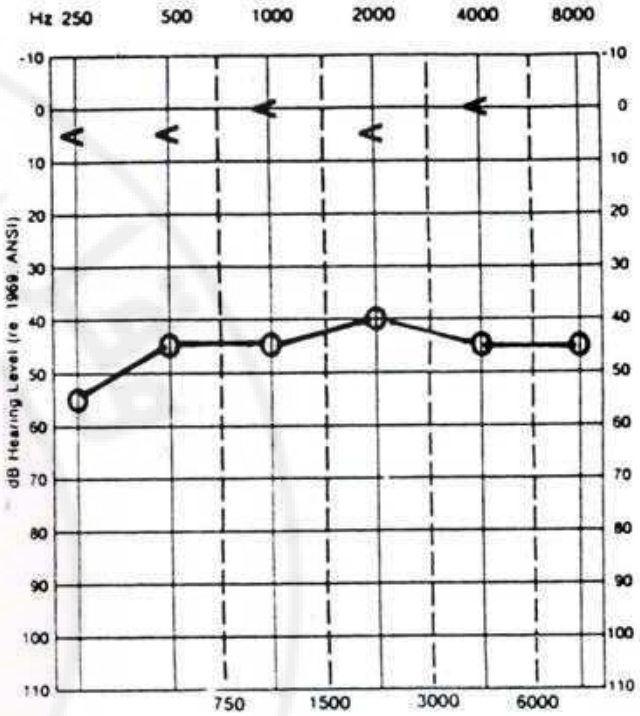
A

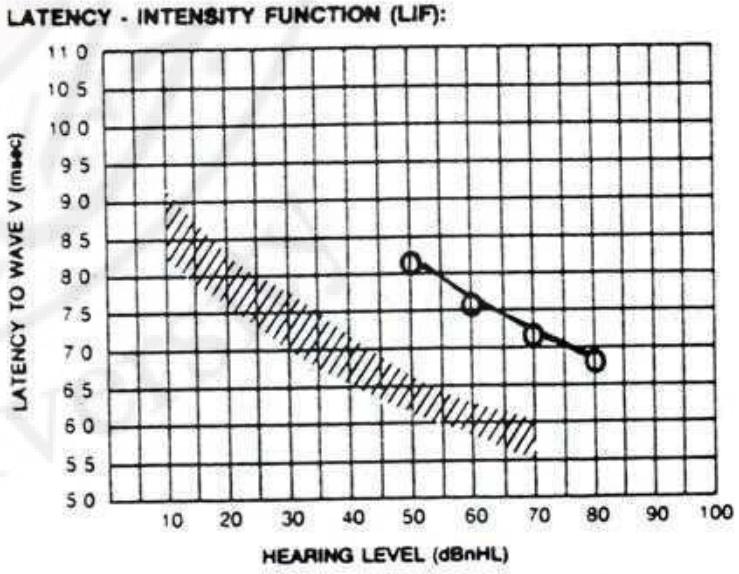


B

Click ABR LIF in CHL

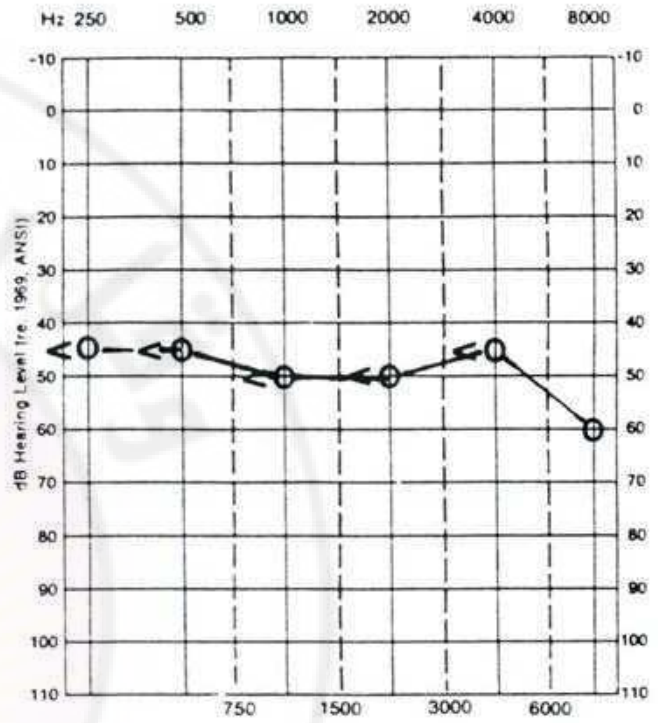
- Slope of LIF is typically normal.
- The latency of wave V at each intensity will be prolonged resulting in an LIF that turns parallel to normal curve but is shifted to the right.

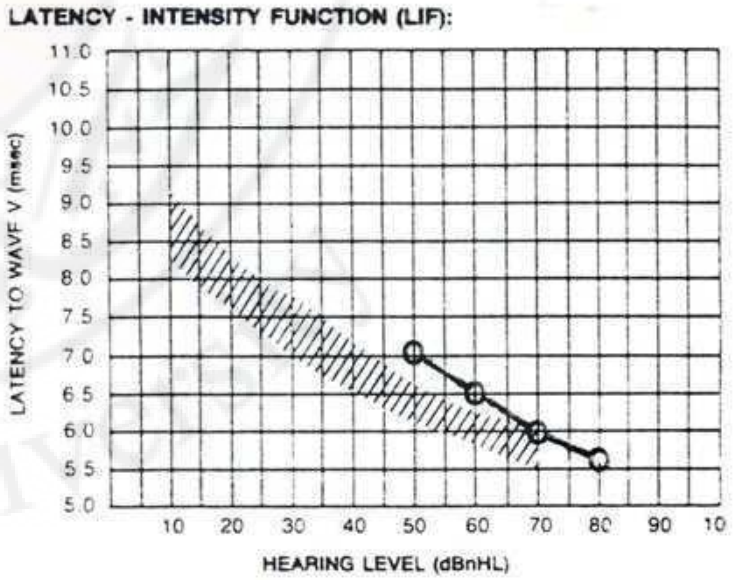




Click ABR LIF in Flat SNHL

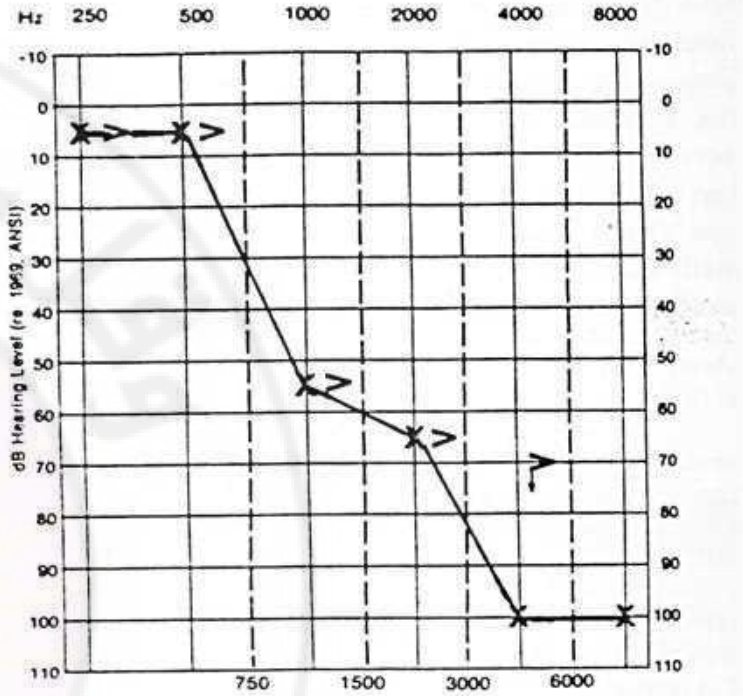
- Wave V latencies may fall within the normal range for all intensities where present or may be slightly prolonged at levels near threshold.
- The prolongation is less than seen for conductive losses.

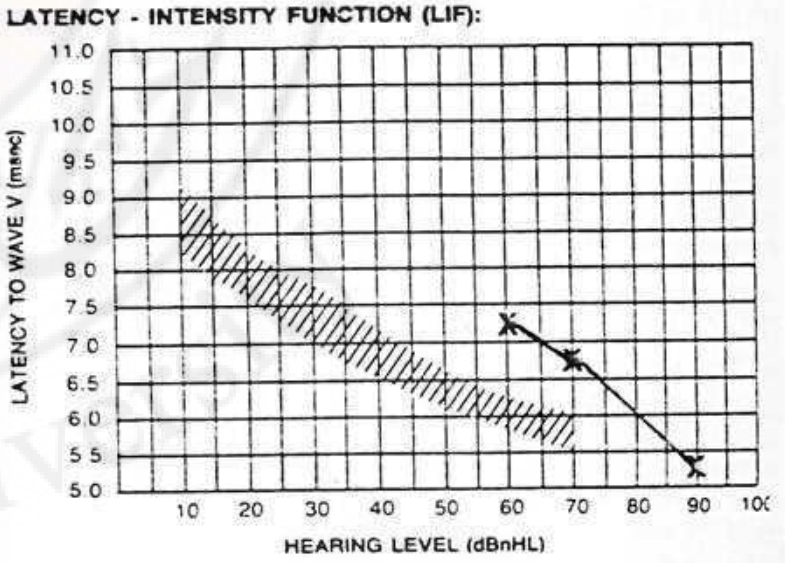




Click ABR LIF in steeply slope SNHL

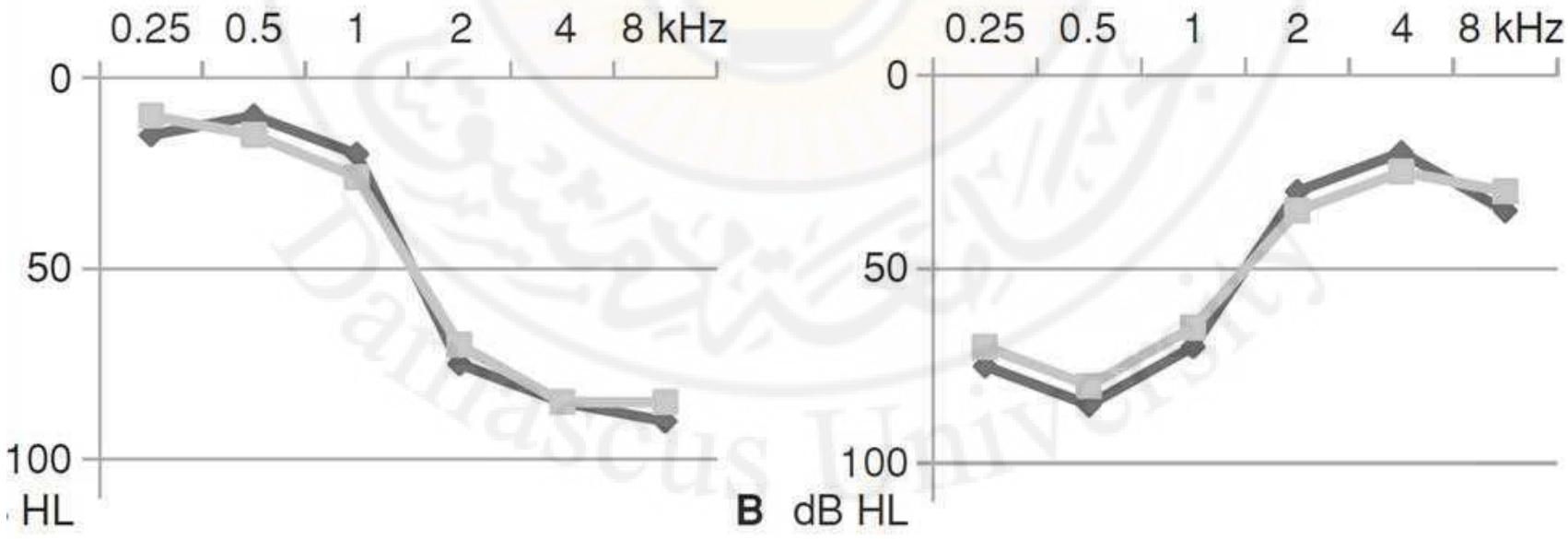
- The slope of LIF is typically steeper than normal.
- Wave V latency is substantially prolonged at and near threshold levels, but is normal or nearly normal at higher intensity levels.





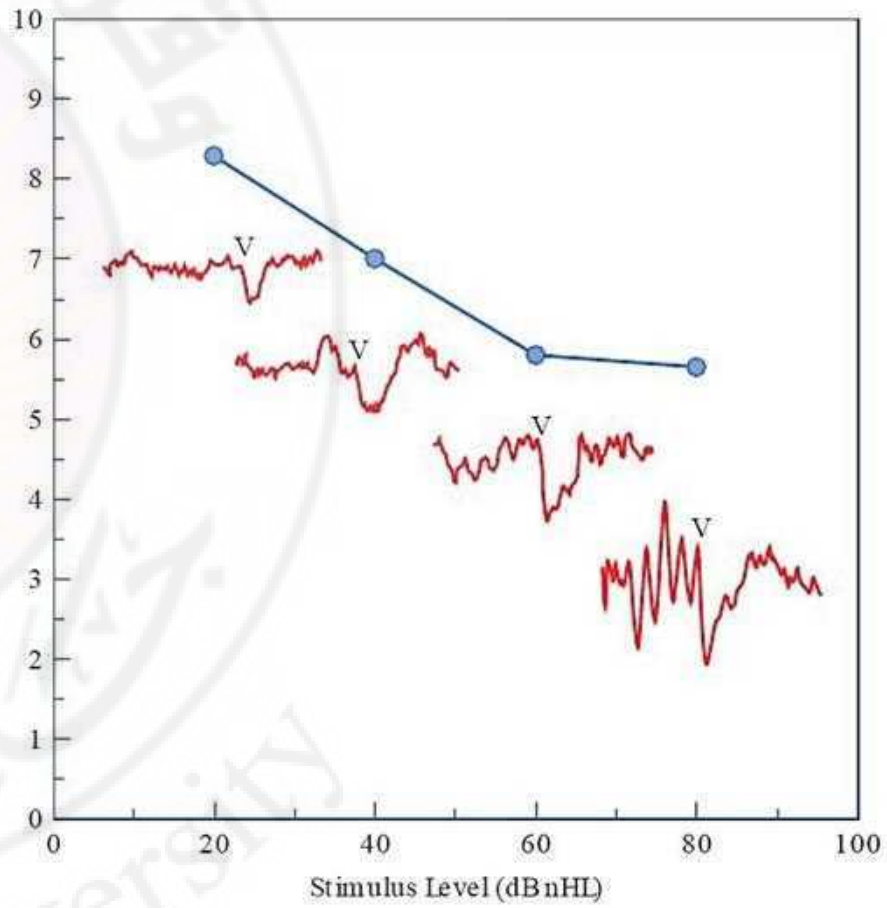
Click ABR is not appropriate for threshold testing

- Because clicks are broad band in nature and also stimulate more basal regions of the cochlea, it is not possible to know the exact frequency range being tested. This is particularly problematic in patients with sloping (either positively or negatively) hearing losses.
- Responses to clicks will be dominated by cochlear basal responses and will not reflect a hearing loss in more apical regions of the cochlea.



Click ABR agreement with puretone thresholds

- A 100-microsecond electrical pulse, impressed on an earphone, generates a broadband signal whose primary frequency emphasis is determined by the resonant frequency of the transducer.
- With earphones typically used in clinical evaluation, the maximum energy peaks of these clicks are focused in the frequency region between 1,000 and 4,000 Hz.
- **The greatest agreement with puretone thresholds is in the 2,000- to 4,000-Hz frequency range**

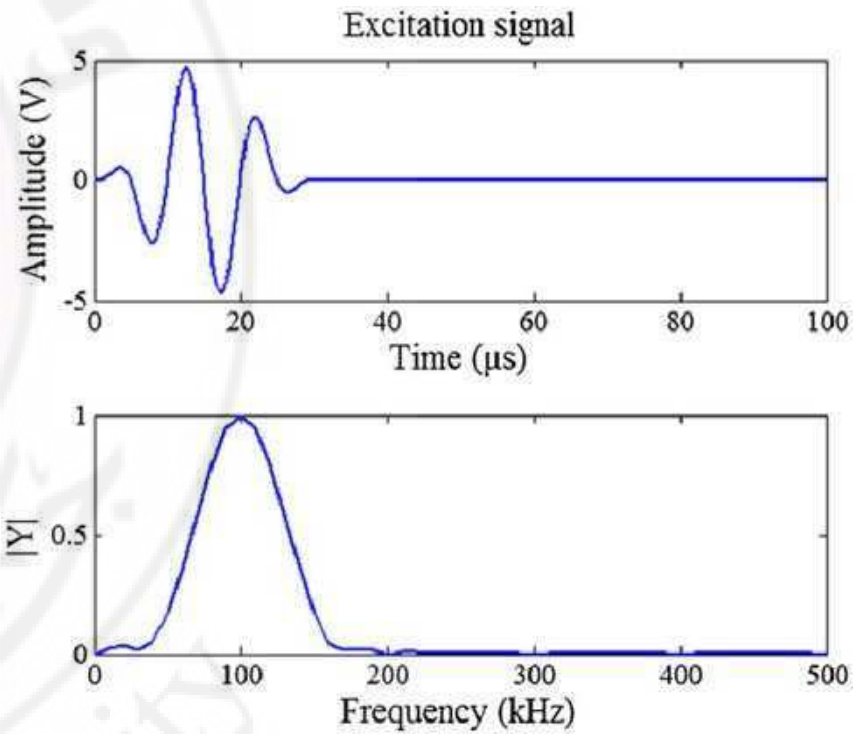


Why continuing to record Click-ABR?

1. Waveform analysis for high intensity click stimulation usually differentiates among major types of hearing loss, specifically conductive, sensory and neural.
2. Analysis of click-evoked ABR waveforms for a modest number of lower intensity levels contributes to prompt distinction between the likelihood of normal hearing sensitivity versus hearing loss.
3. A clear wave I confirms that ABR findings are ear-specific.
4. Click-evoked ABR findings speed up decisions about the next logical steps in hearing assessment such as tympanometry, OAEs, bone conduction ABR and ASSR.
5. Analysis of waveforms elicited with rarefaction polarity versus condensation polarity click stimuli permit the differentiation of CM versus an ABR and identification of ANSD.

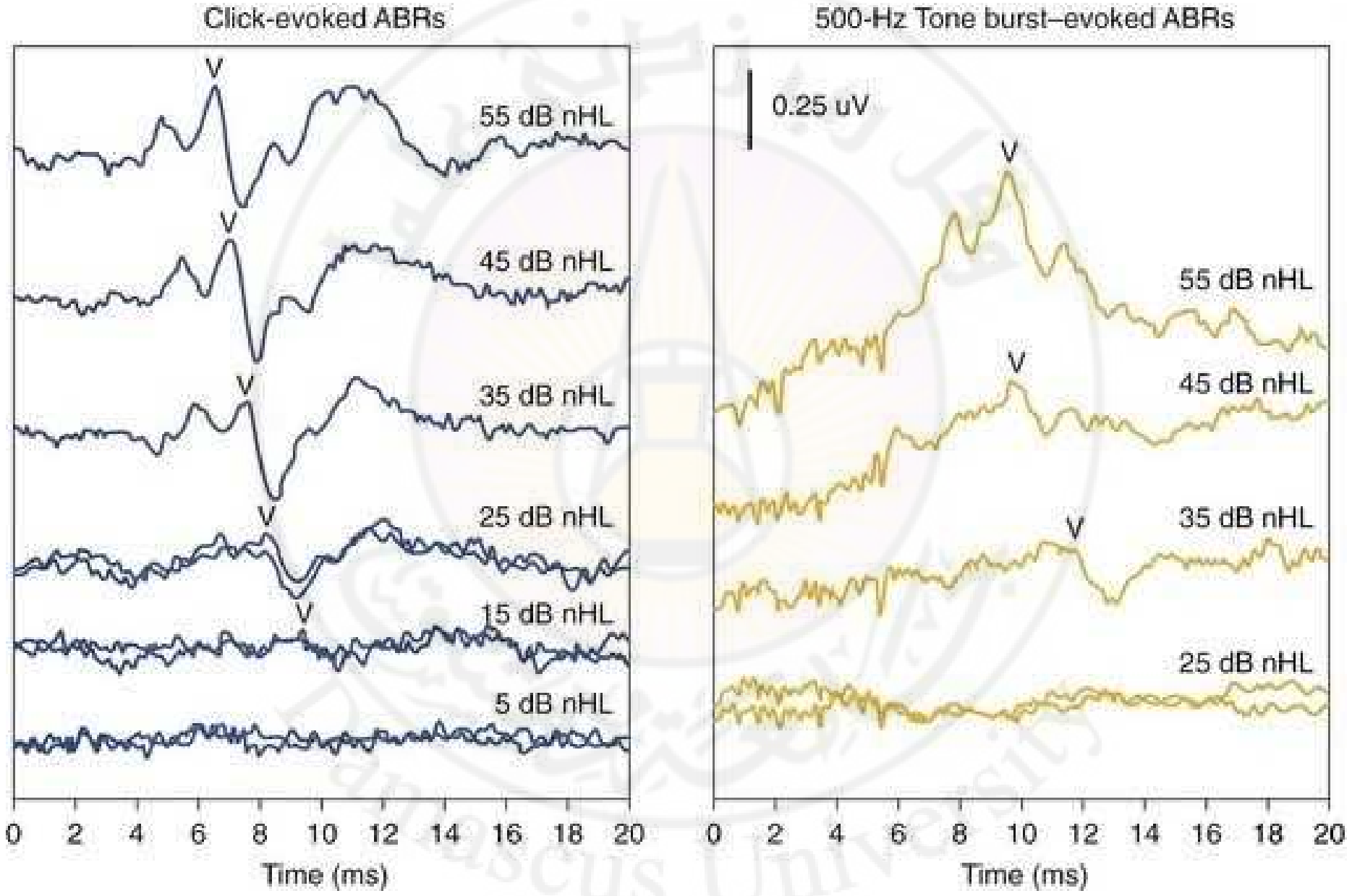
Frequency Specific Stimuli

- The overall objective for clinical application of ABR in infants is diagnosis and **frequency-specific estimation of hearing loss**, information that is essential for appropriate decisions regarding early intervention.
- Several types of stimuli and recording methods have been proposed to obtain responses from narrower frequency regions.
  - **Tone bursts or tone pips**
  - **Filtered clicks**
  - **Tone bursts in notched noise**
  - **High-pass masking of clicks or tone bursts**
- Tone bursts are the most popular option for obtaining frequency-specific responses.



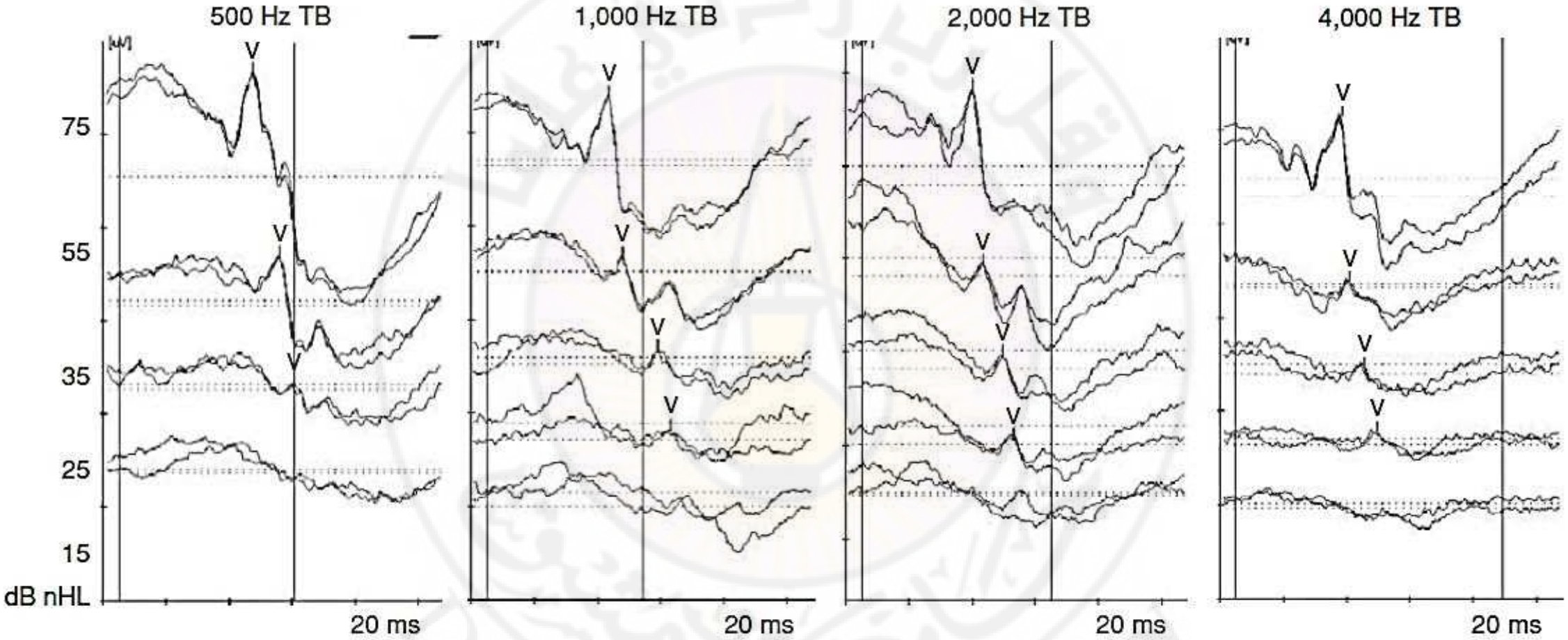
Frequency Specificity vs. Neural synchrony

- **Tone bursts** with longer rise times than clicks, will be **more frequency specific**, but will generate **poorer neural synchrony** which will affect the quality of the ABR.
- The goal of using ABR for threshold prediction is to stimulate isolated regions of the basilar membrane to analyze function in distinct frequency regions. Thus, control of spread of acoustic energy to surrounding frequencies works in opposition to the ability to activate a large number of neural units and obtain a clearly synchronous ABR.
- The more abrupt the acoustic onset of the stimulus, the more synchronous the neural discharge and the clearer the resulting ABR. However, as noted previously, abrupt onset, broadband stimuli have poor frequency specificity.
- the spectrum of the tone burst is considerably narrower than a click and thus stimulation along the basilar membrane is restricted and reasonably frequency specific. It is important to remember that the use of tone bursts results in stimulation of the cochlea at frequency regions surrounding the target frequency as well as at the desired frequency.


Click-evoked ABRs
V
55 dB nHL
45 dB nHL
35 dB nHL
25 dB nHL
15 dB nHL
5 dB nHL
0 2 4 6 8 10 12 14 16 18 20
Time (ms)
500-Hz Tone burst–evoked ABRs
0.25 uV
55 dB nHL
45 dB nHL
35 dB nHL
25 dB nHL
0 2 4 6 8 10 12 14 16 18 20
Time (ms)

Frequency Specificity vs. Place Specificity

- There is a difference between frequency specificity and place specificity.
- **Frequency specificity** refers to the characteristics of the stimulus whereas **place specificity** reflects a region of the cochlea.
- Although the frequency regions activated may be relatively narrow at low intensities, there is considerable spectral spread for moderate-to-high–intensity signals. When presented at higher intensities, on the order of 60 to 80 dB HL or higher, even puretones can activate wider frequency ranges on the basilar membrane surrounding the center frequency of the stimulus.
- **Spread of excitation** can be particularly problematic in underestimating hearing loss in individuals with steeply sloping hearing losses.
- A tone burst presented to an ear with a steeply sloping high-frequency hearing loss may yield a response, but that response may be generated from stimulation of a lower frequency responsive region where thresholds are better.



ABRs to tone bursts centered at 500, 1,000, 2,000, and 4,000 Hz recorded from an individual with normal hearing. The latencies of Wave V at 75 dB nHL are 8.53 ms for a 500-Hz tone burst, 7.70 ms for a 1,000-Hz tone burst, 7.03 ms for a 2,000-Hz tone burst, and 6.53 ms for a 4,000-Hz tone burst, demonstrating the latency decrease as center frequency of the tone burst increases.

Suggested Tone Burst ABR Test Parameters

Parameter	Comments
Stimulus	
Type	Tone burst
Polarity	Condensation for AC, alternating for BC
Intensity	Begin at 75 dB nHL, decrease in 20-dB steps, refine to 10-dB steps
Rate	27.7/s; 39.1/s for 500 Hz
Transducer	Earphone, bone oscillator
Recording	
Time window	20–30 ms
Filter band	High pass 30 or 100 Hz; Low pass 1,500 or 3,000 Hz
Number of sweeps	1,500–2,000 at high intensities, more sweeps nearer threshold
Electrode montage	Noninverting at vertex or high forehead; inverting at mastoid or earlobe; second channel recommended with inverting electrode at nape
Subject	
State	Sleeping, resting quietly, sedated for older infants

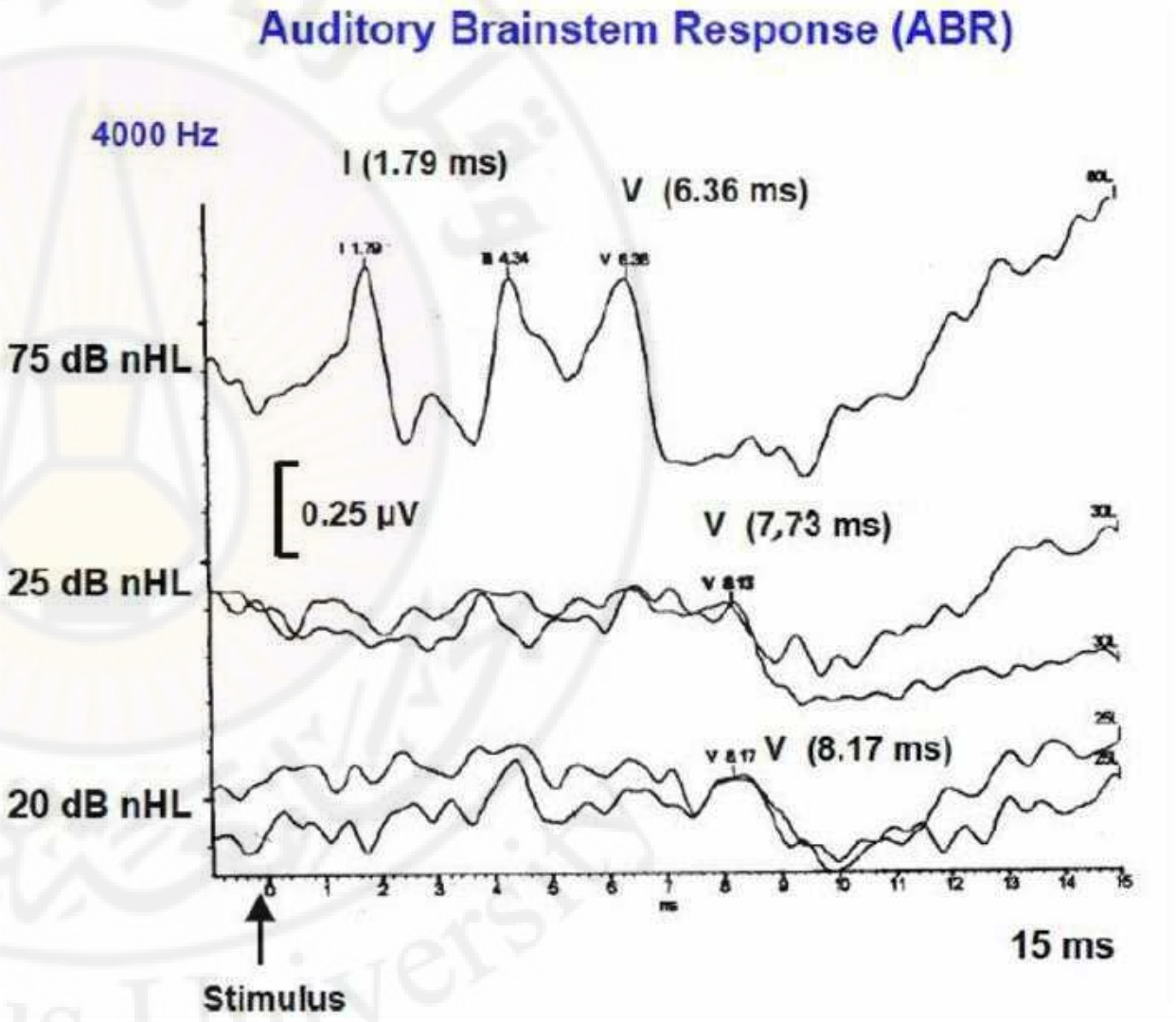
Analysis of Tone Burst ABR Waveforms

- ABR waveforms evoked with some tone burst stimuli differ from click-evoked ABR waveforms.
- ABR waveforms generated with high frequency tone bursts most closely resemble those for click stimuli.
- There are characteristic differences in waveforms for click and high frequency tone burst stimuli versus lower frequency tone burst stimuli.

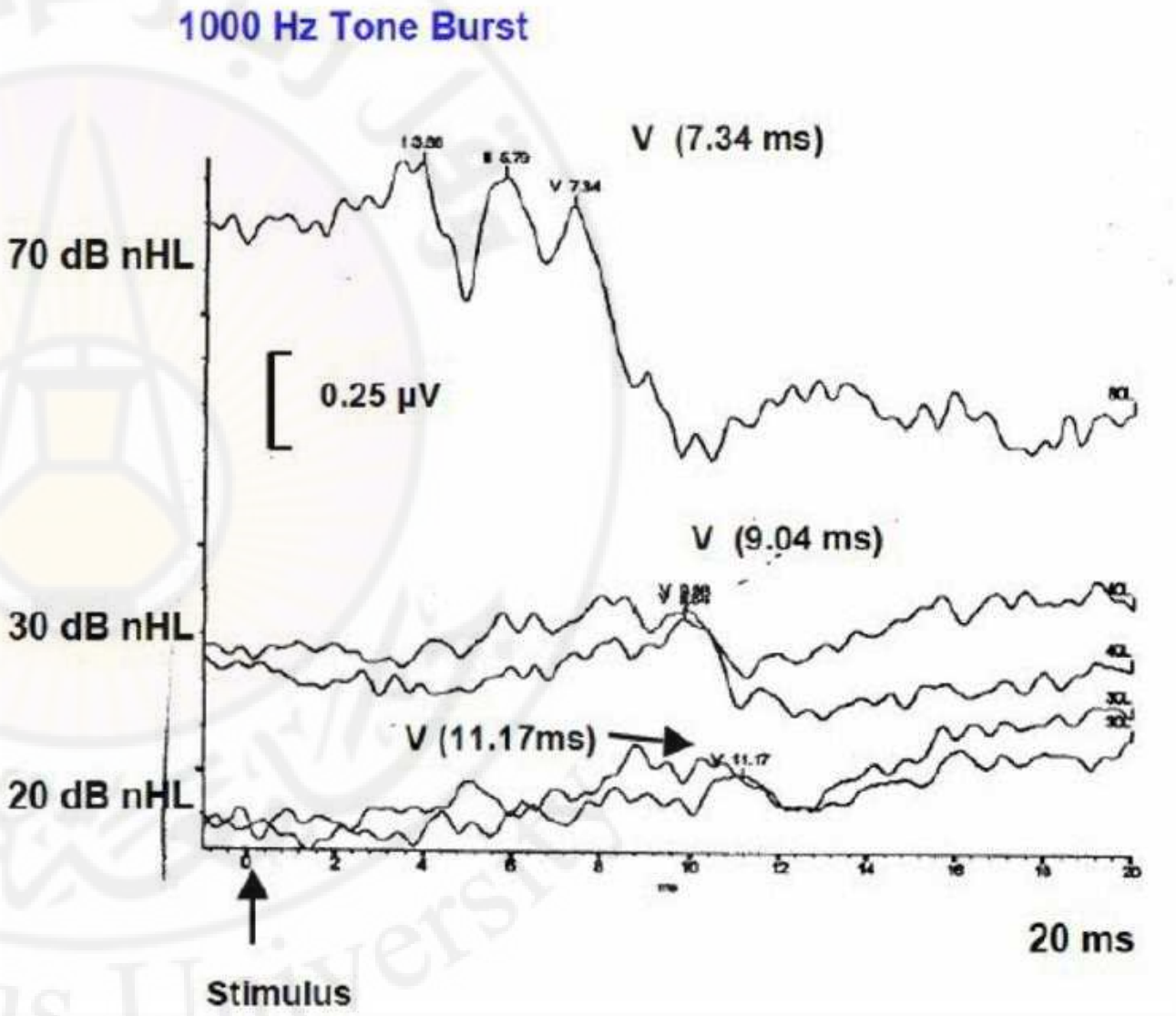
	Waveform Features		
Stimulus	Latency	Peaks	Wave I
Click	Shortest	Sharp	Present
4000 Hz	Shortest	Sharp	Present
1000 Hz	Longer	Less sharp	Usually present
500 Hz	Longest	Rounded	Often absent

Damascus University

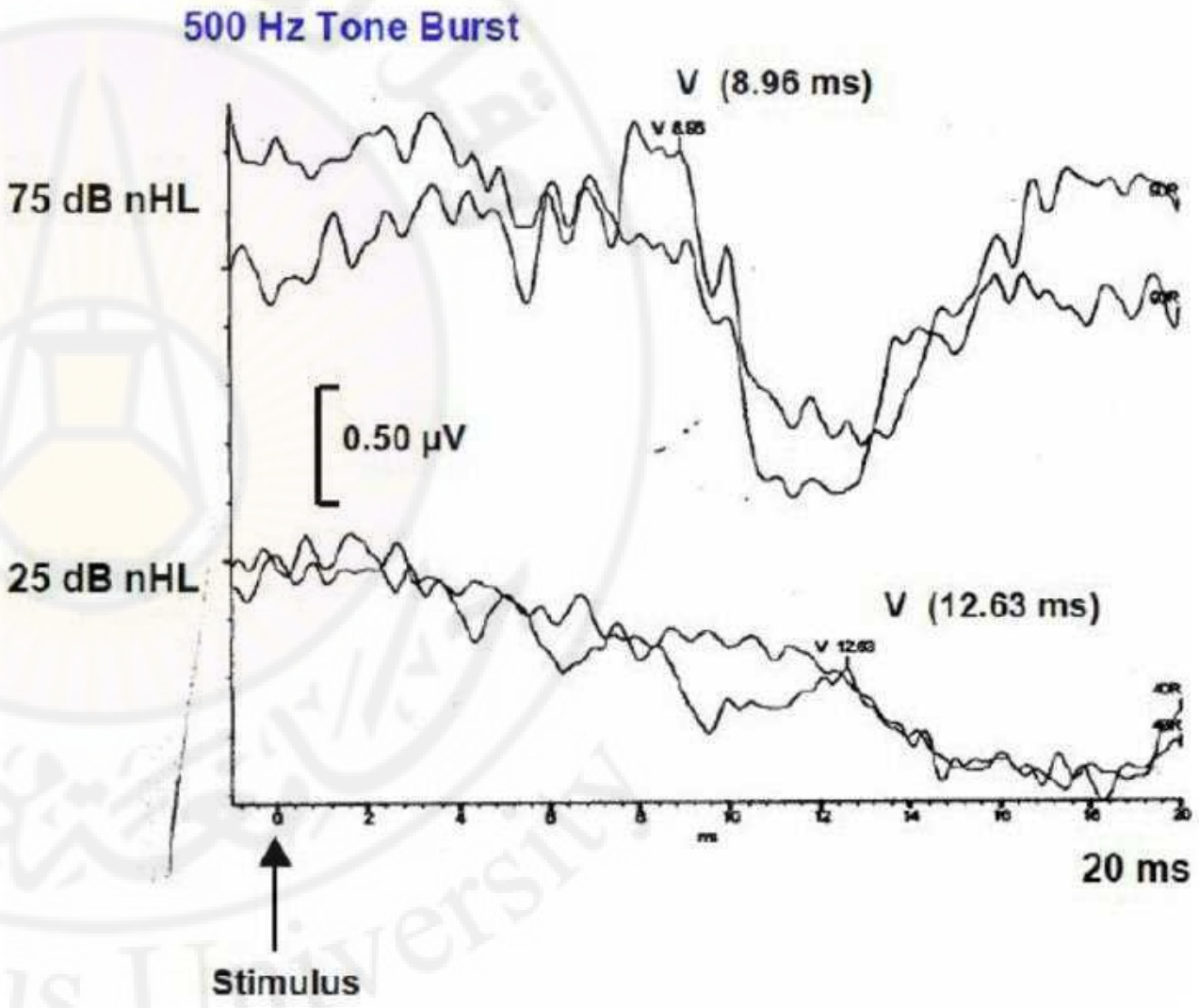
Waveforms for ABR elicited with a **4000 Hz tone burst** stimulus. The patient was a 1.5-year old child undergoing ABR assessment in the operating room under propofol anesthesia.

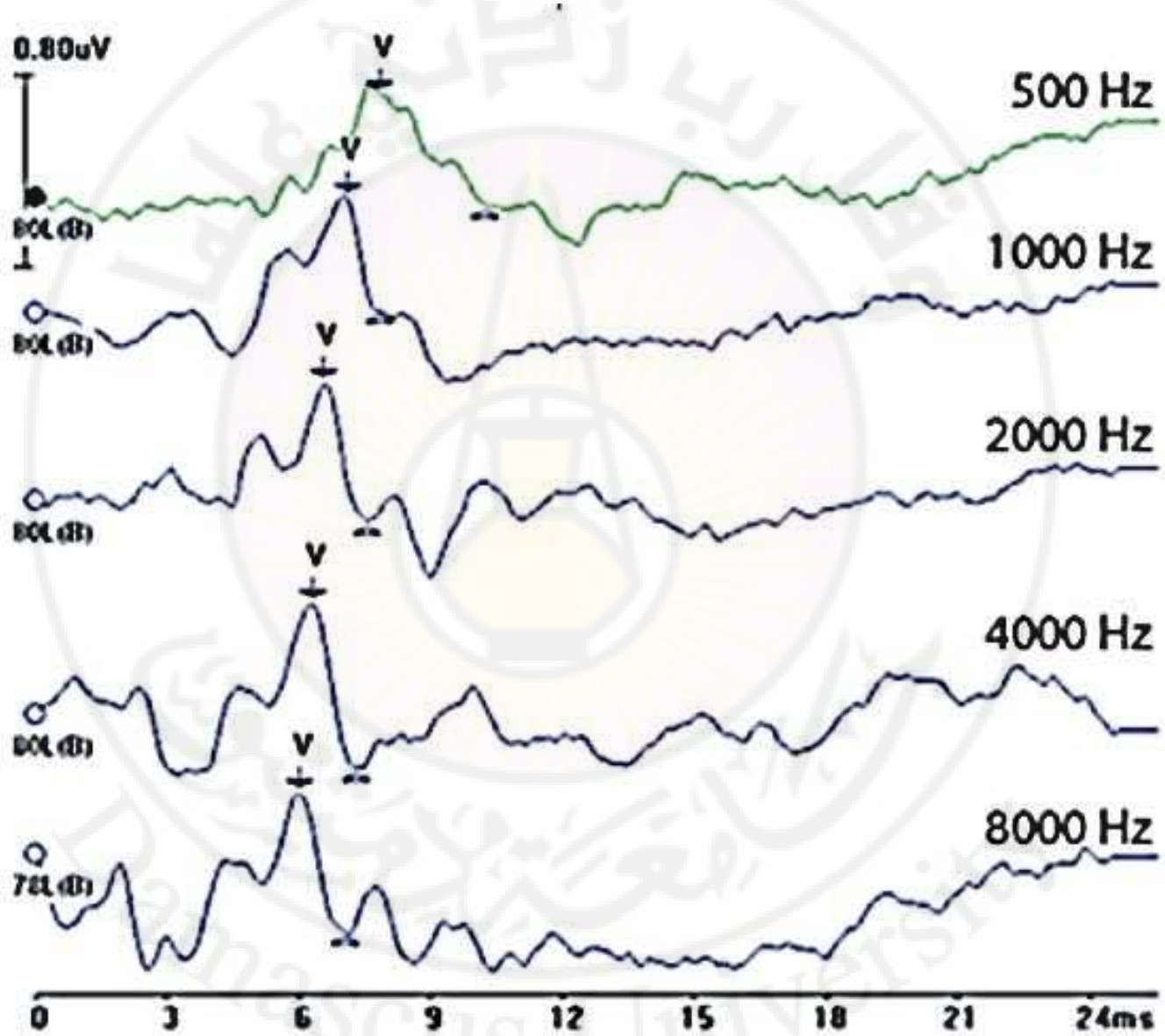


Waveforms for ABR elicited with a **1000 Hz tone burst** stimulus. The patient was a 1.5-year old child undergoing ABR assessment in the operating room under propofol anesthesia.

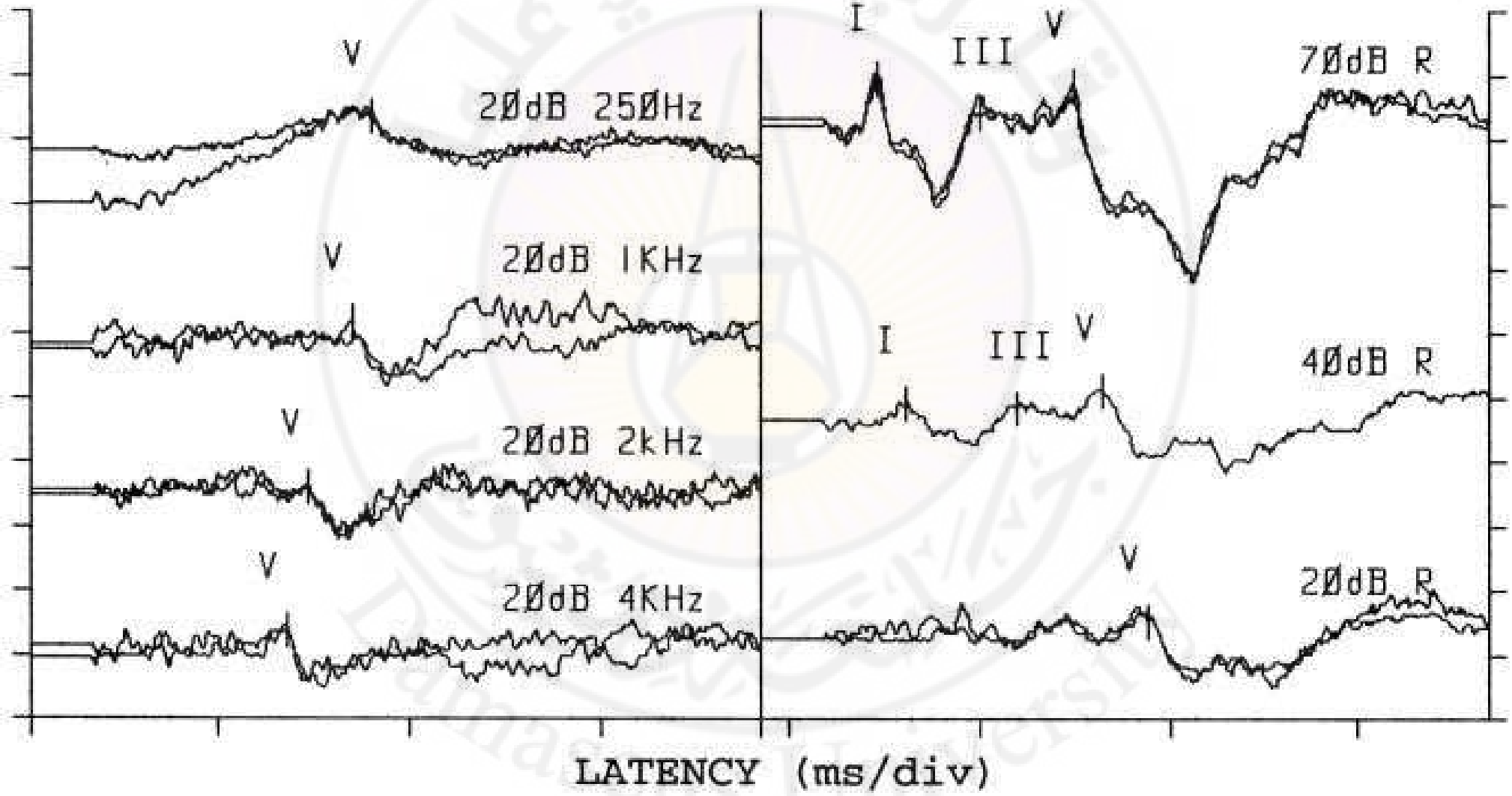


Waveforms for ABR elicited with a **500 Hz tone burst stimulus**. The patient was a 1.5-year old child undergoing ABR assessment in the operating room under propofol anesthesia.

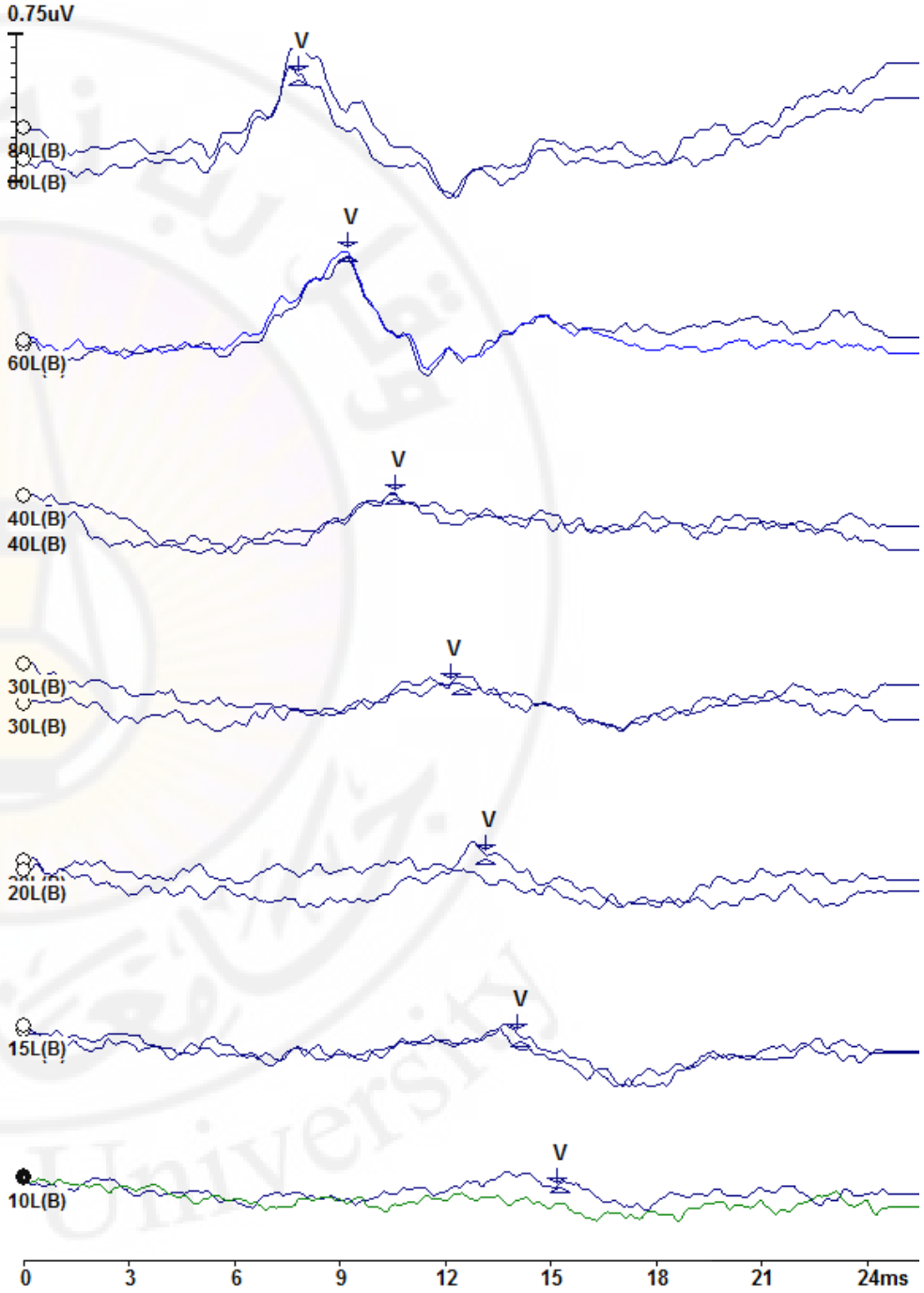



0.80uV
500 Hz
1000 Hz
2000 Hz
4000 Hz
8000 Hz
0
3
6
9
12
15
18
21
24ms

Normal Hearing

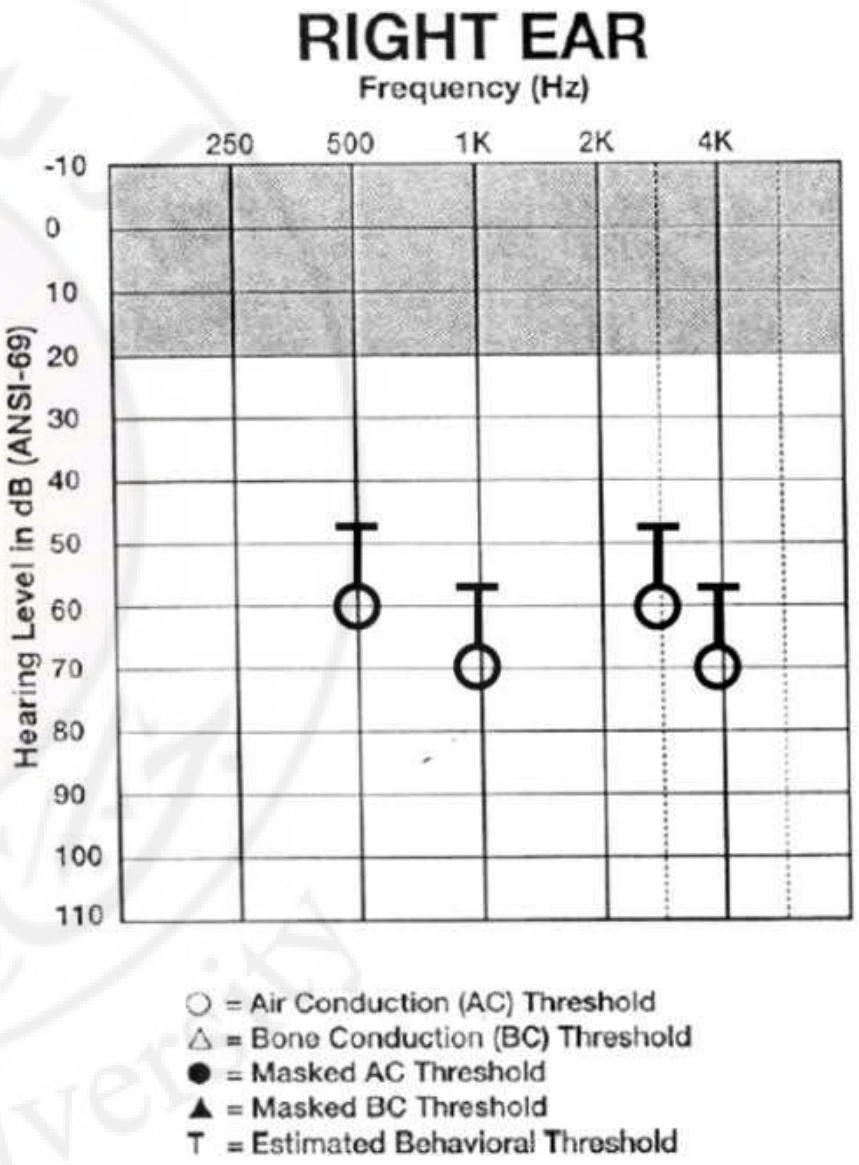


500 Hz evoked responses.



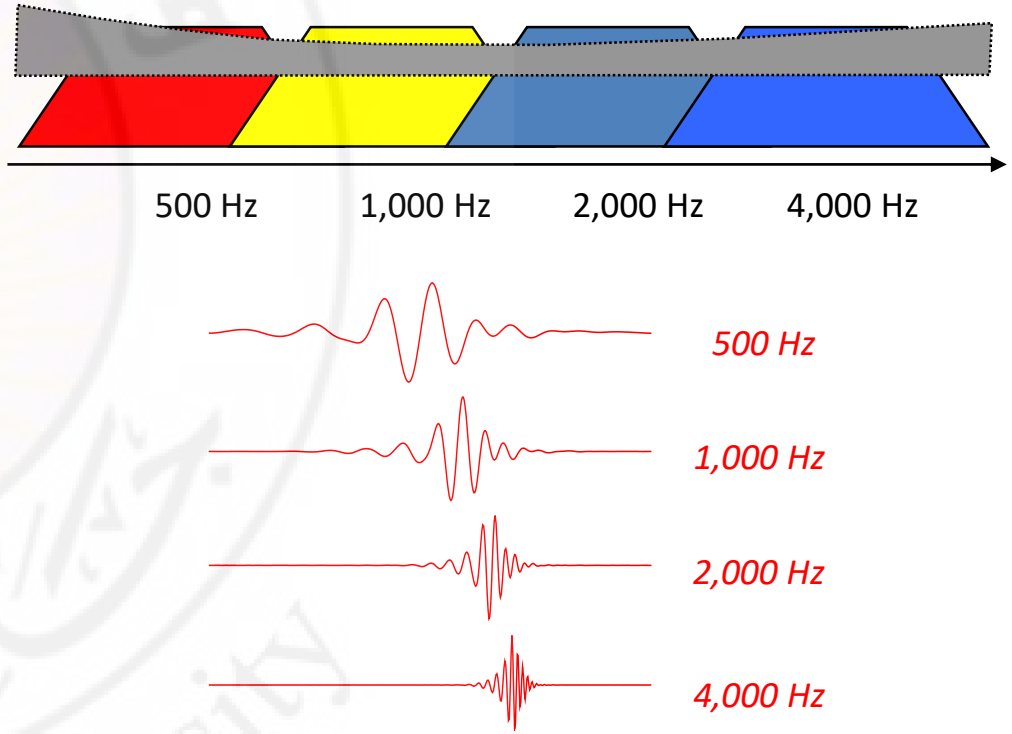
Plotting TB-ABR Thresholds

- After an ABR wave V is detected at minimum stimulus intensity levels for a specific stimulus and test ear, results can be plotted on a form resembling an audiogram.
- The minimum stimulus intensity level at which an ABR wave V is reliably recorded is usually determined in either 10 dB or 5 dB steps.
- The phrase **"minimum ABR level"** or **"minimum response level"** is sometimes used rather than ABR threshold to distinguish between an electrophysiological measure versus actual behavioral hearing threshold.

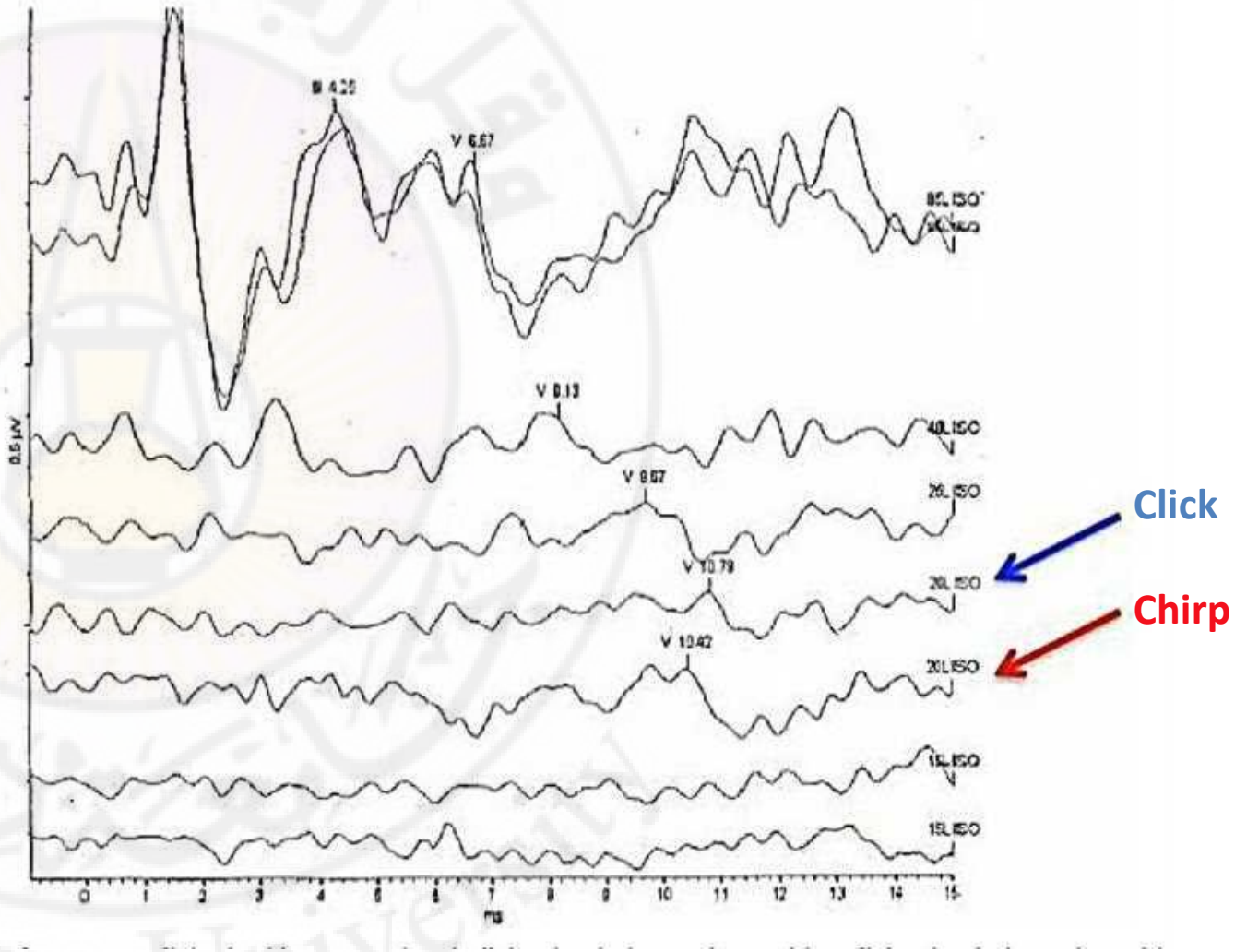


Chirp Stimuli for Frequency Specific ABRs

- Chirp stimuli are now available with some clinical auditory evoked response systems.
- **Broadband chirp** stimuli or chirp versions of clicks are sweep stimuli presented to the ear in a temporally coordinated fashion to effectively and simultaneously activate most of the cochlea. The result in an ABR with amplitudes up to two times larger than expected for conventional click stimulation. As a consequence it takes less test time to reach the minimum SNR ratio required to confirm the presence of an ABR.
- **Tone burst chirp (Narrow band Chirps)** stimuli offer the same advantage in pediatric ABR assessment.

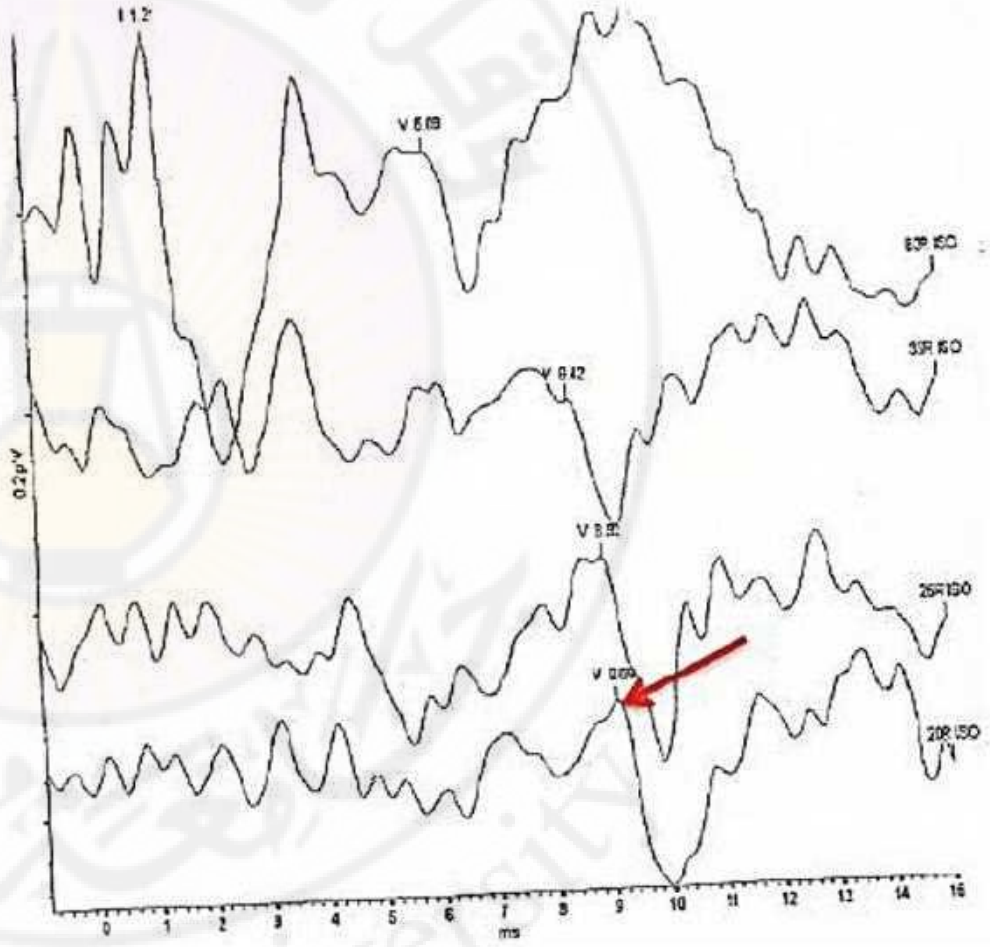


Waveforms for ABRs elicited with conventional **click** stimulation and **CE-chirp** click stimulation. The subject was a 2-year old boy undergoing ABR assessment due to concerns about very delayed speech and language acquisition. Blue arrow points to ABR waveform elicited with conventional click stimulus at 25 dB nHL and red arrow points to ABR waveform elicited with CE-chirp click stimulus at 25 dB nHL.



Waveforms for ABRs elicited with conventional **4000 Hz tone burst** stimulation and a **chirp 2000 Hz tone burst**. The subject was a 2-year old boy undergoing ABR assessment due to concerns about very delayed speech and language acquisition. Stimulus presentation rate was 37.7/second. The red arrow identifies ABR wave V at 20 dB nHL.

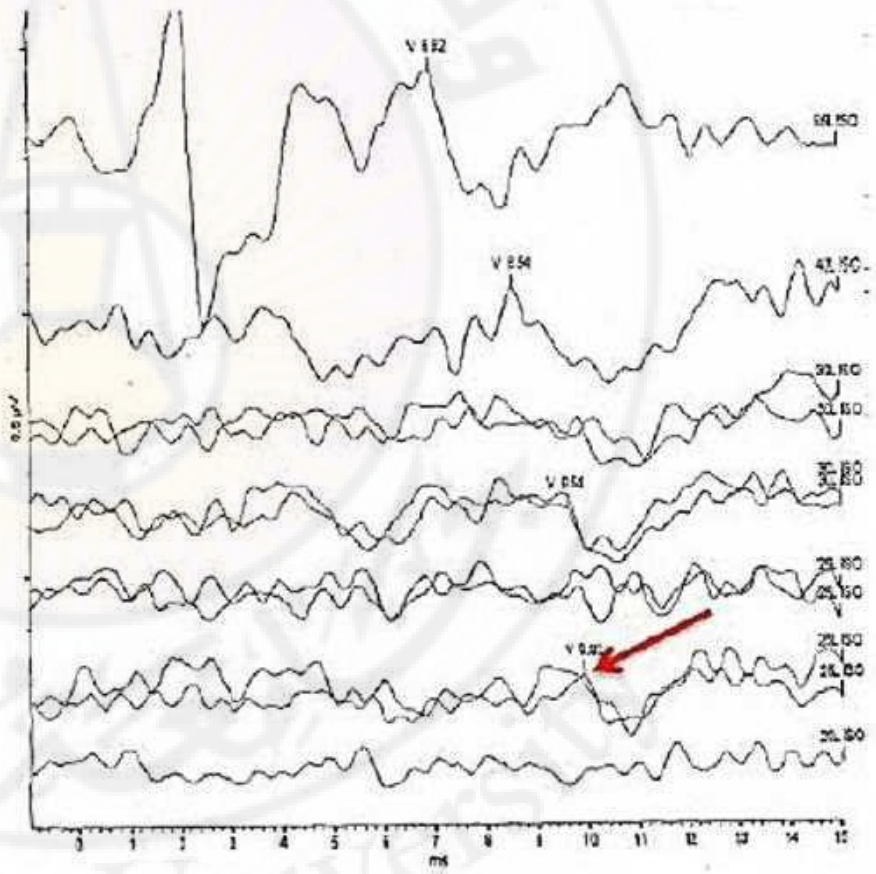
Total test time was only 61 seconds for recording ABRs for all four of the stimulus intensity levels!



20 dB nHL
570 sweeps

Advantages of tone burst chirp stimuli

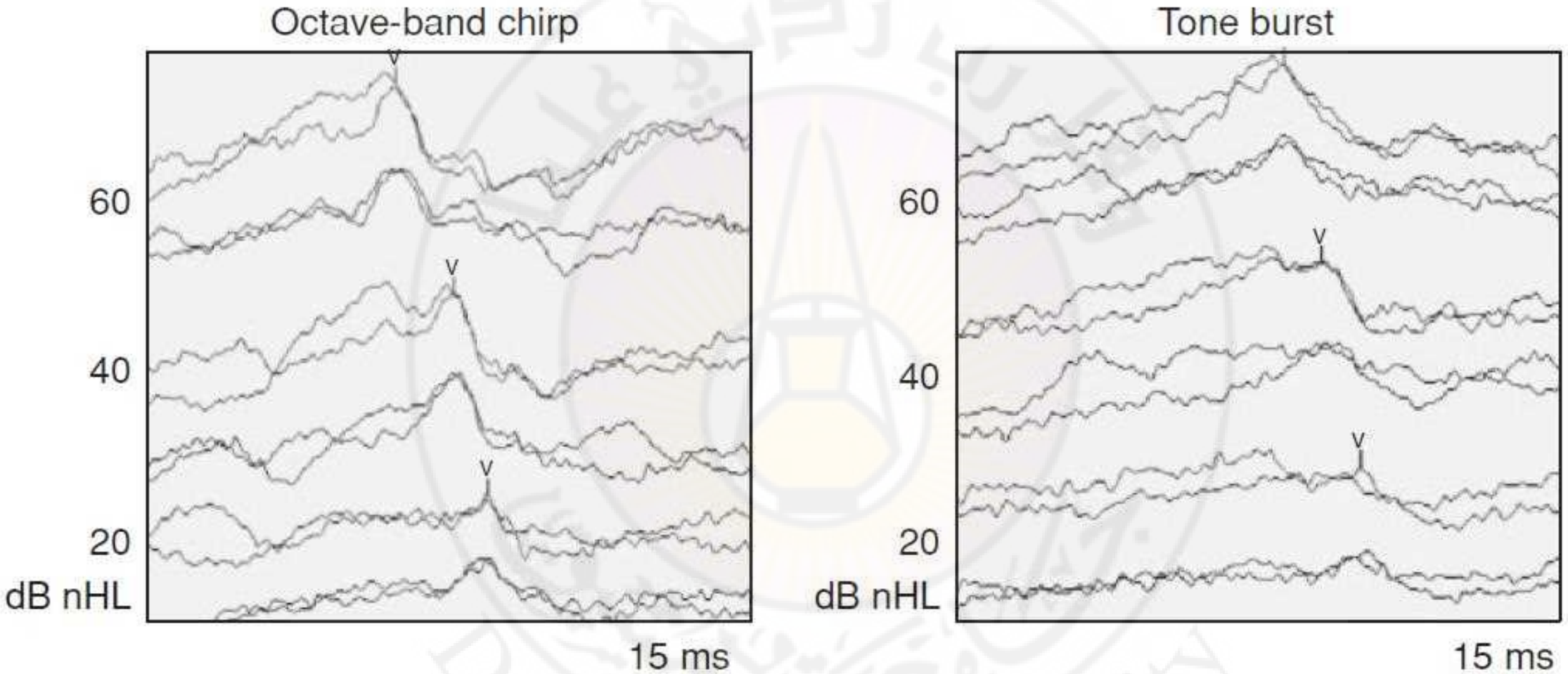
- chirps are designed to offset cochlear delays and increase synchronous neural firing, resulting in increased response amplitude.
- Less time required
- Confirming the presence of an ABR wave V at low intensity levels where conventional tone burst stimuli are insufficient to produce a detectable wave V.



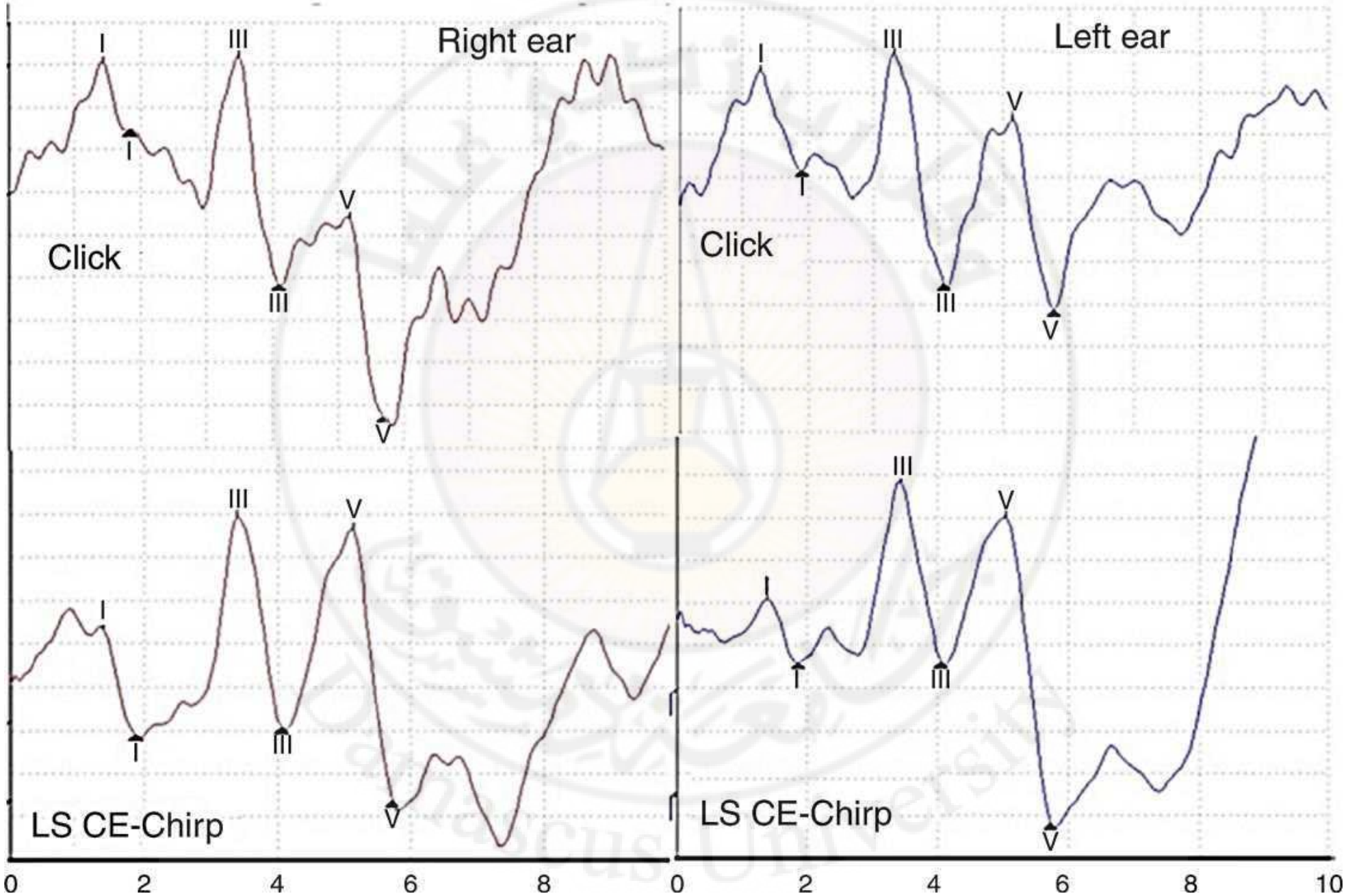
25 dB nHL Tone Burst

25 dB nHL Chirp

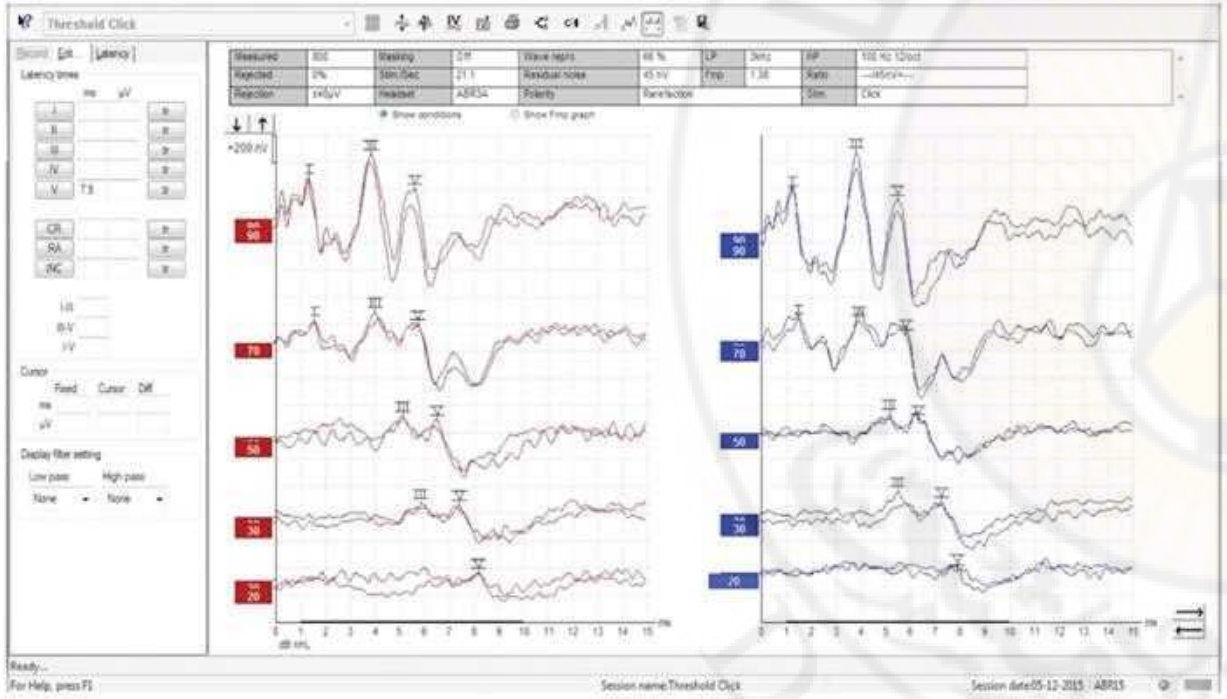
15 dB nHL Chirp



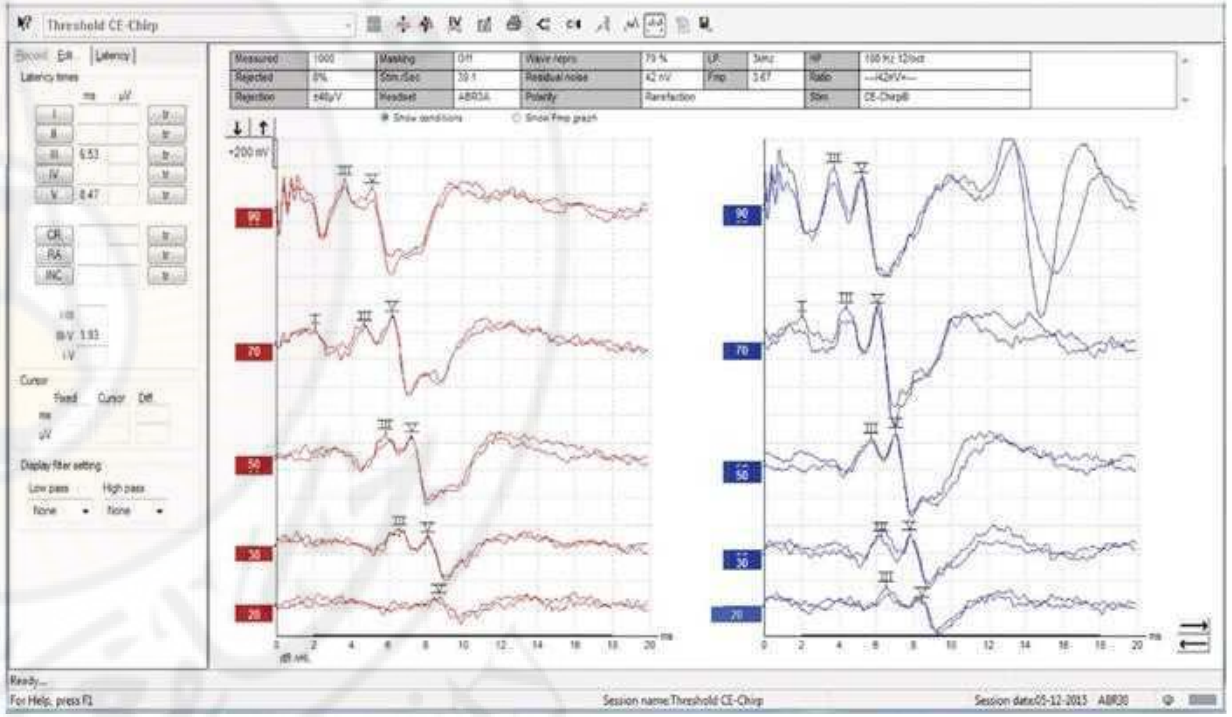
Examples of ABRs to octave-band chirps in the **left panel** and tone bursts in the **right panel** centered at 2,000 Hz recorded from an individual with normal hearing.

