دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی ایران

Clinical Masking in Audiology

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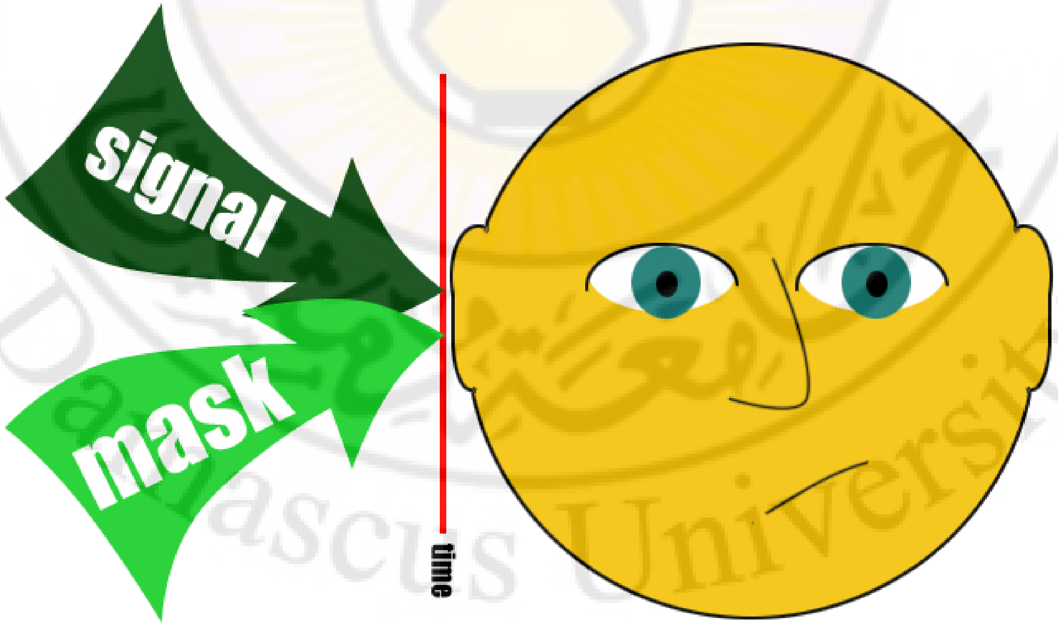
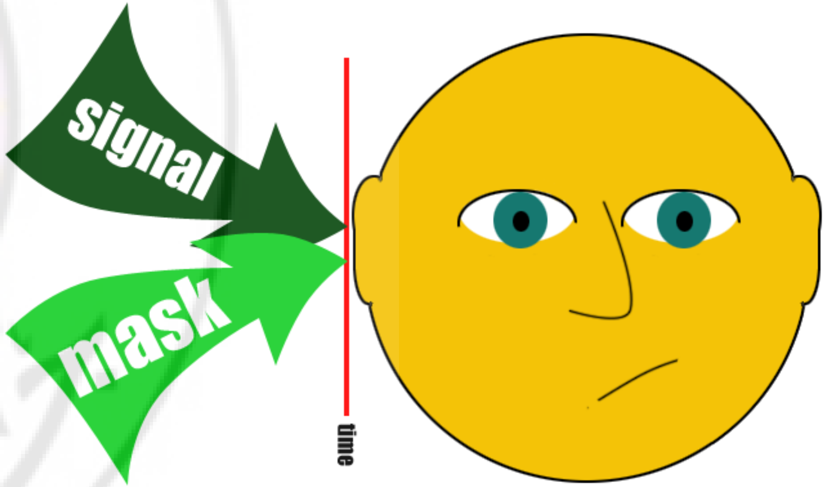
Definition

- **Masking** is a process by which, the sensitivity to one sound is affected by the presence of second sound (i.e. make the other sound inaudible [complete masking]; or reduce the loudness of another sound [Partial masking])



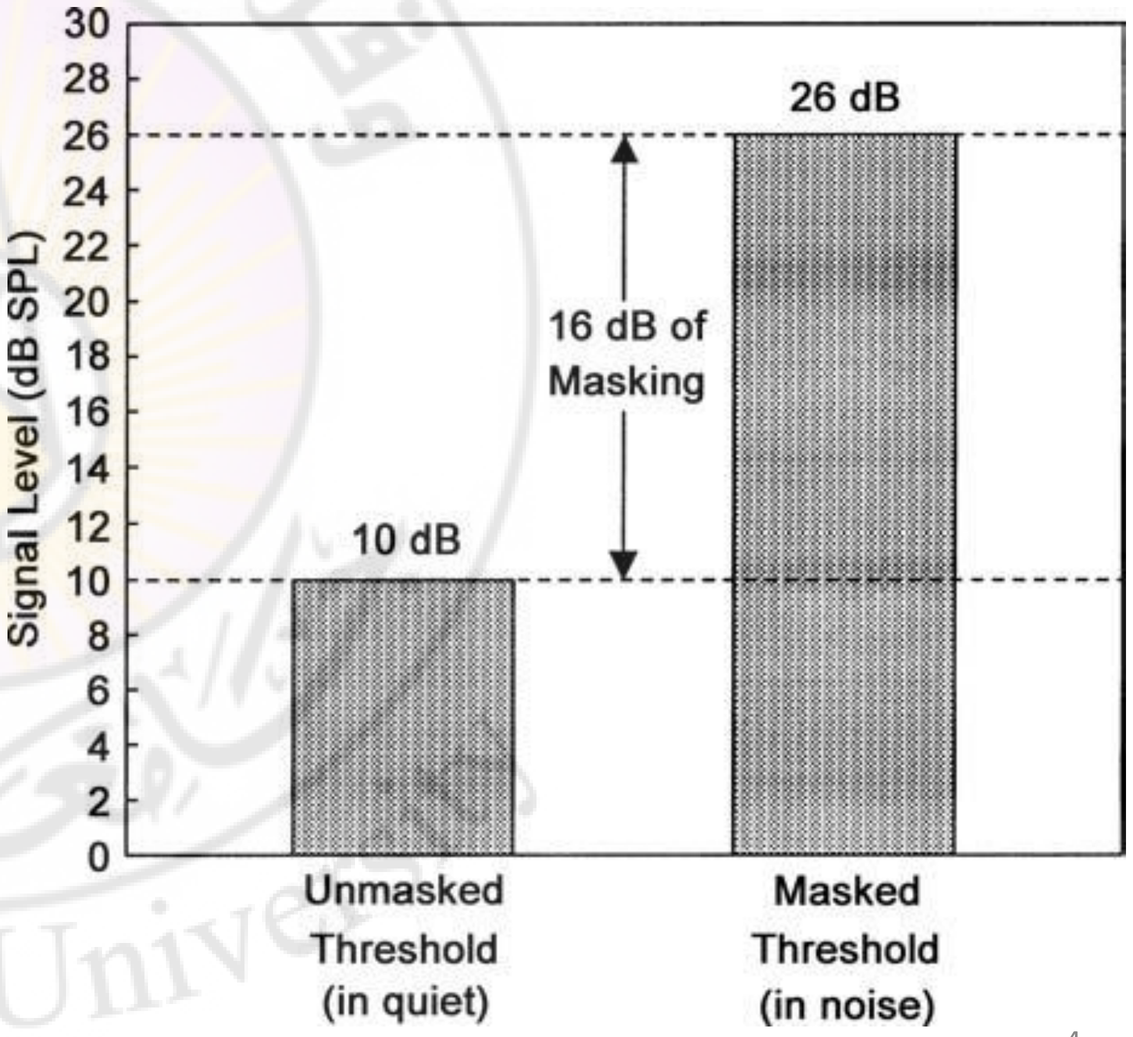
Definition

- If someone listens to a soft and a loud sound at the same time, he or she may not hear the soft sound. The soft sound is masked by the loud sound.
- The loud sound has a greater masking effect if the soft sound lies within the **same frequency range,** but masking also occurs when the soft sound is outside the frequency range of the loud sound.
- **Masking is the process by which the threshold of hearing for one sound is raised by the presence of another sound.**



Terminology

- **Test signal or Probe signal, and Maskee**
- **Masker**
- **Unmasked threshold**
- **Masked threshold**
- **Amount of masking or Threshold shift**



Concept of masking

- Amount of masking produced by a sound is depends on its intensity and frequency spectrum.
- In case of puretones, low freq. Tones can better mask the high frequencies. But high freq. Sounds are not equally efficient for masking the low freq. Tones.
- Masking is more effective when the loud sound is a low-frequency sound and the soft sound is a high-frequency one, rather than the opposite.
- Masking can occur both ways - **forwards and backwards**, and can spread upwards as well as downwards.
- **Upward spread of masking** is low-frequency sounds masking high-frequency sounds.
- **Downward spread of masking** occurs when low-frequency sounds are masked by an intense level of high-frequency sounds.

Concept of masking

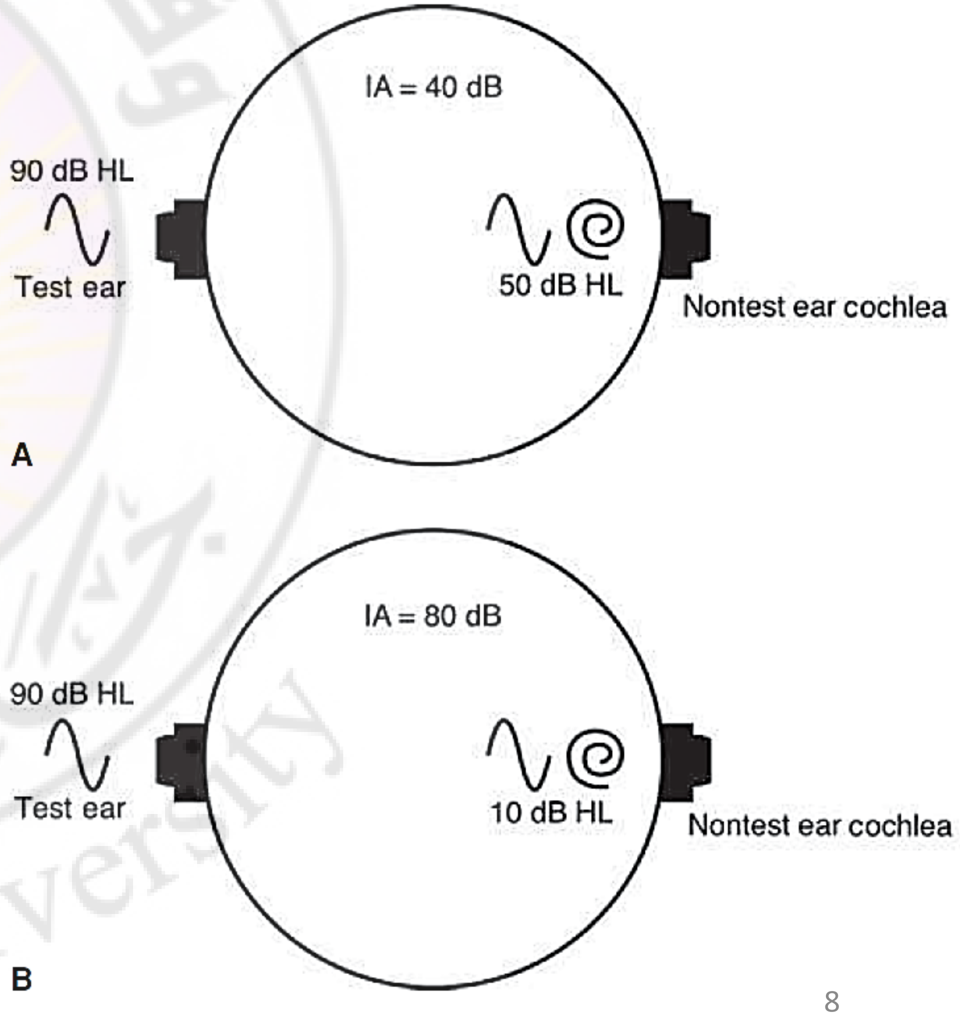
- There are two basic masking paradigms: **ipsilateral and contralateral.**
- In an **ipsilateral masking** paradigm, the test signal and the masker are presented to the same ear.
- In a **contralateral masking** paradigm, the test signal and masker are presented to opposite ears.
- Masking is used clinically whenever it is suspected that the *nontest* ear is participating in the evaluation of the test ear. Consequently, masking is always applied to the nontest or contralateral ear.
- Masking reduces sensitivity of the nontest ear to the test signal.
- The purpose of contralateral masking, therefore, is to raise the threshold of the nontest ear sufficiently so that its contribution to a response from the test ear is eliminated.

Clinical Masking

- A major objective of the basic audiologic evaluation is assessment of auditory function of each ear.
- There are situations during both air-conduction and bone-conduction testing when this may not occur.
- Although a puretone or speech stimulus is being presented through a transducer to the test ear, the nontest ear can contribute partially or totally to the observed response.
- **Whenever it is suspected that the nontest ear is responsive during evaluation of the test ear, a masking stimulus must be applied to the nontest ear to eliminate its participation.**

Cross-Hearing in Air conduction testing

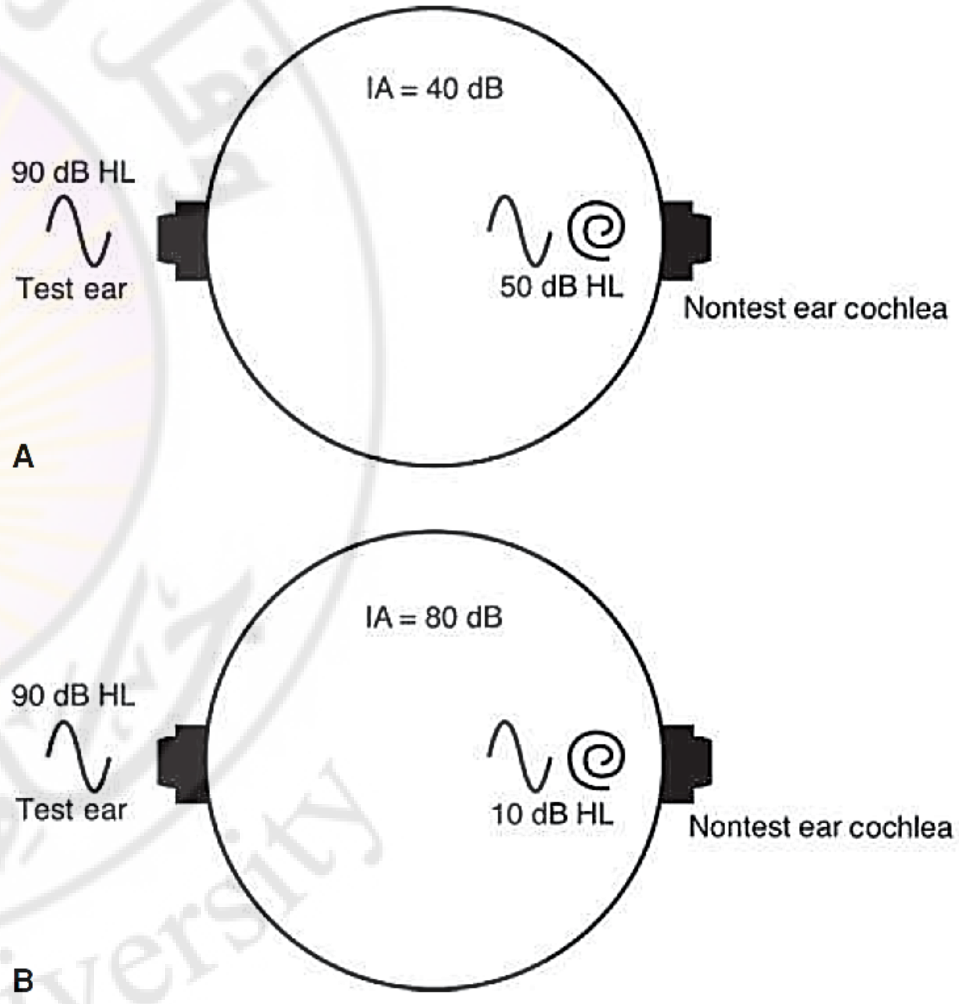
- Cross hearing occurs when a stimulus presented to the test ear **"crosses over"** and is perceived in the nontest ear.
- An earphone essentially can function as a bone vibrator at higher sound pressures. Because both cochleas are housed within the same skull, the outcome is stimulation of the nontest ear cochlea through bone conduction.
- Consequently, cross hearing during air-conduction testing is considered primarily a bone conduction mechanism.



Interaural Attenuation (IA)

- The intensity of the sound reaching the NTE is less than what was originally presented to the TE because it takes a certain amount of energy to transmit the signal across the head. The number of dB that are “lost” in the process of signal crossover is called **interaural attenuation (IA)**

$$IA = dB\ HL_{TestEar} - dB\ HL_{NontestEar}$$



- It is apparent that a greater portion of the test signal can reach the nontest ear **when IA is small.**

Factors affecting IA

- IA during earphone testing is dependent on three factors:
  - Transducer type,
  - frequency spectrum of the test signal, and
  - individual subject.

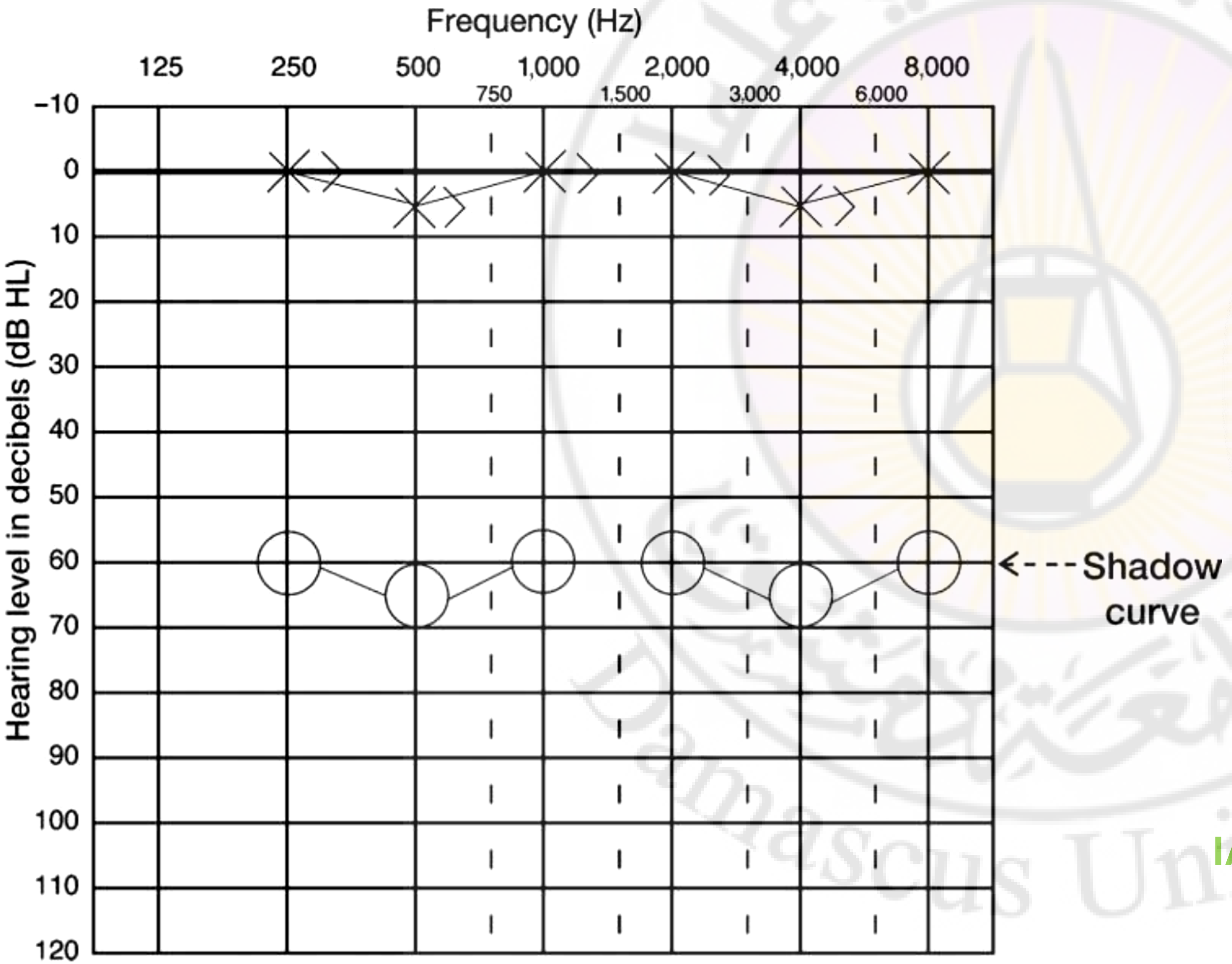
Circumaural

Supraaural

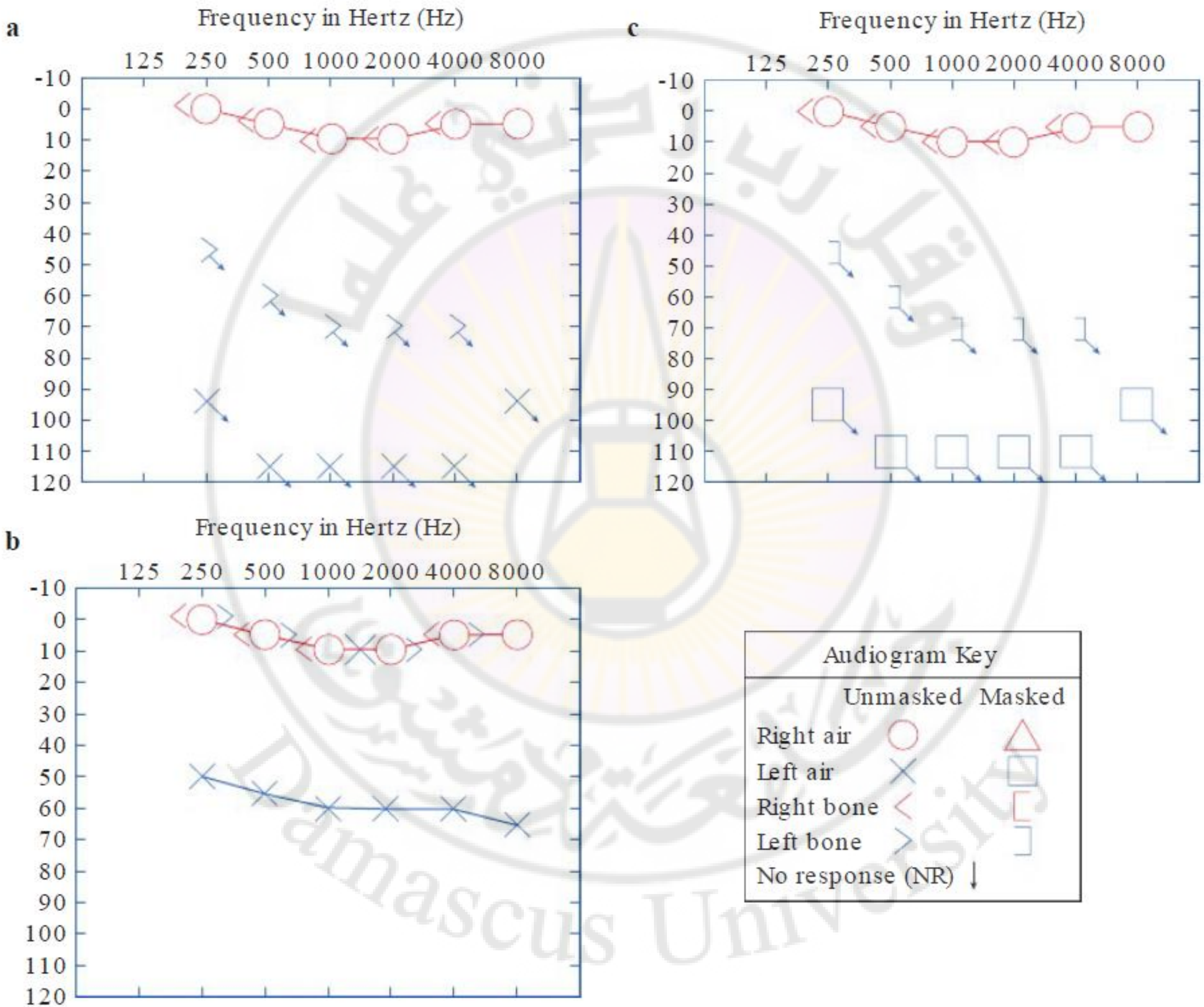
Insert

Generally, IA increases as the contact area of the transducer with the skull decreases.

Shadow Curve



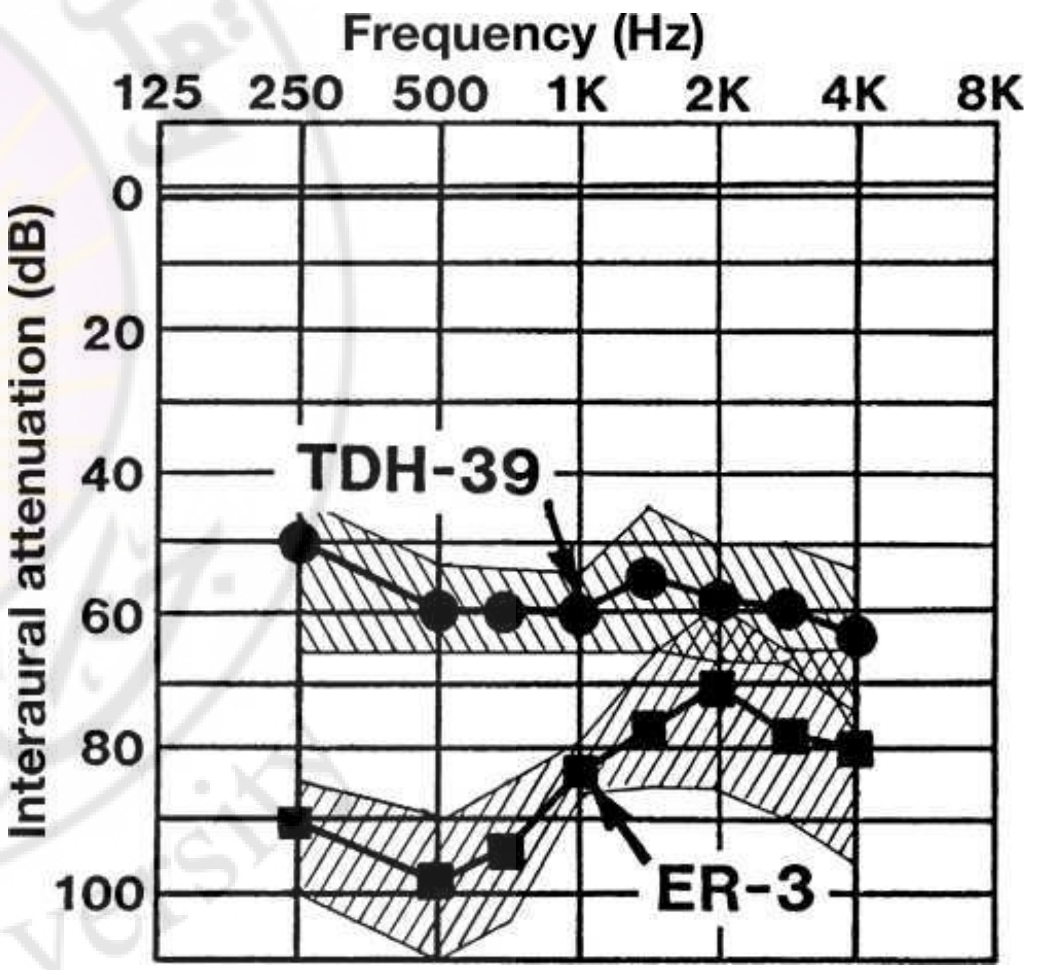
$IA = Unmasked\,AC_{Impaired Ear} - Unmasked\,AC_{Normal Ear}$


a
Frequency in Hertz (Hz)
125 250 500 1000 2000 4000 8000
-10 0 10 20 30 40 50 60 70 80 90 100 110 120
b
Frequency in Hertz (Hz)
125 250 500 1000 2000 4000 8000
-10 0 10 20 30 40 50 60 70 80 90 100 110 120
c
Frequency in Hertz (Hz)
125 250 500 1000 2000 4000 8000
-10 0 10 20 30 40 50 60 70 80 90 100 110 120
Audiogram Key
Unmasked
Masked
Right air
Left air
Right bone
Left bone
No response (NR)

- When using supra-aural earphones, IA for puretone air-conducted signals varies considerably, particularly across subjects, ranging from about **40 to 85 dB.**
- Your assumption about IA will influence the decision about the need for contralateral masking.
- The use of a smaller IA value assumes that there is smaller separation between ears. Consequently, contralateral masking will be required more often.
- When making a decision about the need for contralateral masking during clinical practice, a single value defining the lower limit of IA is recommended.
- ***Based on currently available data, a conservative estimate of IA for supra-aural earphones is 40 dB at all frequencies.***
- Although this very conservative estimate will take into account the IA characteristics of all individuals, it will result in the unnecessary use of masking in some instances.

Increased IA is a primary goal!

- A major advantage of the **insert earphone** is increased IA for air-conducted sound, particularly in the lower frequencies.
- Increased IA with insert earphones is the result of two factors:
  - (1) Reduced contact area of the transducer with the skull and;
  - (2) reduction of the occlusion effect (OE).



What is occlusion effect (OE)?

- OE defines as an increase in loudness for bone-conducted sound at frequencies below 2,000 Hz when the outer ear is covered or occluded.
- There is evidence that the OE influences the measured IA for air-conducted sound.
- there is an inverse relationship between magnitude of the OE and the measured IA in the lower frequencies. Specifically, an earphone that reduces the OE will exhibit increased IA for air-conducted sound.
- The increased IA for air-conducted sound observed in the lower frequencies when using insert earphones (with deeply inserted foam eartips) is primarily related to the significant reduction or elimination of the OE.

IA for Insert phone: 75 dB at <1,000 Hz and 50 dB at frequencies >1,000 Hz.