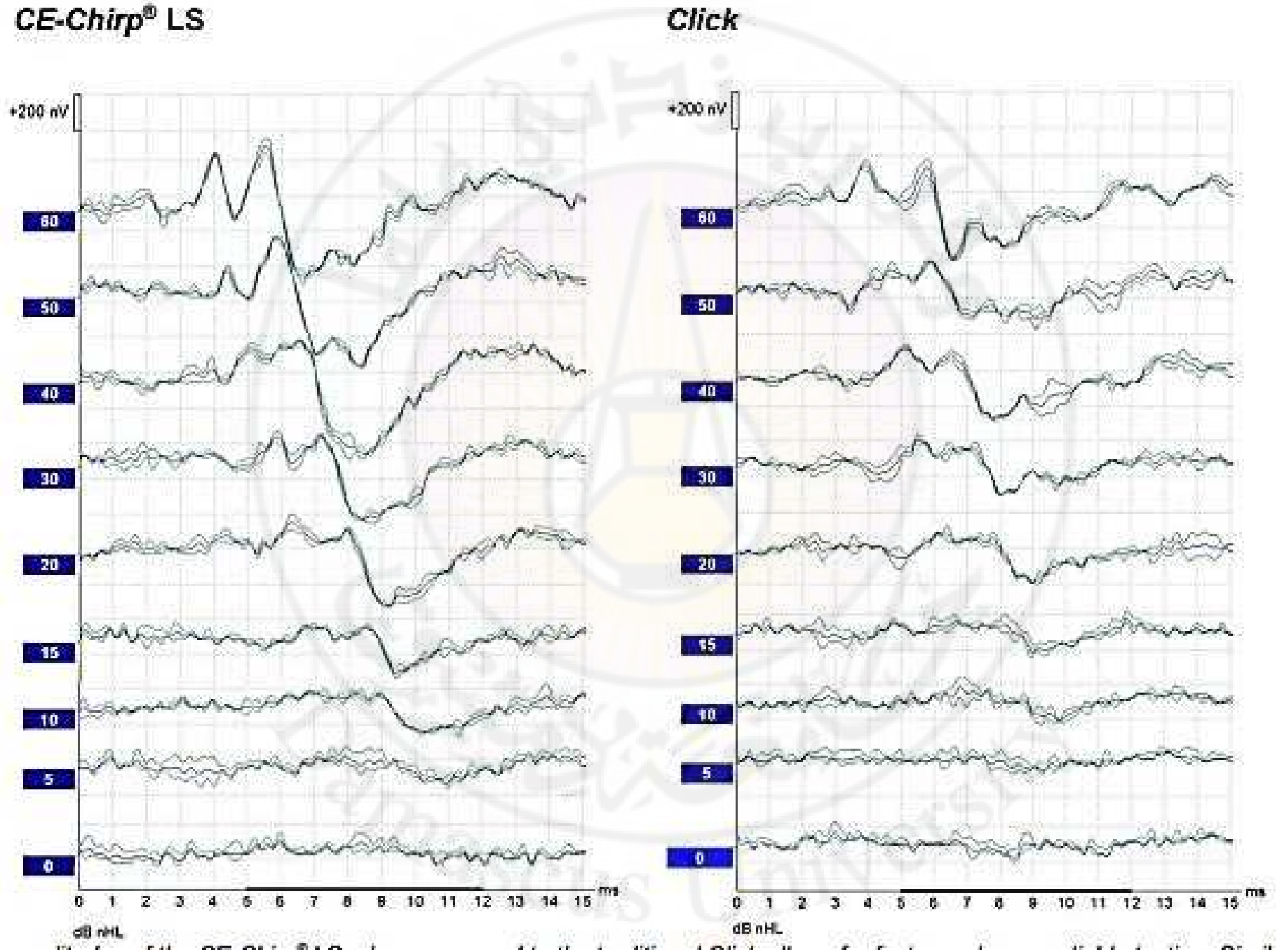

Right ear
Left ear
Click
Click
LS CE-Chirp
LS CE-Chirp
I
III
V
0
2
4
6
8
10

Click



Chirp

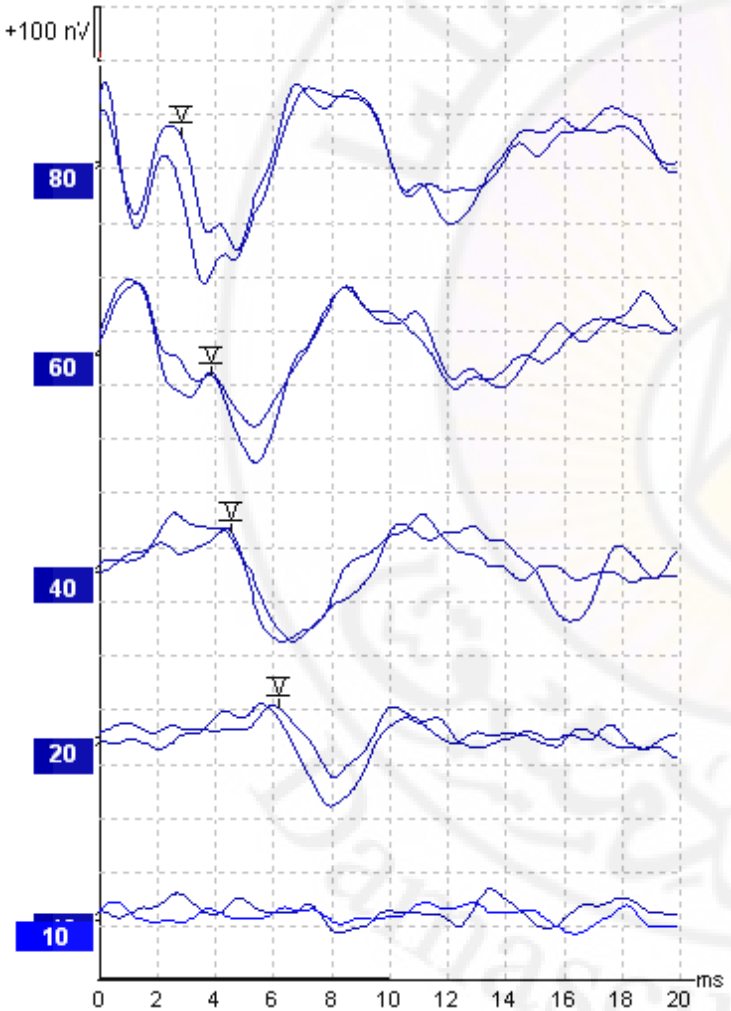



CE-Chirp® LS
Click
+200 nV
60
50
40
30
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ms
dB nHL

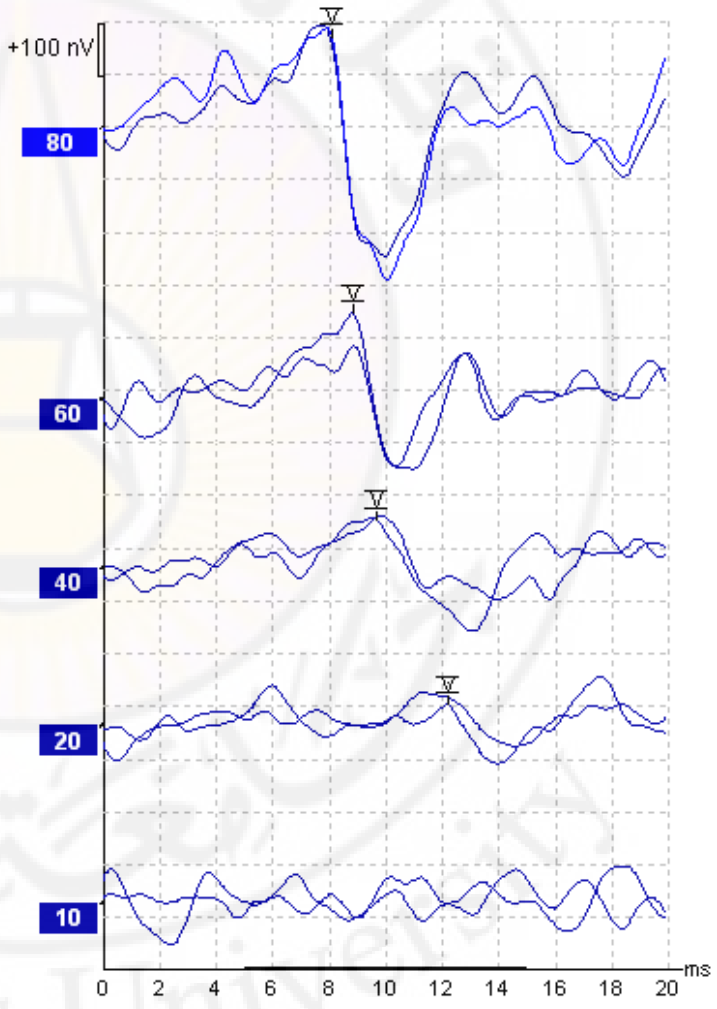
Auditory Evoked Responses

Mohsen Ahadi, Ph.D.
Associate Professor of Audiology
Iran University of Medical Sciences
Rehabilitation Research Center
ahadi.m@iums.ac.ir

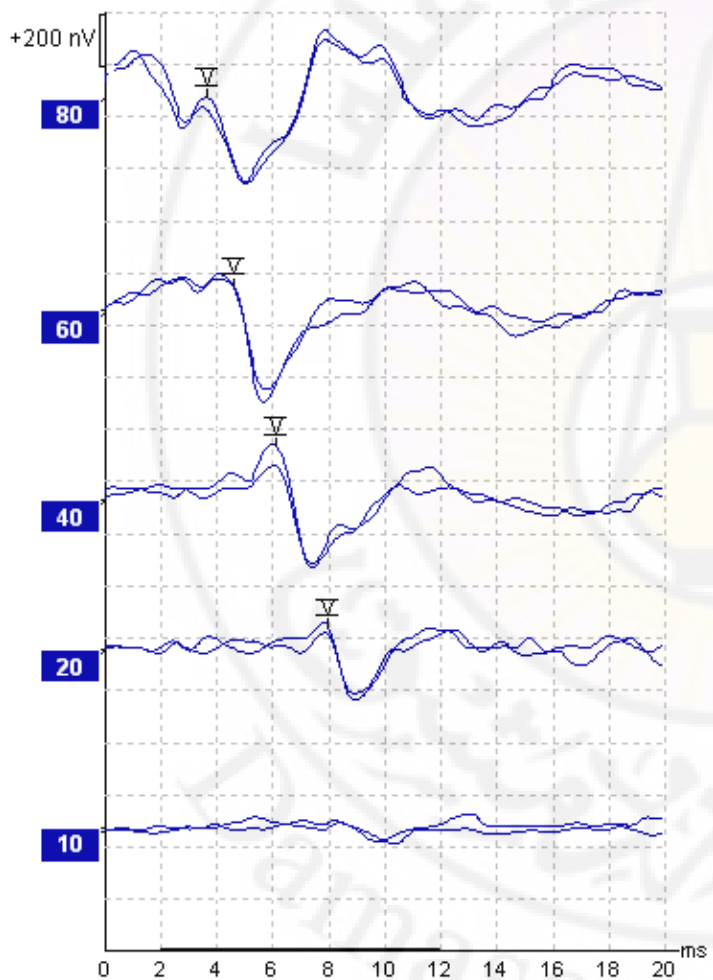
500Hz NB CE-Chirp



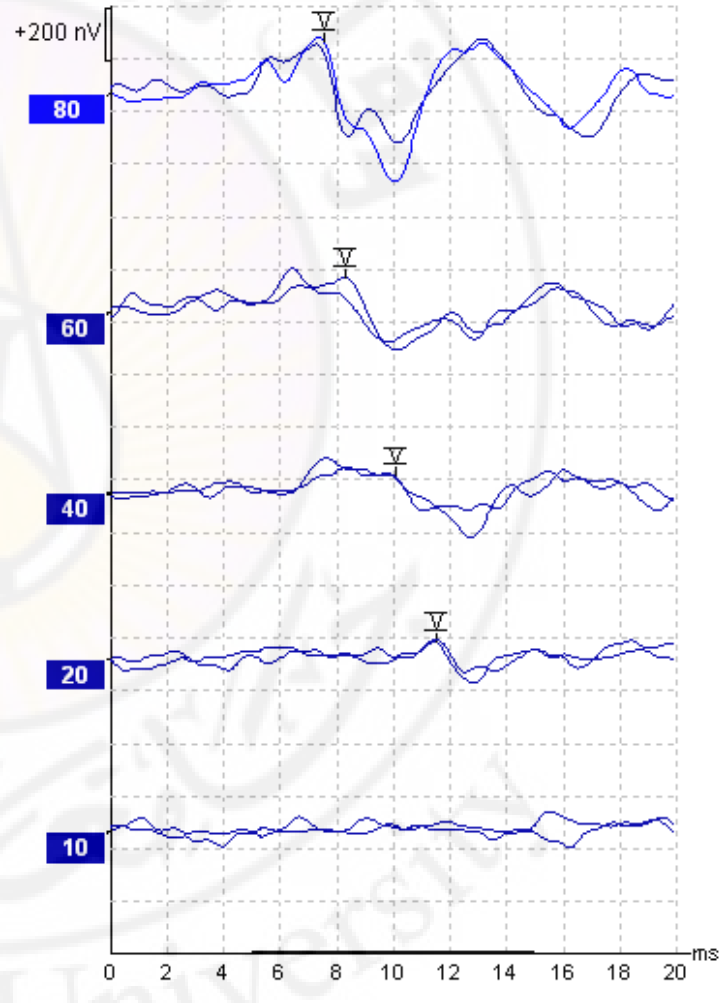
500Hz Tone Burst



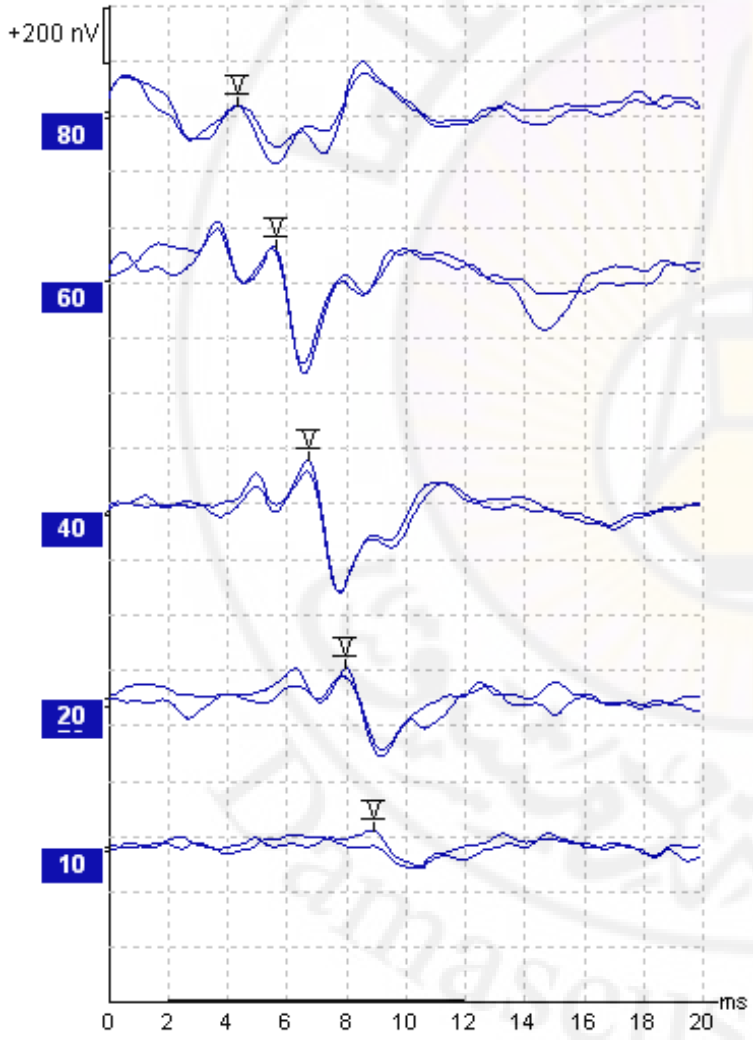
1kHz NB CE-Chirp



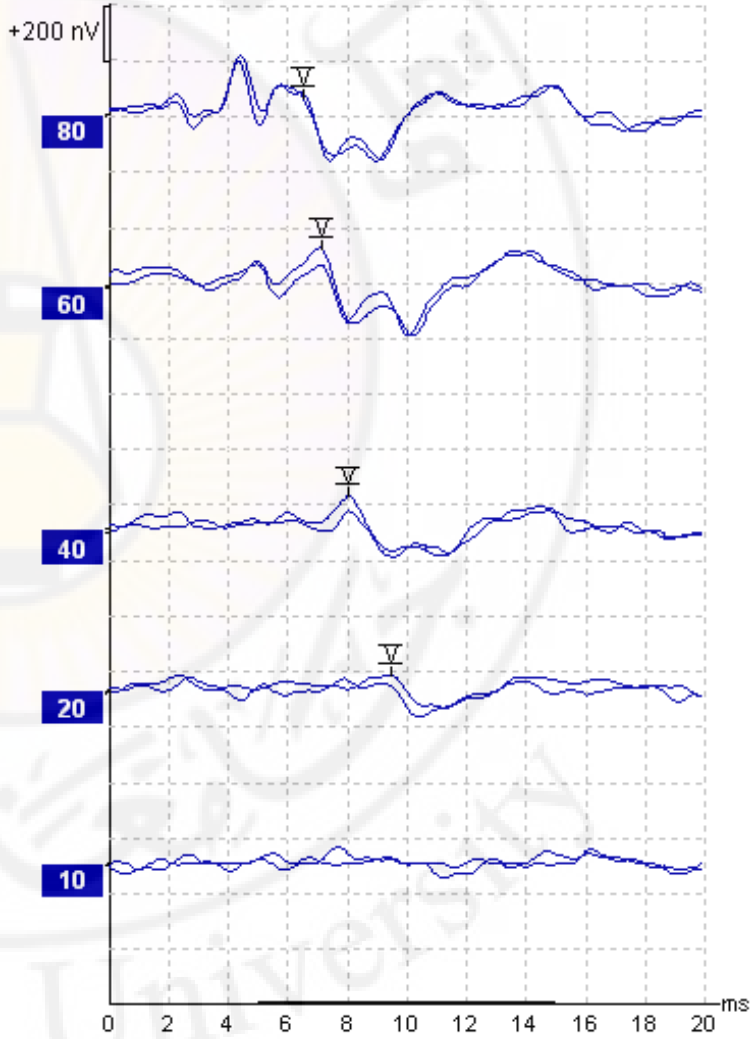
1kHz Tone Burst



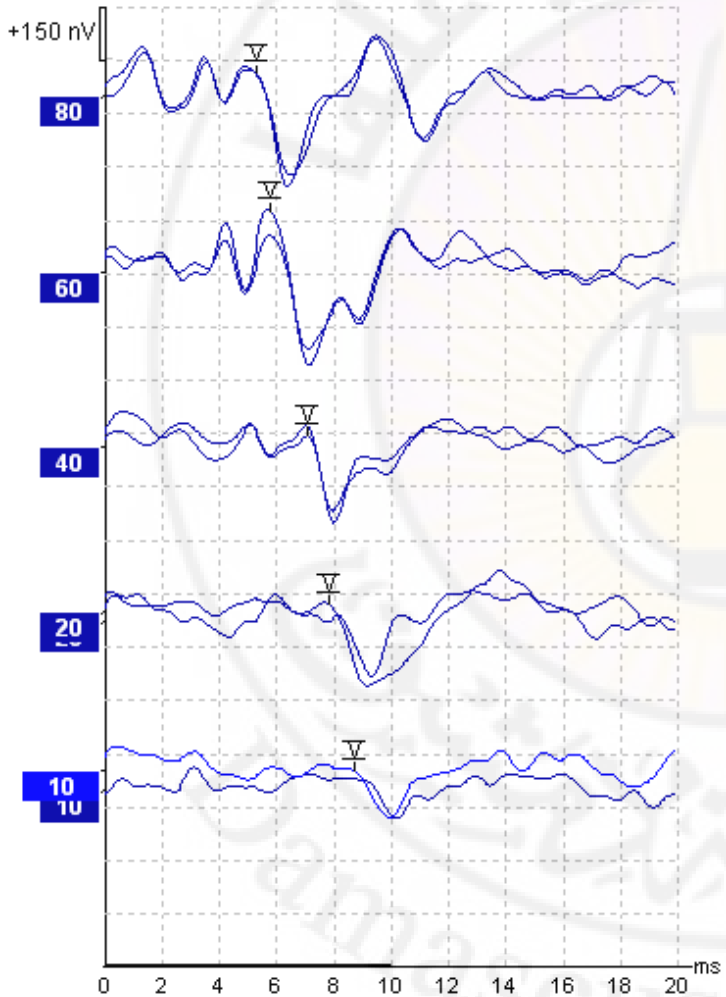
2kHz NB CE-Chirp



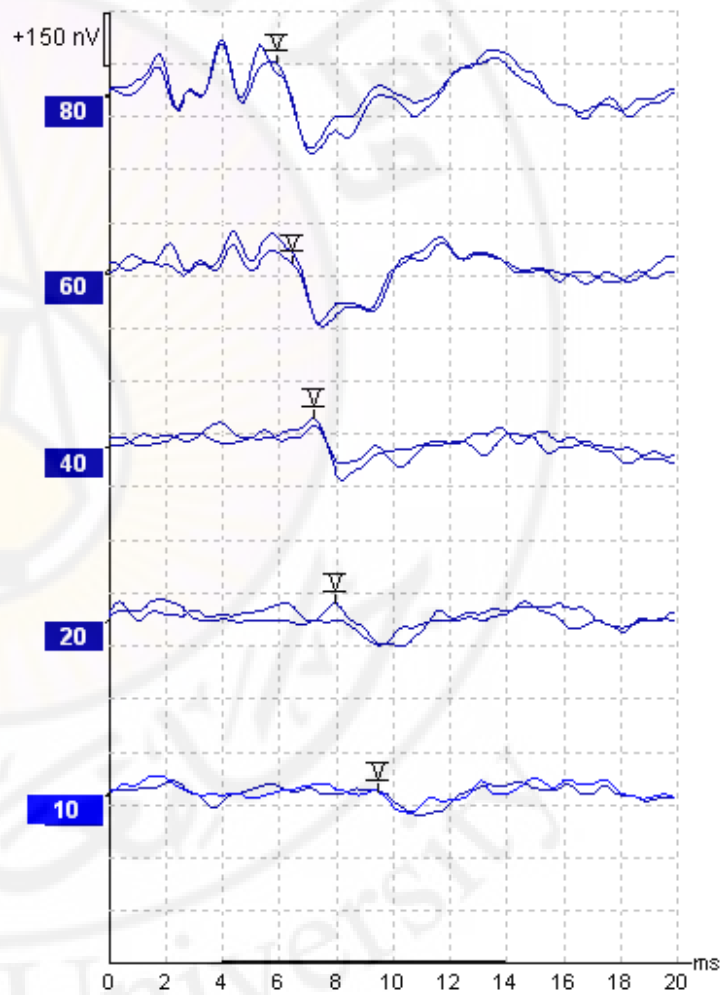
2kHz Tone Burst



4kHz NB CE-Chirp



4kHz Tone Burst



Bone Conduction Stimulation

- The goal of BC-ABR is to estimate **cochlear function** and to help identify the **type** of hearing loss present.
- Responses to air and bone-conduction ABRs are compared (for the same intensity and stimuli).
- ABR assessment with bone conduction click stimulation should be performed whenever there is a possibility of **middle ear dysfunction and conductive hearing loss**, particularly in infants and young children.



Clinical indications for BC-ABR measurement

- History of middle ear disorder
- Atresia, microtia, otitis media
- Infants who have a considerable amount of amniotic fluid in their middle ear space.
- Findings for other auditory tests like otoscopy and aural admittance measures that are consistent with middle ear dysfunction.
- A pattern for air conduction ABR findings suggesting possible conductive hearing loss, namely, abnormally delayed wave I latency at high click stimulus intensity levels.



Placements for Bone Oscillator

- It is recommended that the bone oscillator be placed **high on the temporal bone** and that the inverting electrode is placed on the earlobe, mastoid, or nape of the neck.
- According to ANSI S3.6 1996 using a forehead placement on an adult head can reduce output as much as 15 dB. An infant with a soft spot or fontanel could result in further reduction.
- The placement of the bone oscillator is important and can often be completed using the supplied **headband**. The headband is ideal because it provides the appropriate amount of force and tension to the mastoid; however, the headband is typically too large for most infants' heads.



The tension of the headband can be adjusted to a recommended coupling force of 400 to 450 g using a spring scale.

Hand Held Option

- As an alternative, **Hand-held placement** can be used. Firmly hold the oscillator to the infant's mastoid with 1 index finger. Push the oscillator on the mastoid until you could almost push the child's head away from you.
- Make sure the oscillator is not touching the pinna.
- Transducer placement should be consistent to reduce variability.
- Never use 2 fingers to hold it as this can dampen the output.



Elastic Velcro band option

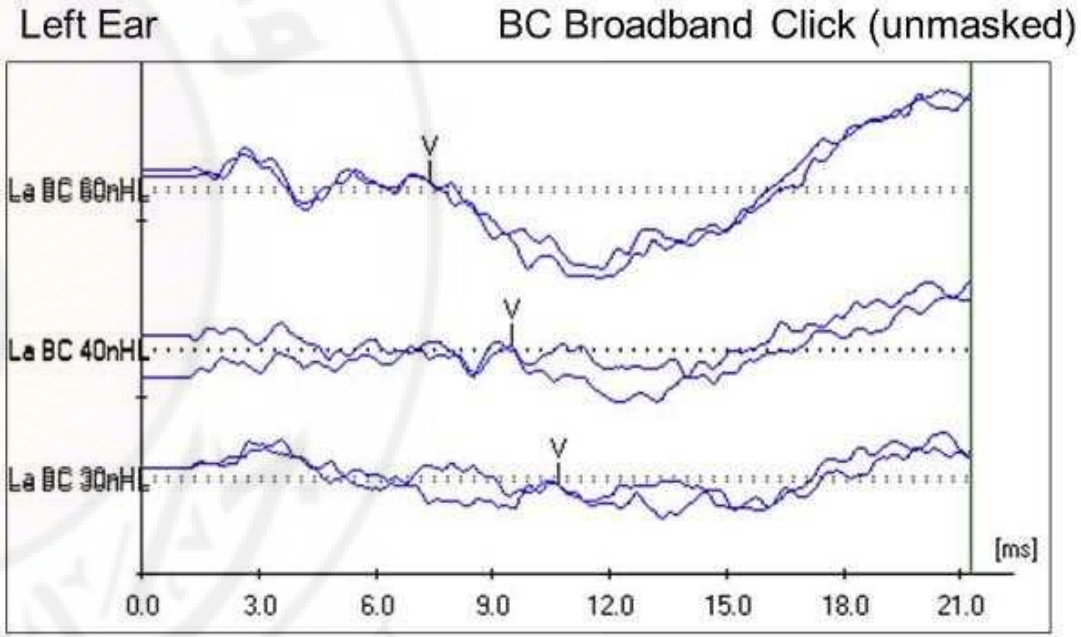
- Place the bone oscillator against the skin of the patient and wrap the Velcro strap around the patient’s head to secure. Make sure the oscillator is not touching the pinna.





BC-ABR threshold investigation method

- Start recording at a moderate level so as not to wake up the baby with the vibrations from the oscillator; around 30 dBnHL.
- Do not exceed 50 dBnHL because you will overdrive the oscillator and will end up collecting artifact.
- Decrease in 10 dB steps to find threshold; 20 dBnHL or below is within normal limits.



Problems with BC-ABR

Artifacts

- It is very common to observe a large amount of artifact while using bone-conduction ABR. This is especially true at high intensities (~50 dB nHL) and at earlier waves (i.e. Wave I).
- To avoid stimulus artifact, it is recommended that the bone oscillator be placed high on the temporal bone and that the inverting electrode is placed on the earlobe, mastoid, or nape of the neck.
- Using an **alternating phase** stimuli should be used to reduce artifact.

Output Limitation

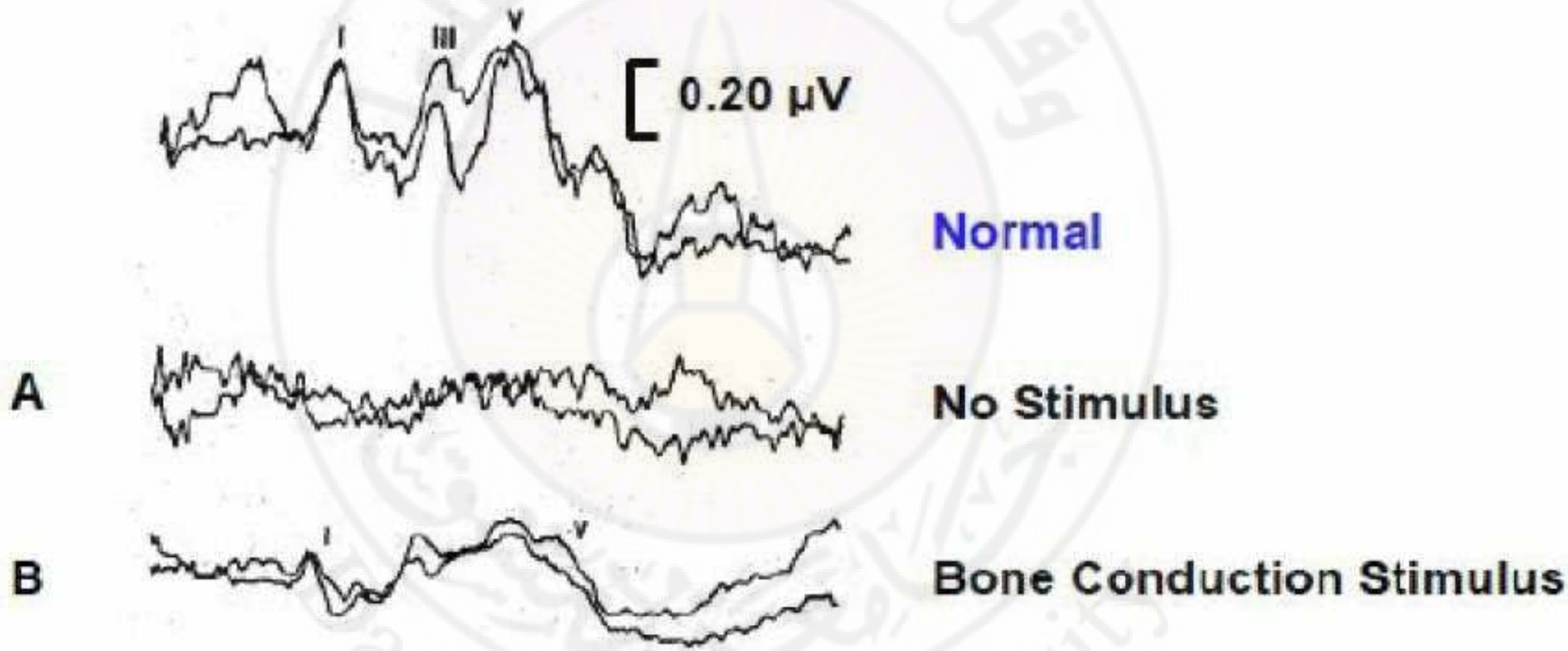
- Since the output of most bone oscillators is around 45 to 55 dB nHL, it becomes difficult to distinguish between sensorineural or mixed hearing losses when the losses by bone exceed this number.

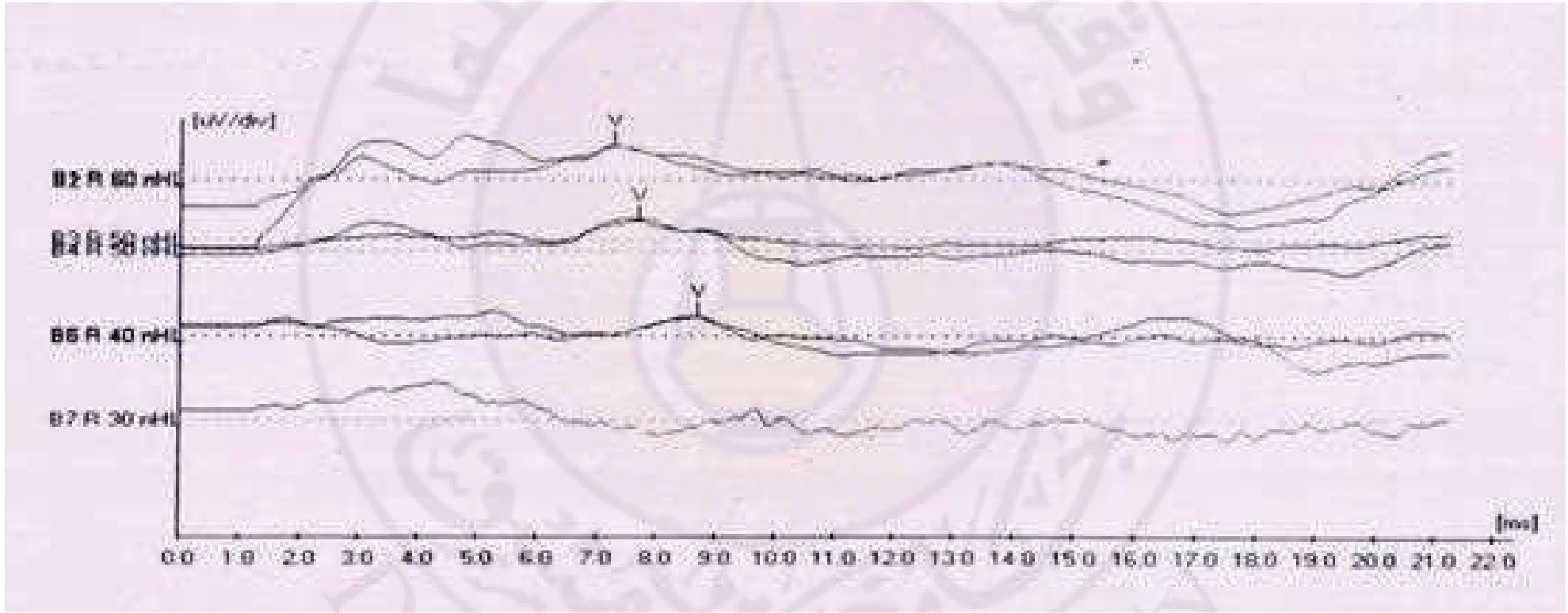
Damascus University

Threshold of Bone-Conduction ABR

- With BC-ABR, the waves are typically more rounded compared with AC-ABR.
- The wave V latency of BC-ABR is approximately **0.5 ms longer** than AC ABR. Such a latency discrepancy has been thought to be due to the low pass filter characteristics of the bone vibrator. In other words, BC stimuli would excite more apical cochlear regions with a longer traveling wave delay than the corresponding AC stimuli
- For **infants**, Wave V latencies for bone-conduction clicks are shorter than the air conduction clicks. These differences can be attributed to changes to the skull due to aging.




I
III
V
0.20 µV
Normal
A
No Stimulus
B
Bone Conduction Stimulus


B2 R 60 nHL
B5 R 40 nHL
B7 R 30 nHL
V
[ms]
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0

Normative values for BC-ABR absolute latencies

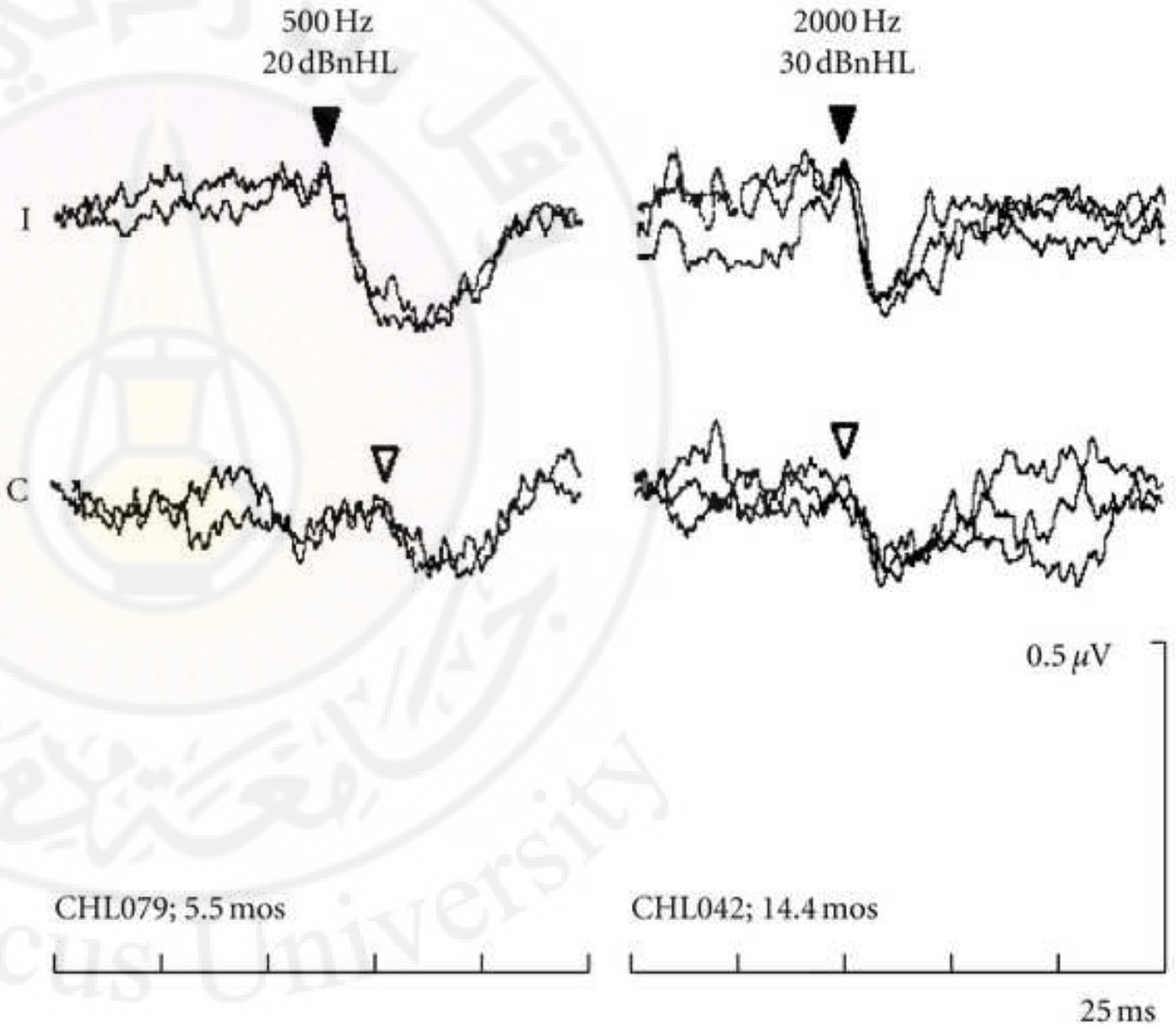
Population	Wave I	Wave III	Wave V
Norm			
Infants (1-20 months)	2.19±0.45	4.83±0.51	6.65±0.33
			7.24±0.36
			8.38±0.36
			8.41±0.44
			8.37±0.54
			11.05±0.84
			9.89±0.87
			8.63±0.32
Adults			6.59±0.36
			6.79±0.41
Pathology			
Atresia	2.27±0.25	4.99±0.44	6.78±0.38

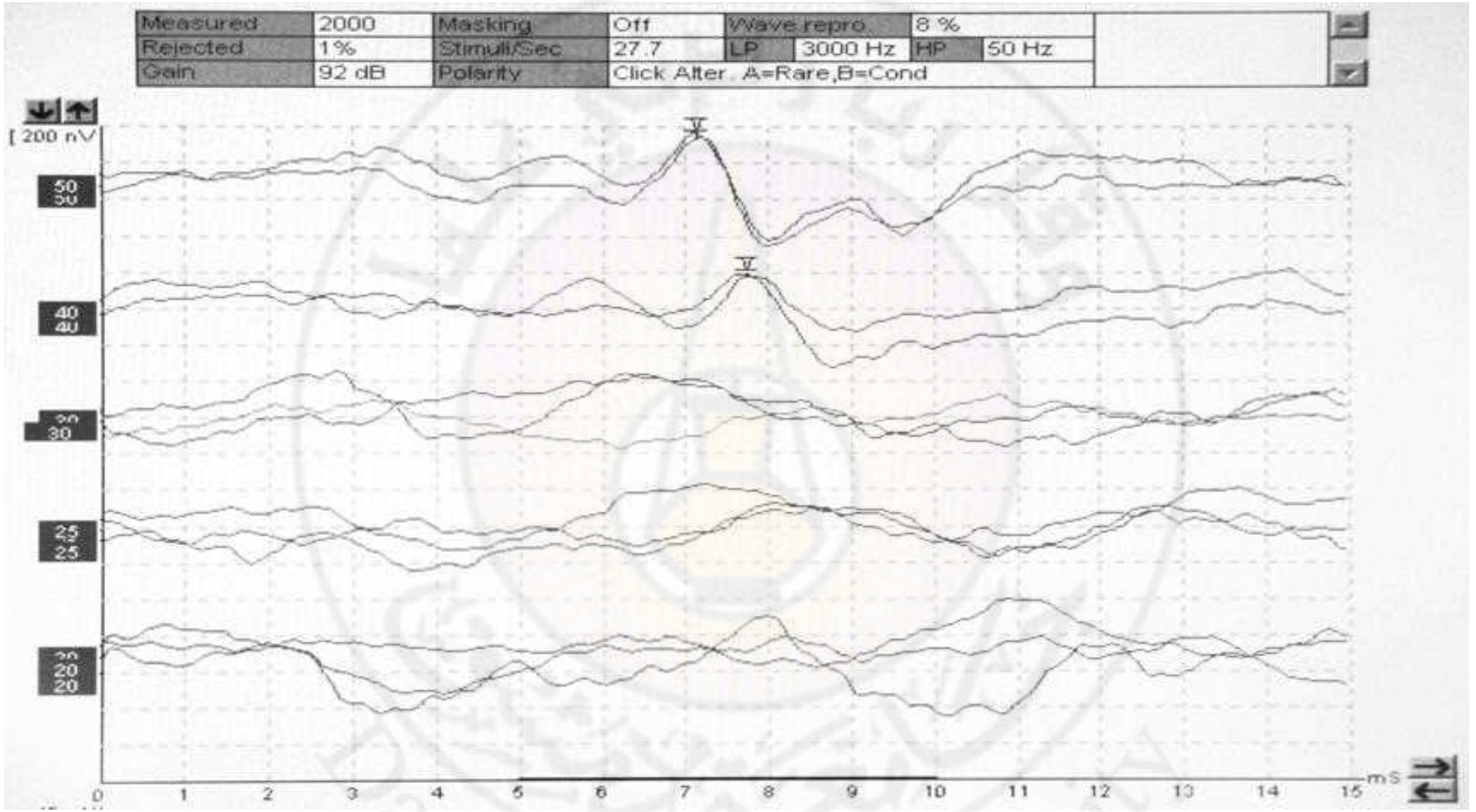
Masking in BC-ABR

- Masking of the contralateral ear, typically required with bone-conduction testing in **adults**, but not necessary in young **infants** (under 6 months); because the Inter-aural attenuation is high (as much as 25 dB) due to inadequate fusion of the cranial bones.
- Clear wave I in an ABR elicited with bone conduction stimulation confirms that the response is ear-specific and masking is not needed.
- If a reliable wave I is not identified then masking of the non-test ear is indicated. A general guideline is masking noise of 50 dB presented via insert earphones.

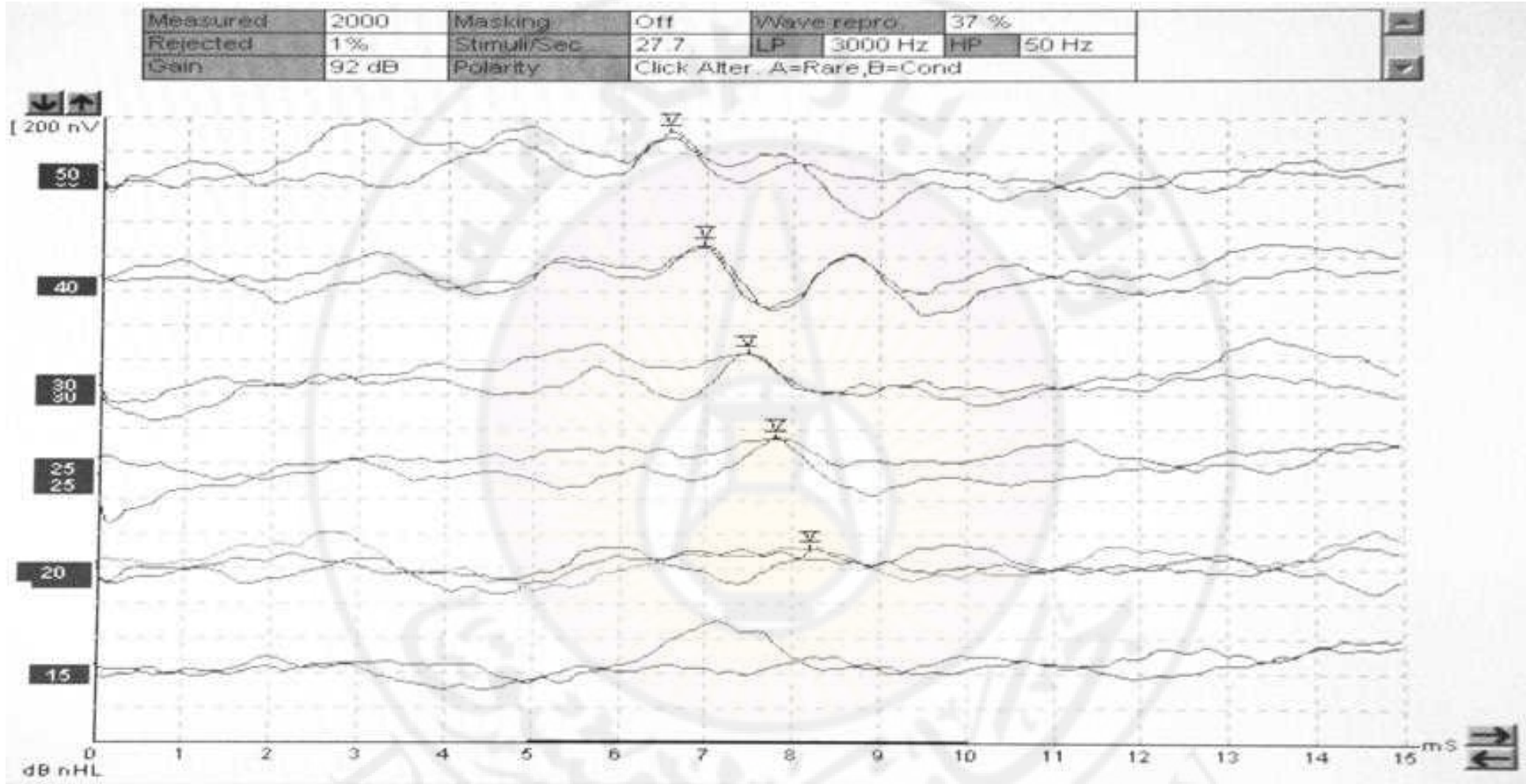


ABRs to 500 and 2000 Hz BC tones, presented at 20 and 30 dBnHL respectively, recorded from two infants with conductive hearing loss at the time of ABR testing.





BC-ABR thresholds in a female subject, with the vibrator positioned on the **forehead**.

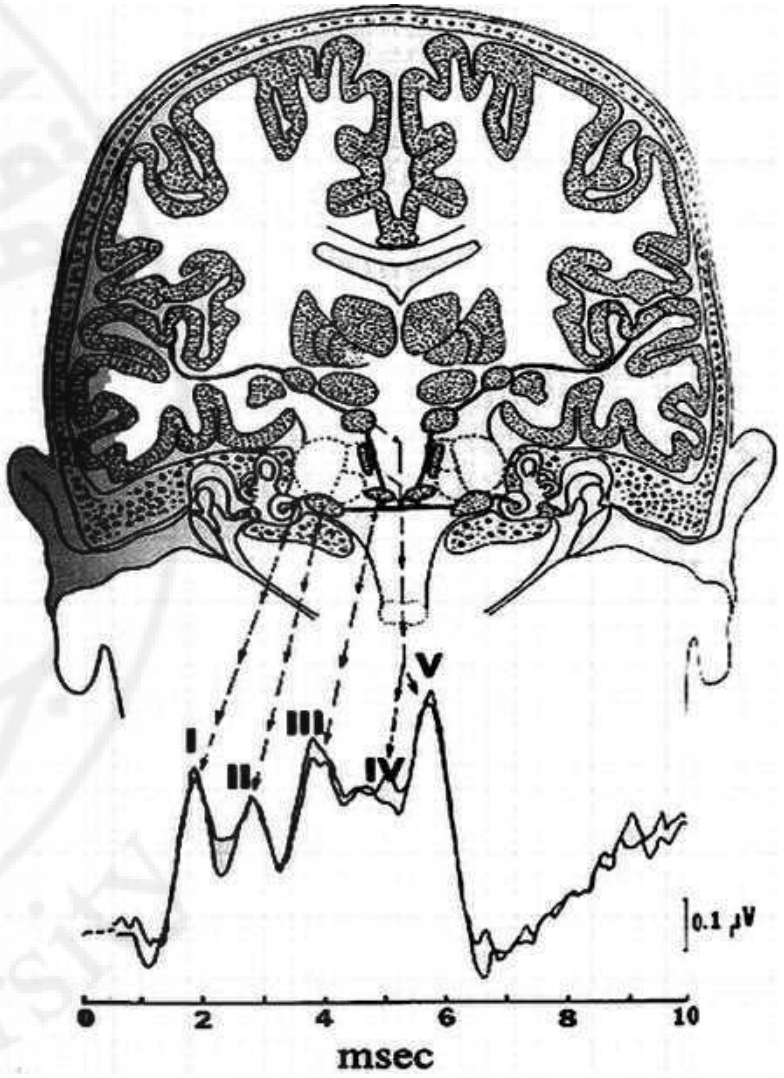


BC-ABR thresholds obtained in a female subject, with the vibrator positioned on the **mastoid**

9. Auditory Brainstem Response: Differential Diagnosis

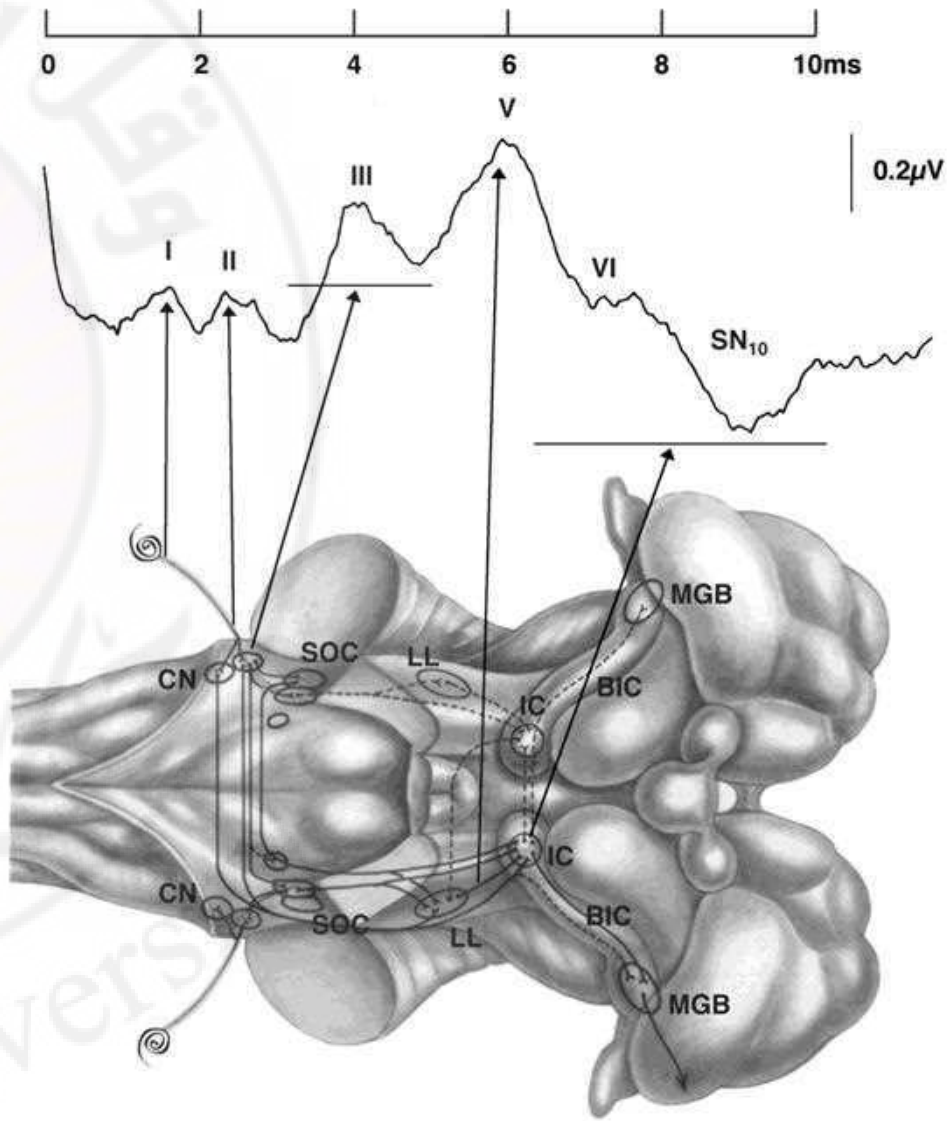
ABR: Diagnostic aspects

- ABRs are measures of the function or physiology of the auditory nerve and brainstem and not measures of the structure or anatomy of these areas.
- By using the pattern of findings obtained for each individual patient through this physiological procedure, it is possible to make inferences about which pathologies may be causing the disruptions in the typical ABR pattern.
- ABR abnormal patterns are dependent on both the size and location of the lesion.
  - **Auditory nerve involvement**
  - **Brainstem dysfunction**



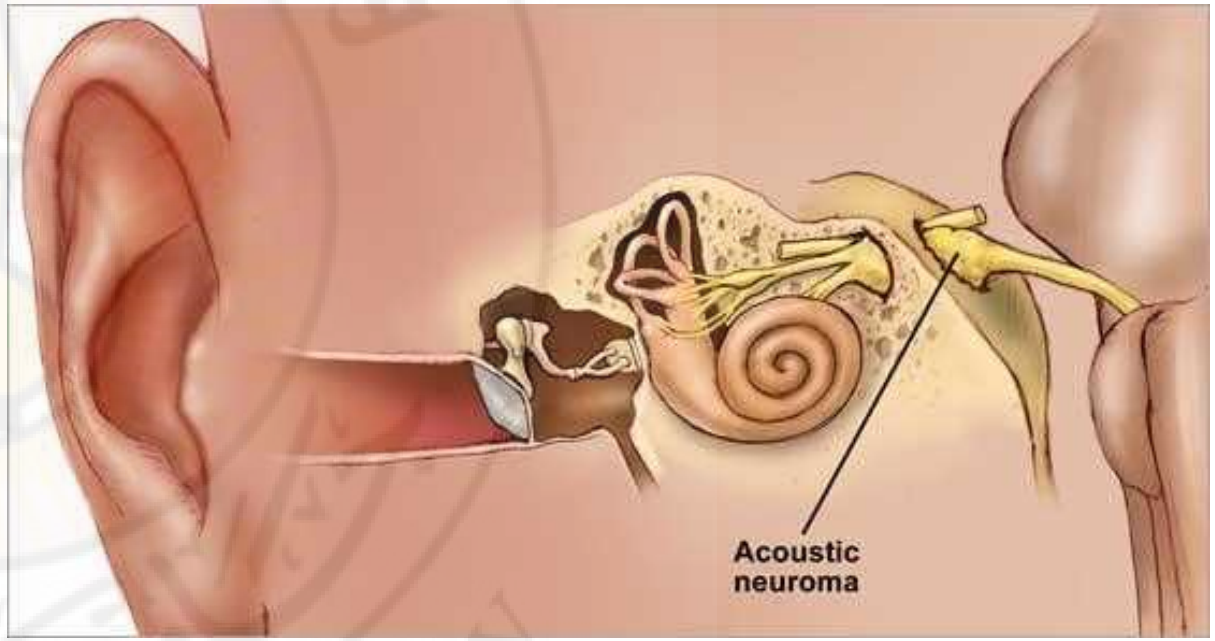
ABR and Retrocochlear involvements

- **Auditory nerve involvement**
  - vestibular schwannoma
  - Auditory neuropathy spectrum disorder (ANSD)
  - other pathologies
    - Charcot–Marie–Tooth (CMT) syndrome
    - vascular loop syndrome
    - Auditory nerve aplasia and hypoplasia
- **Brainstem dysfunction**
  - Multiple Sclerosis
  - Tumors of the Brainstem
  - Hyperbilirubinemia
  - Heavy Metal Exposure
  - Head Injury



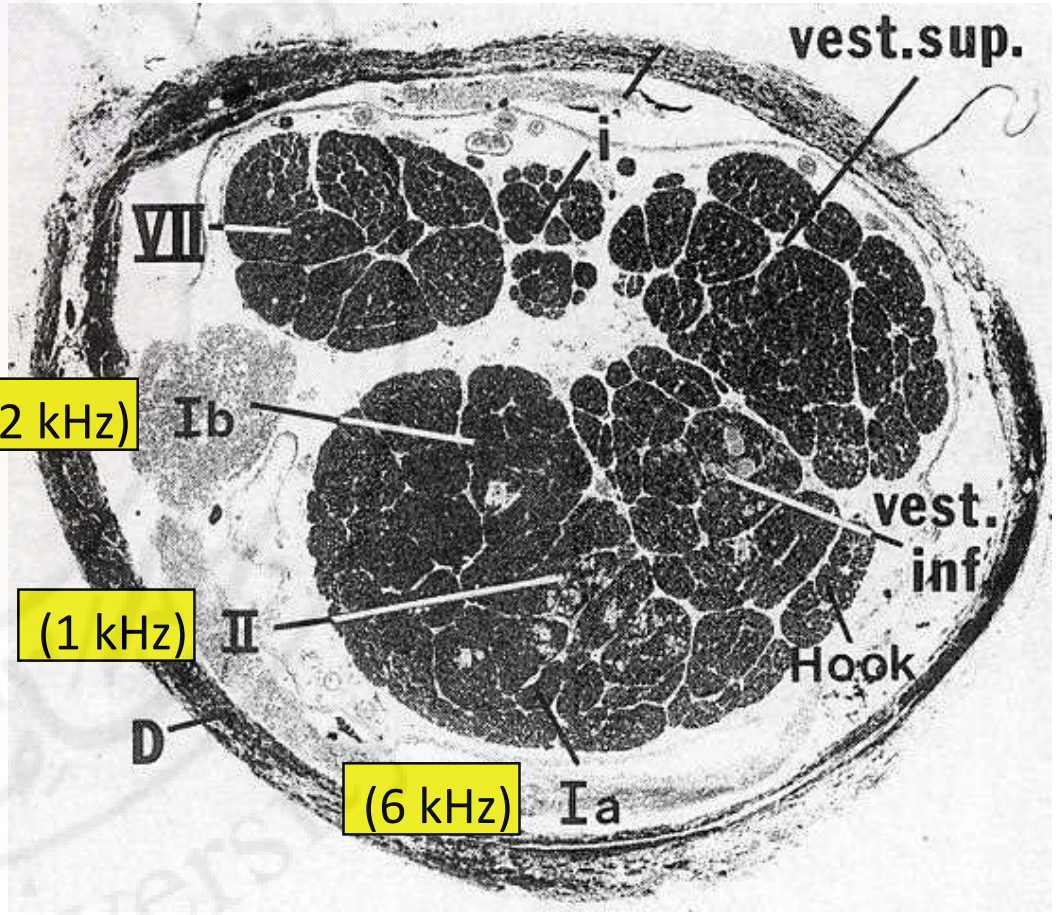
Vestibular Schwannoma

- Vestibular schwannomas (also commonly termed acoustic neuromas, acoustic tumors, or eighth nerve tumors) are structural anomalies that are so named because of their location and the specific cells that are comprised.
- Making up an estimated 90% of all tumors of the temporal bone, vestibular schwannomas generally are benign and slow growing.
- These tumors are estimated to grow between 0.1 and 0.2 cm in diameter per year in many cases; however, there are some documented cases in which the tumor does not change in size.



Vestibular Schwannoma

- **Unilateral** tumors occur in the vast majority of cases (95%), with the most common symptoms being unilateral tinnitus and unilateral progressive high-frequency hearing loss on the side of the tumor.
- Vestibular symptoms are rarely present because of the slow rate of growth for these tumors and the tendency of the central nervous system (CNS) to compensate for these gradual changes.
- If these tumors grow to be larger than about 2 cm in diameter, they may begin to spread into the cerebellopontine angle (CPA), at which point the brainstem may also show signs of compromise.

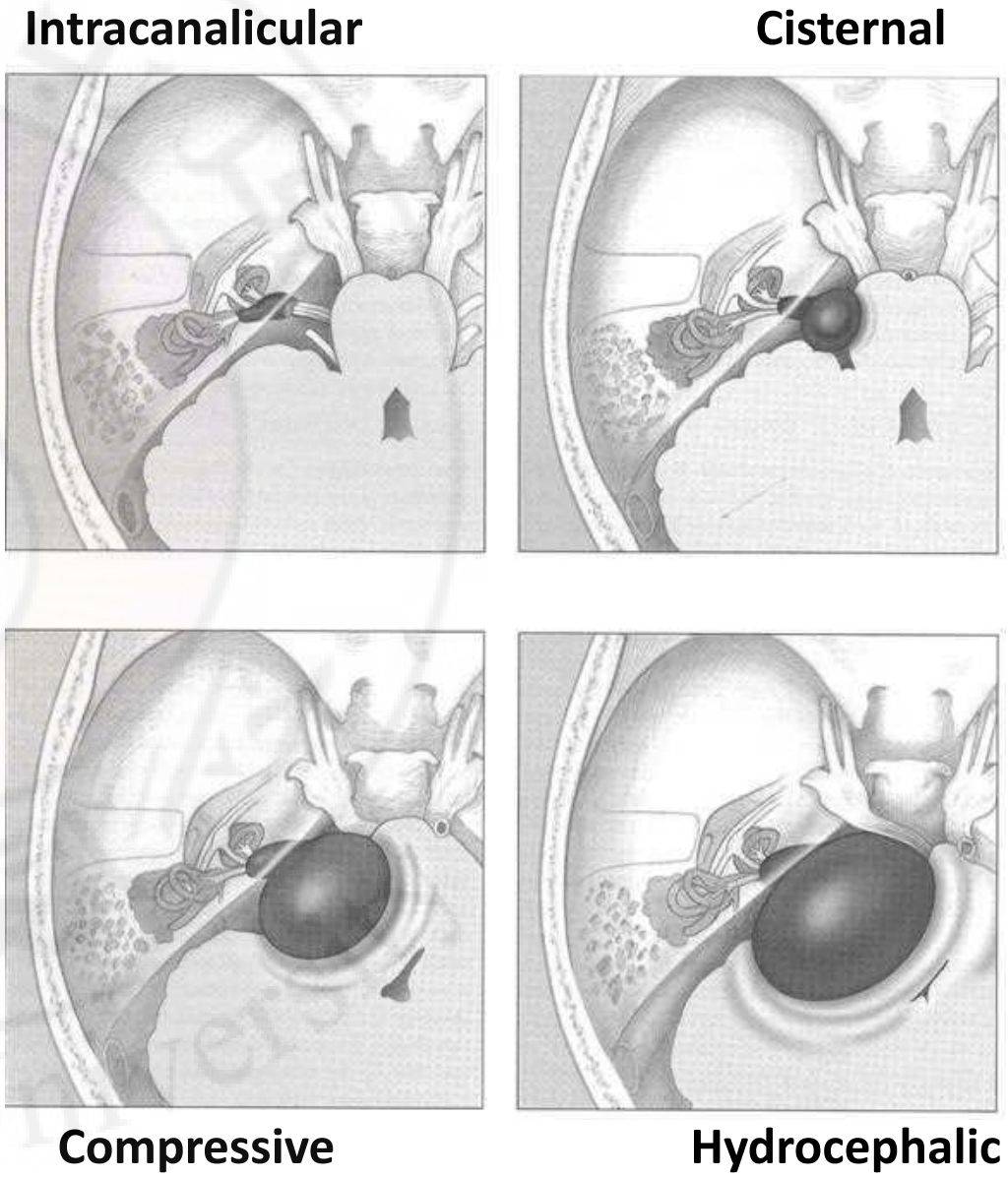


Jackler Staging System

Stage	Tumor Size
Intracanalicular	Tumor confined to IAC
I (small)	< 10 mm
II (medium)	11-25 mm
III (Large)	25-40 mm
IV (Giant)	> 40 mm

Phases of Tumor Growth

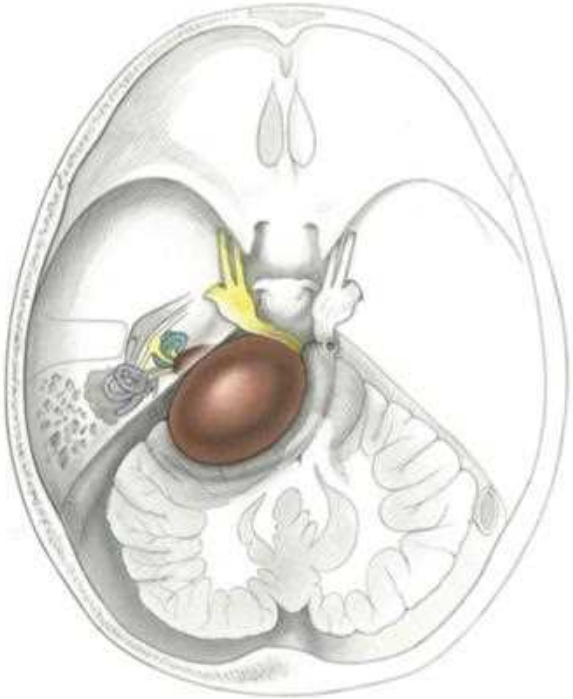
- **Intracanalicular:**
  - Hearing loss, tinnitus, vertigo
- **Cisternal:**
  - Worsened hearing and disequilibrium
- **Compressive:**
  - Occasional occipital headache
  - CN V: Midface, corneal hypesthesia
- **Hydrocephalic:**
  - Fourth ventricle compressed and obstructed
  - Headache, visual changes, altered mental status



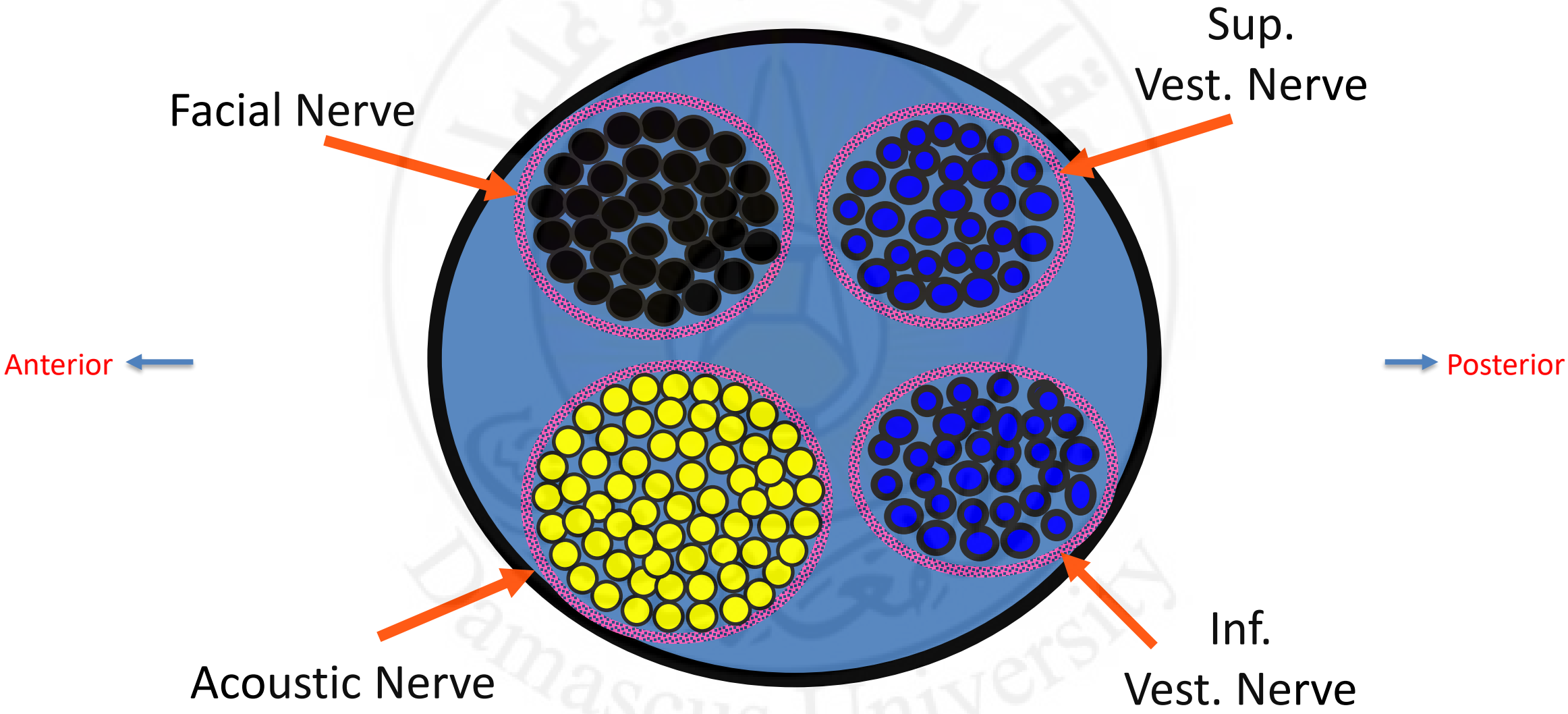
Epidemiology

- 6 % of all Intracranial tumors
- 80 - 90% of CPA tumors
- Incidence in US: 10 per million / year
- Vast majority in adulthood
- 95% Sporadic (unilateral)
- 5% Neurofibromatosis type 2 (bilateral)
- No known race, gender predilection



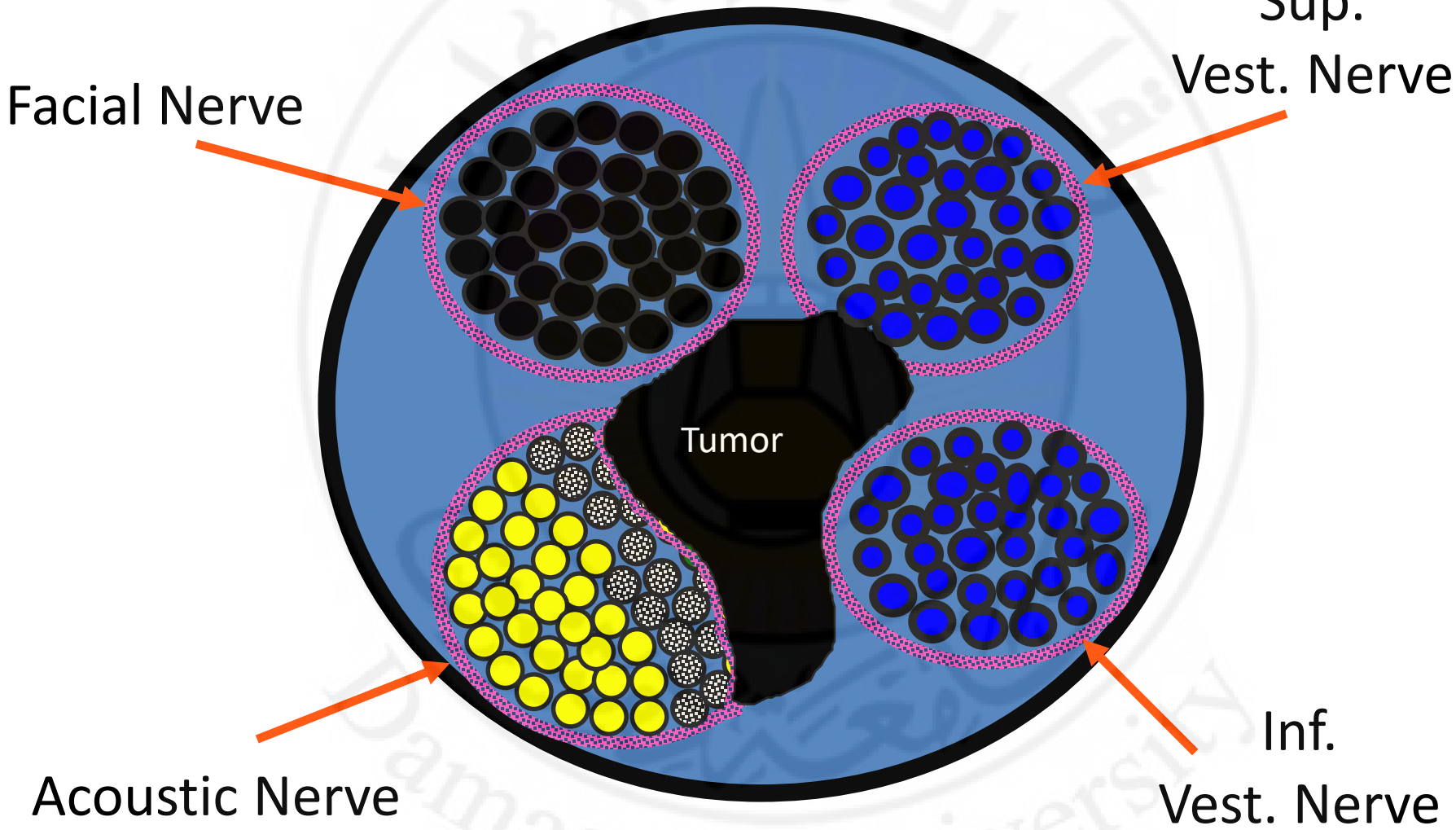


Cross-section of Internal Auditory Canal (IAC)



Damascus University

Medium or Large Tumor in IAC



Damascus University

Diagnosis of Vestibular Schwannoma

- History and Physical Exam
- Audiology testing:
  - Audiogram
  - ABR
  - OAE
- Radiography
  - MRI Gold Standard
  - CT
- Vestibular testing (e.g. VNG, vHIT, VEMP)

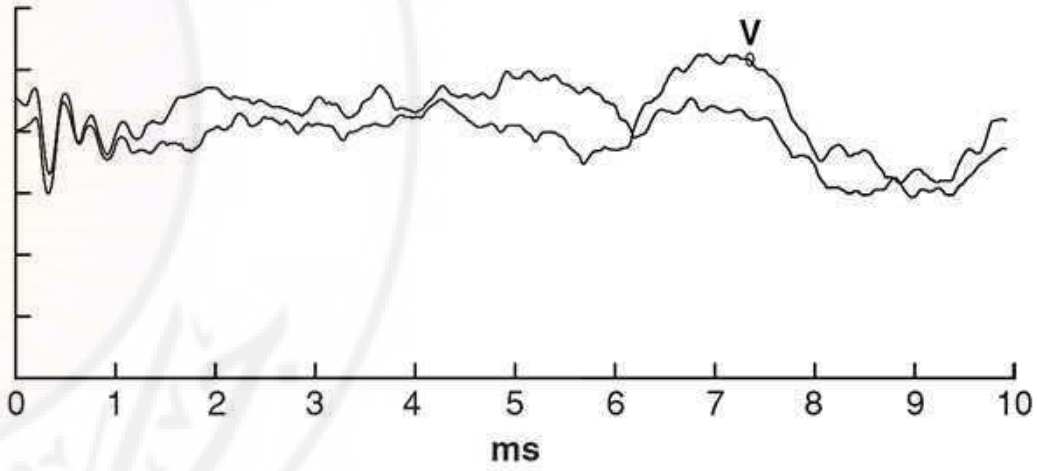


ABR findings associated with Vestibular Schwannoma

- Prolonged latency for wave V.
- Prolonged interwave latency for I to V (as well as for I to III and/or III to V).
- Interaural latency differences.
  - Significant differences between the patient's two ears are considered for both the wave V latency and the interwave latencies.
- Absence of the later waves
- Absence of an ABR (even though hearing is normal or only mildly impaired)
- An ABR waveform that is not replicable
- Abnormally low V:I amplitude ratio.
  - The V:I amplitude ratio is simply the amplitude of wave V over the amplitude of wave I, and is expected to be ≥ 1.0 because wave V is normally larger. One becomes suspicious of a retrocochlear disorder when the V:I ratio is less than 1.0, but this criterion is not as sensitive as the latency measurements.
- Significant shifting of wave V latency when the clicks are presented at a faster rate

Absolute latency delay for Wave V

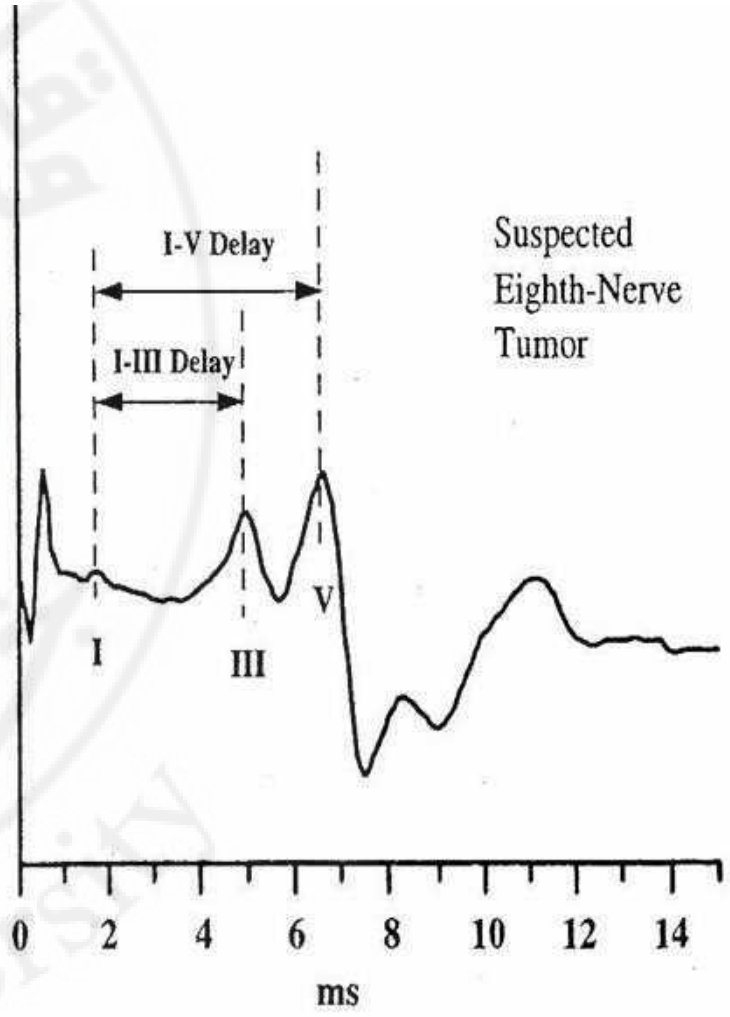
- The measurement of **absolute latency of Wave V** is used when the earlier waves are absent, which can create a diagnostic problem in differentiating retrocochlear from cochlear loss.
- In these situations, other measures of the ABR as well as patient history can become important and helpful.
- When Wave V latency measurements are greater than **6.1 ms** in response to a click stimulus presented at a moderately high intensity level, the possibility of an eighth nerve tumor should be considered.



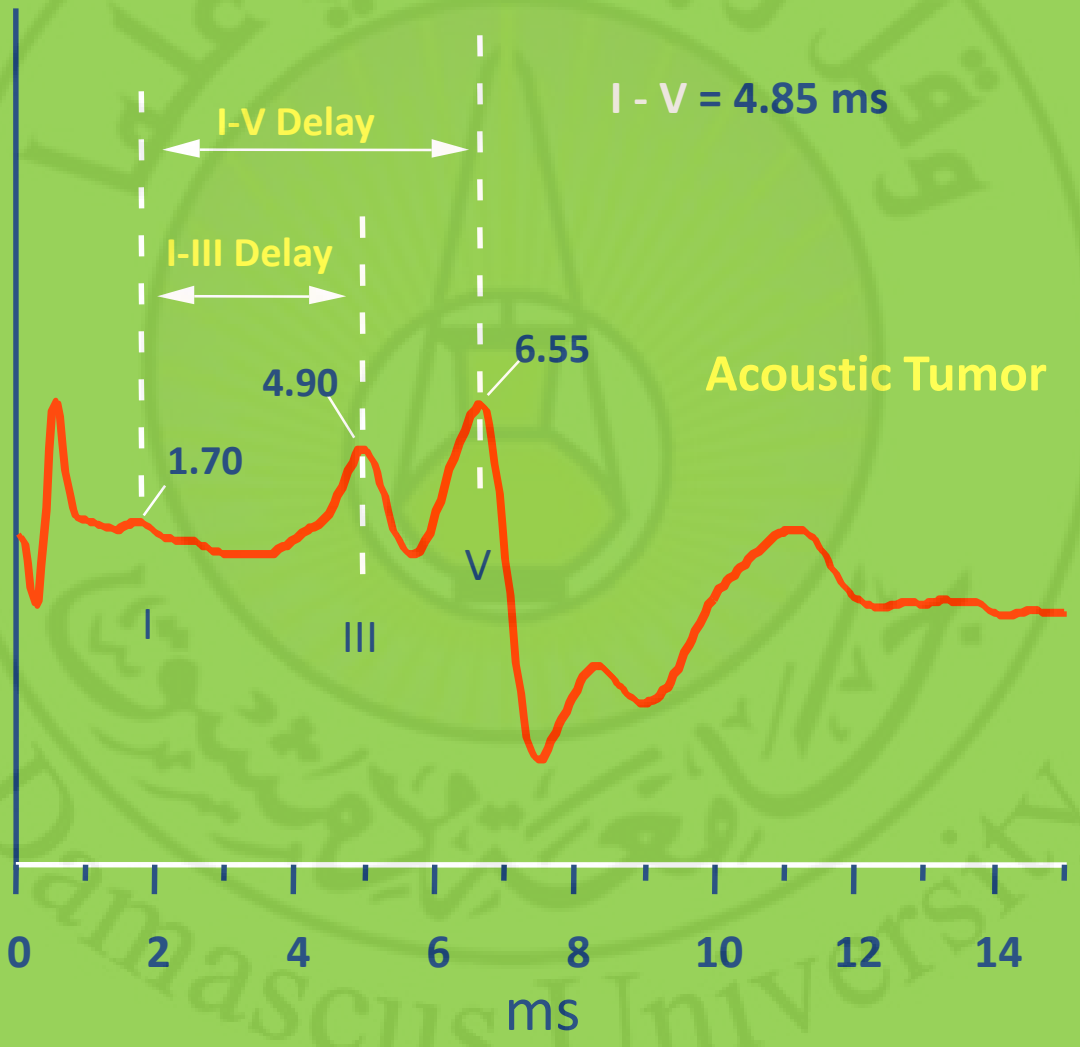
Damascus University

Interwave latency delays

- Because of the fact that most eighth nerve tumors grow between the generator sites of Waves I and III, the I–III interwave interval (IWI) is likely to be extended in these cases.
- In many clinics and laboratories a **I–III IWI extending beyond 2.4 ms** is considered abnormal.
- The I–V IWI may also be used in the detection of vestibular schwannoma, though the extension of this interval is often a reflection of an increased I–III IWI measurement.
- However, in some cases, depending on the precise location and size of the tumor, the III–V IWI may be extended in addition to the I–III IWI making the I–V IWI most helpful to the interpretation. measurements of **the I–V interval that exceed 4.4 ms** are commonly considered abnormal

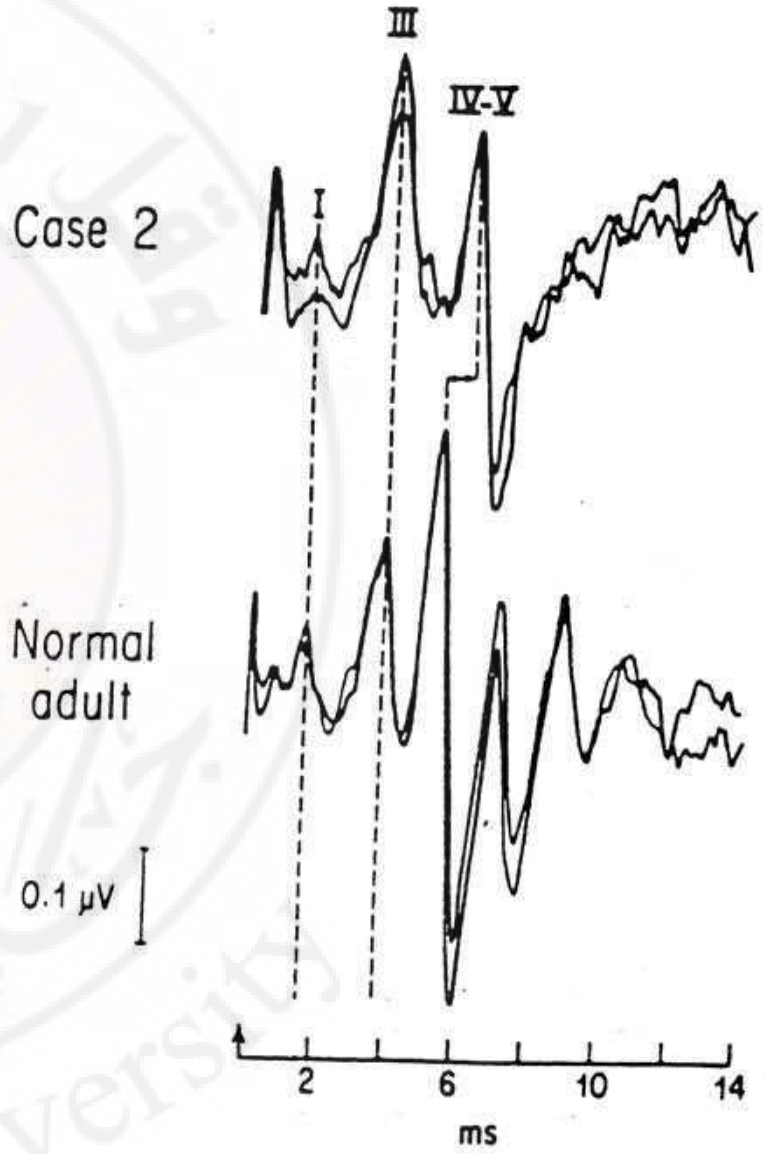


I-V Delay = Latency Difference Between Wave I and V

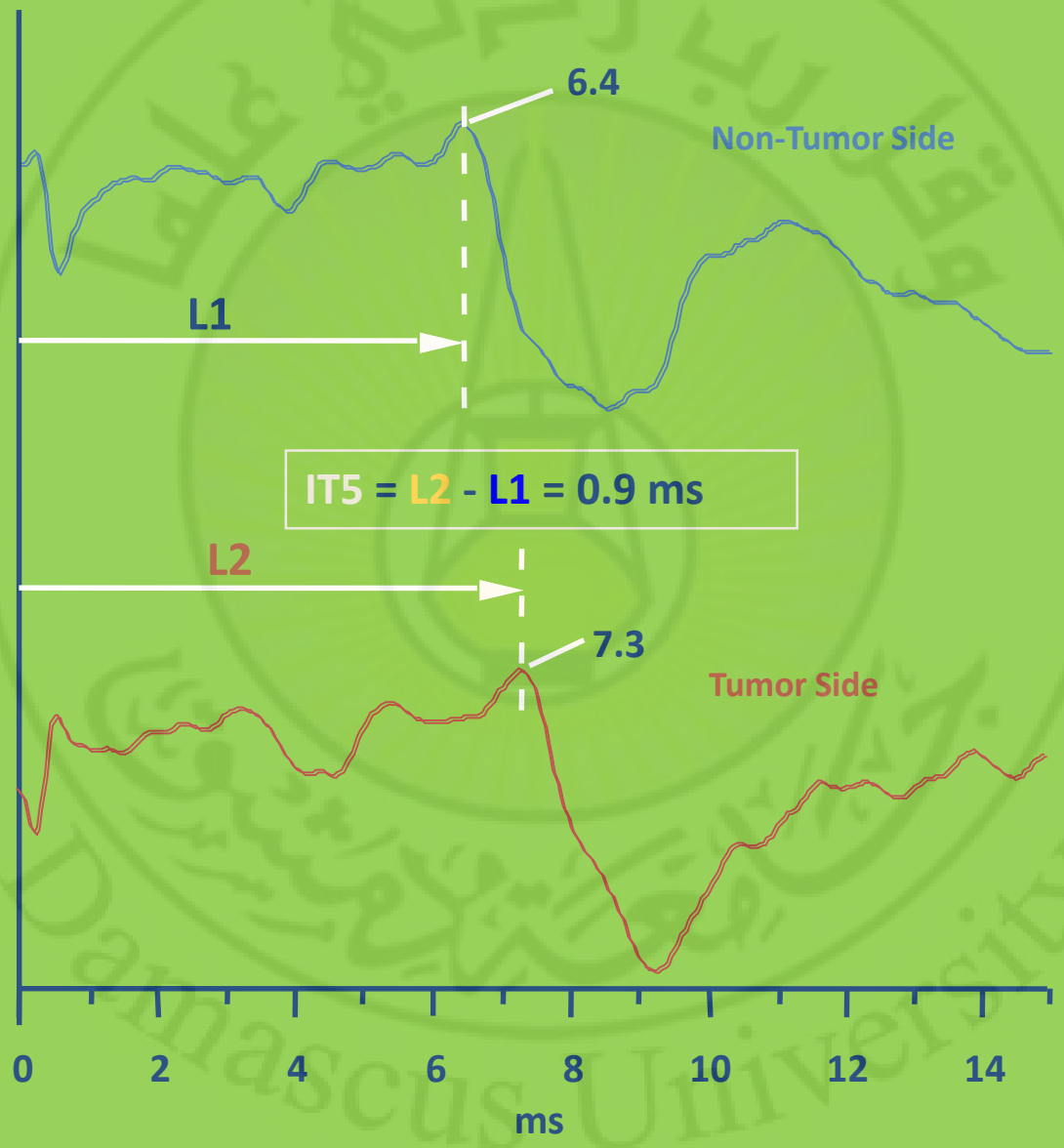


Inter-ear Latency Comparisons

- Interaural latency difference (ILD) using wave V or **IT5**
- Wave V is the only wave of the ABR that is present in each ear
- ILDs (IT5) greater than **0.3 to 0.4 ms** should be considered abnormal and would support a diagnosis of retrocochlear involvement as long as the contribution of a cochlear hearing loss can be ruled out.



IT5 = Interaural time delay for wave V

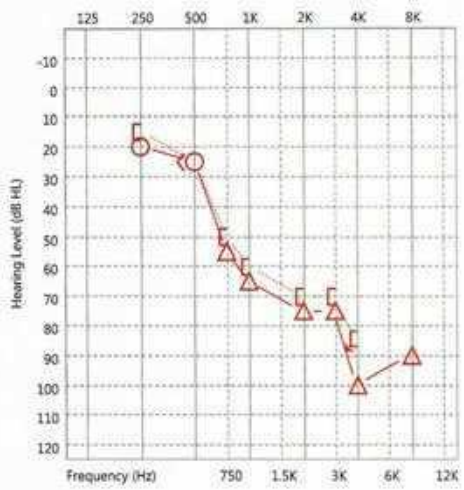


First Name [redacted]
Name
Age
Gender Male

کلینیک گوش تهران

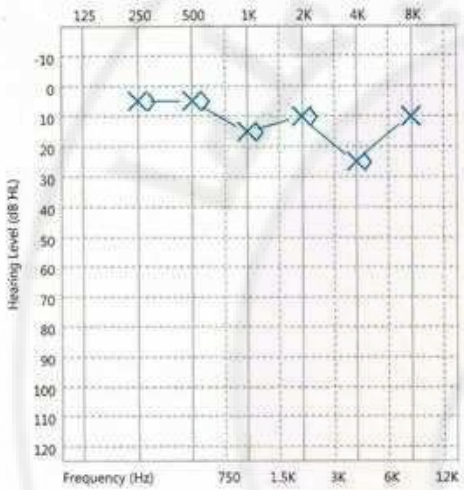
2/6/2022 4:43 PM

Right Ear Audiogram



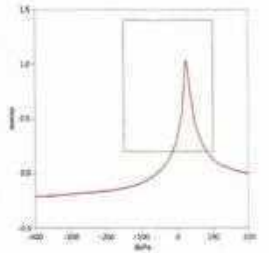
Ear	Test Type	%	dB HL
R	SRT		70
R	MCL		85
R	WRS	68	85

Left Ear Audiogram



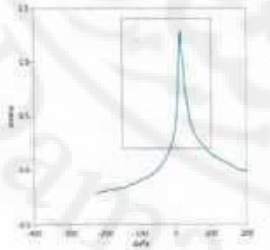
Ear	Test Type	%	dB HL
L	SRT		15
L	MCL		40
L	WRS	100	40

Right Ytm 226 Hz



Tymp	Vea cm3	daPa	mmho	Type
1	0.9	25	1.03	

Left Ytm 226 Hz

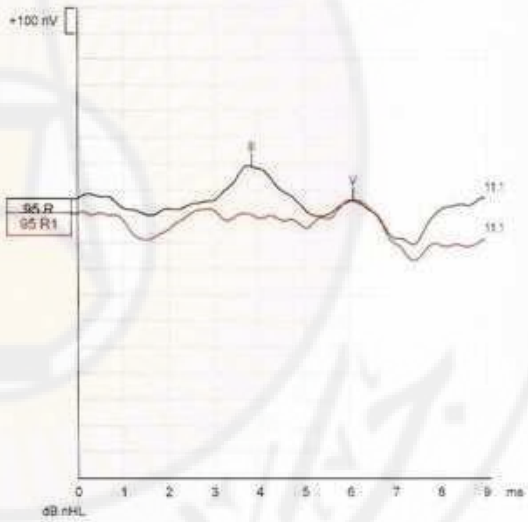


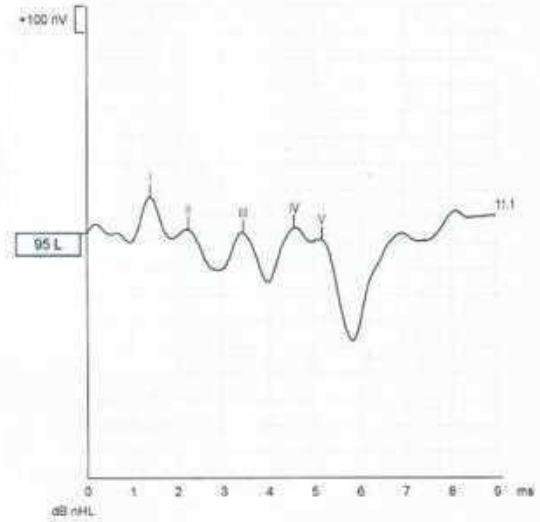
Tymp	Vea cm3	daPa	mmho	Type
1	1.2	14	1.28	

Address: Day Medical Tower Unit C, 9th Floor,, IranTehran

Tel: 021-88205806 Fax: 021-88202934 E-Mail: @tehranearclinic

Last name: [redacted] Sex: M ID no: 4001143
First name(s): Age: 43 years Date of test: 02-08-2022
Address: Day of birth: 10-11-1978
Tel:
Examiner: ADM E-Mail:







Curve	Latencies (ms)								Interlatencies diff. R/L			
	I	II	III	IV	V	I-III	III-V	I-V	I-III	III-V	I-V	V-V
95 L	1.40	2.23	3.43	4.57	5.17	2.03	1.73	3.77		0.50		0.90
95 R			3.83		6.07		2.23			0.50		0.90
95 R1												

مرکز ام آر آی سبحان
Sobhan M.R.I Center

دانشگاه علوم پزشکی و خدمات بهداشتی درمانی
شهید صدوقی یزد

[redacted]

Brain MRI with and without contrast injection:

The images are obtained according to the usual protocol with and without contrast injection which reveals:

Encephalomalacia with peripheral gliosis at left temporoparieto occipital lobes are seen due to old ischemic change.

No evidence of pathological enhancement after contrast injection at surgical site is seen.

Mild thickening and enhancement of dura in left temporo parietal region is noted.

Evidence of abnormal signal mass lesion measures about 16*11 mm in right CP angle extending to right internal auditory canal is seen.

The lesion appears iso signal on T1 and T2 and shows enhancement after contrast injection.

Above findings could be related to vestibular schwannoma, but less likely meningioma should be considerate as differential diagnosis.

F

دکتر سبحان اردکانی - محمد

یزد ، خیابان فرخی ، بیمارستان شهید دکتر رهنمون تلفن : ۲۲ ۲۷ ۲۱ ۳۶ - ۲۰ ۲۷ ۲۱ ۳۶ (۰۳۵)
Rahnemon Hospital-Farokhi.St-Yazd-Iran Tel : (+ 9835) 36272120 - 36272122
www.sobhanmri.ir info@sobhanmri.ir

IT5 & Tumor Size

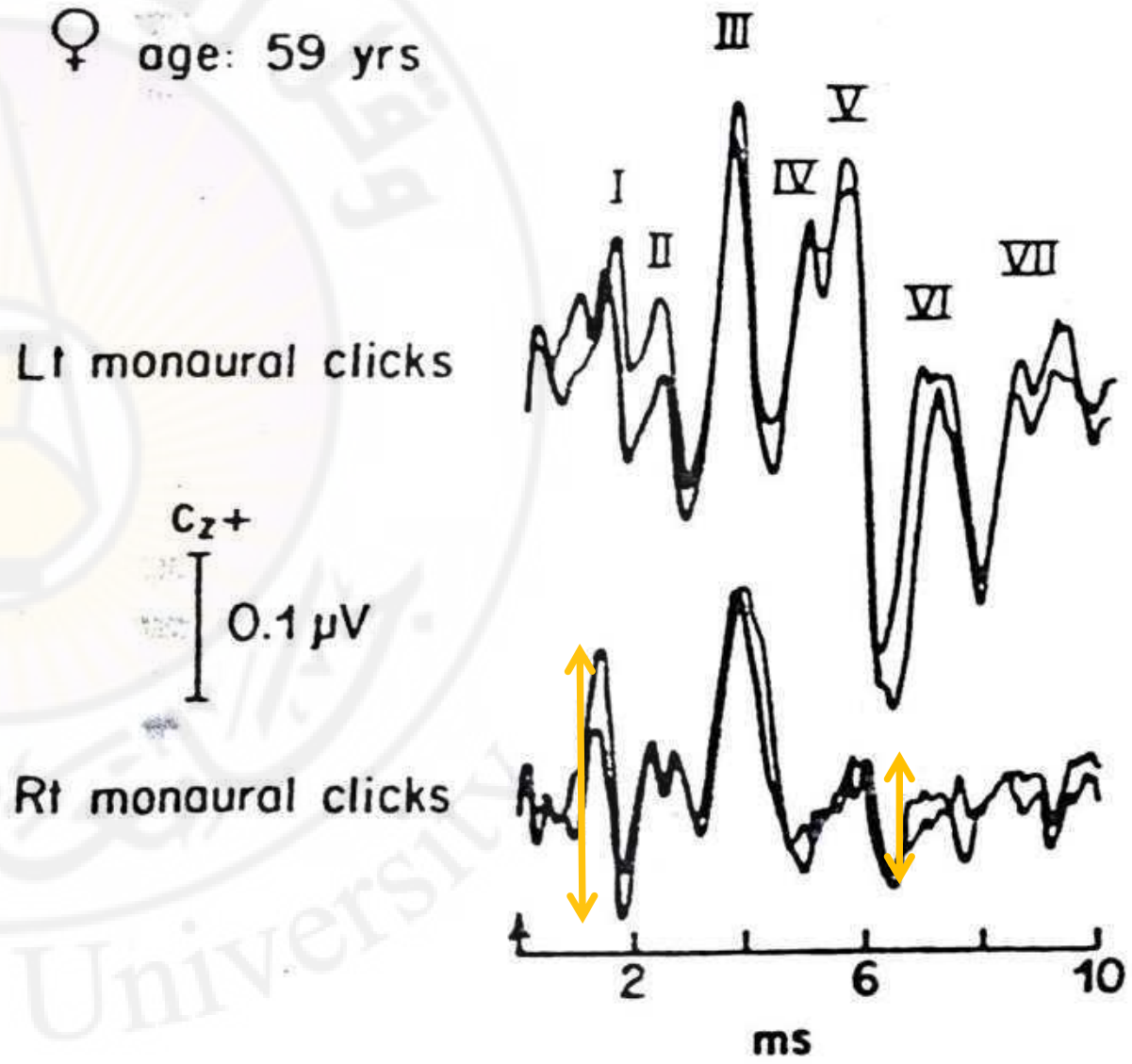
Table 2. Tumor Size by Auditory Brainstem Response Interaural Latency Difference for Wave V (IT5)

	Percentage of Patients		
Size (cm)	***Normal***	***>0.2 ms***	***NR***
≤1.0	16.9	69.2	13.8
1.1–2.0	2.6	71.8	25.6
2.1–3.0	6.5	48.4	45.2
>3.0	0.0	59.1	40.9

NR = no response

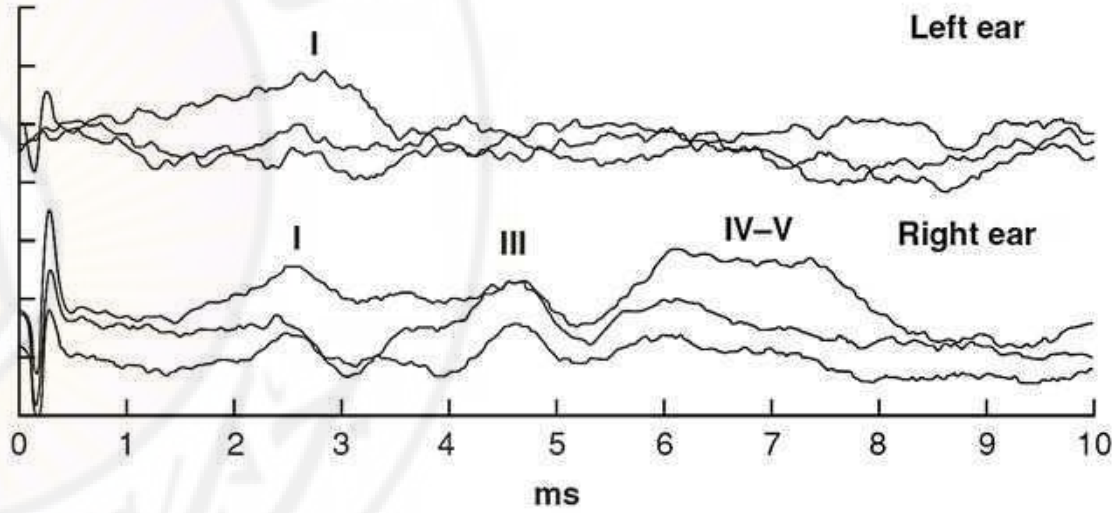
Amplitude Comparison of Waves

- When the Wave V amplitude is **less than 0.75** of the amplitude of Wave I, it is considered abnormal and is suggestive of retrocochlear pathology.
- It should be mentioned that a significantly smaller Wave V than Wave I does not occur very often even in pathology; however, when it does, it should be interpreted with concern.
- The ABR should be replicated at least once, and each waveform's Wave I and V amplitude measurements should not vary by more than 20%.



Waveform Morphology and Absence of Waves

- The presence of an eighth nerve tumor should be considered if all waves of the ABR are missing. The absence of waves must be interpreted along with the audiometric results that were obtained for the patient.
- The most striking indication of a retrocochlear lesion is the **absence of all ABR waves** while audiometric results from that ear indicate relatively normal hearing sensitivity.
- An important interpretation is when **Wave I is present** and the remaining waves are absent. This is a strong indicator of retrocochlear involvement

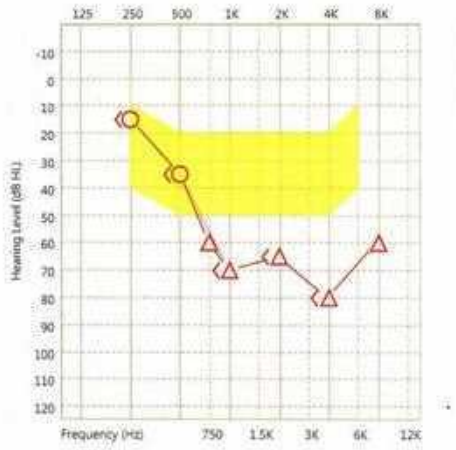


Patient Information

First Name [redacted]
Last Name
Gender
Age

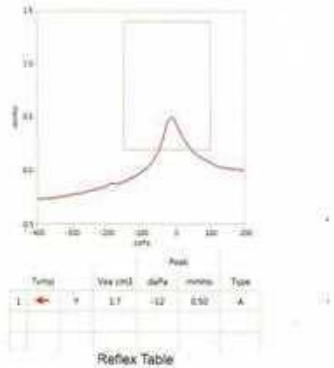
2/20/2021 6:31 PM

Right Ear Audiogram



SRT	MCL	%WRS

Right Ytm 226 Hz



Reflex Table

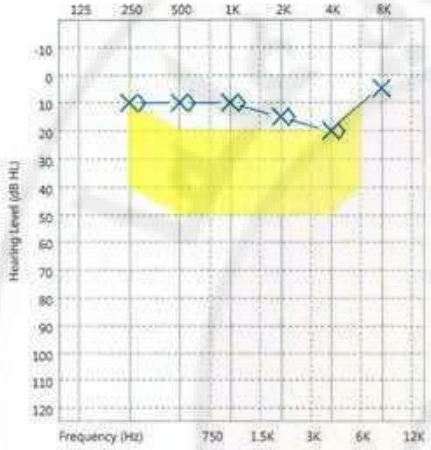
Threshold Ipsilateral R

	500	1000	2000	4000	250
dB HL	NR: 100#	NR: 100#	NR: 100#	NR: 100#	

Contralateral R

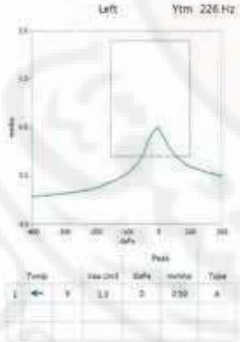
	250	500	1000	2000	4000
dB HL					

Left Ear Audiogram



SRT	MCL	%WRS

Left Ytm 226 Hz



Reflex Table

Threshold Ipsilateral L

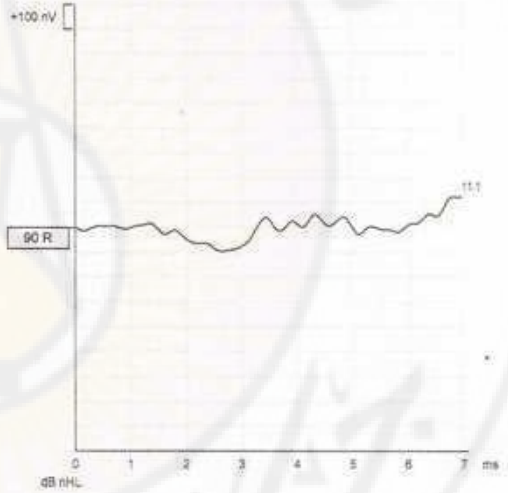
	500	1000	2000	250	4000
dB HL	100#	NR: 100#	NR: 100#		

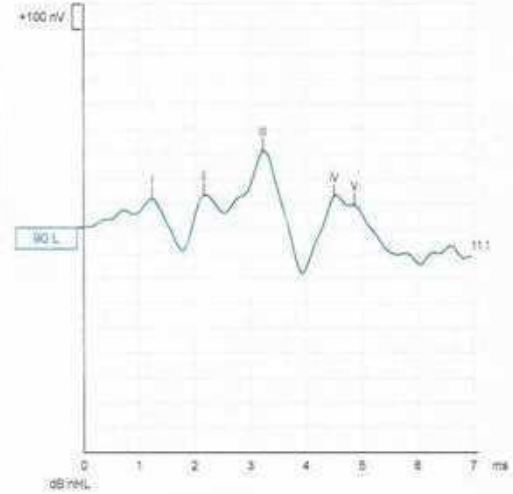
Contralateral L

	250	500	1000	2000	4000
dB HL					

Address: Day Medical Tower Unit C, 9th Floor, Tehran
Tehran, Iran
Tel: 021-88205806 Fax: E-Mail:

Last name: [redacted] Sex: F ID no: 991231
First name(s): Age: 32 years Date of test: 02-20-2021
Address: Day of birth: 02-14-1989
Tel:
Examiner: ADM E-Mail:







Curve	Latencies (ms)								Interlatencies diff. R/L			
	I	II	III	IV	V	I-III	III-V	I-V	I-III	III-V	I-V	V-V
90 L	1.23	2.17	3.23	4.50	4.87	2.00	1.63	3.63				
90 R												

Dana Research Institute Dana Research University

Teb Alreza

Hearing Evaluation Form

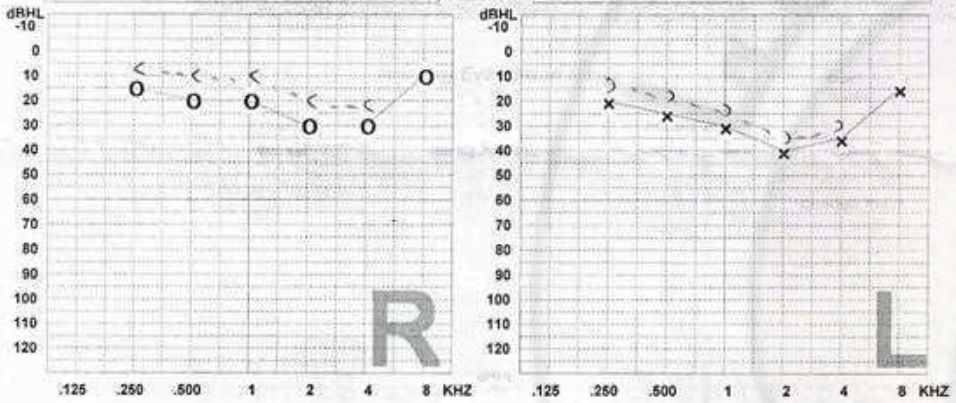
Date: 99/10/7
Number:

Name: [redacted]
Problem of H
More Comm

Sex: Age: Occupation:
Starting date of pain: Referral Source:

Otoscopic Result

Otoscopic Result



PTAve.(2Fq.)	PTAve.(3Fq.)
25.00 dB	23.00 dB

Webber	128	256	512	1024	2048
Result					

PTAve.(2Fq.)	PTAve.(3Fq.)
32.00 dB	31.00 dB

Right Ear	SAT	SRT	MCL	UCL	D.R
SpeechLevel(dB)		25	55		

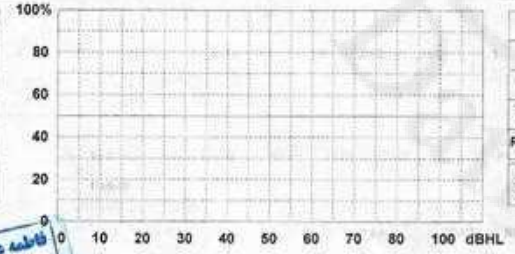
Left Ear	SAT	SRT	MCL	UCL	D.R
SpeechLevel(dB)		30	65		

Right Ear	SDS	SP/N
Score(%)	98	

Left Ear	SDS	SP/N
Score(%)	98	

Right Ear	Graph1	Graph2
PB max(%)		
PB min(%)		
RollOver(%)		
RollOver Indx		

Graph1:without hearing aid
Graph2:with hearing aid



Left Ear	Graph1	Graph2
PB max(%)		
PB min(%)		
RollOver(%)		
RollOver Indx		

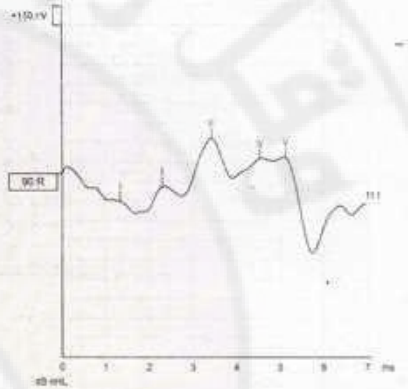
Graph1:without hearing aid
Graph2:with hearing aid

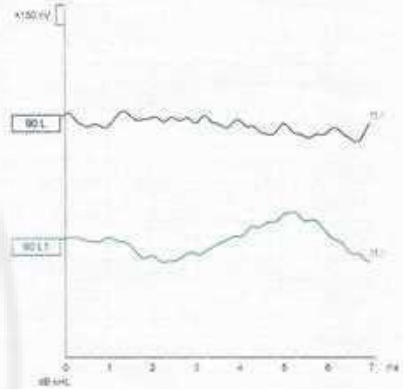
Comments:

فاطمه علیپور دانی یزدانی
ادیولوژیست - ش ۱۱۲۹

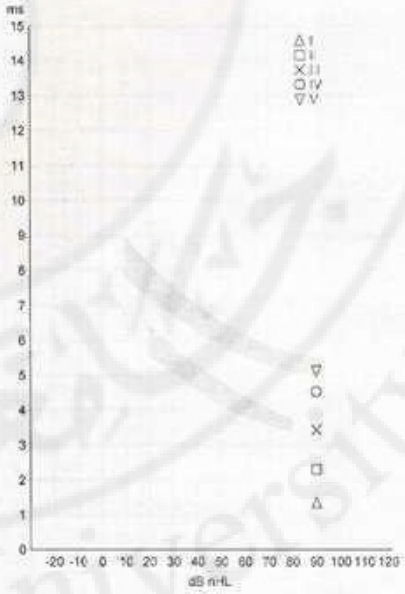
Address: Day Medical Tower Unit C, 9th Floor, Tehran
Tehran, Iran
Tel: 021-88205806 Fax: E-Mail:

Last name: [redacted] Sex: F ID no: 991350
First name(s): Age: 50 years Date of test: 01/06/2021
Address: Day of birth: 02/06/1970
Tel:
Examiner: ADM E-Mail:





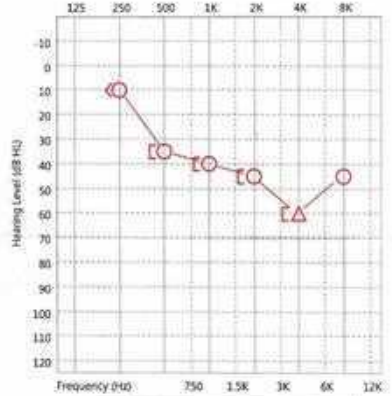
Curve	Latencies (ms) I	II	III	IV	V	I-III	III-V	I-V	Interlatencies d I-III	III-V	I-V
90 R	1.33	2.30	3.43	4.53	5.15	2.10	1.70	3.80			
90 L											
90 L1											



First Name [redacted]
Last Name
Age 10 years
Gender Male

6/19/2022 4:20 PM

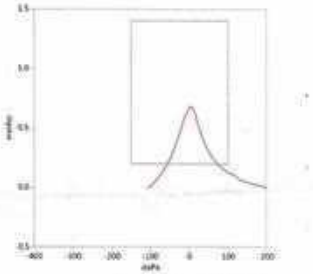
Right Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
R	SRT		40	30
R	MCL		65	40
R	WRS	72	65	40
R	WRS	16	70	65

Speech in noise + 5dBSL

Right 226 Hz

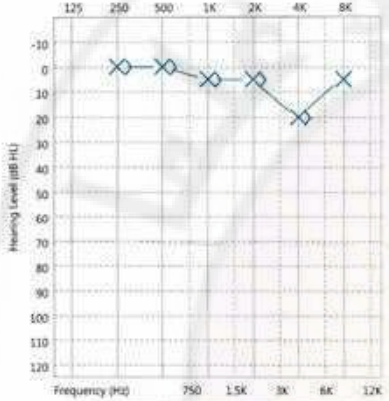


Tymp	Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1 R Y	1.2	4	0.69	80	

Ipsilateral: 1000 500 2000 4000 — dB HL: NR 105

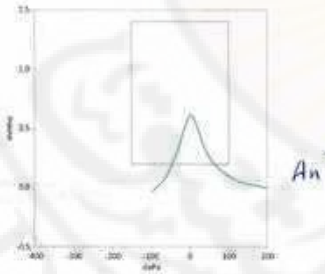
Contralateral: 500 1000 2000 4000 — NR

Left Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
L	SRT		10	
L	MCL		40	
L	WRS	100	40	

Left 226 Hz



Tymp	Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1 L Y	1.1	4	0.61	75	

Ipsilateral: 1000 500 2000 4000 — dB HL: NR 105

Contralateral: 500 1000 2000 4000 — NR

An Type

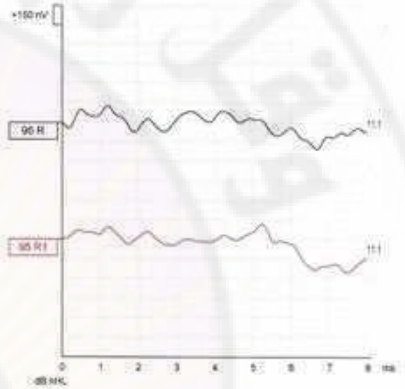
Dear Dr. ABR, MLF test is recommended because of poor speech in noise in the Right ear

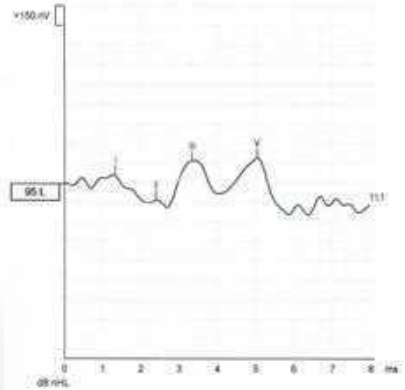
۱۴۰۱/۳/۲۹

Address: Day Medical Tower Unit C, 9th Floor,, IranTehran

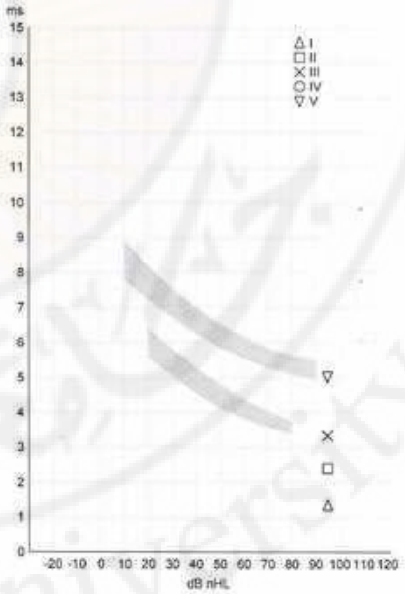
Tel: 021-88205806 Fax: 021-88202934 E-Mail: @tehranearclinic

Last name [redacted] Sex: M ID no: 4010310
First name(s): Age: 10 years Date of test: 06-19-2022
Address: Day of birth: 04-04-2012
Tel:
Examiner: ADM E-Mail:



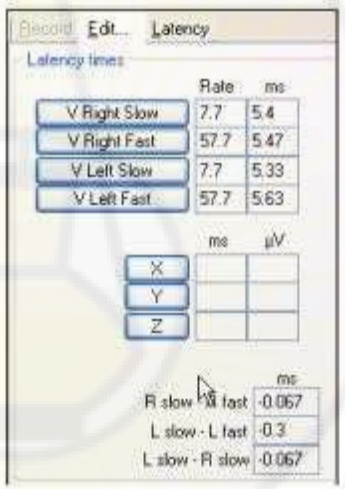


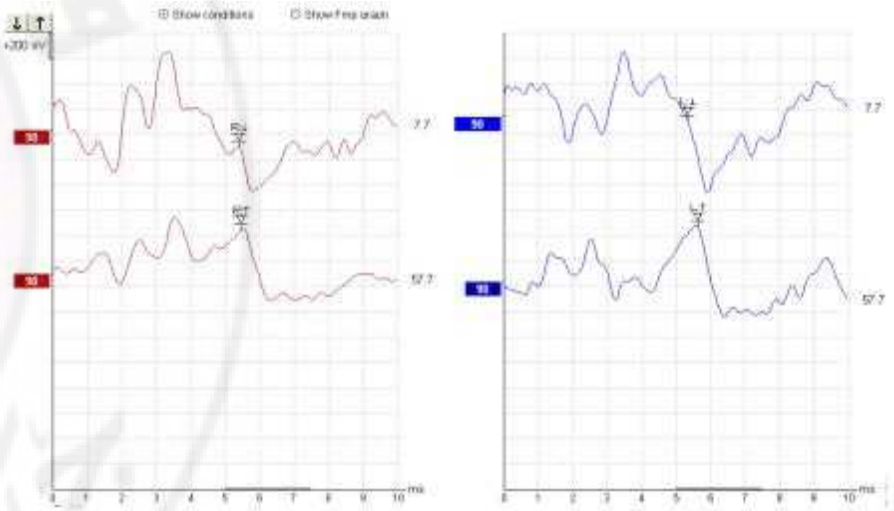
Curve	Latencies (ms) I	II	III	IV	V	Interlatencies I-III	III-V	I-V	Interlatencies diff. R/L I-III	III-V	I-V	V-V
95 L	1.33	2.40	3.33		5.03	2.00	1.70	3.70				
95 R												
95 R1												



Repetition Rate Shifts

- This measure involves the comparison of the latency of Wave V at low and high rates of presentation such as 11 clicks per second to 81 clicks per second. If there is a greater than expected latency increase or a disappearance of Wave V during the high rep rate recording, then the interpretation is for possible eighth nerve pathology.
- An interaural wave V latency difference **greater than 0.2 to 0.4ms** is generally considered abnormal.

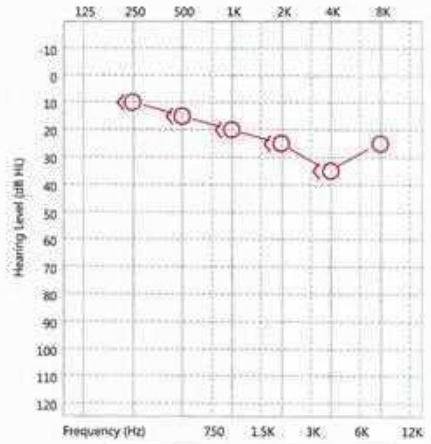




First Name [redacted]
Last Name
Age
Gender Male

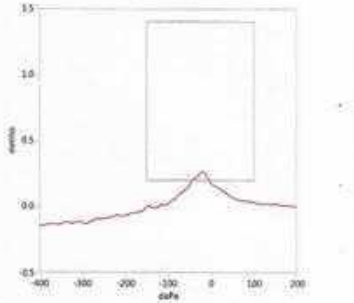
10/29/2022 6:03 PM

Right Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
R	SRT		20	
R	MCL		50	
R	WRS	100	50	

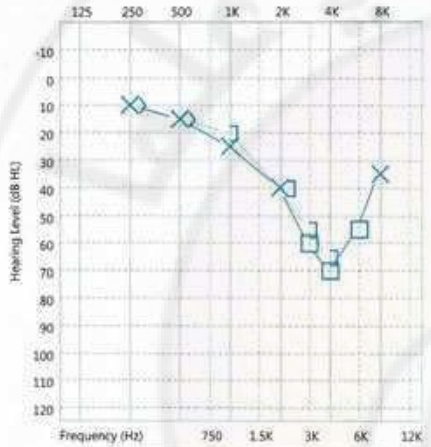
Right 226 Hz



Tymp			Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1	←	Y	1.1	-20	0.27	80	

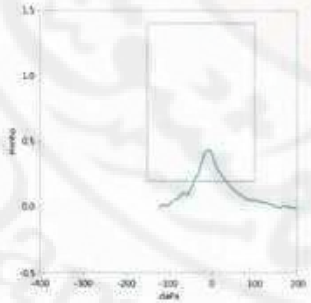
Ipsilateral / Contralateral
1000 500 2000 4000 500 1000 2000 4000
dB HL NR 105

Left Ear Audiogram



Ear	Test Type	%	dB HL	dB EM
L	SRT		25	
L	MCL		55	
L	WRS	100	55	
L	WRS	88	55	45

Left 226 Hz



Tymp			Vea cm3	Peak daPa	Peak mmho	Gradient daPa	Type
1	←	Y	1.0	-7	0.44	65	

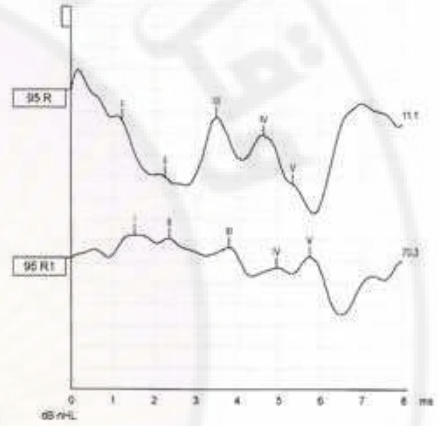
Ipsilateral / Contralateral
1000 500 2000 4000 500 1000 2000 4000
dB HL NR 105

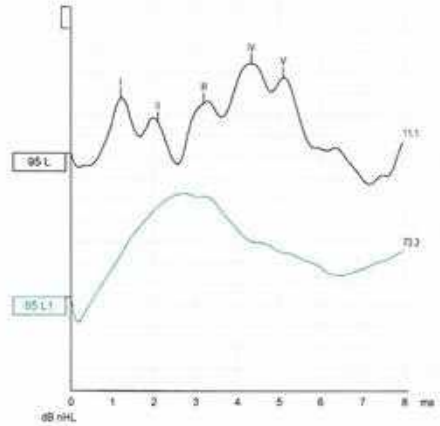
Address: Day Medical Tower Unit C, 9th Floor, IranTehran

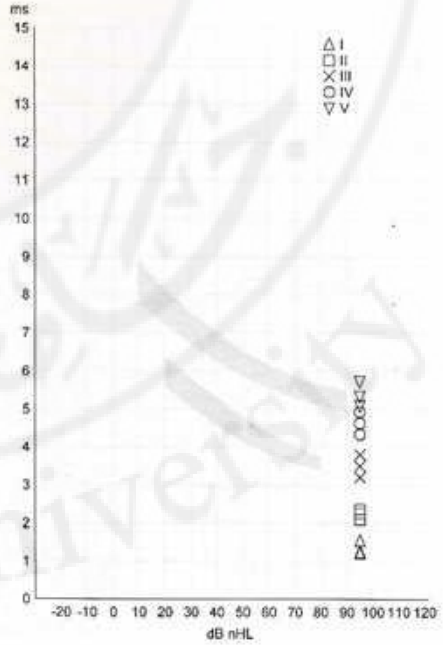
Tel: 021-88205806 Fax: 021-88202934 E-Mail: @tehranearclinic

Last name [redacted] Sex: M ID no: 4010856
First name Age: 56 years Date of test: 10-29-2022
Address Day of birth: 08-10-1966

Tel:
Examiner: ADM E-Mail:







Curve	Latencies (ms) I	II	III	IV	V	I-III	III-V	I-V	Interlatencies diff. R/L I-III	III-V	I-V	V-V
95 R	1.23	2.27	3.50	4.63	5.33	2.27	1.83	4.10	0.27	0.07	0.20	0.2
95 L	1.20	2.10	3.20	4.33	5.10	2.00	1.90	3.90	0.27	0.07	0.20	0.2
95 L1												
95 R1	1.53	2.37	3.80	4.93	5.73	2.27	1.93	4.20	0.27	0.03	0.30	0.6

گاندی
بیمارستان

تاریخ:
شماره:
پیوست:

[redacted]

Brain and CPA MRI (with and without contrast):

Multiplanar, Multislice and multisequence images findings:

- *Cerebral hemispheres: normal size and grey and white matter structures and signal intensity.*
- *No hydrocephalus, mass or midline structural shift.*
- *Brain stem: normal*
- *Cerebellum: normal*
- *IAC and CP angles:* ***6.5 x 4 mm enhancing mass in left internal acoustic canal is seen infavor of acoustic schwannoma.***
- ***Fluid signal in bilateral mastoid air cells suggestive of mild mastoiditis.***
- *Sella turcica and pituitary gland: normal*

Best regards
[redacted]MD
Radiologist

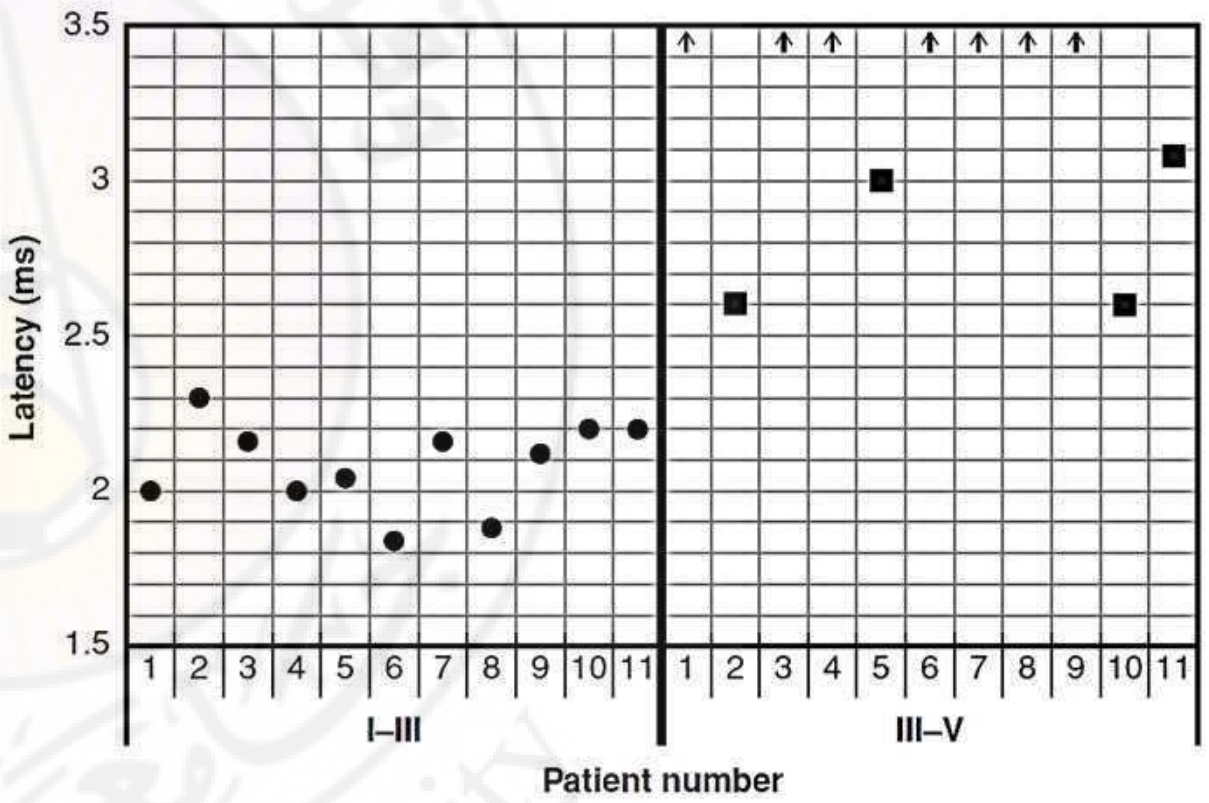
No.130, South Gandhi St., Tehran - IRAN
Tel:+98(21)42624 - 42603000 / Fax:+98(21) 88651208

خیابان گاندی جنوبی، نبش کوچه ترابنده، شماره ۱۳۰
تلفن: ۴۲۶۰۳۰۰۰ - ۴۲۶۲۴ / فکس: ۸۸۶۵۱۲۰۸

WWW.GANDIHOSPITAL.IR

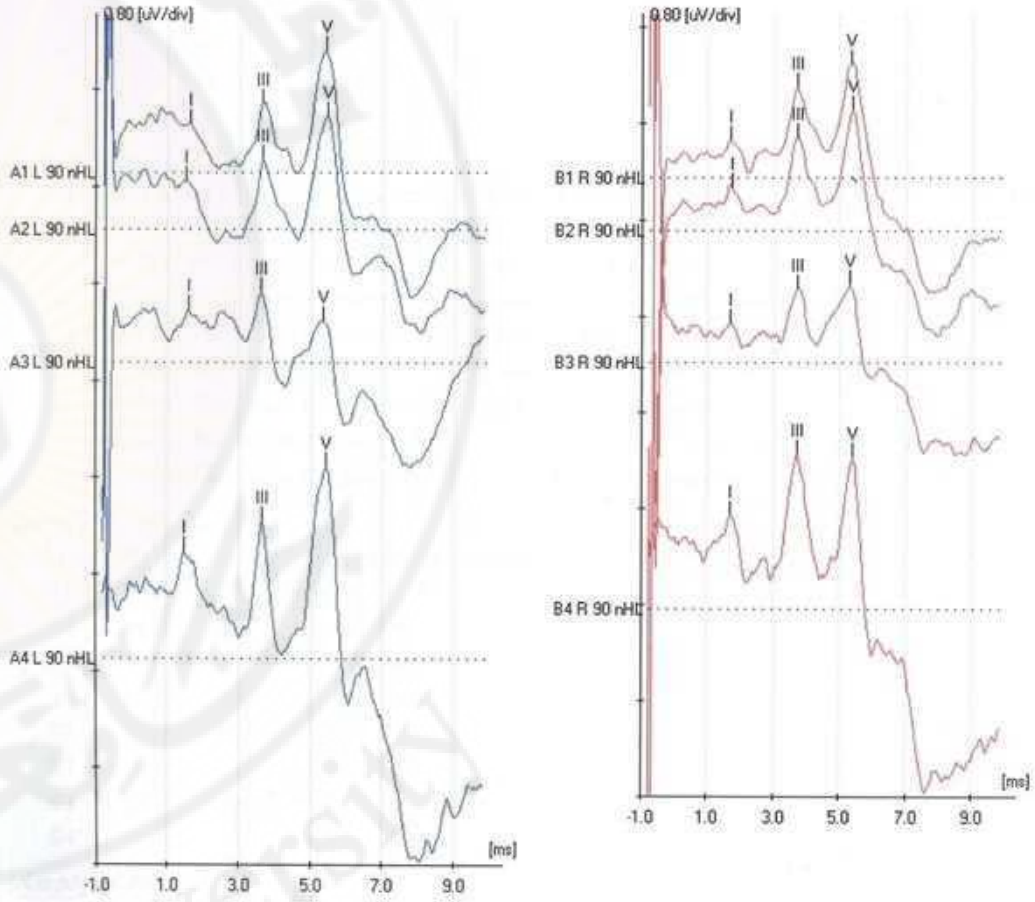
Laterality

- Abnormal ABR findings are generally ipsilateral to the ear of stimulus presentation.
- However, if the tumor grows to a substantial size the **contralateral ABR** can be affected because of compression and possible twisting and displacement of the brainstem from midline.
- When this happens, Wave V or the IV–V complex will be missing, delayed, or reduced in amplitude resulting in a III–V IWI extension or a III–V IWI that cannot be measured.



Threshold Measures

- It is well known that the ABR threshold can closely approximate the behavioral threshold of hearing.
- However, in patients with eighth nerve tumors, the difference between the measured ABR threshold and the behavioral threshold is more than would be expected—often, **30 dB or greater.**



Diagnostic value of ABR

- In patients with eighth nerve tumors, the most reliable diagnostic measurements to use are the I–III and I–V IWI measurements and the ILD, either alone or in combination.
- Using these indices in the interpretation of the ABR results in **hit rates of 90%** or better and false-positive rates of 20% or less.
- The larger the tumor, the easier its detection.

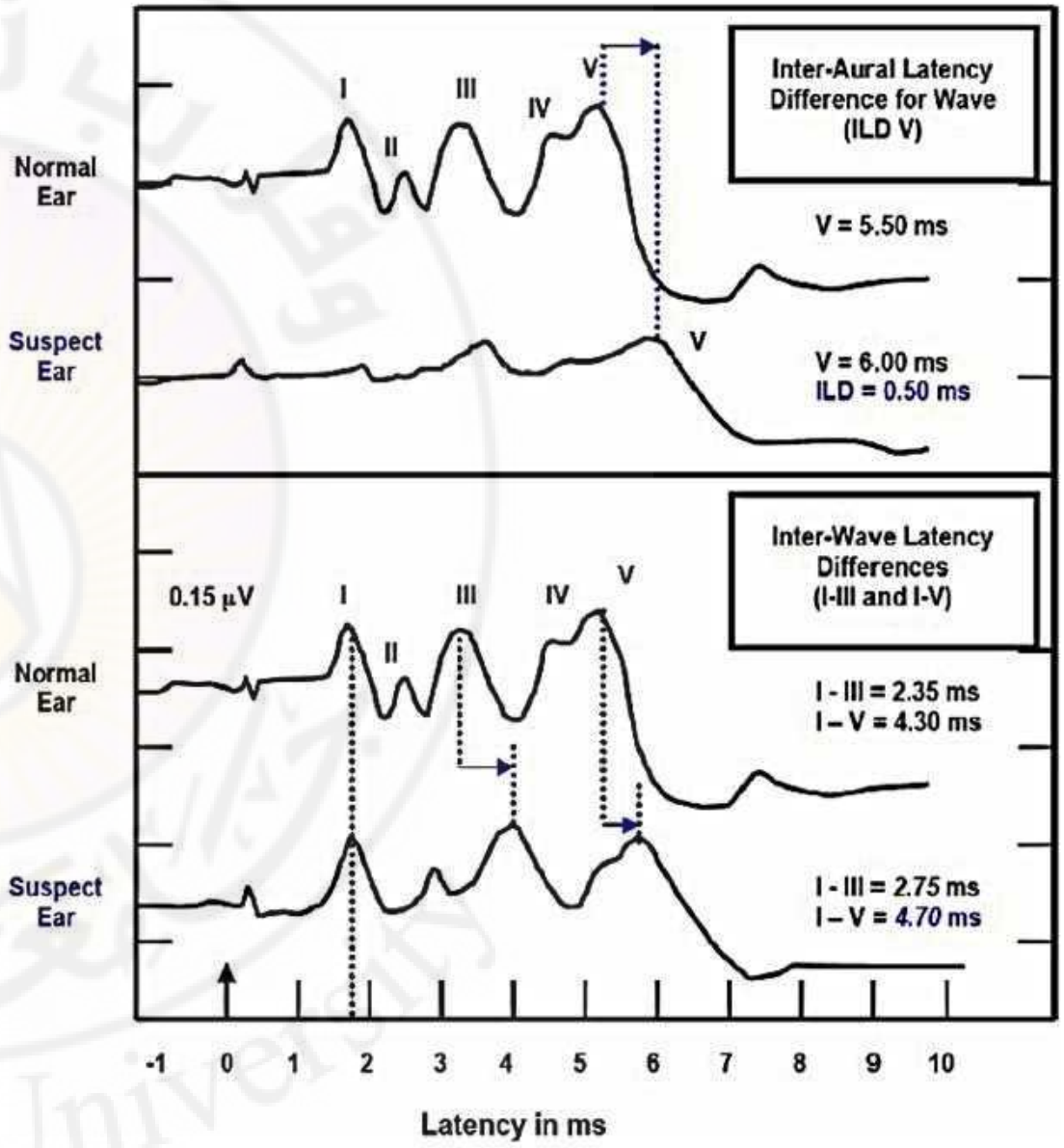


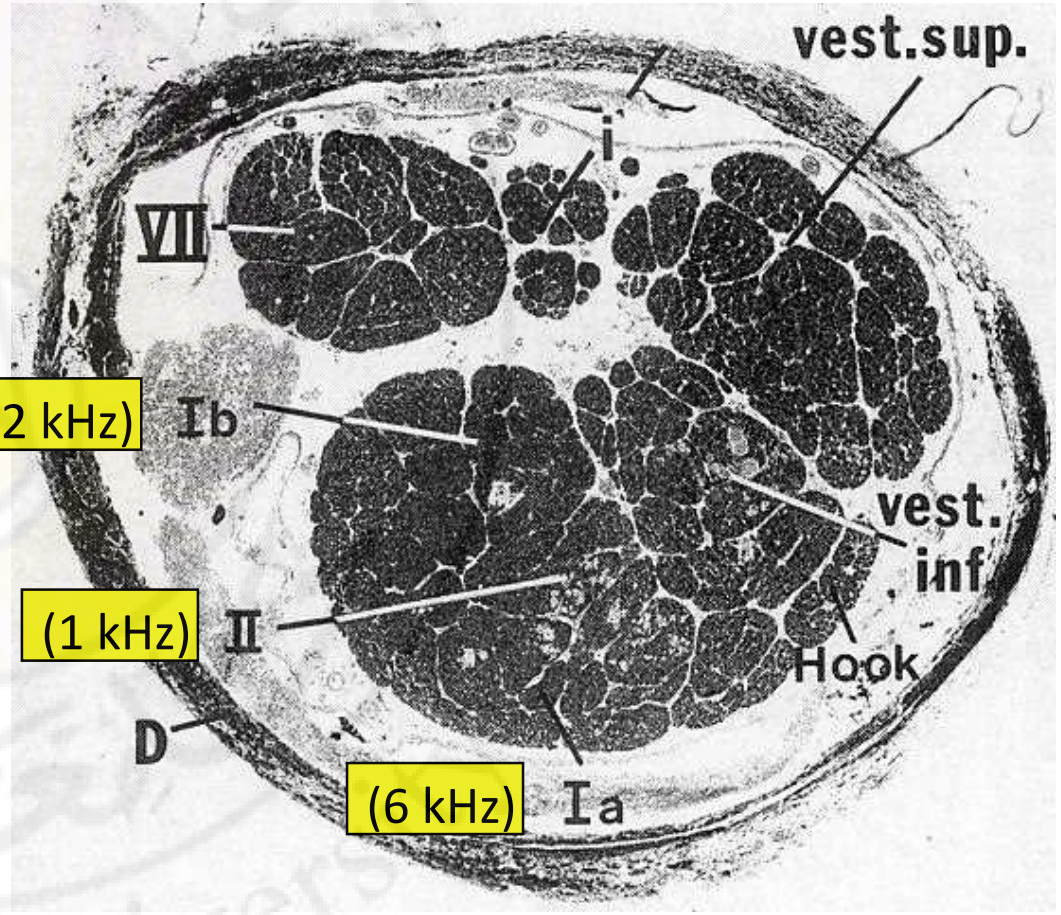
Table 1. Tumor Size versus Auditory Brainstem Response Sensitivity

Total Tumor Size	*n = 105*	*False Negatives* (n = 13)*	*Sensitivity (%) (mean, 87.6%)*
≥2.5 cm	12	0	100
2.1–2.4 cm	6	0	100
1.6–2.0 cm	29	4	86
1.0–1.5 cm	45	5	89
≤9 mm (includes intracanalicular tumors)	13	4	69

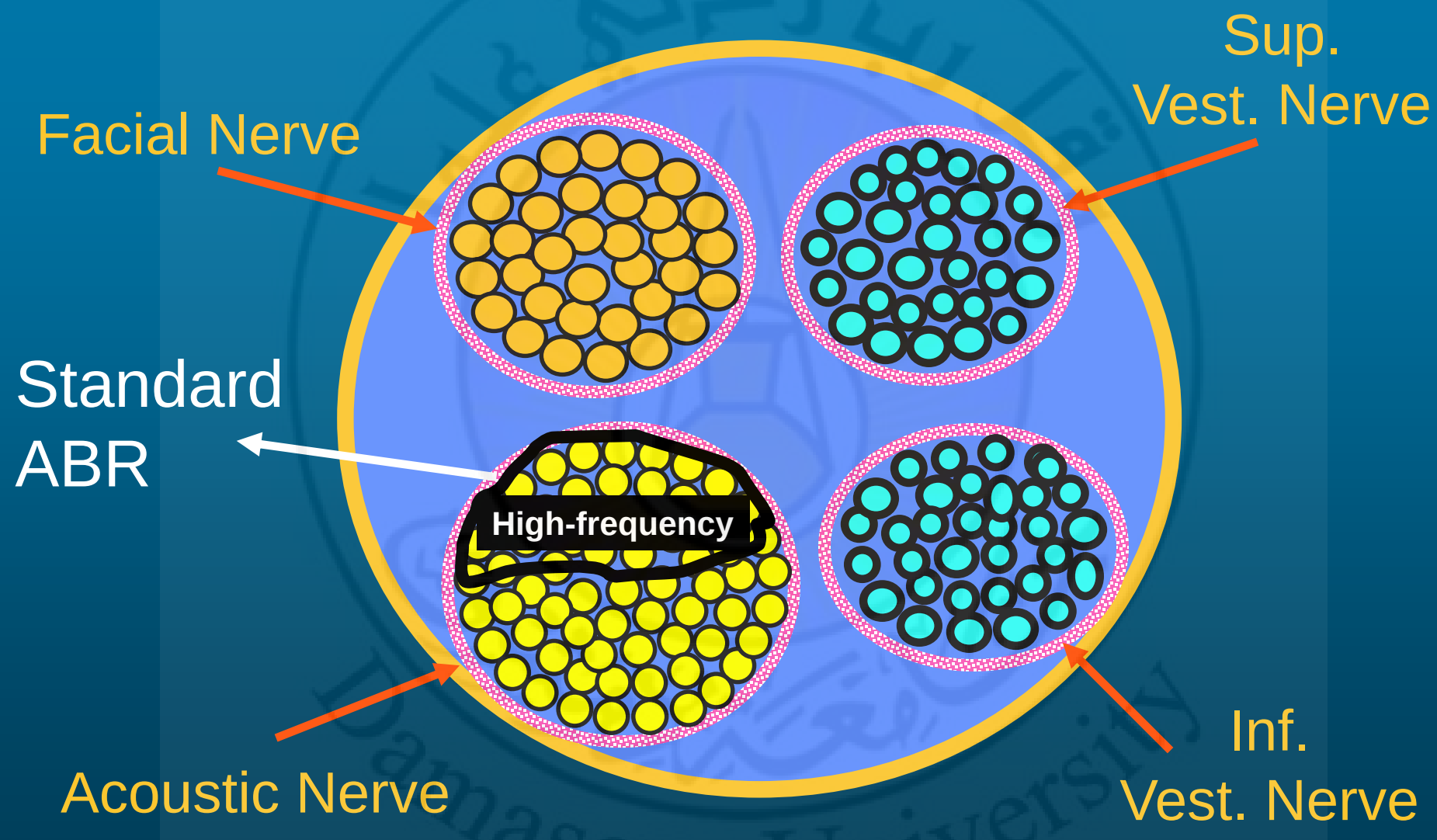
*Normal ABR

ABR limitation in small size tumors

- Although the ABR has high hit rates and low false-positive rates for medium- and large-sized vestibular schwannomas, **smaller sized** tumors are often missed because of the small number of nerve fibers affected by the growth.
- **Tumor location** may also lead to false-negative results on the ABR.

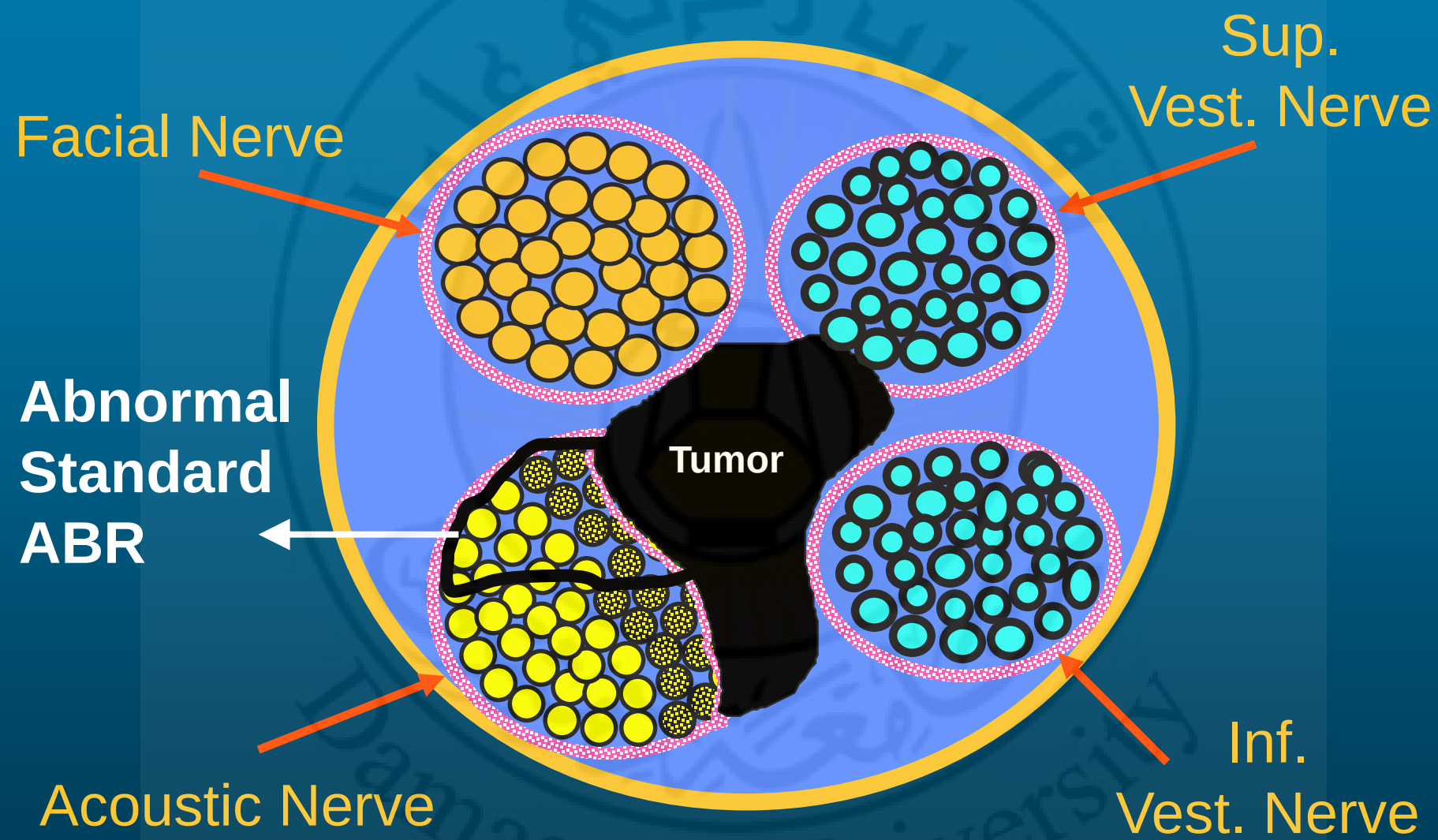


Normal Internal Auditory Canal (IAC)

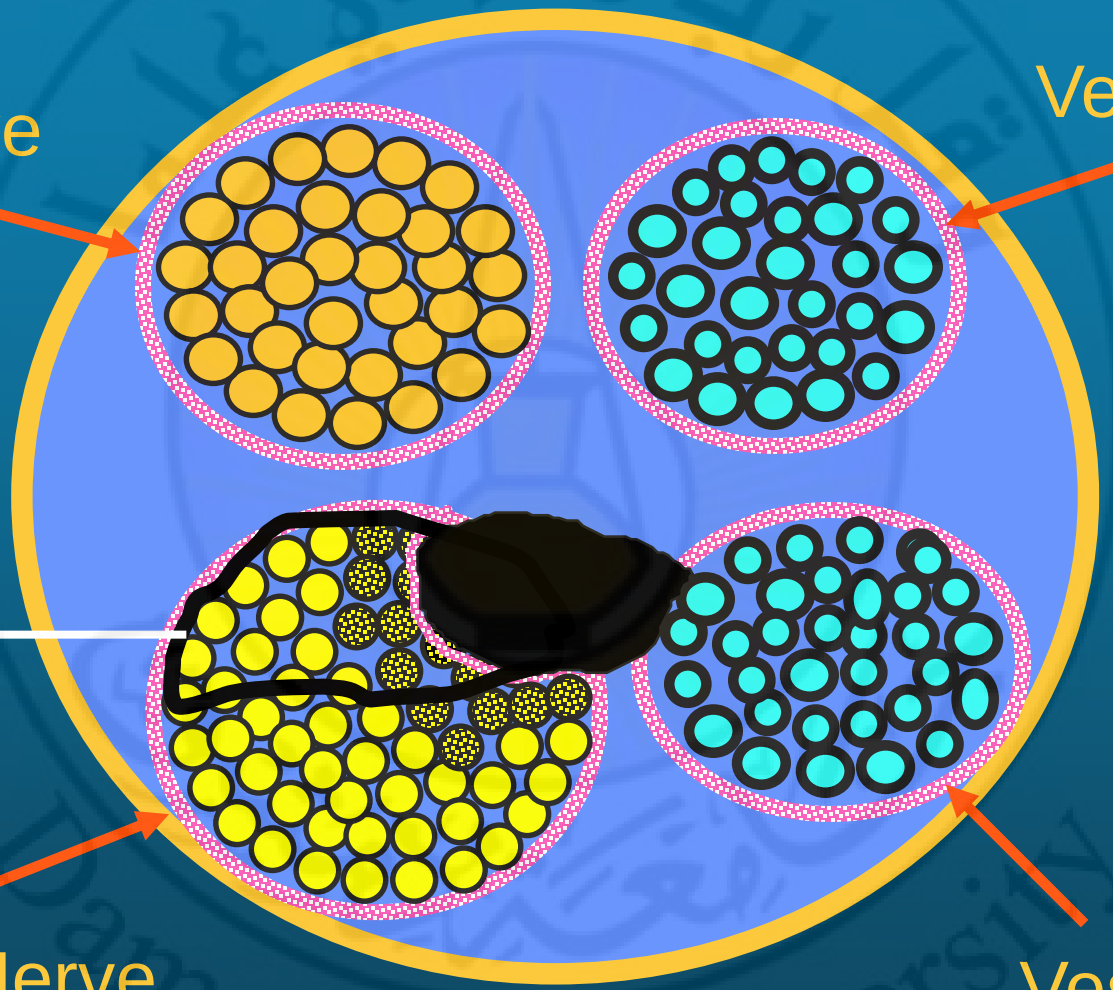


In the standard ABR, wave V latency is dominated by HF regions because lower frequency contributions are phase-cancelled

Medium or Large Tumor in IAC



Small Tumor in IAC



Facial Nerve

Sup.
Vest. Nerve

Abnormal
Standard
ABR

Acoustic Nerve

Inf.
Vest. Nerve

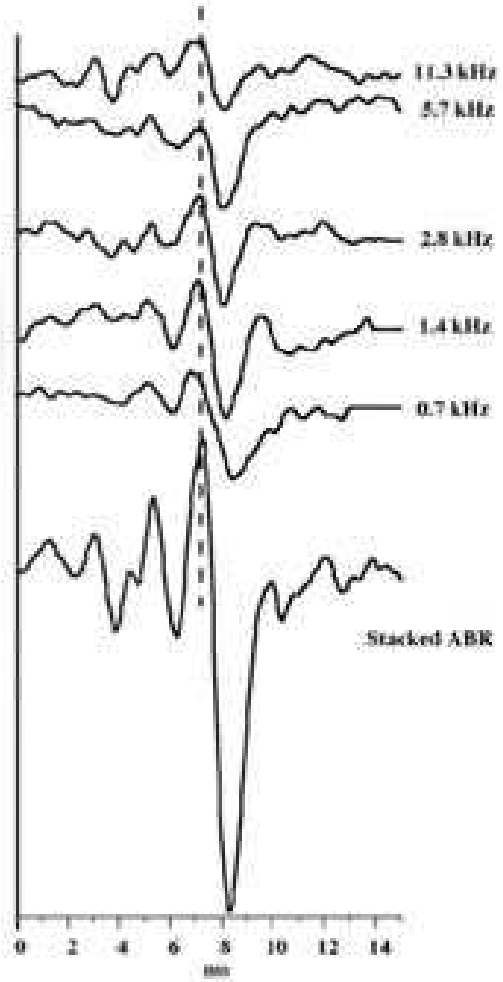
Small Tumor in IAC



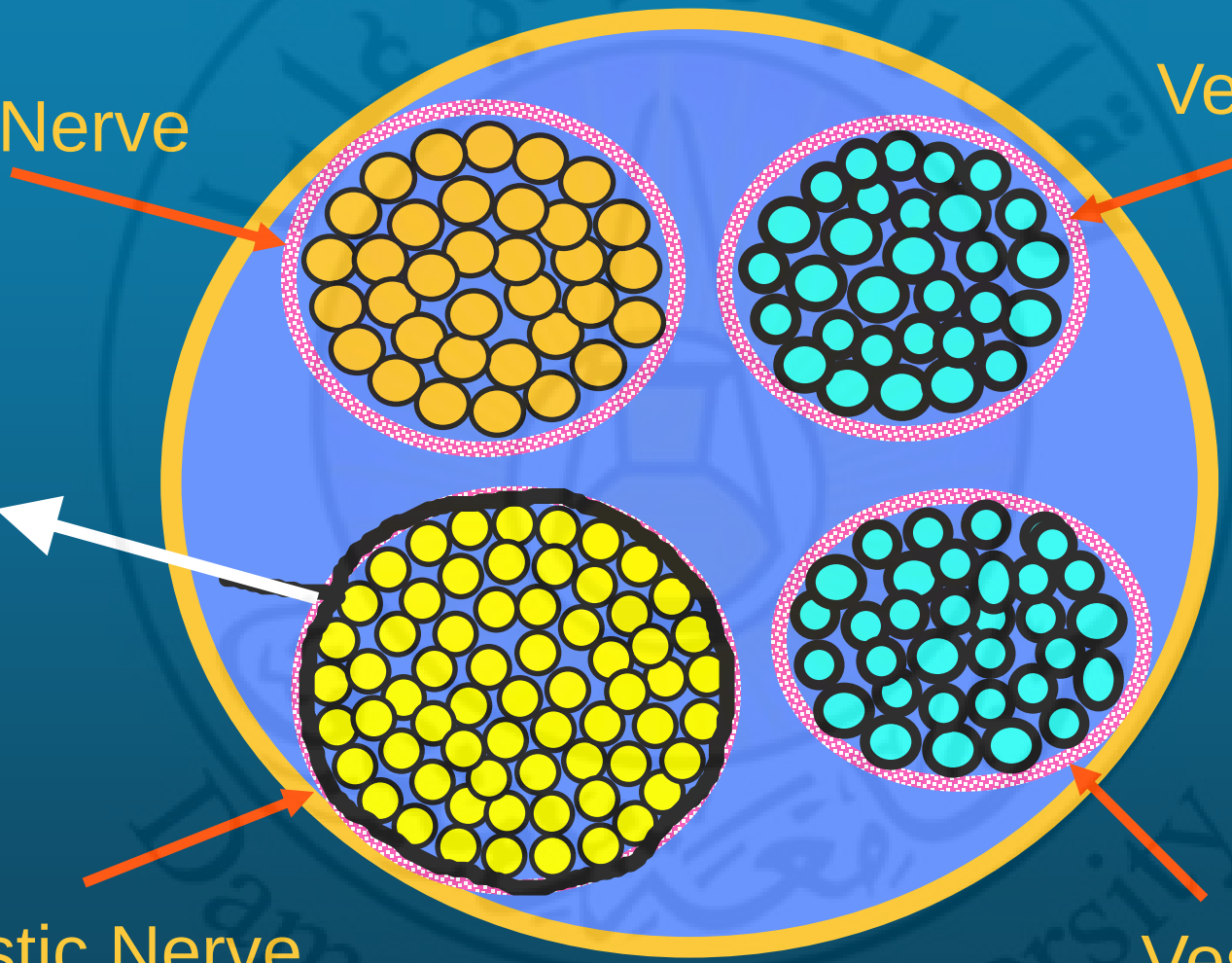
If the tumor does not affect these HF fibers sufficiently, the standard ABR latencies will be normal.