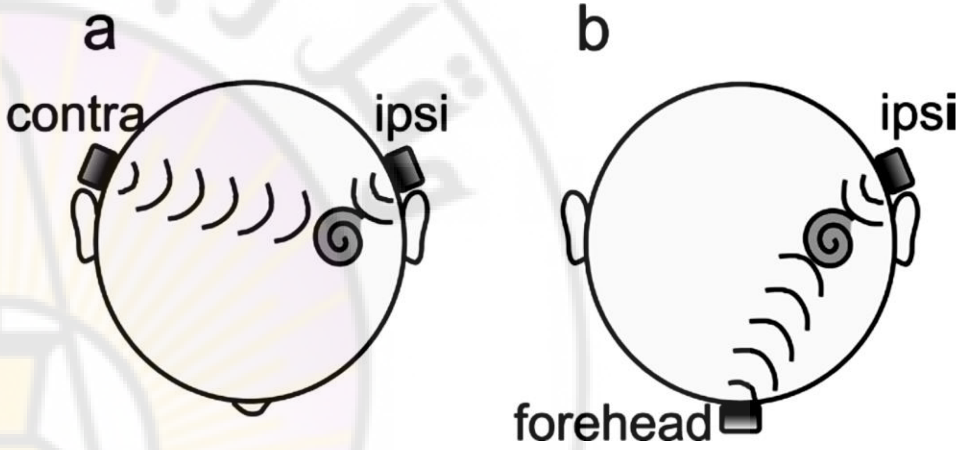
IA for speech

- IA for speech is typically measured by obtaining speech recognition thresholds (SRTs) in individuals with unilateral, profound sensory/neural hearing loss. Specifically, the difference in threshold between the normal ear and impaired ear without contralateral masking is calculated:

$$\text{Speech IA} = \text{Unmasked SRT}_{\text{ImpairedEar}} - \text{SRT}_{\text{Normal Ear}}$$

- *Based on currently available data, conservative estimates of IA for all threshold and suprathreshold measures of speech are **40 dB for supra-aural earphones** and **60 dB for insert earphones** with deeply inserted foam eartips.*

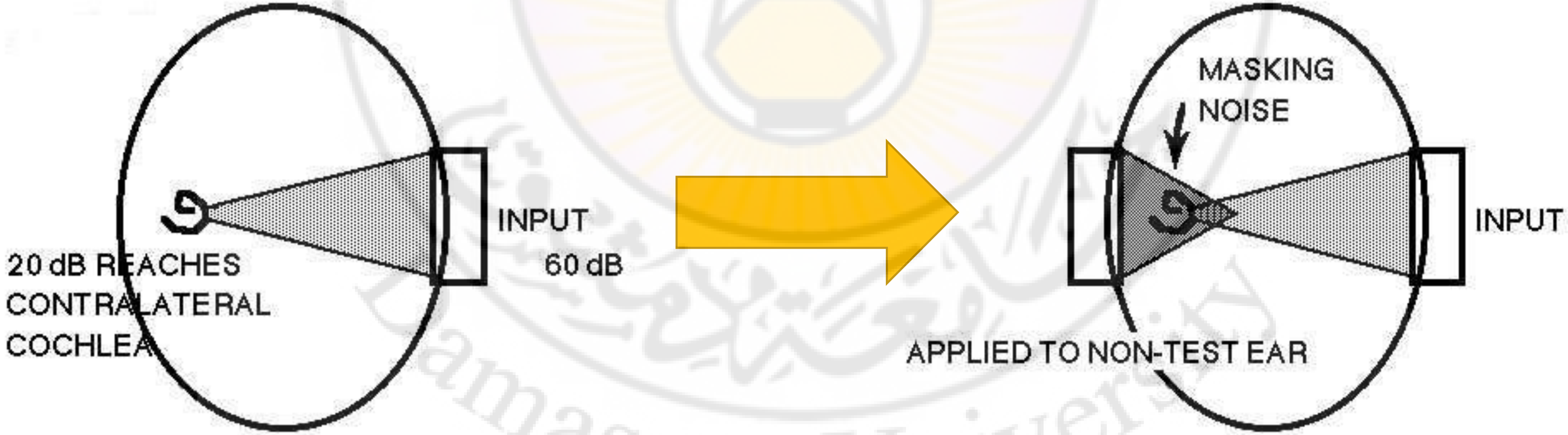
Cross-Hearing in Bone-Conduction Testing



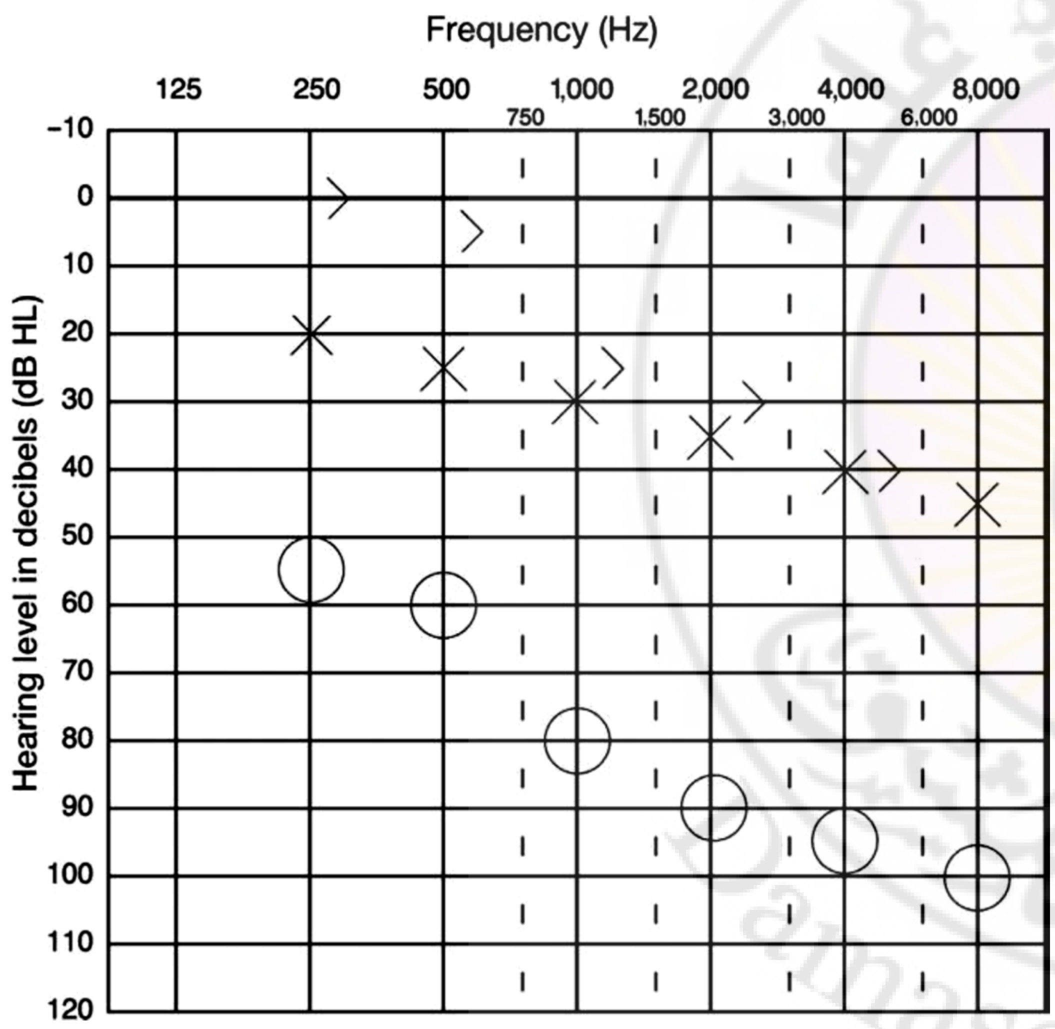
- IA for bone-conducted sound when using a bone vibrator placed at the **forehead** is essentially 0 dB at all frequencies; IA when using a **mastoid** placement is approximately 0 dB at 250 Hz and increases to about 15 dB at 4,000 Hz.
- **Regardless of the placement of a bone vibrator (i.e., mastoid vs. forehead), it is generally agreed that IA for bone conducted sound at all frequencies is negligible and should be considered 0 dB**

WHEN TO MASK?

- Contralateral masking is required whenever there is the possibility that the test signal can be perceived in the nontest ear. IA is one of the major factors that will be considered when evaluating the need for masking



Puretone Audiometry: Air Conduction



$$AC_{TestEar} - AC_{NontestEar} \geq IA$$

- when the unmasked air-conduction threshold in the test ear equals or exceeds the apparent bone conduction threshold (i.e., the unmasked bone-conduction threshold) in the nontest ear by a conservative estimate of IA (40 dB):

$$AC_{TestEar} - BC_{NontestEar} \geq IA$$

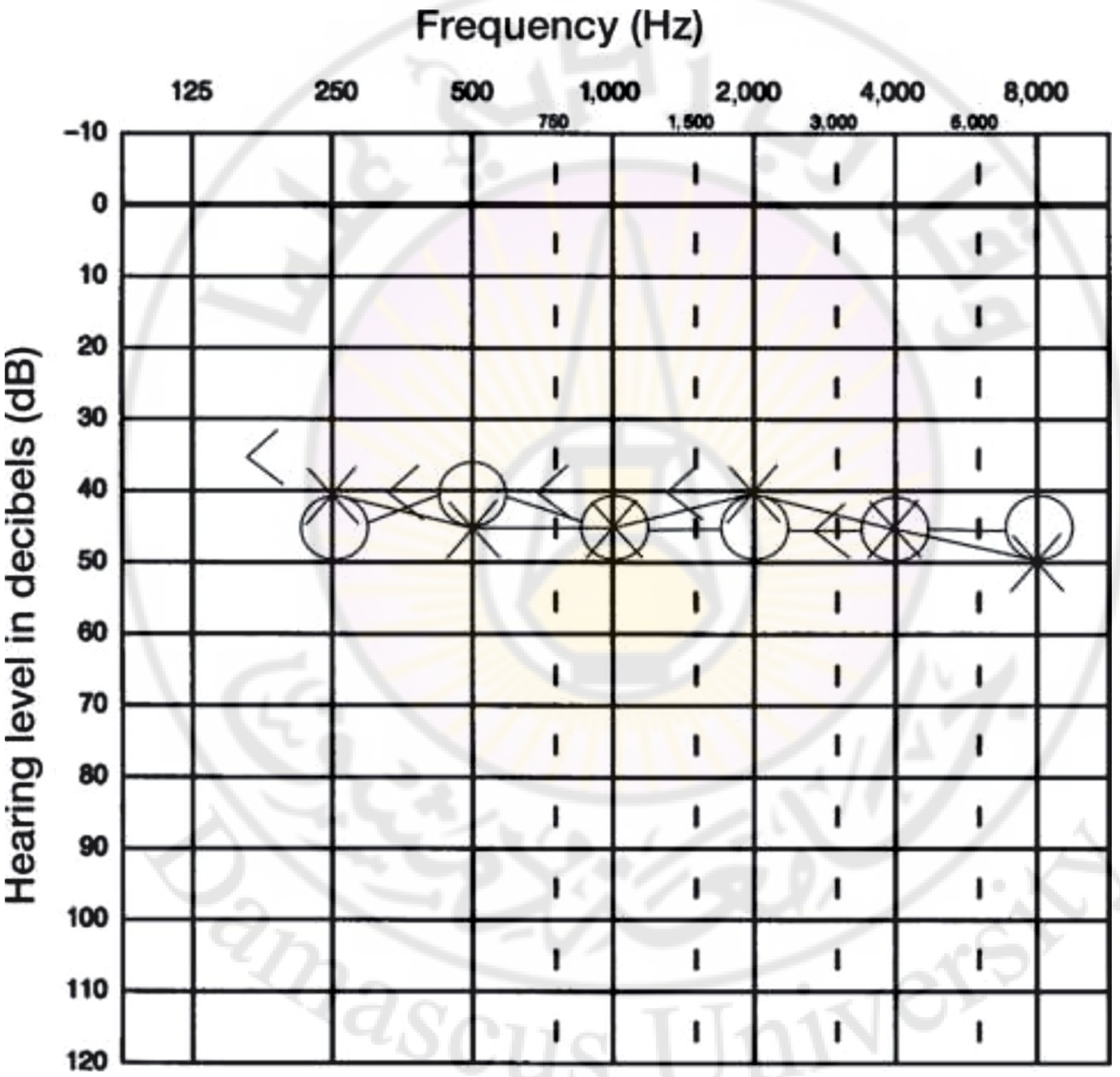
Many audiologists will obtain air-conduction thresholds prior to measurement of bone-conduction thresholds. A preliminary decision about the need for contralateral masking can be made by comparing the air-conduction thresholds of the two ears. it will be necessary to re-evaluate the need for contralateral masking during air conduction testing following the measurement of unmasked bone-conduction thresholds.

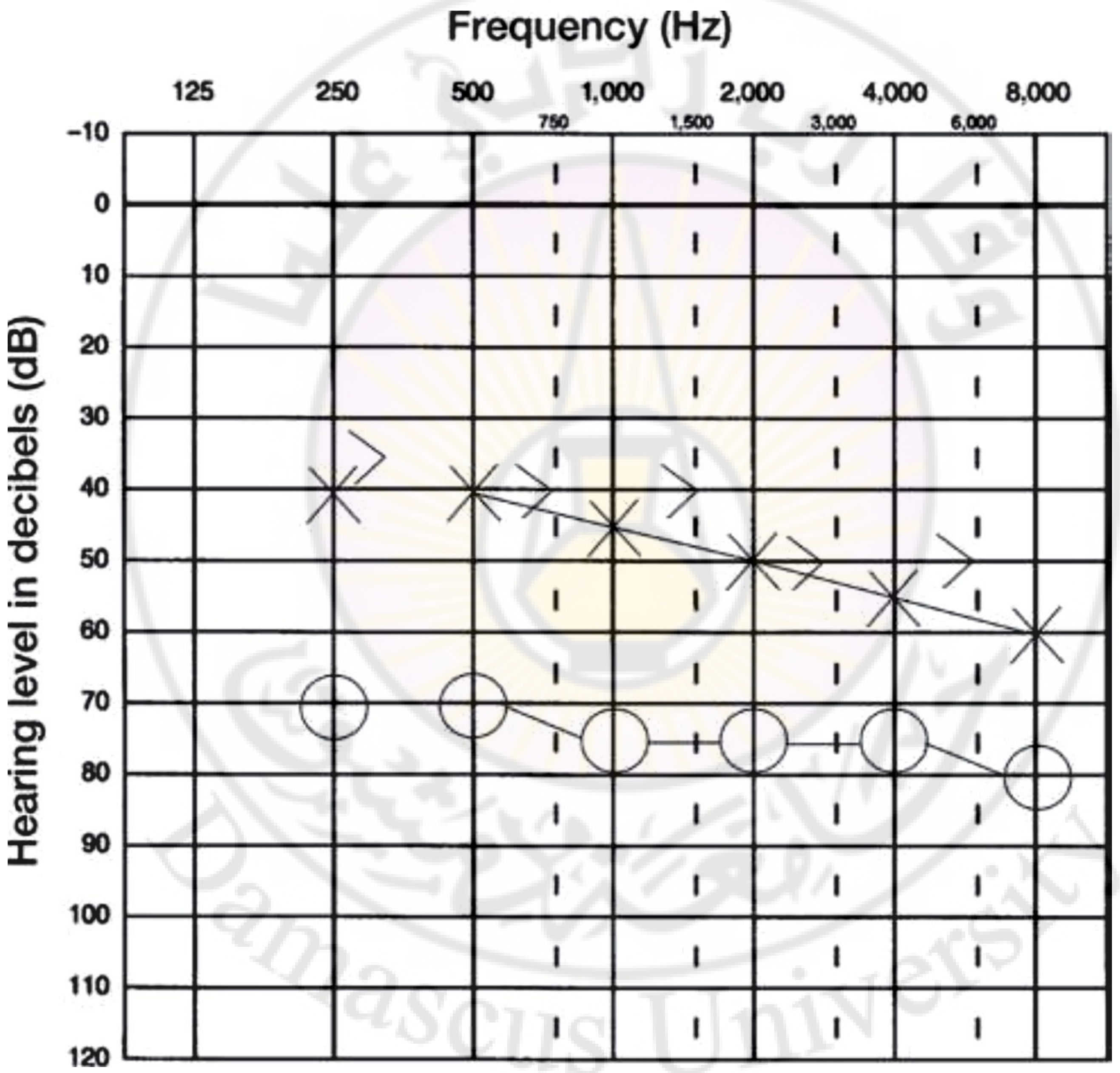
Puretone Audiometry: Bone Conduction

- The use of contralateral masking is indicated whenever the results of unmasked bone-conduction audiometry suggest the presence of an air-bone gap in the test ear (Air Bone Gap $_{\text{Test Ear}}$) of 15 dB or greater.
  - *(ASHA 2005: 10 dB)*

Air-Bone Gap $_{TE}$ ≥ 15 dB

Air-Bone Gap = AC$_{\text{Test Ear}}$ - Unmasked BC


Frequency (Hz)
125
250
500
1,000
2,000
4,000
8,000
750
1,500
3,000
6,000
Hearing level in decibels (dB)
-10
0
10
20
30
40
50
60
70
80
90
100
110
120


Frequency (Hz)
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250
500
1,000
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3,000
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0
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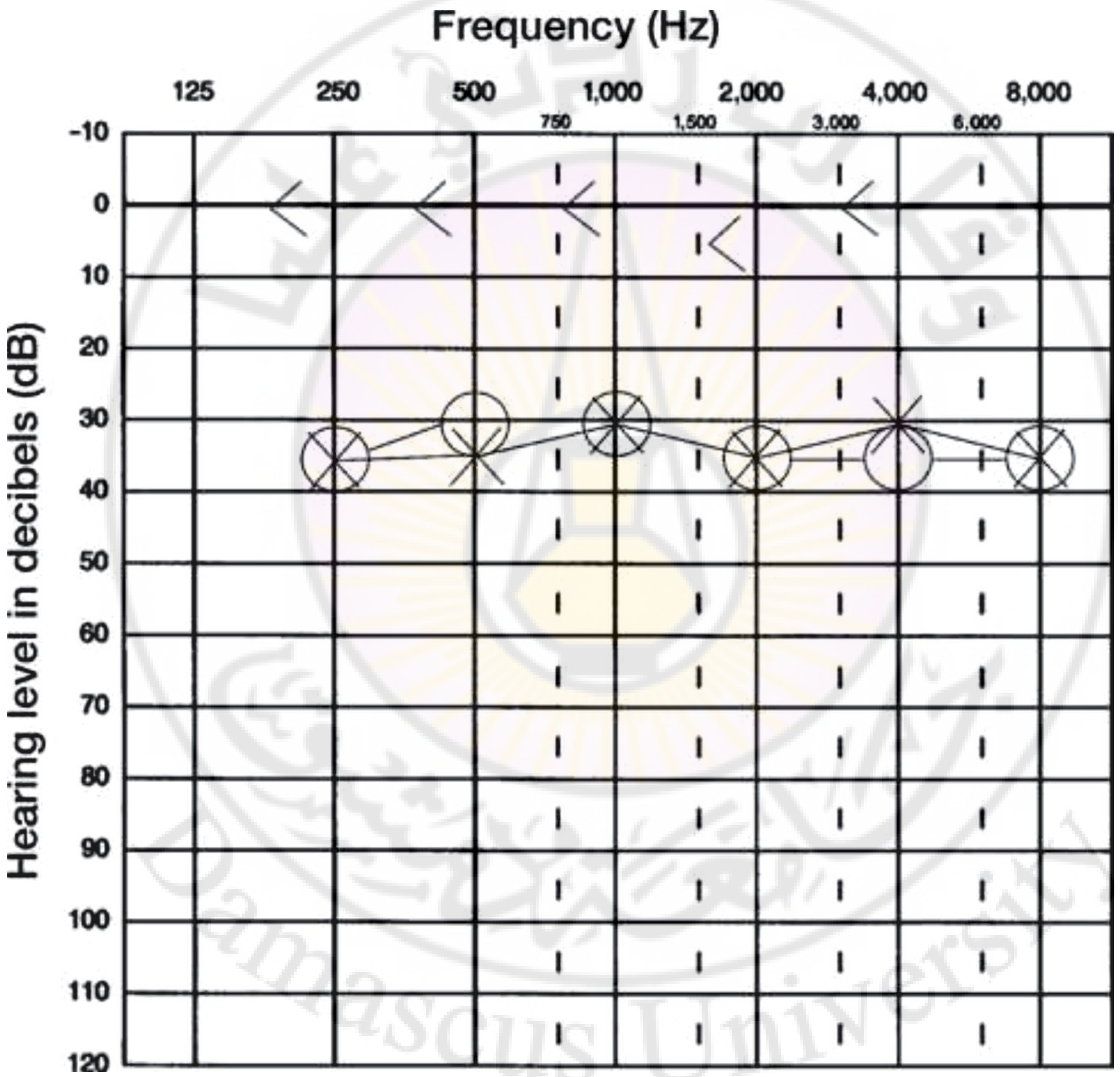
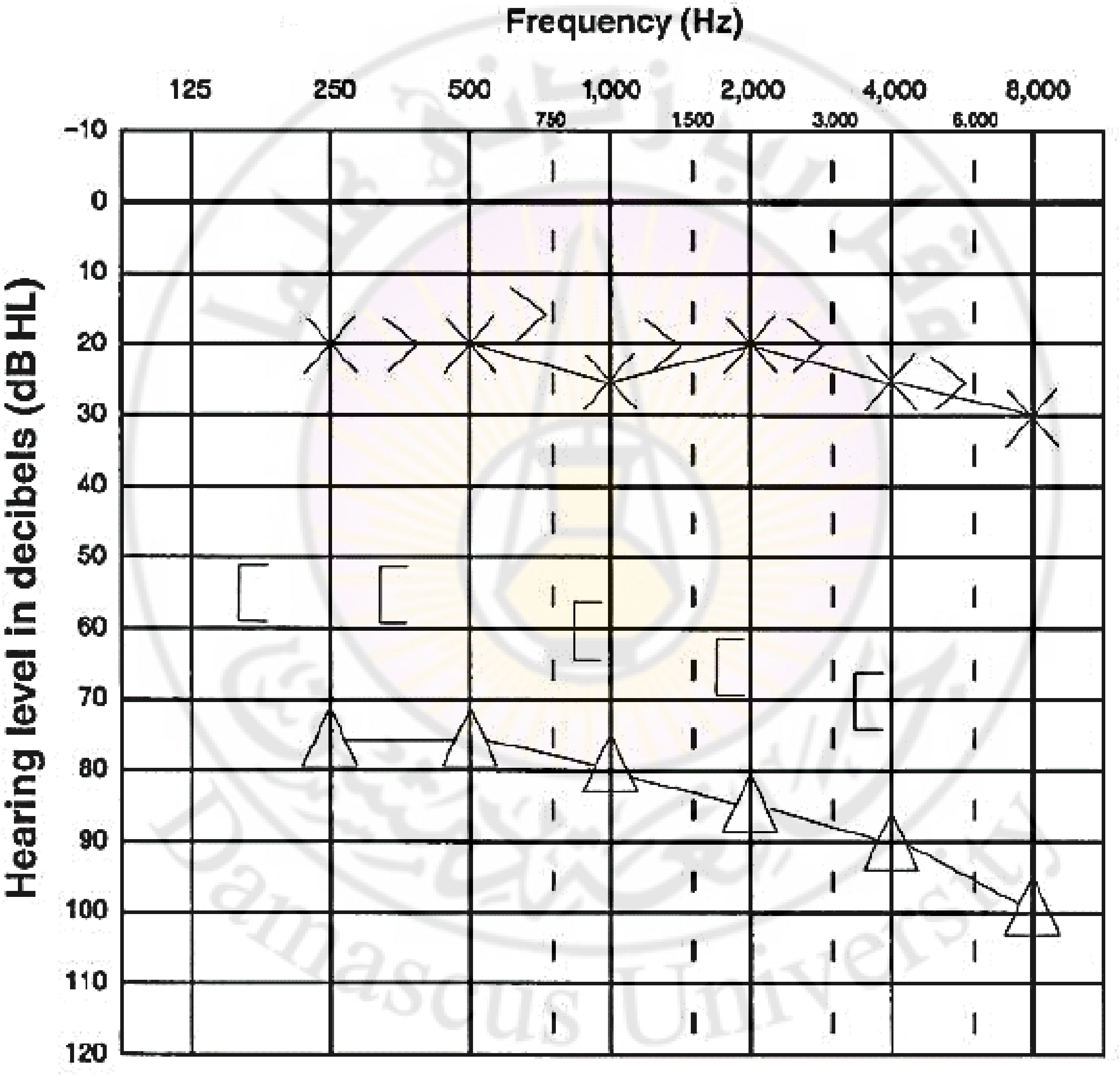


Frequency (Hz)
125
250
500
1,000
2,000
4,000
8,000
750
1,500
3,000
6,000
Hearing level in decibels (dB)
-10
0
10
20
30
40
50
60
70
80
90
100
110
120

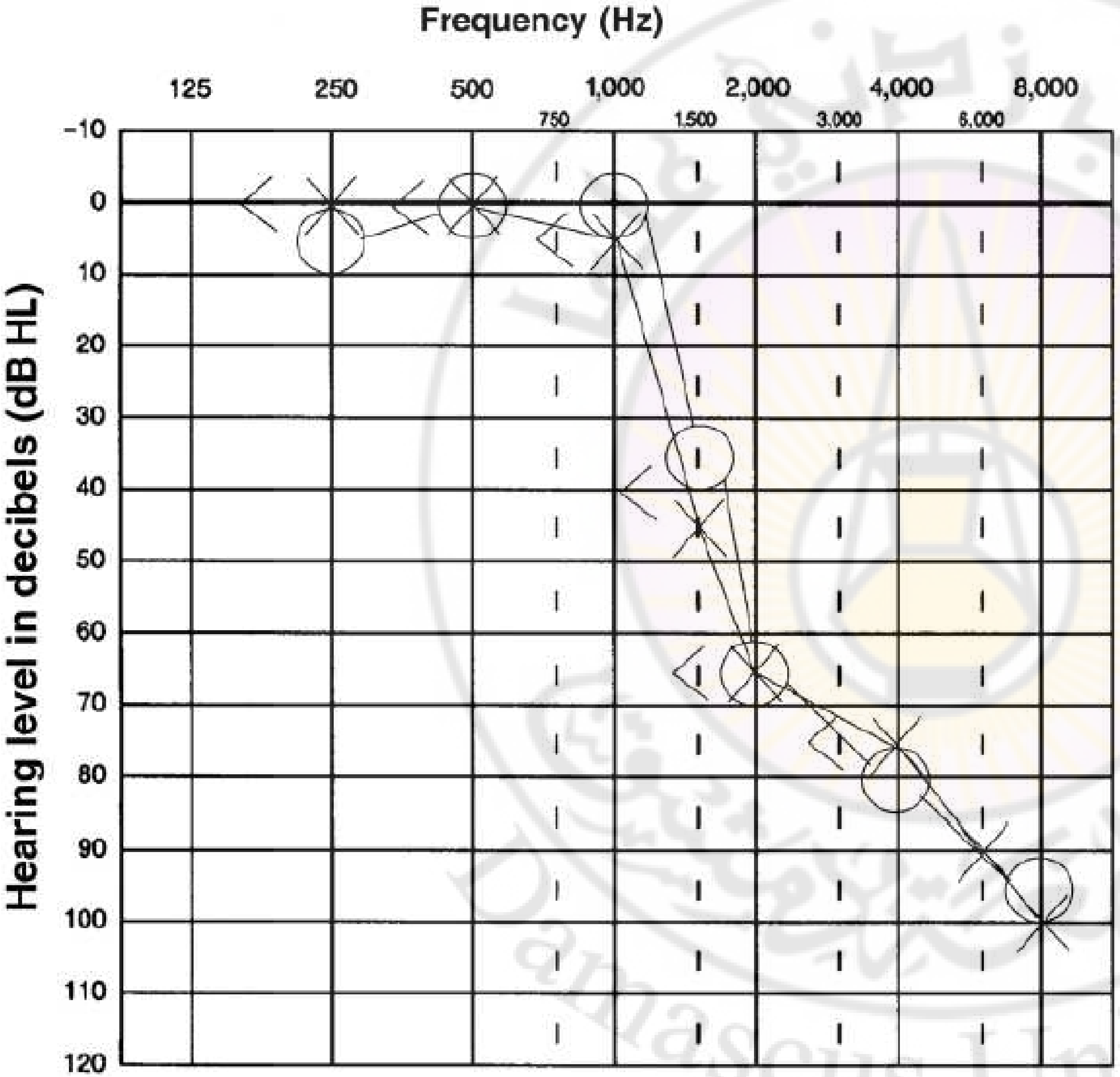
Speech Audiometry

- Because speech audiometry is an air-conduction procedure, the rules for when to mask will be similar to those used during puretone air-conduction audiometry.
- There are three factors to consider when making a decision about the need for contralateral masking during speech audiometry:
  - (1) IA,
  - (2) presentation level of the speech signal (in dB HL) in the test ear, and
  - (3) bone-conduction hearing sensitivity (i.e., threshold) in the nontest ear
- **Contralateral masking is indicated during speech audiometry whenever the presentation level of the speech signal (in dB HL) in the test ear (Presentation Level$_{\text{Test Ear}}$) equals or exceeds the best puretone bone-conduction threshold in the nontest ear (Best BC$_{\text{Nontest Ear}}$) by a conservative estimate of IA (40 dB).**

$$\text{PresentationLevel}_{\text{TestEar}} - \text{BestBC}_{\text{NontestEar}} \geq \text{IA}$$



Frequency (Hz)
125
250
500
1,000
2,000
4,000
8,000
750
1500
3,000
6,000
Hearing level in decibels (dB HL)
−10
0
10
20
30
40
50
60
70
80
90
100
110
120