Stacked ABR for detection of small tumors

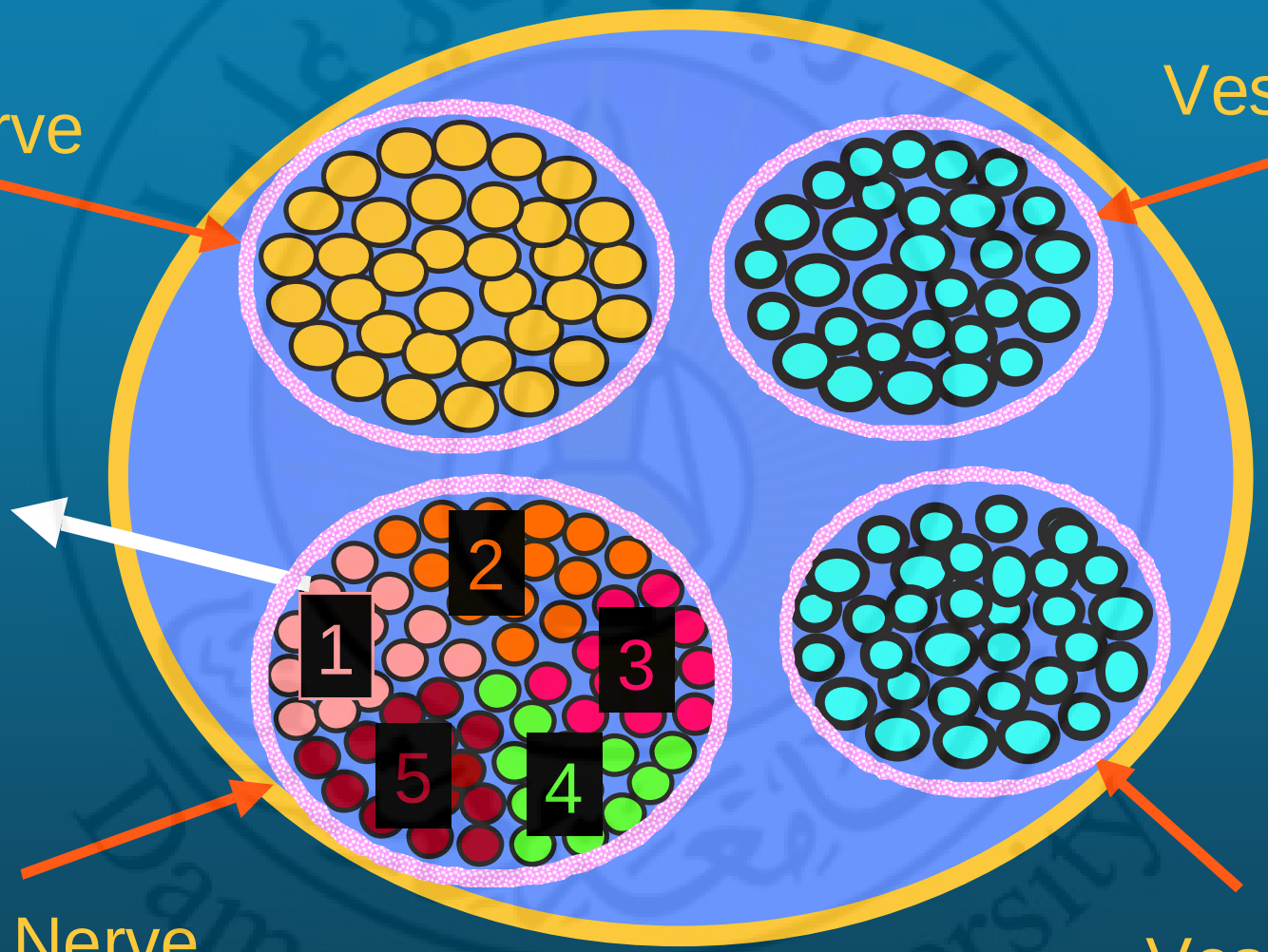
- Don et al. (1997) developed a method of detecting tumors that are missed by standard ABR testing because of either tumor location or size. In order to detect small tumors, ABR must measure activity from essentially all fibers, not just a subset.
- The **Stacked ABR** aims to measure neural activity not just from a narrow portion of the cochlea (as is the case when the standard ABR is employed), but from **the length of the cochlea as a whole**.
- The ABR results would then be a reflection of the neural synchrony lost because of the presence of a tumor regardless of which fibers are affected by that tumor.



Normal IAC

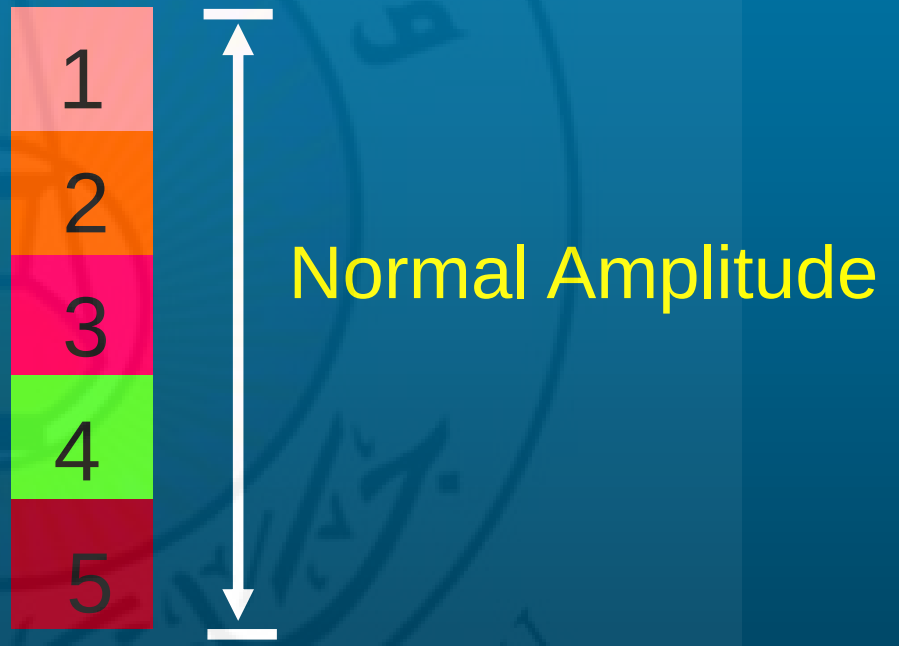

Facial Nerve
Sup.
Vest. Nerve
New
ABR
Acoustic Nerve
Inf.
Vest. Nerve

Normal IAC


Facial Nerve
Sup.
Vest. Nerve
New
ABR
1
2
3
4
5
Acoustic Nerve
Inf.
Vest. Nerve

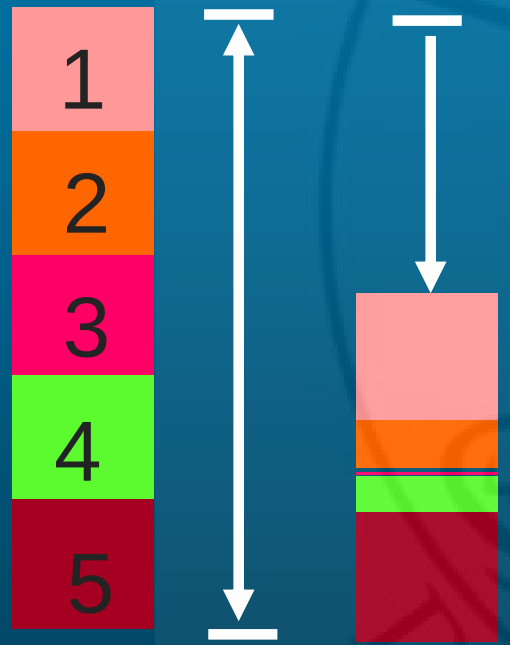
Diagnostic Test: If you add the activity from each of the five areas, is the amplitude normal?

Activity from area 1
+
Activity from area 2
+
Activity from area 3
+
Activity from area 4
+
Activity from area 5



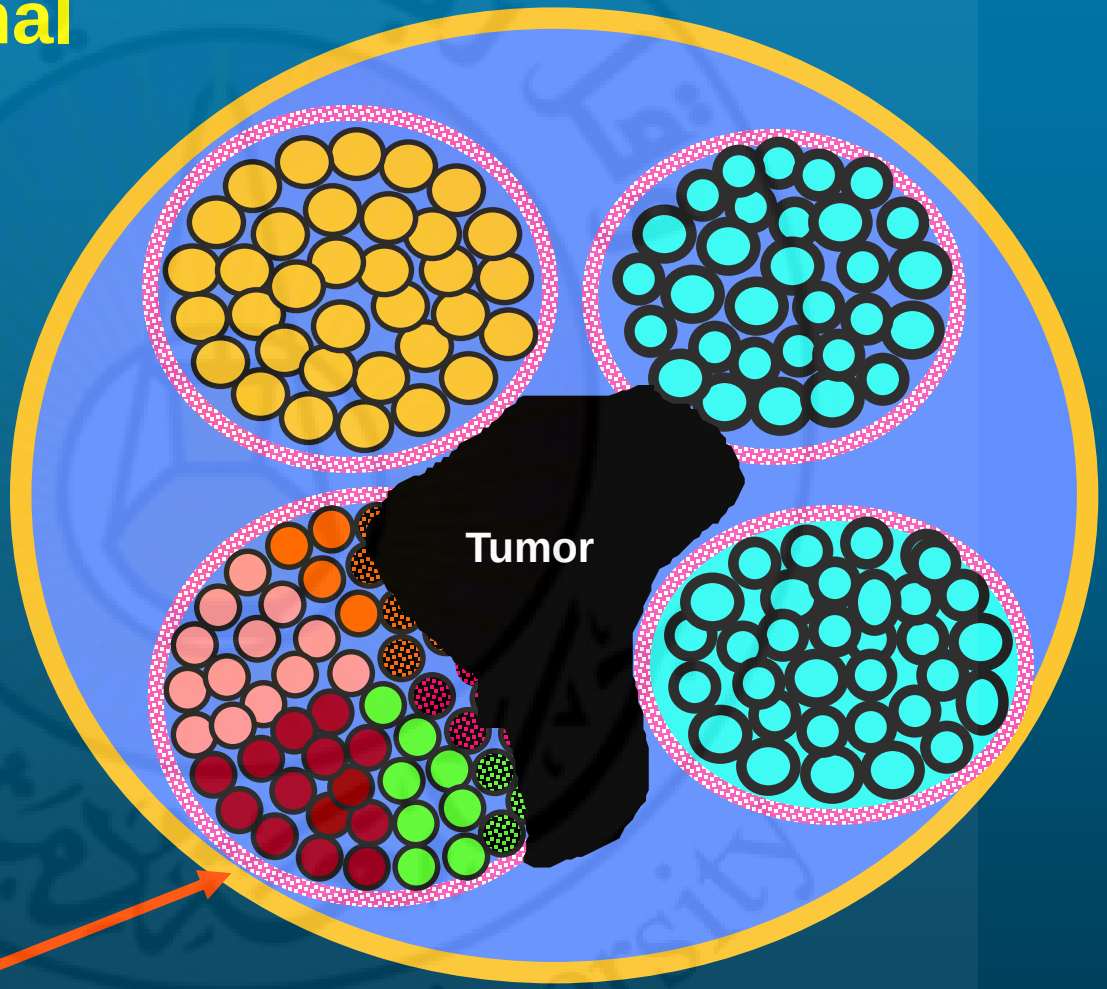
Medium or Large Tumor in IAC

New ABR: Abnormal



Normal

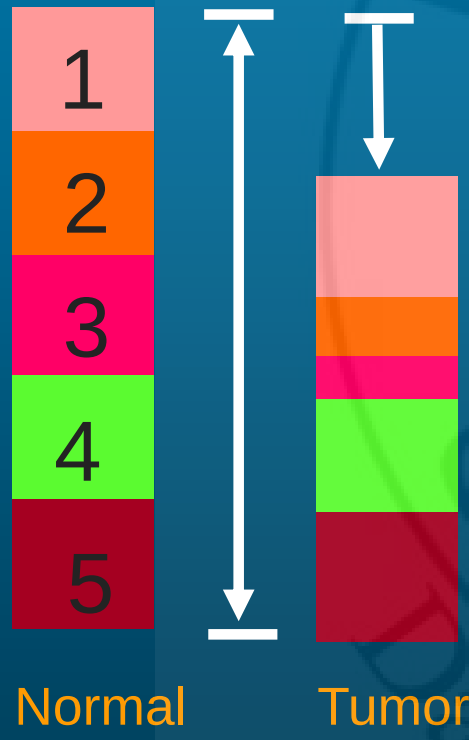
Tumor

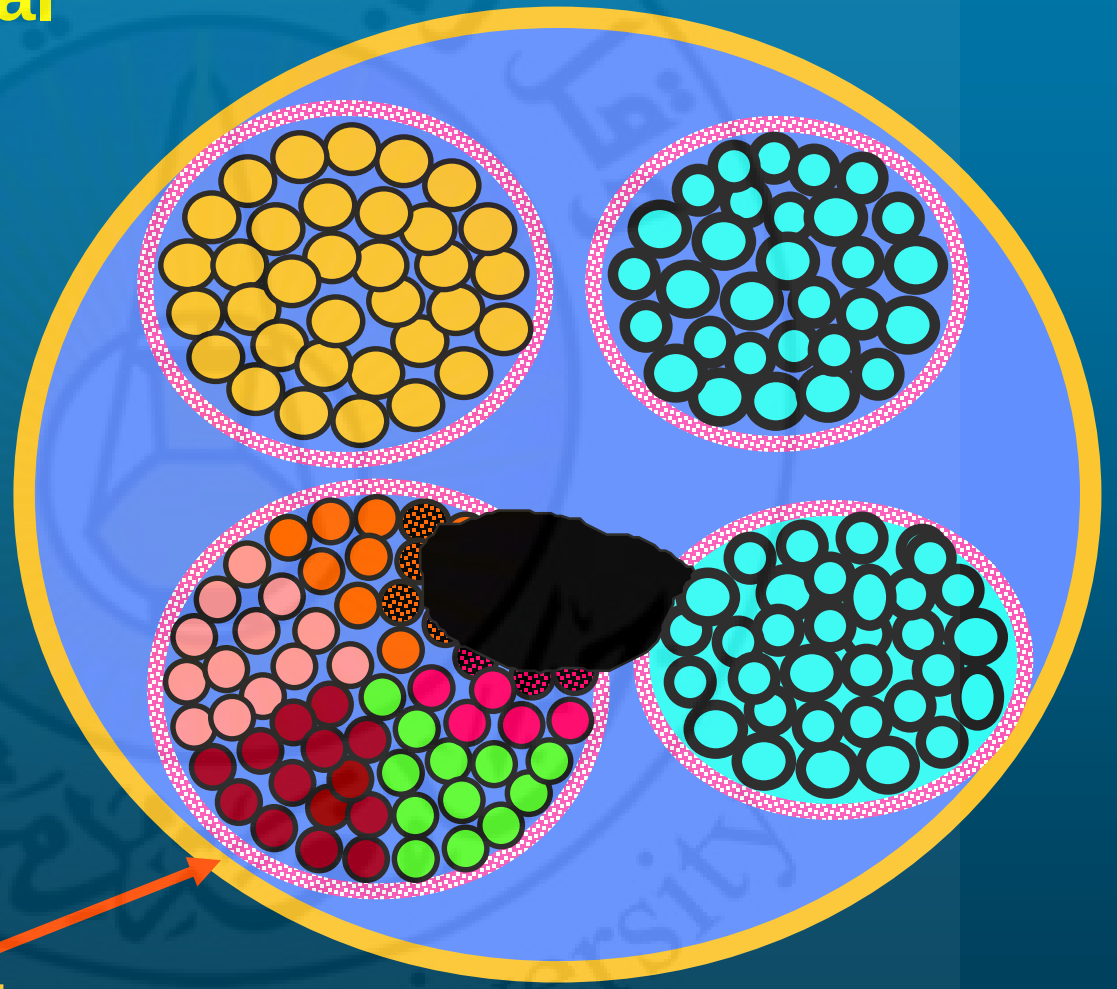


Acoustic Nerve

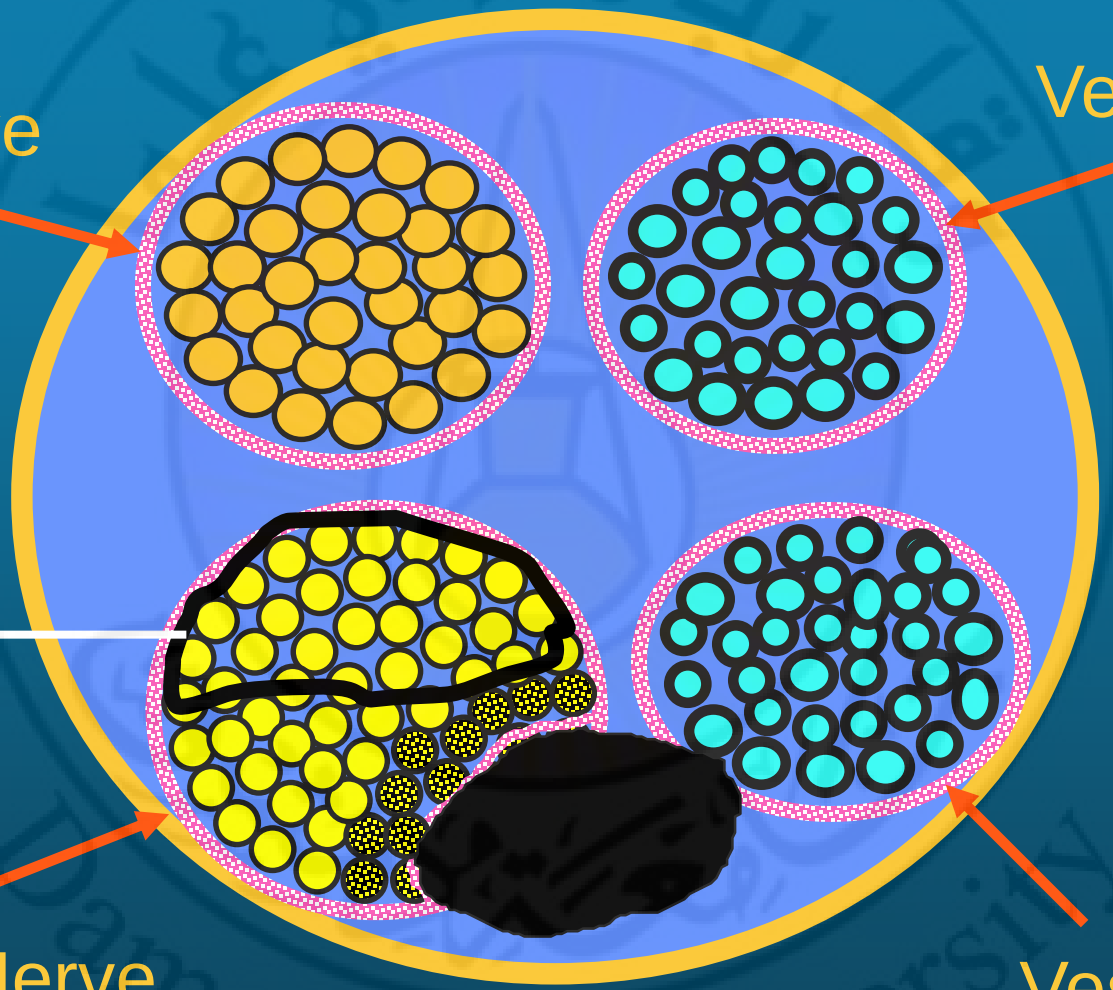
Small Tumor in IAC

New ABR: Abnormal





Small Tumor in IAC



Facial Nerve

Sup.
Vest. Nerve

Normal
Standard
ABR

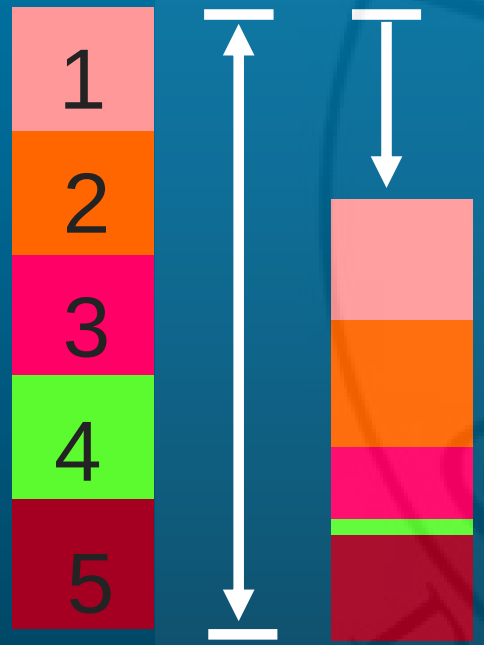
Acoustic Nerve

Inf.
Vest. Nerve

Damascus University

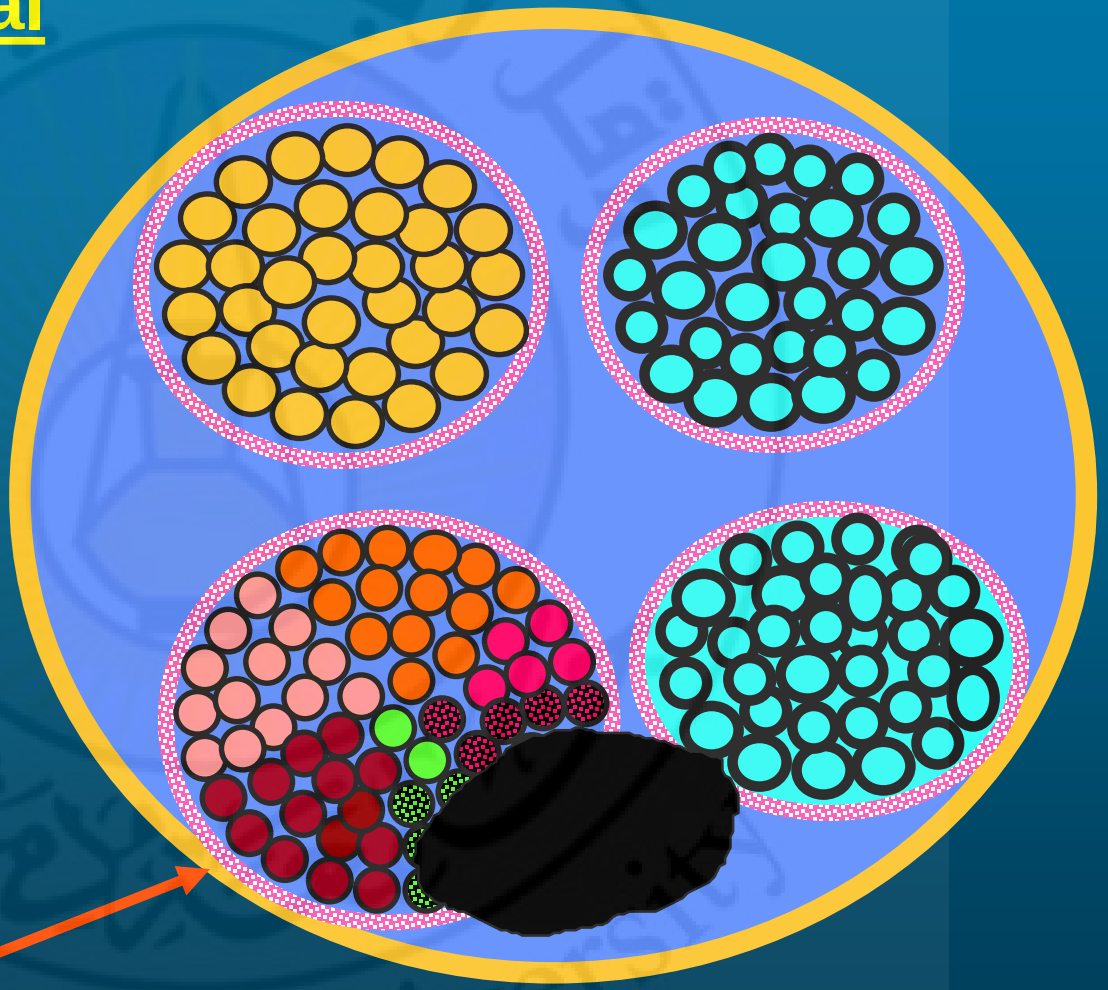
Small Tumor in IAC

New ABR: Abnormal



Normal

Tumor



Acoustic Nerve

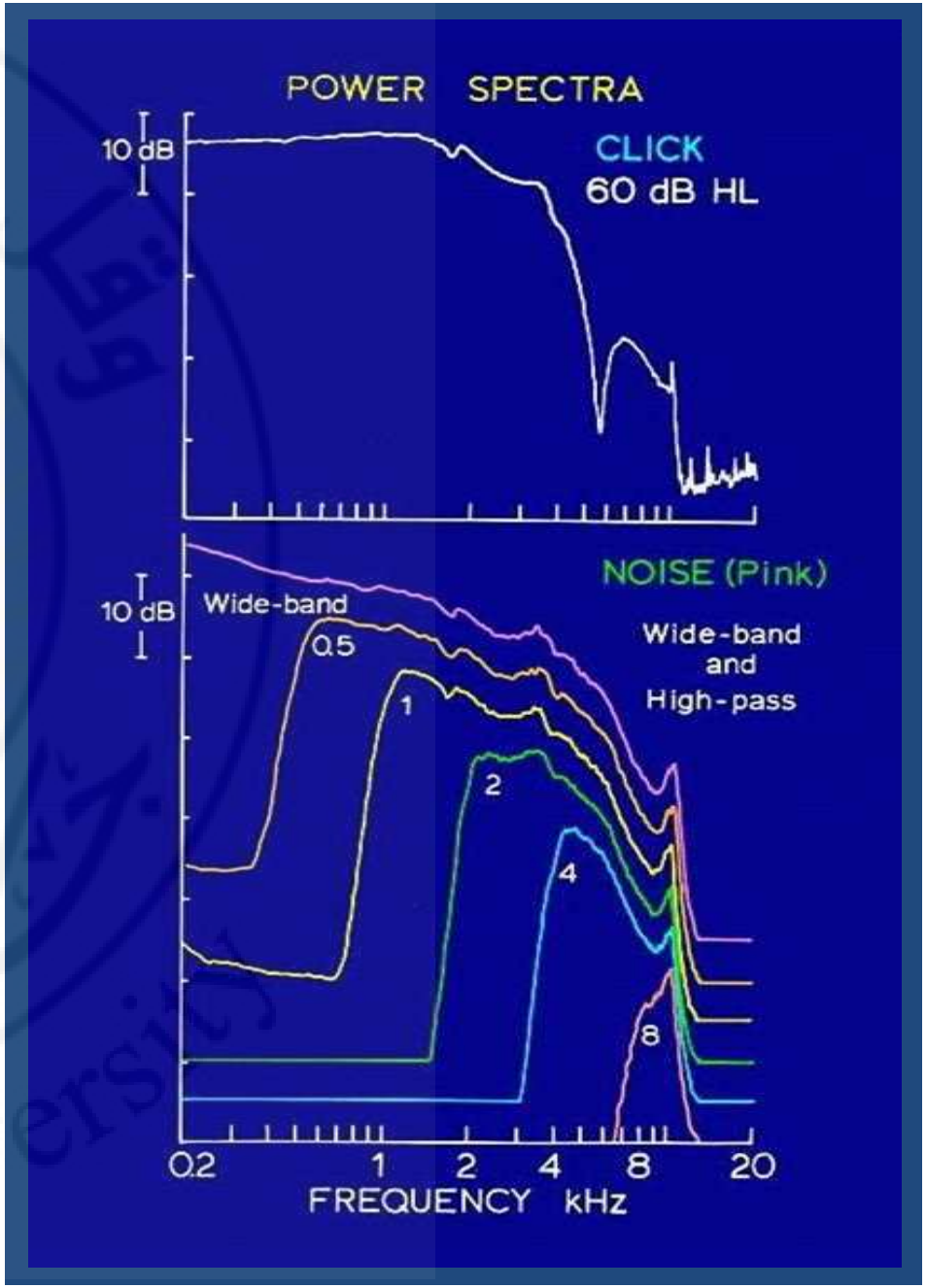
Stacked ABR Measure

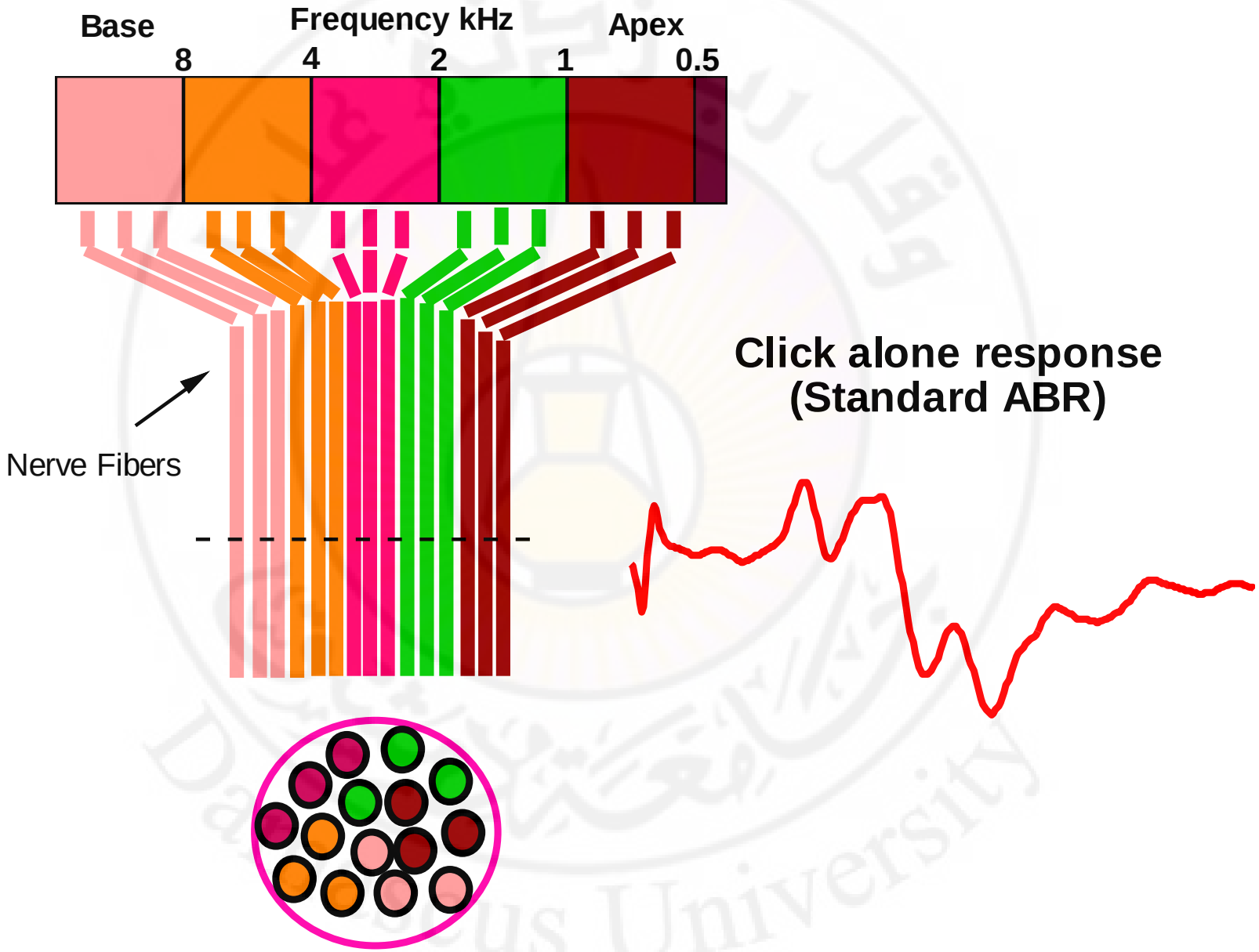
Requirements		Proposed Methods
1. An auditory signal that stimulates essentially all frequency regions of the cochlea	→	Wideband Click
2. A method for separating the responses from different frequency regions of the cochlea	→	The Derived-band ABR Technique
3. A procedure for summing the responses to approximate total neural activity	→	The Stacking Technique

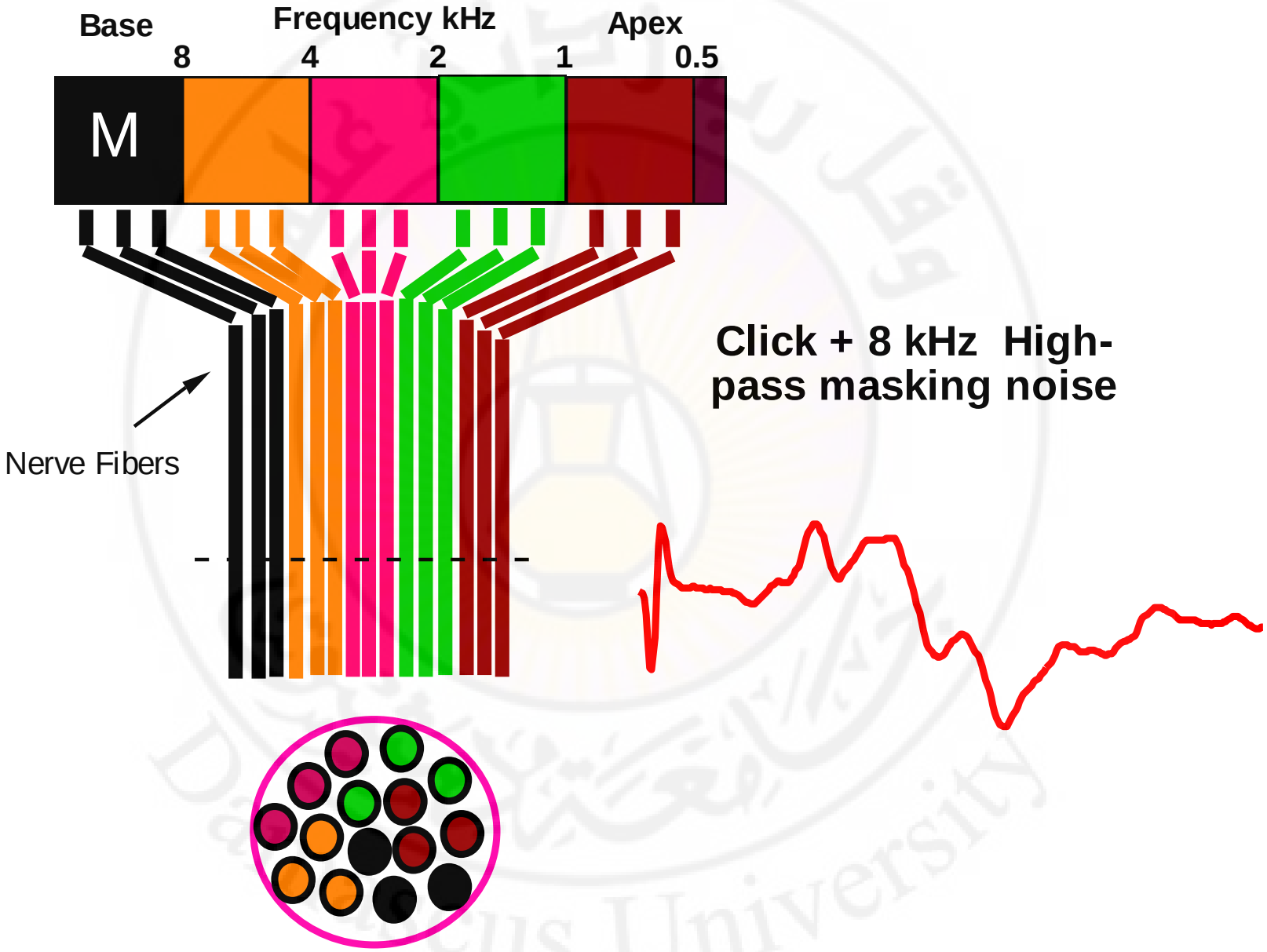
- Six stimulus conditions are used to obtain these ABRs and consist of clicks alone without masking and clicks presented along with five variations of simultaneous ipsilateral highpass pink noise (cutoff frequencies of 0.5, 1, 2, 4, and 8 kHz).

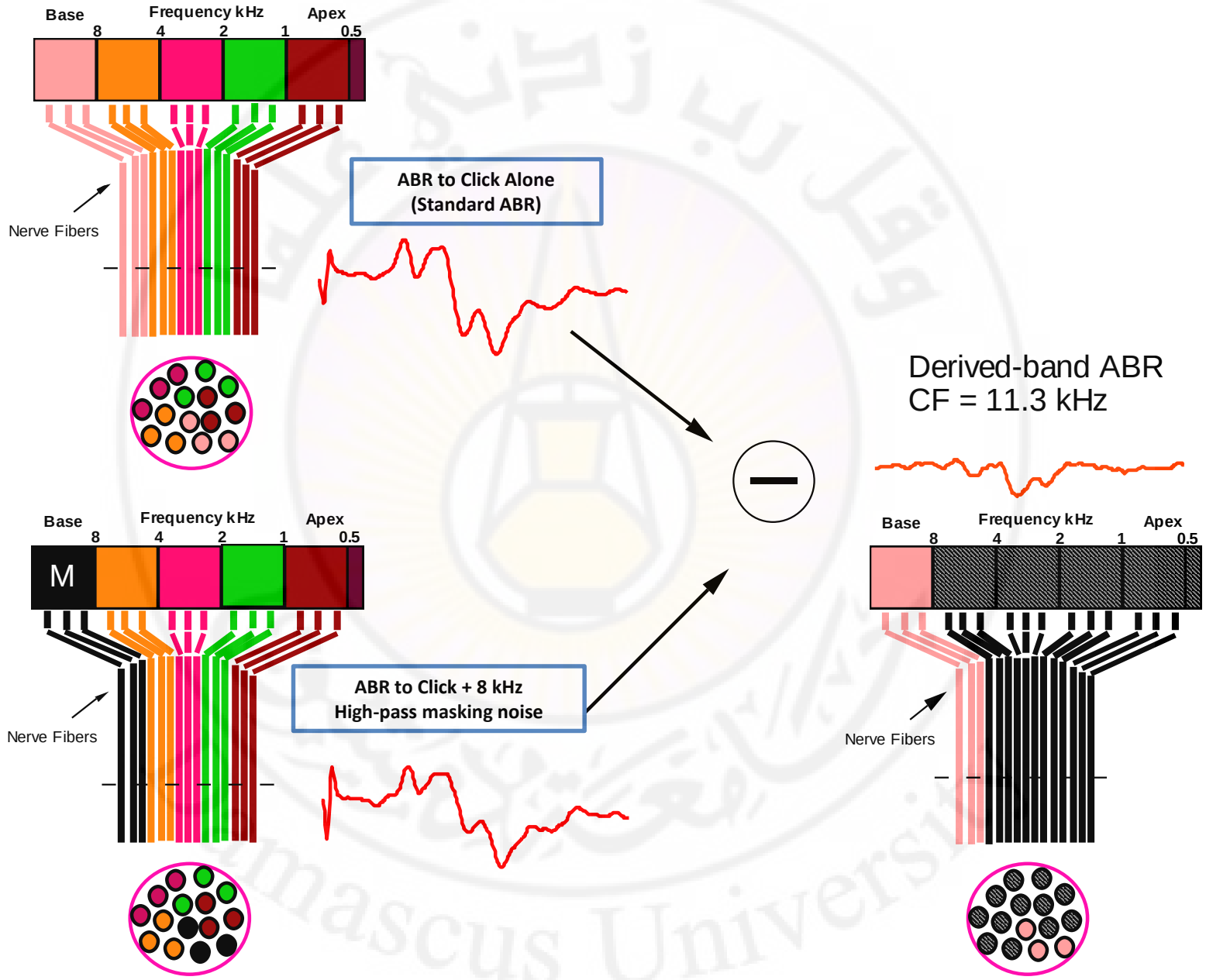
Click

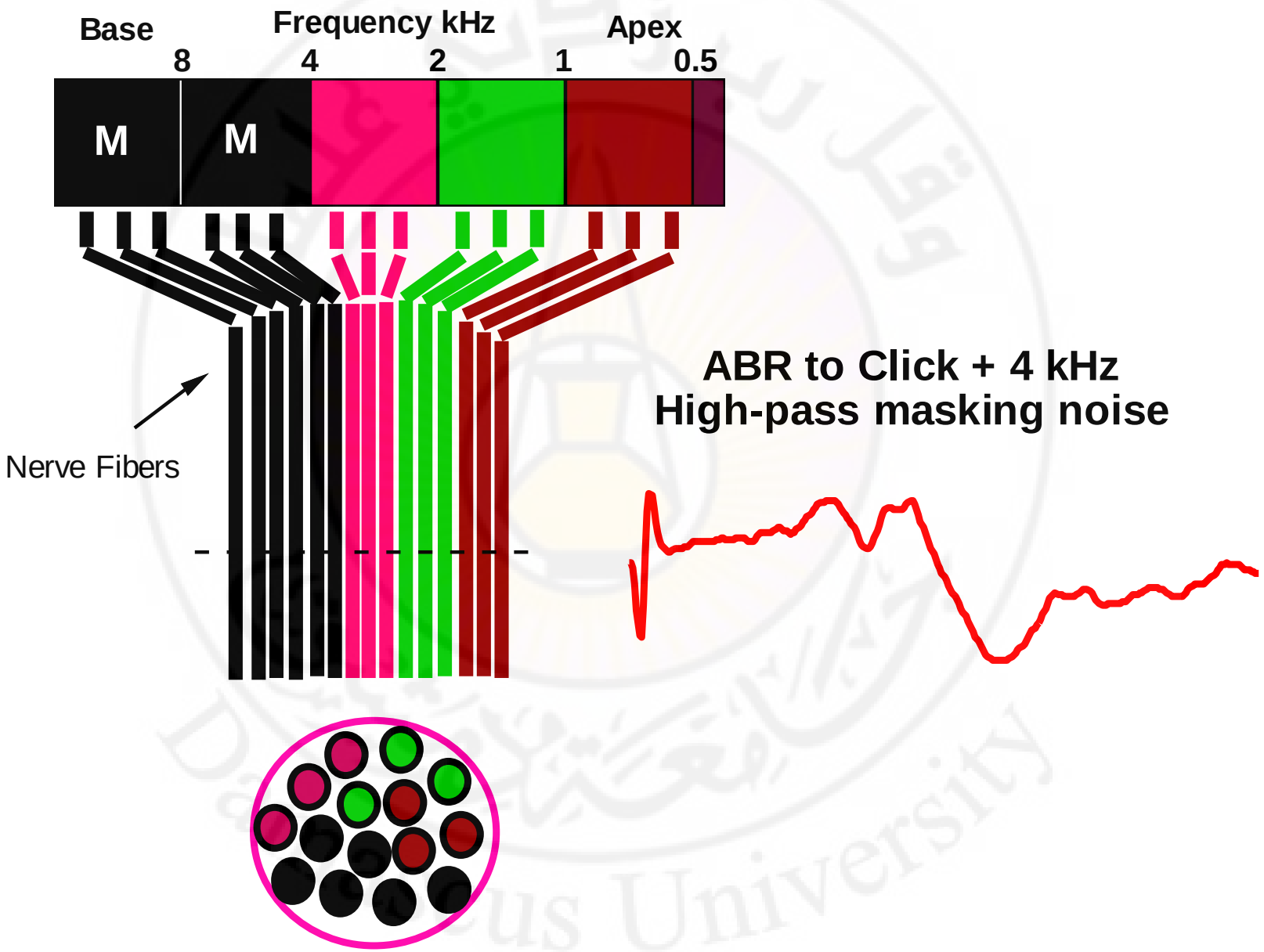
High-pass Masking Noise

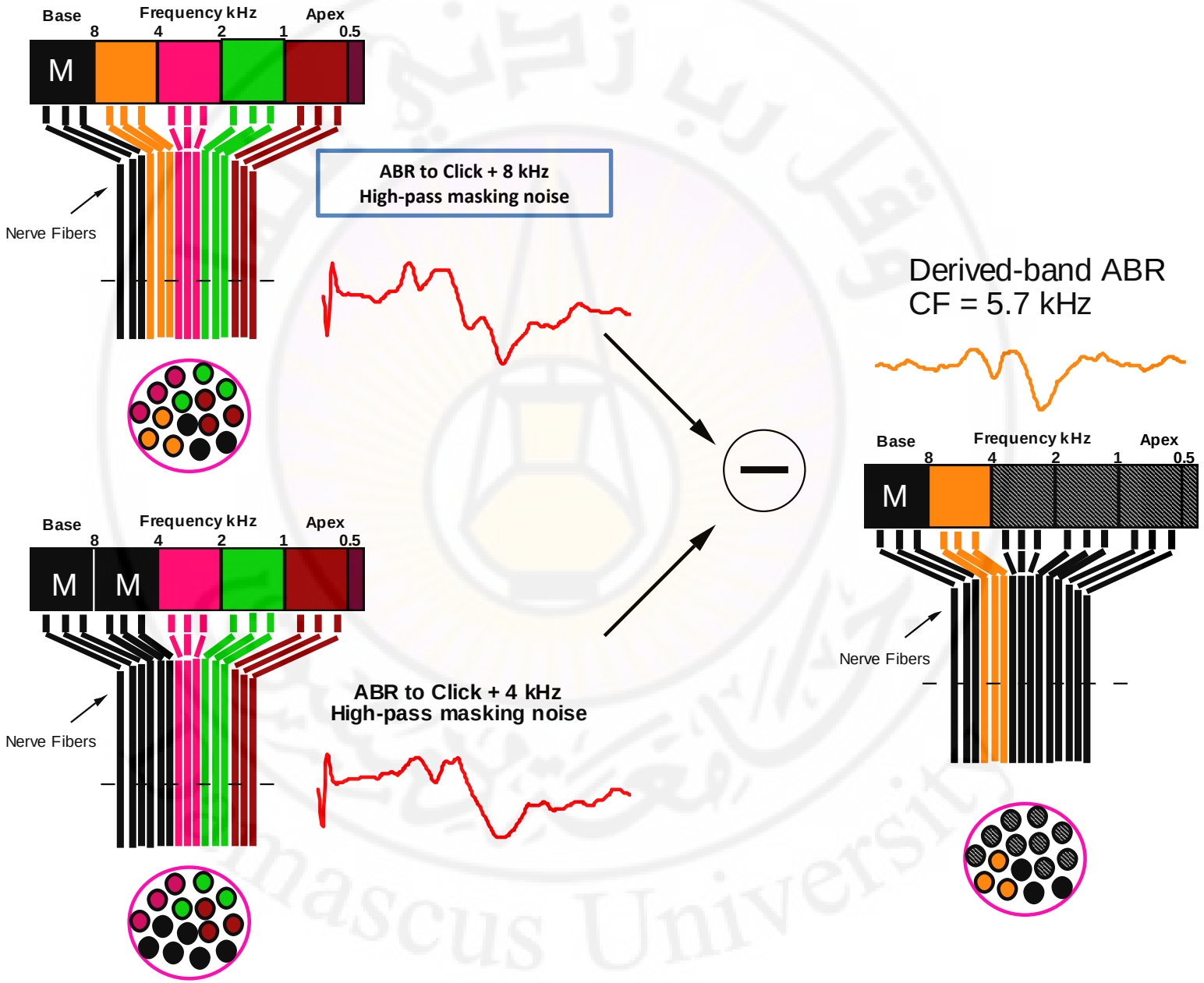


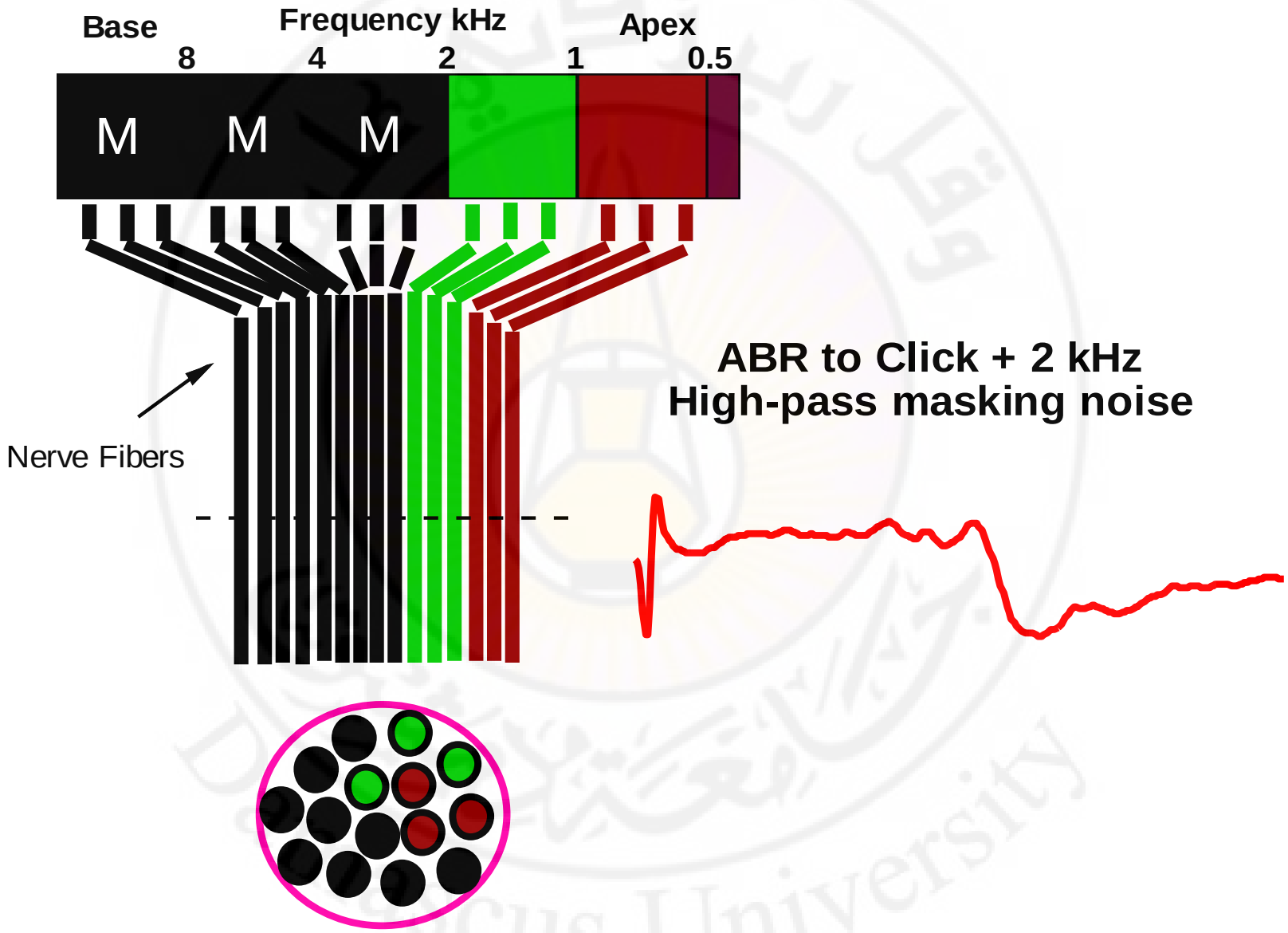

Base
Frequency kHz
Apex
8
4
2
1
0.5
Nerve Fibers
Click alone response
(Standard ABR)

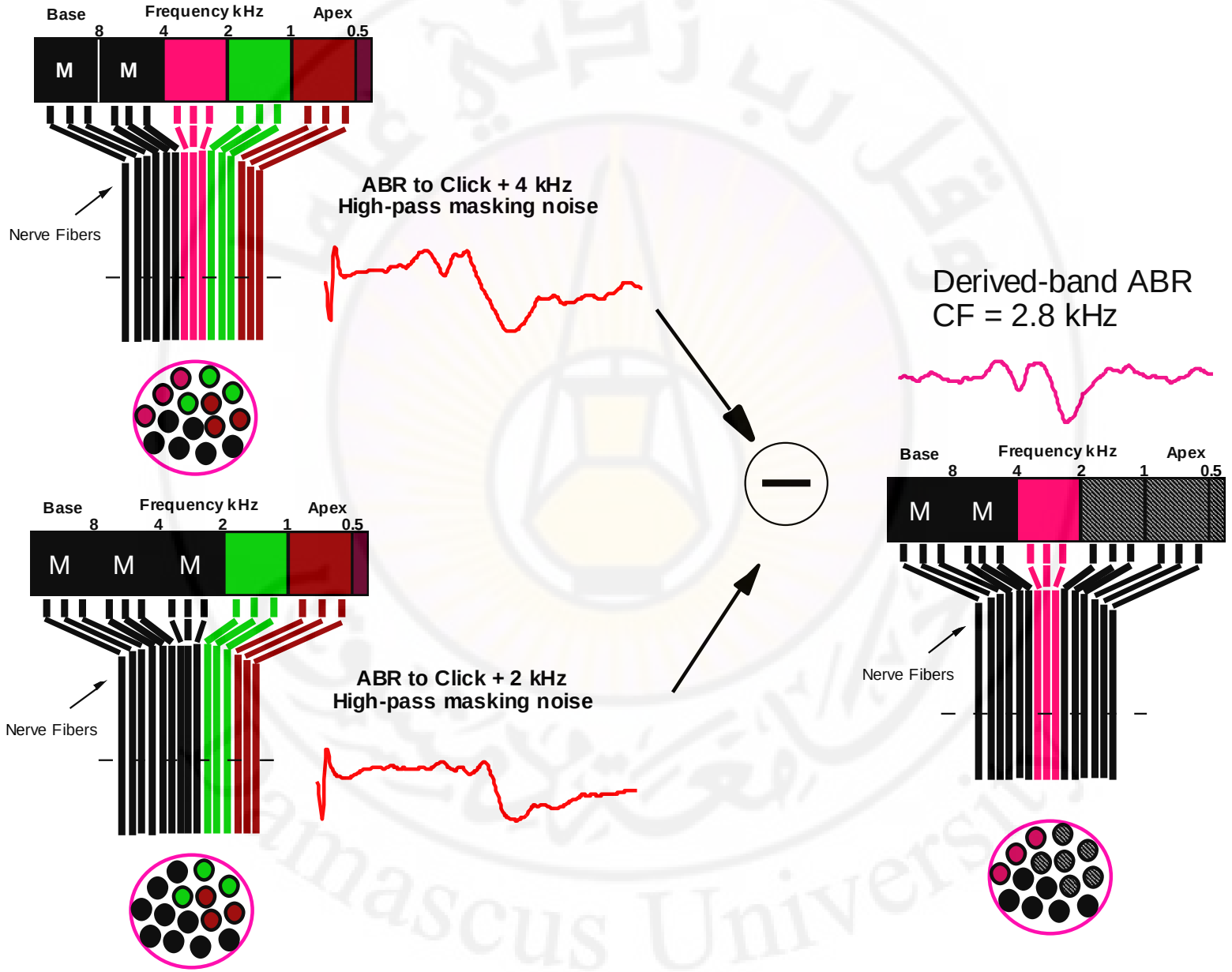

Base
Frequency kHz
Apex
8
4
2
1
0.5
M
Nerve Fibers
Click + 8 kHz High-pass masking noise

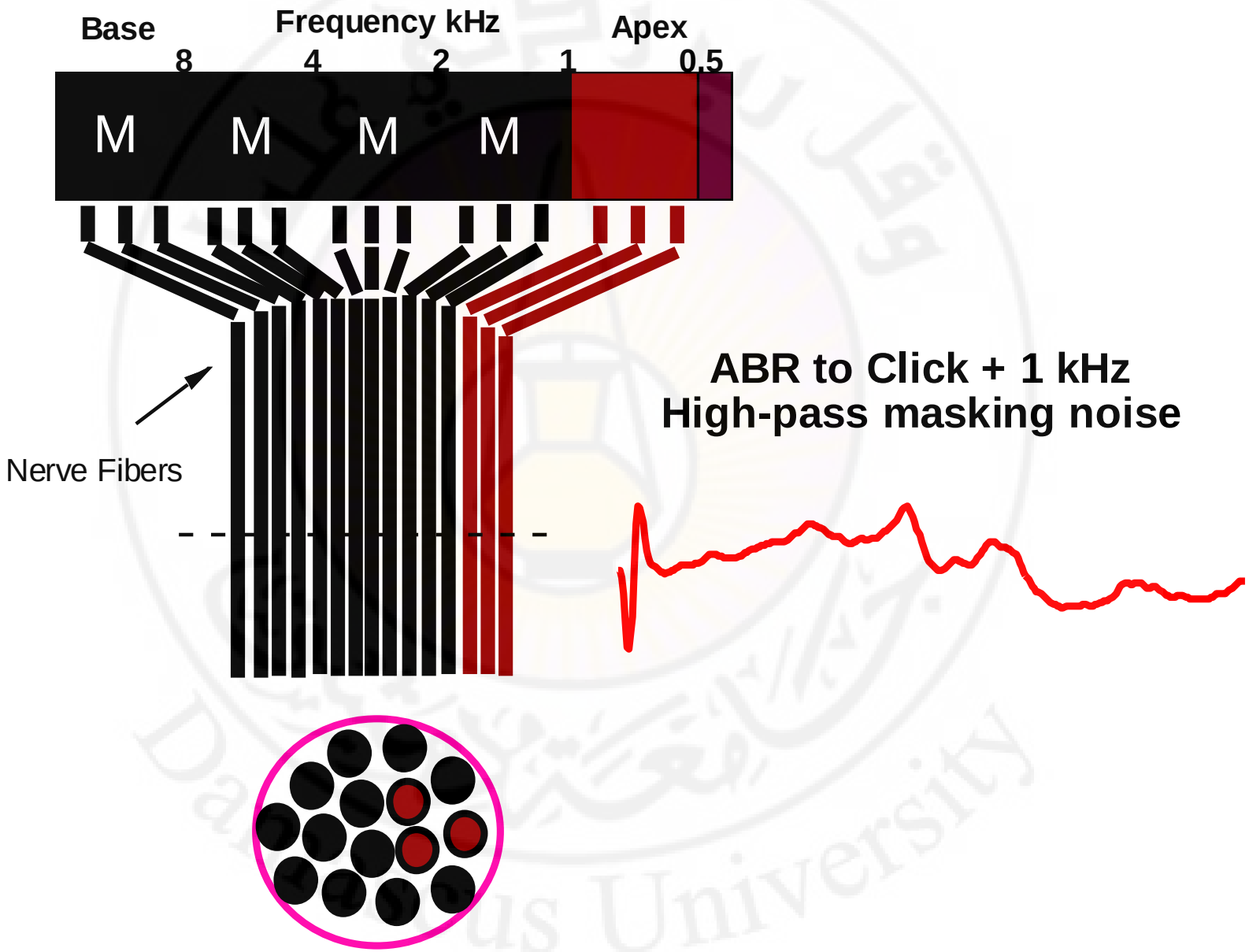

Base
Frequency kHz
Apex
8
4
2
1
0.5
Nerve Fibers
ABR to Click Alone
(Standard ABR)
M
ABR to Click + 8 kHz
High-pass masking noise
Derived-band ABR
CF = 11.3 kHz

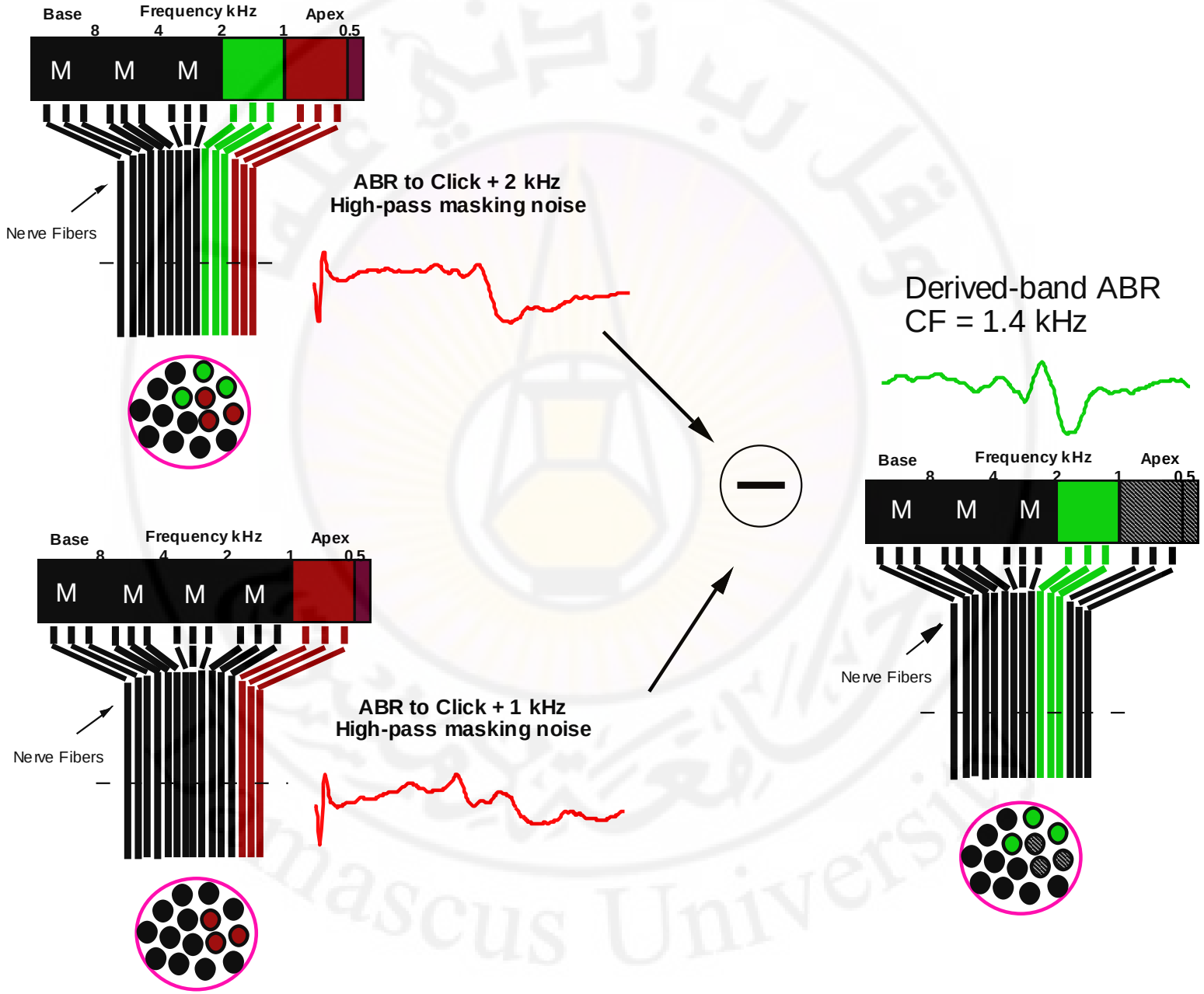

Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
Nerve Fibers
ABR to Click + 4 kHz
High-pass masking noise

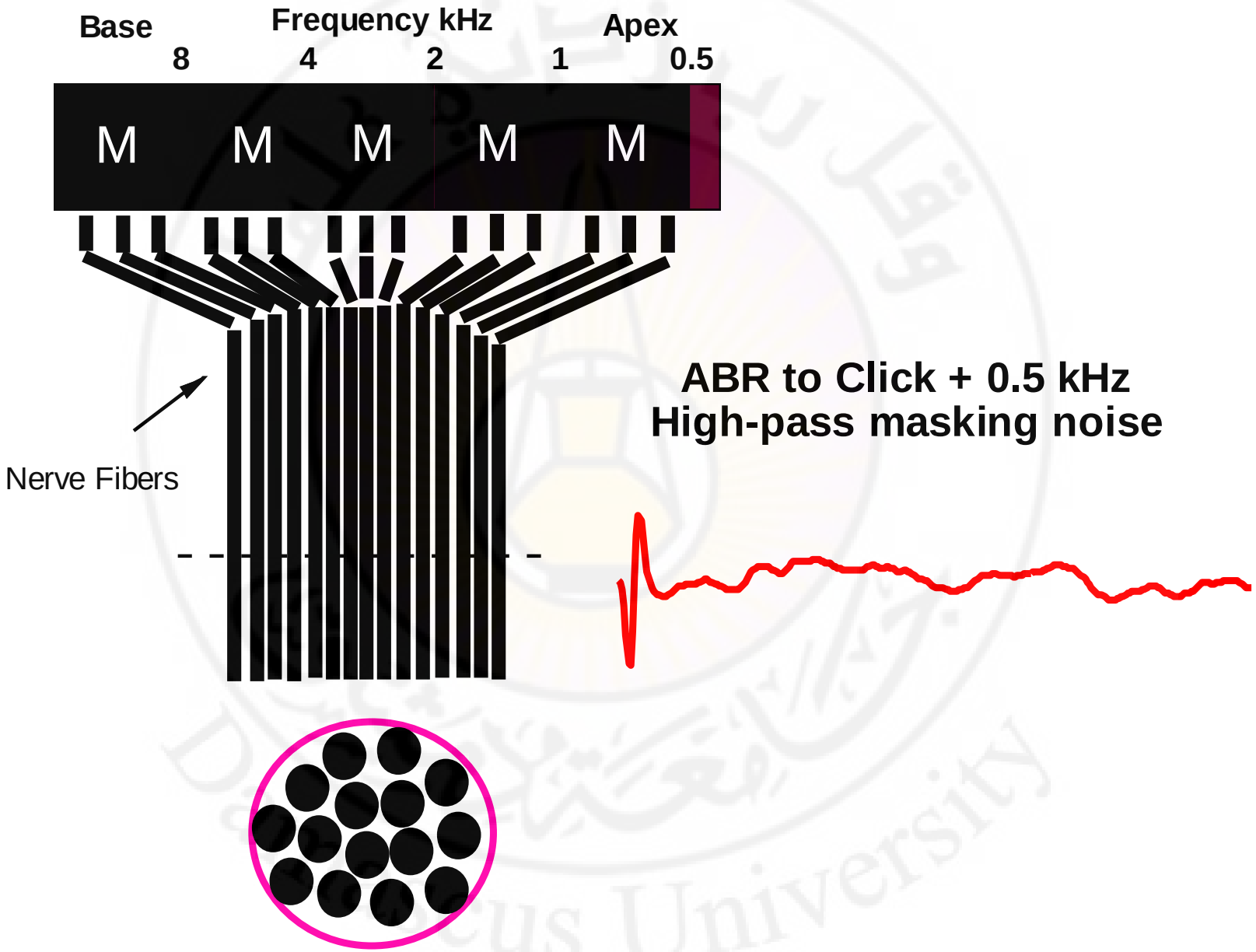

Base
Frequency kHz
Apex
8
4
2
1
0.5
M
Nerve Fibers
ABR to Click + 8 kHz
High-pass masking noise
M
ABR to Click + 4 kHz
High-pass masking noise
Derived-band ABR
CF = 5.7 kHz

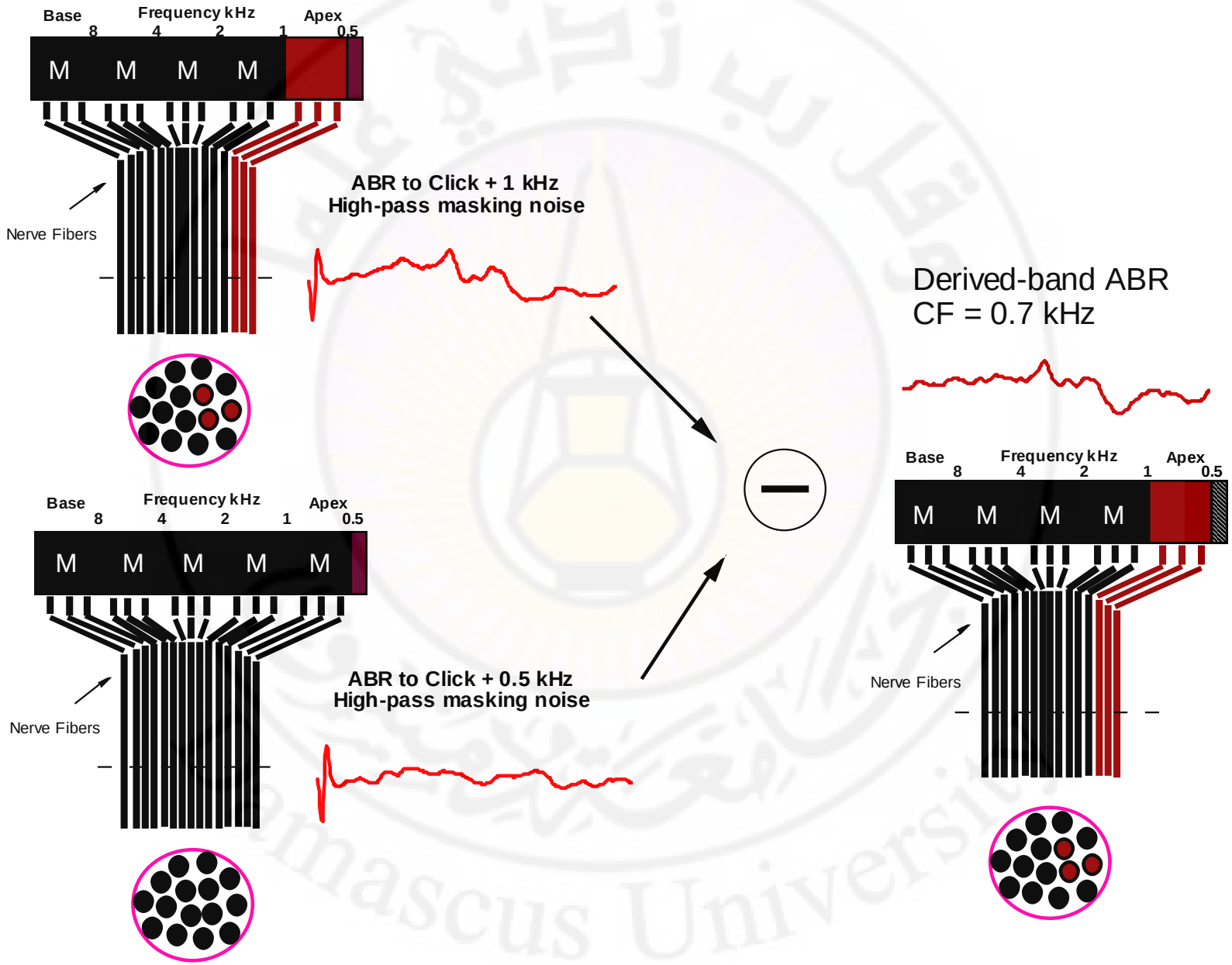

Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
M
Nerve Fibers
ABR to Click + 2 kHz
High-pass masking noise


Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
Nerve Fibers
ABR to Click + 4 kHz
High-pass masking noise
M
M
M
ABR to Click + 2 kHz
High-pass masking noise
Derived-band ABR
CF = 2.8 kHz


Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
M
M
Nerve Fibers
ABR to Click + 1 kHz
High-pass masking noise


Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
M
Nerve Fibers
ABR to Click + 2 kHz
High-pass masking noise
ABR to Click + 1 kHz
High-pass masking noise
Derived-band ABR
CF = 1.4 kHz

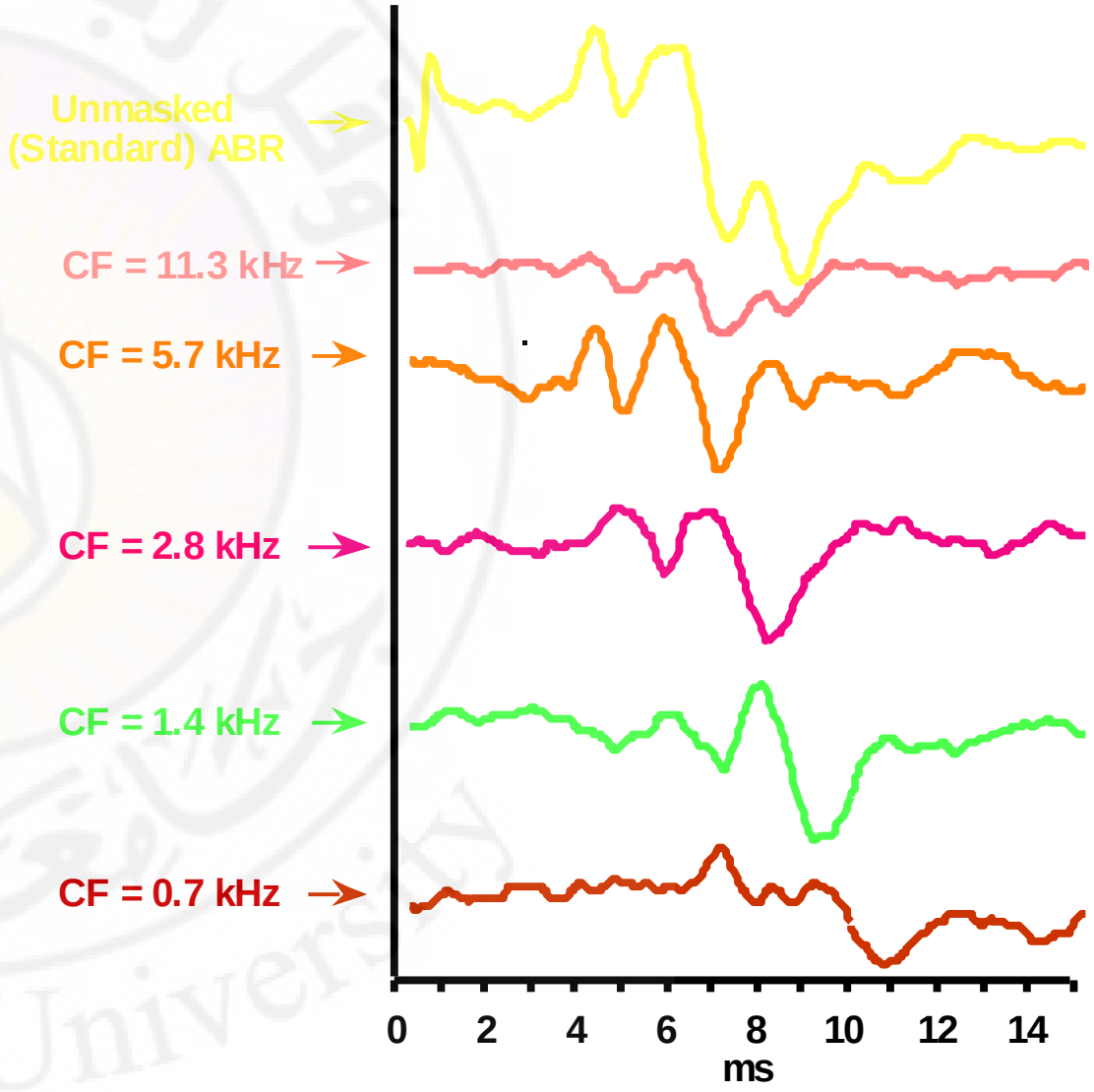

Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
M
M
M
Nerve Fibers
ABR to Click + 0.5 kHz
High-pass masking noise


Base
Frequency kHz
Apex
8
4
2
1
0.5
M
M
M
M
Nerve Fibers
ABR to Click + 1 kHz
High-pass masking noise
ABR to Click + 0.5 kHz
High-pass masking noise
Derived-band ABR
CF = 0.7 kHz

Derived-band ABR Summary

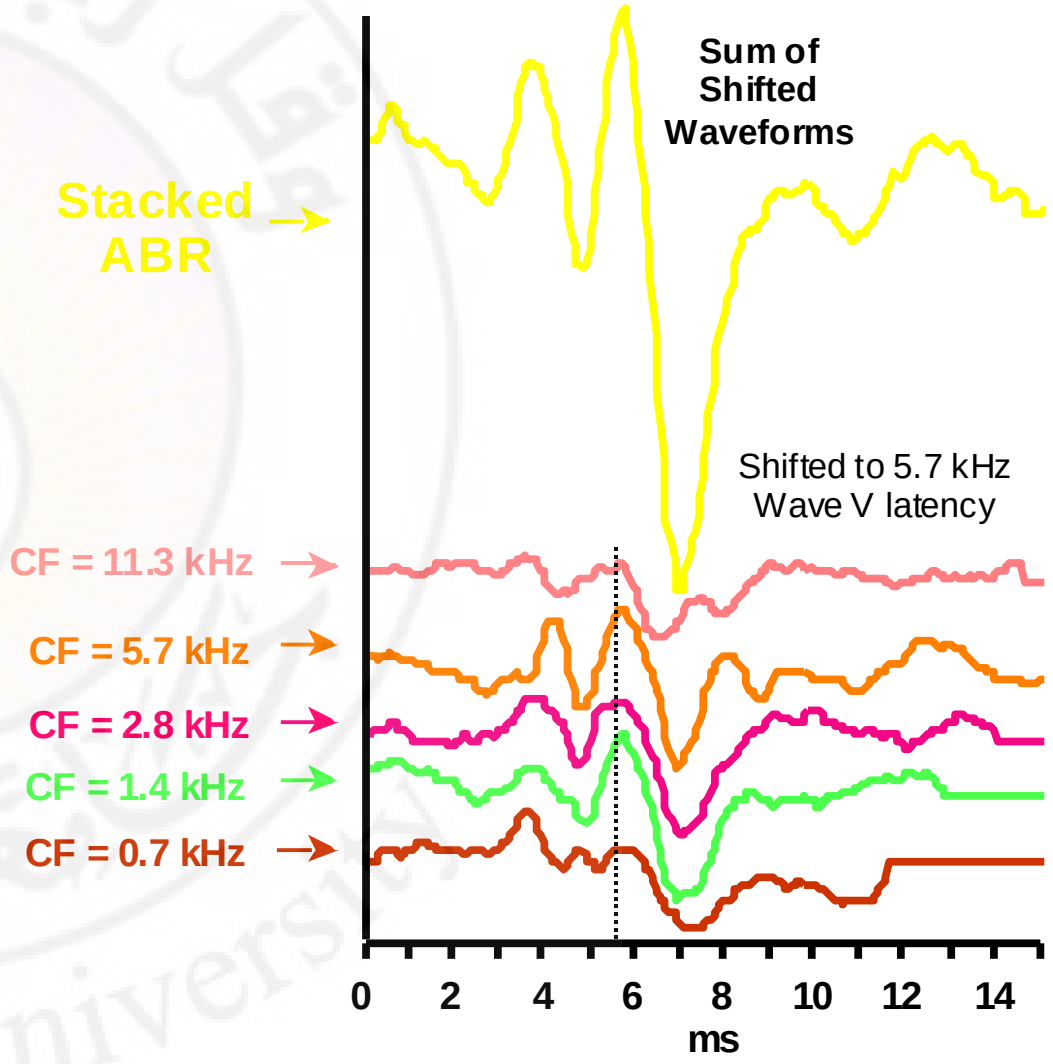
- Neural contributions from different frequency regions of the cochlea can be obtained using the **derived-band ABR** method.

- Derived-band ABRs represent activity from more specific frequency regions than moderate-to-high level toneburst-evoked ABRs.

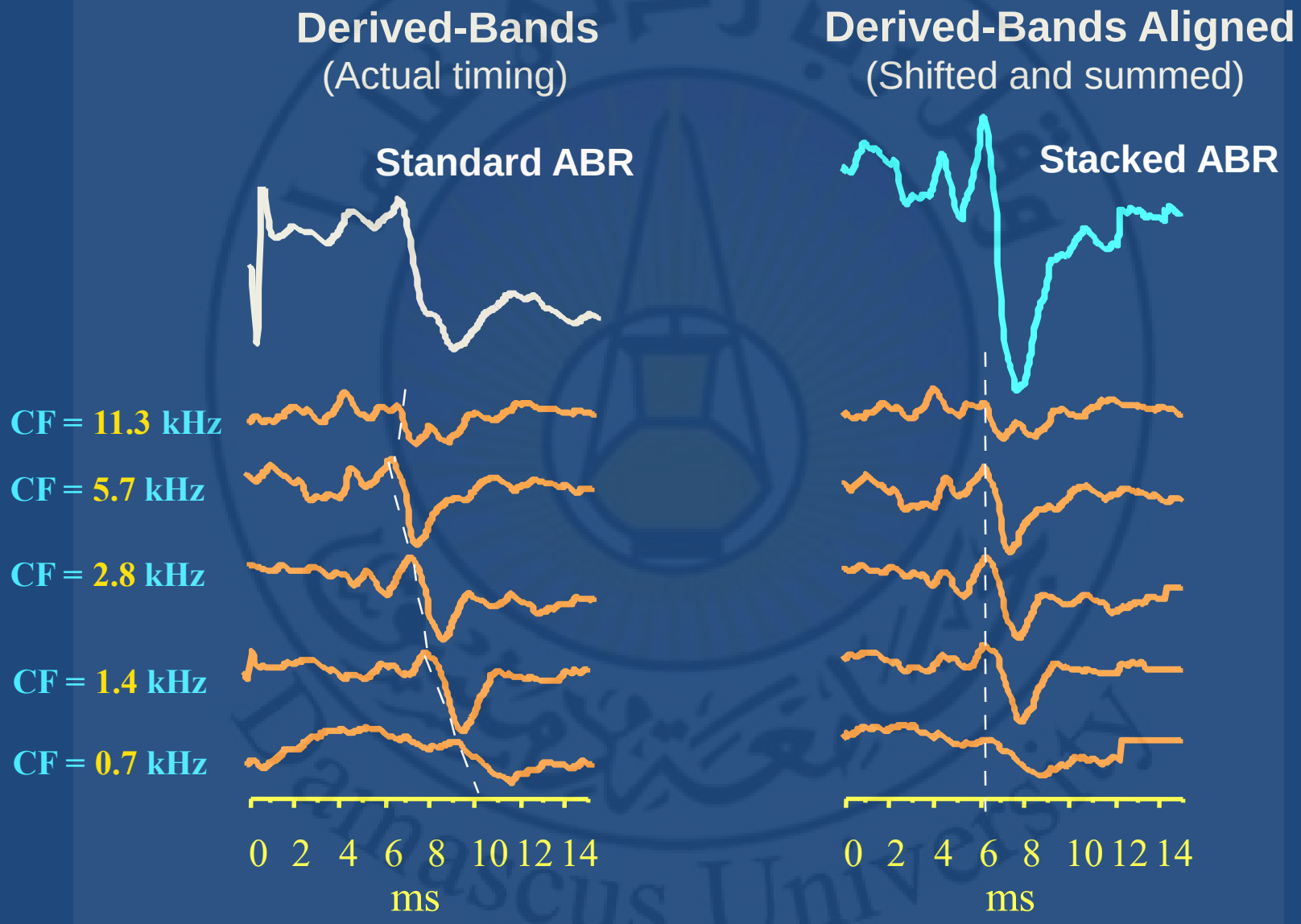


The Stacked ABR Technique

- The Stacked ABR is formed by first temporally aligning wave V of the derived-band ABRs, then summing the responses.
- Aligning the derived-band ABRs eliminates phase cancellation of lower frequency activity. Thus, the Stacked ABR amplitude reflects activity from all frequency regions of the cochlea, not just the high frequencies.
- Reduction of any neural activity due to a tumor, even a small tumor, will result in a reduction of the Stacked ABR amplitude.



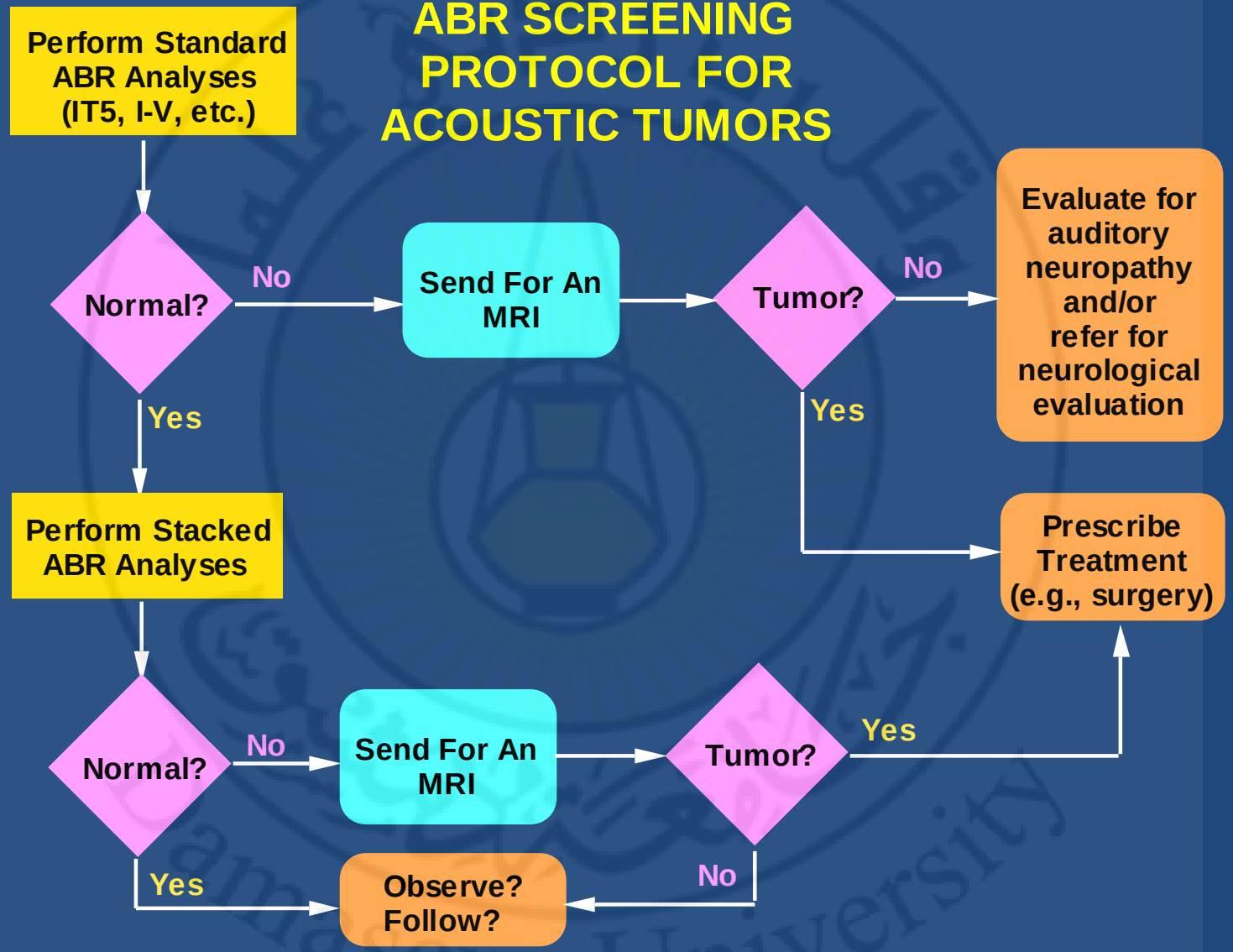
Stacked ABR


Derived-Bands
(Actual timing)
Derived-Bands Aligned
(Shifted and summed)
Standard ABR
Stacked ABR
CF = 11.3 kHz
CF = 5.7 kHz
CF = 2.8 kHz
CF = 1.4 kHz
CF = 0.7 kHz
0 2 4 6 8 10 12 14
ms
0 2 4 6 8 10 12 14
ms

Stacked ABR Summary

when a small tumor is present or when the tumor affects more low-frequency– tuned nerve fibers, Wave V from the Stacked ABR will be smaller in amplitude than the amplitude noted in the standard ABR. When tumors are 1 cm in diameter or smaller, the Stacked ABR is highly sensitive (95%) and specific (83%)

ABR SCREENING PROTOCOL FOR ACOUSTIC TUMORS

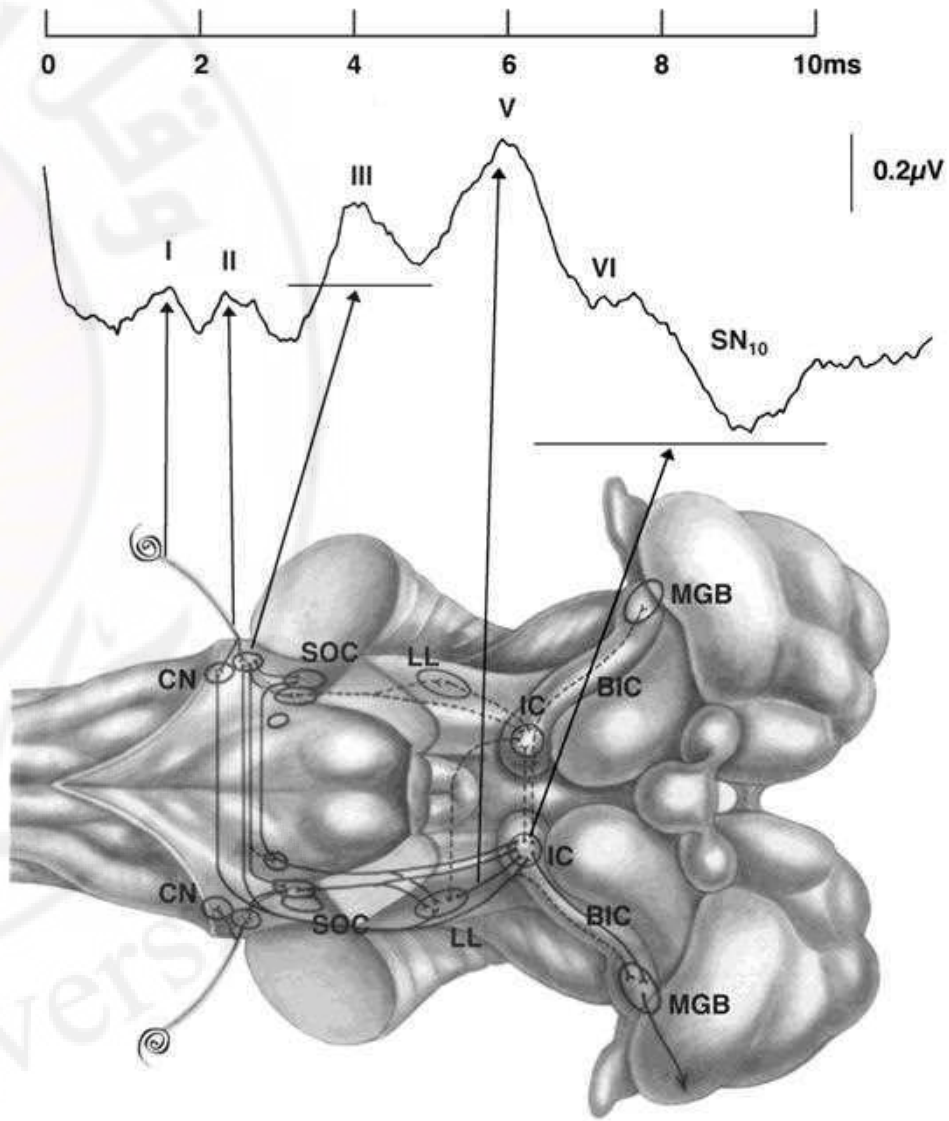


Auditory Evoked Responses

Mohsen Ahadi, Ph.D.
Associate Professor of Audiology
Iran University of Medical Sciences
Rehabilitation Research Center
ahadi.m@iums.ac.ir

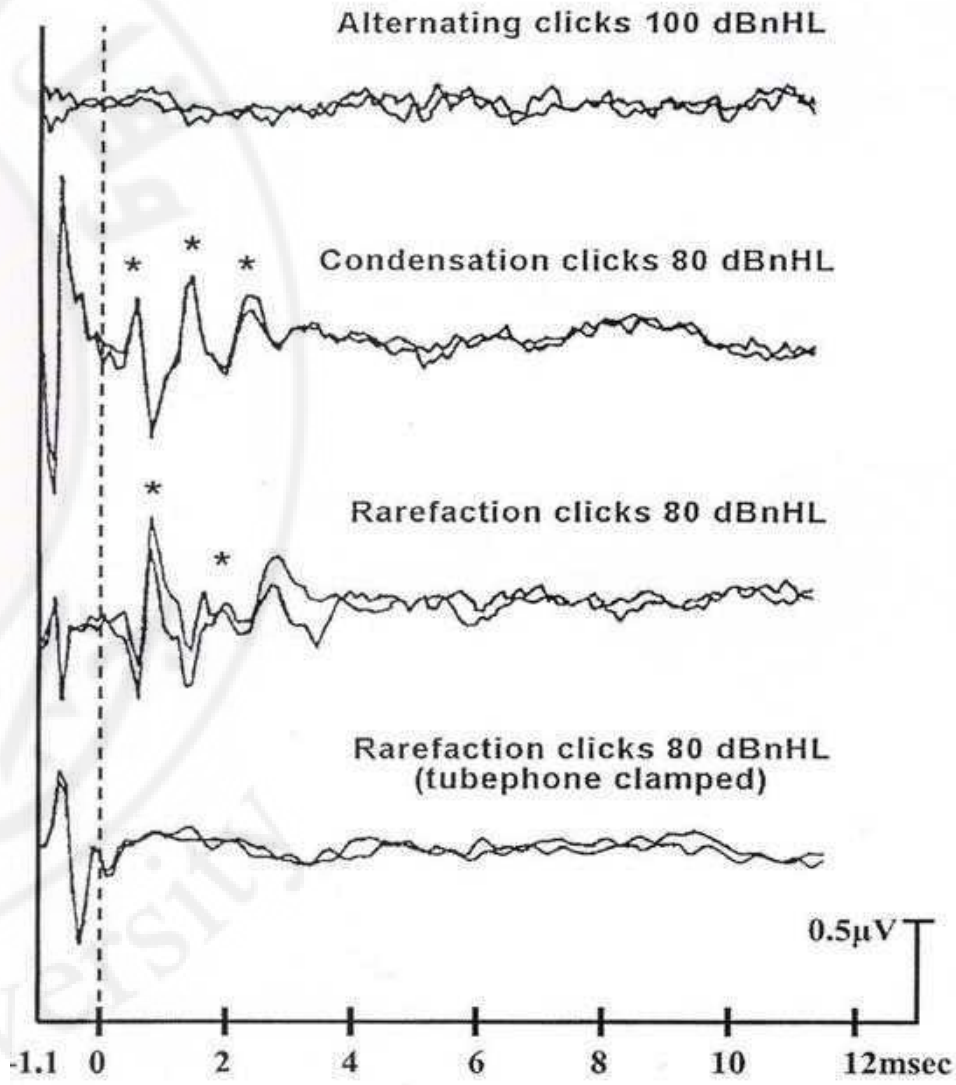
ABR and Retrocochlear involvements

- **Auditory nerve involvement**
  - vestibular schwannoma
  - Auditory neuropathy spectrum disorder (ANSD)
  - other pathologies
    - Charcot–Marie–Tooth (CMT) syndrome
    - vascular loop syndrome
    - Auditory nerve aplasia and hypoplasia
- **Brainstem dysfunction**
  - Multiple Sclerosis
  - Tumors of the Brainstem
  - Hyperbilirubinemia
  - Heavy Metal Exposure
  - Head Injury

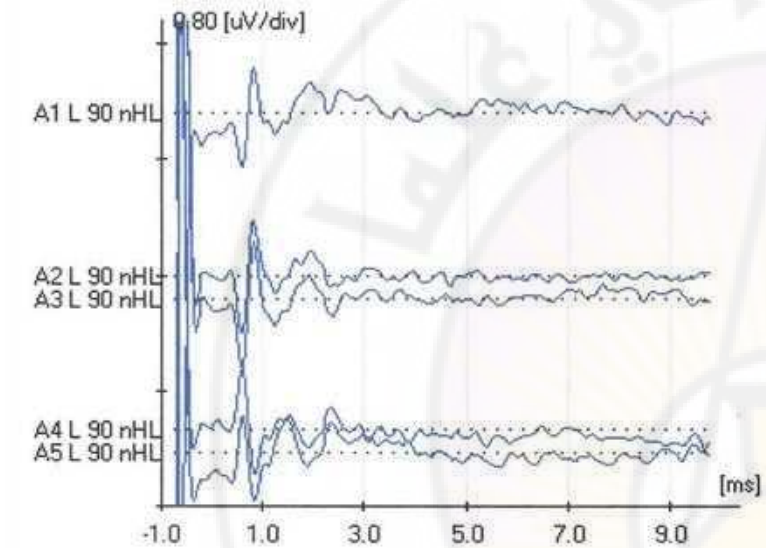


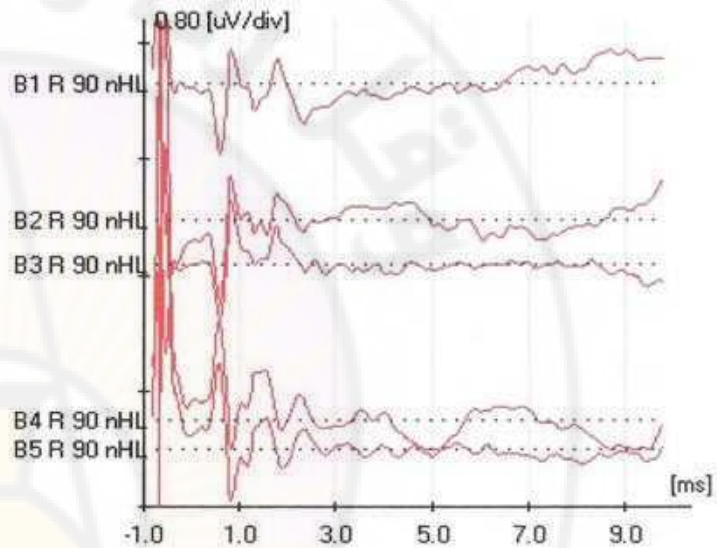
Auditory Neuropathy Spectrum Disorder

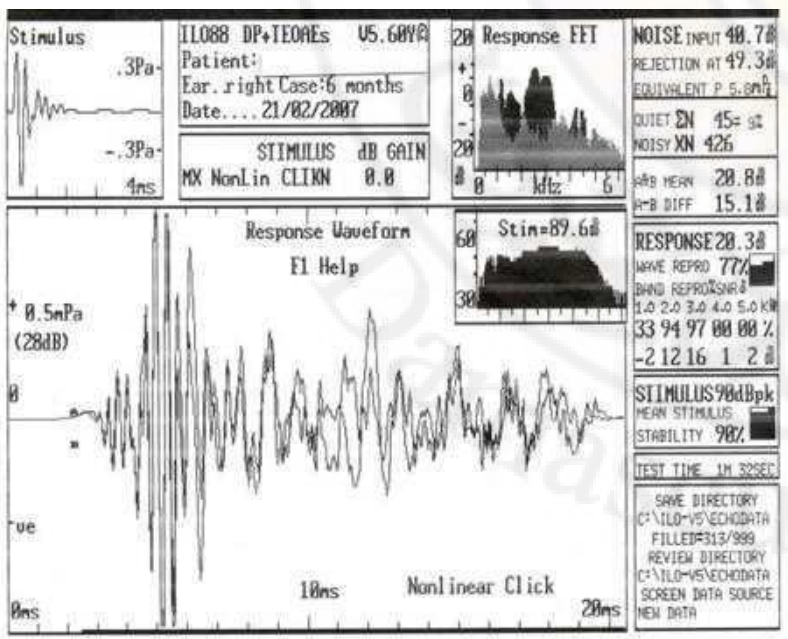
- **ANSD** is a purely functional or physiological abnormality that can include effects on the function of the auditory nerve.
- Imaging (i.e., MRI) results in cases of pure ANSD are not remarkable.
- The strict definition of ANSD is the presence of otoacoustic emissions (a measurement of outer hair cell function) in the complete absence of the ABR.

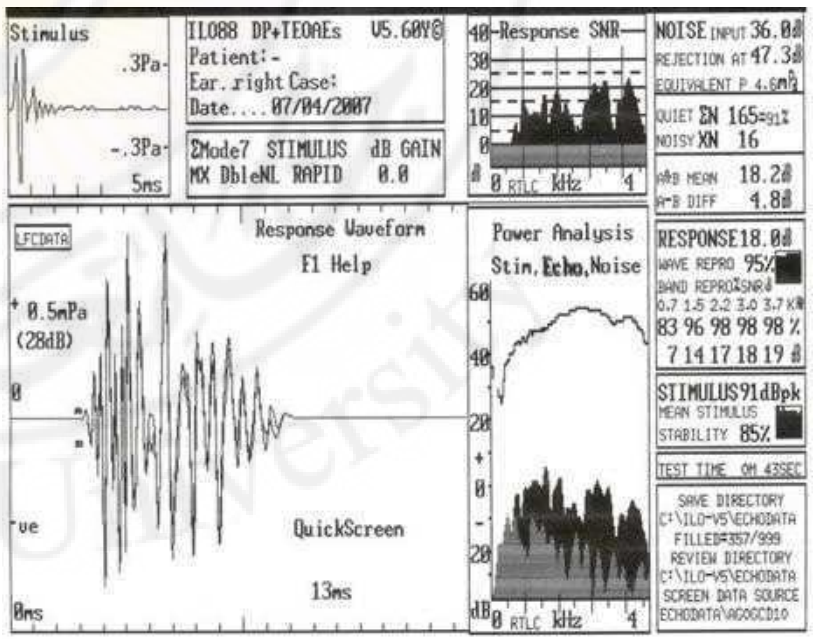


12 Months Child With History Of Hyperbilirubinemia



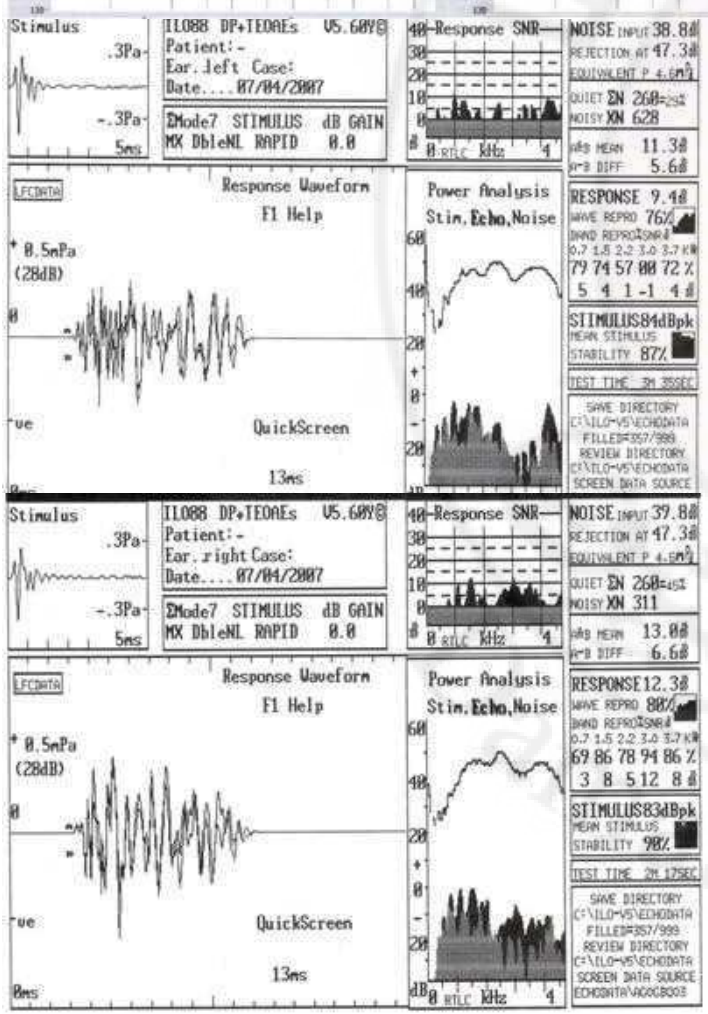


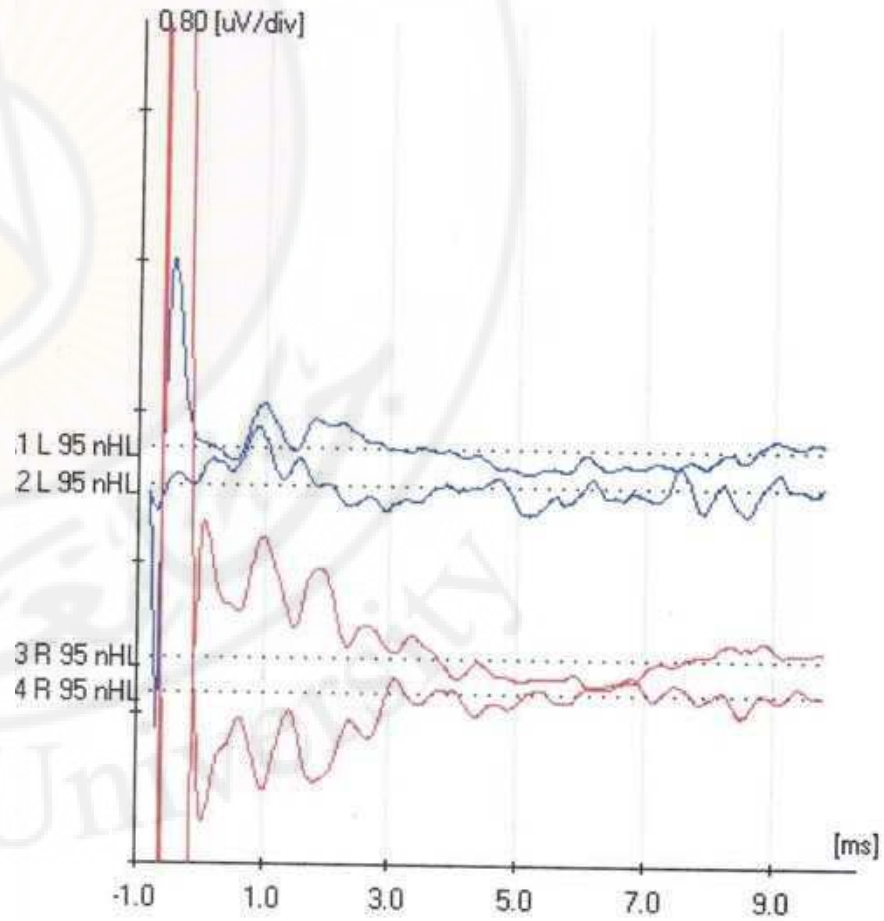


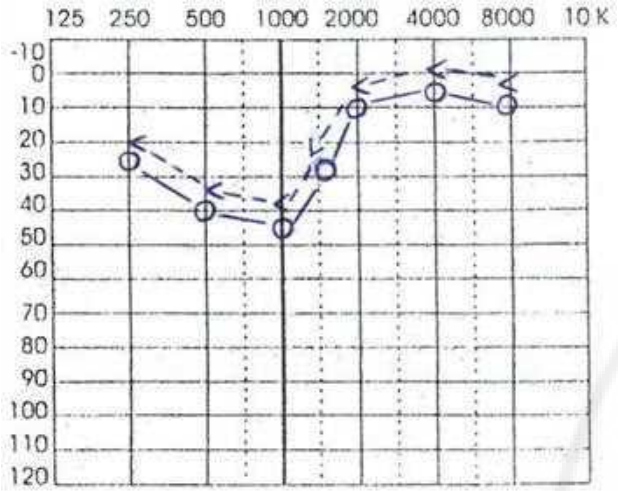


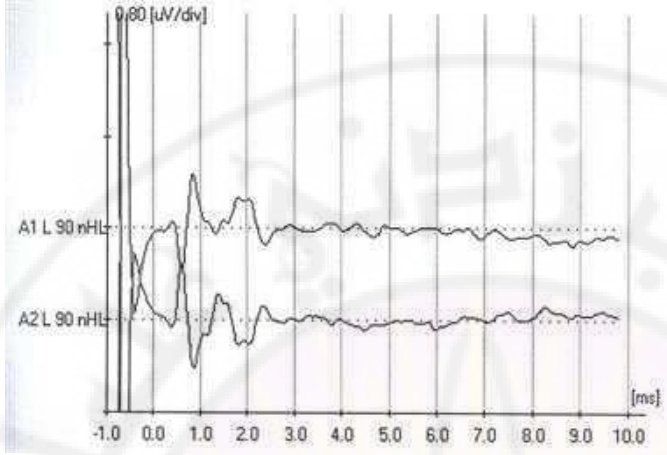
14 Months Child With no remarkable birth history

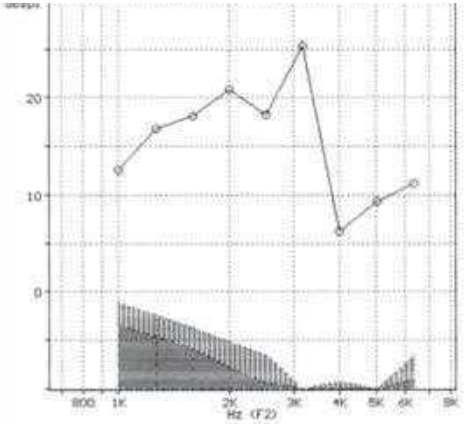


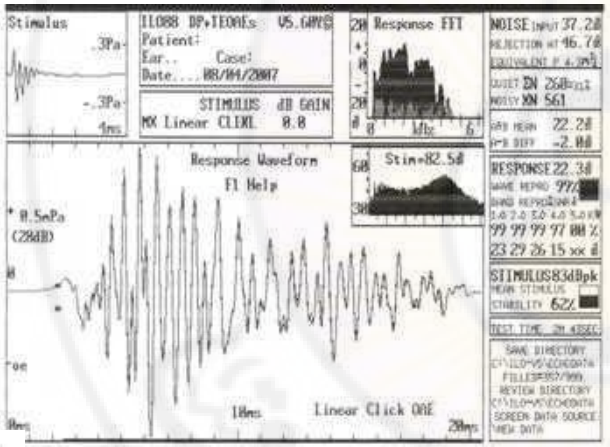


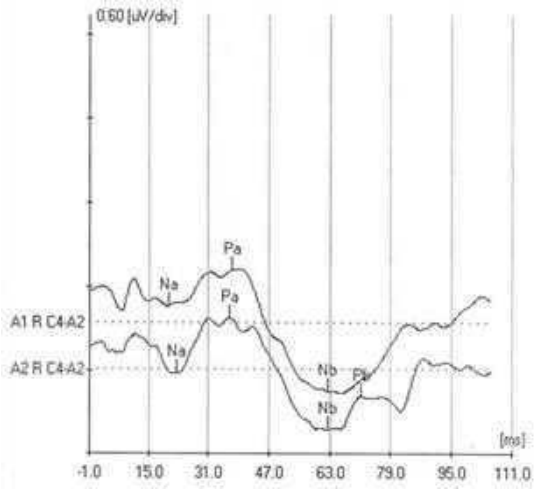


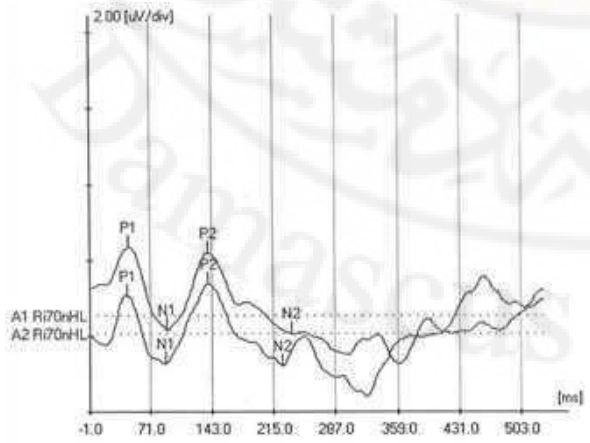






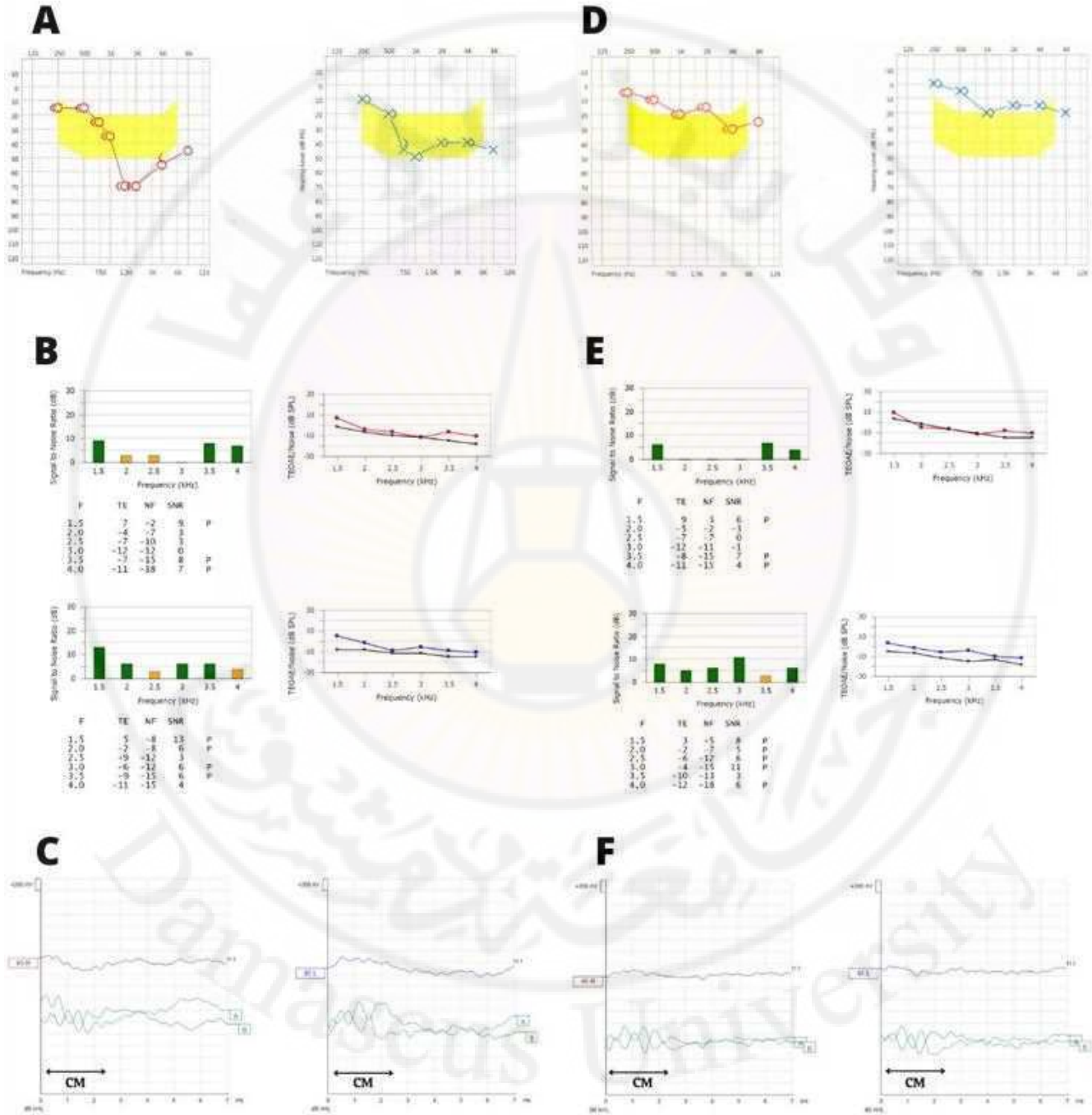


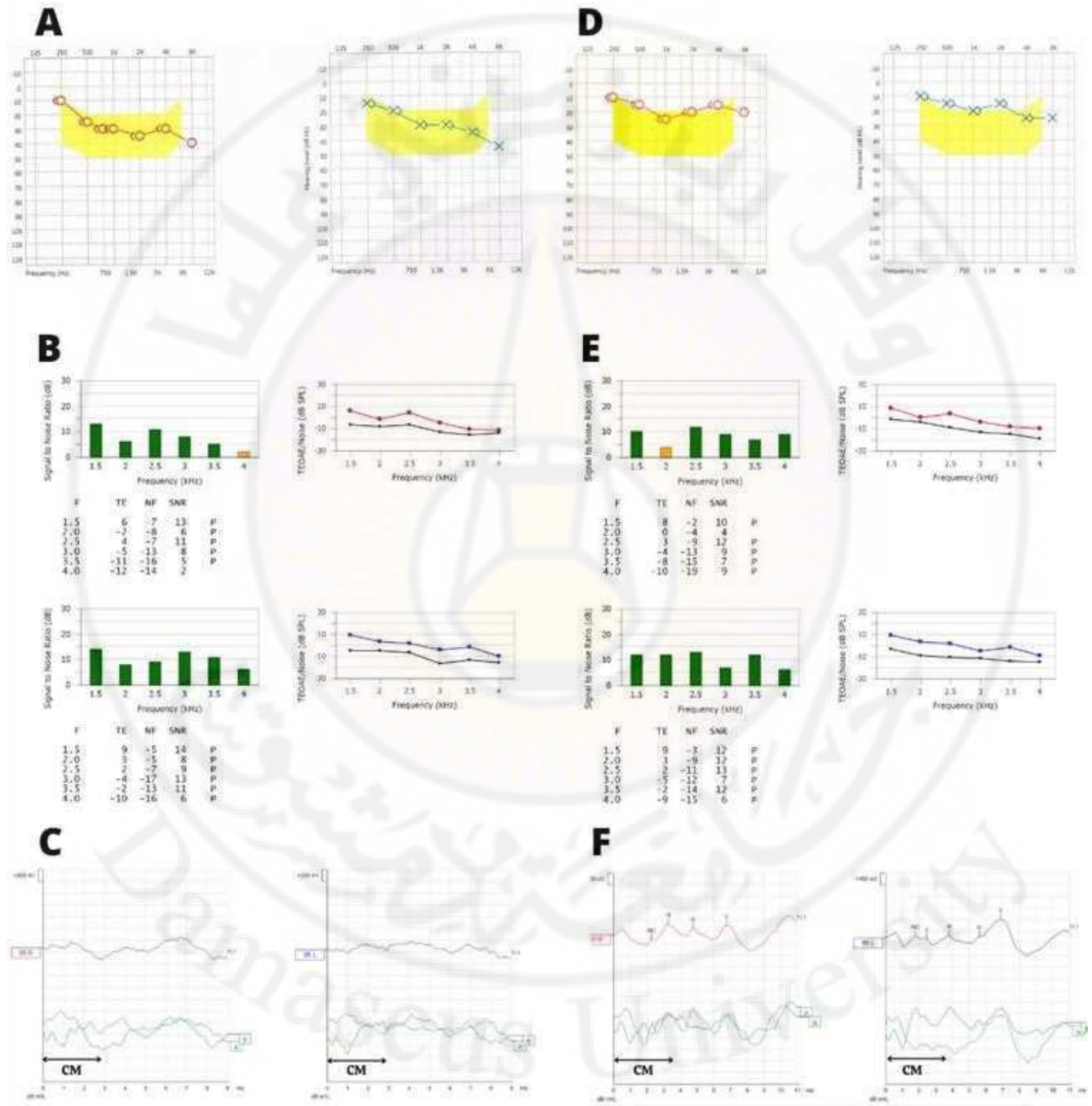




General Neuropathy

- 19 Y/O girl
- Beginning of symptoms from 16 years old
- Visual problems


A
D
B
E
C
F
CM
CM
CM
CM


A
D
B
E
C
F
CM
CM
CM
CM

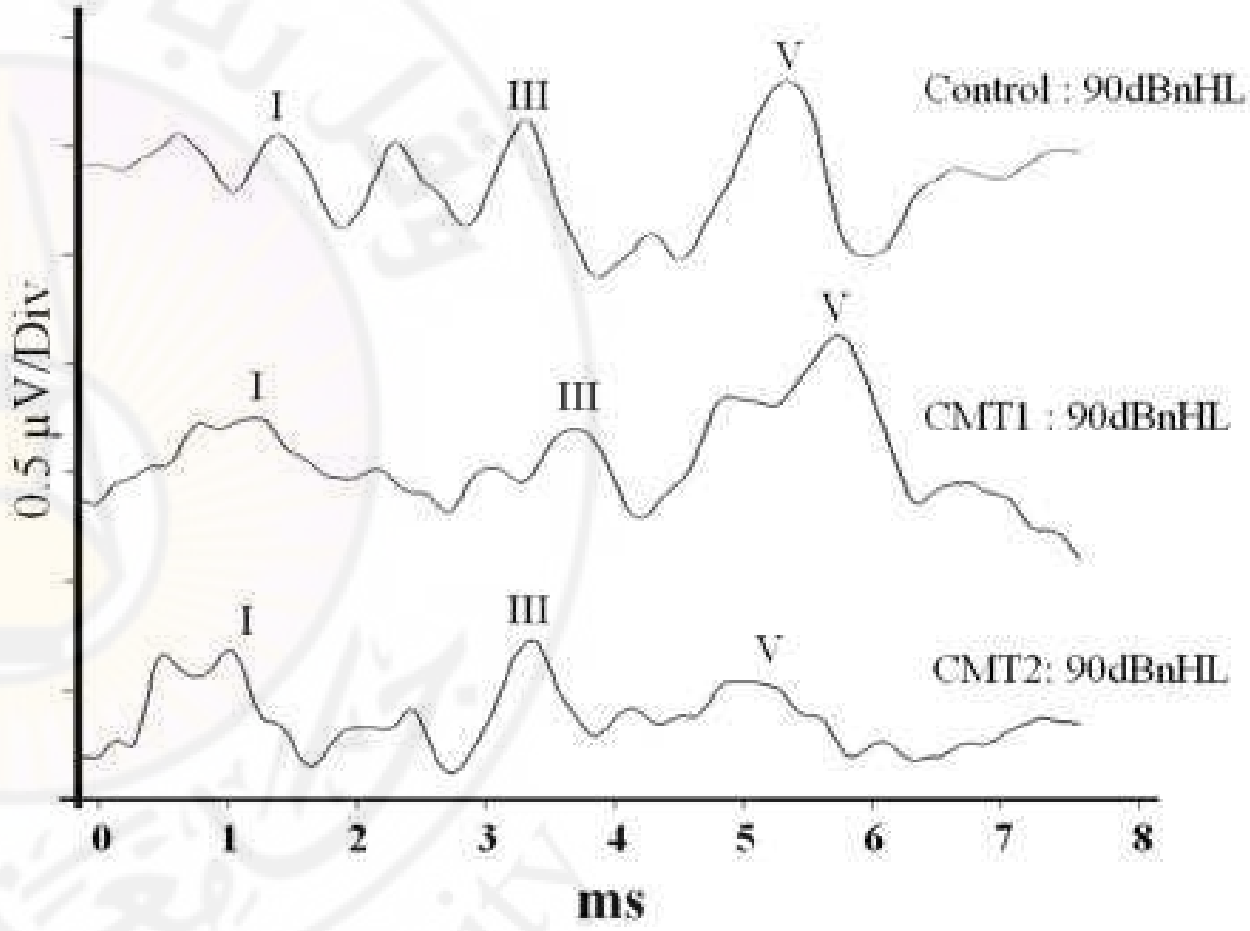
Charcot–Marie–Tooth Syndrome

- **CMT** also known as hereditary motor and sensory neuropathy **(HMSN)** disease is an inherited peripheral motor neuron disease and could be viewed as a **specific type of auditory neuropathy.** However, it stands as a well-recognized disorder on its own.
- Weaknesses of hands and feet are often noticed with some cases clearly having auditory complaints.
- CMT is characterized by disruptions in myelin along the nerve axon or damage to the axon itself, which affects the velocity and size of the impulses conducted down the axon and communication among nerves.



ABR findings in CMT

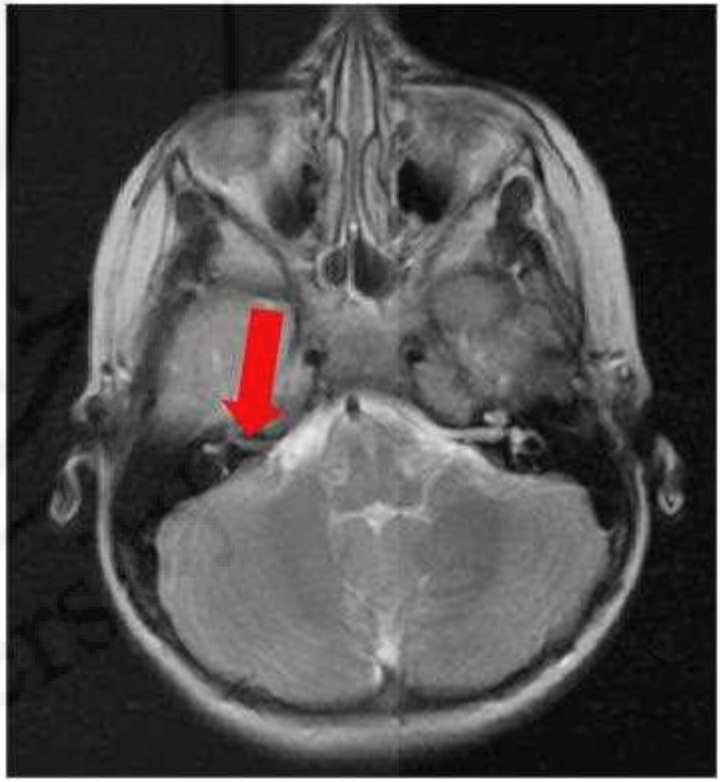
- Some forms of CMT may involve the auditory system and some may not.
- Clearly, abnormal ABRs have been reported in various groups of CMT patients with delays in the later ABR waves, as well as compromised amplitudes for Wave V.
- In apparent longstanding disease, auditory degeneration results in absent ABRs.

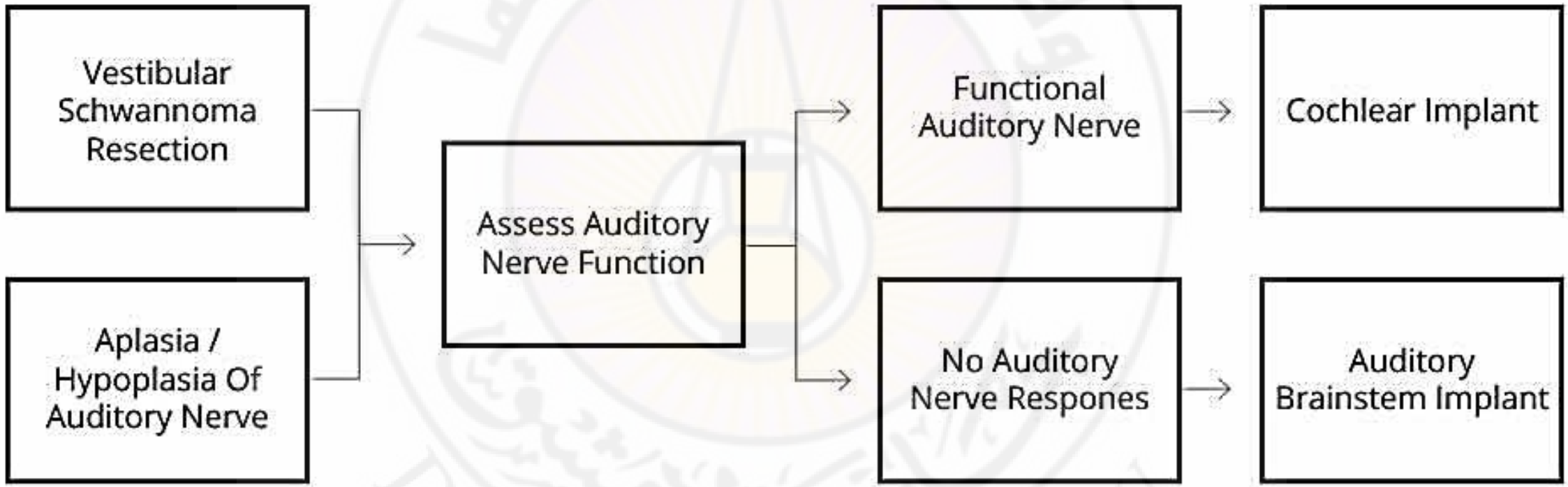


Auditory brainstem response recordings to acoustic clicks presented at 90 dB above normal hearing level.
CMT1: Dominantly inherited type 1
CMT2: Dominantly inherited axonal type 2

Auditory Nerve Aplasia (Agenesis) and Hypoplasia

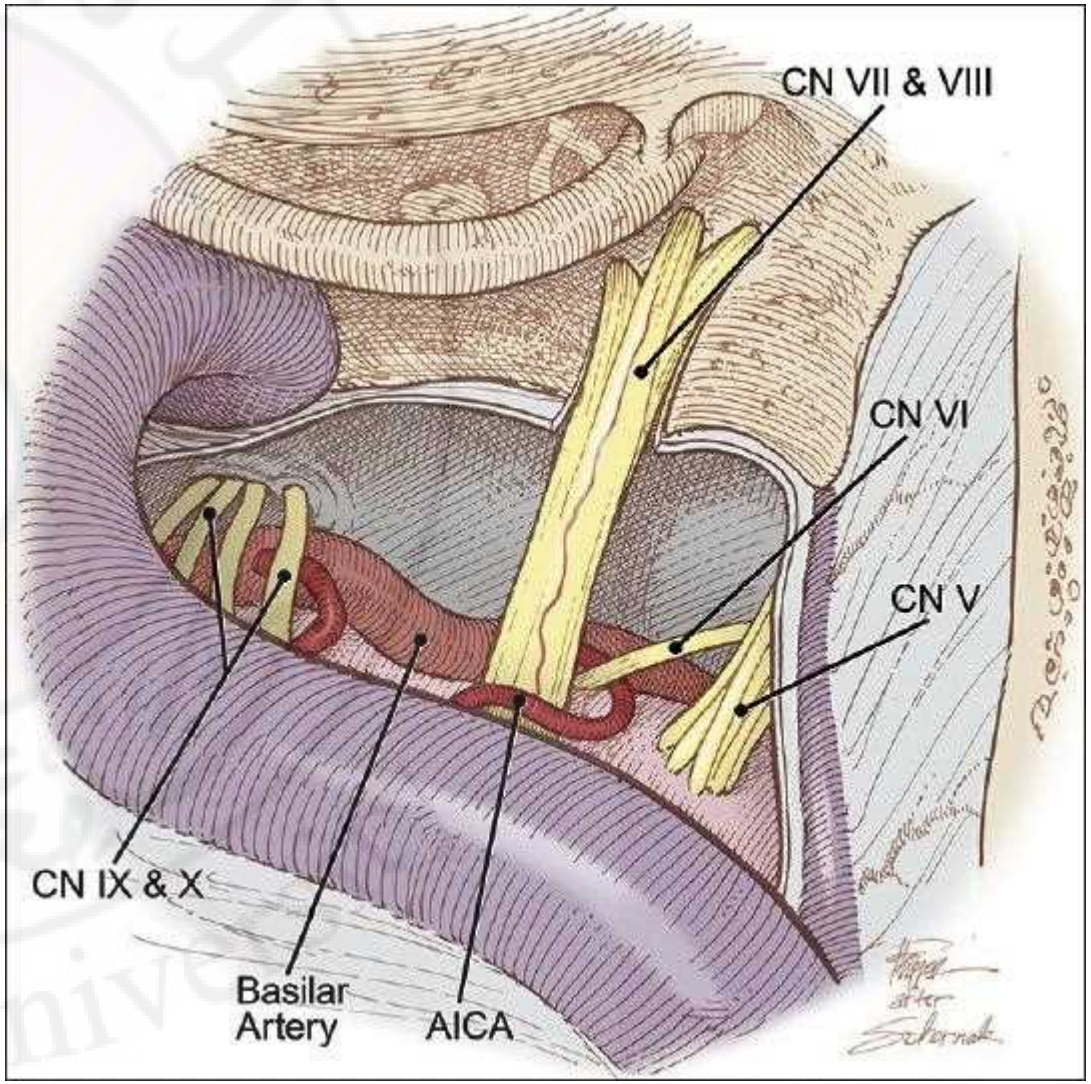
- It is also possible for the auditory nerve to be **missing (aplasia or agenesis)** or **underdeveloped (hypoplasia).**
- In both cases, the malformation is congenital with the possibility of stenosis of the IAM or cochlear malformations.
- **Auditory nerve aplasia:**
  - Absent ABR
  - Absent Acoustic reflexes
  - Normal Tympanogram
  - OAEs may / may not present
- **Auditory nerve hypoplasia**
  - Absent ABR or Elevated thresholds
  - OAEs may / may not present




Vestibular Schwannoma Resection
Aplasia / Hypoplasia Of Auditory Nerve
Assess Auditory Nerve Function
Functional Auditory Nerve
No Auditory Nerve Respones
Cochlear Implant
Auditory Brainstem Implant

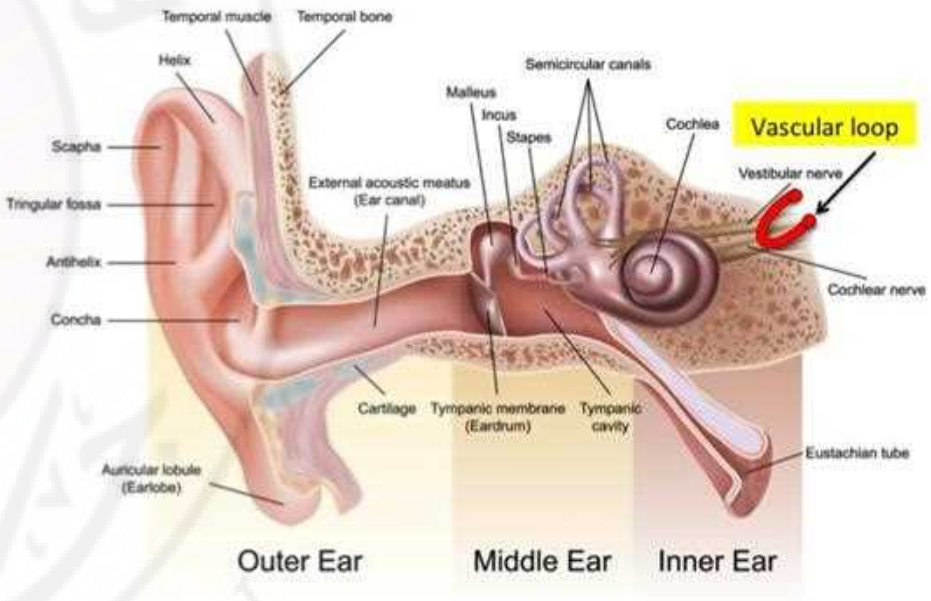
Vascular Loop Syndrome

- **Vascular loop syndrome** is a condition in which the cranial nerves (including the eighth cranial nerve) in the vicinity of the CPA are compressed by a blood vessel, with the anterior inferior cerebellar artery **(AICA)** being the most commonly affected vessel.
- This compression may result in a variety of auditory, vestibular, or facial symptoms among individuals depending on the location and amount of compression.



ABR findings in Vascular Loop Syndrome

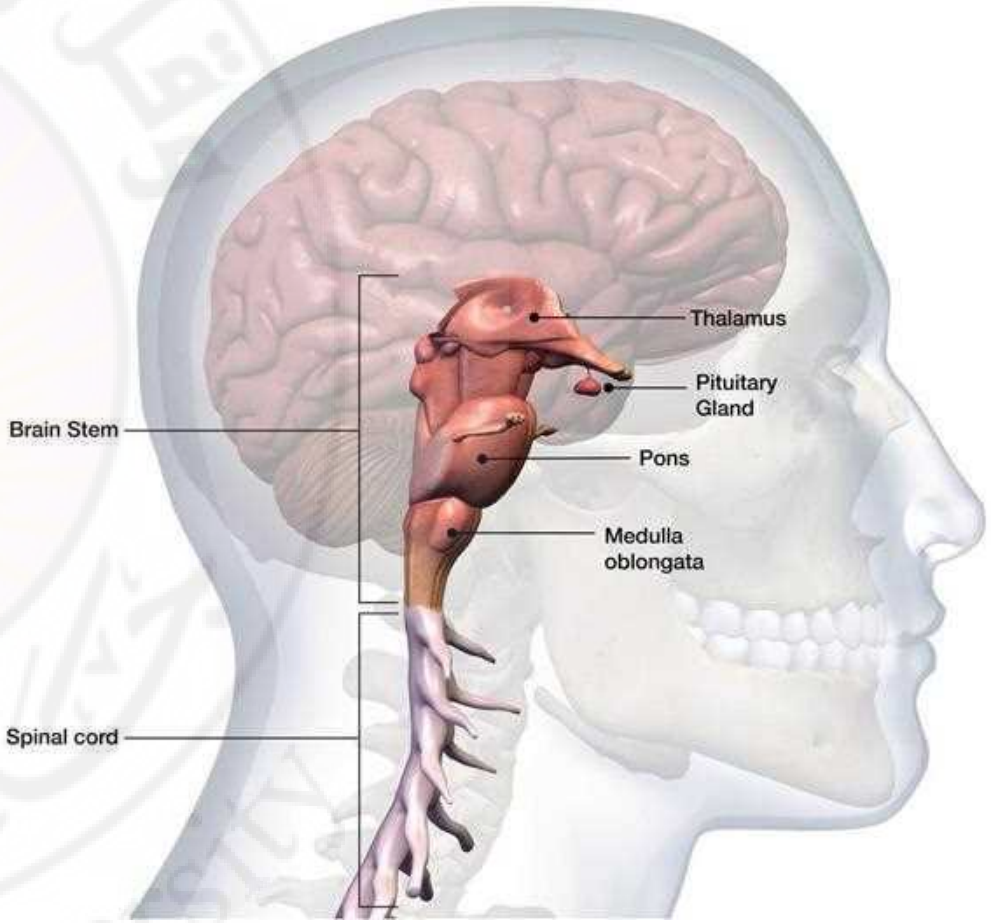
- When compression is present on the auditory portion of the eighth cranial nerve, ABR results are often abnormal.
- Extensions of the I–II and/or I–III interwave latencies on the affected side are typical, with these findings likely to improve with surgical intervention.
- ABR findings from vascular loop syndrome may not differ from those described for vestibular schwannoma; and differentiation should be made with MRI and CT scan.
- Also, a cochlear type of hearing loss with good speech discrimination and normal caloric testing should raise suspicion of a vascular loop.



2. Brainstem involvement

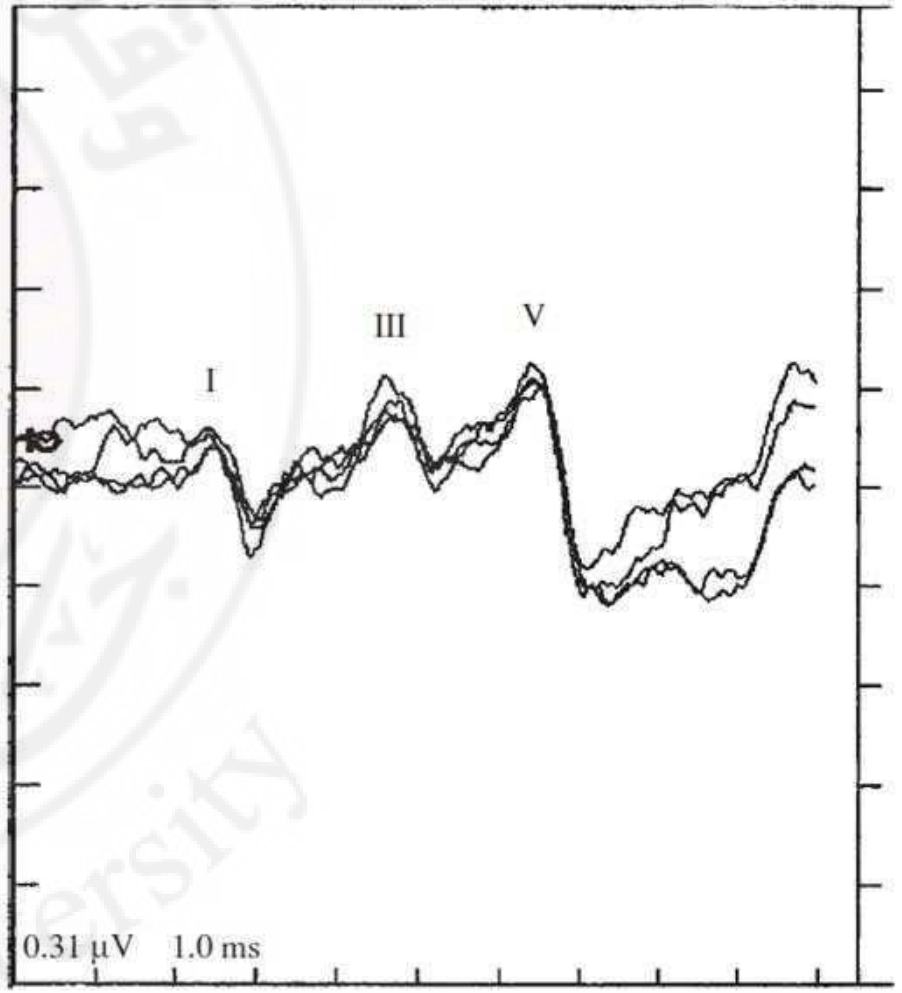
Introduction

- the ABR is not quite as sensitive to a wide variety of brainstem disorders (with the exception of intra-axial lesions) as it was for vestibular schwannomas.
- There are a wide variety of known neurologic disorders that may affect the brain, whereas there are relatively few that compromise the auditory nerve.
- Also, some neurologic disorders may or may not target the auditory brainstem pathway (such as MS).
- ABR testing is highly useful for those lesions affecting the brainstem for which imaging is of little help.



ABR findings in brainstem Involvement

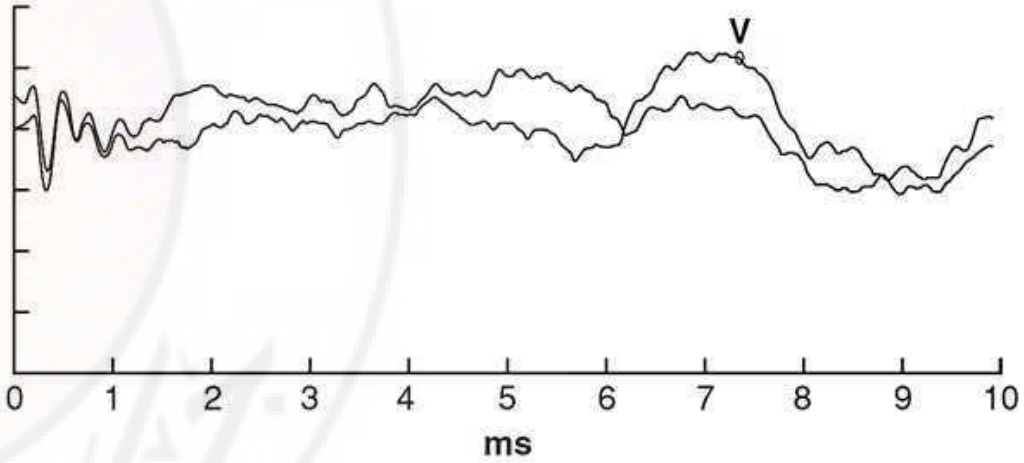
- Absolute Latency Delay
- Interwave Latency Delay
- Inter-ear Latency Comparisons
- Amplitude Comparison of Waves
- Waveform Morphology and Absence of Waves
- Contralateral Effects
- Repetition Rate Shifts



Damascus University

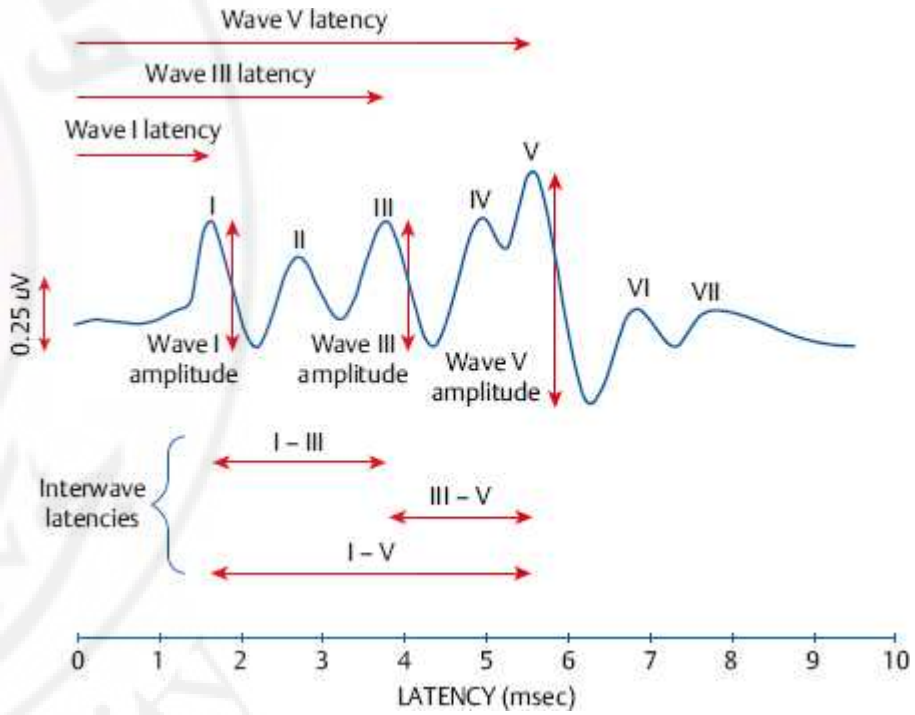
Absolute Latency Delay

- In regard to brainstem involvement, a delayed Wave I would not be highly useful.
- A delayed Wave III or IV–V without Wave I could be indicative of a number of different sites of lesions.
- A delayed Wave III with a normal III–V interval or a delayed V with absence of Waves I or III often occurs, but the clinician would have to utilize additional measures to determine if there is brainstem involvement.



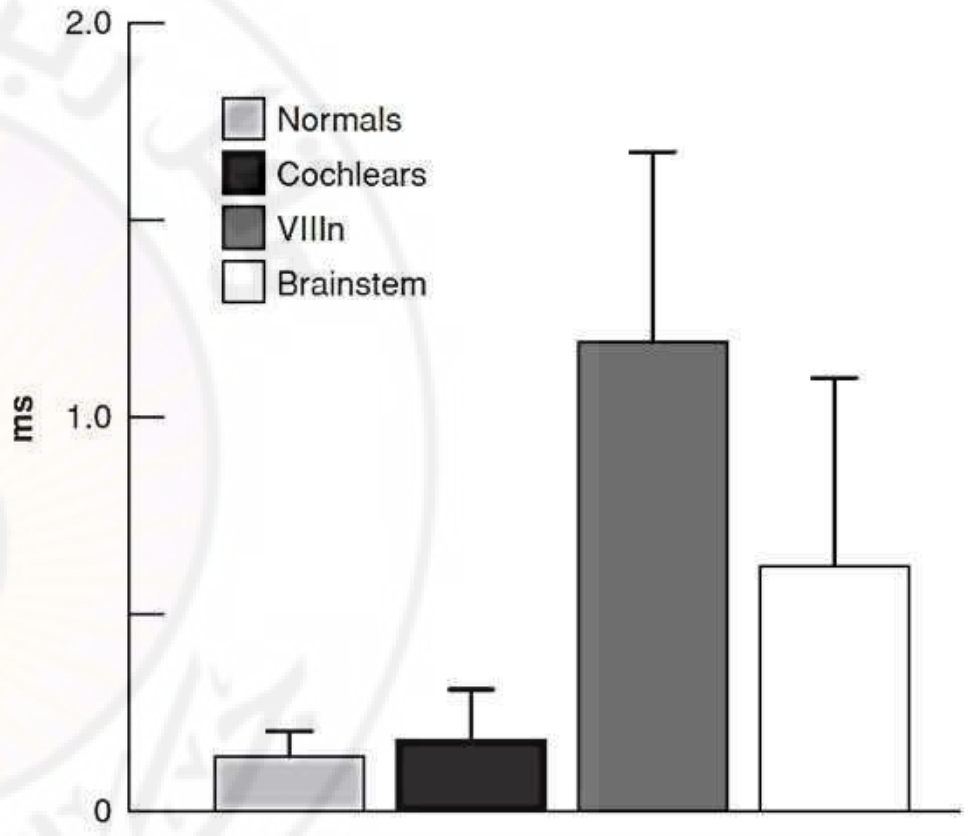
Interwave Latency Delay

- The extension of the I–III, III–V, or I–V IWIs is perhaps the most revealing measurement of brainstem involvement. This is because these indices involve the brainstem generators of Waves III, IV, and V.
- Based on generator sites, a III–V interval increase is firmly interpreted as brainstem involvement. It is possible that the III–V interval extension can result from an eighth nerve tumor, but generally these tumors would have to be quite large, affecting the brainstem considerably for this ABR abnormality to be seen



Inter-ear Latency Comparisons

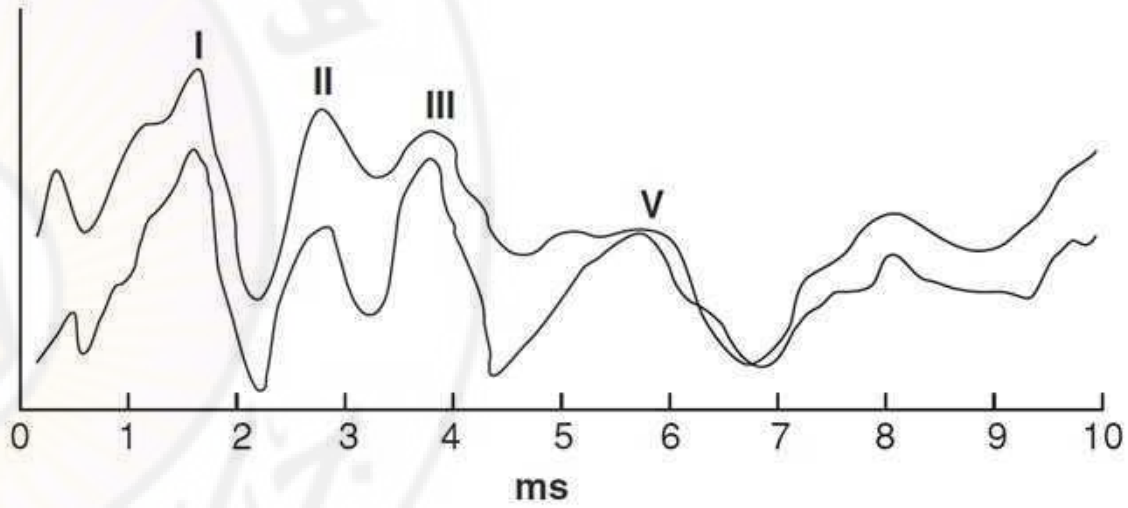
- Brainstem lesions more often affect both brainstem tracts (ipsilateral and contralateral) either directly or indirectly because of the profuse number of cross-over tracts and commissures in the brainstem.
- These anatomical factors could lead to Wave V latency delays for both ears, and hence a nonsignificant ILD.



Plot of the mean and one standard deviation for the interaural latency difference (ILD) for subjects with normal hearing, cochlear involvement, eighth nerve tumors, and brainstem lesions.

Amplitude Comparison of Waves

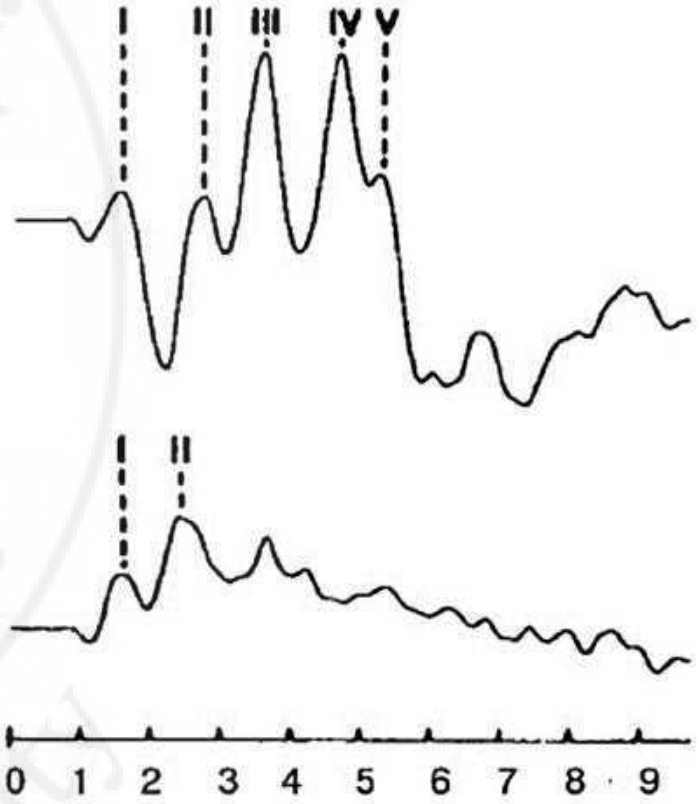
- It is well known that Wave V or the IV–V complex is normally larger than Wave I in adults possibly because more neurons are available as one progresses up the auditory pathway.
- In patients with pathologic conditions, potential damage to the more rostral brainstem fibers may result in the usually larger response (i.e., Wave V or the IV–V complex) being compromised.



The ABR from a young adult with an extra-axial brainstem lesion. All latencies were normal; however, Wave I was quite large (~0.7 µV) yielding an abnormal amplitude ratio.

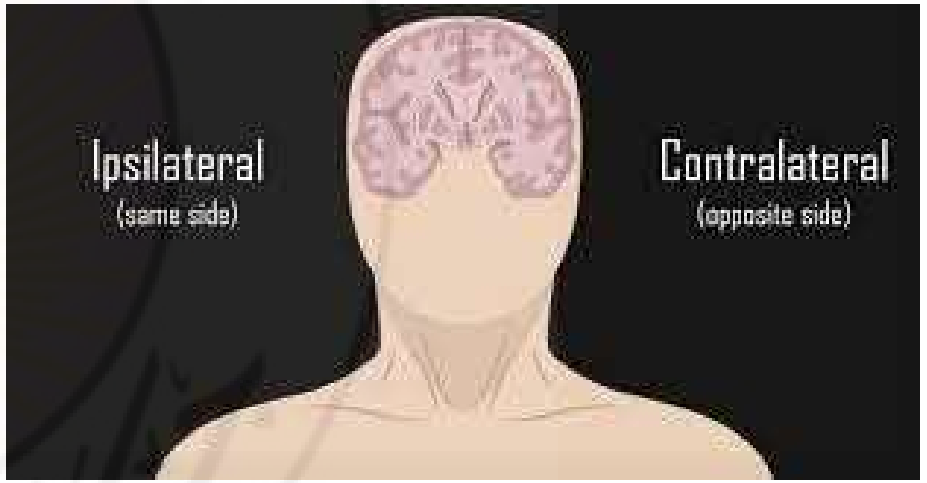
Waveform Morphology and Absence of Waves

- Brainstem involvement often suspected when Waves I and III are present and the IV–V complex or Wave V is absent.
- Brainstem and auditory nerve compromise is also probable when Wave I is present and Waves III and V are absent.
- Presence of Wave IV and absence of Wave V is an indication of brainstem involvement (make sure to change the polarity and re-establish ABR).
- The absence of all waves can also occur in individuals with brainstem involvement, but this finding usually occurs when there is concomitant peripheral hearing loss that prohibits the early waves from evolving.



Contralateral Effects

- Large mass lesions on one side, such as an acoustic neuroma, can compress and torque the brainstem sufficiently to cause an ABR brainstem finding on the opposite side when stimulating that ear.
- The ear opposite the large lesion, if the hearing is reasonably good, will show normal Waves I and III and an abnormal III–V interval or compromised V or IV–V complex.