SRT at both ears: 0 dB HL

Presentation level for WRS: 50 dB HL

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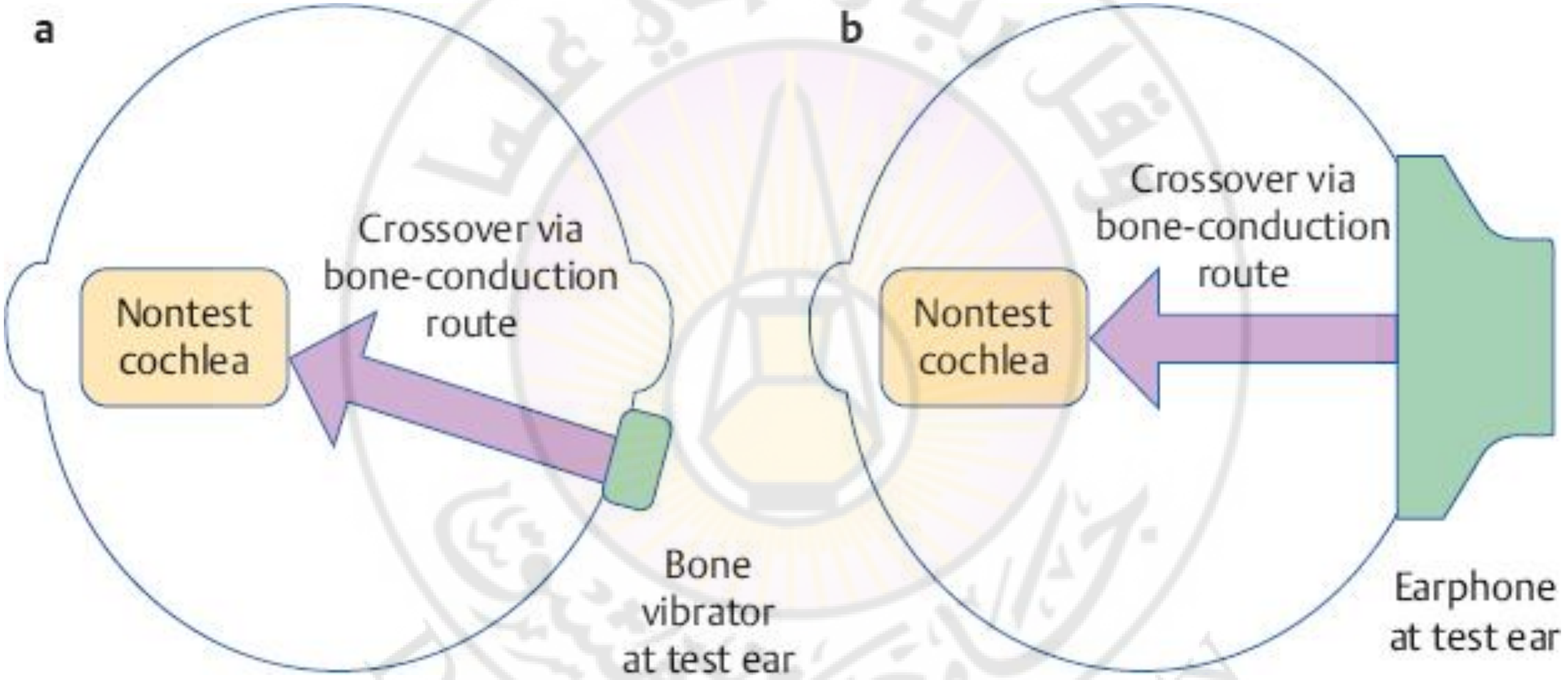
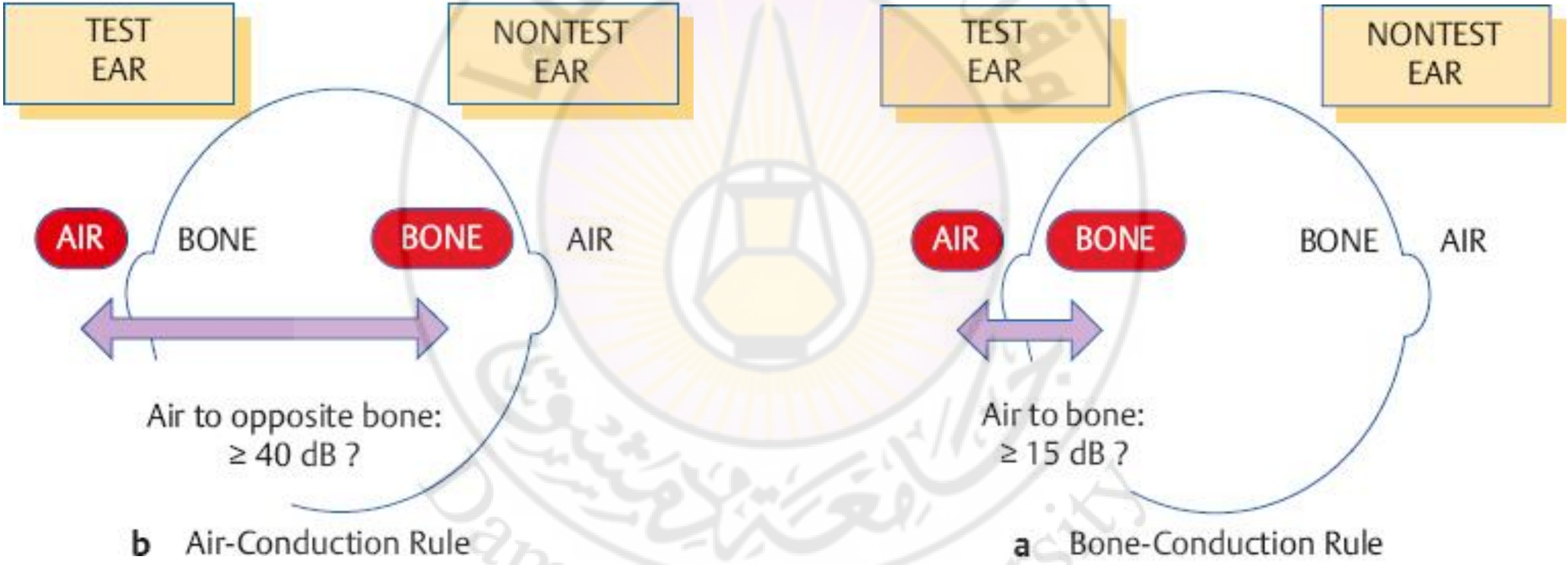
Brief review



Signal crossover and cross-hearing occur via the bone-conduction route to the opposite cochlea

Brief review

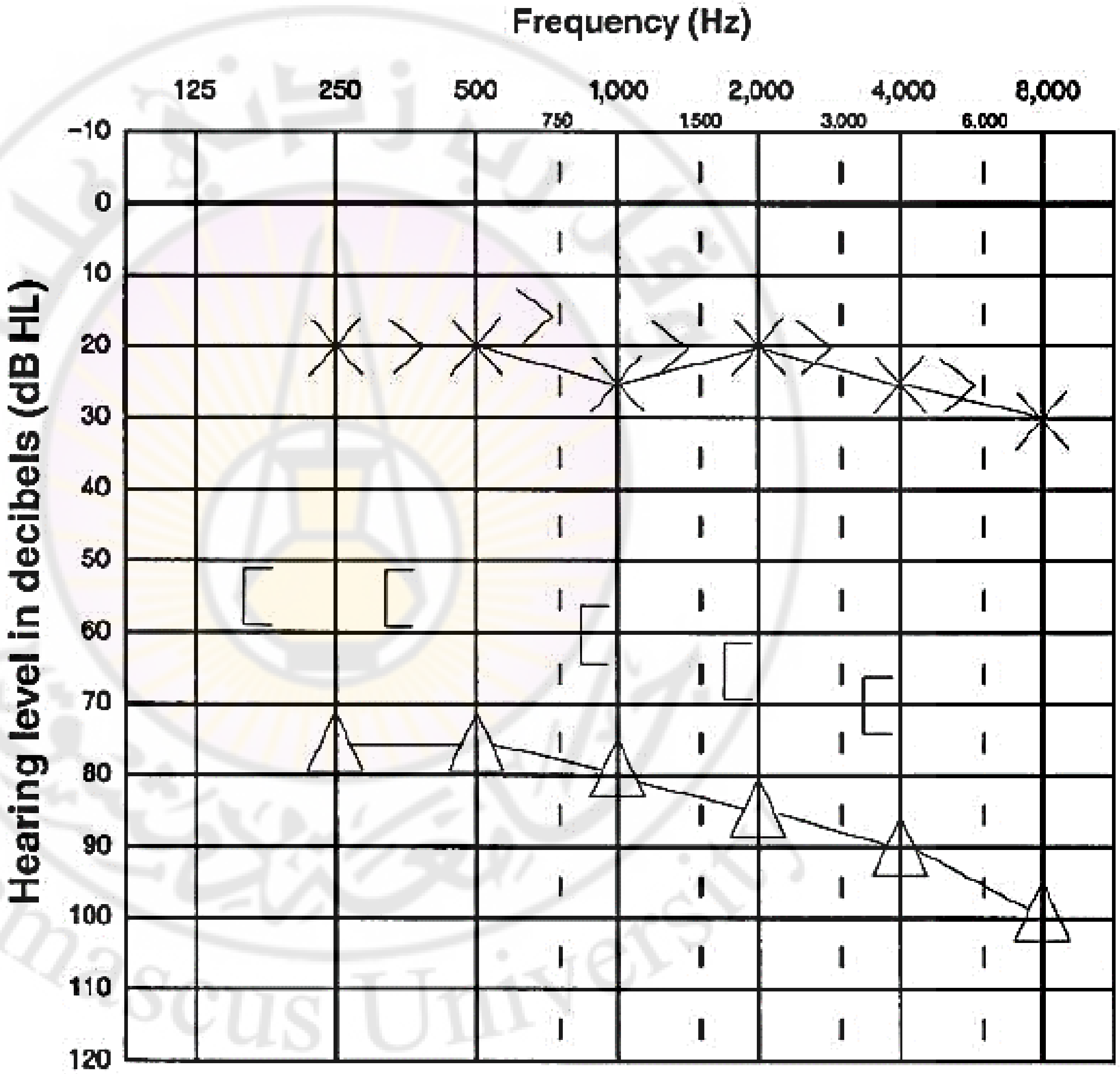


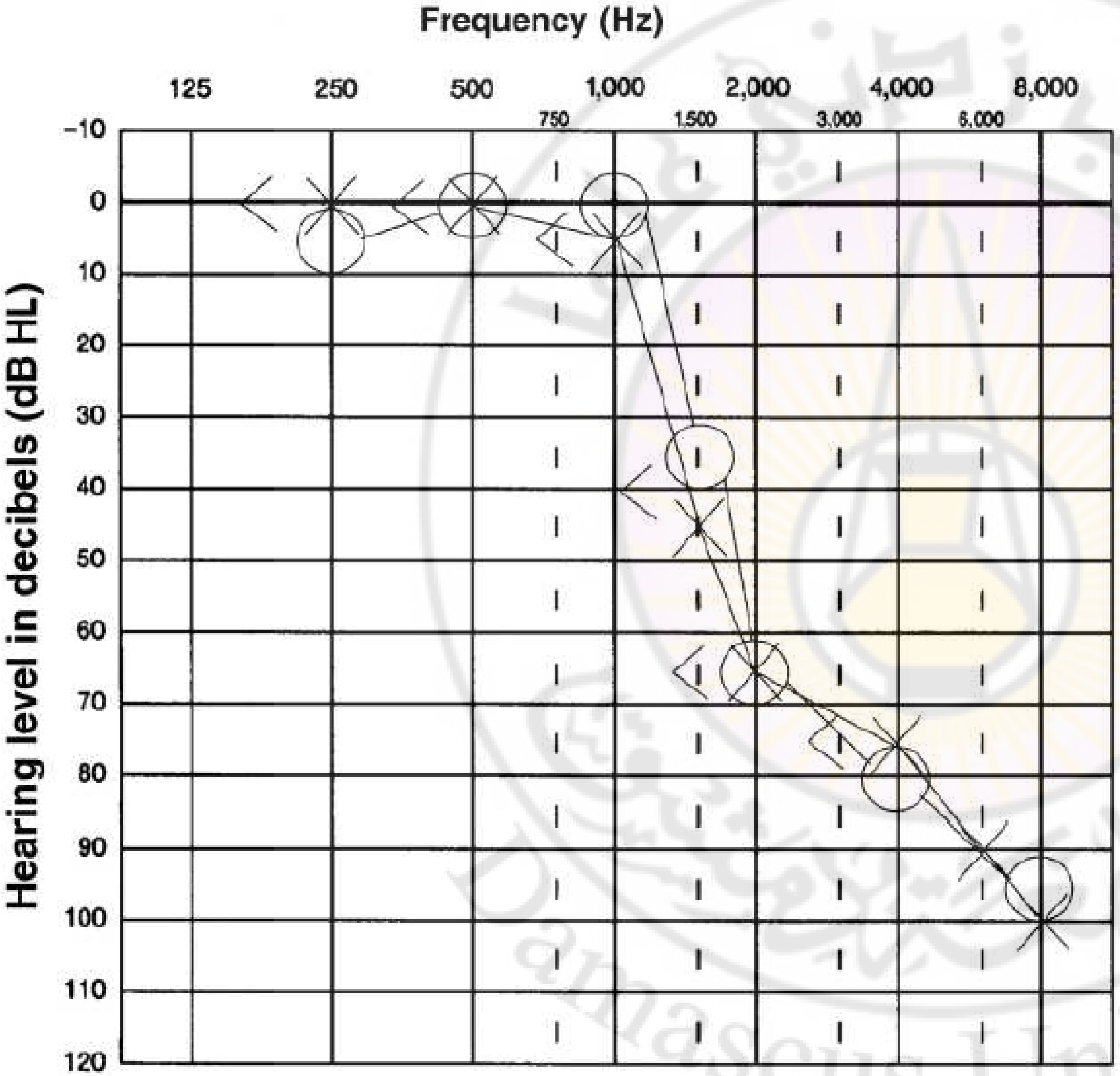
AOBG ≥ 40 dB.

ABG ≥ 15 dB.

Brief review

Masking for SRT is required

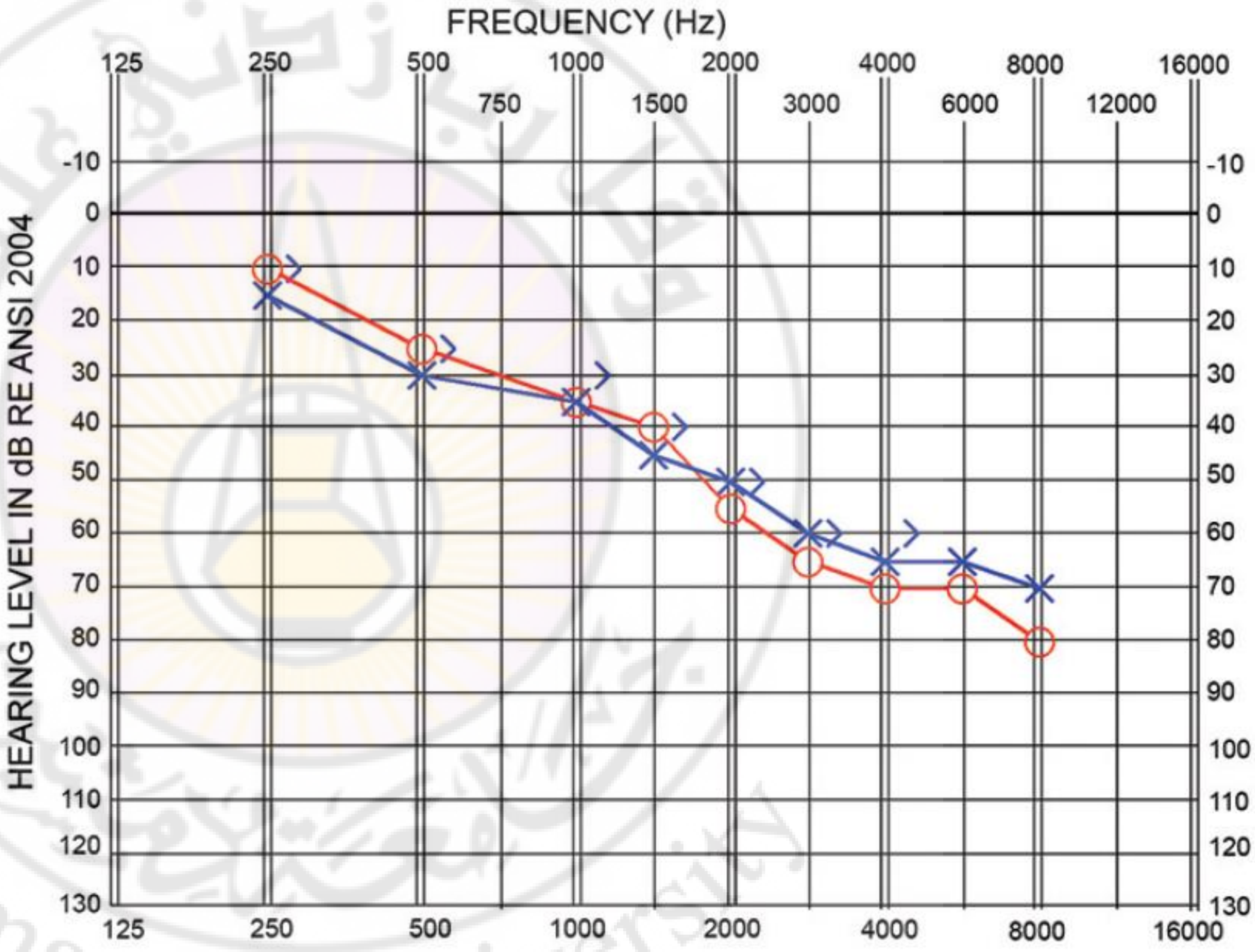




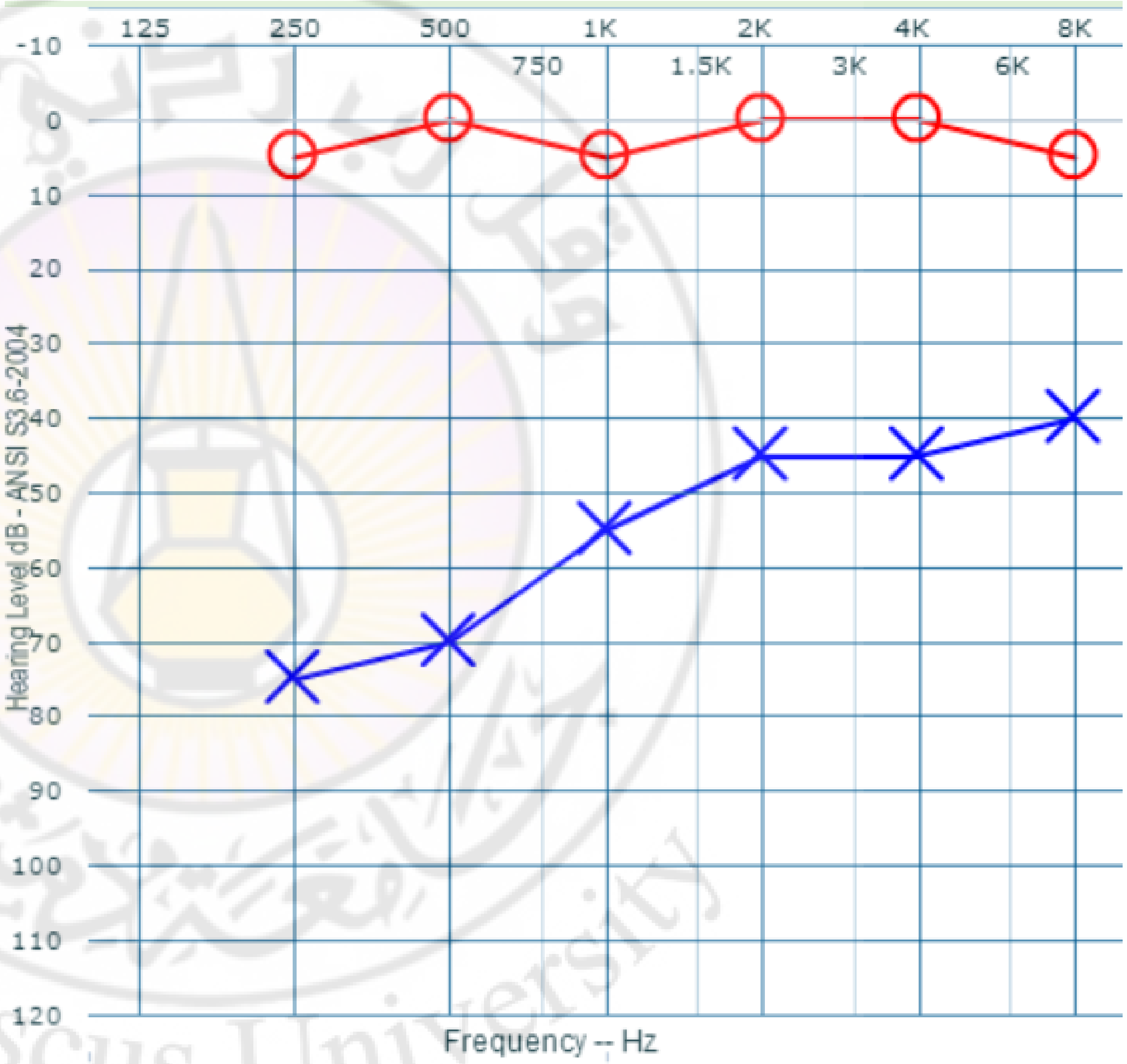
SRT at both ears: 0 dB HL

Presentation level for WRS: 50 dB HL

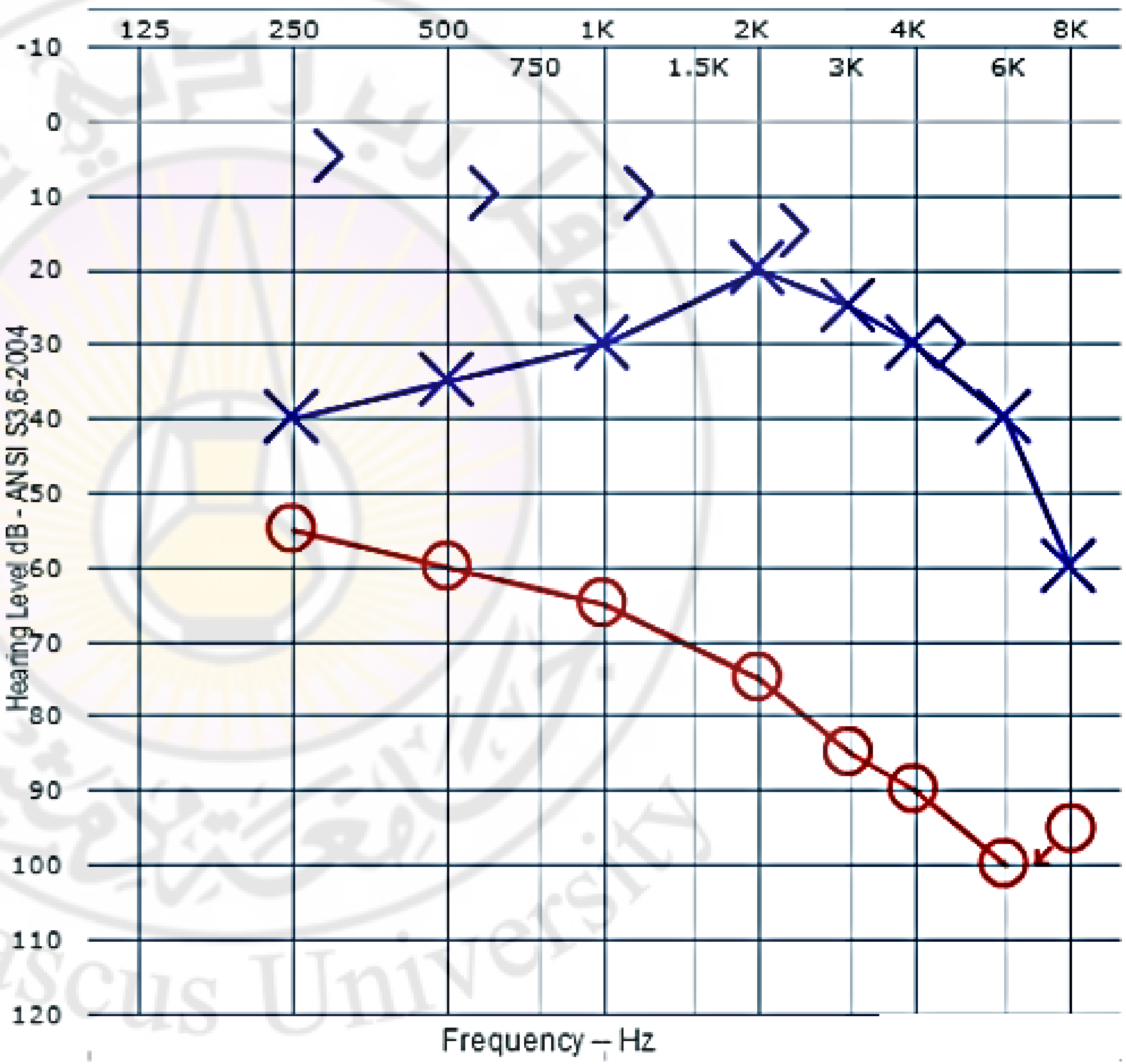
Brief review



Brief review



Brief review



Masking Noise Selection

- **What kind of noise should be used to mask the non-test ear?** The answer to this question depends on the signal being masked. If the signal being masked has a wide spectrum, such as speech or clicks, then the masker must also have a wide spectrum.

- Standard diagnostic audiometers provide three types of masking stimuli:
  - Narrowband noise
  - Speech spectrum noise
  - White noise

- **Puretone audiometry ➢ Narrowband noise (NBN)**

- **Speech Audiometry ➢ Speech spectrum noise or White Noise**

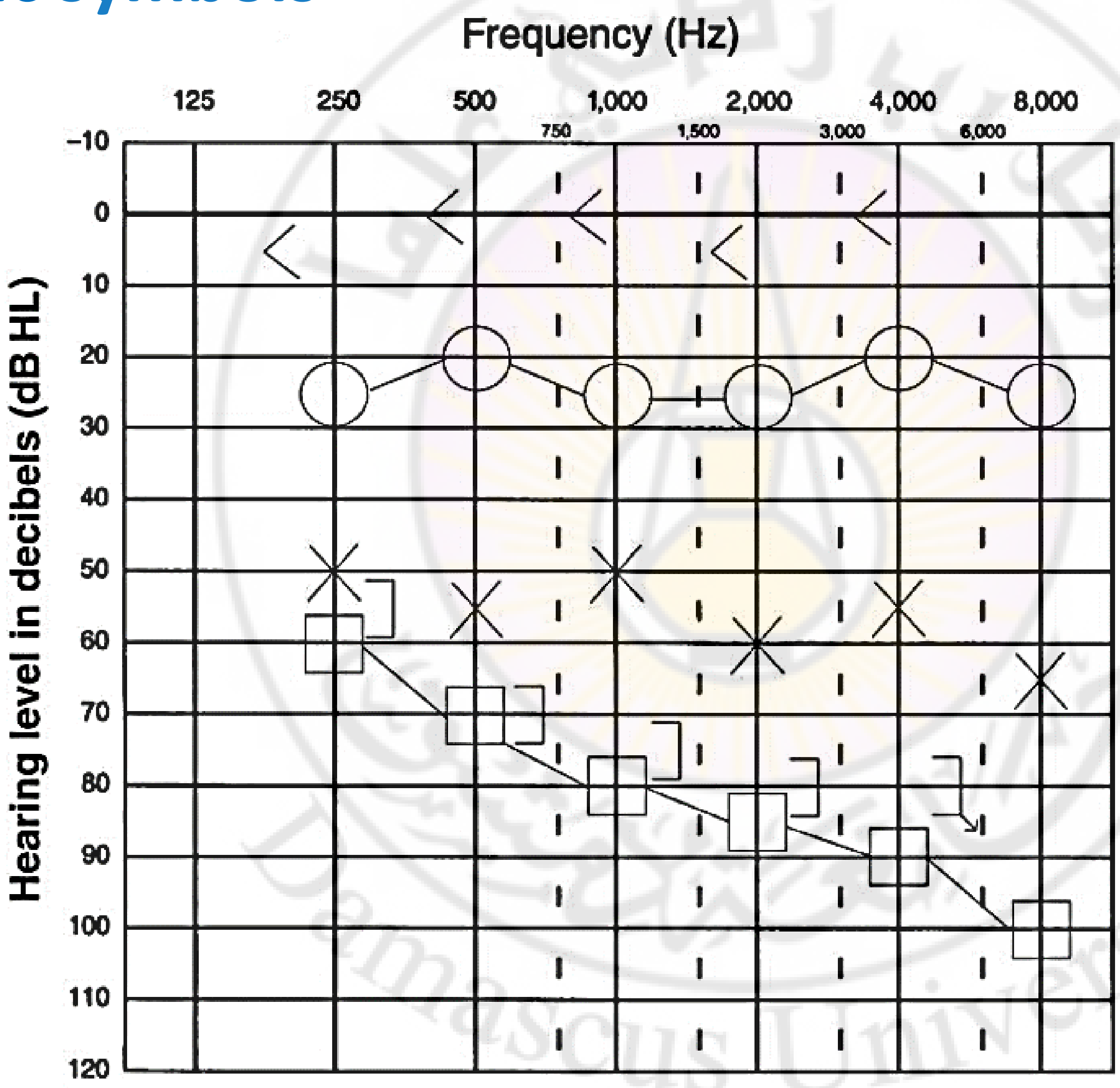
The optimal masking noises for pure tones would be **critical bands**. In practice, however, audiometers actually provide masking noise bandwidths that are wider than critical bands. This type of masking noise is called **narrow-band noise (NBN).**

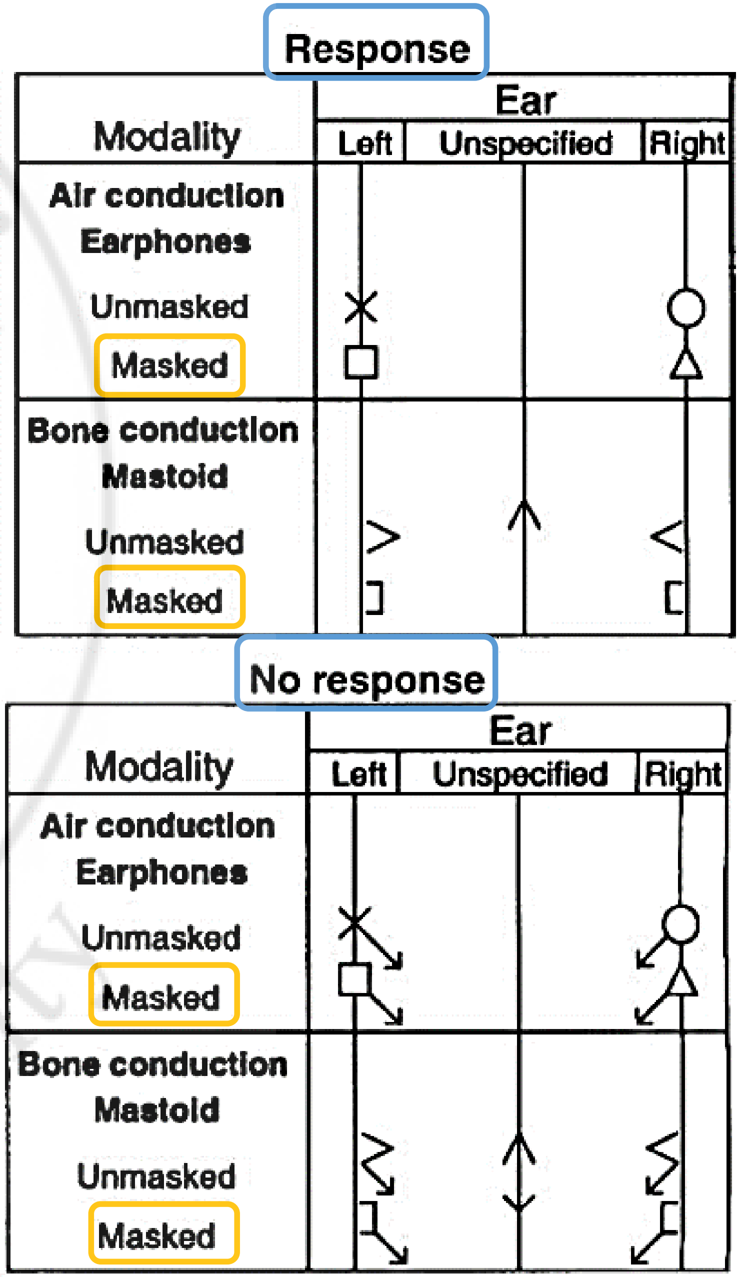
Table 9.1 Allowable lower and upper cut-off frequencies for narrow-band masking noises[a]

	Frequency (Hz)										
	125	**250**	**500**	**750**	**1000**	**1500**	**2000**	**3000**	**4000**	**6000**	**8000**
Lower cutoff frequency (Hz)											
Minimum	105	210	420	631	841	1260	1680	2520	3360	5050	6730
Maximum	111	223	445	668	891	1340	1780	2670	3560	5350	7130
Upper cutoff frequency (Hz)											
Minimum	140	281	561	842	1120	1680	2240	3370	4490	6730	8980
Maximum	149	297	595	892	1190	1780	2380	3570	4760	7140	9510

[a]Based on ANSI S3.6-2010.