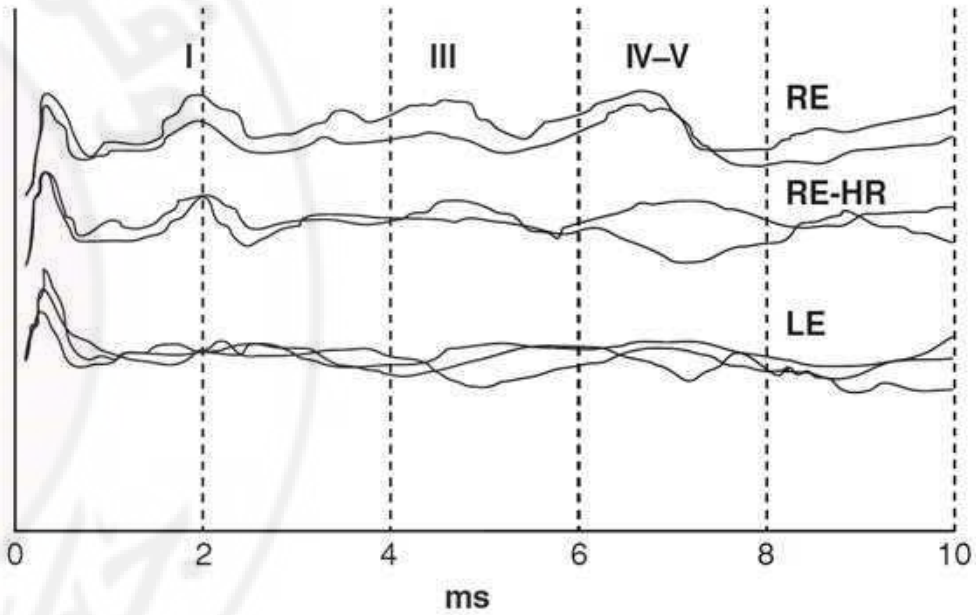
Repetition Rate Shifts

- Increasing the repetition rate during ABR testing would place greater physiological strain on the auditory nervous system, and in turn may **uncover subtle brainstem abnormalities**.
- There have been a number of reports that have shown ABR abnormalities at high rep rates, which were not as obvious at lower rates of stimulation.



Multiple Sclerosis

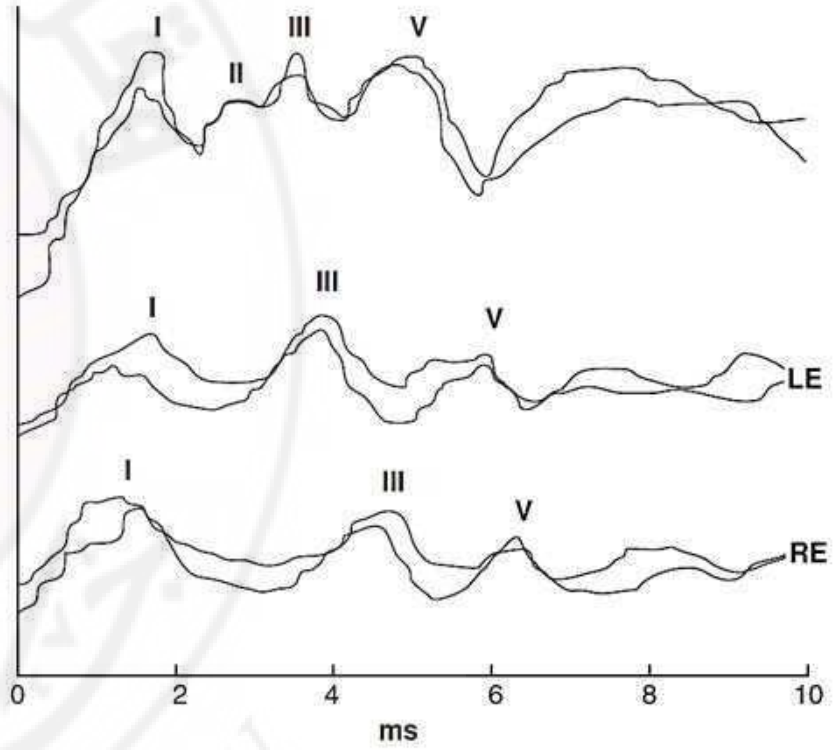
- MS is classified as a demyelinating disease that is often progressive.
- If the auditory nerve fibers are involved, auditory symptoms will often be noted. Even though most of the auditory brainstem pathways are myelinated, only a portion of the auditory nerve tract is myelinated.
- Extended central conduction times, that is, extended Waves I–III, III–V, or I–V intervals, are commonly seen in patients with MS.
- Further, ABR findings can be influenced by the degree of involvement and the time of evaluation relative to an exacerbation of symptoms. During or close to a period of exacerbation, the **ABR could be absent** only to recover over a period of days.



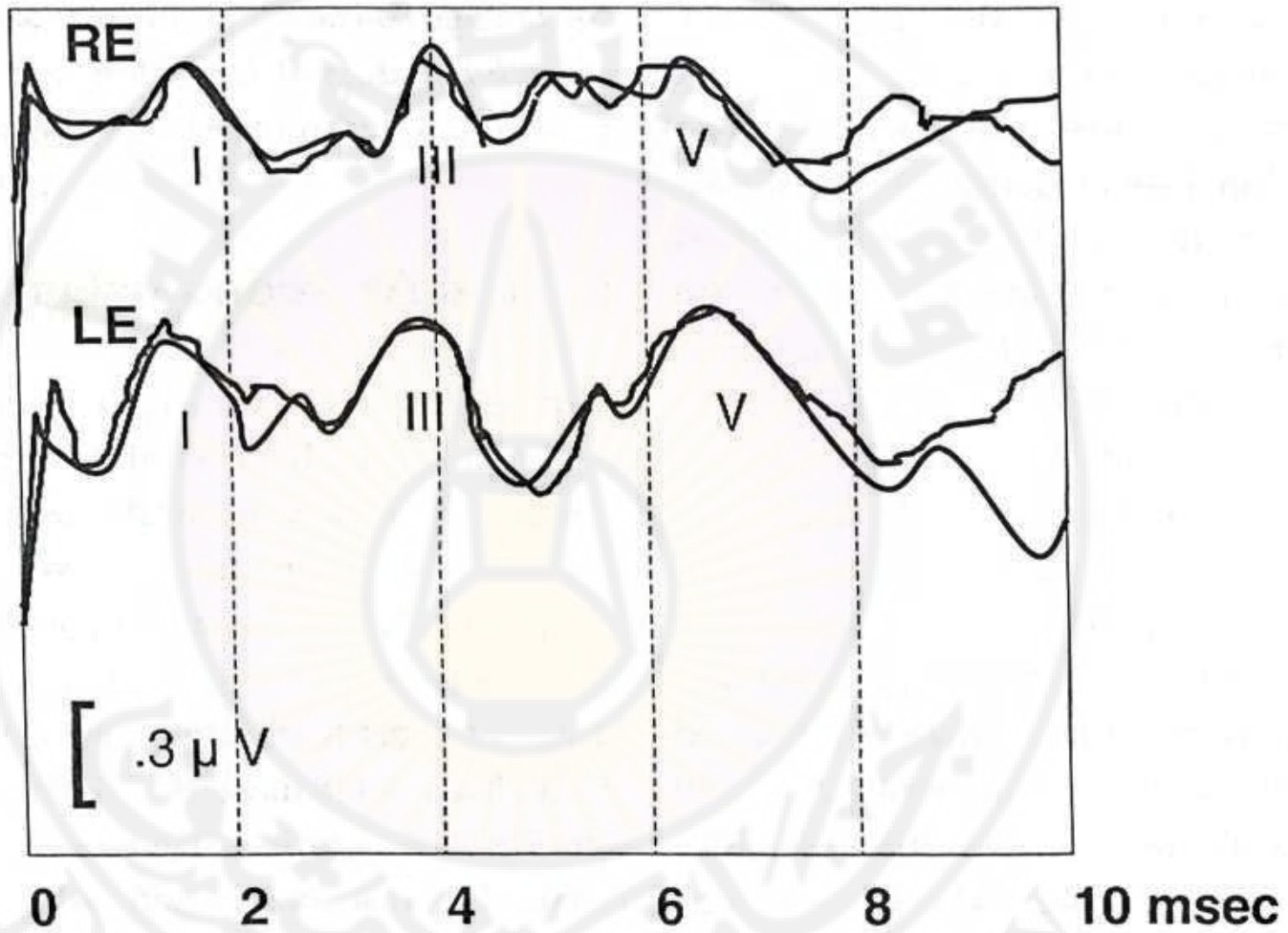
An ABR from a young adult with multiple sclerosis and a slight high-frequency hearing loss (Key: RE, right ear; LE, left ear; RE-HR, right ear, high rep rate @ 77.9 clicks per second).

Tumors of the Brainstem

- **Extra-axial:** Those tumors that encroach on the brainstem from outside of this structure (such as large vestibular schwannoma).
- With the exception of an eighth nerve tumor, most extra-axial lesions, like MS, result in extended central conduction times, though the particular site of involvement does influence which of the specific ABR indices will be affected.
- **Intra-axial:** Tumors that arise from within the brainstem with the most common being gliomas. Similar to other brainstem lesions, IWIs are often abnormal when intra-axial tumors are present.



The top tracing is a normal ABR. The next two tracings are from a patient with a meningioma in the right cerebellopontine angle. Note the extended I–III (3.0 ms) and I–V (4.7 ms) interwave intervals on the involved side.



Intra-axial tumor in the Pons level. Increased III-V IPLs is evident especially in the left side.

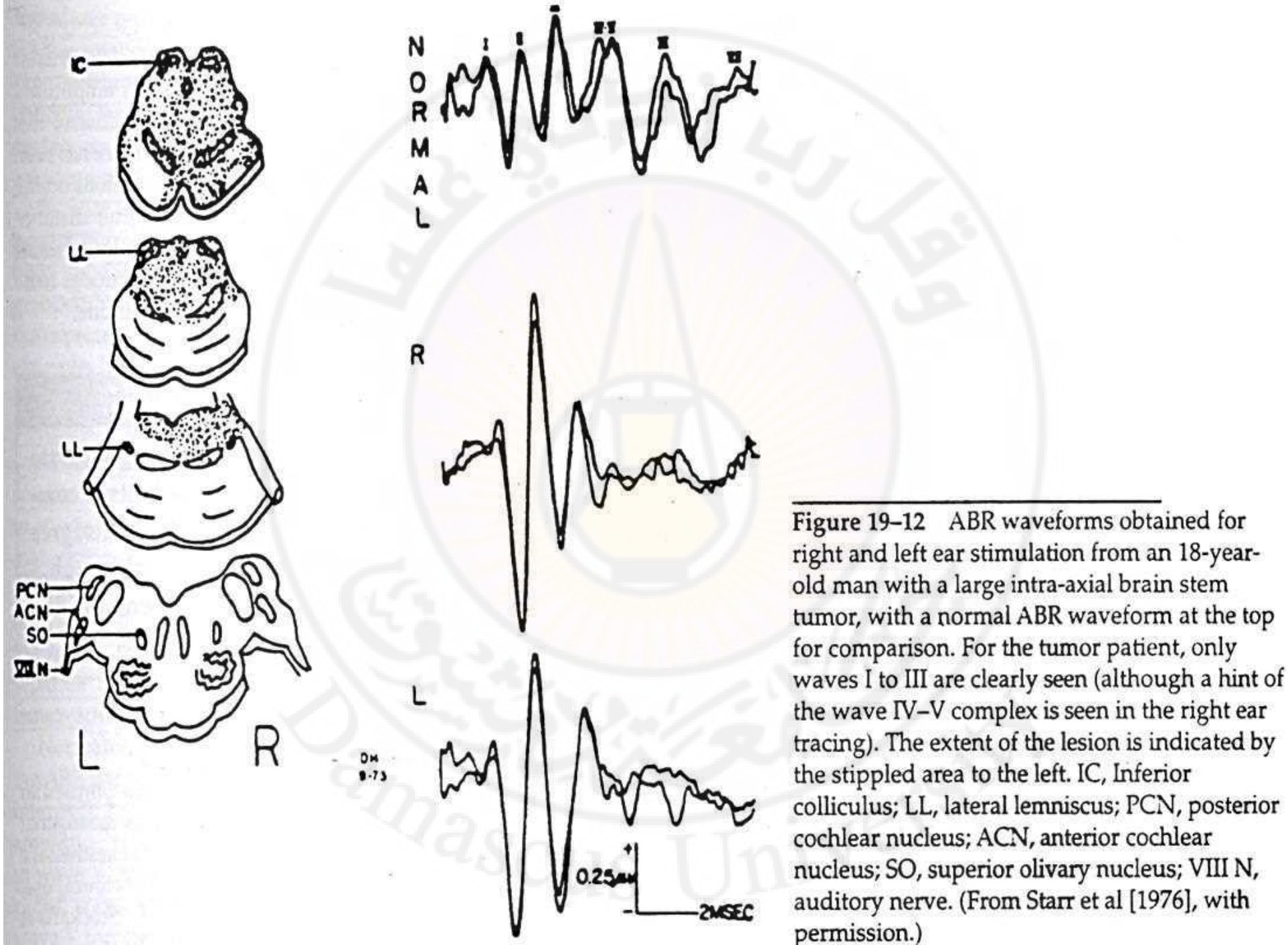
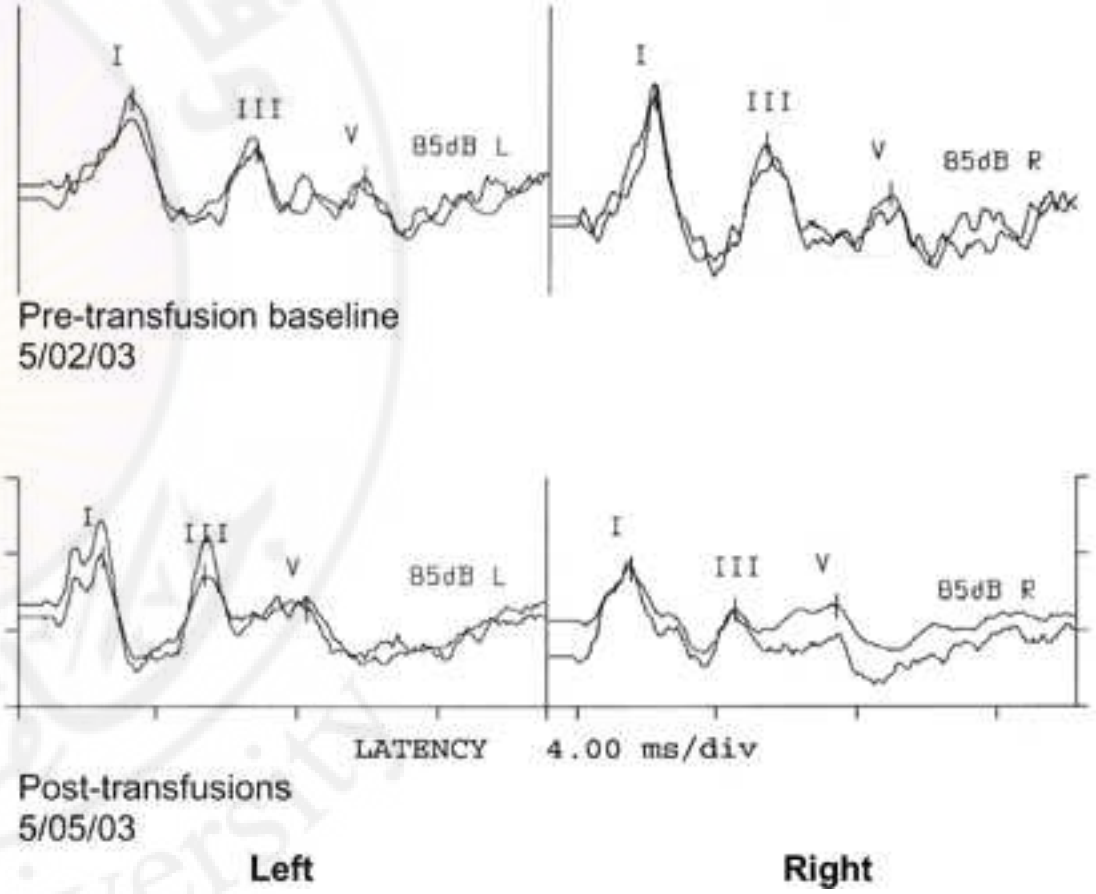


Figure 19–12 ABR waveforms obtained for right and left ear stimulation from an 18-year-old man with a large intra-axial brain stem tumor, with a normal ABR waveform at the top for comparison. For the tumor patient, only waves I to III are clearly seen (although a hint of the wave IV–V complex is seen in the right ear tracing). The extent of the lesion is indicated by the stippled area to the left. IC, Inferior colliculus; LL, lateral lemniscus; PCN, posterior cochlear nucleus; ACN, anterior cochlear nucleus; SO, superior olivary nucleus; VIII N, auditory nerve. (From Starr et al [1976], with permission.)

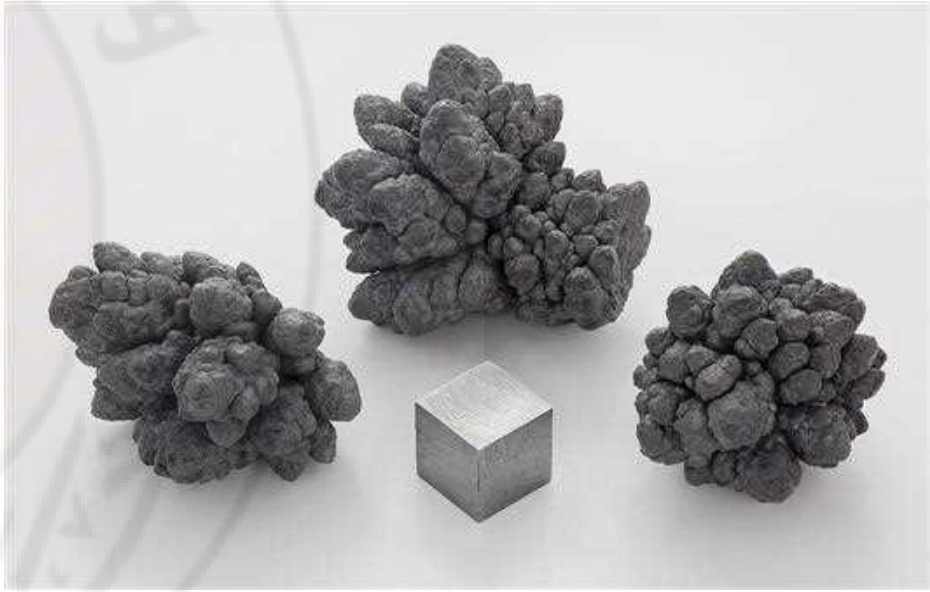
Hyperbilirubinemia

- High bilirubin levels can damage the CNS and the central auditory nervous system. Specifically, the **CN** is often damaged resulting in hearing difficulties.
- Increased absolute latency of Wave V appears to be a relatively common finding in patients with HB and ABR central conduction times (i.e., IWIs) are often abnormal in individuals with this disorder.
- Since the HB lesion site is in the central auditory system, otoacoustic emissions may not be a prudent choice for screening these infants.
- It is also important to note that with the timely application of therapy, HB resolves and the ABR improves, often to within normal limits.



Heavy Metal Exposure

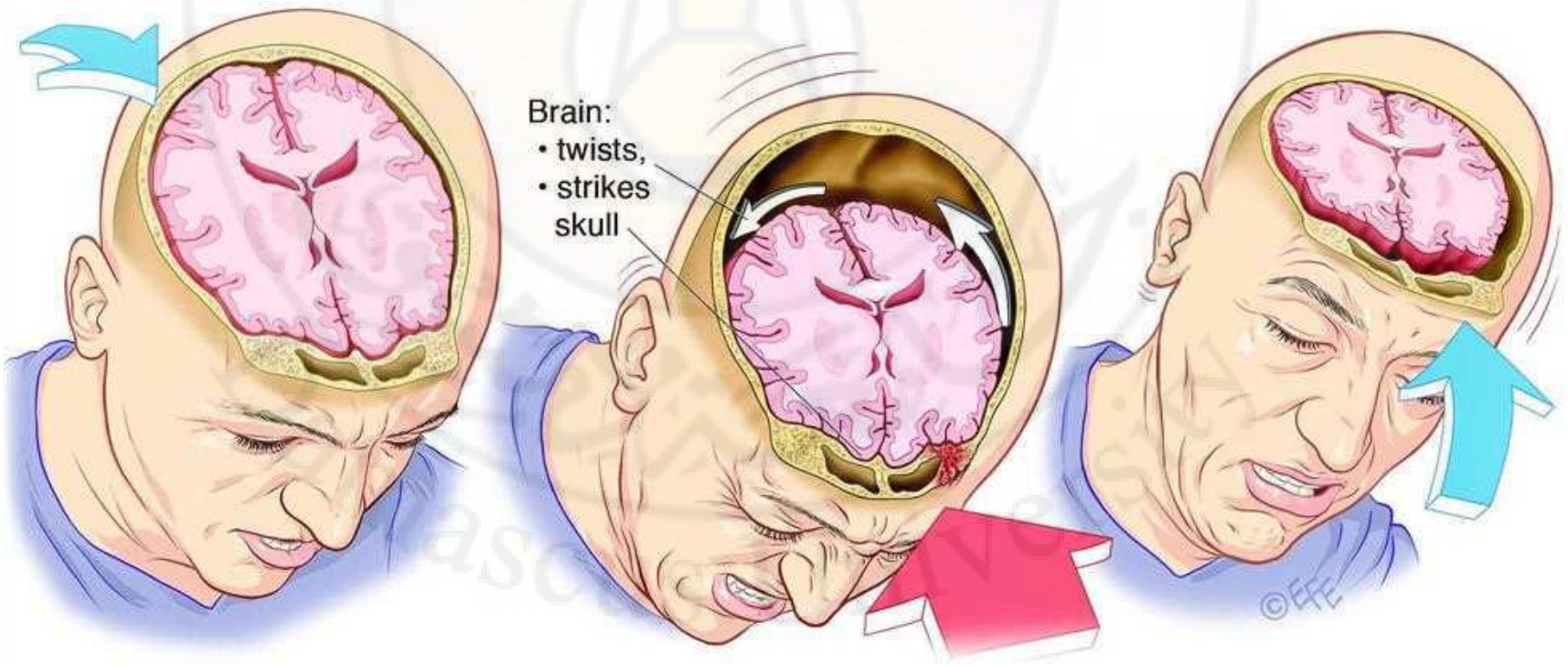
- Heavy metals such as lead, mercury, cadmium, and arsenic can compromise auditory function and the ABR can be useful in determining the effects from such exposures.
- Increased central conduction times during ABR testing are commonly noted in individuals exposed to heavy metals.
- In some subjects, central auditory nervous system can be adapted to lead exposure, and normal or near-normal ABRs can be found.



Damascus University

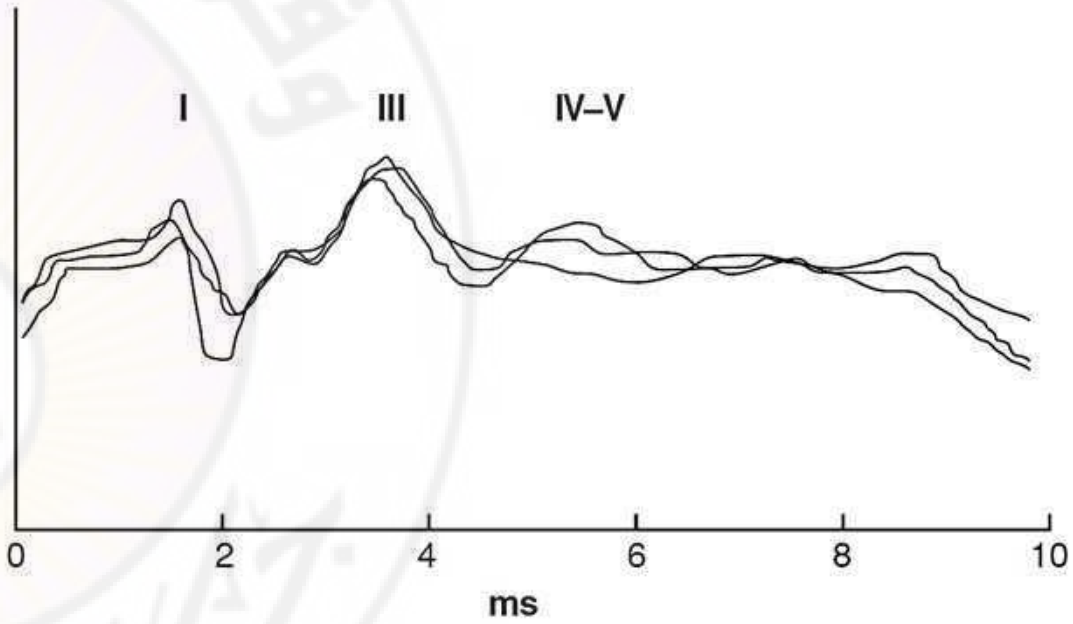
Head Injury

- Head injury (i.e., traumatic brain injury) may have central auditory deficits that is related to the high acceleration and deceleration of the brain within the confines of the cranium. This can result in contusions, hemorrhage, and axon injury (including myelin damage).



ABR findings in head injury

- ABR to be abnormal in about 50% of people with head trauma, with the I–V interval of central conduction time being perhaps the most sensitive ABR index.
- Also, increases in the latencies of Wave V and the I–V IWI of the ABR have been shown with increases in the severity of the head injury or traumatic brain injury.

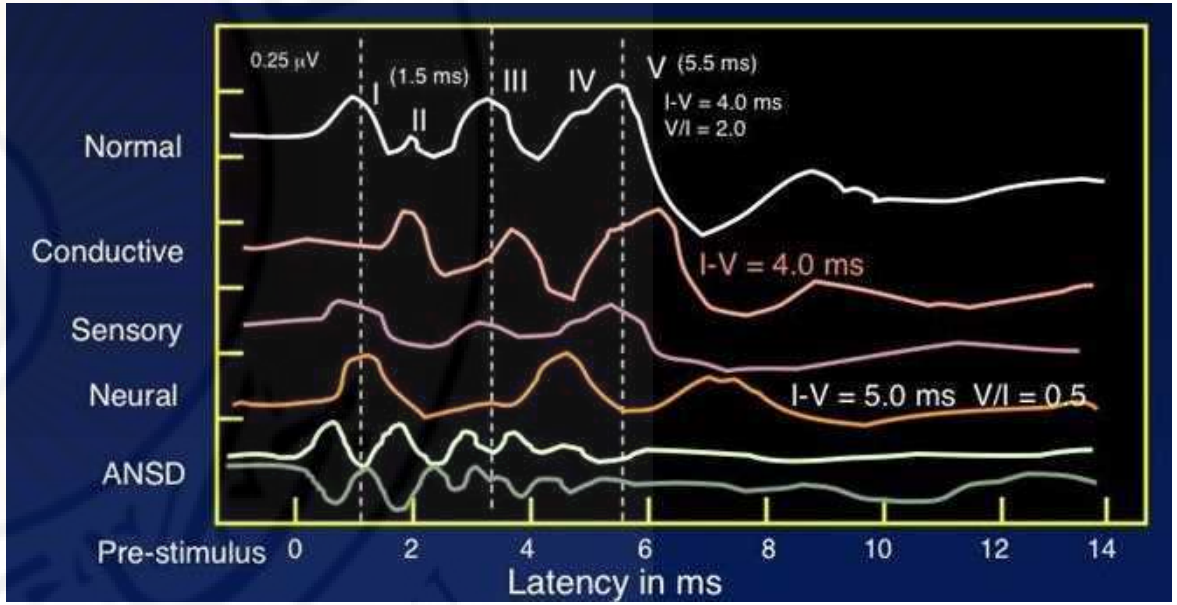


The ABR from a patient with a head injury (pontine contusion). This patient's symptoms of "difficulty in hearing" on the involved side resulted in a detailed audiologic evaluation including the ABR.

3. Cochlear Hearing Loss

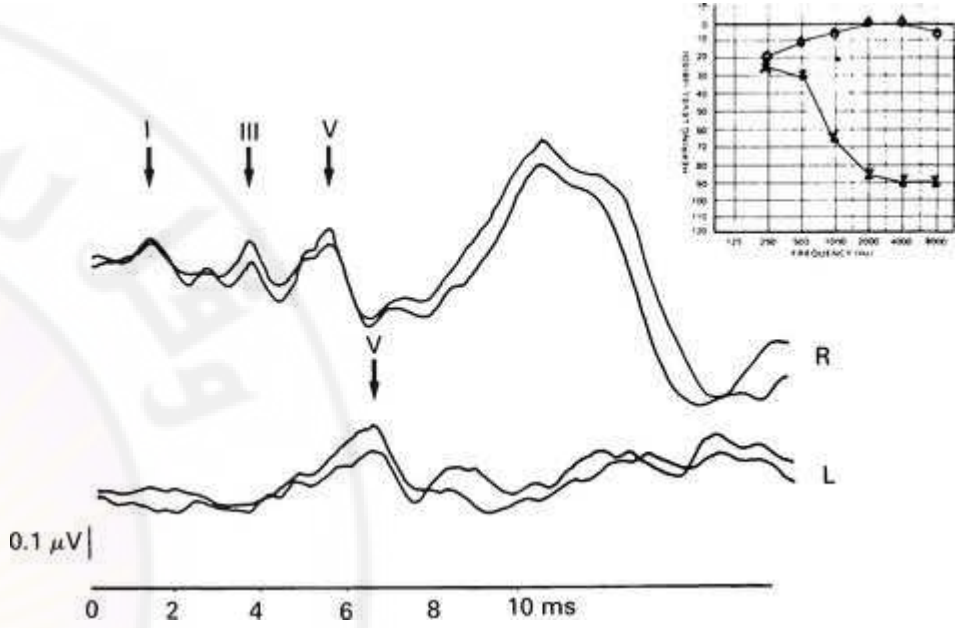
Effects Of Cochlear Hearing Loss On The ABR

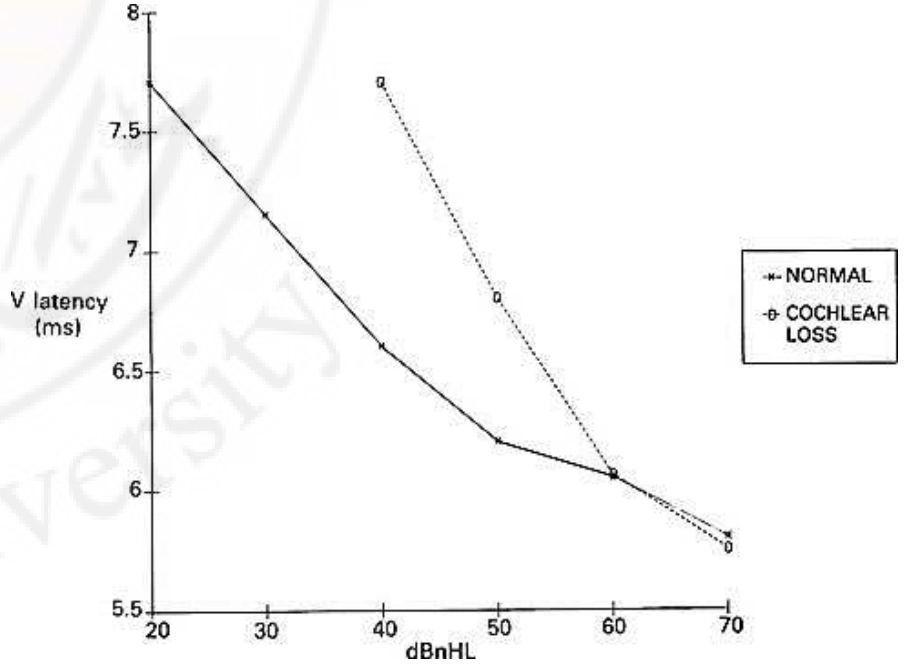
- A peripheral hearing loss can potentially affect the ABR, frequently resulting in test results that could be mistakenly attributed to the presence of a neural site of lesion.
- The one consistent observation is that the **interwave latency (IWI)** measures are largely **unaffected** by a peripheral hearing loss (both conductive and cochlear).
- Various studies have shown subtle effects of hearing loss on IWIs, but these effects have been subtle and often **decrease** the IWIs



Cochlear Hearing Loss & ABR

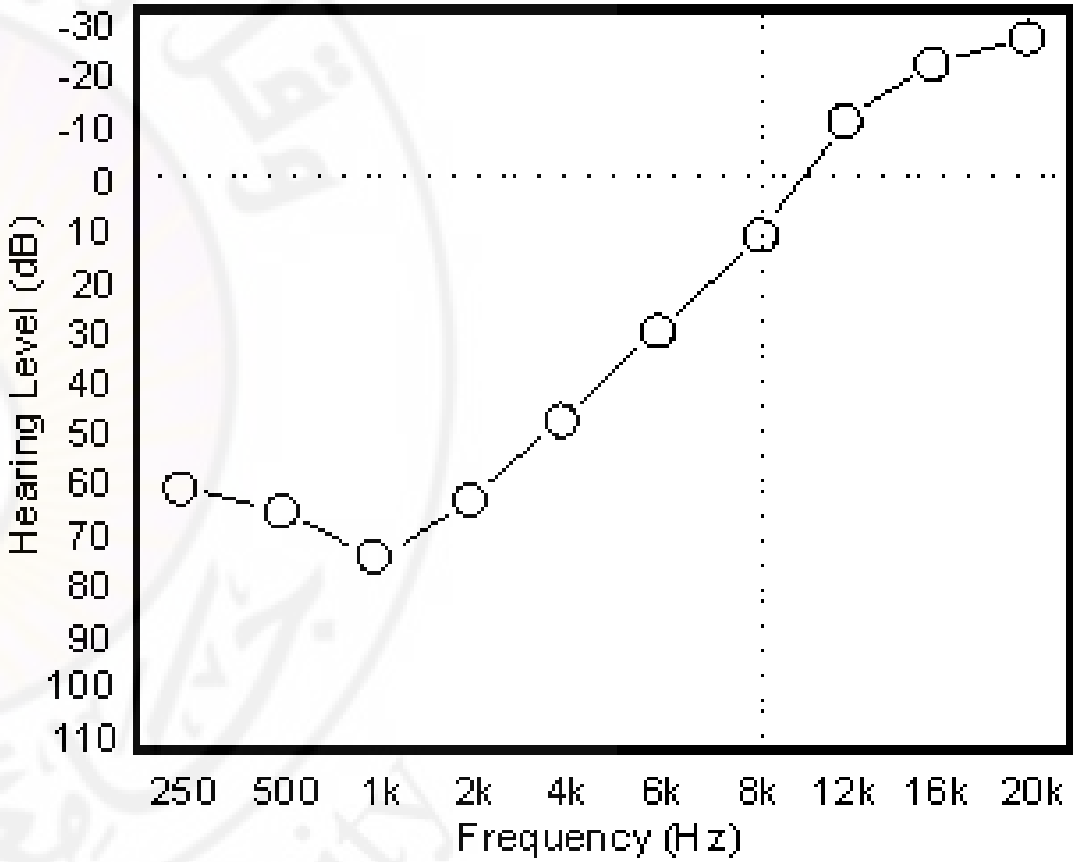
- Moderate to severe high-frequency hearing loss may have greater effect on **wave I** than on wave V, because generators of wave I contribute relatively more from the basal region (rendering the derivation of one or more of the typical IWI measures (I–III, III–V, I–V) impossible).
- In the absence of measureable IWIs, the audiologist must rely on other ABR measures, such as the absolute latency of Wave V, an ILD for Wave V, and/or the absence of ABR waves, all of which can be affected by a cochlear hearing loss or retrocochlear involvement.





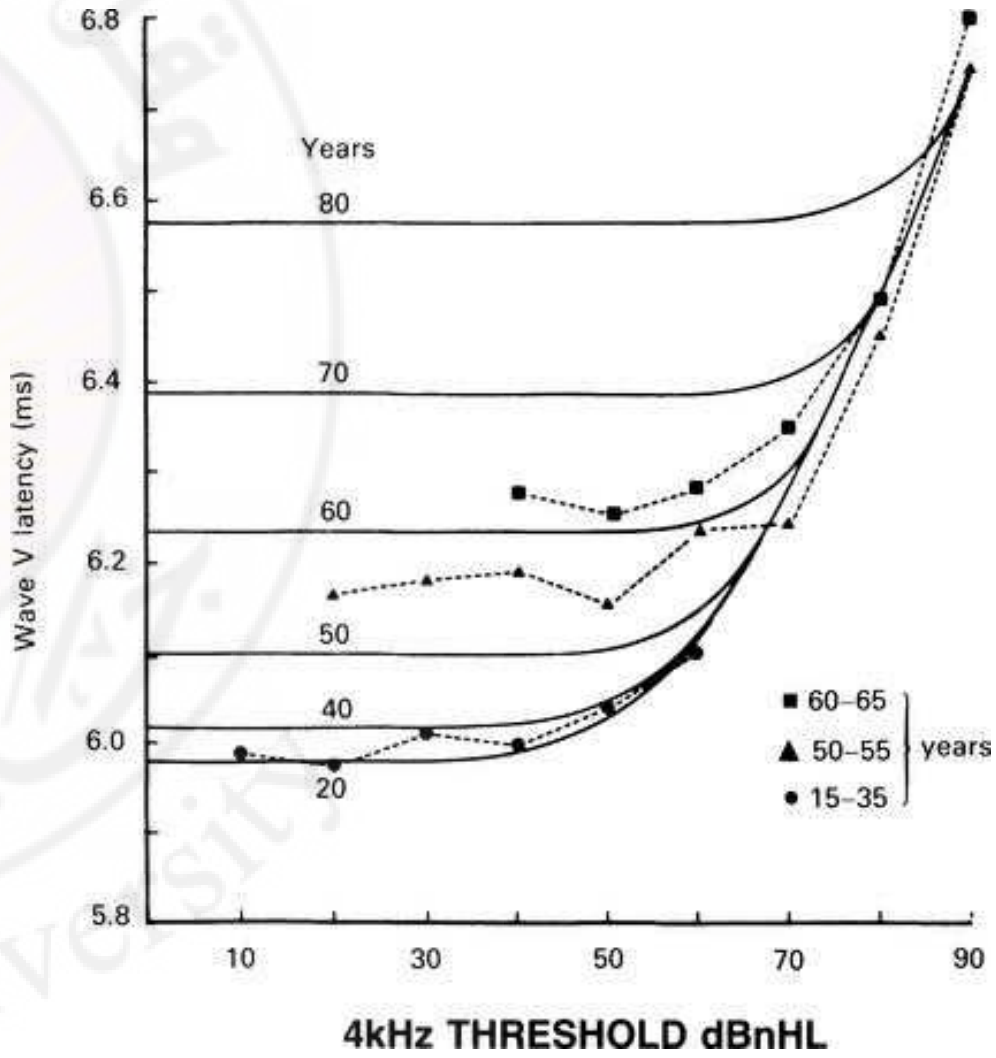
Cochlear Hearing Loss & ABR

- If the audiogram is worse then 75 dB at 1000 and 2000 Hz, with no hearing at 4000 Hz, an ABR response for click stimuli of 95 dBnHL may not be obtained.
- **Low frequency cochlear** hearing loss does not have a significant effect on ABR parameters elicited by click.
- In **symmetric** cochlear hearing loss, the interaural latency difference among waves V (IT5) has a standard deviation of about 0.2 ms.



Formulas to account For High-frequency Hearing Loss

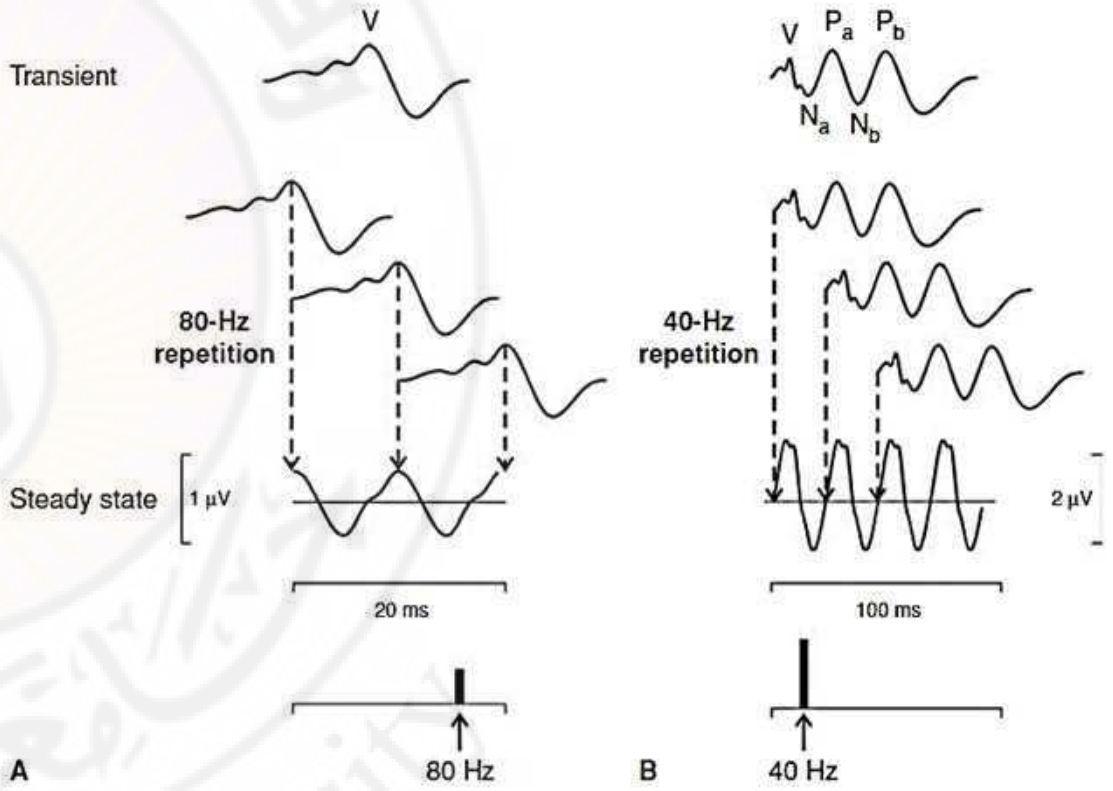
- For losses greater than 55 dB, there is a latency increase of **0.15 ms for every subsequent 10 dB** of hearing loss.
- In elderly subjects, the latency of wave V starts off at higher values compared with young subjects, and does not begin to increase further until much larger hearing losses are encountered. If the age variable is not controlled, then the observed effect of hearing loss may vary in an unpredictable manner. Therefore, both hearing loss and age must be taken into account when interpreting ABR.



10. Auditory Steady State Response (ASSR)

Auditory steady-state responses (ASSR)

- Auditory steady-state responses (ASSRs) are rhythmic (Periodic) brain potentials evoked by regularly repeating stimuli such as clicks, amplitude-modulated (AM) noise or tones, or frequency- modulated (FM) tones.
- ASSR can be thought of as an electro physiologic response (similar to ABR) to rapid auditory stimuli.
- ASSR is a method for objective measurement of hearing sensitivity with the goal of creating an **estimated audiogram**.



Classification of Human Auditory Evoked Potentials

Function	Anatomy	Latency	Relationship to Stimulus		
			Transient	Steady State	Sustained
Sensory	Cochlear and eighth nerve	First (0–5 ms)	Eighth nerve CAP, ABR waves I, II	Cochlear microphonic	Summating potential
	Brainstem	Fast (2–20 ms)	ABR (waves III, IV, V)	FFR, >60-Hz ASSR	Pedestal of FFR
	Early cortical	Middle (10–100 ms)	Middle-latency AEP (MLAEP: Na, Pa, Nb)	~40-Hz ASSR	
	Cortical	Slow (50–300 ms)	Slow "vertex" potential (P1, N1, P2, N2)	<20-Hz ASSR	Cortical sustained potential
Processing contingent potentials	Cortical	Late (150–1000 ms)	Mismatch Negativity (MMN) Processing Negativity (Nd) N2b P3a, P3b N400, P600		CNV

CAP, compound action potential; ABR, auditory brainstem response; MLAEP, middle latency auditory evoked potential; FFR, frequency following response; ASSR, auditory steady-state response; CNV, contingent negative variation.

What produces the ASSR?

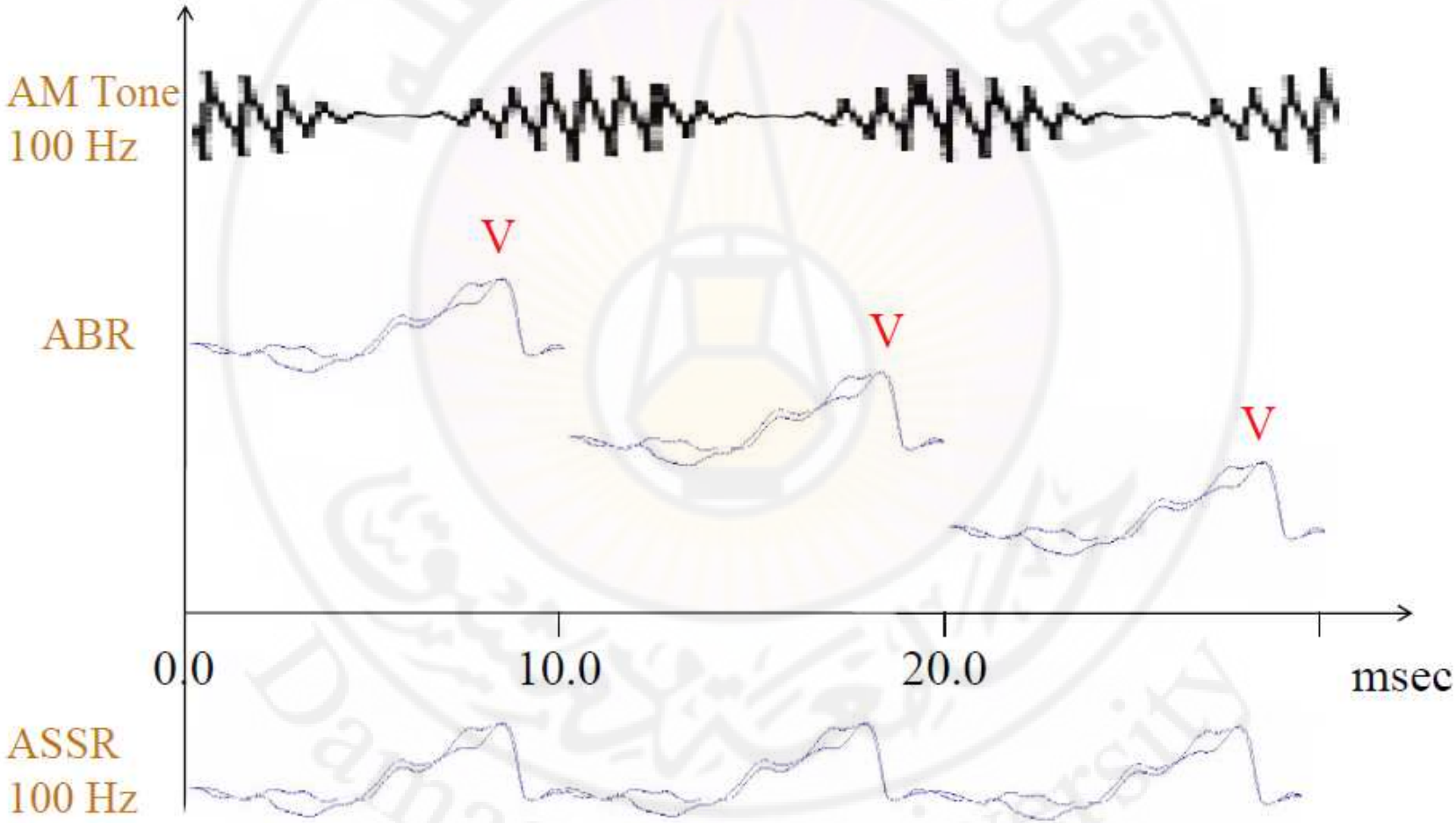
- Still a matter of conjecture
- **May arise from auditory pathway channels particular to modulated stimuli**
  - Lins & Picton, (1995): non-linearities in the way modulation is represented by the IHCs and spiral ganglion could produce ASSRs
- **• Superposition of transient responses**
  - Galambos et al., (1981)



Robert Galambos
American neuroscientist

High Rate ASSR (MF: 100 Hz)

Consecutive recordings of the transient ABR



Damascus University

ASSR is a very small Auditory EP signal

Signal	Frequency, Hz	Amplitude, nV
EP Signals		
ASSR	70-110	10 - 50
ABR	**50-3,000**	**100-1,000**
MLR	**3-300**	**500-3,000**
LLR	**1.5-15**	**200-16,000**
P_{300}	**1-15**	**5,000-20,000**
Noises		
Electrooculogram (EOG)	**0.5-10**	**10,000-500,000**
EEG awake	**3-40**	**5,000-10,000**
EEG sleep	**3-16**	**2,000-400,000**
Electrocardiogram (ECG)	**0.5-50**	**80,000-2,000,000**
Electromyogram (EMG)	**30-500**	**10,000-2,000,000**
Line, Radio frequency (RF)	**50/60 Hz, MHz, GHz**	**Up to 10,000,000**

When to do What?

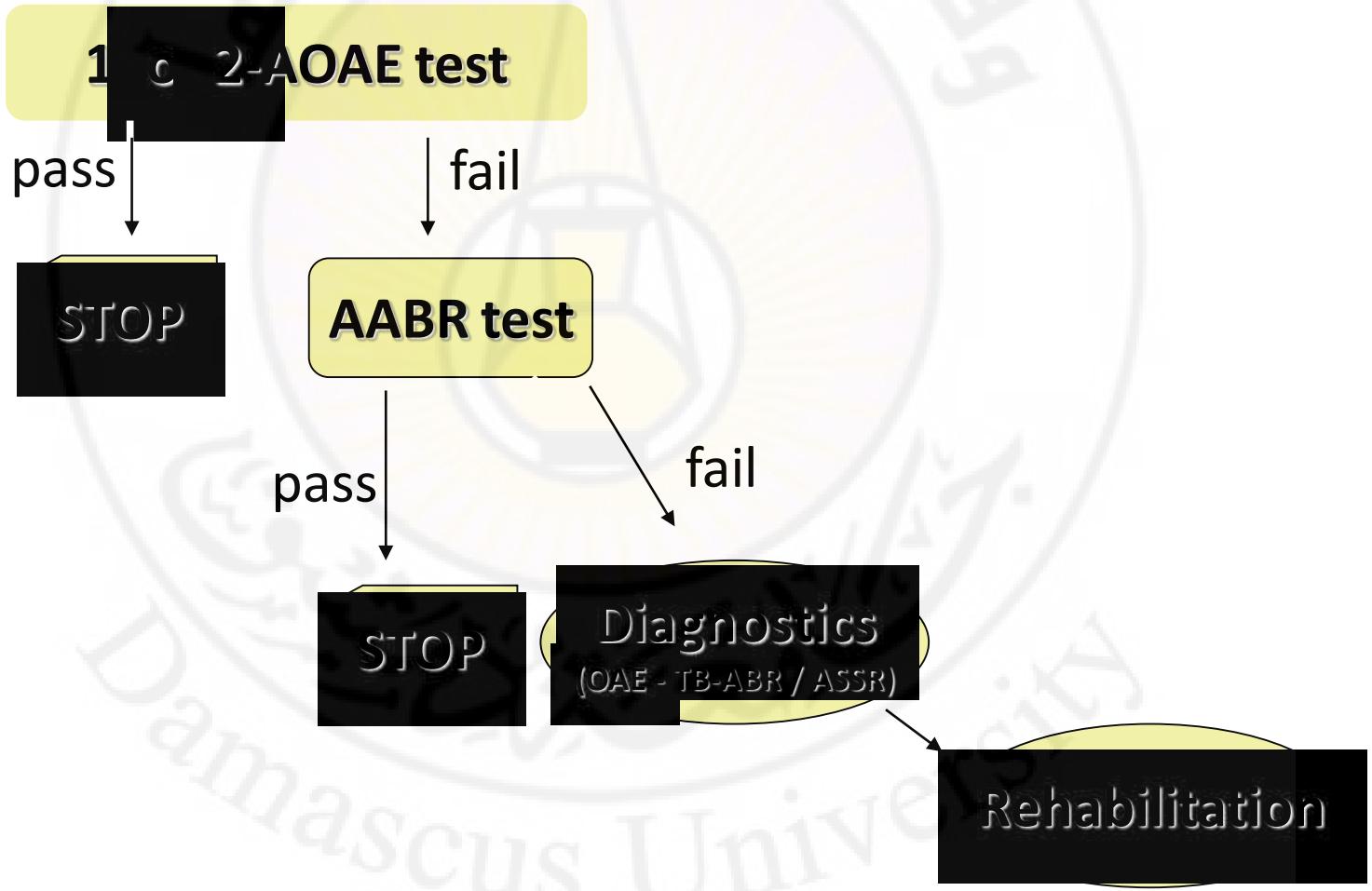
- Screening < 1 month
- Assessment < 3 months
- Intervention < 6 months



Objective Audiometry needed for the audiogram.

Only method is ABR or ASSR

From Screening to Rehabilitation



The Only Two Ways to Obtain the Audiogram:

- The ASSR (Auditory Steady State Response)
- The Tone Burst ABR



Damascus University

ABR & ASSR - Similarities

- Both record bio-electrical activity
- Both may use similar electrode arrays
- Both are classified as auditory evoked potentials
- Both use similar transducers (inserts being predominant) – presenting controlled acoustic stimuli



ABR & ASSR - Differences

ASSR

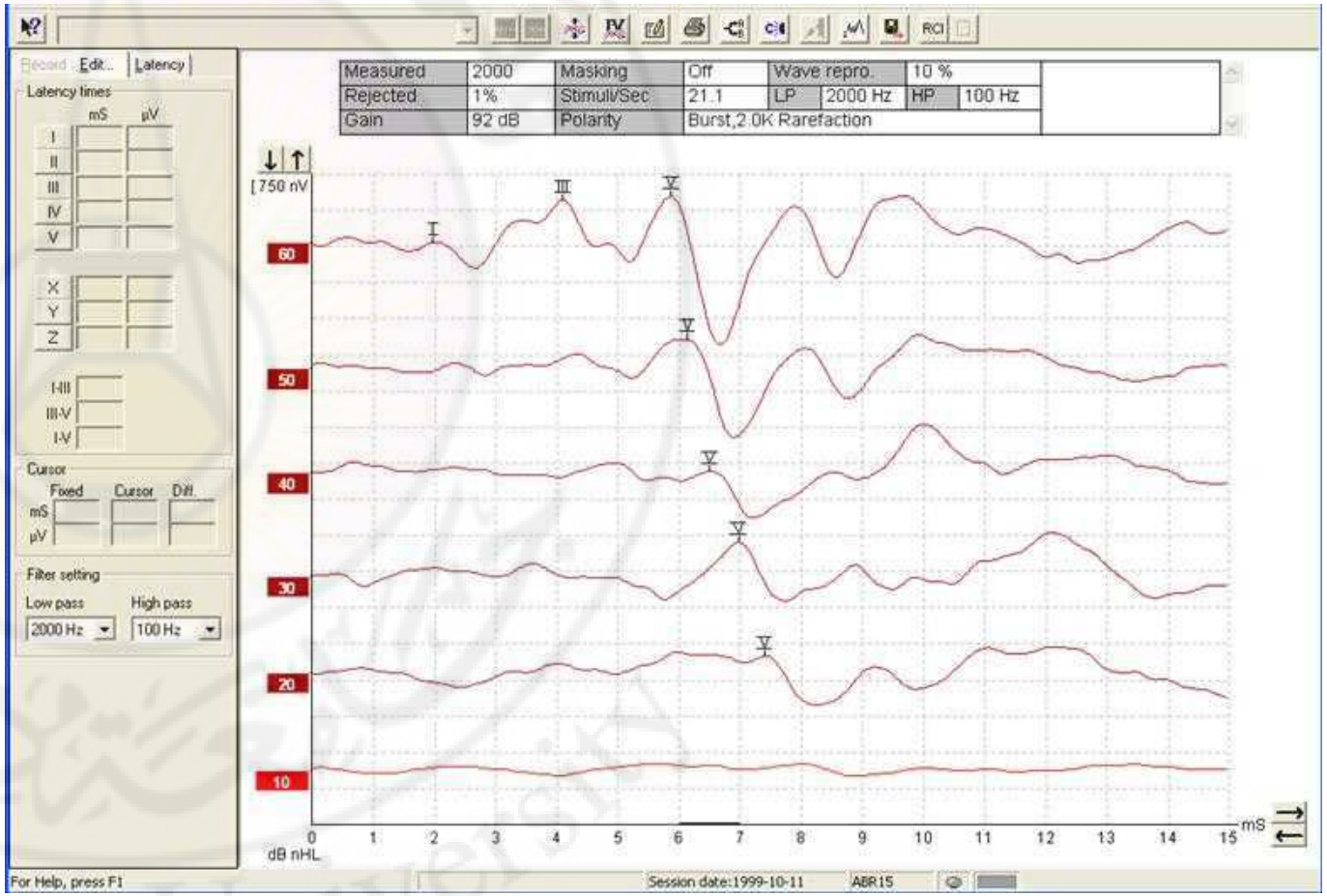
1. ASSR uses amplitudes and phases in the spectral (i.e. frequency) domain
2. ASSR is evoked using repeated sound stimuli presented at a high repetition rate.
3. ASSR uses sophisticated, mathematical detection algorithms to objectively detect responses.
4. ASSR can simultaneously test binaurally, typically up to 4 frequency specific stimuli in each ear.
5. ASSR is more efficient in detecting down to 500Hz and for severe-profound losses.

ABR

1. ABR depends on amplitude and latency (Time domain)
2. ABR is evoked using brief sounds presented at a relatively low repetition rate.
3. ABR typically requires subjective analysis by a trained professional.
4. ABR tests with a click or single tone burst stimuli one ear at a time.
5. ABR is useful in detecting thresholds from 1-4KHz but requires a highly trained professional

Very Different Recording Techniques

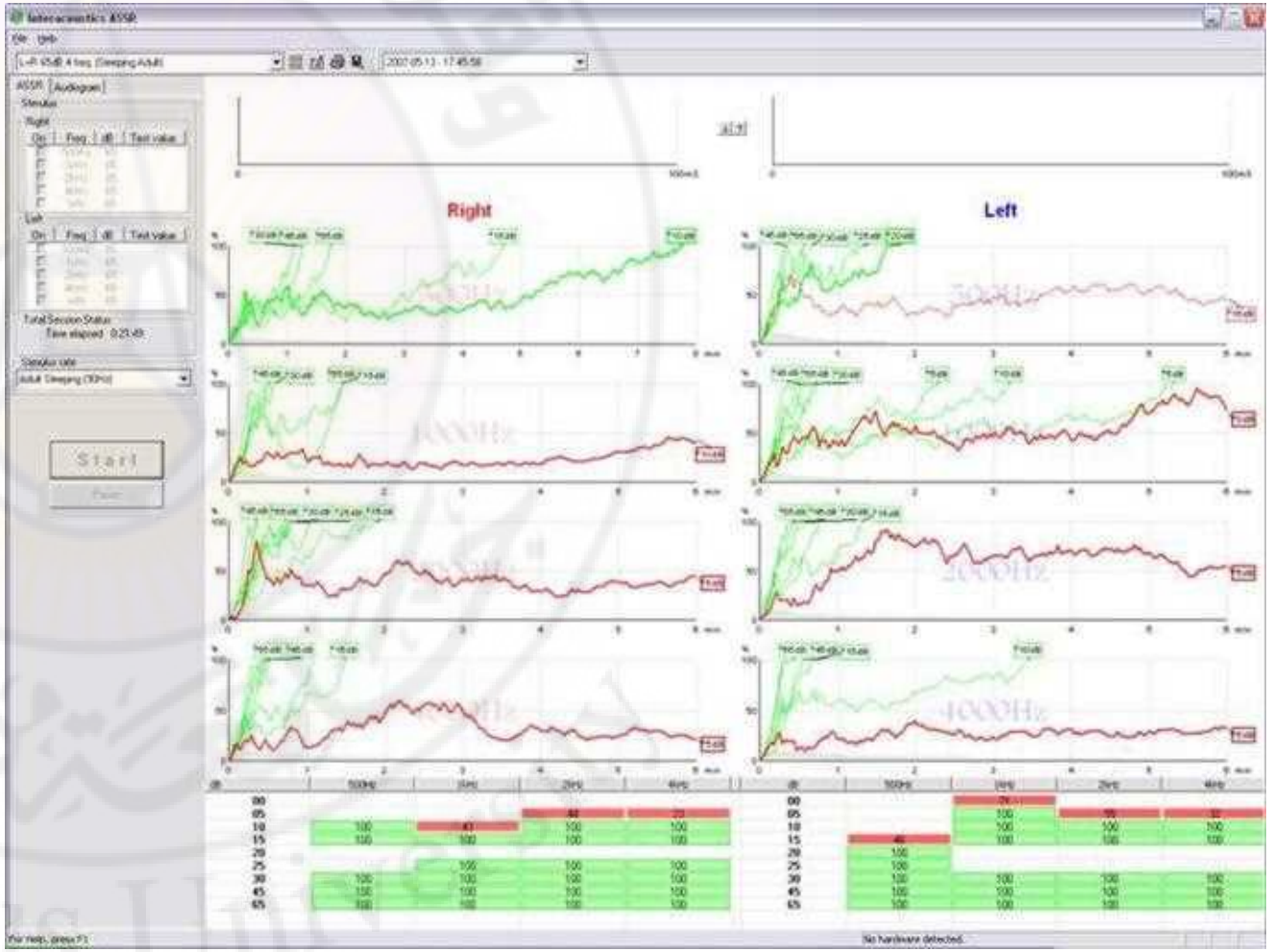
- ABR is analyzed in the time domain:



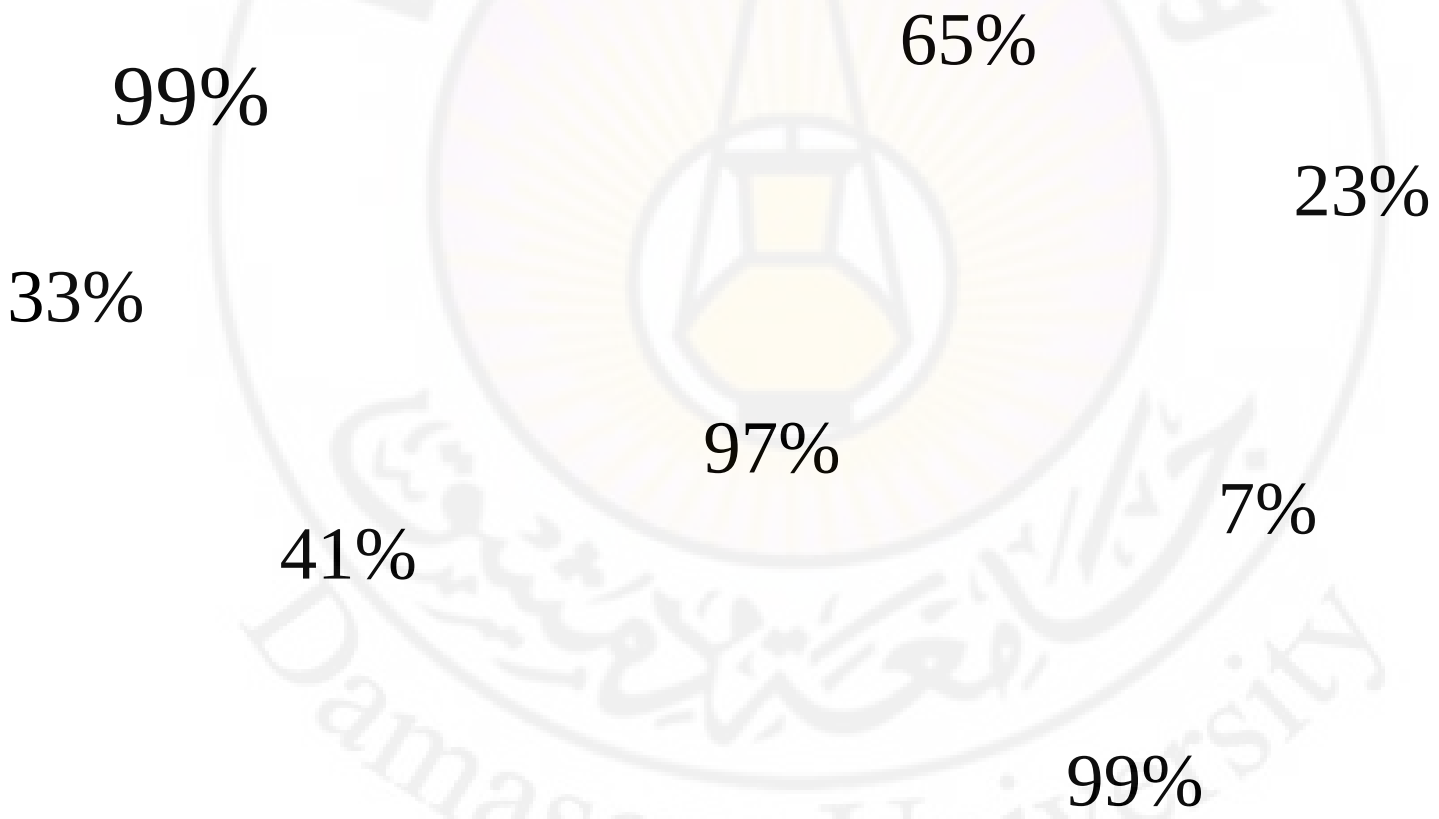
…producing the well-known waveforms…

Very Different Recording Techniques

- ASSR is analyzed in the **frequency domain**, and has no meaningful waveform to present…



An ASSR Result is Just a Statistic Response Likelihood….



ASSR relies on statistical measures to determine if and when a threshold is present across multiple frequencies

Confusing terminology

- Auditory steady state responses (ASSR)
- Amplitude modulated following response (AMFR)
- Envelope following response (EFR)
- Frequency following response (FFR)
- Steady state evoked response (SSER)
- Steady state evoked potential (SSEP)

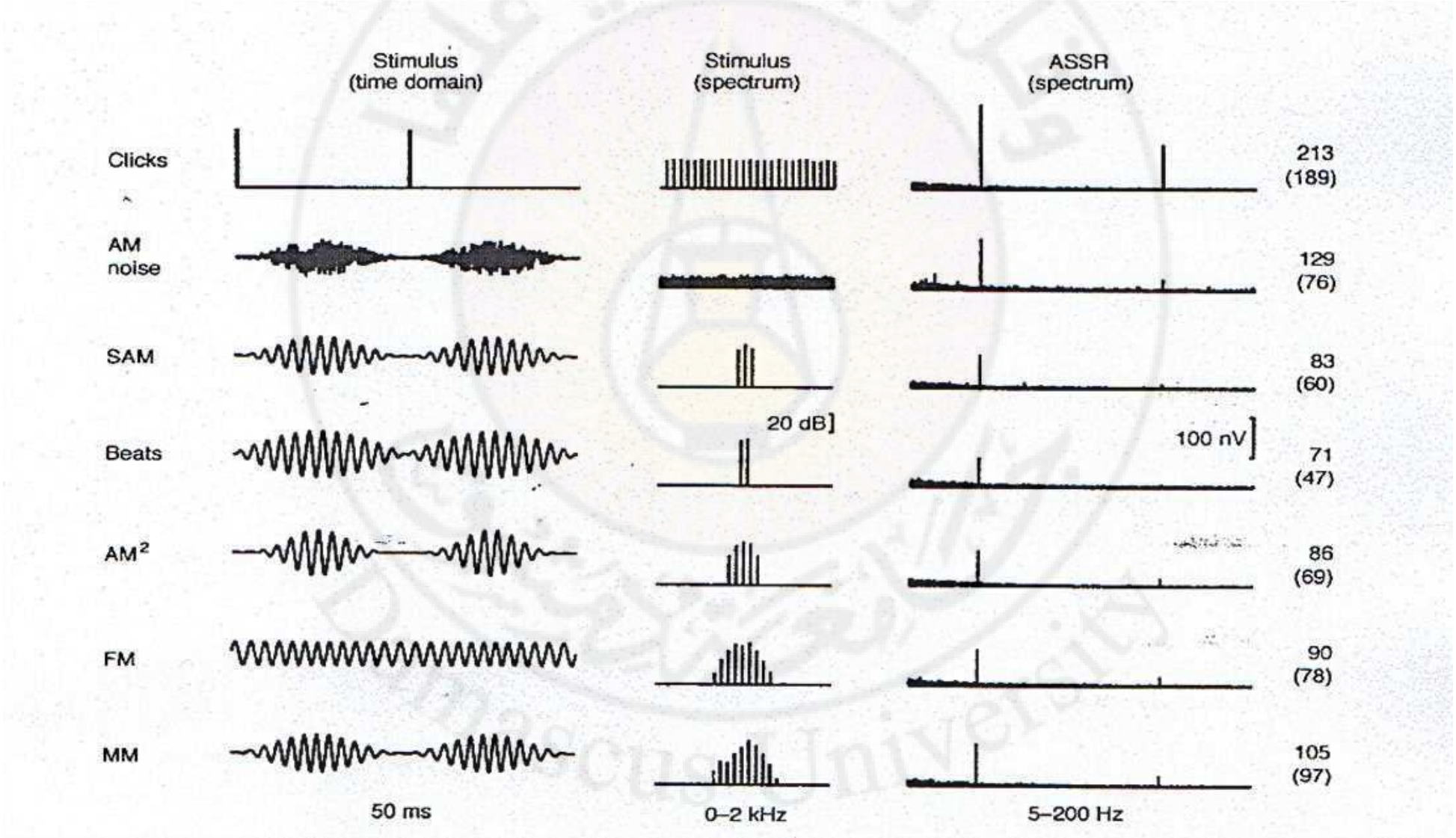


ASSR Stimulation

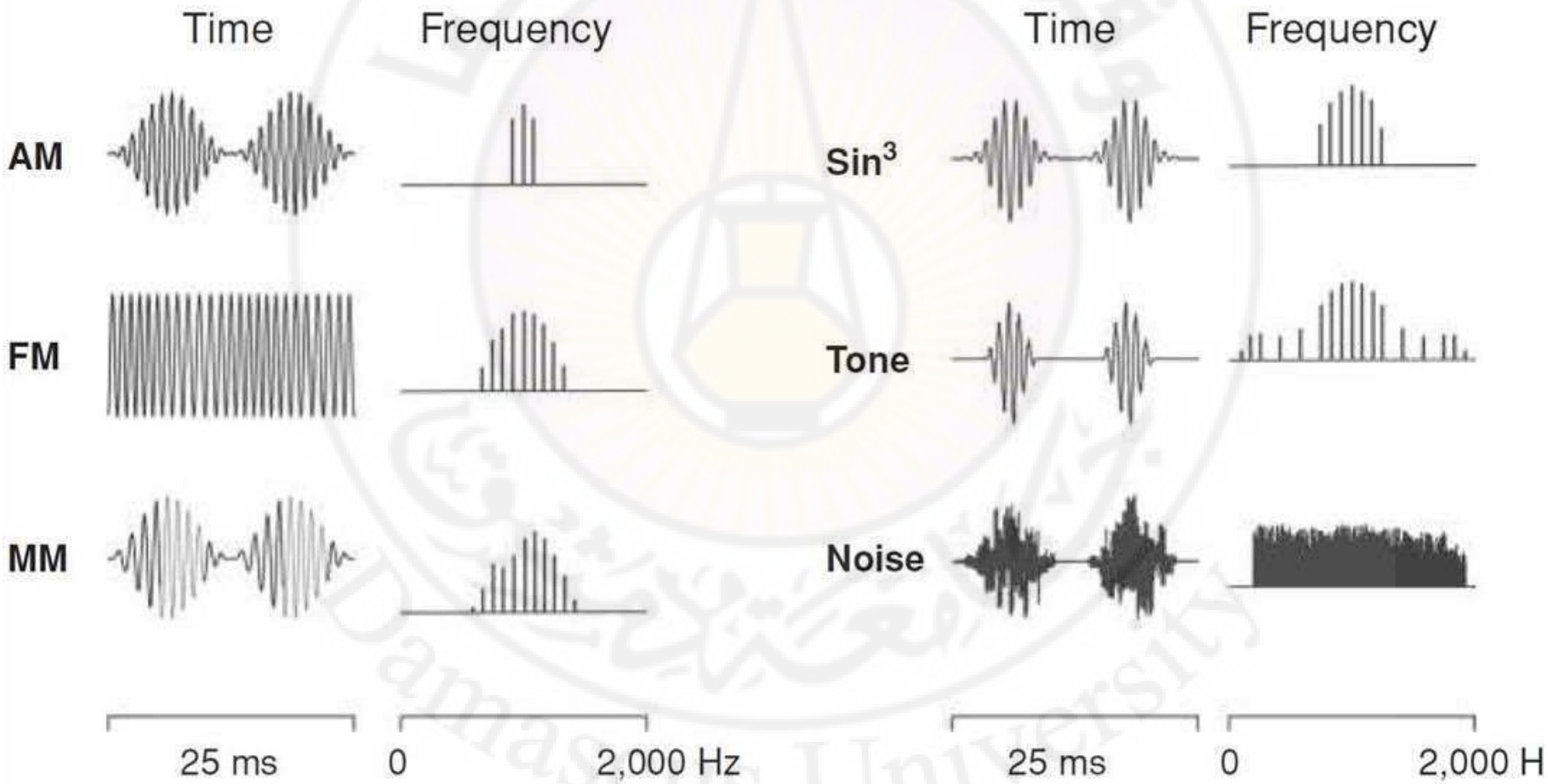
- Currently, there is no universal standard for ASSR instrumentation. Stimulus and recording parameters and methods are designed (and may vary) by each manufacturer.
- ASSR can be recorded using either **broadband** (ie, frequency nonspecific) or **frequency-specific** stimuli. Broadband stimuli include clicks, noises, amplitude modulated noise, and chirps. Frequency-specific stimuli include filtered clicks, band-limited chirps, narrow-band noise bursts, tone bursts, amplitude modulated narrow-band noise, or amplitude and frequency modulated pure tones.
- **"Chirps"** are a recent addition to the broadband family.
- Some newer ASSR systems use special chirp stimuli. **Band-limited chirps** provide highly synchronized stimulation of specific frequency bands.

Damascus University

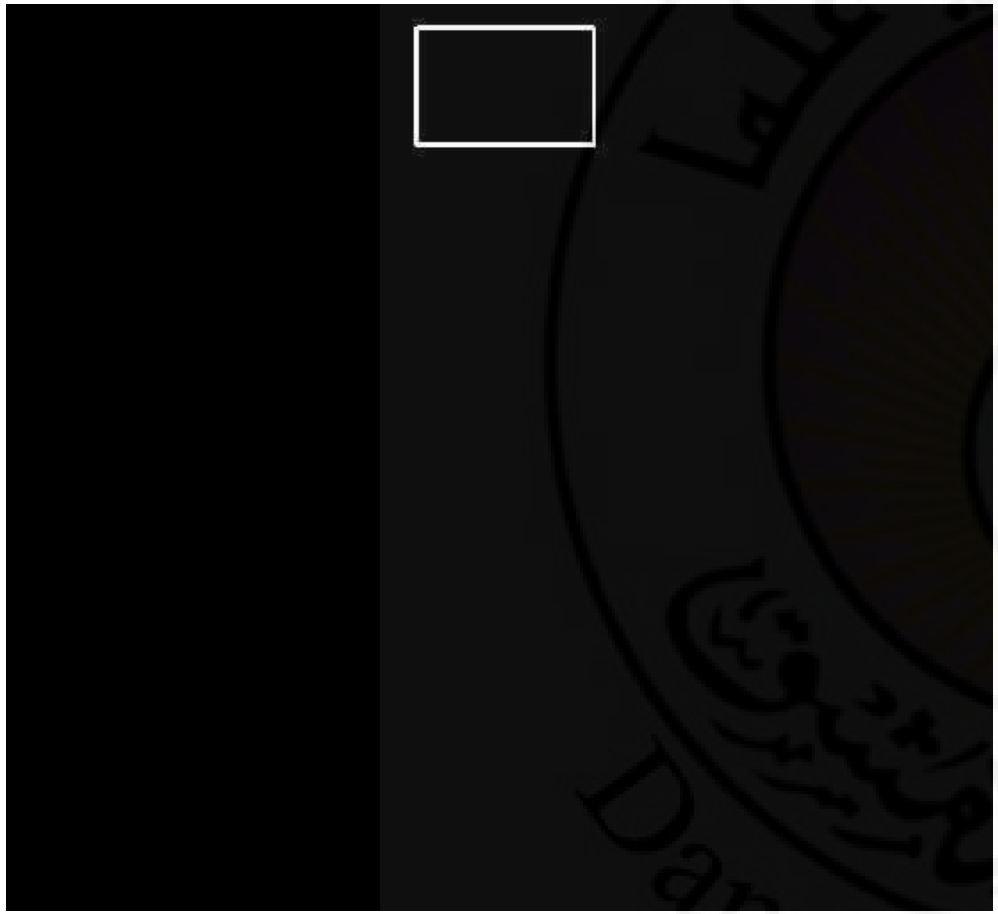
Auditory Steady State Response To Various Stimuli

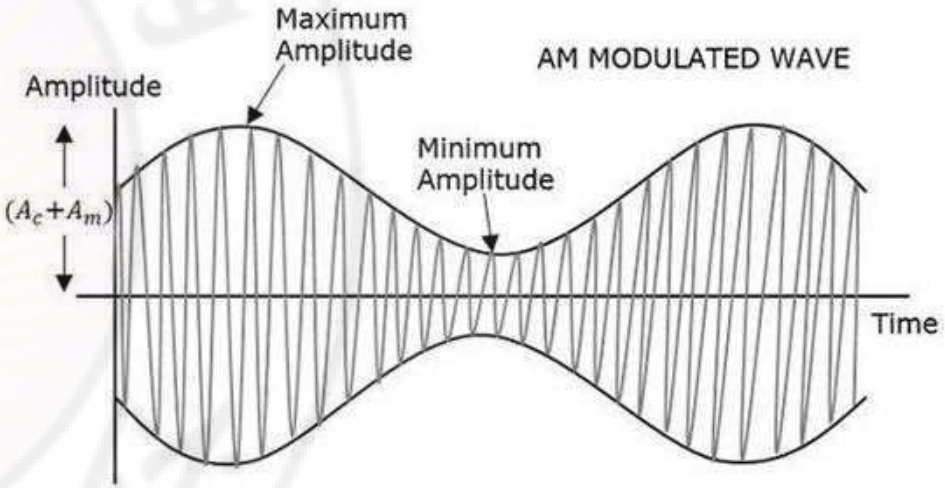


Time- and frequency domain representation of stimuli used for ASSR



Amplitude Modulation (AM)



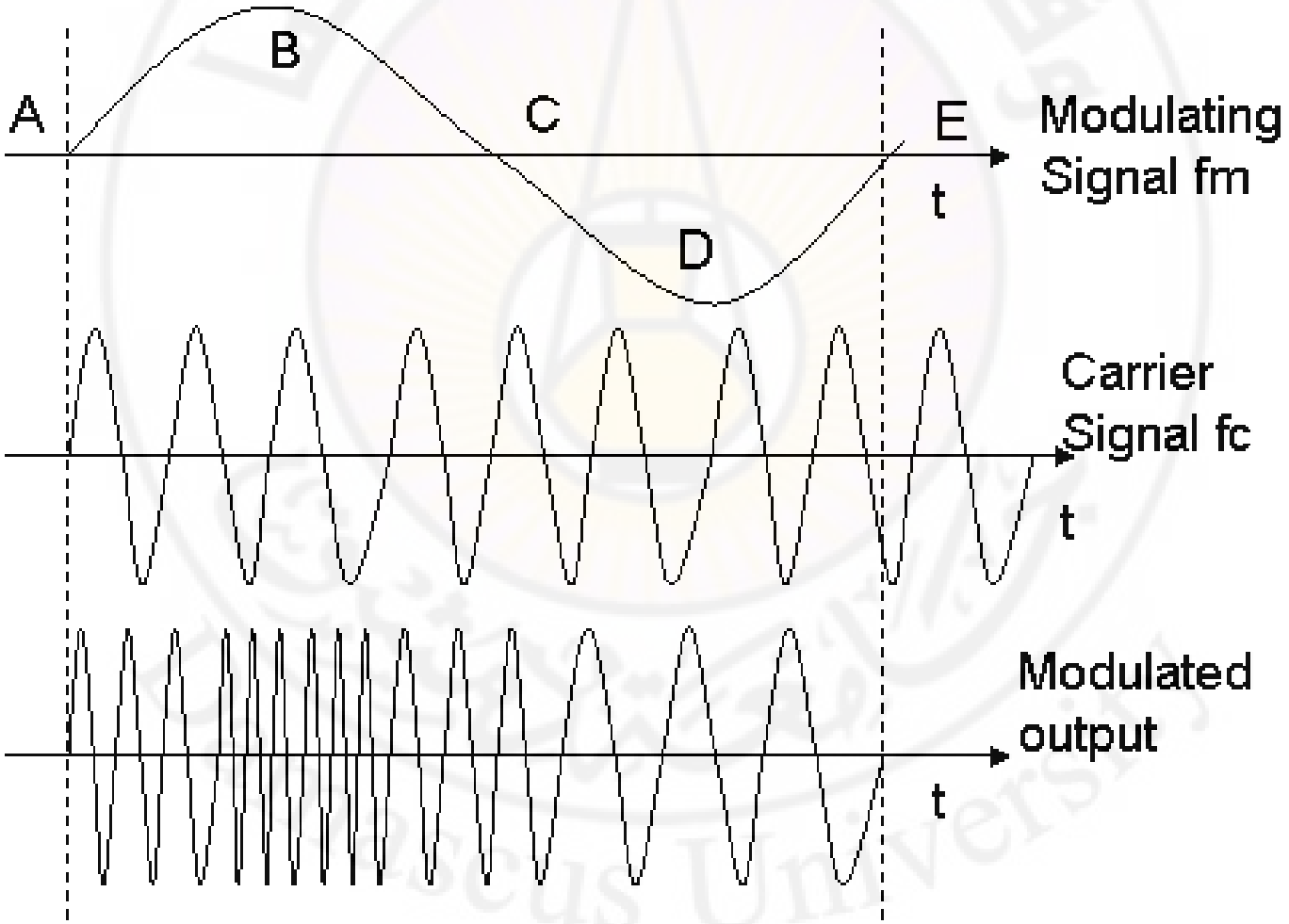


1000 Hz +/- 100 Hz = 900 – 1100 Hz

CF MF

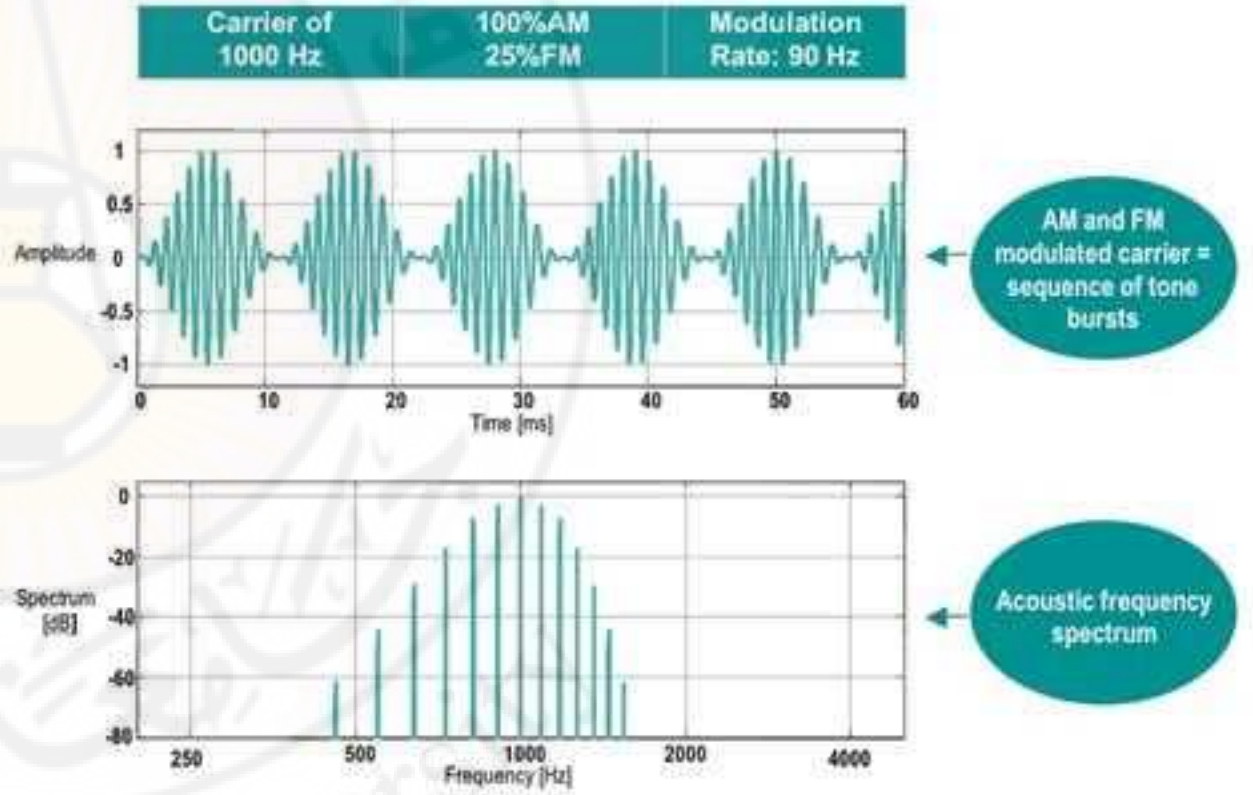
A 100% amplitude modulation (AM) is often used

Frequency Modulation (FM)

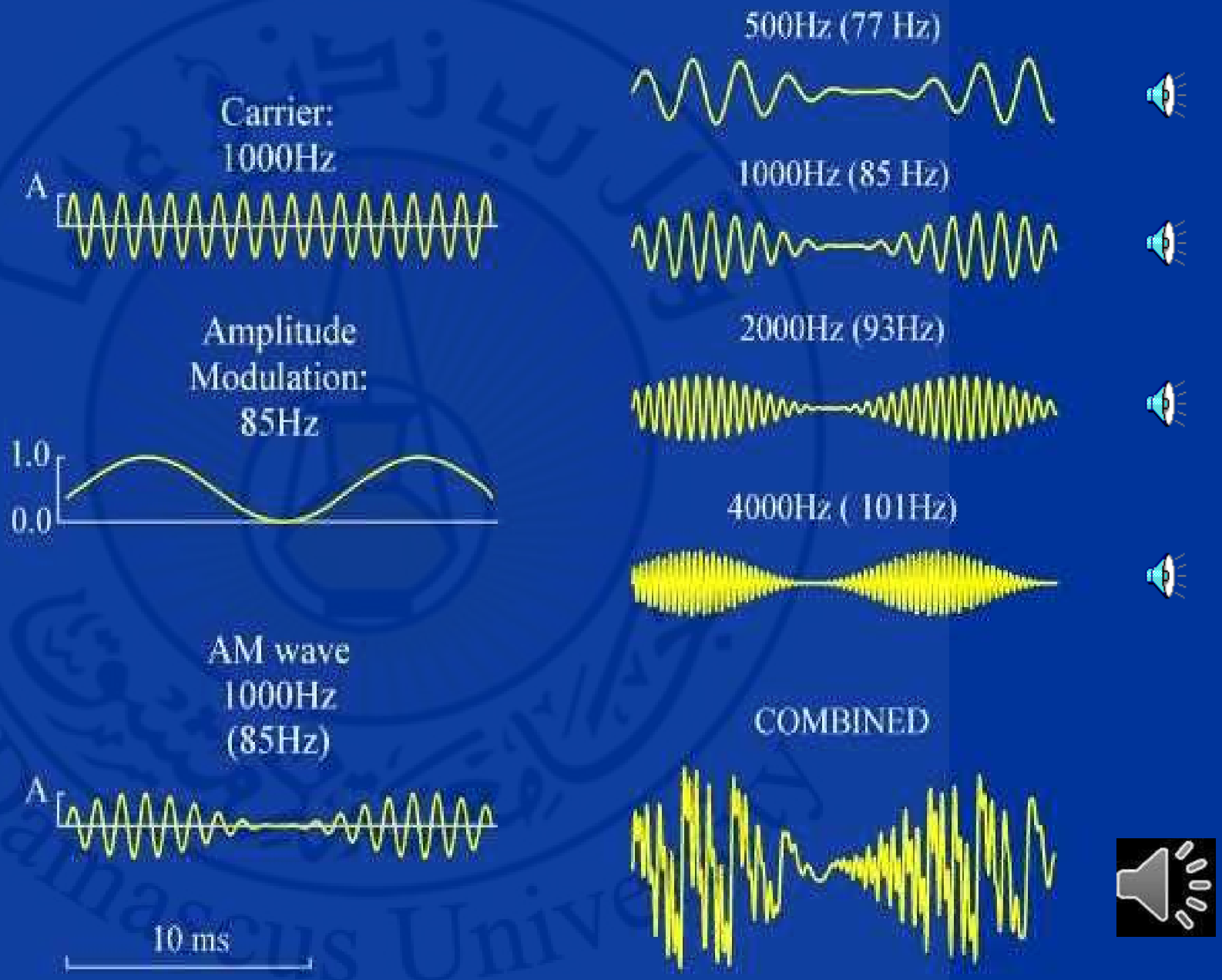


AM & FM (Mixed) Modulation

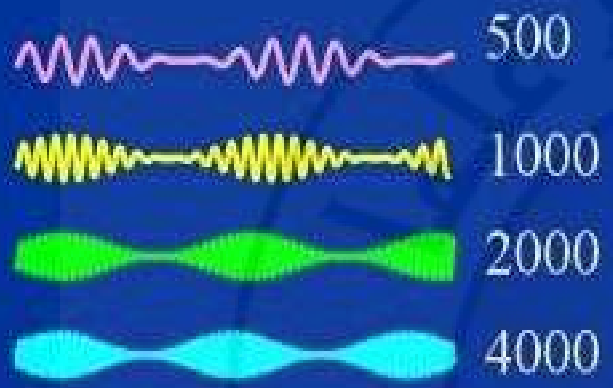
- Some manufacturers offer a 20% to 25% frequency modulation (FM), which, combined with AM, typically enhances the response as compared to AM-only.



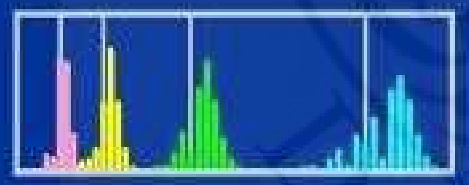
Some ASSR systems are capable of simultaneous, multiple-frequency binaural stimulation.

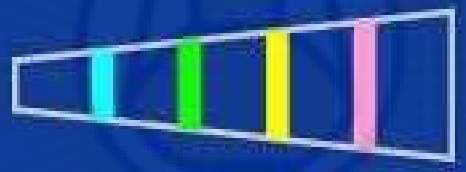


Four stimuli presented simultaneously to one ear









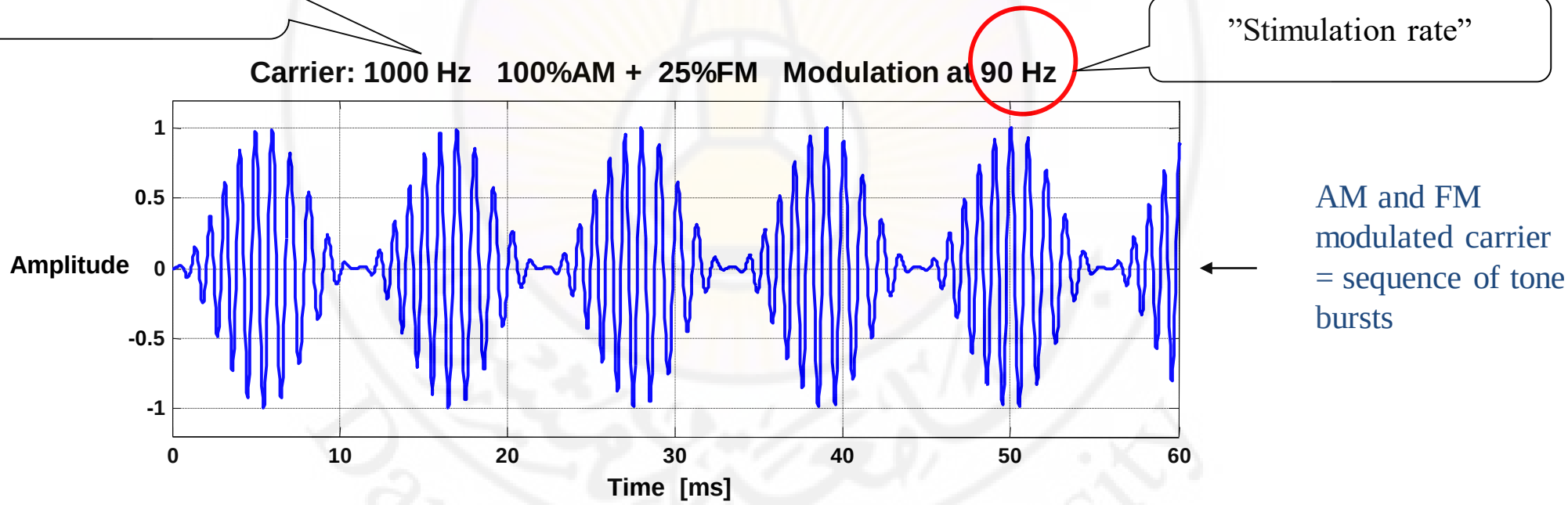


Sound Cochlea Brain

The Normal ASSR Stimulus

The Audiogram Point

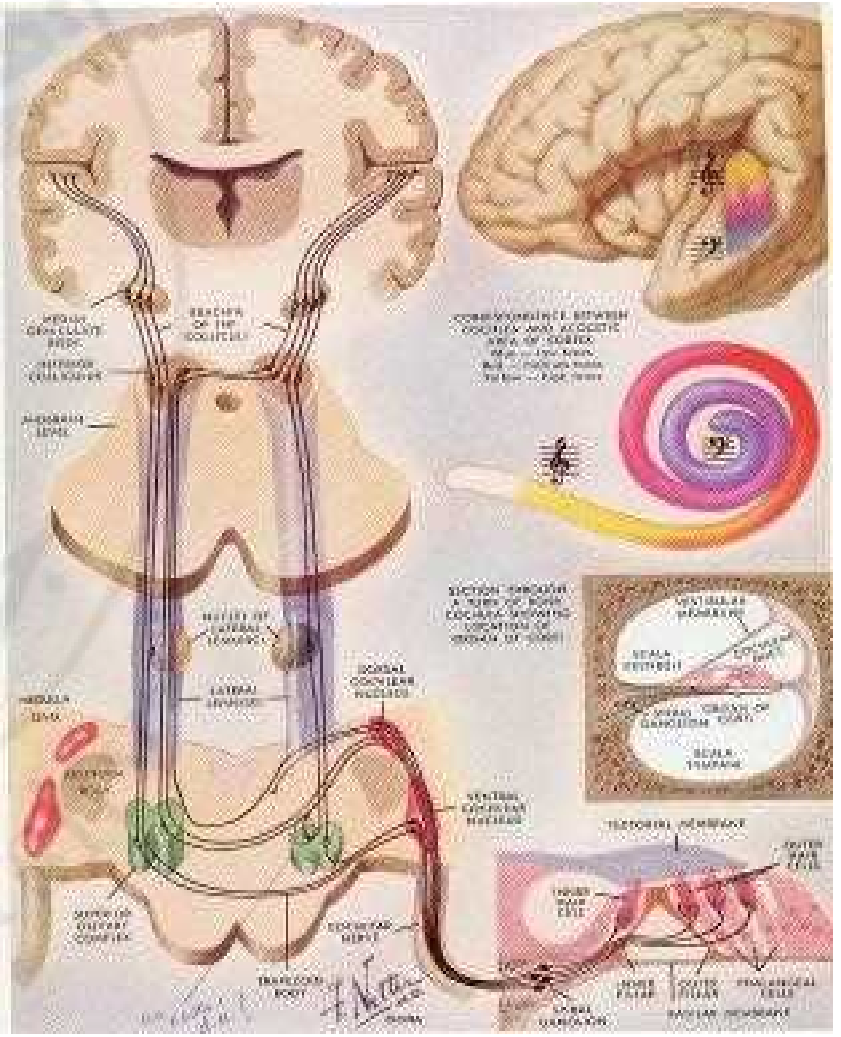
”Stimulation rate”



AM and FM modulated carrier = sequence of tone bursts

Modulation Rates vs. Neural Generators

- ASSR has multiple generators, although the contributions of the generators vary with MF.
- **Lower frequency modulation** rates may be used (i.e., MFs <40 Hz) but do include components of the middle latency response (MLR) and are therefore influenced by test subject conditions.
- **Higher modulation rates** (i.e., MFs >80 Hz) generate bioelectrical responses derived from the brainstem (like ABR) and are, therefore, less susceptible to patient state (although the contribution of cortical generators is still present).



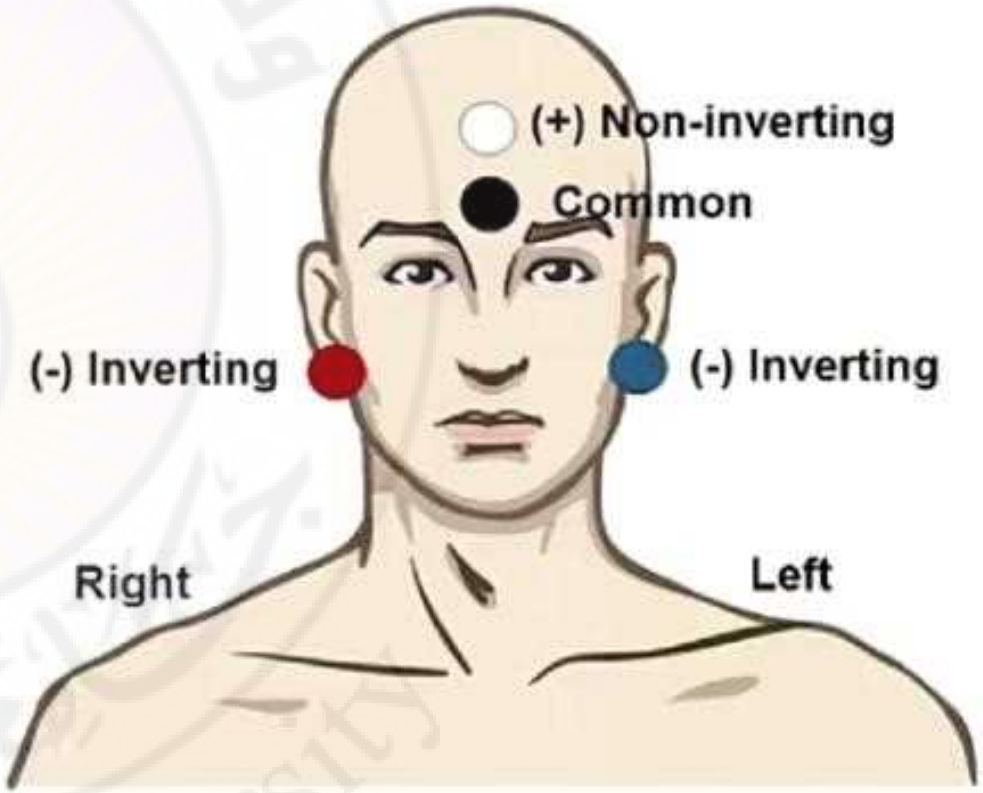
ASSR & Age

- ASSR threshold decreases (improve) with age during **infancy**.
- The 40-Hz ASSR does not change significantly with increasing age in **adulthood**, although even slight-mild hearing loss among older adults may be a confounding variable.
- Larger amplitudes for the ASSR have been found among the **elderly** who have hearing levels at the “lower” end of normal (e.g., 20 to 25 dB HL), likely because of a recruitment-like phenomenon.



Electrode Montage

- Electrode placement for ASSR is often the same or similar to traditional recording montages used for ABR recordings.
- If the instrument is collecting data simultaneously from both ears, a **two-channel preamplifier** is used to benefit from the binaural electrode montage.



- Best electrode montage may be differ in various instruments. Refer to the user manual of your instrument!

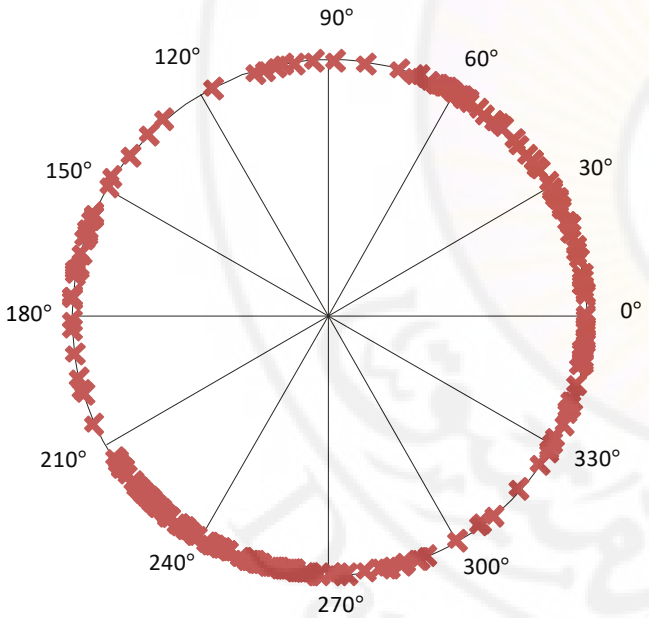
ASSR Analysis & Detection Methods

- ASSR analysis is based on the fact that related bioelectric events coincide with the stimulus repetition rate. Therefore, ASSR analysis is **mathematically based**.
- *The specific method of analysis will be dependent on the manufacturer's statistical detection algorithm.*
- ASSR analysis occurs in the spectral (i.e., frequency) domain and is composed of specific frequency components that are harmonics of the stimulus repetition rate.

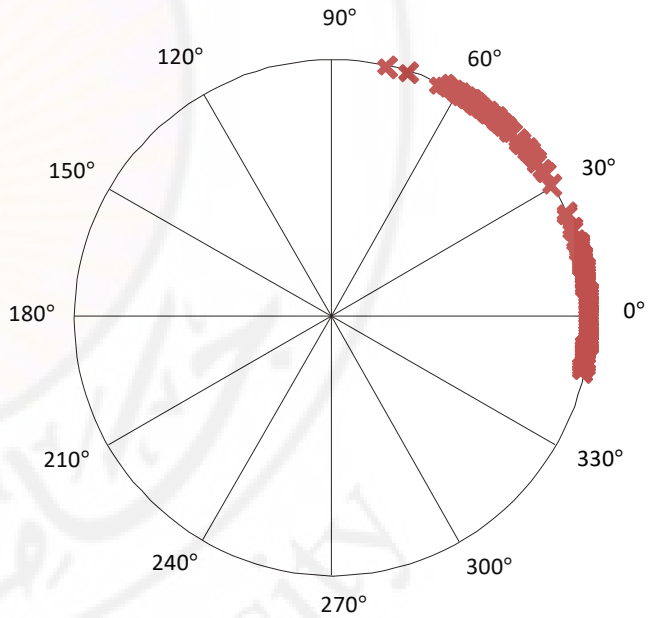


Phase Coherence

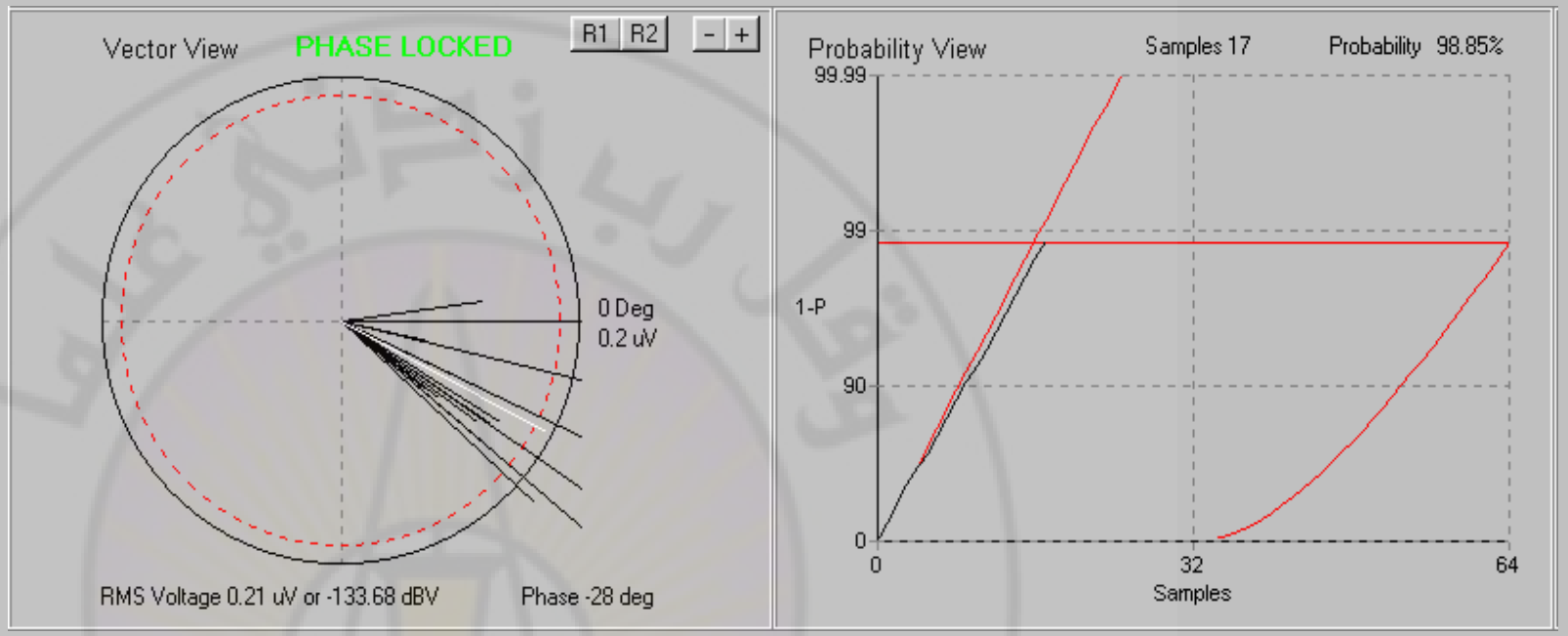
No response

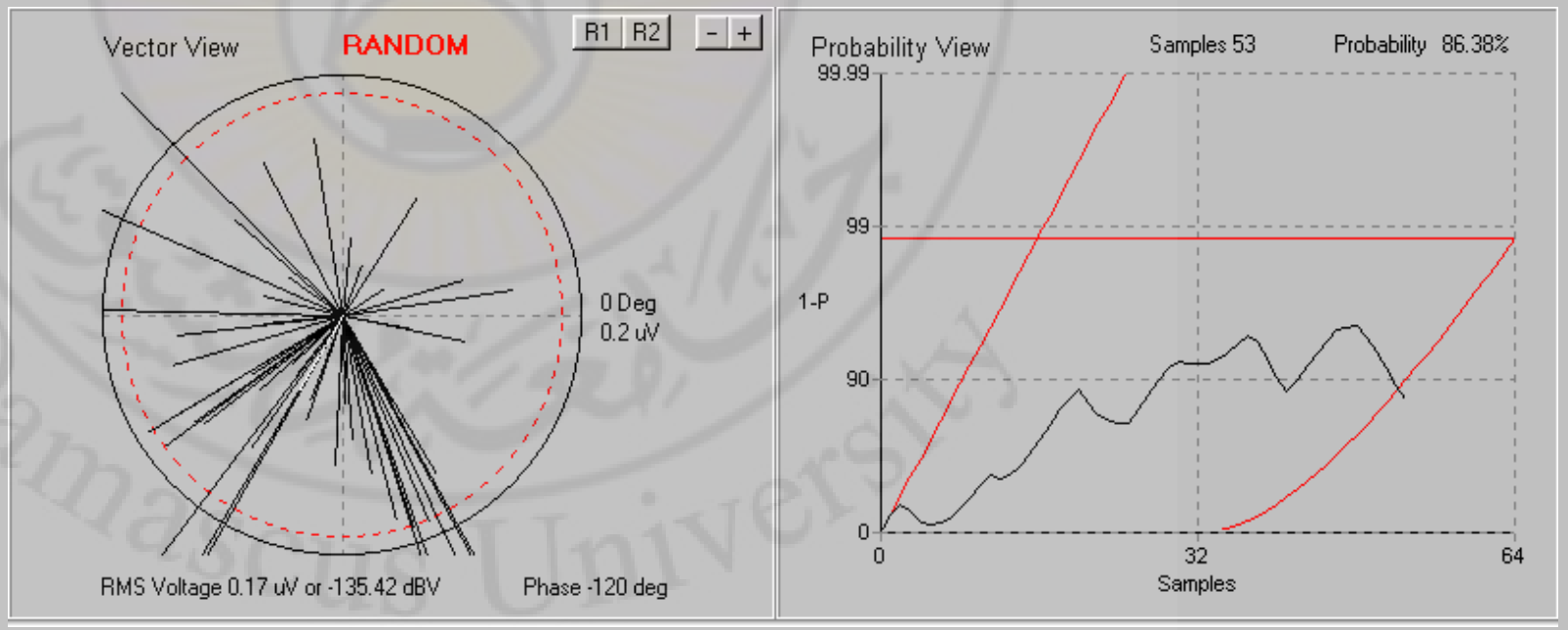


With response

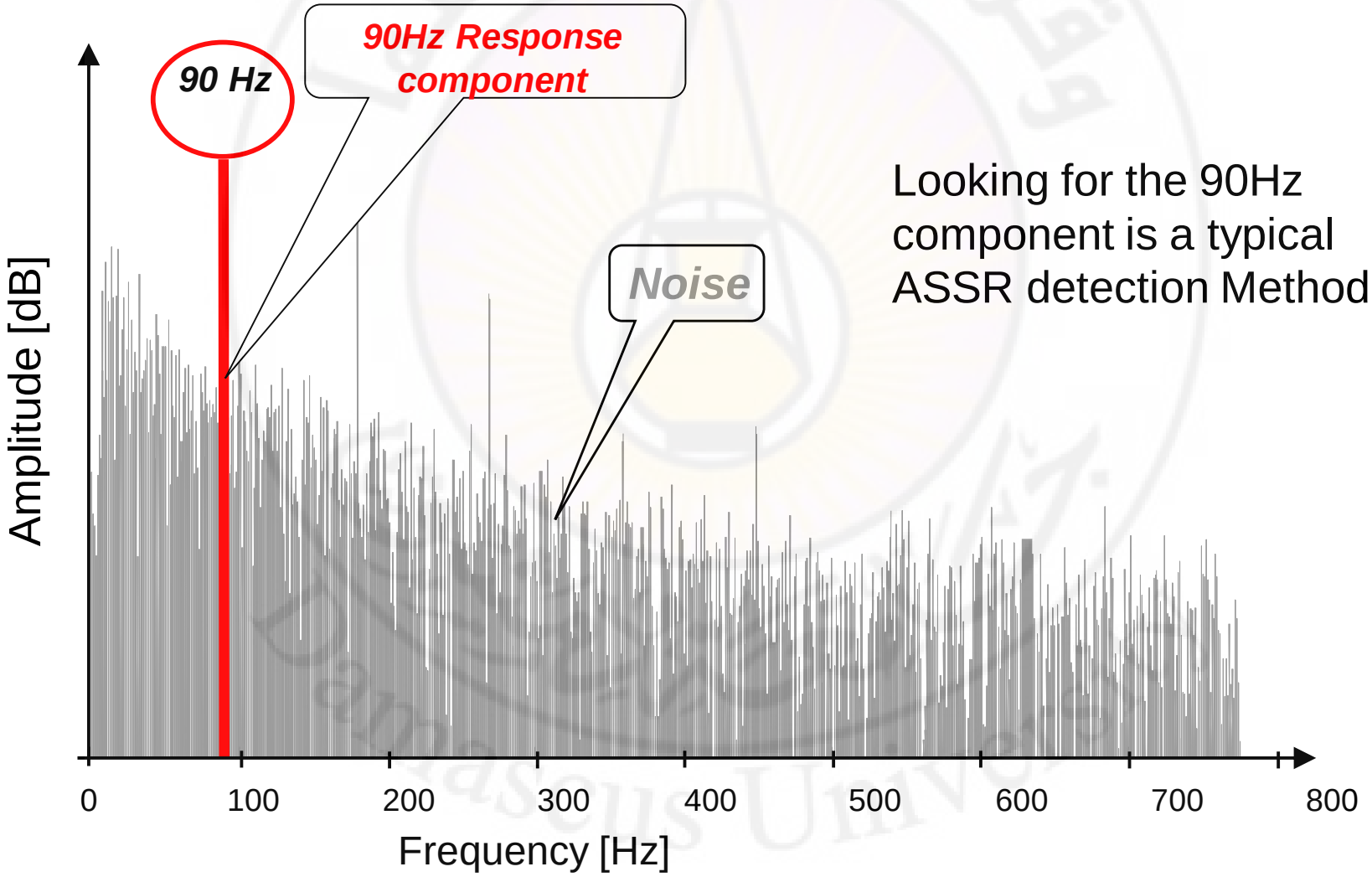


Phase Coherence



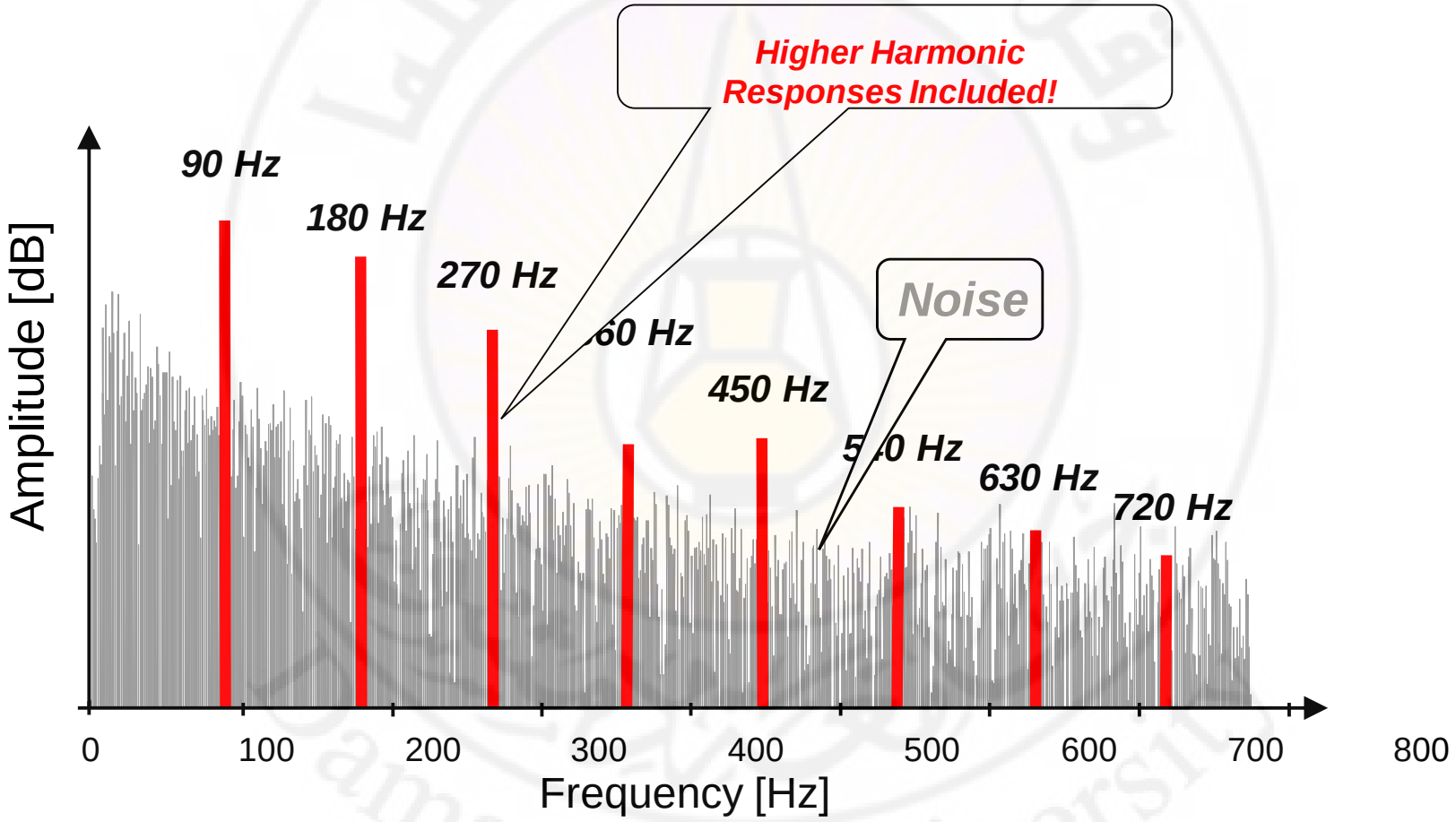


Amplitude Spectrum of a 90Hz ASSR Response



Looking for the 90Hz component is a typical ASSR detection Method

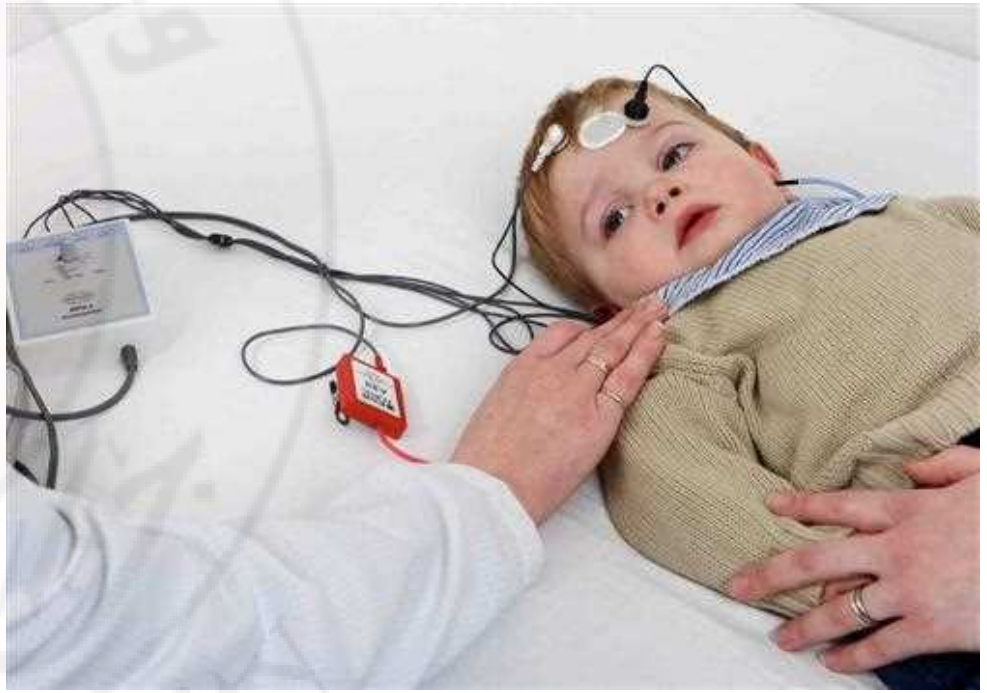
Full Spectrum Detection Engine



Early ASSR systems considered the first harmonic only, whereas newer systems also incorporate higher harmonics in their detection algorithms.

Acquisition parameters

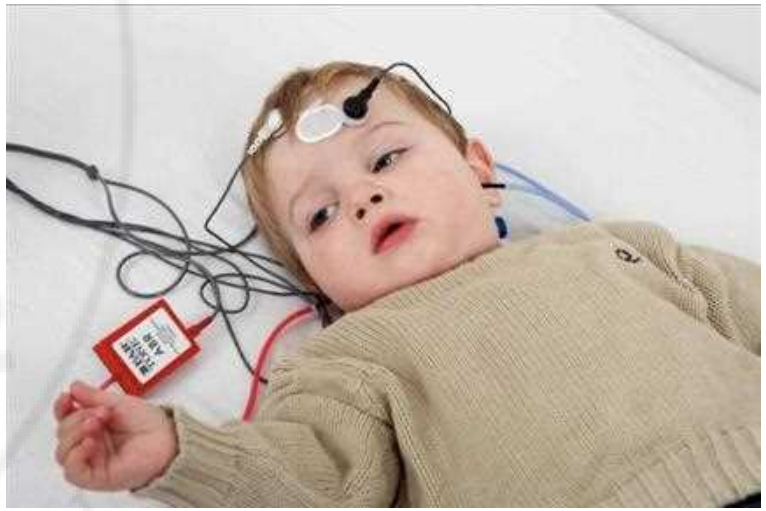
- ASSR **filter settings** are not like ABR settings. For ASSR, depending on the specific situation, the high pass filter might be approximately 40 Hz to 90 Hz, and the low pass filter might be between 320 Hz and 720 Hz. Typical filter slopes are 6 dB per octave.
- **Amplifier Gain** settings of 10,000 are common for ASSR.
- **Artifact rejection** is left “on.”



Damascus University

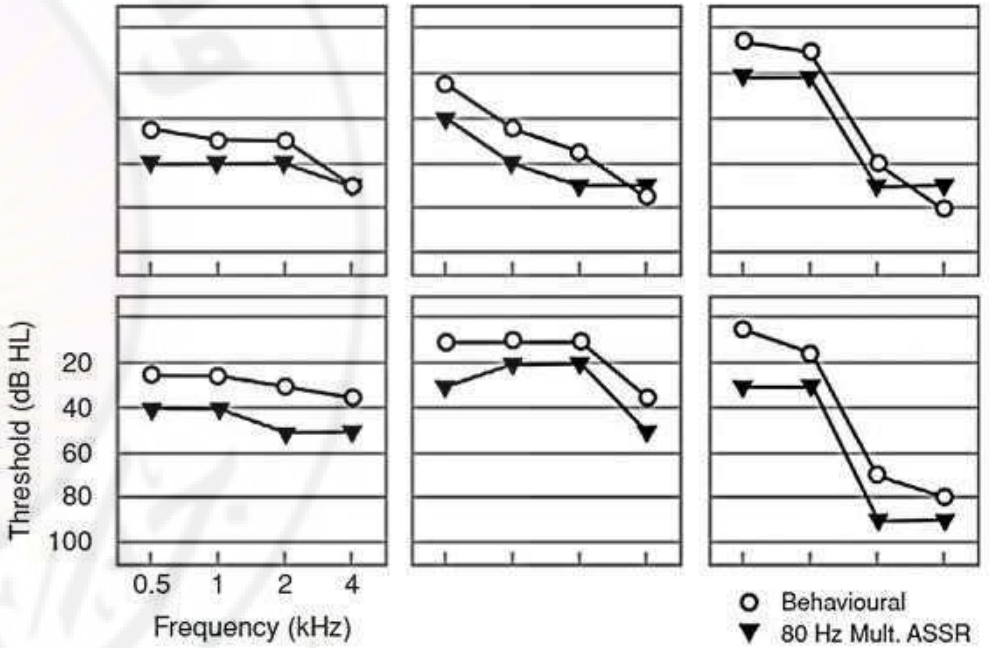
Patient Population

- ASSR can be used to estimate hearing thresholds for those who cannot or will not participate in traditional behavioral measures.
- Therefore, primary candidates for ASSR would include:
  - Newborn infants for screenings and follow-up diagnostic assessments
  - Babies in the neonatal intensive care unit (NICU)
  - Unresponsive and/or comatose patients,
  - People who are suspect due to the nature of their visit (i.e., workers' compensation, legal matters, insurance claims, etc.)
  - Ototoxicity monitoring
  - and others…



Audiogram Prediction by ASSR

- A driving concept in ASSR research is the objective determination of the puretone audiogram.
- The goal of **objectivity** should be met in three ways.
  - First, the threshold determination is based on a physiological response, not on a subjective perception of the subject.
  - Second, the presence of a response is determined by the use of statistical tests, or “objective” detection algorithms.
  - Third, the interpretation of the results is also bound by objective methods and decision-making rules.



A variety of audiometric configuration can be estimated using ASSRs.

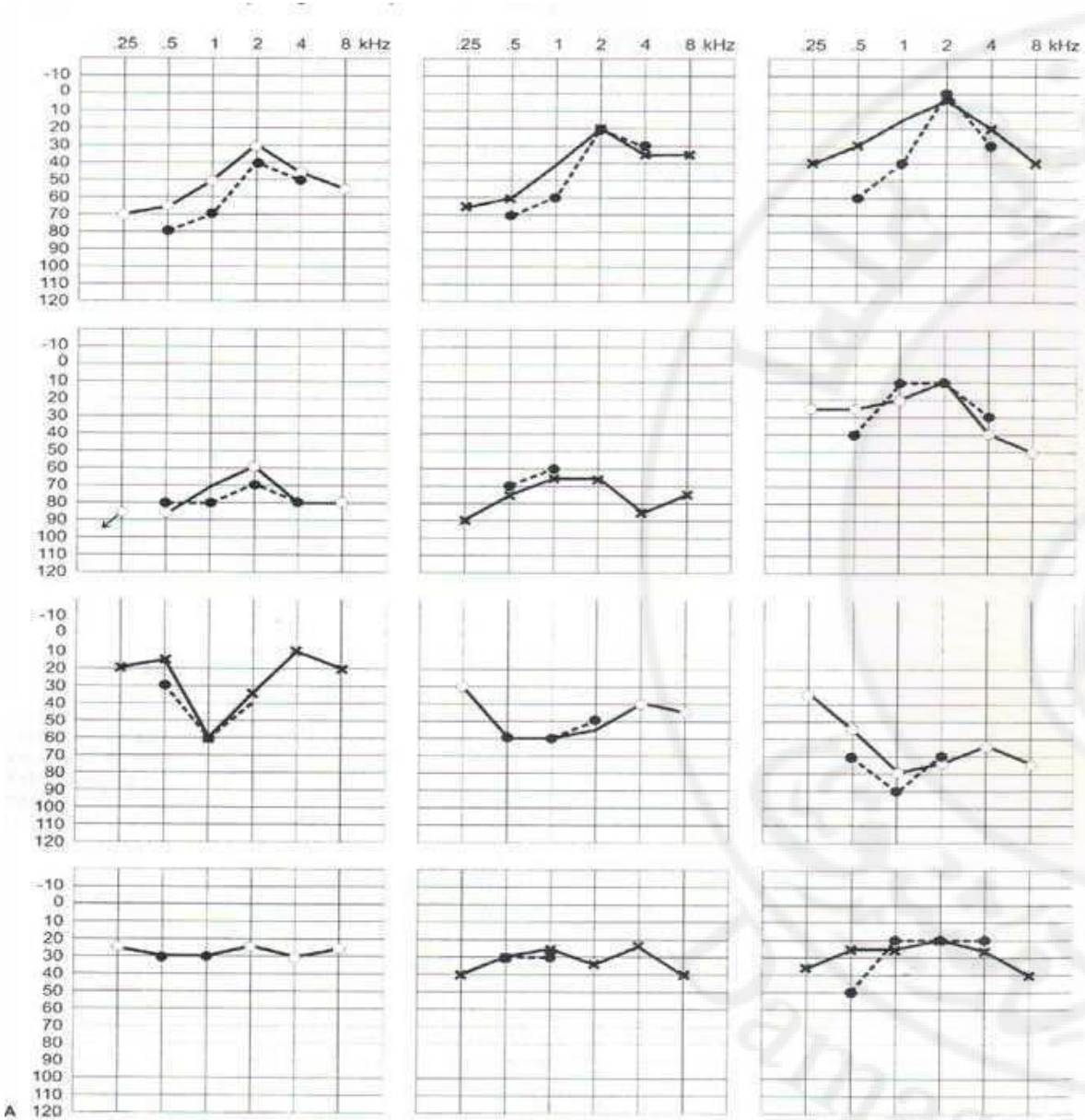


FIGURE 15.8 Auditory steady-state response (ASSR) results from Aoyagi et al. (1999). ASSR thresholds provide excellent estimates of puretone thresholds for both **(A)** low- and **(B)** high-frequency sloping audiometric configurations.

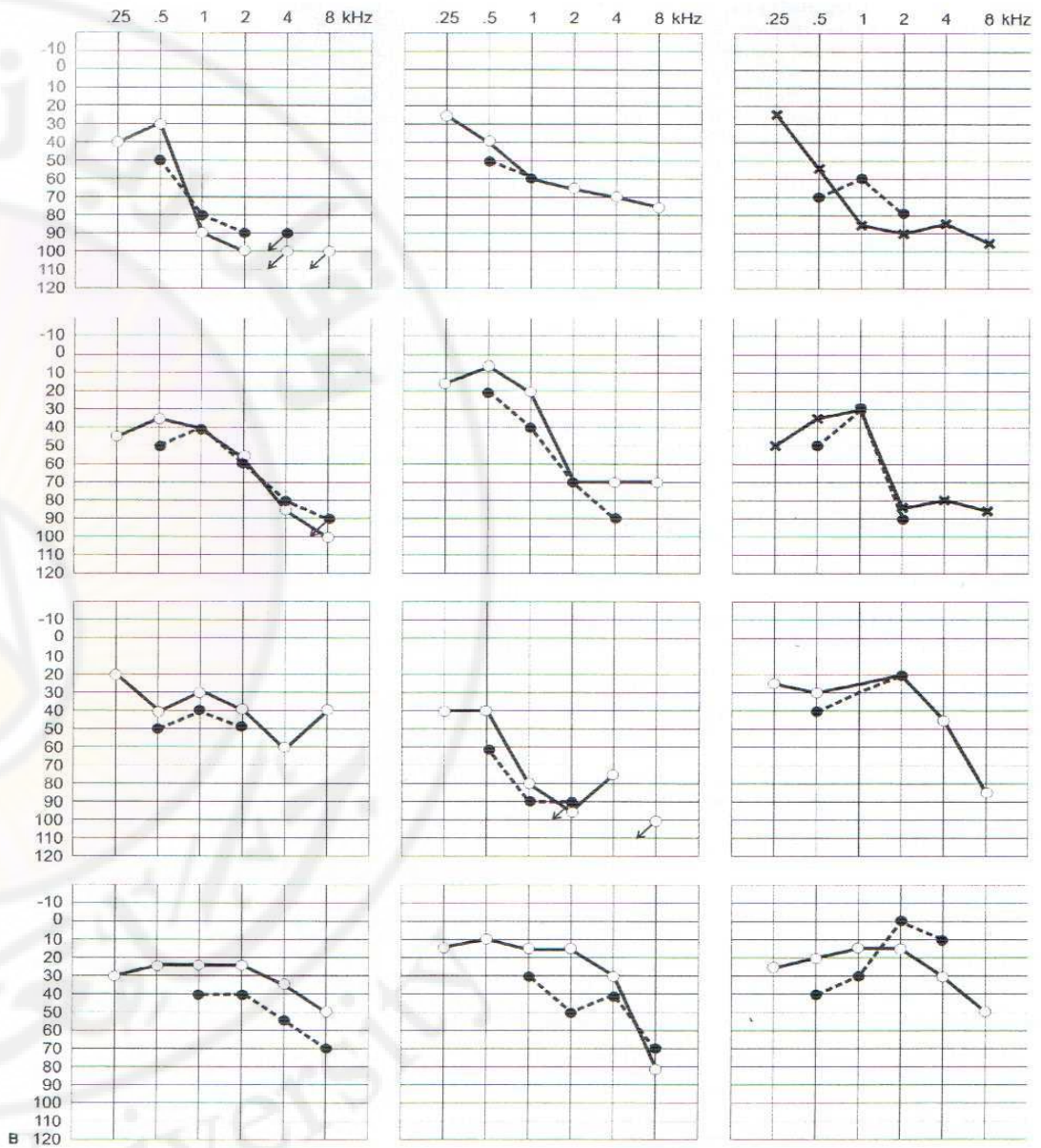
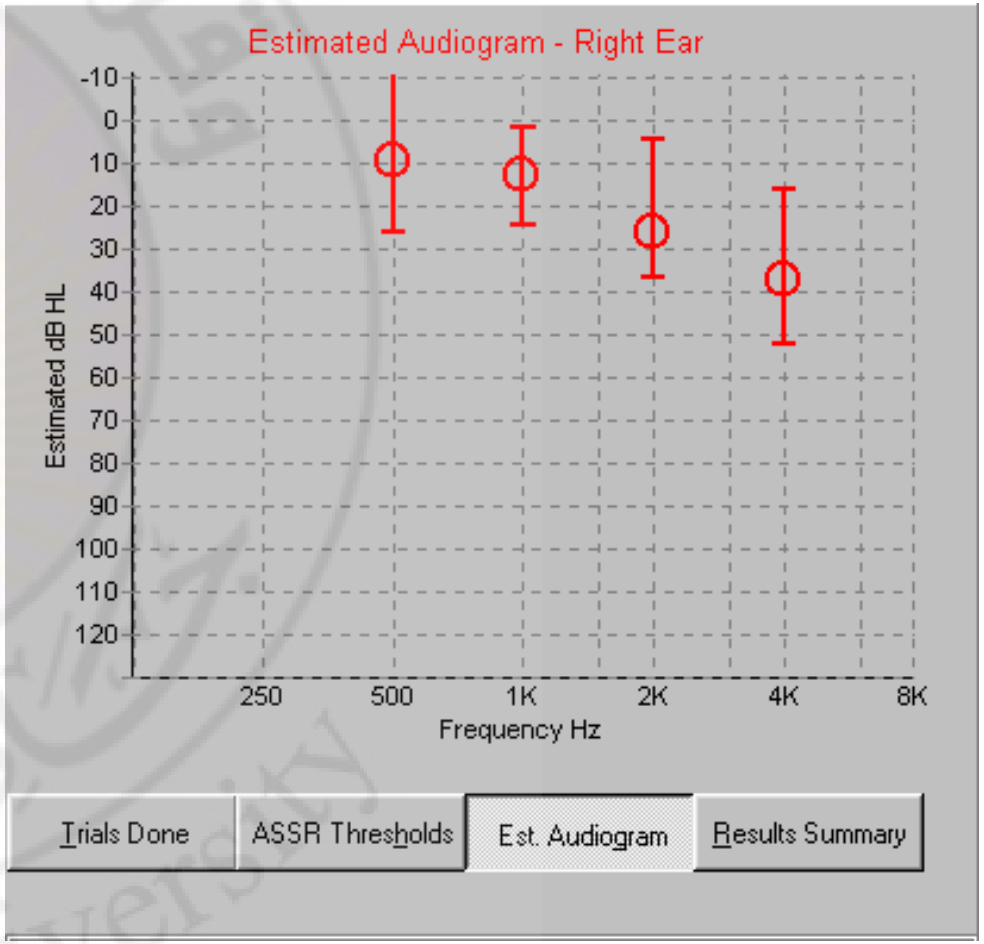


FIGURE 15.8 (*Continued*)

ASSR Normative Data

- ASSR thresholds are within 10 dB to 15 dB of audiometric thresholds. There are variances across studies, and actual correction data depends on many variables such as: equipment used, frequencies collected, collection time, age of the subject, sleep state of the subject, stimulus parameters used, and more.
- Regardless of the equipment used, the clinician should refer to the data and references provided by the manufacturer when estimating audiograms.



Correction Table

System setup

Auto Tests | General Setup | Report Templates | Correction Factors

Predefined correction templates :

Selected correction: Standard Correction v. 1.00 (Preliminary)

Name of correction:

New... Save Delete... Cancel

ASSR to Audiogram Correction Factors

dB ASSR

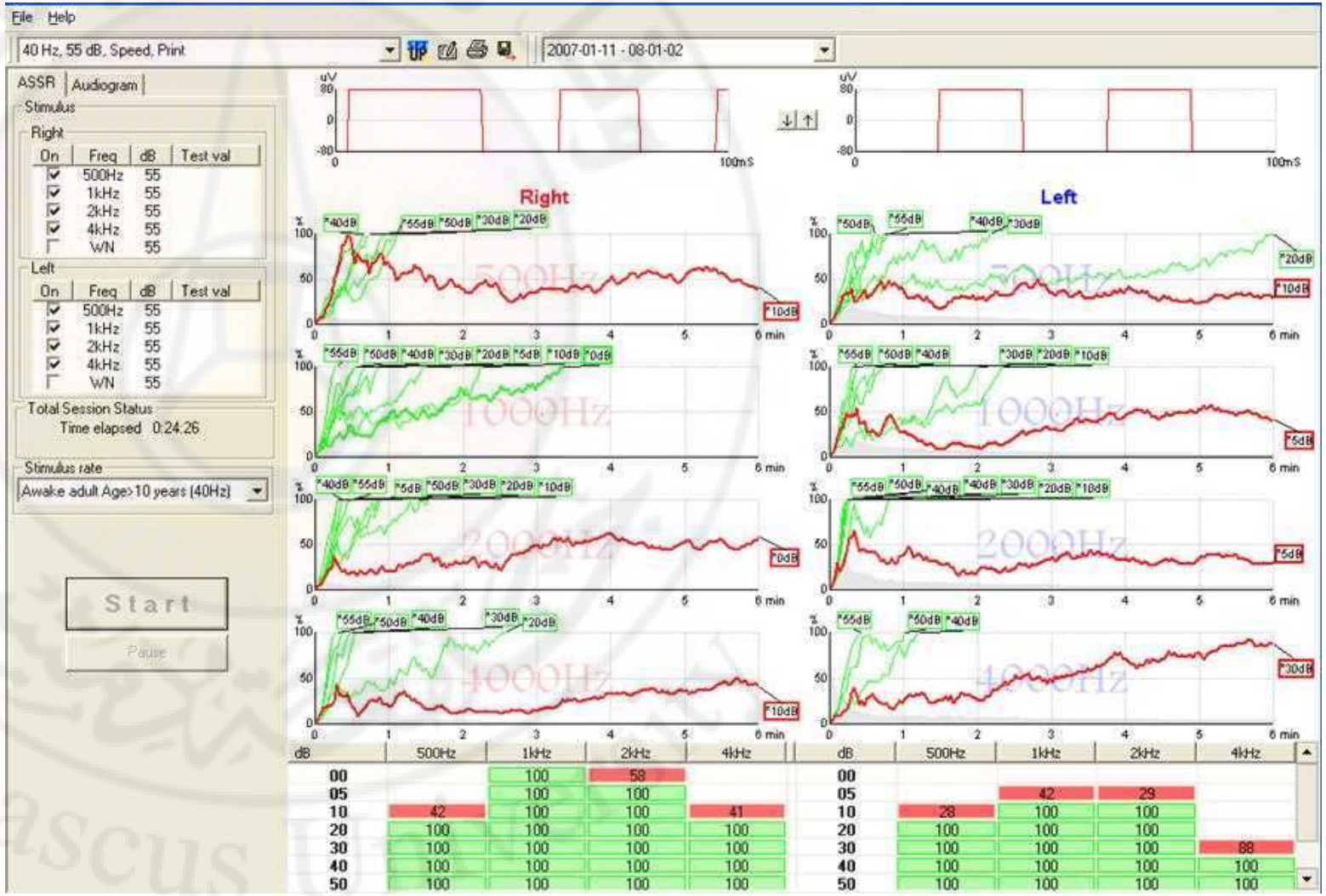
	0/5	10/15	20/25	30/35	40/45	50/55	60/65	70/75	80/85	90/95	100
500Hz	15	15	15	10	10	10	5	5	5	0	0
1kHz	10	10	10	10	5	5	5	5	0	0	0
2kHz	5	5	5	5	5	5	0	0	0	0	0
4kHz	15	15	15	10	10	10	5	5	5	0	0

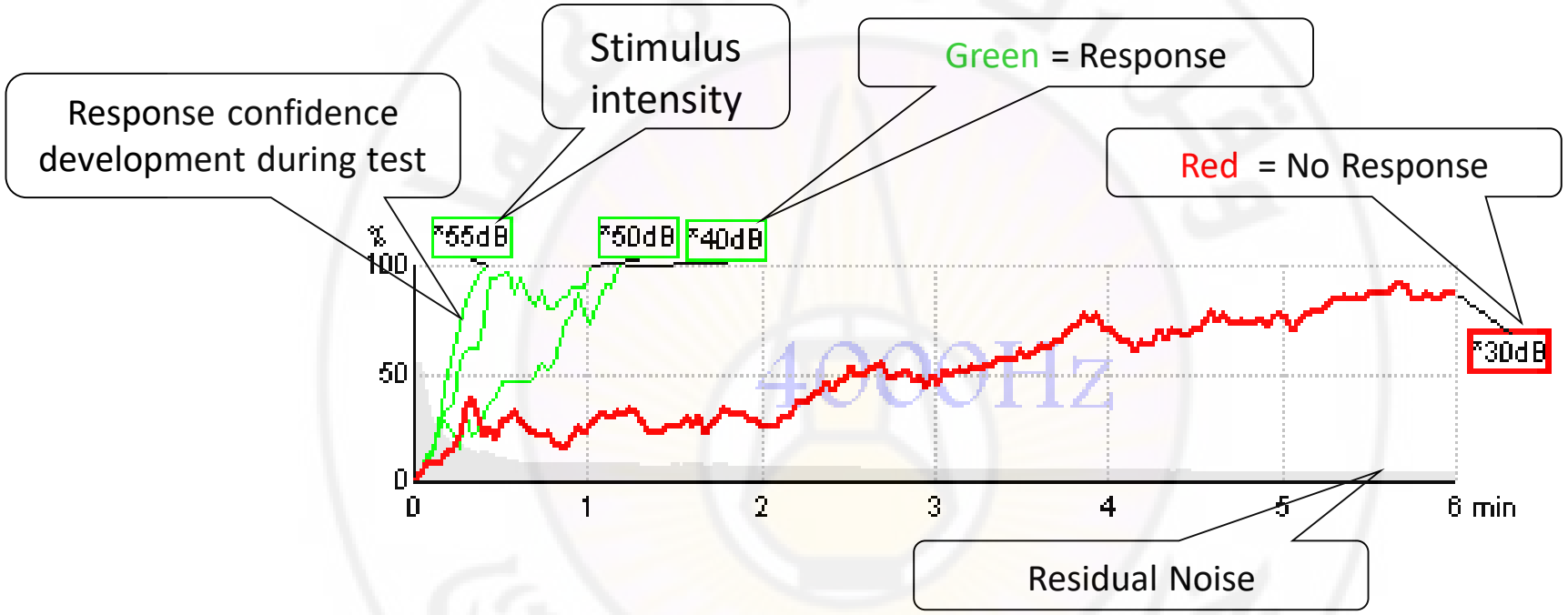
Most ASSR equipment provides correction tables for converting measured ASSR thresholds to estimated HL audiograms.

ASSR Recording

- ASSR is an exciting technology that provides quick and reliable **multiple frequency**, **ear-specific** hearing threshold information.

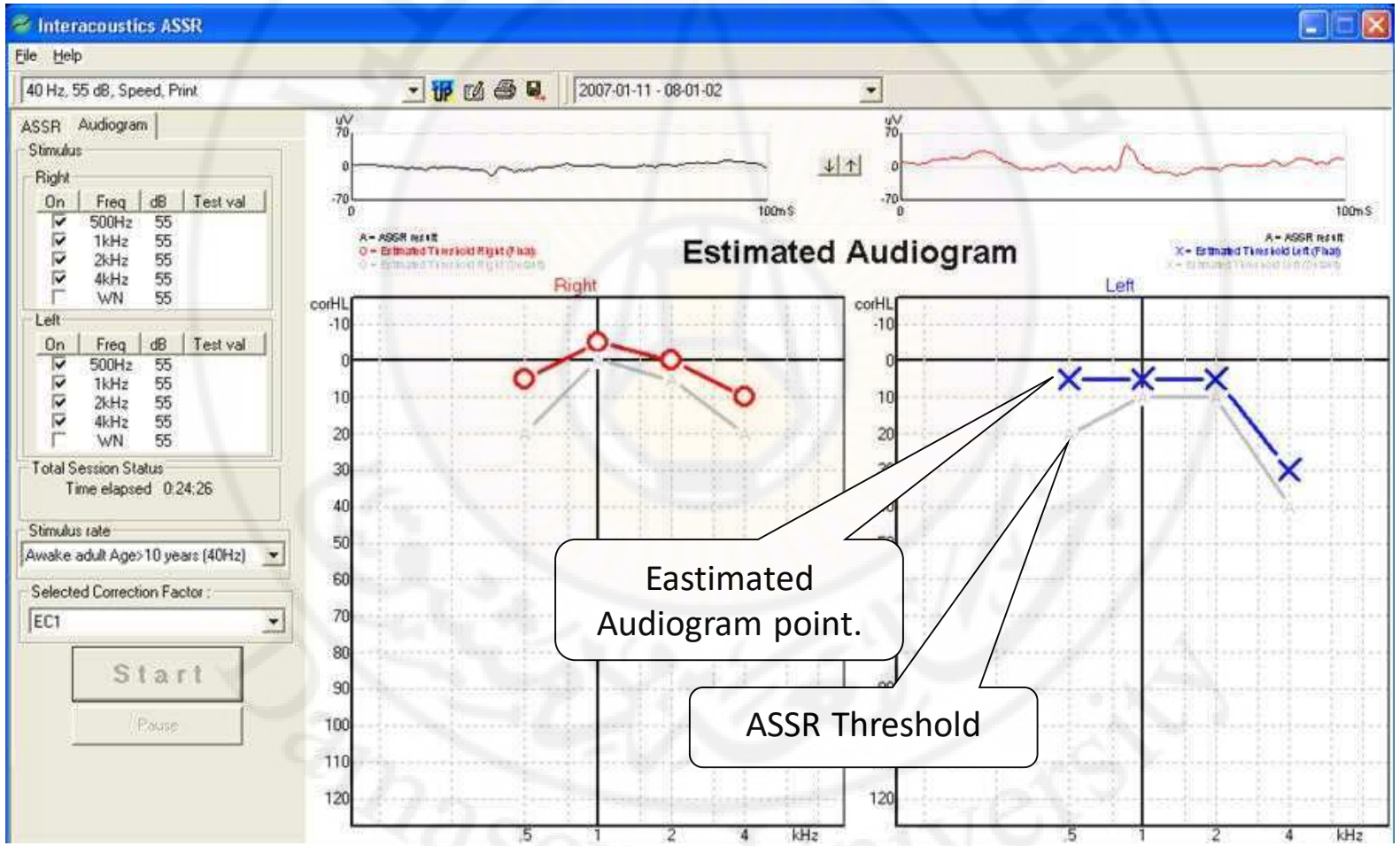
- ASSR continues to “raise the bar” with regard to test speed and accuracy.

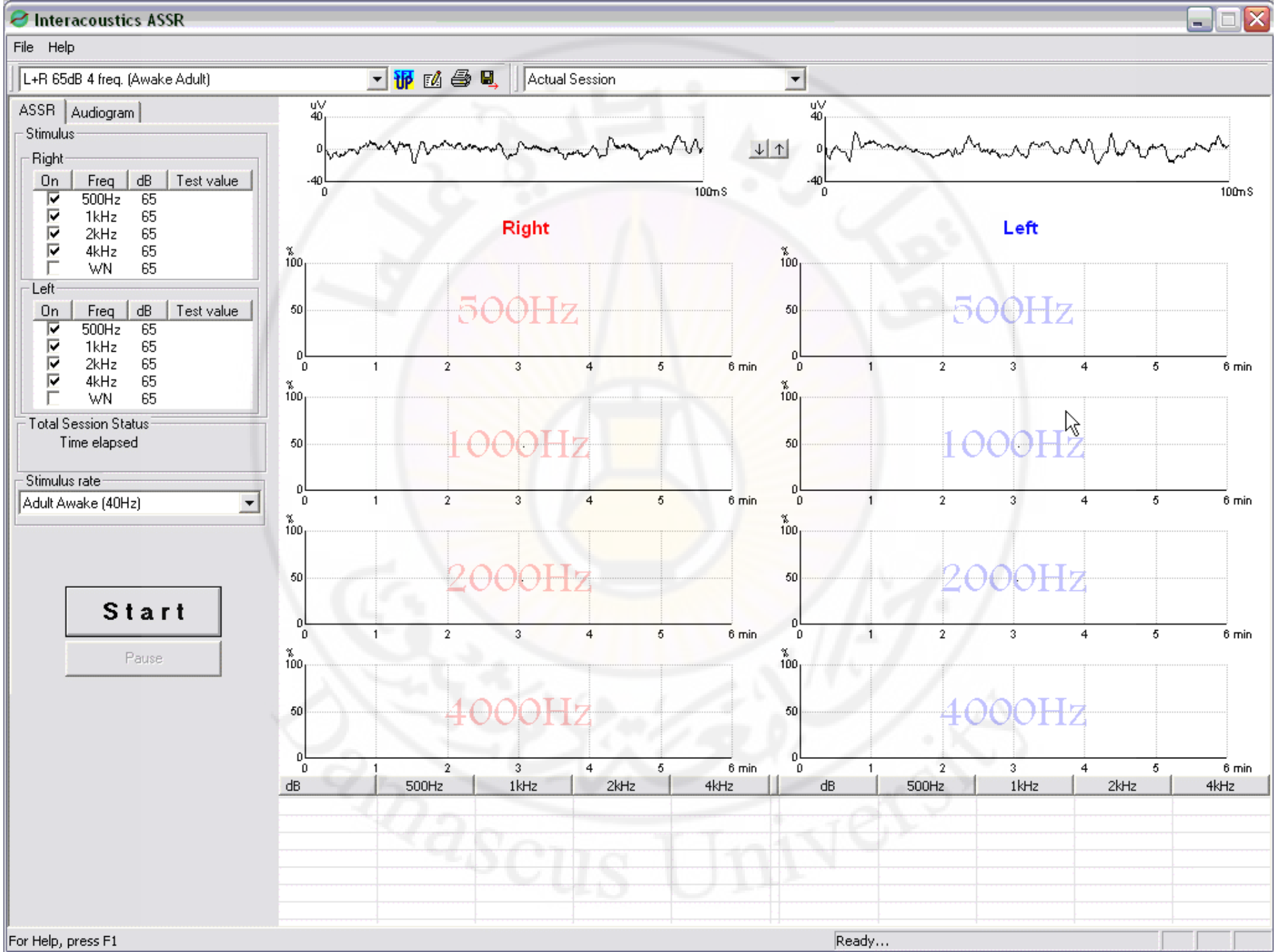


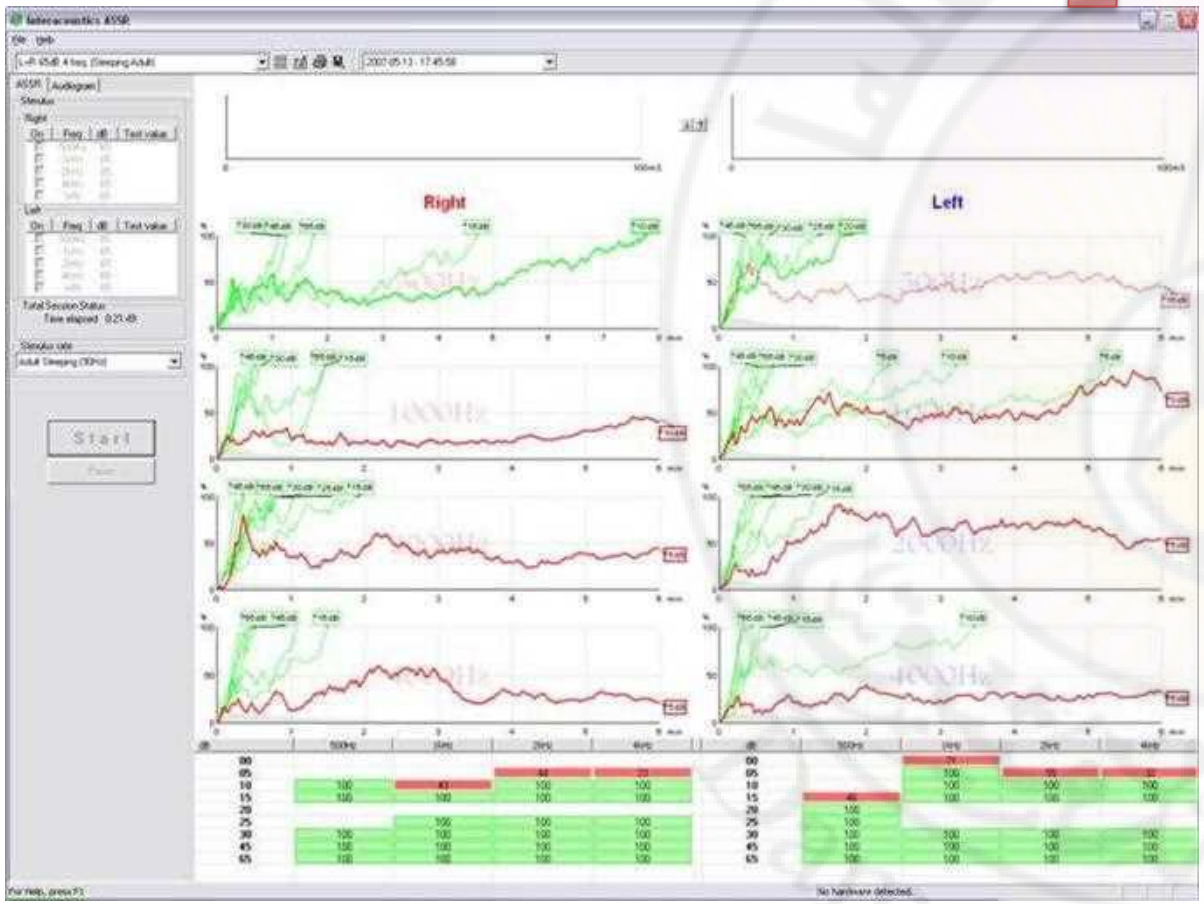


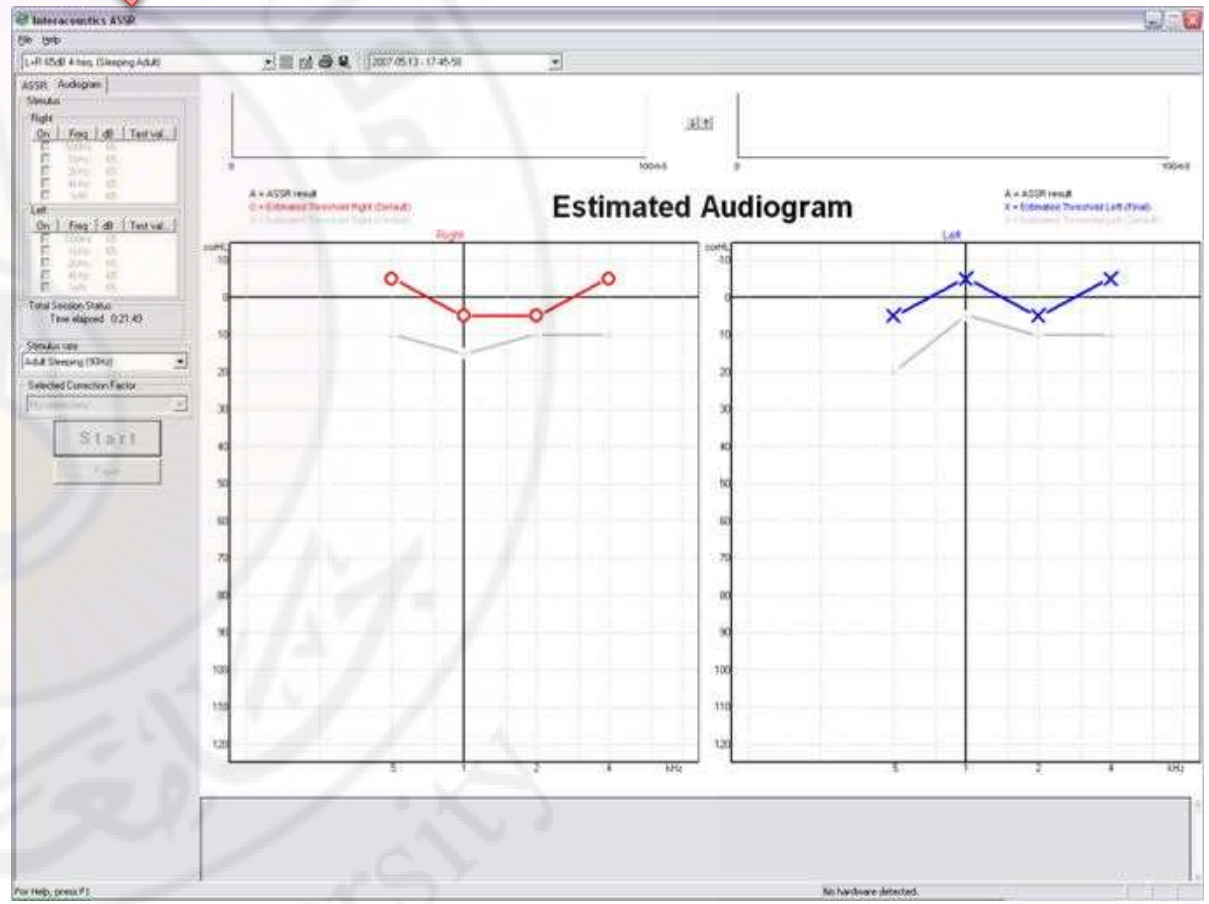
To optimize session strategy decisions as test progresses, the response confidence is tracked over time for each test frequency.