Audiometric symbols

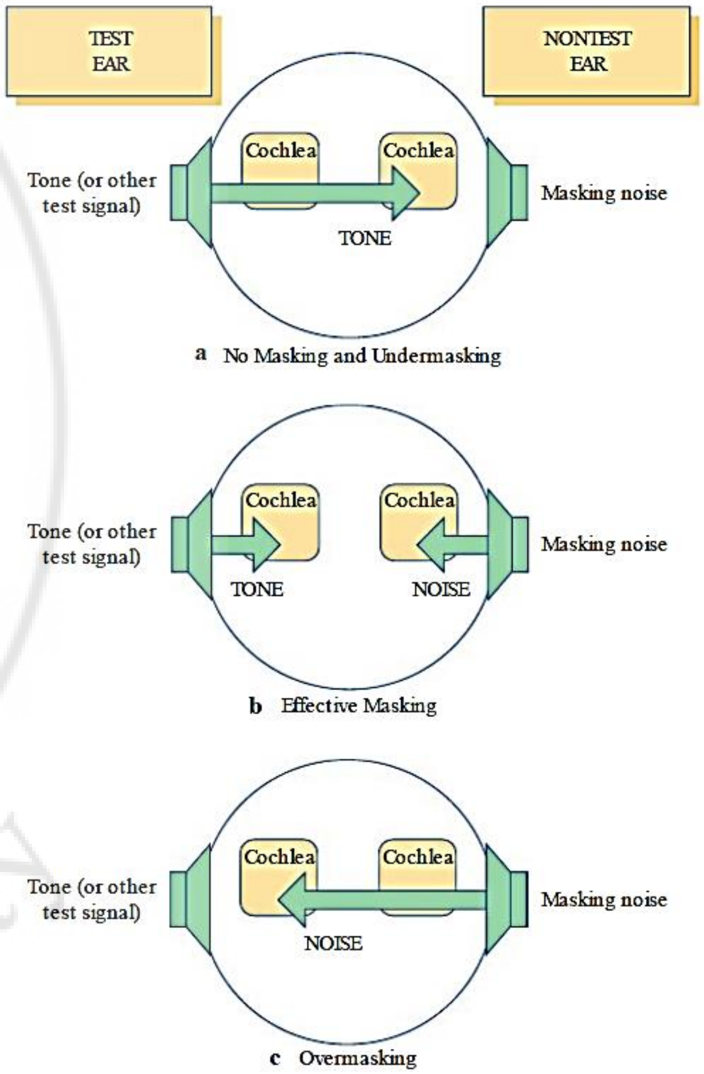




CLINICAL MASKING PROCEDURES

Undermasking and Overmasking

- All approaches to clinical masking address two basic questions:
- First, what is the **minimum level of noise** that is needed in the nontest ear to eliminate its response to the test signal? Stated differently, this is the *minimum masking level* that is needed to avoid ***undermasking*** (i.e., even with contralateral masking, the test signal continues to be perceived in the nontest ear).
- Second, what is the **maximum level of noise** that can be used in the nontest ear that will not change the true threshold or response in the test ear? Stated differently, this is the *maximum masking level* that can be used without ***overmasking*** (i.e., with contralateral masking, the true threshold or response in the test ear has been changed).



The major goal of any clinical masking procedure is the avoidance of both undermasking and overmasking

Major approaches to clinical masking

- **Psychoacoustic procedures (threshold shift or shadowing methods)** are "those based upon observed shifts in the measured threshold as a function of suprathreshold masker effective levels in the nontest ear". ➢➢ *Appropriate for threshold measurements*

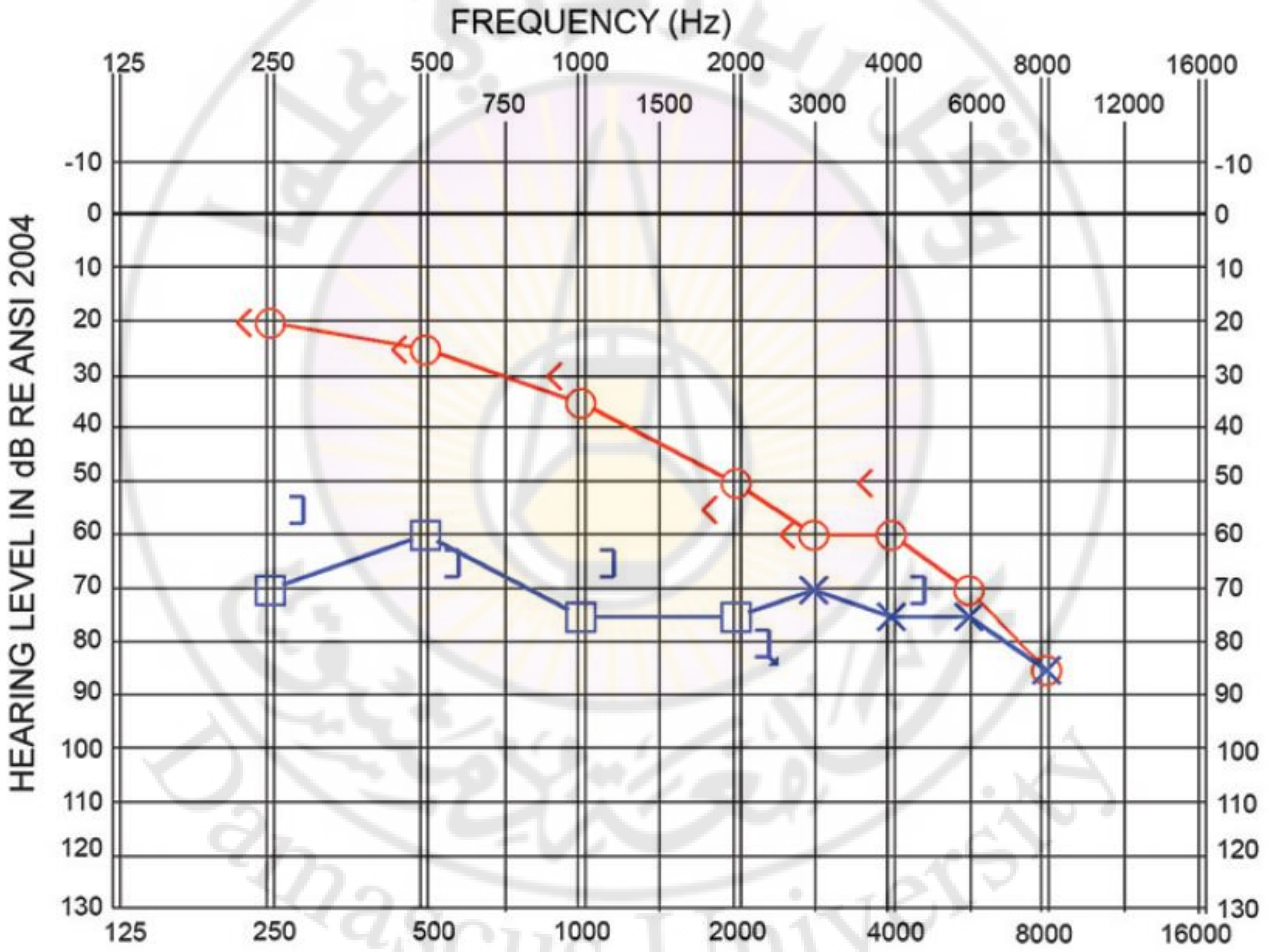
- **Acoustic procedures (calculation or formula methods)** are "those based upon calculating the approximate acoustic levels of the test and masker signals in the two ears under any given set of conditions and on this basis deriving the required masking level". ➢➢ *Appropriate for suprathreshold measurements*

The Initial Masking Level for Air-Conduction

$$IML = HL_{(NTE)} + MEMC + SF$$

- **MEMC** is the minimum effective masking correction (5dB)
- **SF** is the safety factor (10 dB)

$$\mathbf{IML = HL_{(NTE)} + 15\ dB}$$


FREQUENCY (Hz)
125
250
500
1000
2000
4000
8000
16000
750
1500
3000
6000
12000
HEARING LEVEL IN dB RE ANSI 2004
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130

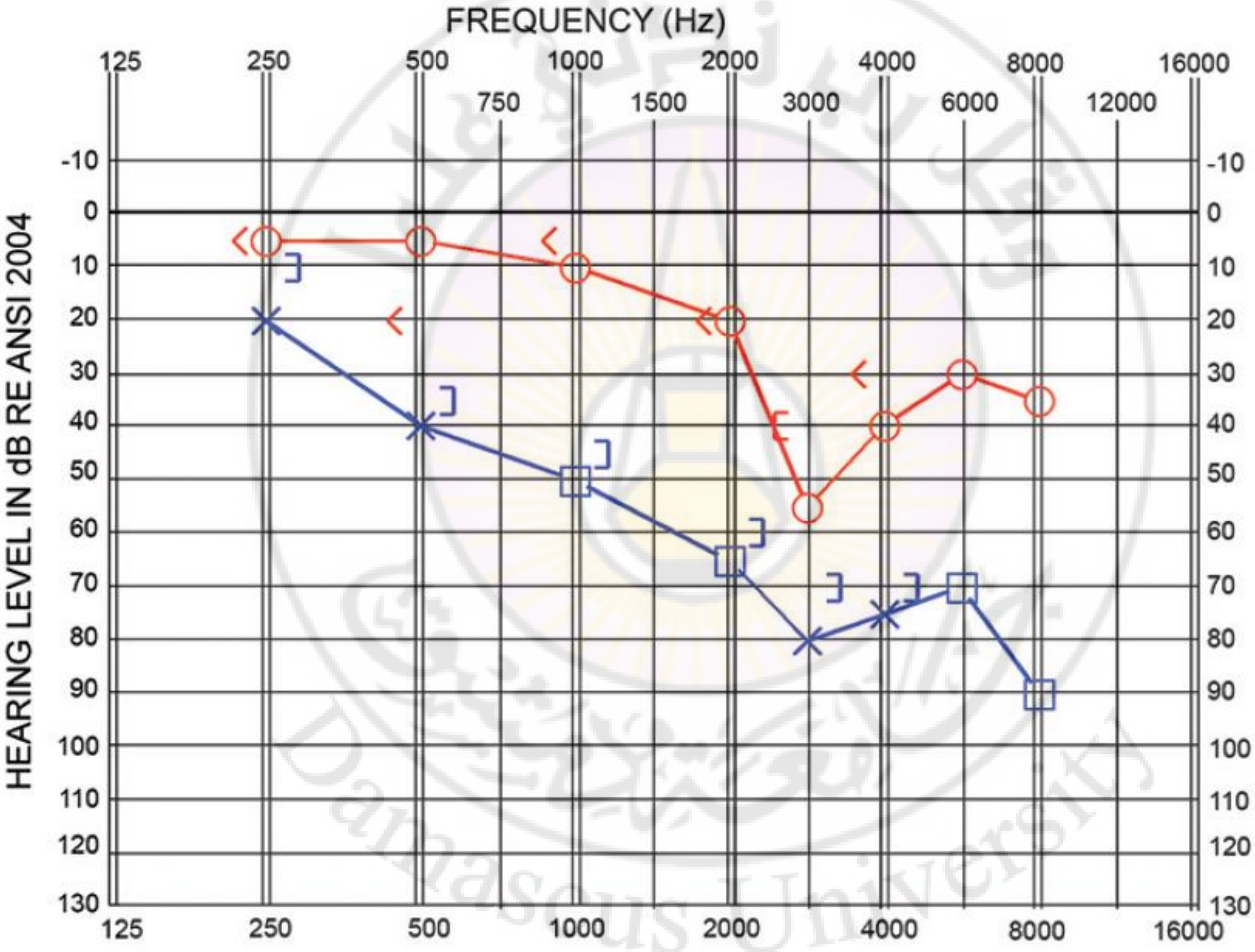
The Initial Masking Level for Bone-Conduction

$$IML = HL_{(NTE)} + MEMC + SF + OE$$

- **MEMC** is the minimum effective masking correction (5dB)
- **SF** is the safety factor (10 dB)
- **OE** is the Correction for the Occlusion Effect (15dB)

$$IML = HL_{(NTE)} + 30\ dB$$

OE is decreased or absent in ears with **conductive** hearing impairment. If the nontest ear exhibits a potential air-bone gap of 20 dB or more, then the OE **should not be added** to the initial masking level at that frequency.

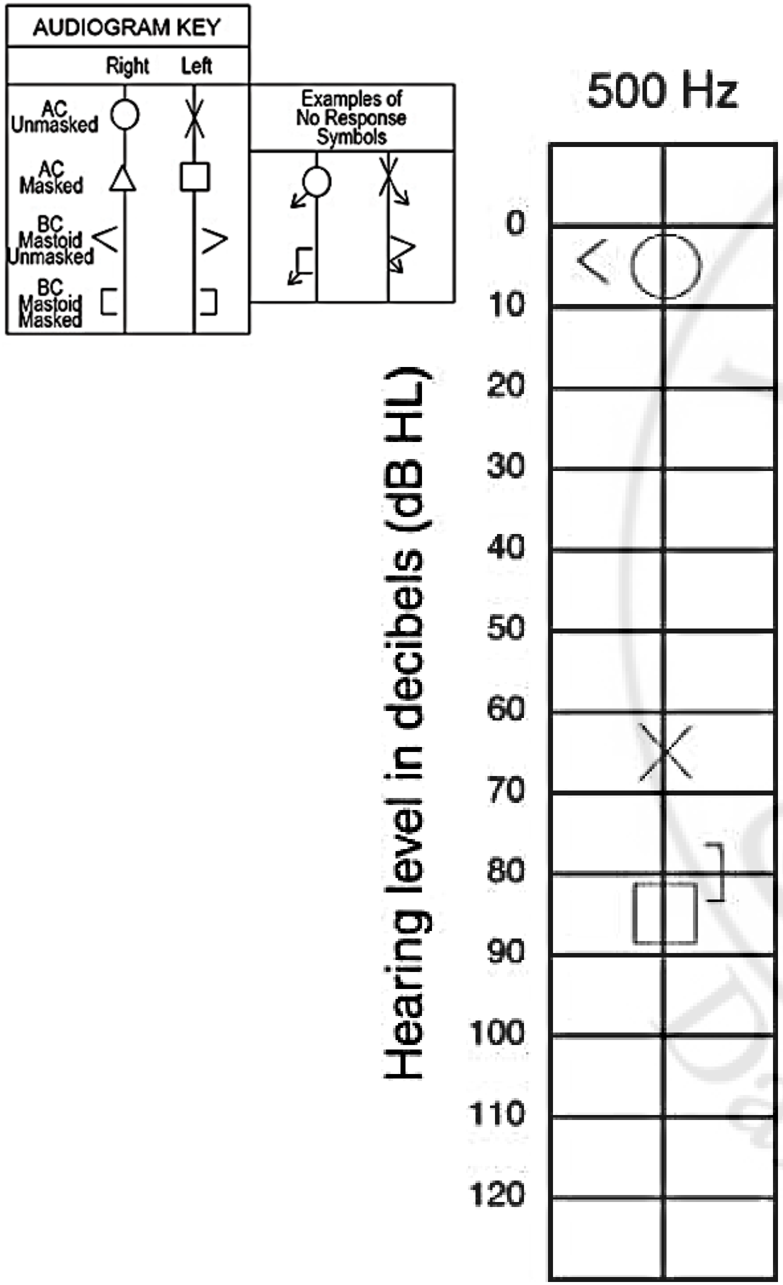

FREQUENCY (Hz)
125 250 500 1000 2000 4000 8000 16000
750 1500 3000 6000 12000
HEARING LEVEL IN dB RE ANSI 2004
-10 0 10 20 30 40 50 60 70 80 90 100 110 120 130

Maximum Masking Level

- Maximum masking level refers to the maximum level of noise that can be used in the nontest ear that will not shift or change the true threshold in the test ear (Overmasking).
- Two factors influence maximum masking level during puretone audiometry:
  - (1) The bone-conduction threshold of the test ear ($BC_{Test\ Ear}$) and
  - (2) IA of the air-conducted masking stimulus

$$M_{Max} = BC_{TestEar} + IA - 5dB$$

Overmasking is more of a potential problem when bone-conduction sensitivity is very good in the test ear.



Question!

Calculate the maximum masking level that can be used during both masked air- and bone-conduction audiometry?

$$M_{Max} = BC_{Test\,Ear} + IA - 5\text{ dB}$$
$$= 80\text{ dB HL} + 60\text{ dB} - 5\text{ dB}$$
$$= 135\text{ dB EM}$$

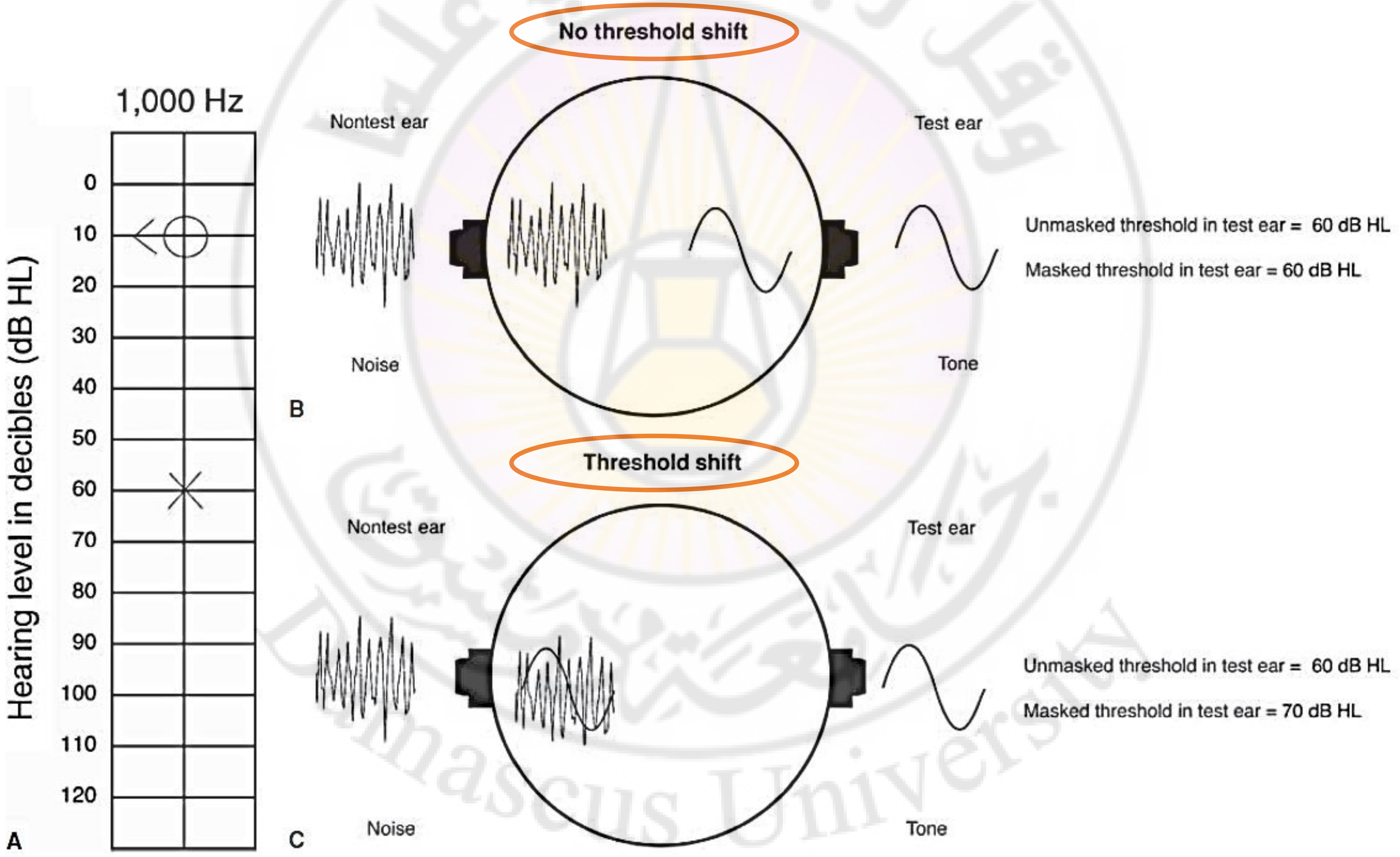
Overmasking…

- the true bone-conduction threshold (obtained with appropriate contralateral masking) in the test ear is typically not known when maximum masking level is estimated during both air- and bone-conduction threshold audiometry. Because only an unmasked bone-conduction threshold is available at the time that masking levels are determined, we are required to use the unmasked threshold as the estimate of bone-conduction hearing sensitivity in the test ear.

- Whenever an unmasked bone-conduction threshold is used during determination of maximum masking, the resultant value is **typically smaller** than the masking level that will actually result in overmasking.

- Although the actual calculation of maximum masking level during puretone threshold audiometry is often of limited use, consideration of the maximum level of noise that can be used in the nontest ear can alert the audiologist to the possibility of overmasking, ***particularly in cases of conductive hearing loss*** when bone-conduction hearing sensitivity is very good.

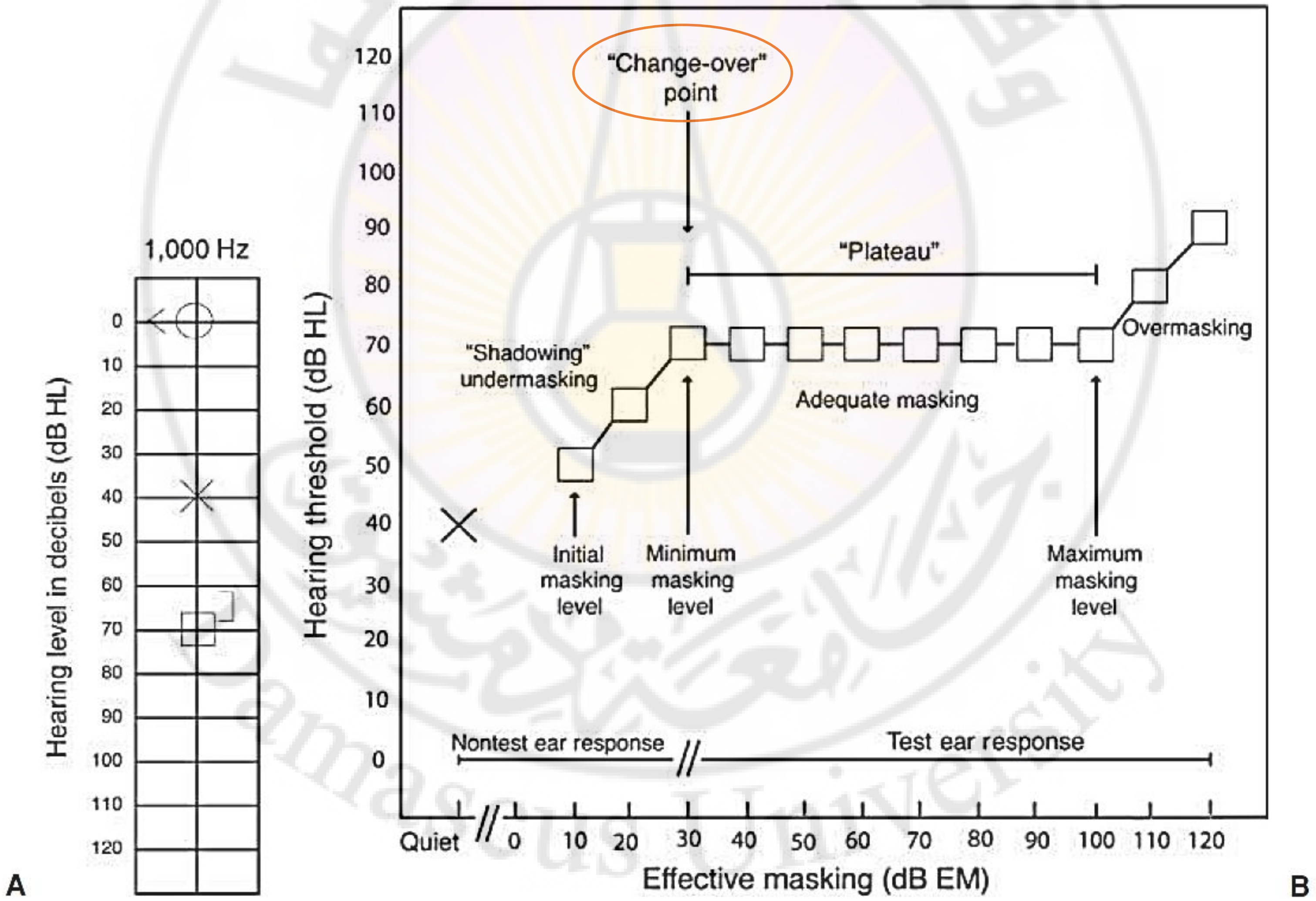
Recommended Clinical Procedure



Recommended Clinical Procedure

The underlying concept of the **Hood procedure** is that the introduction of masking to the nontest ear will produce a masking effect (i.e., a threshold shift) only if the nontest ear is contributing to the observed response. Decisions about which ear is contributing to the measured threshold are based on whether a threshold shift occurs when masking is introduced to the nontest ear.

The Plateau Method; Hood (1960)



The Plateau Method; Hood (1960)

1. Masking noise is introduced to the nontest ear at the initial masking level. Puretone threshold is then re-established.

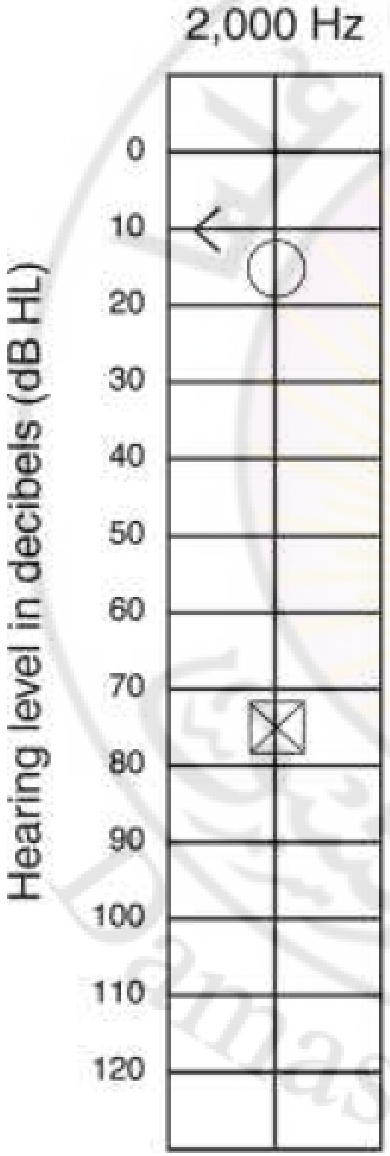
2. Level of the tone or noise is increased subsequently by 5 dB.

- If there is a response to the tone in the presence of the noise, the level of the **noise** is increased by 5 dB.
- If there is no response to the tone in the presence of the noise, the level of the **tone** is increased in 5-dB steps until a response is obtained.

3. A plateau has been reached when the level of the **noise** can be increased **over a range of 15 to 20 dB without shifting the threshold** of the tone. This corresponds to a response to the tone at the same HL when the masker is increased in **three to four** consecutive levels.