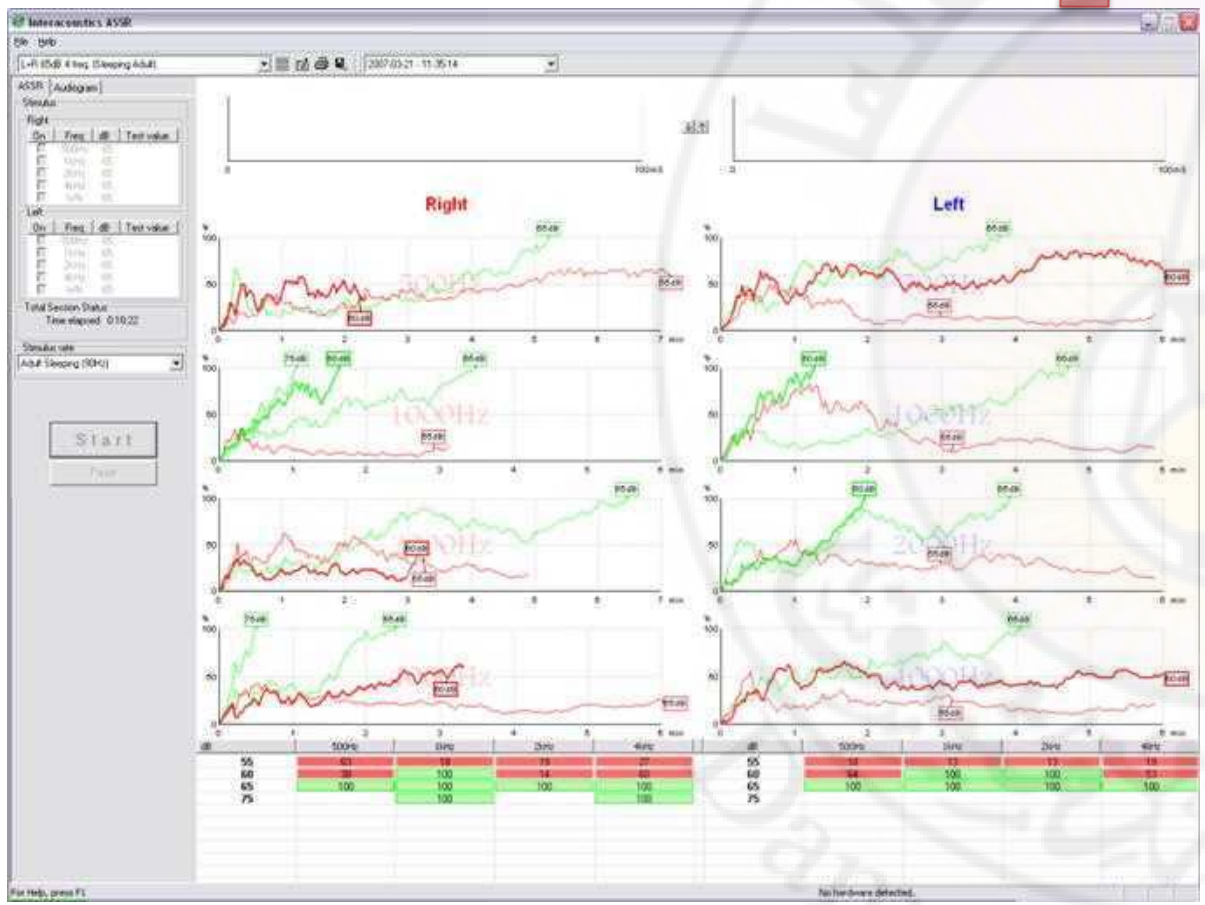
An Estimated Audiogram is Automatically Provided

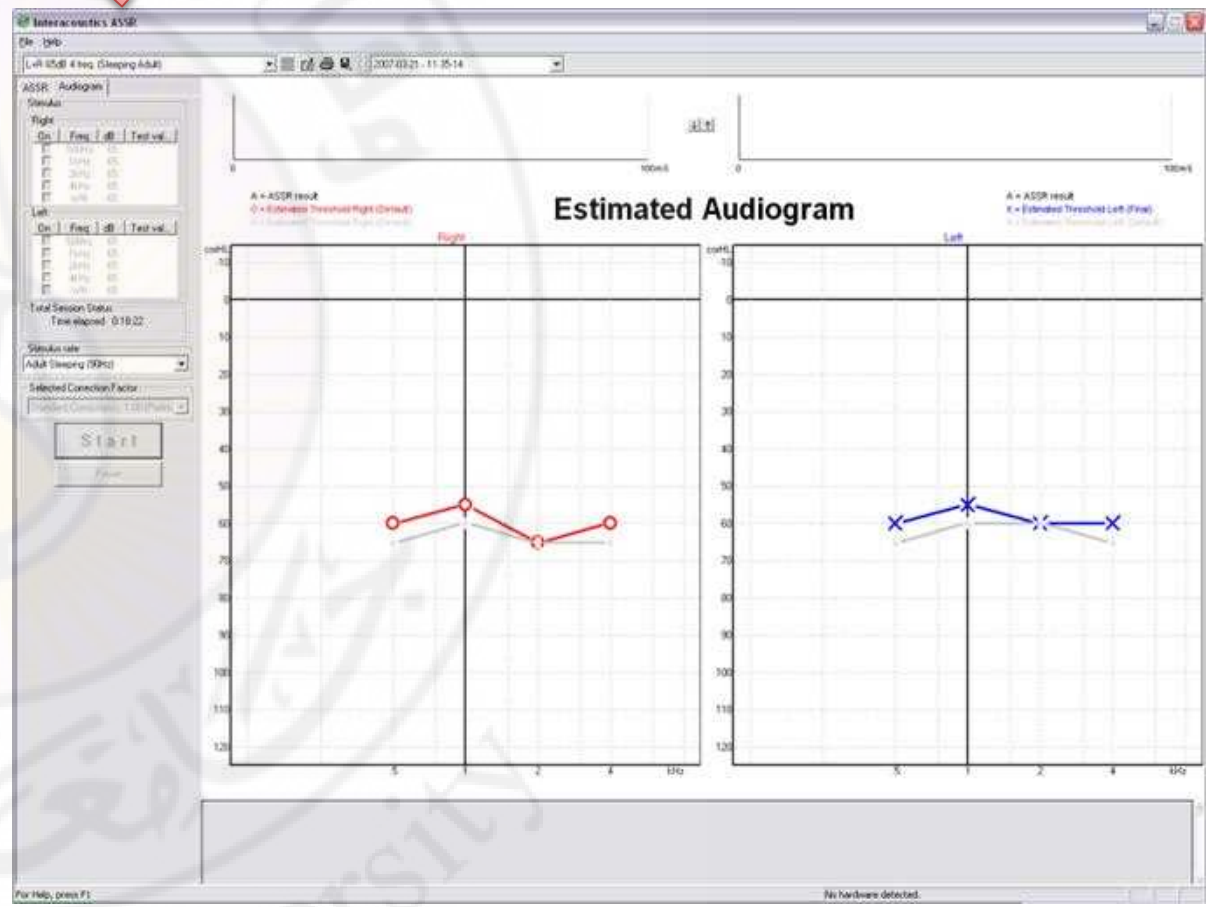



Interacoustics ASSR
File Help
L+R 65dB 4 freq. (Awake Adult)
Actual Session
ASSR
Audiogram
Stimulus
Right
On Freq dB Test value
500Hz 65
1kHz 65
2kHz 65
4kHz 65
WN 65
Left
On Freq dB Test value
500Hz 65
1kHz 65
2kHz 65
4kHz 65
WN 65
Total Session Status
Time elapsed
Stimulus rate
Adult Awake (40Hz)
Start
Pause
uV
40
0
-40
100mS
Right
Left
500Hz
1000Hz
2000Hz
4000Hz
%
100
50
0
1 2 3 4 5 6 min
dB 500Hz 1kHz 2kHz 4kHz
For Help, press F1
Ready...


Right
Left


Estimated Audiogram
Right
Left

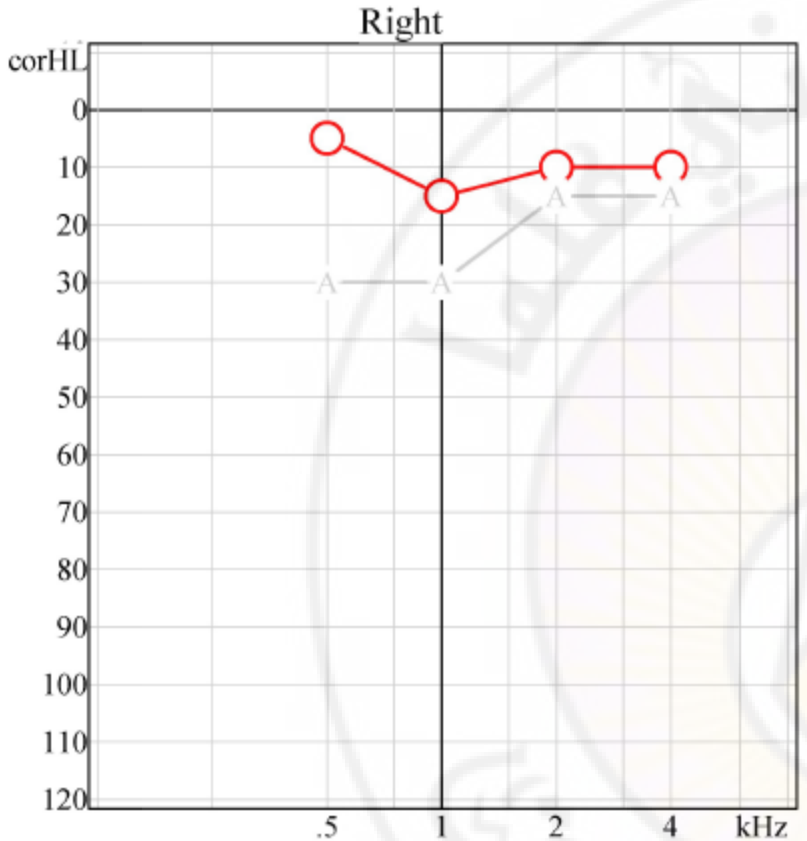

Right
Left
Start


Estimated Audiogram
Right
Left
Start

ASSR Threshold–Behavioral Hearing Threshold Difference, in Adults, Children, and Infants with Hearing Loss

Study	Subjects	Stimulus	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz
Van der Werff and Brown [2005] [flat loss]	10	MM	11 ± 5	8 ± 4	7 ± 5	6 ± 5
Van der Werff and Brown [2005] [sloping loss]	10	MM	18 ± 8	10 ± 7	8 ± 6	5 ± 4
Picton et al. [2005]	10	MM	11 ± 18	−4 ± 9	2.5 ± 11	5 ± 12
Luts and Wouters [2005] ["Master"]	10	MM	17 ± 12	12 ± 8	17 ± 8	19 ± 12
Luts and Wouters [2005] ["Audera"]	10	MM	20 ± 8	14 ± 7	13 ± 7	14 ± 13
Herdman and Stapells [2003]	29	AM	14 ± 13	8 ± 9	10 ± 10	3 ± 10
Dimitrijevic et al. [2002]	31	MM	13 ± 11	5 ± 8	5 ± 9	8 ± 11
Rance and Briggs [2002]	184	MM	6 ± 9	6 ± 7	4 ± 8	3 ± 11
Van Maanen and Stapells [2005]	23	MM	17 ± 11	15 ± 7	19 ± 9	4 ± 10
D'haenens et al. [2009]	21, 18, 13, 4 [mild]	MM	14 ± 11	13 ± 8	14 ± 7	13 ± 6
	11, 15, 20, 27 [mild]	MM	14 ± 7	10 ± 10	9 ± 6	11 ± 9
Lin et al. [2009]	142	AM	17 ± 14	15 ± 9	14 ± 8	11 ± 87
Ishida et al. [2011][a]	13 [flat]	MM	6 ± 12	4 ± 13	3 ± 13	2 ± 11
	10 [gradual slope]	MM	18 ± 8	7 ± 10	4 ± 13	0 ± 9
	15 [steep slope]	MM	25 ± 13	16 ± 11	11 ± 12	2 ± 10

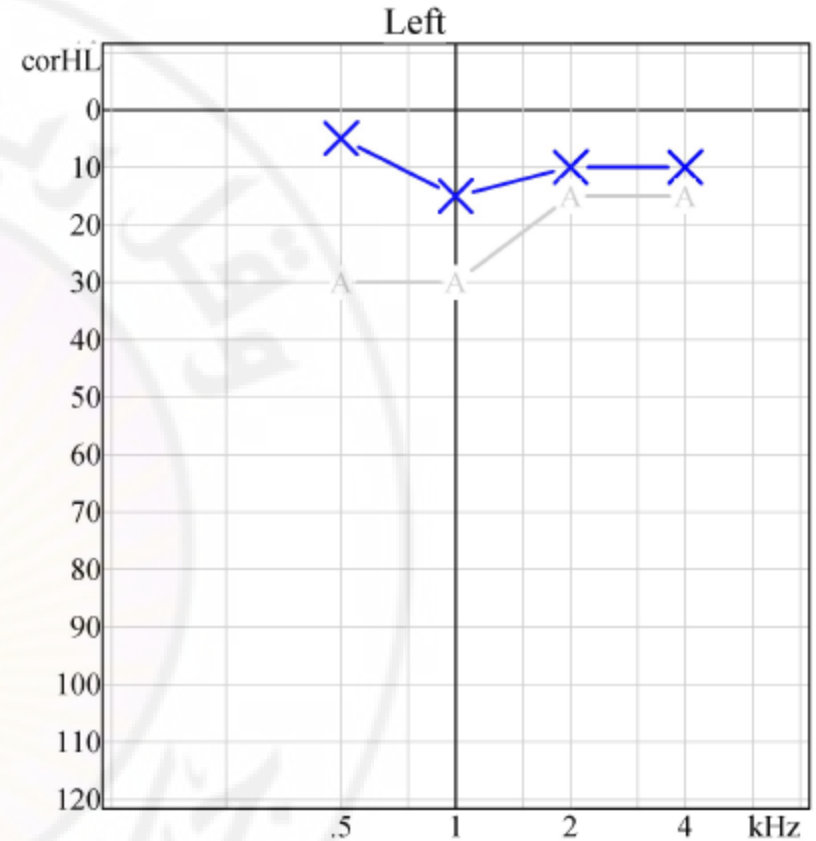
It is a general opinion that ASSR-based hearing diagnostics has **inaccurate** threshold estimation in subjects with normal hearing or mild hearing losses.



Correction Factor :Child (90Hz) Insert phone - v. 2.1

Right (Insert phone)

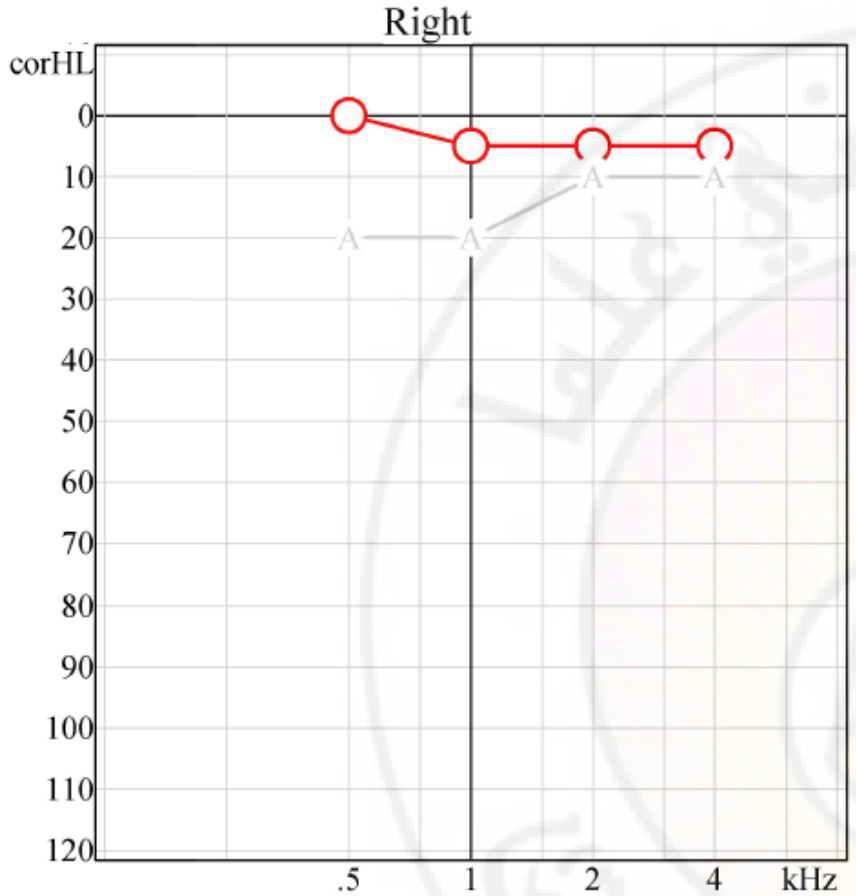
dB	500Hz	1000Hz	2000Hz	4000Hz
15		44% 18nV	100% 21nV	100% 42nV
20	37% 27nV			
30	100% 52nV	100% 67nV	100% 111nV	100% 93nV
50	100% 63nV	100% 68nV	100% 116nV	100% 137nV



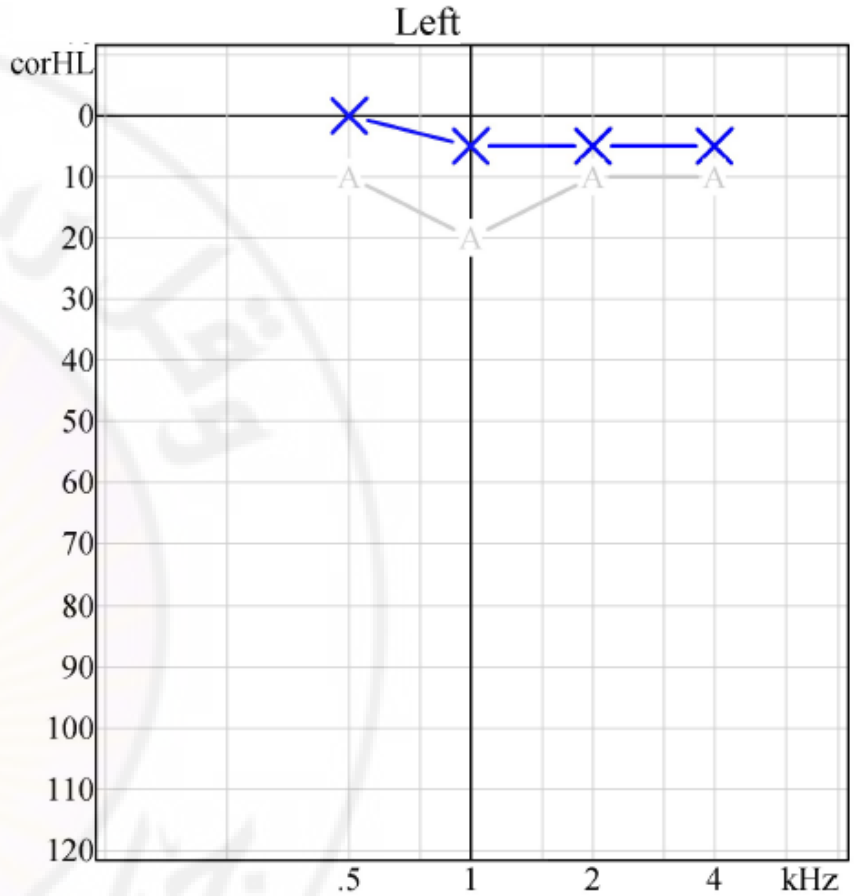
Correction Factor :Child (90Hz) Insert phone - v. 2.1

Left (Insert phone)

dB	500Hz	1000Hz	2000Hz	4000Hz
15		45% 49nV	100% 58nV	100% 75nV
20		25% 28nV		
30	100% 43nV	100% 95nV	100% 75nV	100% 181nV
50	100% 105nV	100% 128nV	100% 236nV	100% 175nV



Correction Factor :Child (90Hz) Insert phone - v. 2.1



Correction Factor :Child (90Hz) Insert phone - v. 2.1

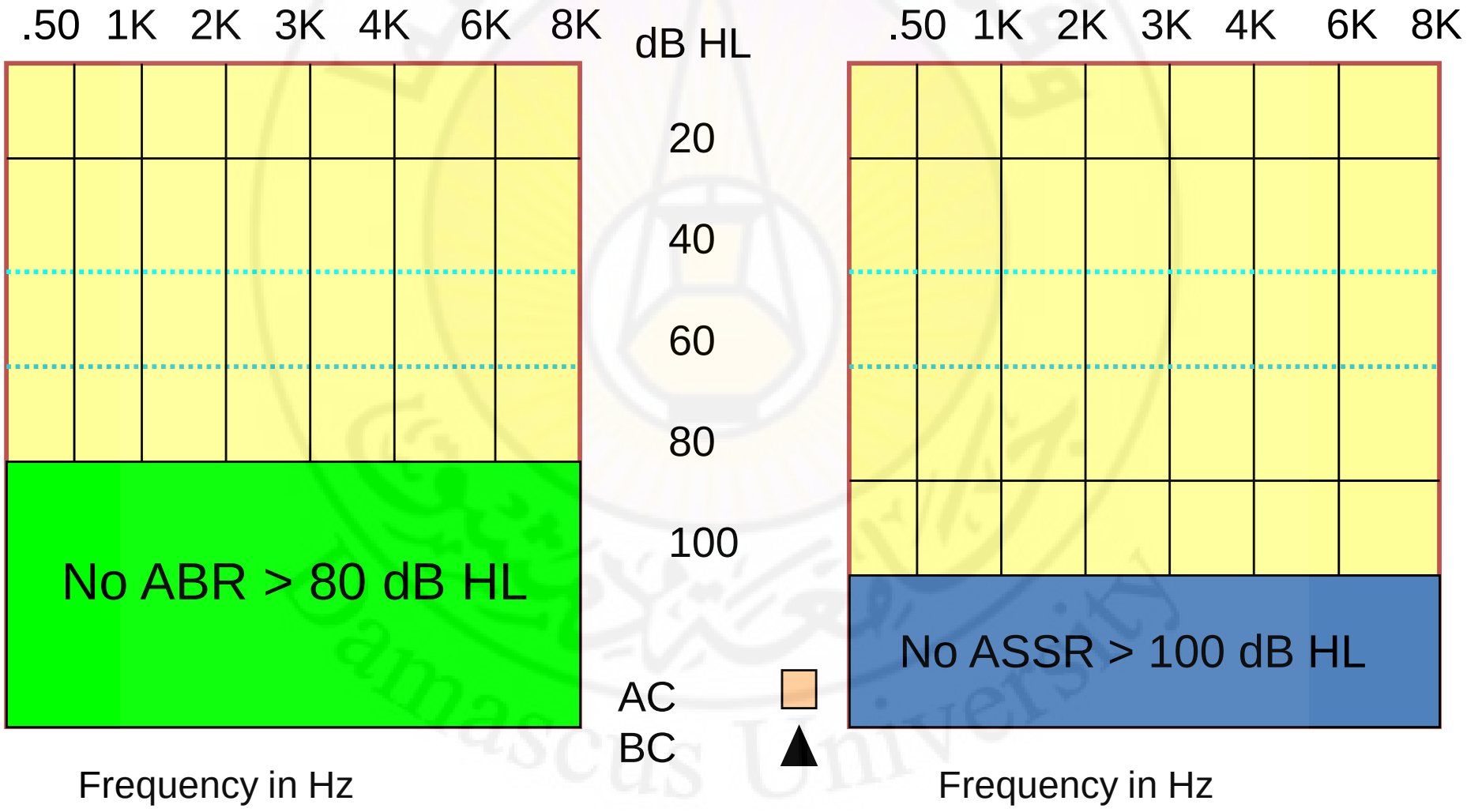
Right (Insert phone)

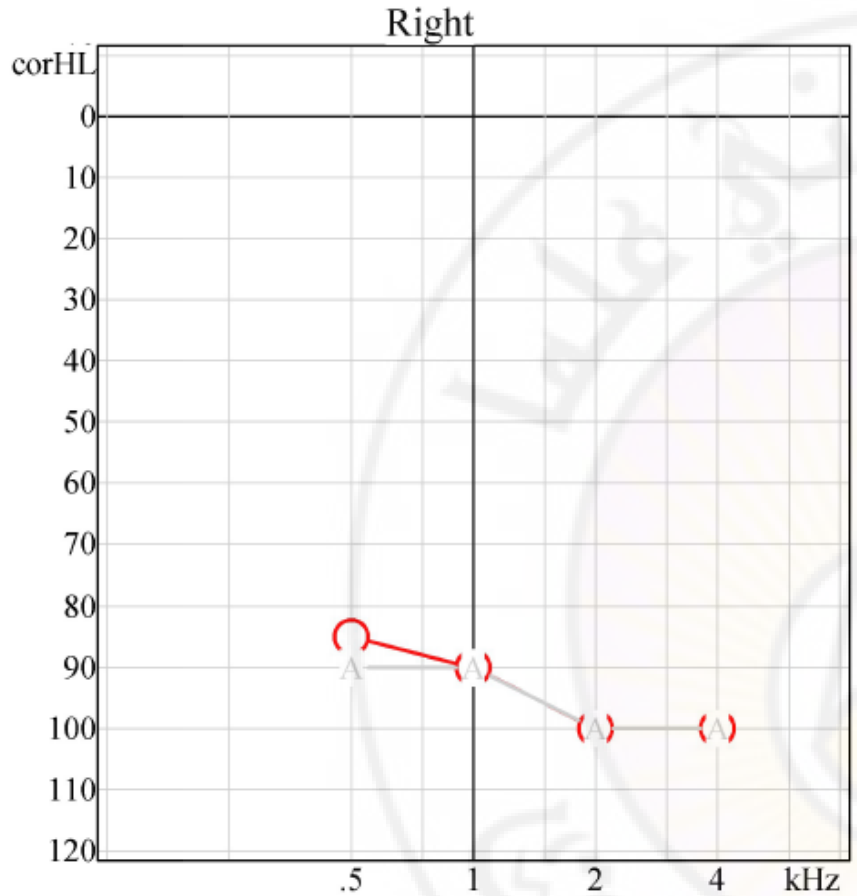
dB	500Hz	1000Hz	2000Hz	4000Hz
10		74% 14nV	100% 21nV	100% 27nV
20	100% 29nV	100% 41nV		
30			100% 43nV	100% 52nV
35				
50	100% 43nV	100% 43nV	100% 51nV	100% 57nV

Left (Insert phone)

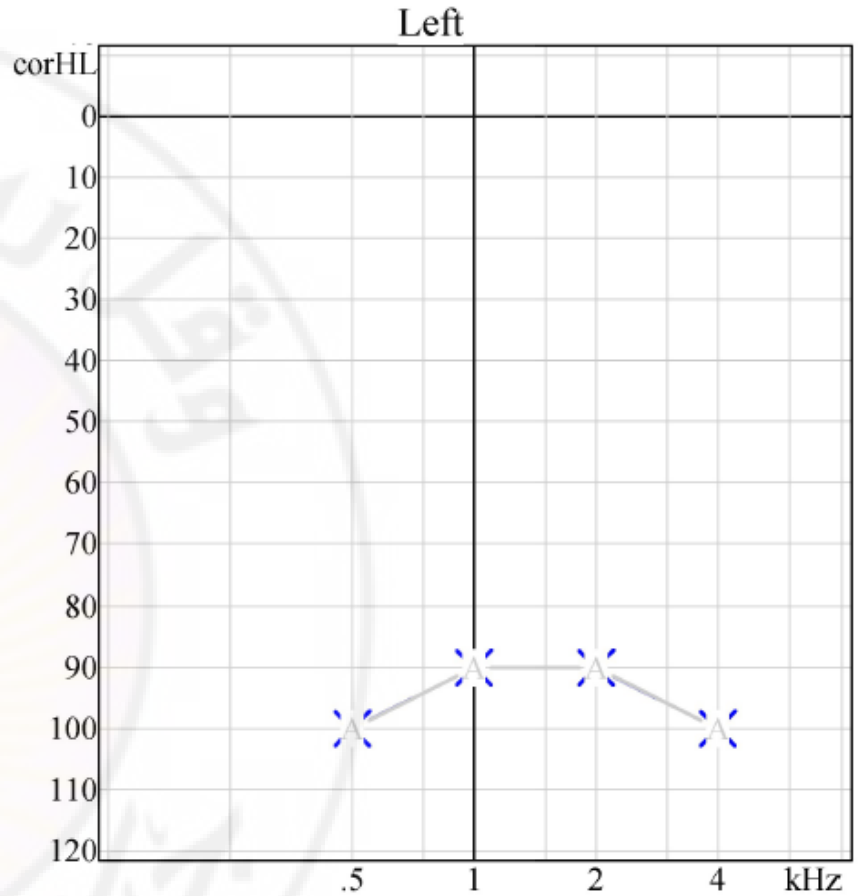
dB	500Hz	1000Hz	2000Hz	4000Hz
10	100% 16nV	67% 15nV	100% 27nV	100% 29nV
20		100% 26nV	100% 37nV	
30	100% 27nV			100% 34nV
35				22% 89nV
50	100% 36nV	100% 33nV	100% 33nV	100% 36nV

ABR vs. ASSR


.50 1K 2K 3K 4K 6K 8K
dB HL
20
40
60
80
100
No ABR > 80 dB HL
AC
BC
Frequency in Hz
.50 1K 2K 3K 4K 6K 8K
No ASSR > 100 dB HL
Frequency in Hz



Correction Factor :Child (90Hz) Insert phone - v. 2.1



Correction Factor :Child (90Hz) Insert phone - v. 2.1

Right (Insert phone)

dB	500Hz	1000Hz	2000Hz	4000Hz
50	39% 10nV	48% 10nV	28% 10nV	37% 10nV
70	22% 13nV	37% 13nV	41% 13nV	34% 13nV
80				
90	100% 58nV	100% 40nV	37% 8nV	40% 8nV
100	100% 12nV	100% 18nV	100% 18nV	100% 19nV

Left (Insert phone)

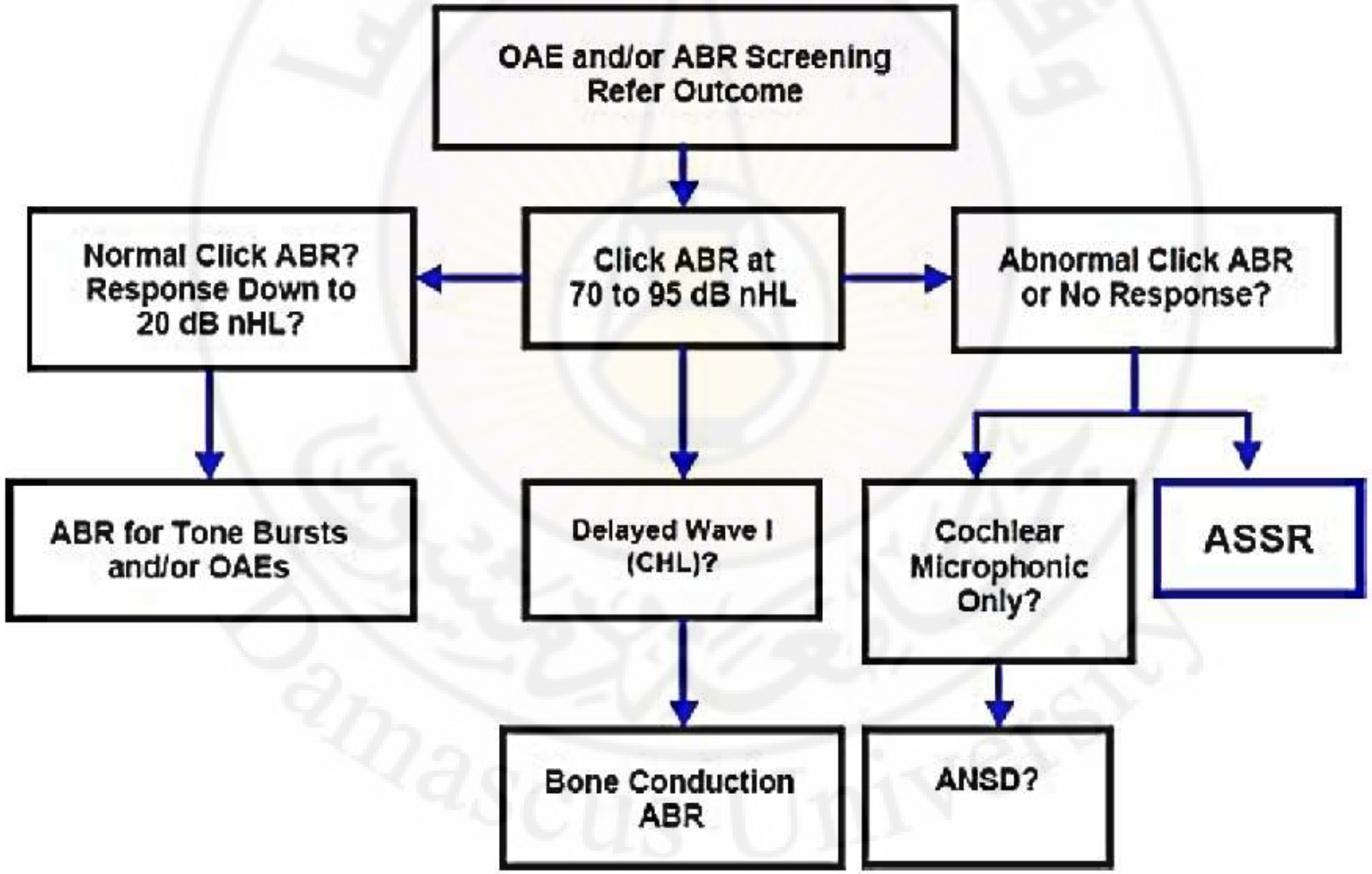
dB	500Hz	1000Hz	2000Hz	4000Hz
50	41% 15nV	30% 15nV	27% 15nV	45% 15nV
70	19% 15nV	51% 15nV	27% 15nV	30% 15nV
80		40% 20nV	34% 20nV	
90	54% 8nV	100% 29nV	100% 19nV	29% 9nV
100	100% 12nV		100% 27nV	100% 16nV

Tone Burst ABR vs. ASSR

Auditory dysfunction	ABR	ASSR
Normal hearing	accurate estimation	may over-estimate thresholds if patient is not sedated
Conductive HL	ear-specific findings BC without masking (wave I Presence)	bone conduction tone-burst measures but masking required
Sensory HL	accurate only to moderate HL degree	accurate from moderate to profound HL
Neural / Auditory Neuropathy	identified with wave I or CM	cannot distinguish profound sensory versus neural HL

Role of ASSR in

Frequency-Specific Estimation of Hearing Sensitivity in Infancy



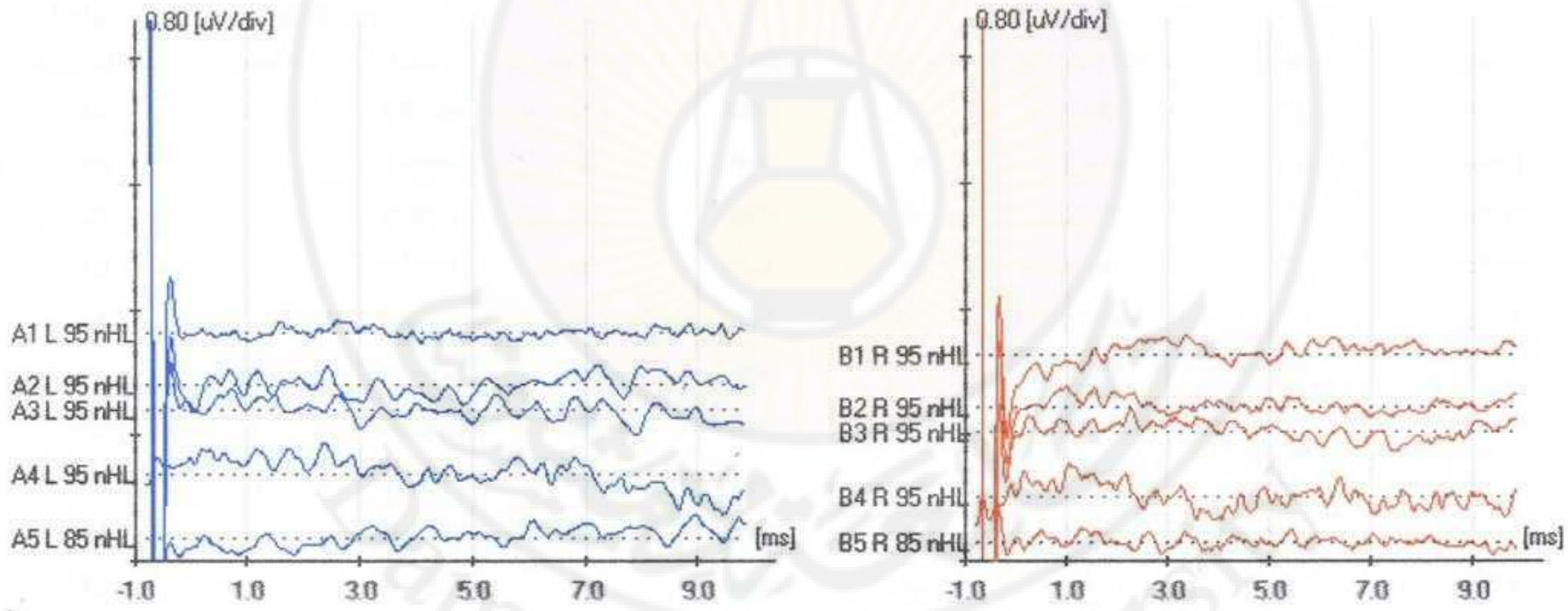
Conclusion…

- ABR and ASSR each can contribute importantly and rather uniquely to diagnostic auditory assessment of children.
- It is very important, however, to realize and consistently remember that neither the ABR nor the ASSR is a test of hearing. Each technique must be applied within an appropriate evidence based test battery consistent with the **crosscheck principle** and with clinical guidelines for pediatric hearing assessment (JCIH, 2007).
- Based on review of the literature and clinical experience, wise clinicians will adhere to Dr. David Stapells who advises: **"The ASSR … is appropriate if it used in conjunction with the tone-evoked ABR"**

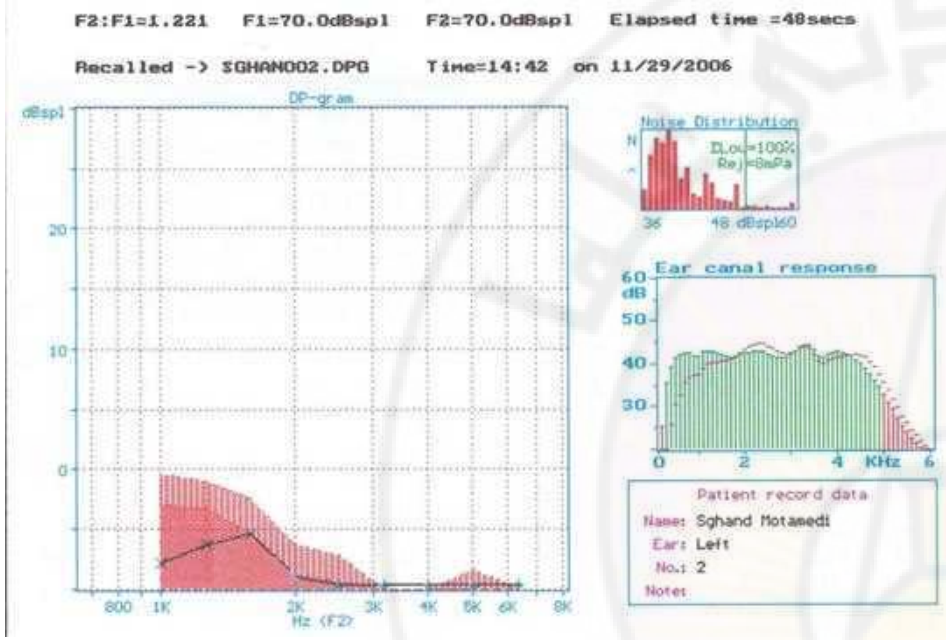


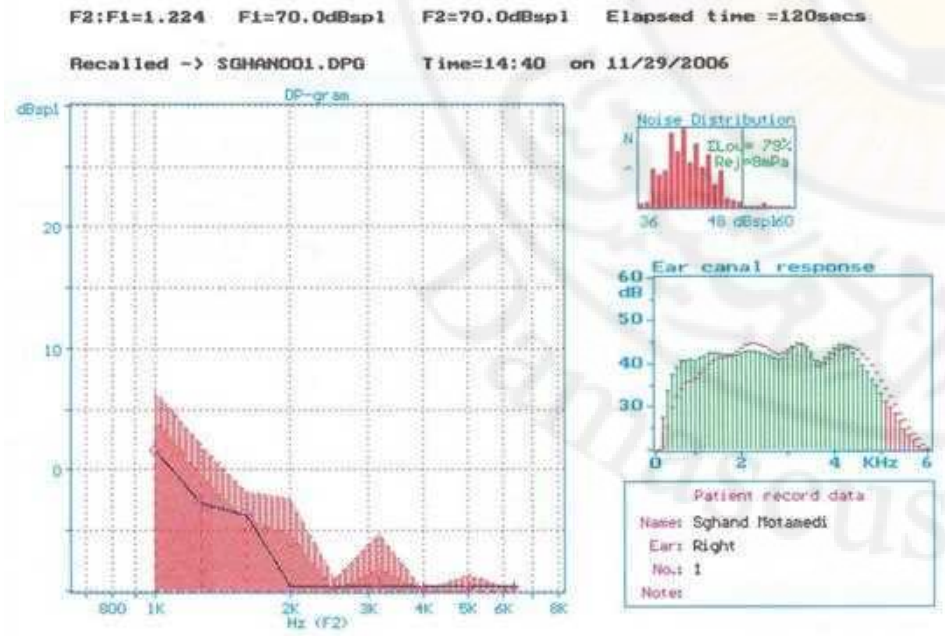
ASSR Case Reports

Case 1: ABR


0.80 [uV/div]
A1 L 95 nHL
A2 L 95 nHL
A3 L 95 nHL
A4 L 95 nHL
A5 L 85 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0
0.80 [uV/div]
B1 R 95 nHL
B2 R 95 nHL
B3 R 95 nHL
B4 R 95 nHL
B5 R 85 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0

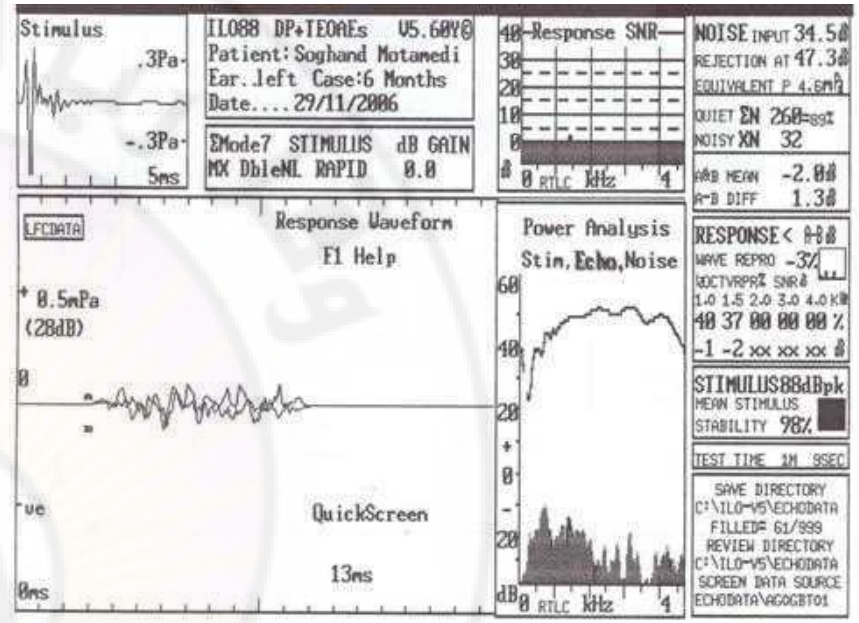
DPOAE

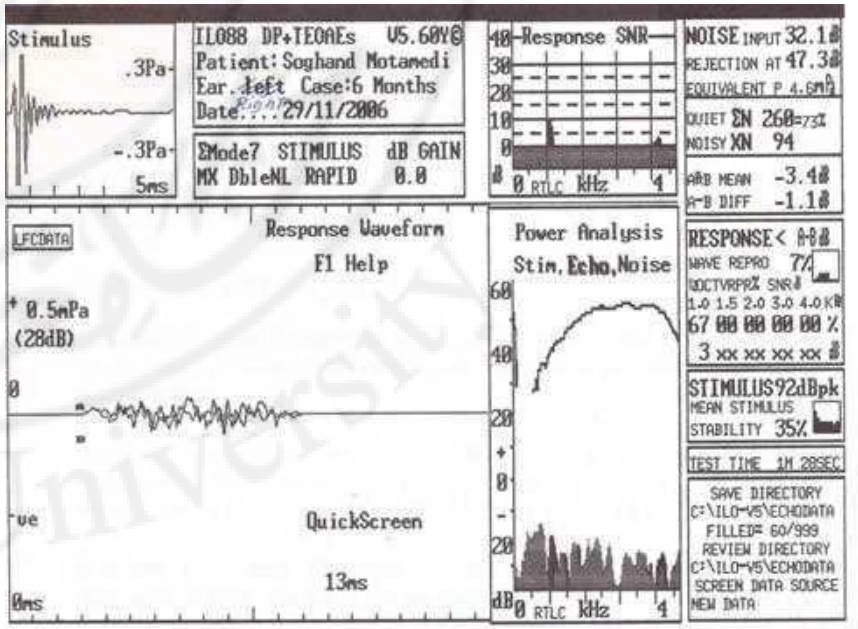




TEOAE

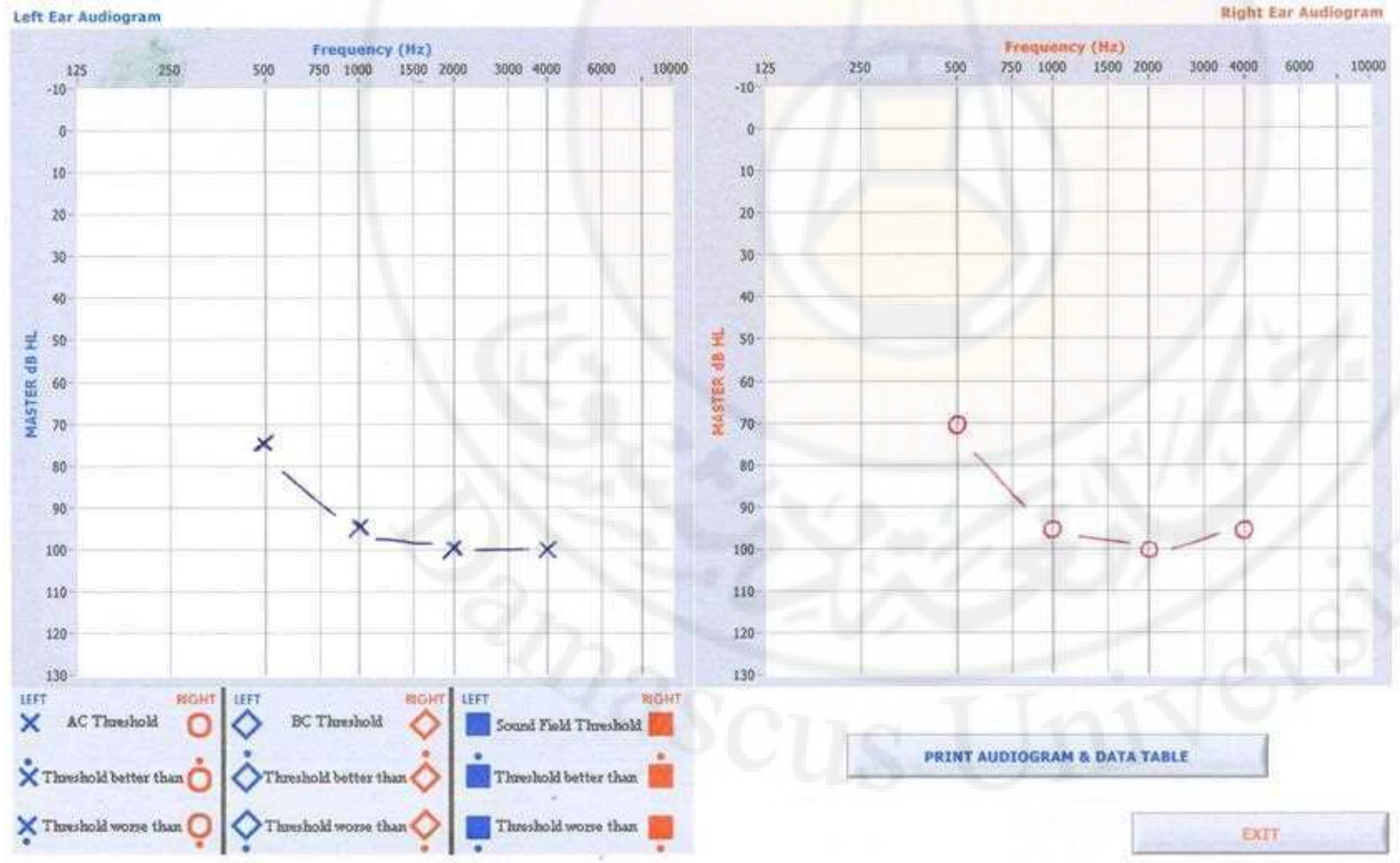
Case 1



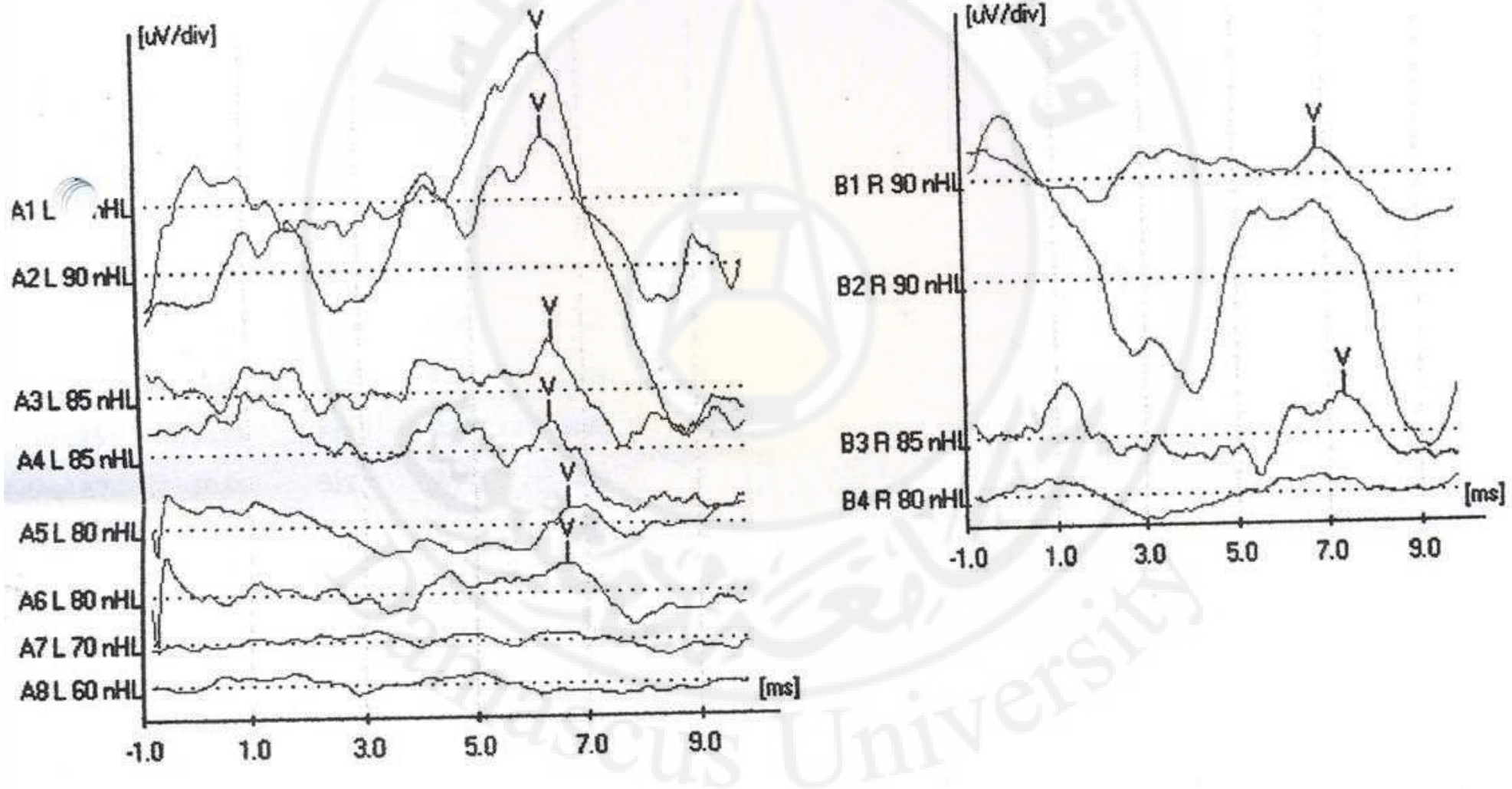


Case 1: ASSR

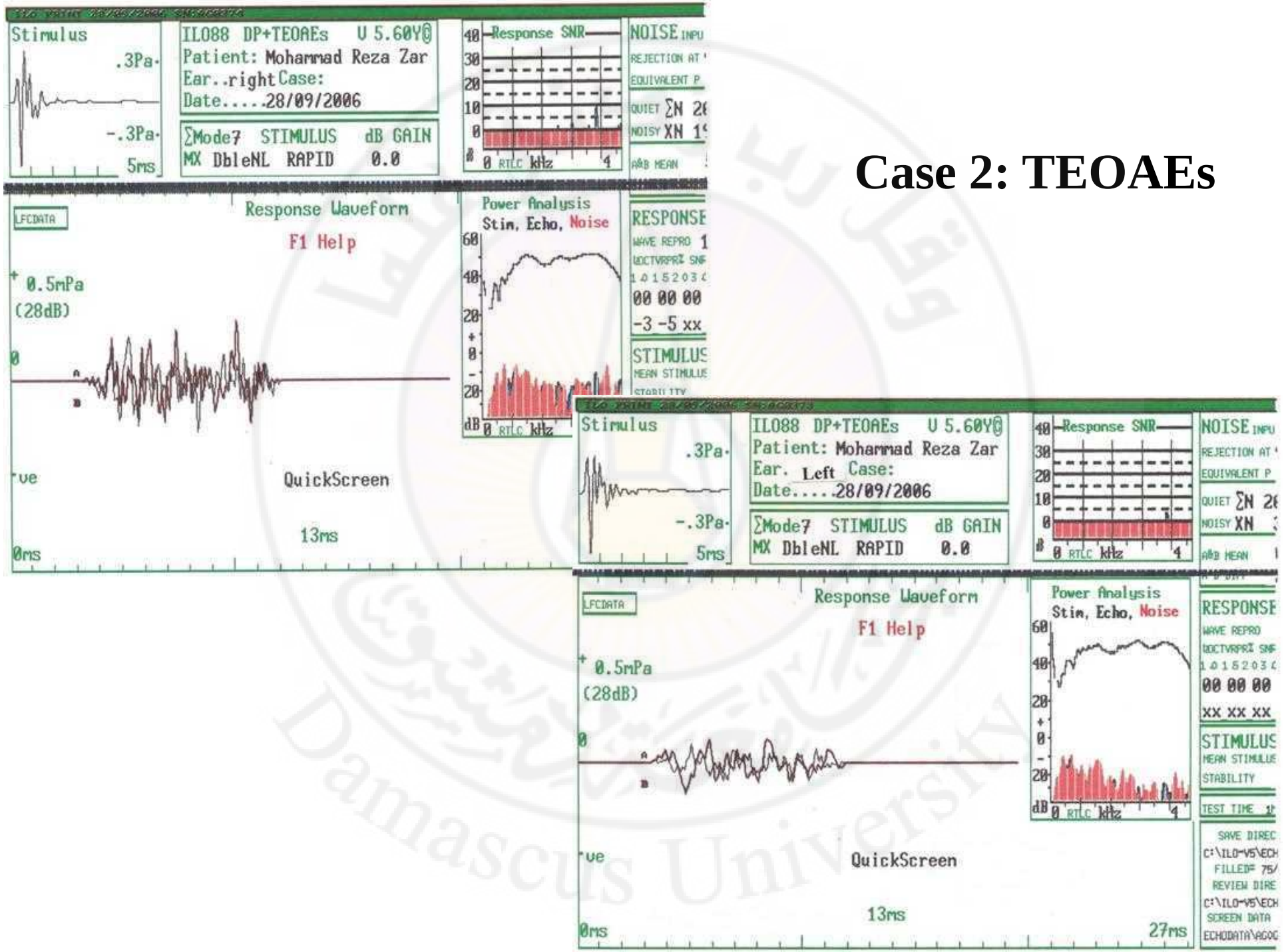

Left Ear Frequencies
Right Ear Frequencies
Hearing Threshold Table
EXIT
Generate Audiogram (Do not Save Threshold values)
Generate Audiogram (Save Threshold values)


Left Ear Audiogram
Right Ear Audiogram
Frequency (Hz)
MASTER dB HL
AC Threshold
BC Threshold
Sound Field Threshold
Threshold better than
Threshold worse than
PRINT AUDIOGRAM & DATA TABLE
EXIT

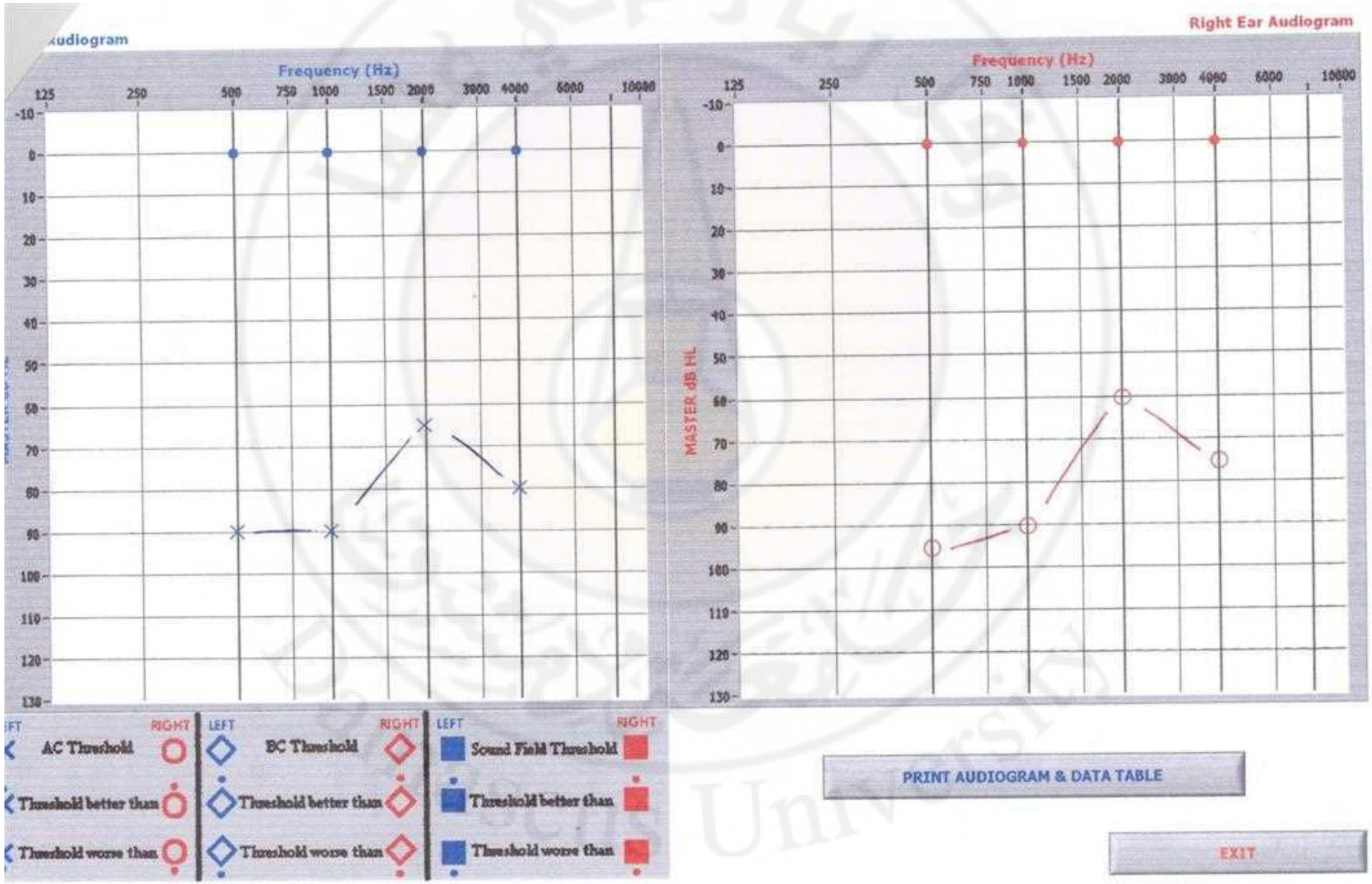
Case 2: ABR


[uV/div]
A1 L .nHL
A2 L 90 nHL
A3 L 85 nHL
A4 L 85 nHL
A5 L 80 nHL
A6 L 80 nHL
A7 L 70 nHL
A8 L 60 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0
[uV/div]
B1 R 90 nHL
B2 R 90 nHL
B3 R 85 nHL
B4 R 80 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0

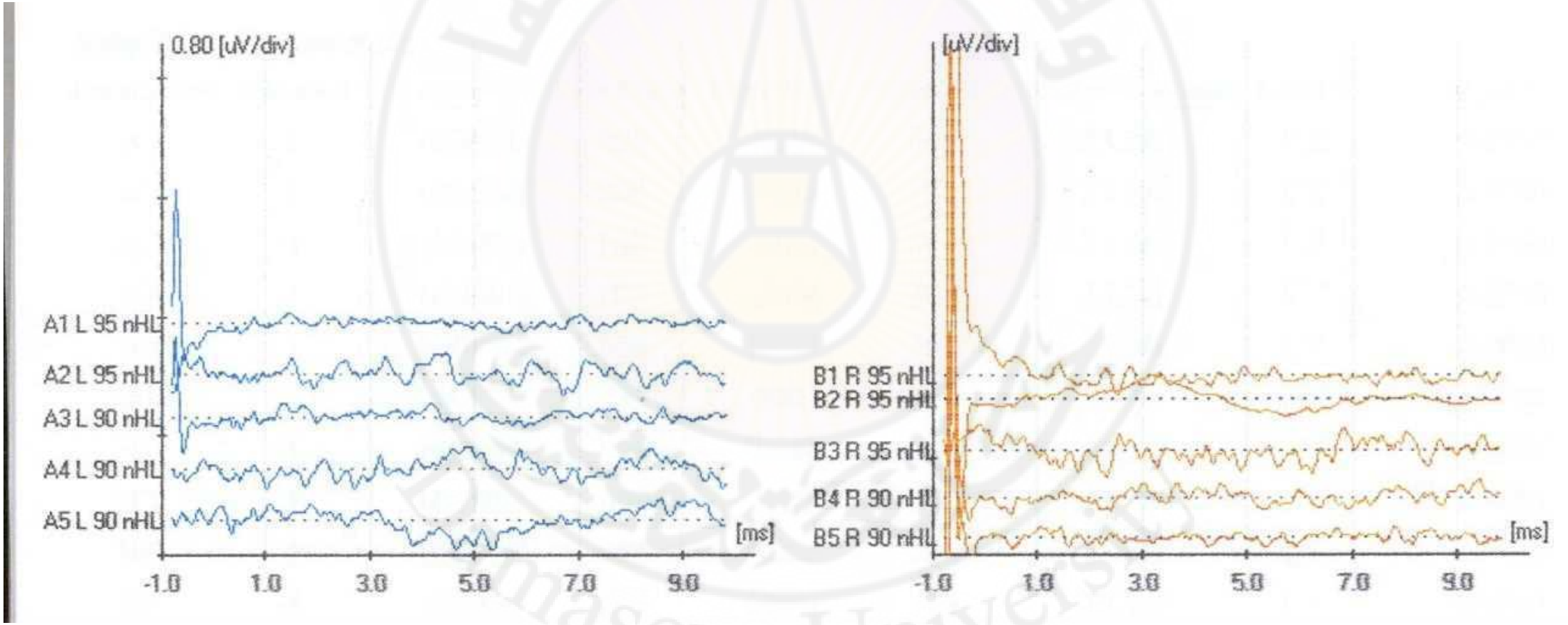
Case 2: TEOAEs



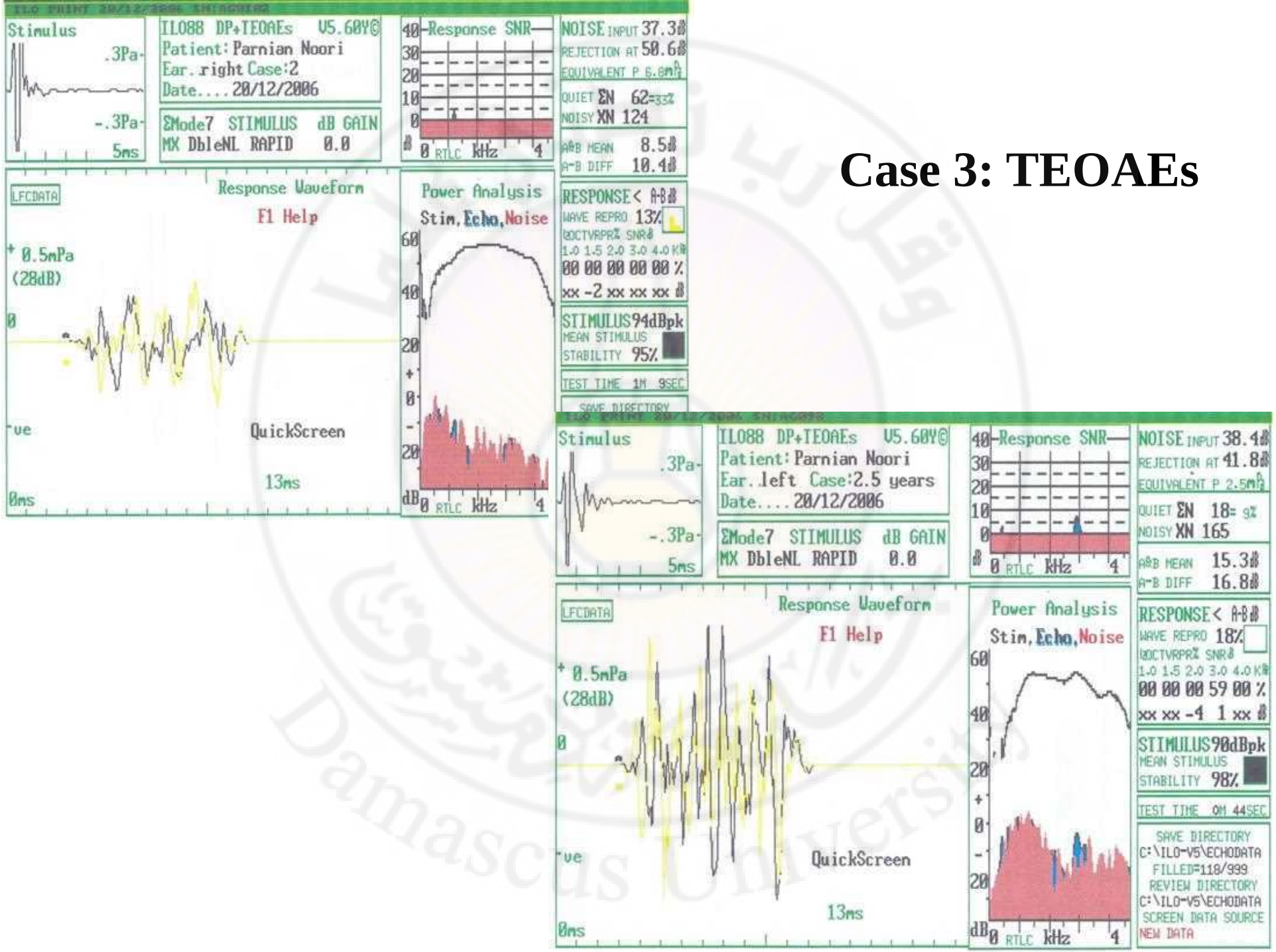
Case 2: ASSR


udiogram
Frequency (Hz)
125 250 500 750 1000 1500 2000 3000 4000 6000 10000
-10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
Right Ear Audiogram
Frequency (Hz)
125 250 500 750 1000 1500 2000 3000 4000 6000 10000
-10 0 10 20 30 40 50 60 70 80 90 100 110 120 130
MASTER dB HL
LEFT RIGHT
AC Threshold
Threshold better than
Threshold worse than
LEFT RIGHT
BC Threshold
Threshold better than
Threshold worse than
LEFT RIGHT
Sound Field Threshold
Threshold better than
Threshold worse than
PRINT AUDIOGRAM & DATA TABLE
EXIT

Case 3: ABR

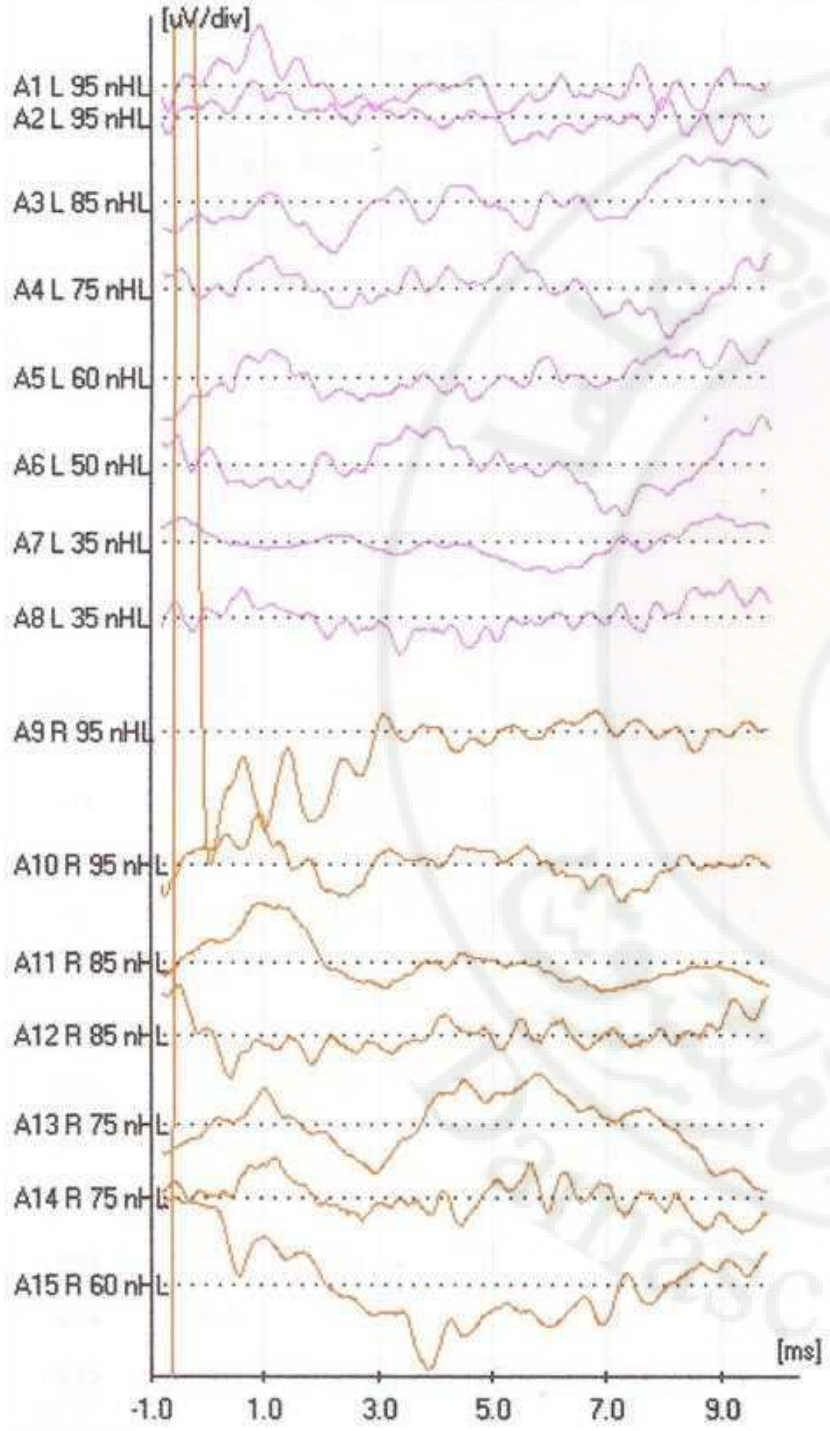

0.80 [uV/div]
A1 L 95 nHL
A2 L 95 nHL
A3 L 90 nHL
A4 L 90 nHL
A5 L 90 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0
[uV/div]
B1 R 95 nHL
B2 R 95 nHL
B3 R 95 nHL
B4 R 90 nHL
B5 R 90 nHL
[ms]
-1.0
1.0
3.0
5.0
7.0
9.0

Case 3: TEOAEs



Case 3: ASSR 250-8 kHz

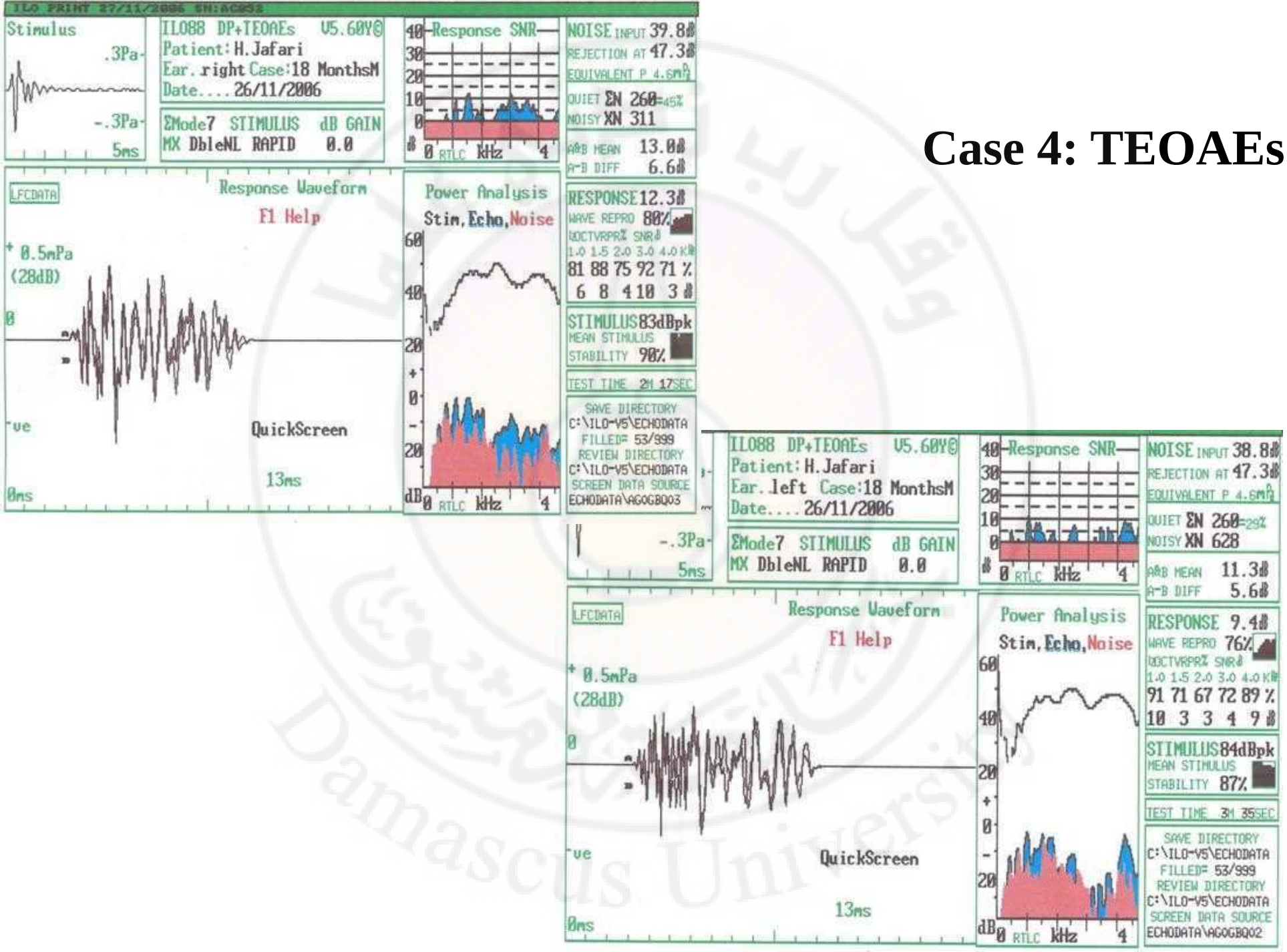




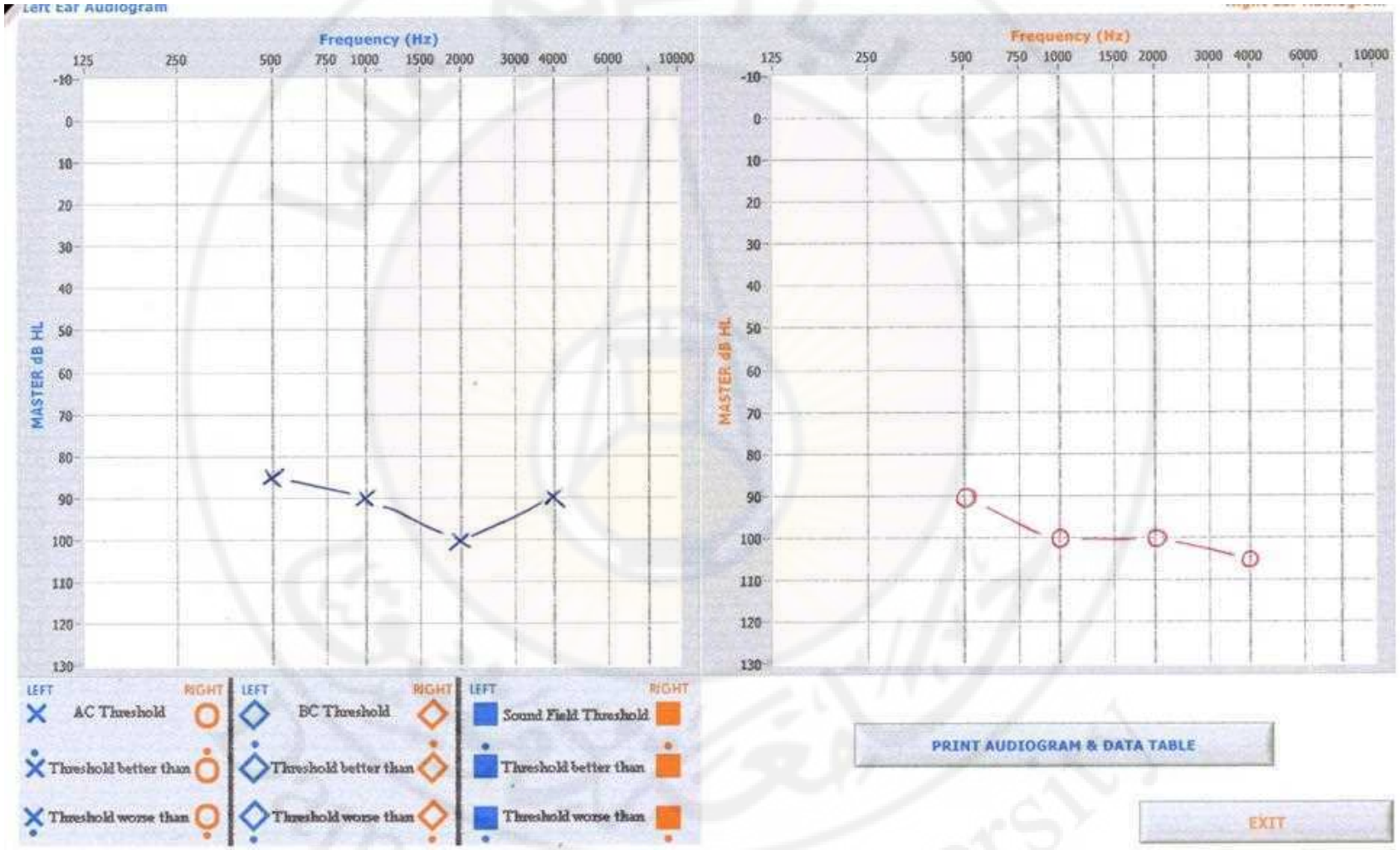
Case 4: ABR

suspected to auditory neuropathy

Case 4: TEOAEs



Case 4: ASSR



Absence of ASSR does not differentiate between profound sensory hearing loss versus ANSD.

Thank you!

Damascus University