4. Masked puretone threshold corresponds to the HL of the tone at which a masking plateau has been established.

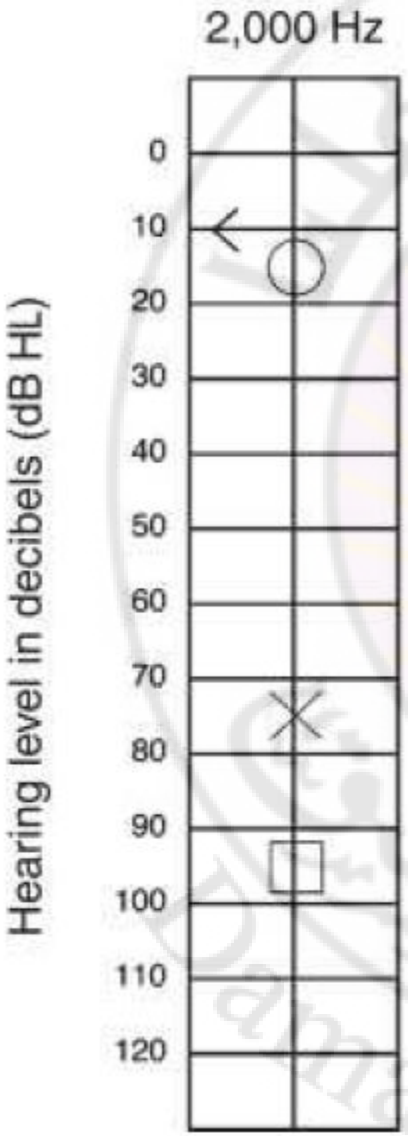
Outcome 1



dB EM	dB HL
--	75
25	75
30	75
35	75
40	75
45	75

Threshold = 75 dB HL

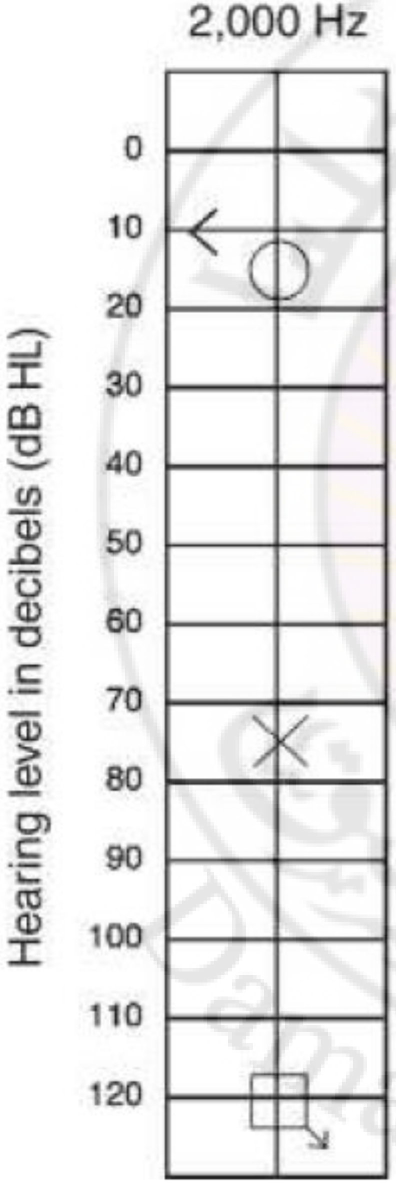
Outcome 2



dB EM	dB HL
--	75
25	85
30	90
35	95
40	95
45	95
50	95
55	95

Threshold = 95 dB HL

Outcome 3



dB EM	dB HL
--	75
25	85
30	90
35	95
40	100
45	105
50	110
55	115
60	120
65	NR

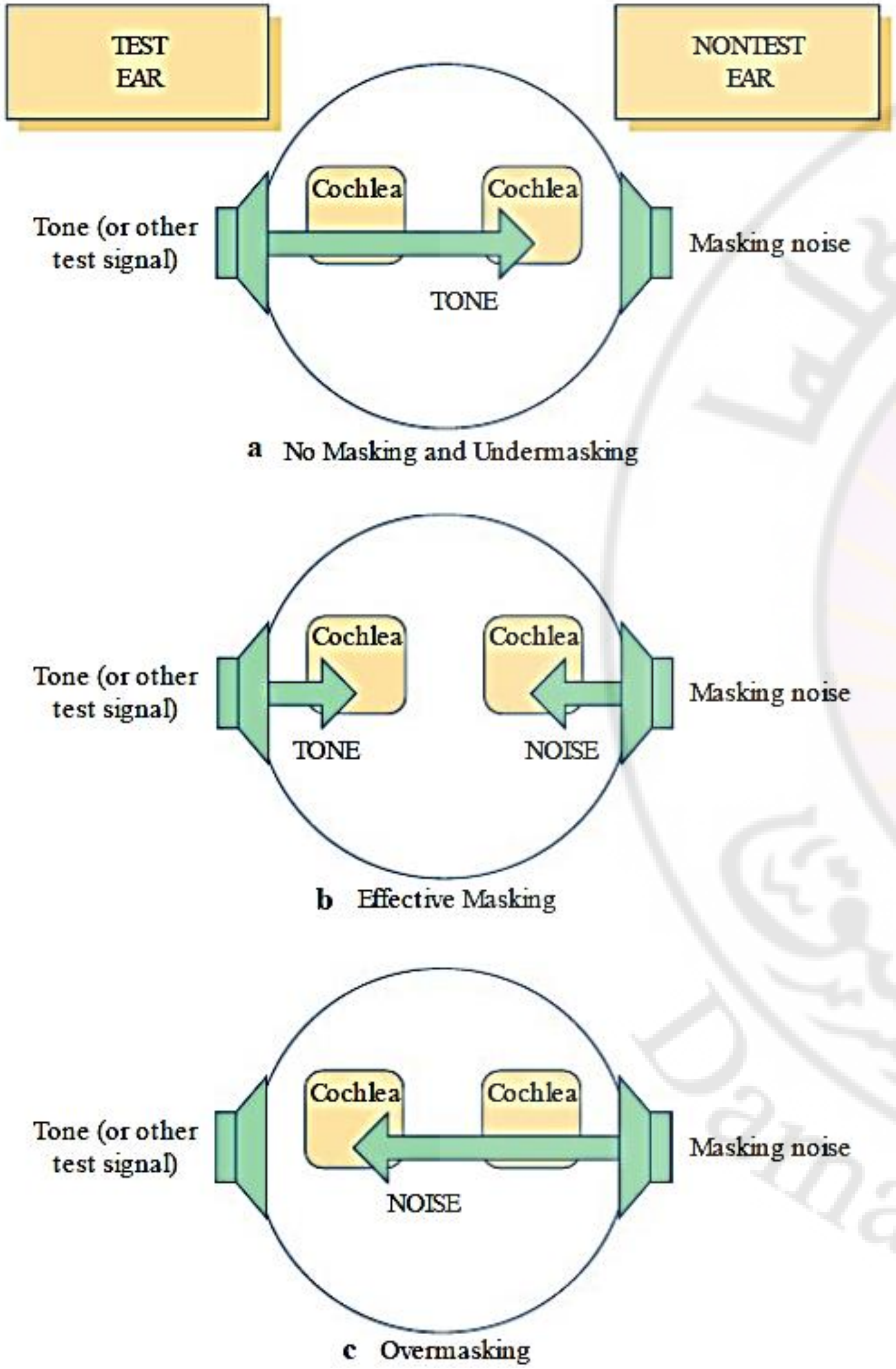
No response at 120 dB HL

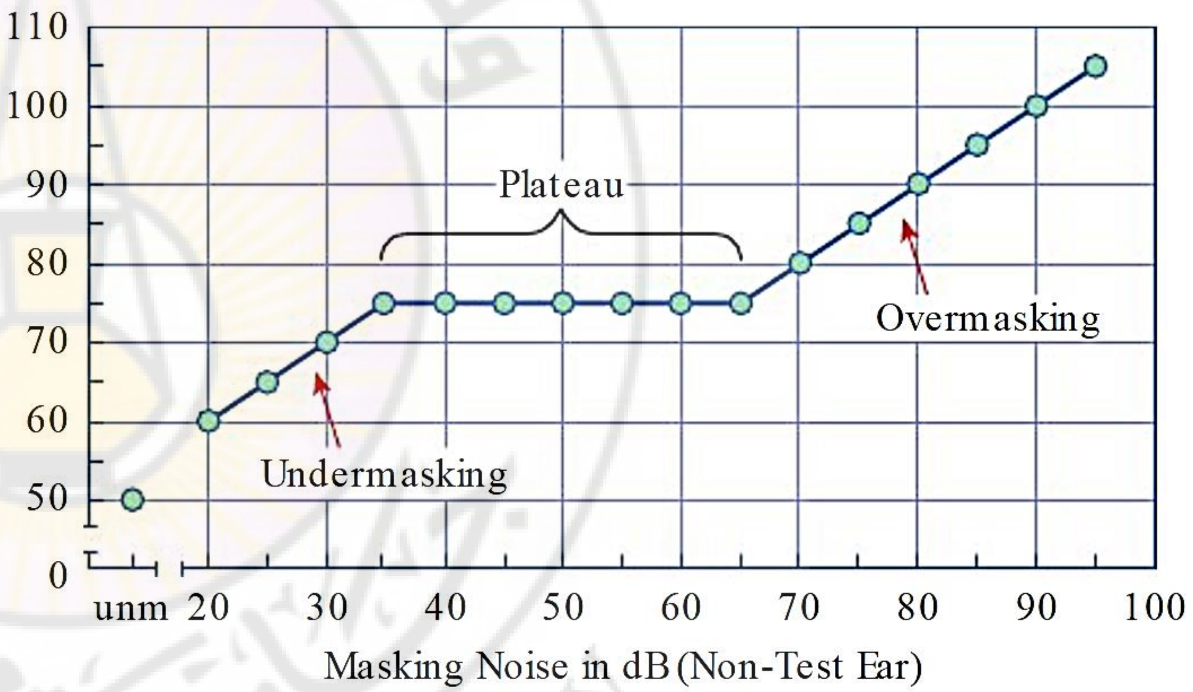
The Plateau Method; Hood (1960)

- The clinical goal of the plateau procedure is to establish the HL at which puretone threshold remains unchanged with increments in masking level.

- Clinically, it is neither time efficient nor necessary to measure the entire masking plateau.

- It is generally agreed that a masking "plateau" has been established when masker level can be increased over a range of at least 15 to 20 dB (3 steps of 5 dB increments) without shifting puretone threshold.


TEST
EAR
NONTEST
EAR
Cochlea
Cochlea
Tone (or other
test signal)
Masking noise
TONE
a No Masking and Undermasking
Cochlea
Cochlea
Tone (or other
test signal)
Masking noise
TONE
NOISE
b Effective Masking
Cochlea
Cochlea
Tone (or other
test signal)
Masking noise
NOISE
c Overmasking


110
100
90
80
70
60
50
0
Plateau
Overmasking
Undermasking
unm 20 30 40 50 60 70 80 90 100
Masking Noise in dB (Non-Test Ear)

Arrangement of the bone vibrator and earphones during masking for bone-conduction.

REVIEW TABLE 5.1 Masking for Pure-Tone Hearing Tests*

Test	*Air Conduction (AC)*	*Bone Conduction (BC)*
When to mask	When difference between AC (test ear) and BC (nontest ear) exceeds minimal IA.	When there is an air-bone gap greater than 10 dB in the test ear.
How to mask	Initial masking: IM = AC of nontest ear plus the predetermined correction factor. If tone not heard, plateau.	Same as AC plus occlusion effect in masked ear.
Overmasking occurs	When EM level in masked ear minus IA is equal to or greater than BC of test ear at same frequency.	Same as AC.

** Minimal interaural attenuation (IA) is considered to be 40 dB for supra-aural earphones. IA varies by frequency for insert earphones as described in the text.*

Behavioral Tests for Audiological Diagnosis

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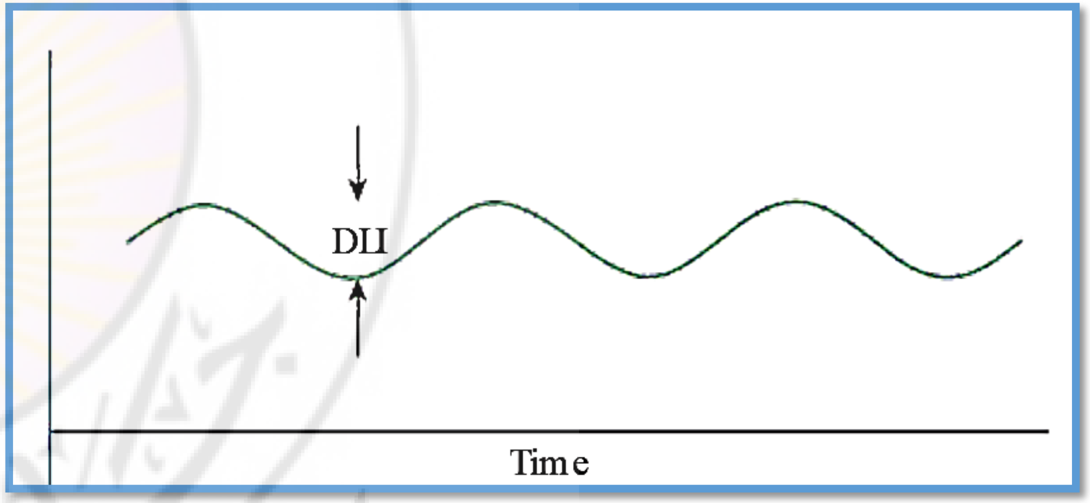
Intensity Difference Limen Tests

- the smallest difference in intensity that can be perceived is called the **difference limen for intensity (DLI)** or **Just noticeable difference (JND)**.
- The DLI is smaller than normal in patients who have loudness recruitment, and thus several DLI tests have found their way into and out of clinical use over the years.
- The DLI tests assess one ear at a time, so they can be used with either bilateral or unilateral hearing losses.
- **DLI tests**
    - **Lüscher-Zwislocki test**
    - **Denes-Naunton test**
    - **The SISI Test**

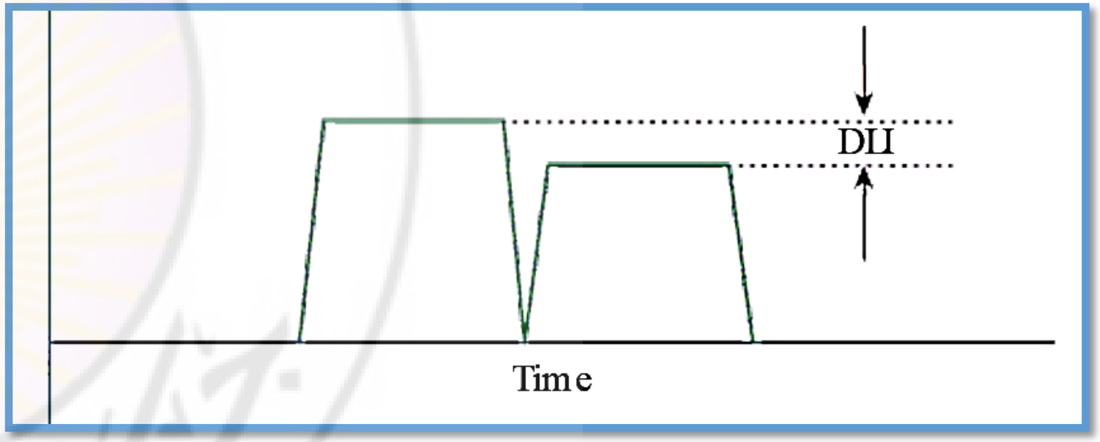
Lüscher-Zwislocki test

- In the **Lüscher-Zwislocki test** (1949) the patient heard an *amplitude-modulated (AM) tone* at 40 dB SL. The AM tone undulates in level at a regular rate such as twice per second.
- The patient was asked to listen to this tone and to indicate whether it sounded **continuous** or if it seemed to **undulate** in level.
- The smallest amount of AM that could be detected was thus the patient's difference limen for intensity.
- The DLIs were smaller for patients who had recruitment than for those without recruitment.
- This test was originally done at 40 dB SL, but modifications have been done at ≥ 80 dB HL (Lüscher 1951) and at 15 dB SL (Jerger 1952).



Denes-Naunton test

- Here, the patient was presented with a pair of tones, one after the other, and had to decide whether they were equal or if one was louder than the other.
- Many pairs of tones were presented to the patient. To find the DLI, the first tone was always kept at the same level, but the second tone would be changed in level (or vice versa).
- The procedure continued until the tester found the smallest level difference that the patient could detect.
- This was done for tone pairs presented at **4 dB SL and at 44 dB SL.** The test was interpreted by comparing the *relative* sizes of the DLIs obtained at these two SLs.
- Intensity DLs were found to stay the same or get larger going from 4 dB SL to 44 dB SL in ears with **recruitment**.
- On the other hand, the DLIs were smaller at the higher SL in ears without **recruitment**.

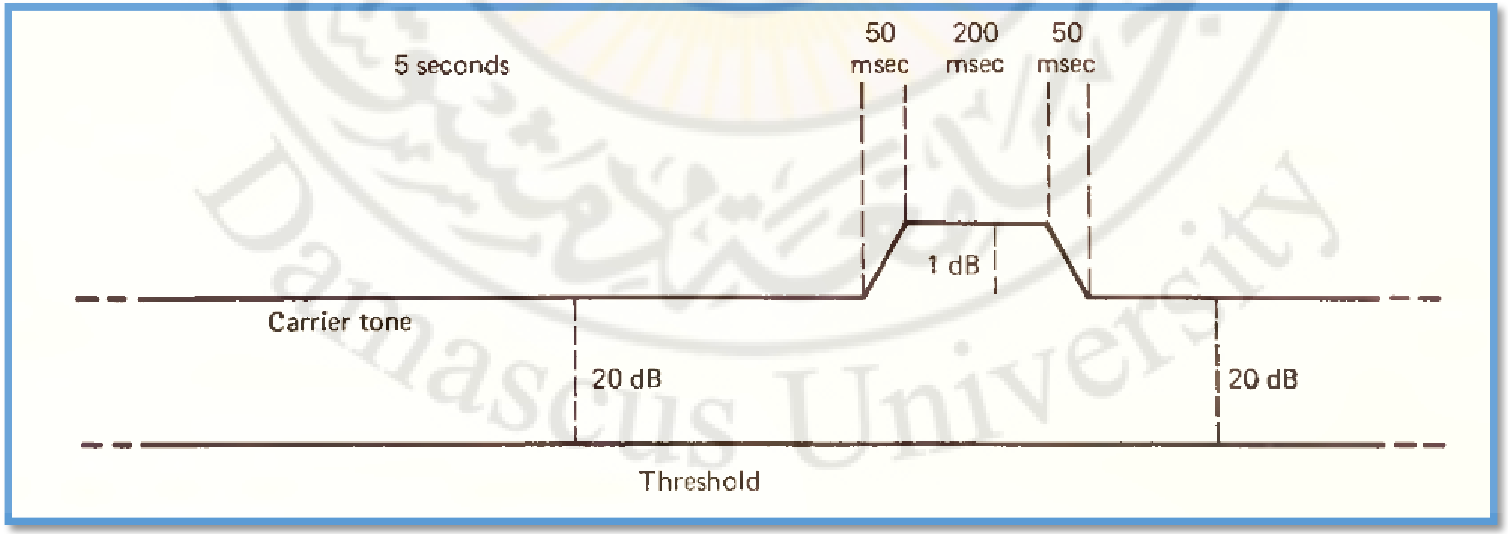


Short Increment Sensitivity Index (SISI)

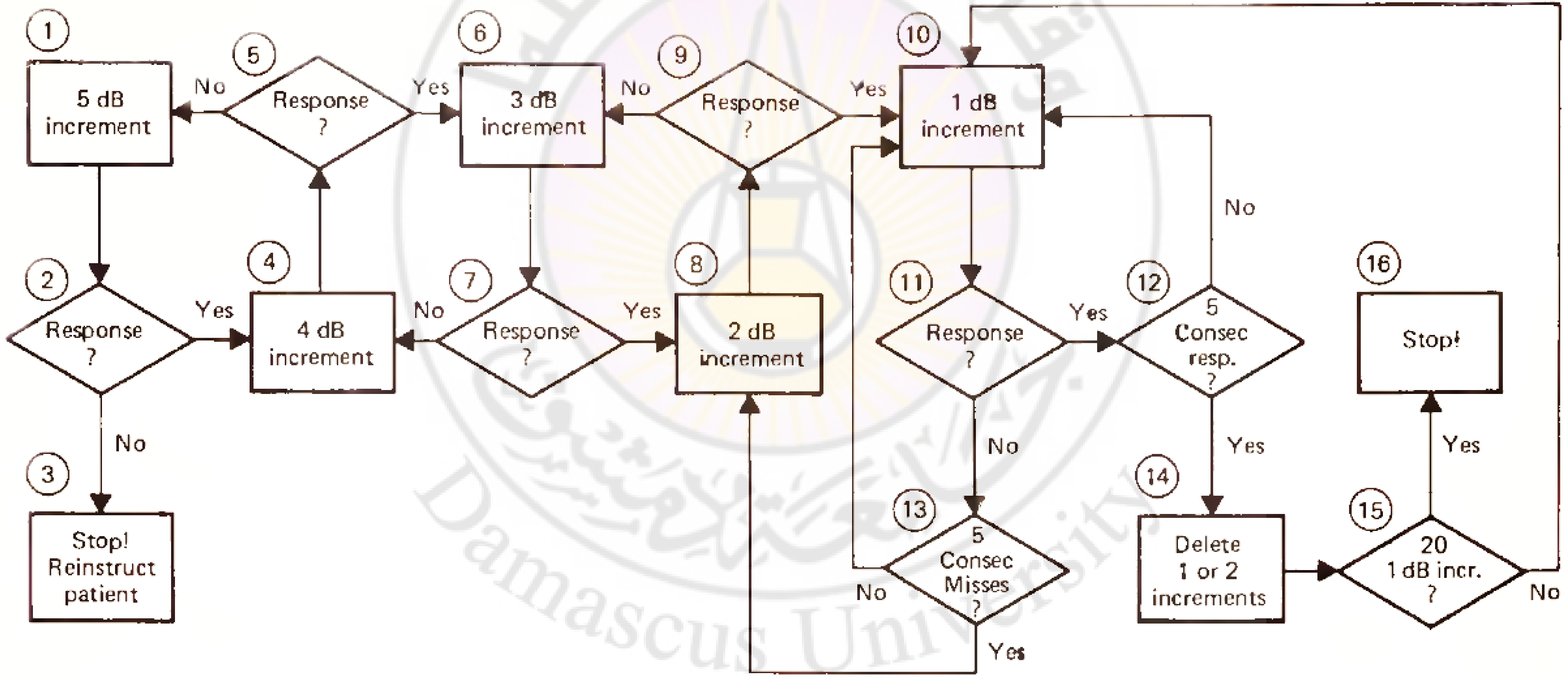
- Developed by Jerger et al (1959), it is a simple test where the patient should indicates when a steady tone increased in loudness.
- Jerger has suggested that the SISI test should not be viewed as a test for recruitment rather it is a site of lesion test
- It's results are complement to loudness balance testing. However, they are different tests

Conventional (or 20 dB SL) SISI test: Procedure

- A steady or carrier tone presented at **20 dB SL** with reference to the puretone threshold for the test frequency, with small increases in intensity occurring every 5 seconds.
- The patient is to report whenever an increase in loudness is perceived.
- Originally, the test was to begin with several 5-dB increments-typically heard by most patients-followed by 20 1-dB test increments.



Flow Chart for performance of the SISI



Conventional SISI test: Interpretation

- Response to each of the 1-dB increments is worth 5%.
- Typically, those with cochlear losses hear most of the 1-dB increments (high or positive SISI scores).
- Those with normal hearing or non cochlear lesions perceive few or no increments (low or negative SISI scores).
- For example, a SISI score of 100% means that all 20 pulses were heard, and a score of 40% means that only 8 of them were detected.

- **Its recommended to perform the SISI test at 2000 Hz and above.**

- **Jerger has divided the scores as follow;**

- **0-20 %** >>> Negative or low SISI scores (normal hearing person, CHL or Retrocochlear pathology (eight nerve lesions)

- **25 – 65 %** >>> questionable

- **70- 100 %** >>> High or positive SISI scores (cochlear dysfunction)

Procedural Variations on the SISI Test

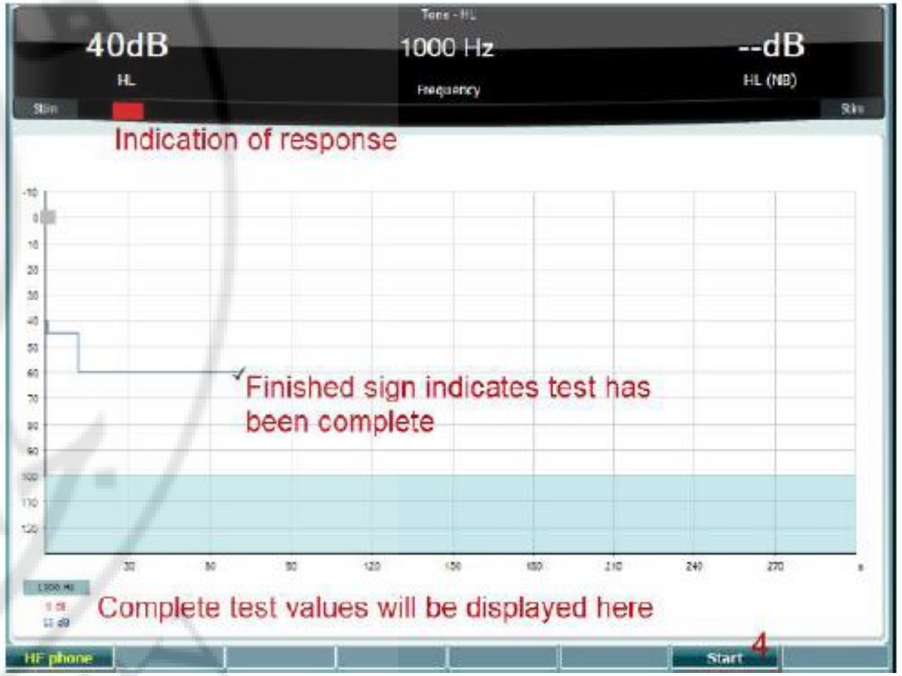
- To reduce false positives for the patient responding to most of the 1-dB increments, one should periodically delete the increment.
- Conversely, for a patient responding to none or few increments, periodically one should present increments greater than 1-dB.
- If patients either hear most, or all, the test increments or hear few, or none, of them, you can use of 10 rather than 20 increments per frequency to save clinical time.
- For 10 times increments, each correct response worth 10 %

Non-classical SISI test (High level SISI)

- To increase the diagnostic accuracy of SISI to identify the **retrocochlear lesions**, some researchers recommend to perform the SISI test at high presentation levels such as **75 to 90 dB HL**.
- With this high level, normal people and those with cochlear loss will show high scores (70 to 100%) and those with retrocochlear loss will show low scores (0-20 %).
- In actuality, the high-level SISI correctly identifies an average of ~90% of cochlear disorders but only 69% of retrocochlear pathologies across studies.
- All in all, SISI, like loudness-balance procedures, is a good test to detect cochlear problems but lacks sensitivity relative to retrocochlear lesions.

Tone Decay Tests

- A continuous tone sounds less loud after it has been on for some time compared with when it was first turned on, or it may fade away altogether.
- The decrease in the tone's loudness over time is usually called **loudness adaptation**, and the situation in which it dies out completely is called **threshold adaptation** or **tone decay**.
- Adaptation is due to the reduction of the neural response to continuous stimulation over time, and is common to all sensory systems (Marks 1974).
- Adaptation per se is a normal phenomenon, but excessive amounts of adaptation reflect the possibility of certain pathologies. It is for this reason that adaptation tests are often used as clinical site-of-lesion tests.



Tone Decay Tests

- It's a test involves presenting a constant pure tone at **threshold** **or** **supra-threshold** level as a starting level
- The patient task is to indicates when the tone is present and when it disappears
- Usually the hand is raised as long as the tone is there and lowered when the tone dies (or pressing the response button)
- Test done at 500, 1000, 2000 and 4000 Hz
- Numerically, it's the difference between the threshold and the level at which the test terminated.

TD various procedures

Threshold Tone Decay Methods

- Schubert Method (1944)
- Hood Method (1956)
- **Carhart Method** (1957)
- Rosenberg Method (1958)
- Green Method (MTDT) (1963)
- Owens Method (1964)
- Lilly & Willy Method (1980)
- Yantis Method (1959)
- Sorensen Method (1960, 1962)

Supra-Threshold Tone Decay Methods

- Jerger & Jerger (1975); **STAT** method
- Olsen & Nofsinger (1974); **20 dB SL** method

Carhart Tone Decay Test

1. Test starts at threshold (0 dB SL) and the stopwatch started too
2. If the tone is heard for the whole **one minute**, the test is done at that frequency and there is no decay.
3. If the patient lowered his hand before the end of one minute, the heard time is recorded, the intensity raised by 5 dB and the time is reset
4. The previous step will be repeated until either,
    1. The patient hears the tone for the whole one minute
    2. The audiometer limit reached
5. All of these steps will be repeated for all frequencies and for both ears (this is clinic time consuming)

Important aspects of TD

Amount of decay

amount of tone decay is the sensation level (SL) at which the tone was heard for 60 seconds.

- For **normal hearers**, the amount of decay is usually from 0-10 dB across all frequencies
- For **cochlear loss**, the amount of decay is usually from 0-15 and it might reaches 25 dB at higher frequencies and it's rarely reaching 30 dB
- Maximum decay seen in **retro-cochlear loss** (8th nerve lesion), it is about 30 to 35 dB up to the audiometer limits across the frequencies (more at high frequencies)

RATE OF DECAY (TIME)

- *The rate of decay* differs between CP and RCP
- For **cochlear loss**, at successive 5- dB increments, tone **audibility is longer** and longer
- For **RCP,** the **rate** is quiet rapid but **does not significantly change** with intensity increments

Olsen-Nofsinger Tone Decay Test

- Its identical to the Carhart TDT except that the test tone is initially presented at **20 dB SL** instead of at threshold.
- This modification is simpler for the patients, easier to distinguish it from any tinnitus, can shorten the test time by as much as 4 minutes for every frequency.
- **The outcome is recorded as follows:** If the patient hears the initial (20 dB SL) test tone for a full minute, then one records the results as "≤ 20 dB tone decay." Greater amounts of tone decay are recorded in the same way as for the Carhart TDT.

Other Modifications of the Carhart TDT

- The **Yantis** (1959) modification begins testing at **5 dB SL** instead of at threshold.

- **Sorensen's** (1960, 1962) modification requires the patient to hear the test tone for **90 seconds** instead of 60 seconds, and is performed **only at 2000 Hz.**

- The **Rosenberg** (1958,1969) modified tone decay test begins like the Carhart test but the whole test **lasts for 1 minute** per test frequency. Sustained tone presented at threshold level and the stopwatch is started. Each time the patient lower his hand, the intensity increases in 5 dBs until the end of the 1 minute. Then, the amount of decay will be calculated.

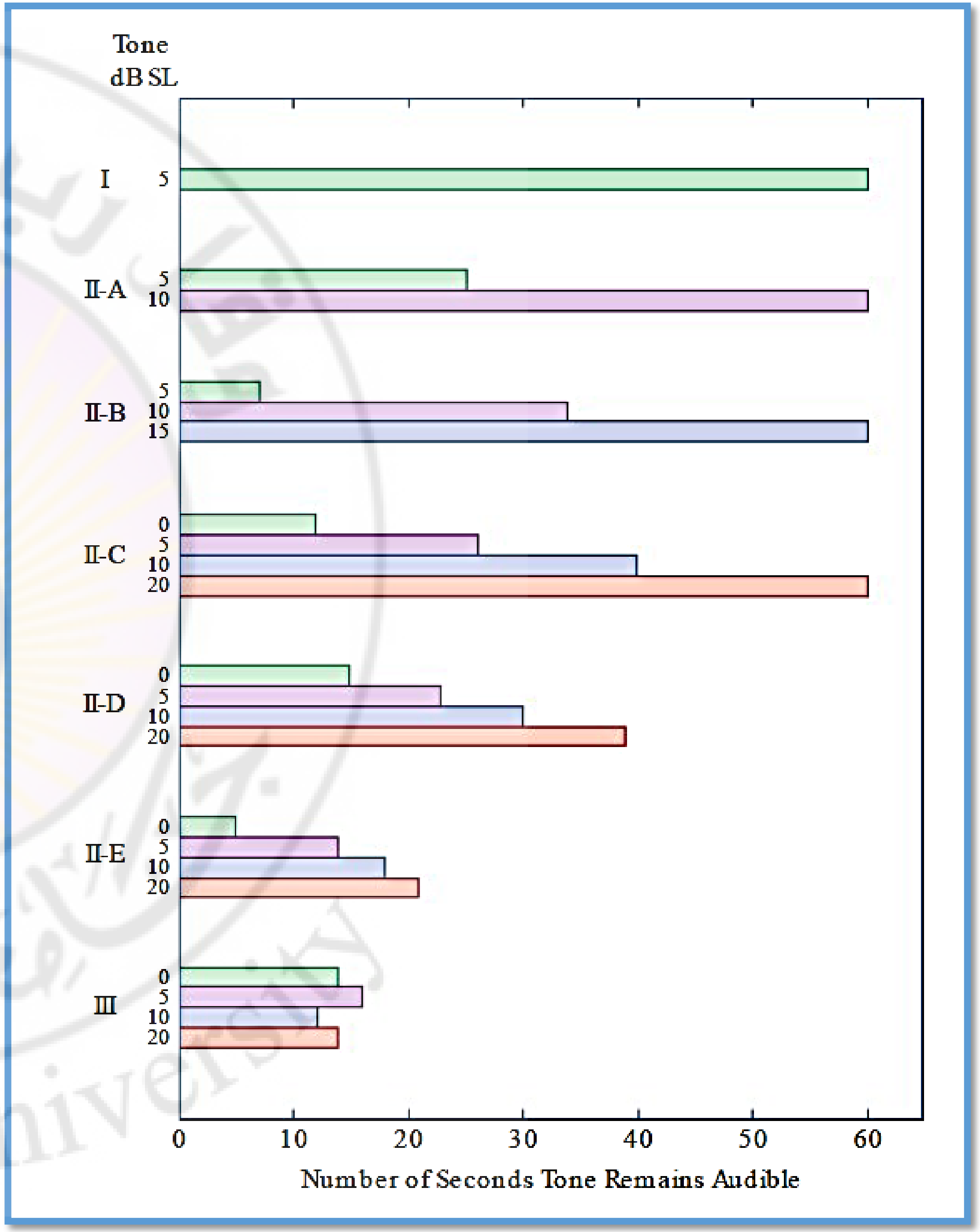
- **Green's** (1963) modified tone decay test is a **1-min** test like Rosenberg method, but have a **different instruction** and consider the changes in **tonal quality** (atonality or tone perversion)

Owens Tone Decay Test

- Unlike the Carhart test and its modifications, which concentrate on the *amount* of adaptation, the **Owens tone decay test** focuses upon the ***pattern*** of tone decay.
- Test starts at 5 dB SL (60 sec periods), and increased in 5 dB steps, max. to 20 dB SL (4 step of 5dB) if patient could not hear the tone for 60 sec.
- Between each 5 dB increase, **20 sec. resting (recovery) period** is given to the patient.
- The audiologist records how many seconds the tone was heard at each of the levels presented, and the test is interpreted in terms of the pattern of how many seconds the tone was heard at each of the four test levels.

Owens TDT interpretation

- The **type I pattern** involves being able to hear the initial (5 dB SL) tone for a full minute, and is associated with normal ears and those with cochlear impairments.
- There are five **type II patterns**, called **II-A through II-E**. The type II patterns share two characteristics: (1) the tone fades away before 60 seconds for at least the lowest sensation level, and (2) the tone is heard progressively longer at increasingly higher sensation levels. In the type II-D pattern, the tone fades away in less than a minute at all four sensation levels, but it does remain audible for appreciably longer periods of time with each successively higher sensation level. Cochlear impairments are most commonly associated with types II-A through II-D. In the type II-E pattern each 5 dB rise in sensation level produces only a small increase in how long the tone is heard (averaging 4 to 7 seconds per 5 dB level). This pattern is found in either cochlear or retrocochlear abnormalities.
- The **type III pattern** is principally associated with retrocochlear disorders. Here, increasing the sensation level does not cause the tone to be heard for longer periods of time (**Atypical** pattern).



Example of Owens TDT

Levels above Threshold	Type I	Patterns of Decay: Type II					Type III
		A	B	C	D	E	
dB							
5	60	25	7	12	15	5	14
10		60	34	26	23	14	16
15			60	40	30	18	12
20				60	39	21	14

* Numbers in the table represent seconds of time the tone was heard at the intensity level indicated before fading to inaudibility. A 20-sec rest was given between 5-dB increments. (From E. Owens: *Journal of Speech and Hearing Disorders*, 29, 14–22, 1964.)

Modification of Owens TDT

- Wiley and Lilly (1980) proposed a modification of the Owens TDT in which:
  - (1) the rest period between tones is reduced to 10 seconds, and
  - (2) the test level continues to be raised until the tone remains audible for a full minute (or the audiometer's maximum level is reached).

- This modification allowed them to distinguish between the rates of tone decay in the two ears of a patient who had a cochlear disorder in one ear and an acoustic tumor in the other ear.

Suprathreshold Adaptation Test (STAT)

- Jerger and Jerger (1975)
- A ***continuous*** test tone lasting a total of 60 seconds is presented at 110 dB SPL (~ 105 dB HL at **1000** Hz, and 100 dB HL at **500** Hz or **2000** Hz)
- If the high-intensity tone is heard for the full minute, then the test is over and the result is **negative**.
- If the tone fades away before 60 seconds are up, then the patient is retested with a ***pulsing*** tone for confirmatory purposes.
- If the patient keeps her hand up for the full 60 seconds in response to the pulsing tone, then her failure to keep responding to the continuous tone is attributed to abnormal adaptation (**Positive STAT**, suggesting a retrocochlear disorder).
- If patient fails to respond to the pulsing tone for 1 minute, then the test result is not considered to be valid because tone decay should not occur with a pulsed tone.

Behavioral Tests for Audiological Diagnosis

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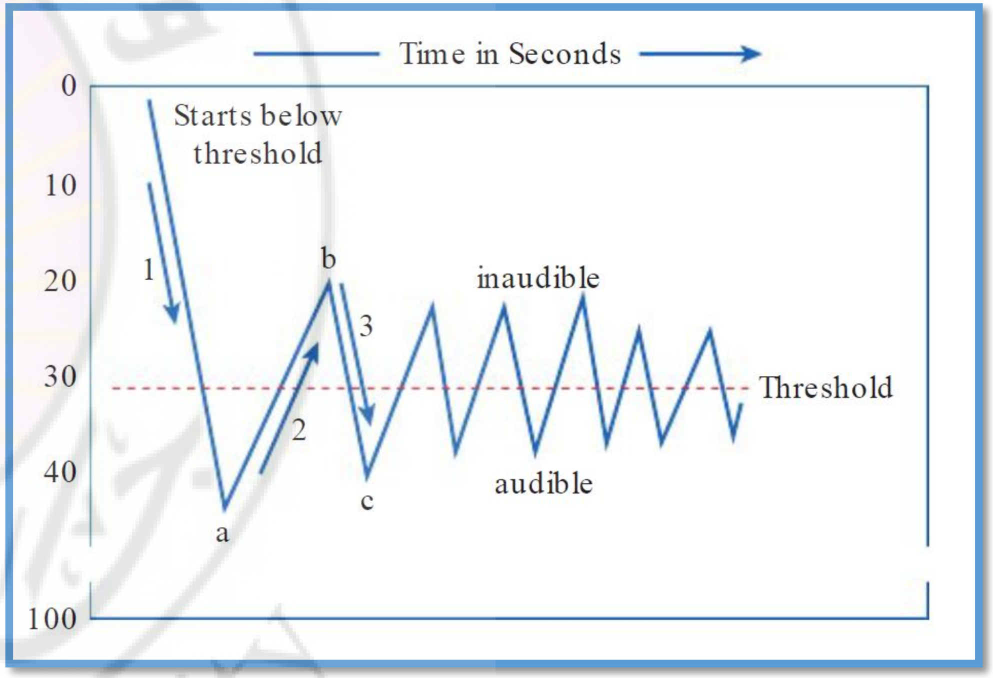
Bekesy Audiometry

- **Bekesy (1947)** audiometry allows the patient to track his own threshold by pressing and releasing a button.
- The button controls a motor, which in turn controls the attenuator, so that the level increases and decreases at a given rate (usually **2.5 dB/s**).
- The patient is told to hold the button down when he can hear the tone and to release it when he cannot hear the tone.
- This course of events will cause the level of the tone to rise and fall around the patient's threshold. At the same time, the motor also controls a pen that tracks the level of the tone on paper, resulting in a **zigzag pattern** around the patient's threshold.
- The width of the zigzags is often called the **excursion width**, and the patient's threshold is the midpoint of these excursions

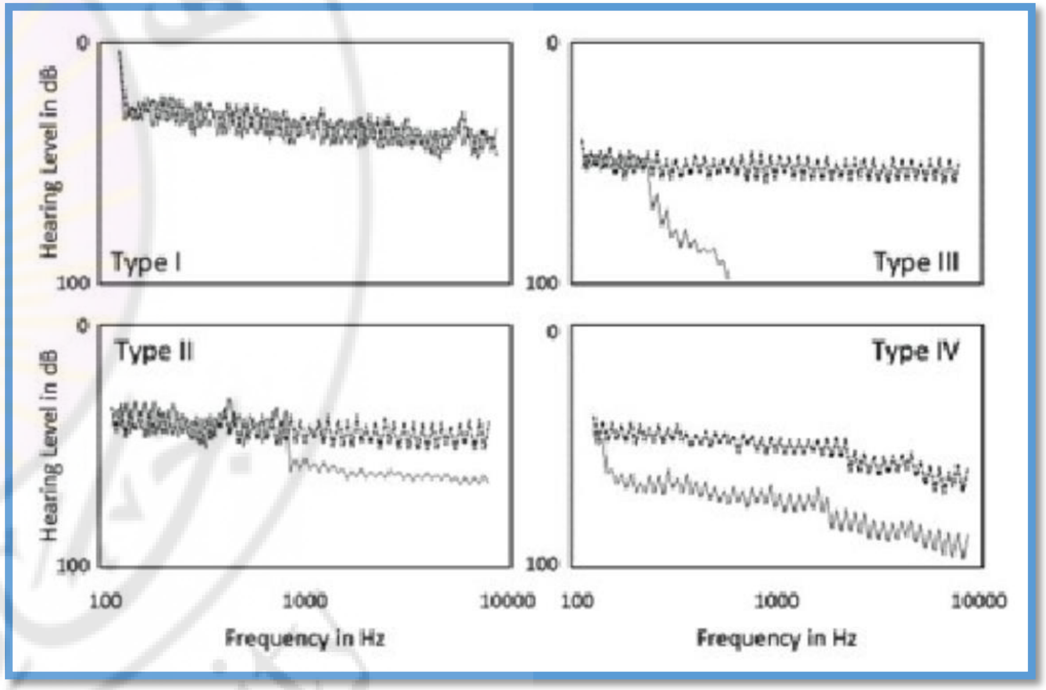


Bekesy Audiometry

- Bekesy audiograms are obtained either one frequency at a time or while the test frequency slowly changes from low to high.
- During sweep-frequency **Bekesy audiometry** the patient tracks his threshold while the frequency of the test tone increases smoothly from 100 to 10,000 Hz at a rate of one octave/second.
- During Fixed-frequency **Bekesy audiometry**, the patient tracks his threshold at one frequency for a given period of time, such as 3 minutes.
- Each Bekesy audiogram is tracked twice, once using a continuous tone and once using a tone that pulses on and off 2.5 times a second, and the results are interpreted by comparing the continuous and pulsed (or interrupted) tracings.

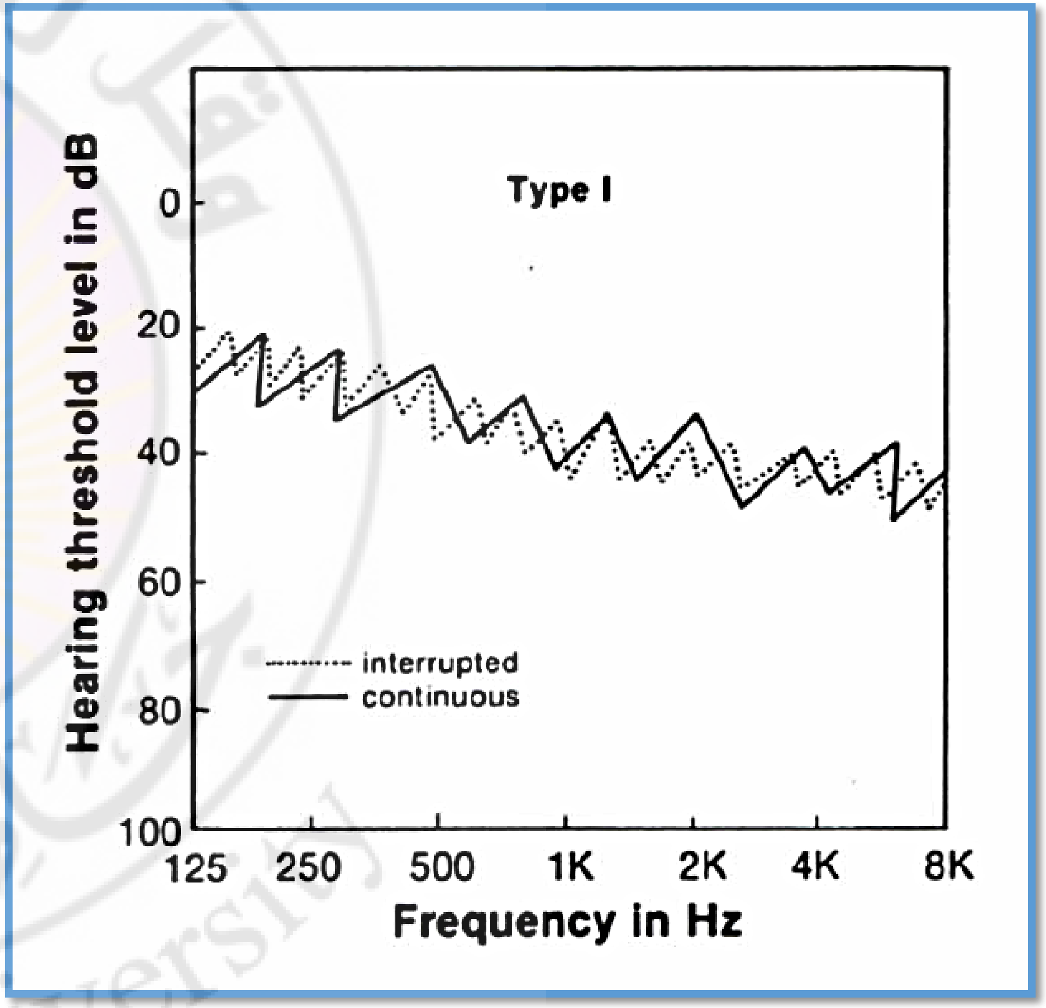
Bekesy Classification

- Clinical interpretation involves comparison of the C to the I tone tracing, whether done in the sweep- or fixed frequency mode.
- The I tracing can be thought of as the baseline performance and should approximate pure tone thresholds.
- The C tone tracing is compared to the I ,with regard to the amount of separation between them.
- Jerger's 1960 classification scheme resulting in four "types" (I, II, III, IV) of tracing patterns.



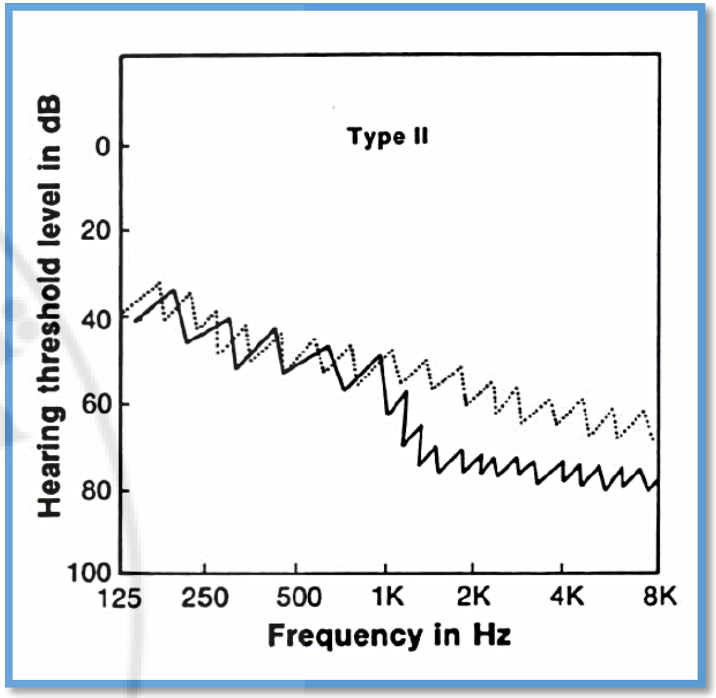
Type I

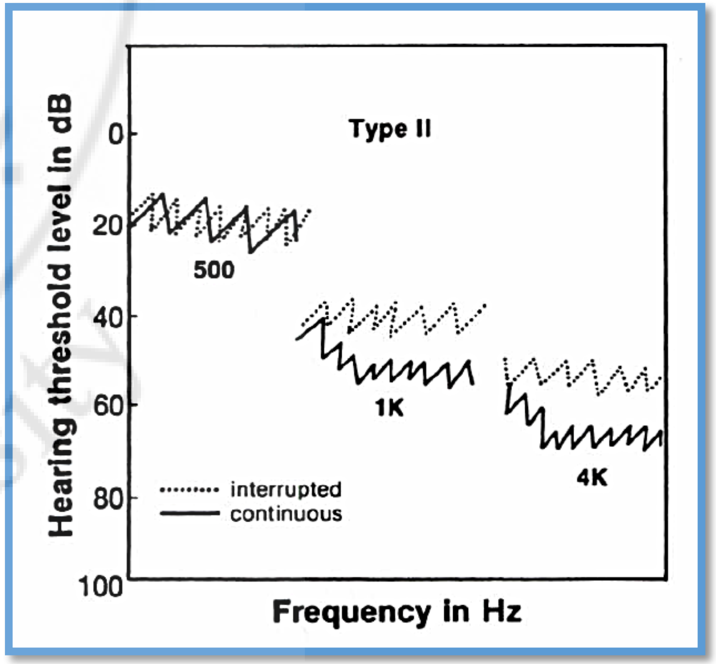
- Overlapping of I and C tracings, with a tracing width of about 10 dB (following the pattern of the patient’s audiogram)
- A similar pattern is seen for the fixed-frequency mode.
- This type is associated with those who have **normal** hearing or **conductive** hearing losses.



Type II

- The pulsed and continuous tracings are linked for frequencies up to roughly 1000 Hz.
- Two things happened at higher frequencies:
  - First, the continuous tracing falls below the pulsed tracing by an amount that is usually less than 20 dB, and then runs parallel to it.
  - In addition, the excursions of the continuous tracing narrow considerably, becoming only ~ 3 to 5 dB wide.
- This type is associated with **cochlear** impairments.

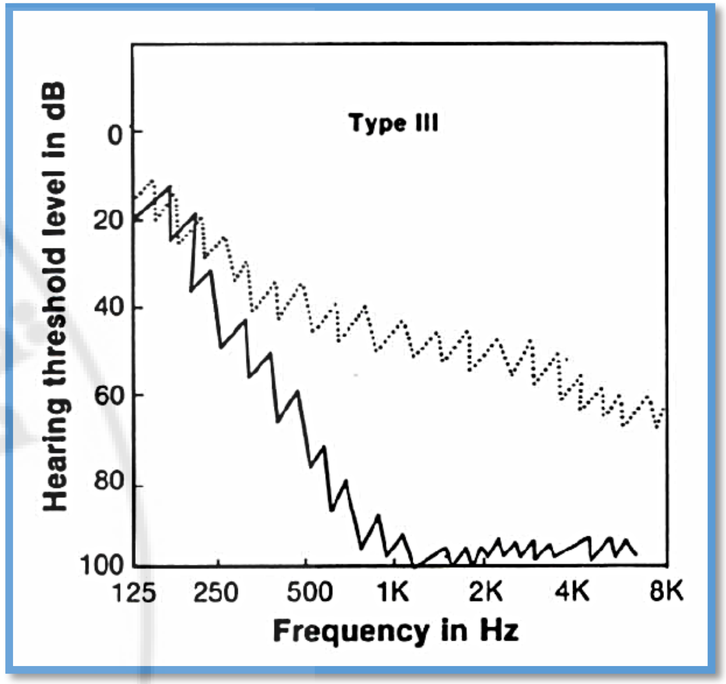


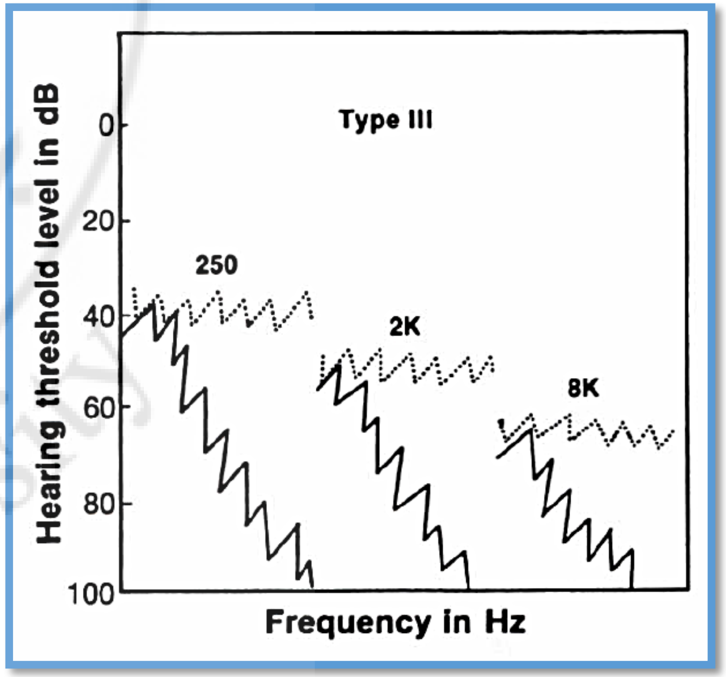


Type III

- The continuous tracing diverts very quickly from the pulsed tracing, often shifting to the limits of the audiometer.

- Type III is associated with **retrocochlear** pathologies.

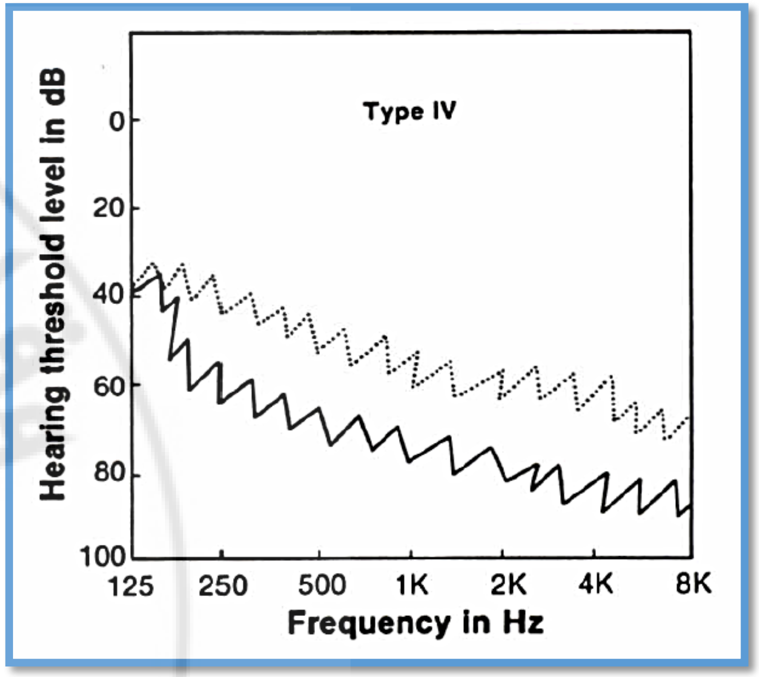


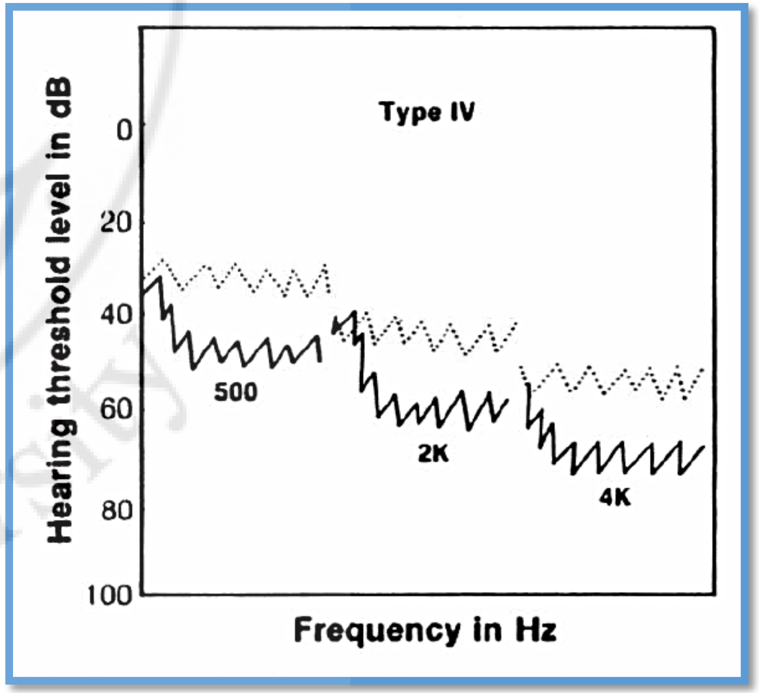


Type IV

- The continuous tracing quickly falls more than 20 dB below the pulsed audiogram (but not to audiometer limits), and then runs parallel to it.

- Type IV Bekesy audiograms may occur in patients with cochlear or retrocochlear disorders, but they are often taken to suggest the possibility of the **retrocochlear** pathologies.



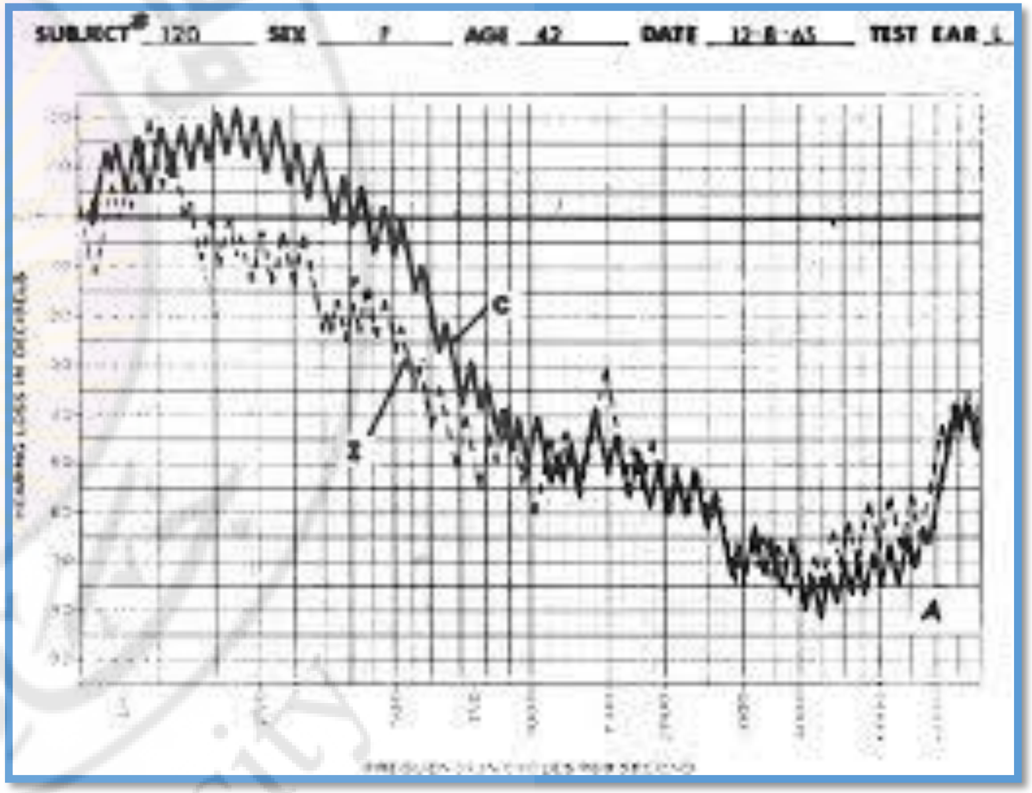


Type V

- **type V**, was described by Jerger and Herer (1961).

- It is distinctive because the pulsed (I) tracing falls below the continuous (C) one.

- The type V Bekesy audiogram is associated with **functional (or nonorganic)** hearing loss.

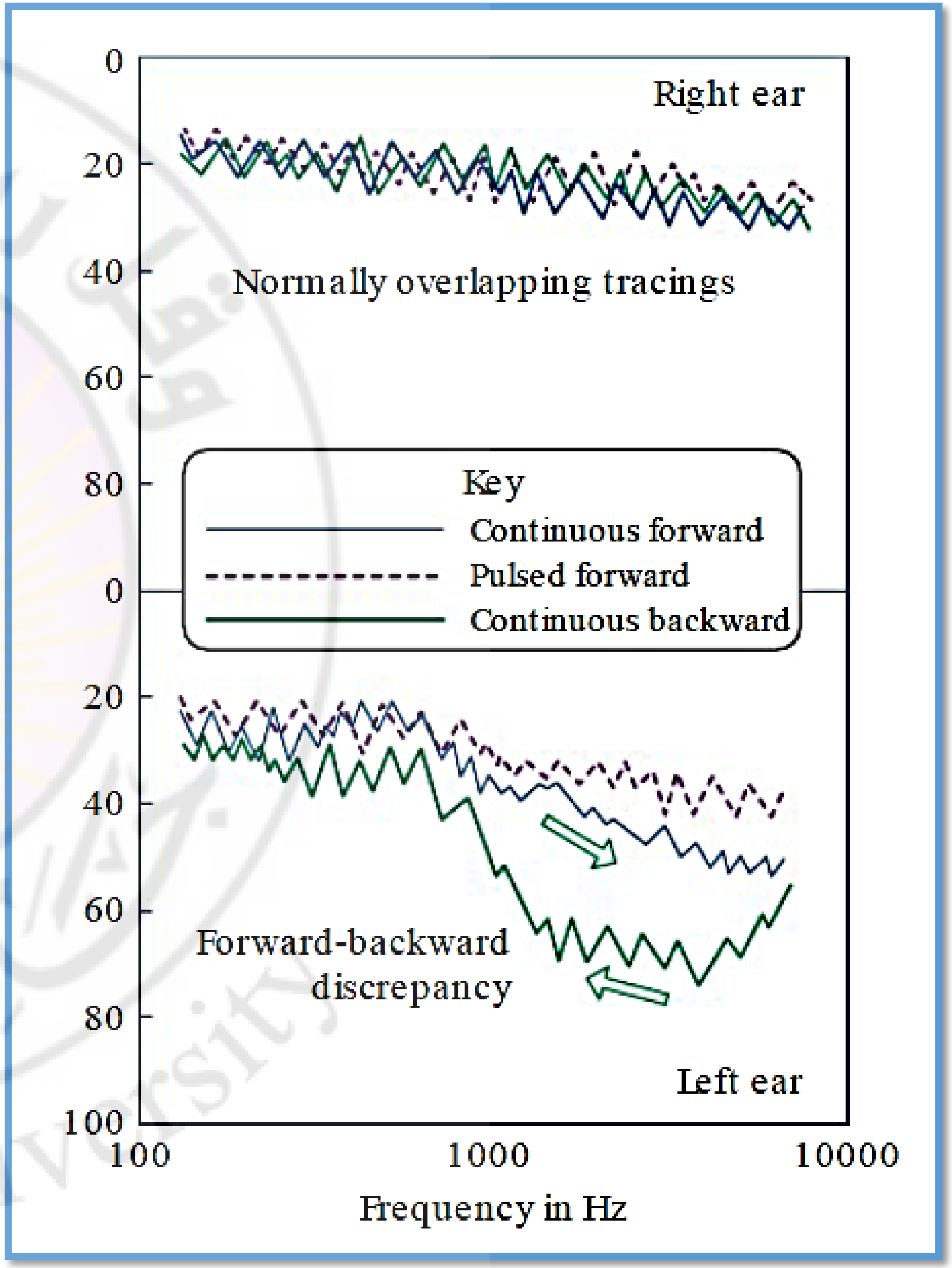


Modifications of Bekesy Audiometry

- Two modifications of conventional Bekesy audiometry seem to improve the accuracy of diagnostic results, compared with those of the original procedure:
  - **Reverse Bekesy tracings (Forward-Backward Bekesy / FBB)**
  - **Bekesy Comfortable Loudness (BCL)**
- Neither requires modification of the equipment.

Reverse Bekesy tracings

- Reverse Bekesy tracings have been suggested to better separate cochlear from retrocochlear disorders.
- Initially, conventional sweep tracings are collected, i.e.; low to high frequency.
- The patient then traces the C tone again but in the reverse direction; i.e., high to low frequency.
- Comparisons of forward and reverse tracings of the C tone show little difference in most cases, except for those ears showing the abnormal adaptation that is associated with **retrocochlear** disorder.
- The greatest separation is seen in retrocochlear patients whose reverse C threshold tracing is poorer than the forward trace, usually for the middle and high frequencies.



Bekesy Comfortable Loudness

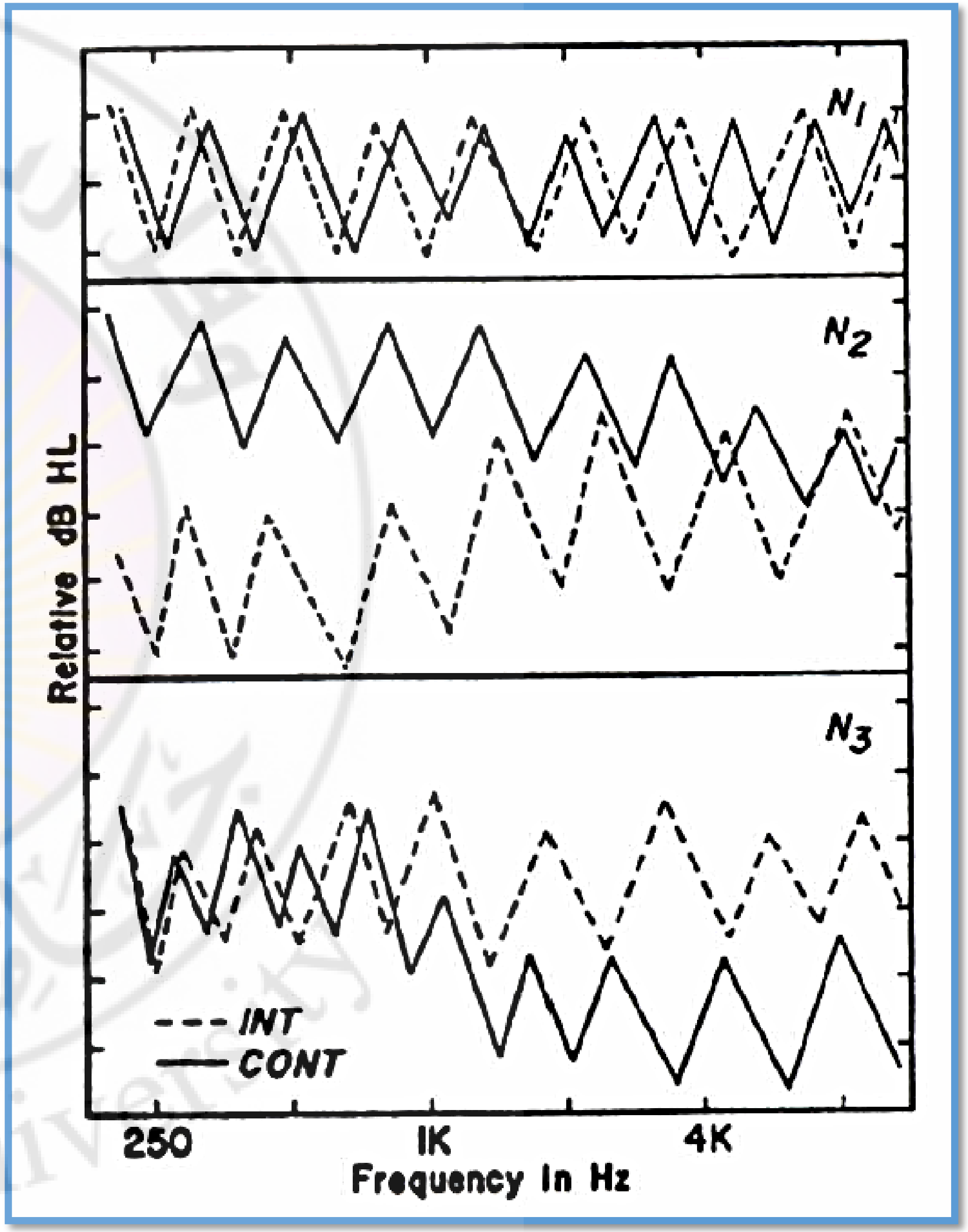
- **Bekesy Comfortable Loudness (BCL)** testing is similar to conventional sweep-frequency audiometry except the patient is instructed to press and release the response button to keep the tone "at a comfortable loudness level, neither too loud nor too soft".
- In addition, patients are told that they will hear a continuous noise (masking) in the nontest ear during the procedure.
- Jerger and Jerger identify 6 BCL configurations:
  - 3 Negative BCL
  - 3 Positive BCL

Negative BCL patterns

- three BCL configurations considered to be negative because they were associated with **normal** hearing and with **conductive** and **cochlear** impairments.

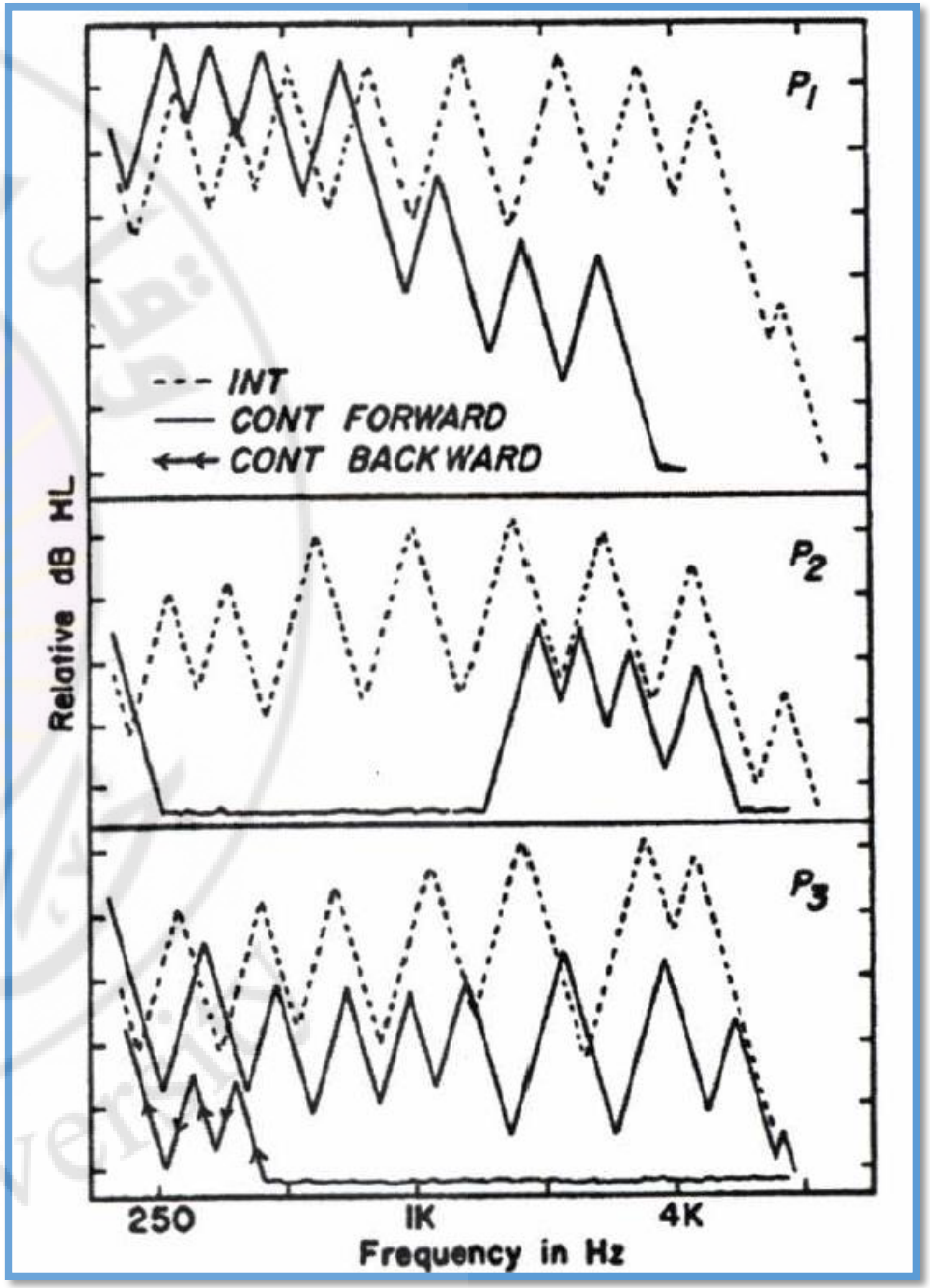
- The pulsed and continuous tracings were linked in type N1.

- The continuous tracing tracked above the pulsed in type N2 and below it in type N3.



Positive BCL patterns

- There were also three positive BCL patterns that were associated with **retrocochlear** disorders:
- The continuous tracings fell very far below the pulsed tracings at high frequencies in the type **P1** pattern and at low and/or middle frequencies in type **P2**.
- The **P3** pattern involved a forward-backward discrepancy for the BCL tracings.
- Nineteen (19%) percent of the retrocochlear cases and 8% of the other ears did not fit into the six categories.



Summary of Bekesy Audiometry

- On average across studies, the correct identification rates for cochlear and retrocochlear disorders, respectively, are ~93% and 49% for conventional Bekesy audiometry, 95% and 71% for forward-backward Bekesy, and 92% and 85% for Bekesy Comfortable Loudness.

- Conventional Bekesy audiometry is effective in detecting cochlear disorders. However, the value of Bekesy audiometry in identifying retrocochlear disorders in the cited studies ranged from 100 to 47%.

Percentage of Audiologists' Reported Use of Behavioral Site-of-Lesion Tests Surveyed by Martin and Colleagues from 1972 to 1997

	1972	1978	1985	1992	1997
Békésy audiometry	71	70	20	8	4
SISI	83	74	45	30	17
ABLB	82	78	45	25	19
Tone decay	64	99	86	72	61

Adapted from Martin FN, Champlin CA, Chambers JA (1998) Seventh survey of audiometric practices in the United States. J Am Acad Audiol; 9: 95–104.

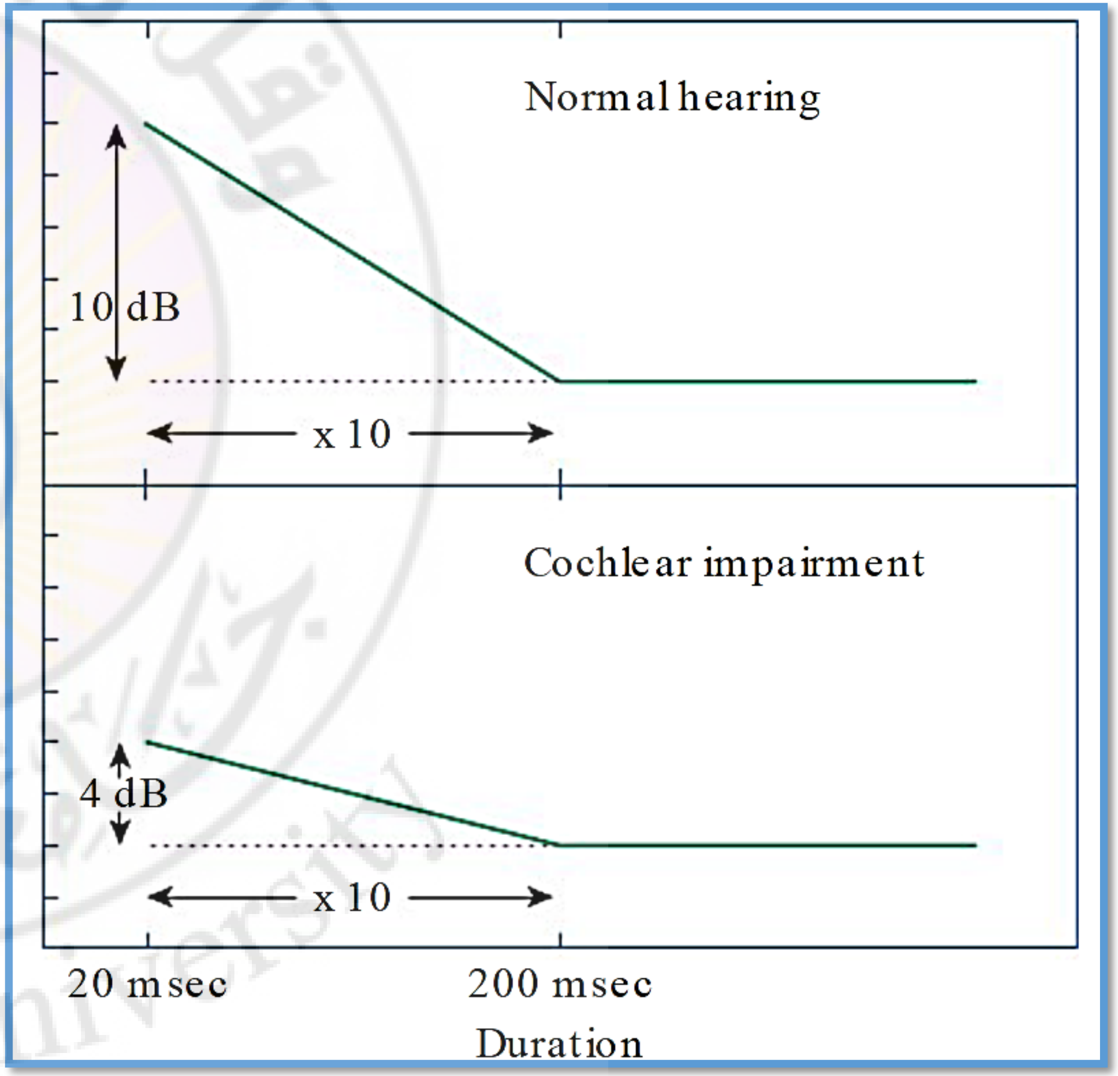
Percentage Sensitivity and Specificity of Six Site-of-Lesion Tests

Procedure	Eighth Nerve (%)		Cochlear (%)	
	Worthington	Hall	Worthington	Hall
Békésy[a]	42	84	95	96
SISI	68	64	90	92
ABLB	51	68	88	90
Tone decay[b]	75	64	91	91
ABR	97	96	88	88
Acoustic reflex/decay	86	85	86	84

Adapted from Worthington (1988) and Hall (1991).
[a]Békésy comfortable loudness tracings not included.
[b]STAT tone-decay test not represented.

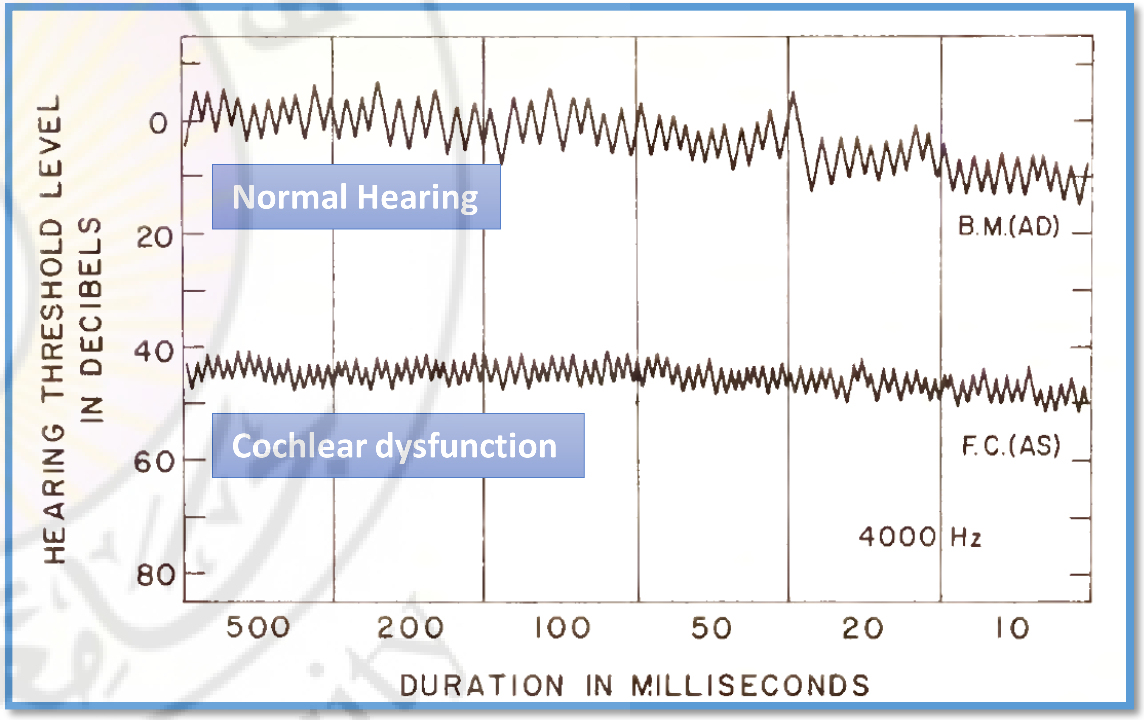
Brief Tone Audiometry

- **Brief-tone audiometry** involves measuring the thresholds of tones having very short durations.
- When the duration of a tone is progressively decreased below 1 sec, the intensity required to maintain its audibility must be continuously increased. This phenomenon is due to the psychophysiological process of **temporal summation (Integration).**
- The intensity-duration relationship (the temporal integration function) is typically shallower than normal when there is a **cochlear impairment**.



How to perform BTA

- Brief-tone audiometry usually involves **Bekesy audiometry**.
- Where Bekesy audiometry compares the threshold for pulsed tones at a *fixed duration* to that obtained for a continuous tone, BTA examines the relative threshold differences among pulsed tones which ***vary in their duration.***
- Bekesy audiograms are obtained using pulsing tones with various durations **(Usually 20 and 500 ms),** and the resulting thresholds are assessed to determine how much of a threshold change is needed to offset a duration difference.



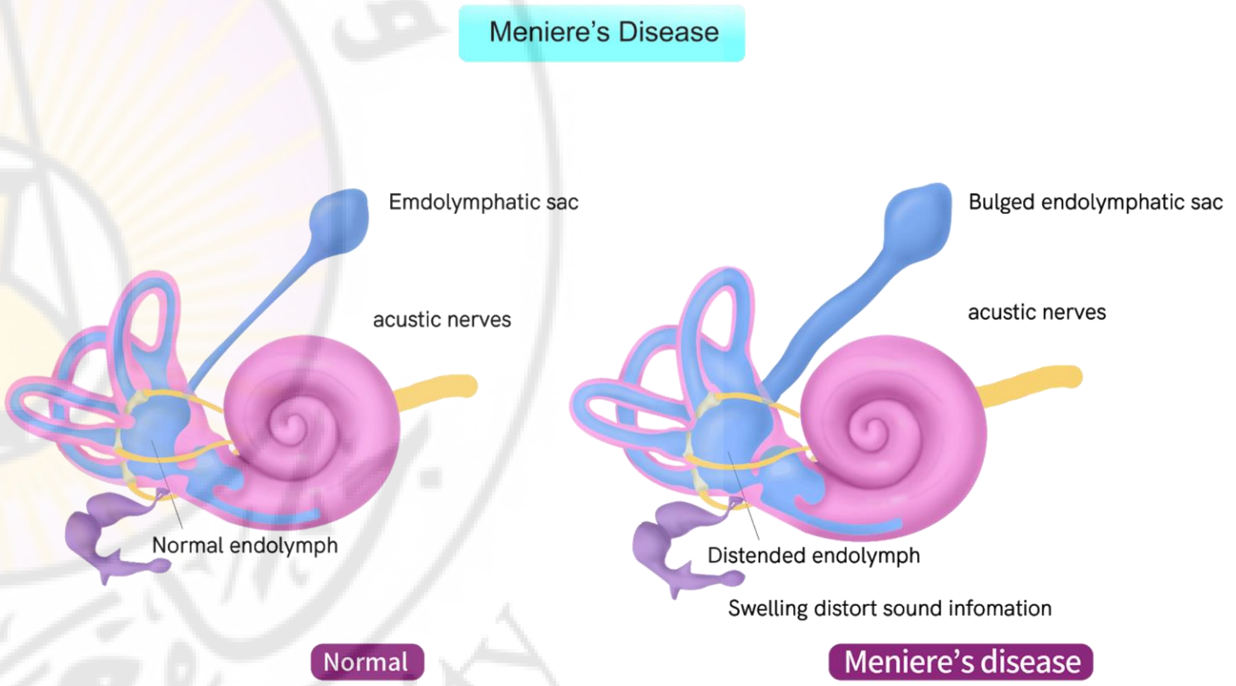
Interpretation of BTA

- When the threshold difference between 500- and 20-msec tones is on the order of **10 dB**, this is consistent with *normal hearing, conductive hearing loss, or nerve VIII dysfunction*.
- When the threshold difference is **5 dB or less**, the audiologic differential is *cochlear involvement*.
- When the threshold difference is **15 dB or more**, this is audiologic support for *temporal lobe dysfunction or pseudohypacusis (non-organic hearing loss).*

- So, normal and cochlear-impaired ears are typically distinguished with brief-tone audiometry, but BTA is not very useful in distinguishing between cochlear and retrocochlear disorders.

Glycerol test

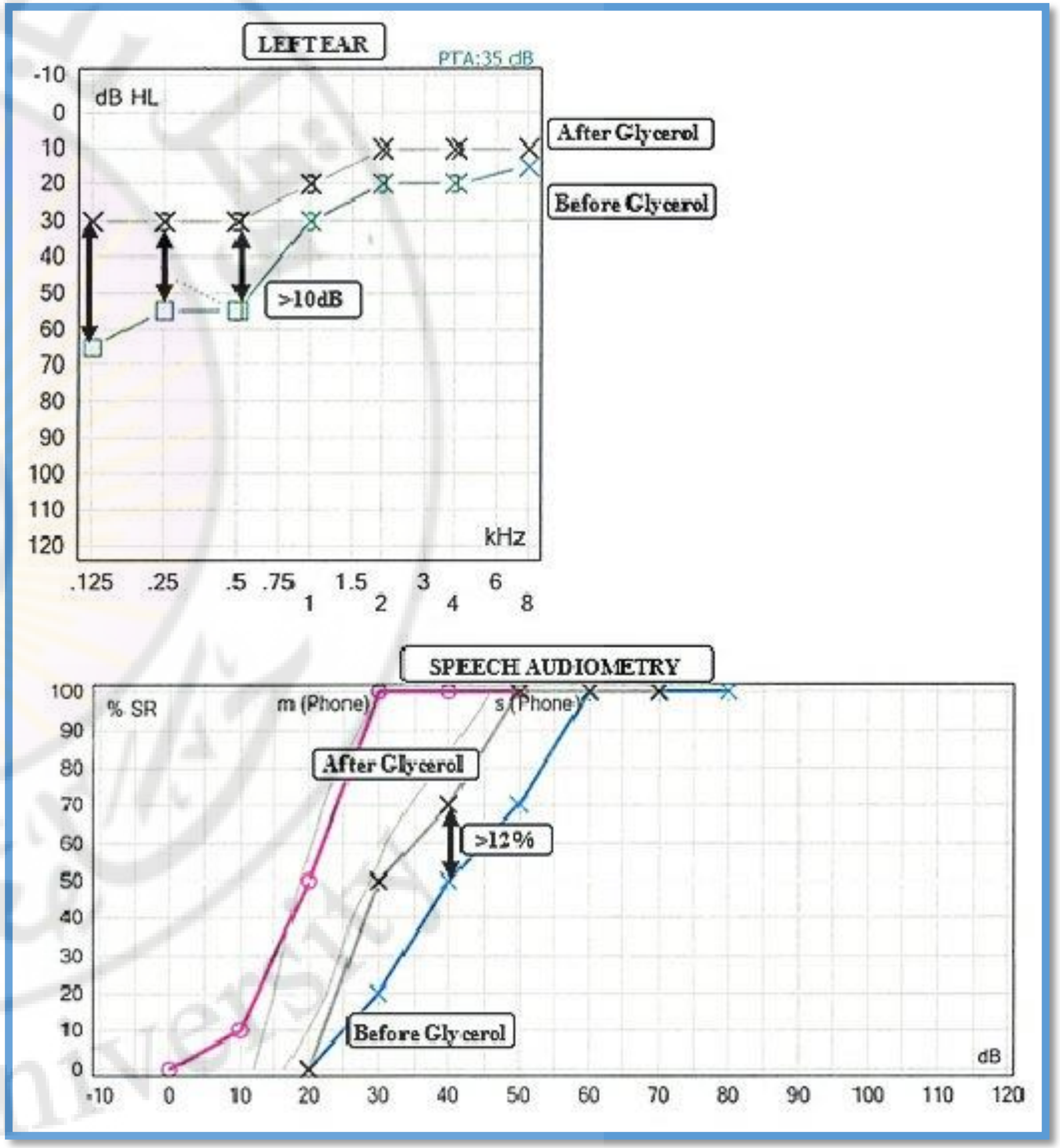
- Glycerol test is used to diagnose **Meniere's disease**.
- Meniere's disease is a progressive disorder characterized by recurrent episodes of spontaneous vertigo, sensorineural hearing loss and tinnitus, often with a feeling of fullness in the ear.
- The assumption is that an increase in *endolymph volume*, affects labyrinthine membrane behavior and producing in part, the hearing loss and vestibular deficit in Meniere's disease.
- The principal audiological investigation is pure tone audiometry combined with a glycerol test.



Glycerol test

- Dehydrating agents like glycerol can reduce the endolymph volume abnormalities in inner ear and produce an improvement in behavioral audiometric test results.

- Glycerol is administered orally to patients to reduce fluid abnormalities in the inner ear. It affects hearing temporarily (for a few hours), the results of which are measured by audiogram.



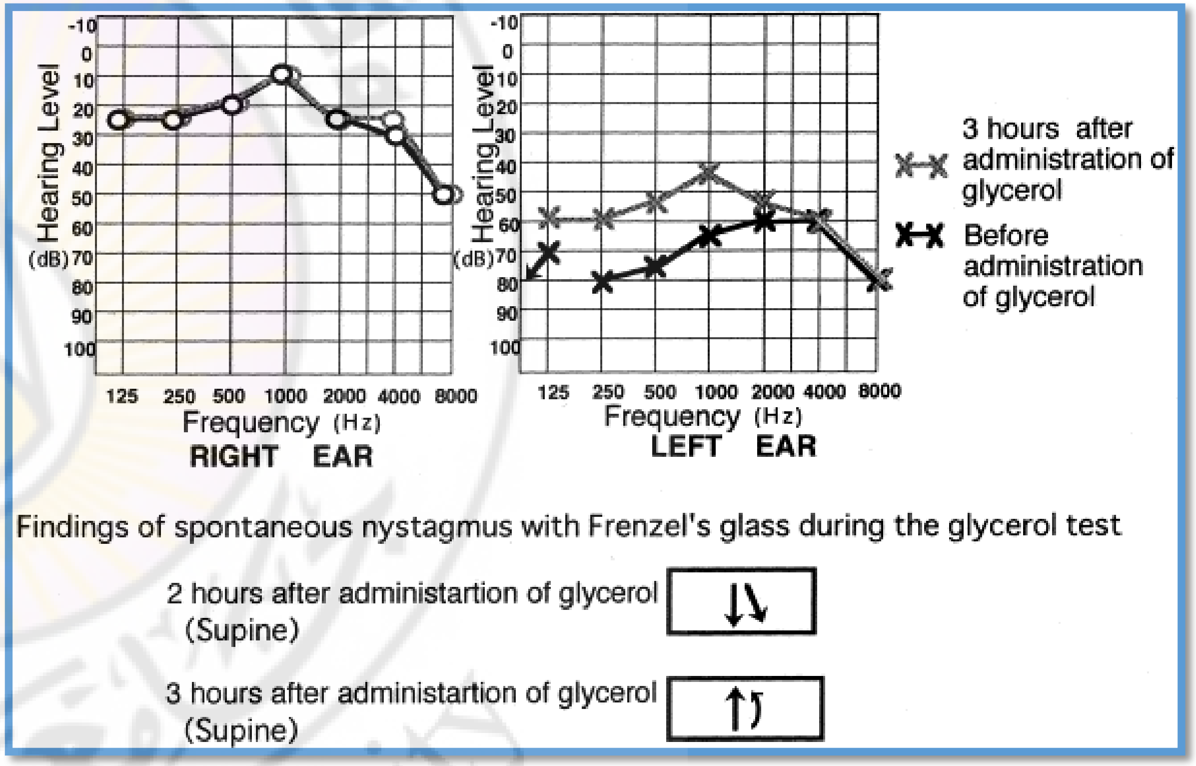
Method of glycerol test

- The patients are advised to report empty stomach on the day of investigation.
- PTA test is performed before the administration of glycerol and then patient is administered a solution of 86% of glycerol **(1.2 mg/kg of body weight)** dissolved in equal volume of physiological saline.
- Pure tone audiometry is then repeated **at 1, 2 and 3 hours after glycerol administration**.

- Be cautious in patients with heart problems.
- Most patients may suffer headache and nausea after drinking the glycerol for post-glycerol audiometric evaluation, which usually subsides after few hours.

Interpretation of glycerol test

- The glycerol test is regarded as **positive**:
  1. When the hearing threshold is lowered at least 15 dB at minimum three frequencies or
  2. When there is a total pure tone threshold shift of 25 dB at three consecutive frequencies or
  3. When there is a 16% improvement in speech discrimination.



دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی ایران

Behavioral Tests for Audiological Diagnosis

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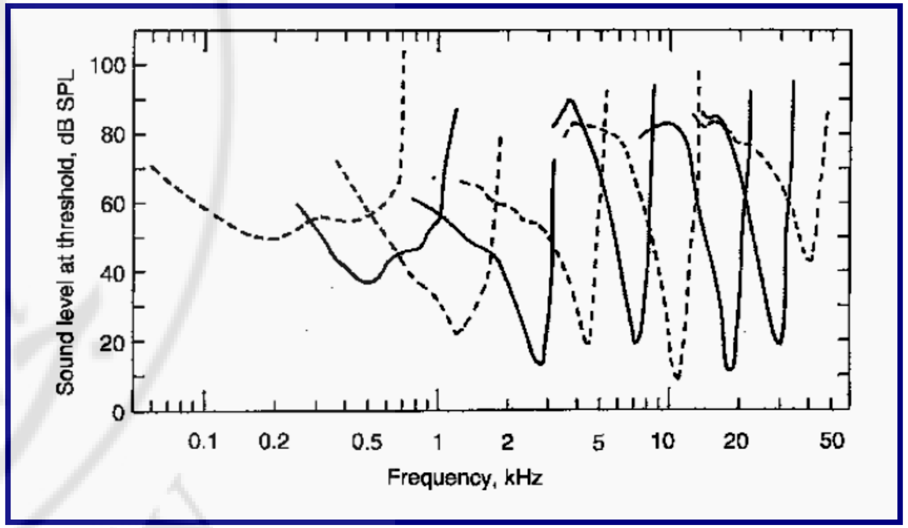
2. Assessment of Cochlear Dead Regions

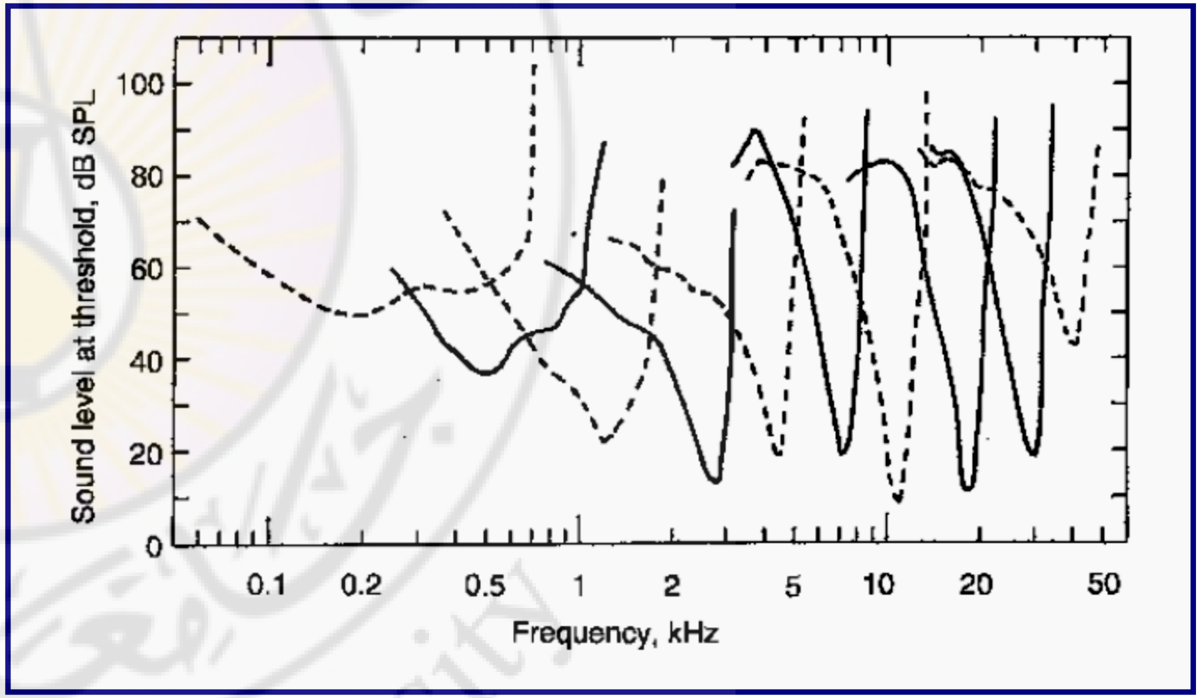
Normal Auditory System

- In an ear with normal hearing, the patterns of vibration on the basilar membrane are strongly influenced by the activity of the **outer hair cells (OHCs),** which are minute sensory cells forming rows along the length of the basilar membrane.
- The OHCs play a role in what is called the “active mechanism” in the cochlea.
- They do this by changing their stiffness and length in response to the vibrations on the basilar membrane. This activity of the OHCs enhances the response to weak sounds (increasing the amplitude of vibration) and sharpens the tuning on the basilar membrane.
- This sharpening increases the frequency selectivity of the auditory system (ie, its ability to separate the different frequencies that are present in complex sounds such as speech and music).



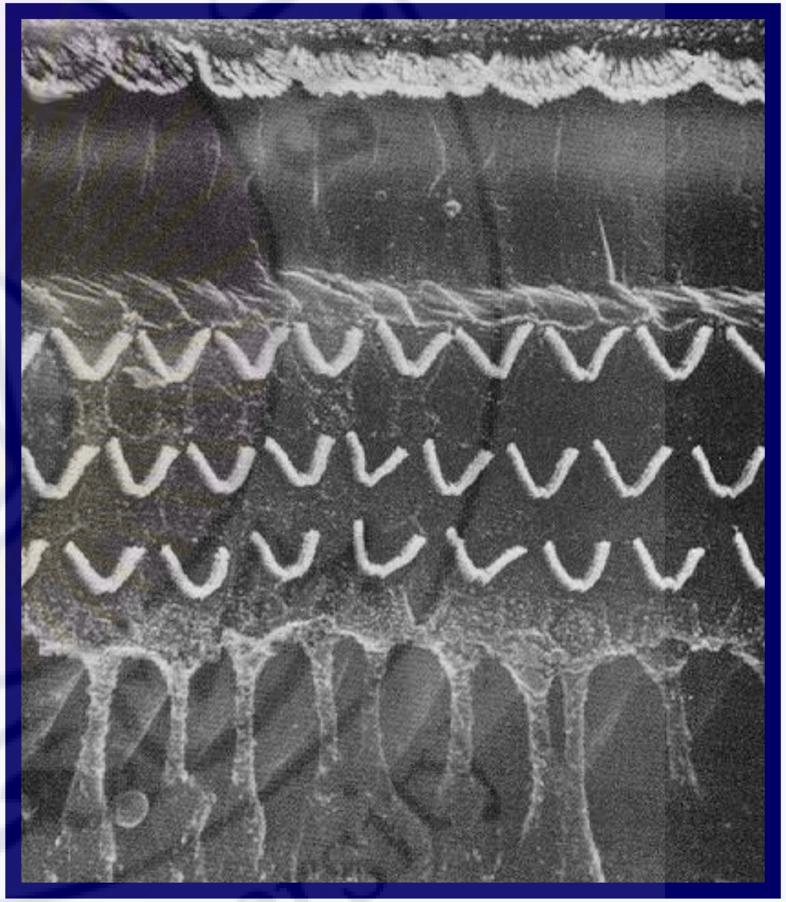
Normal Auditory System

- The amplified vibrations are then detected by the inner hair cells (IHCs), which form a single row running along the length of the basilar membrane. In response to vibrations on the basilar membrane, the IHCs release neurotransmitter, and this leads to neural activity in the auditory nerve.



OHCs & IHCs Damage

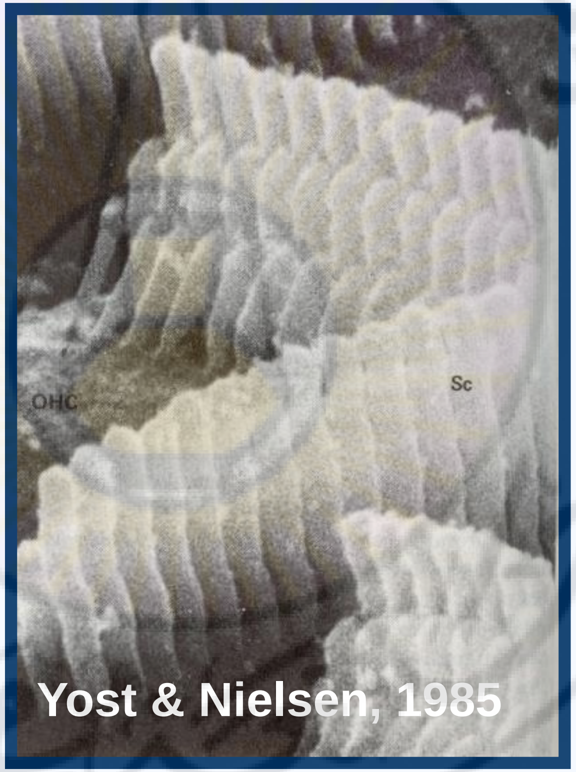
- What is damage?
- What effects has?



OHCs damage

OHC damage impairs the active mechanism in the cochlea, resulting in reduced basilar membrane vibration for a given low sound level. Hence, the sound level must be greater than normal to give a just-detectable amount of vibration.

Normal

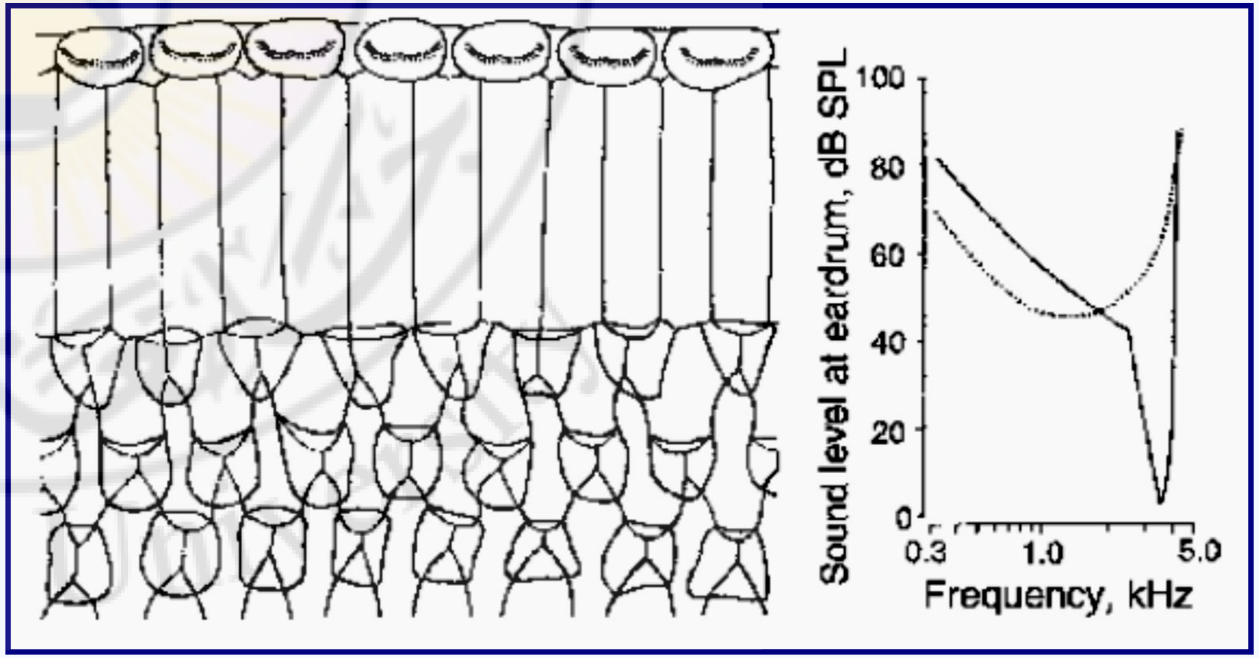


Damaged

A hearing loss due to OHC damage cannot be greater than about 50 dB in LF and 65 dB in HF. Most people with milder losses have primarily OHC damage

Consequences of OHC damage

- Elevated absolute thresholds
- Widening of frequency tuning curves and decreased freq. selectivity
- Speech perception problems especially in noise
- Linear input-output function
- Loudness recruitment



IHCs damage

IHCs are the primary sensory receptors of the auditory system. IHC damage can result in less efficient stimulation of the auditory nerve. As a result, the amount of basilar membrane vibration needed to reach the hearing threshold is larger than normal.

Normal

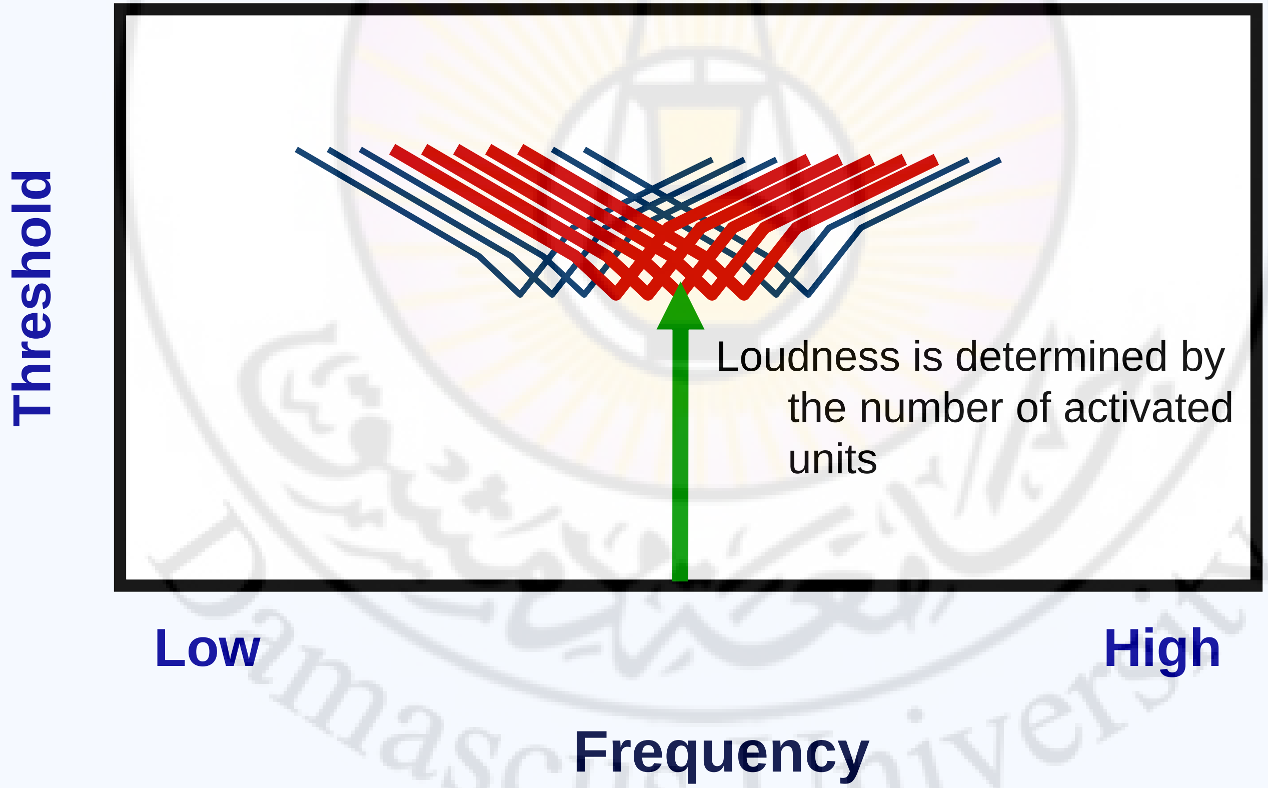
Yost & Nielsen, 1985

Damaged

A hearing loss greater than 55 dBHL nearly always involves some loss of function of OHCs and IHCs. From measurement of the audiogram alone, it is not possible to determine what proportion of the hearing loss is due to OHC damage and what proportion to IHC damage.

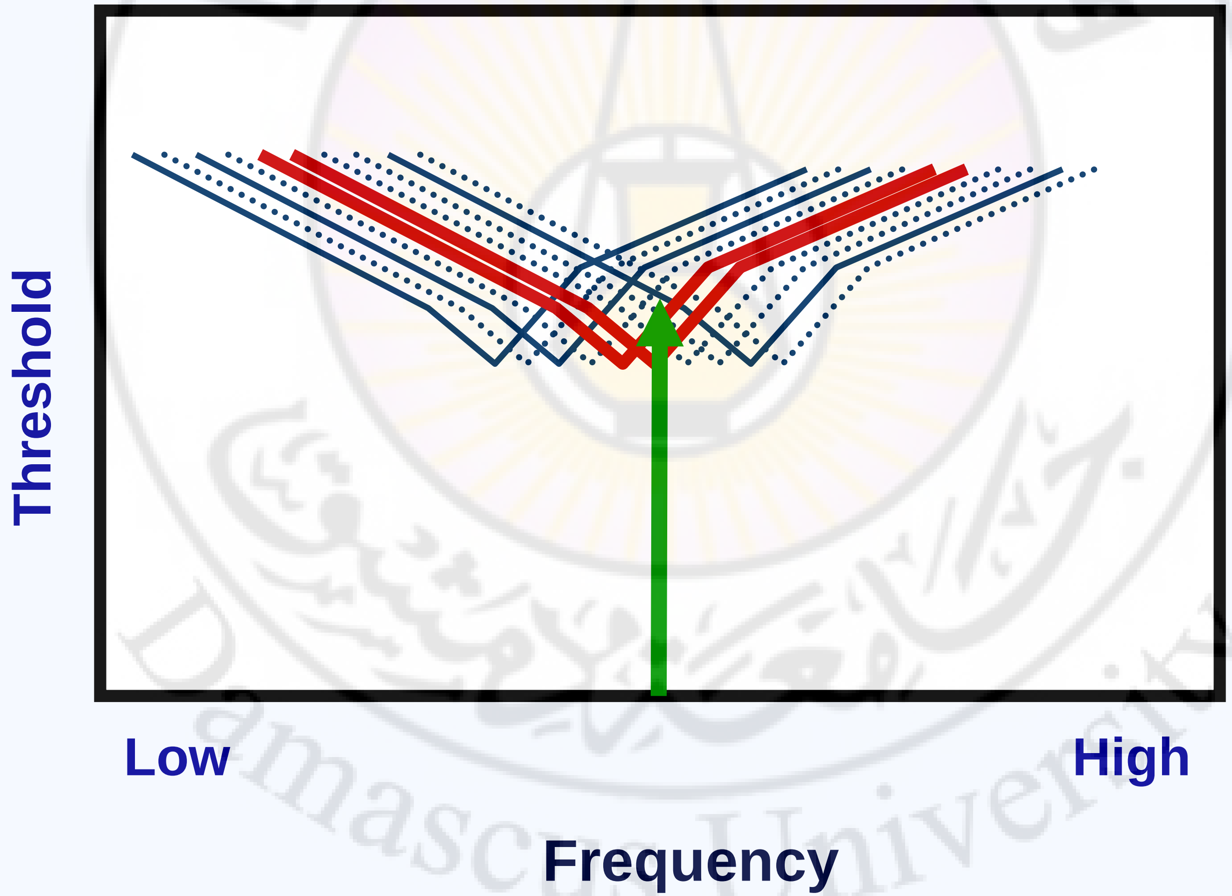
Pattern of activation in IHCs

Moderate SNHL: most IHCs are functional

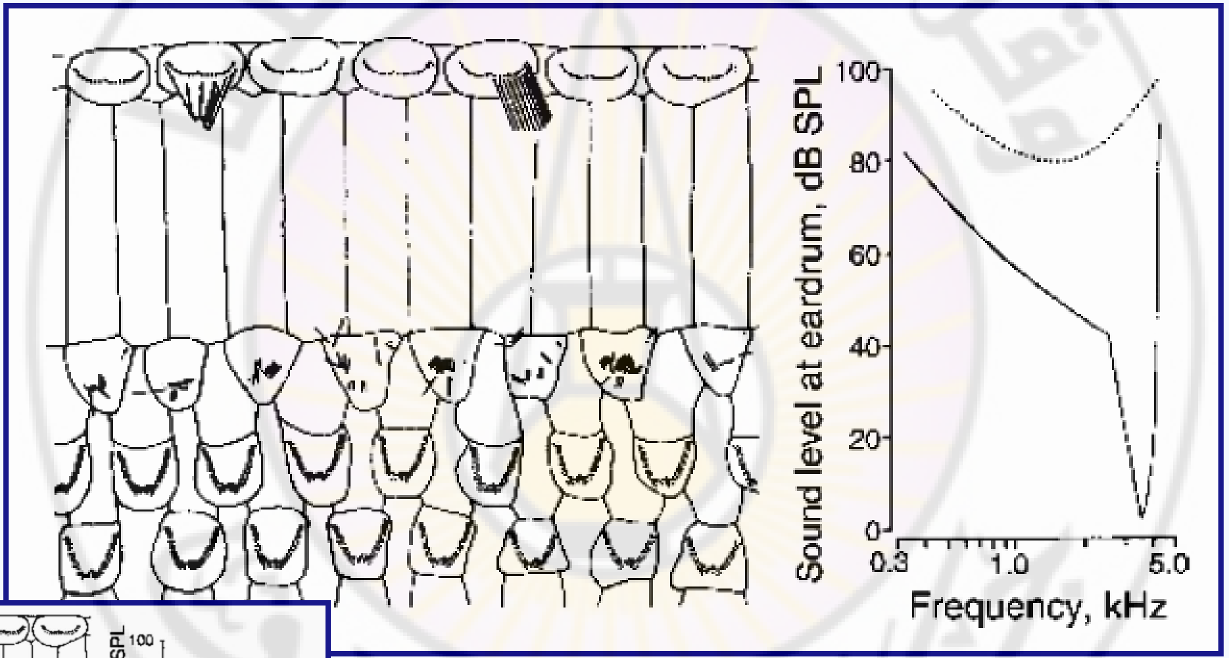


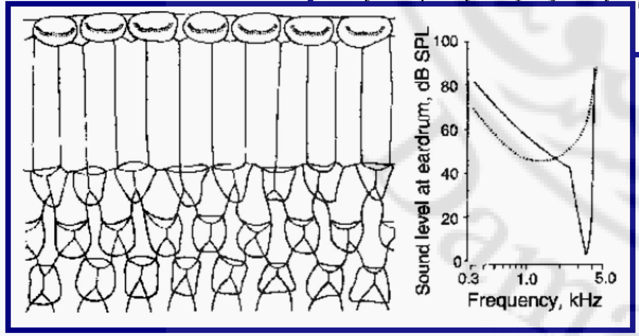
Pattern of activation in IHCs

Severe SNHL: severe damage to IHCs



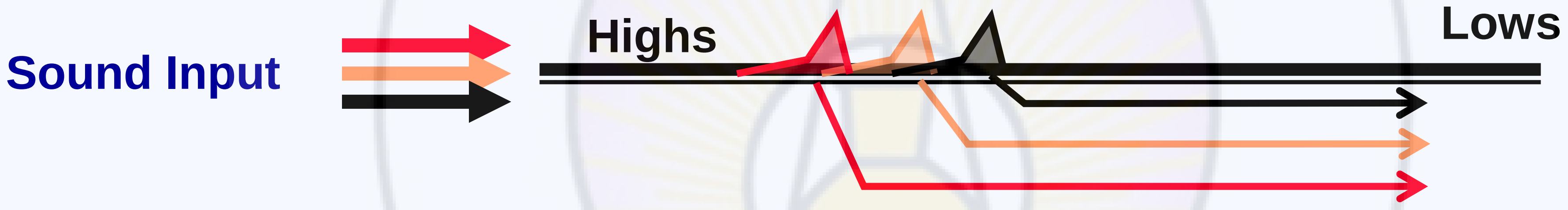
Severe damage to IHCs

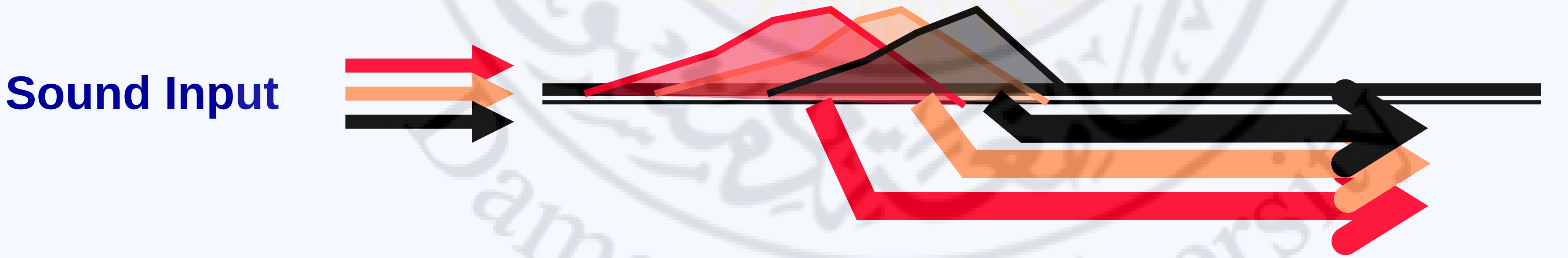




Cochlear Signal Processing

Normal Hearing: Discrete and specific preservation of frequency specific input to the auditory system.



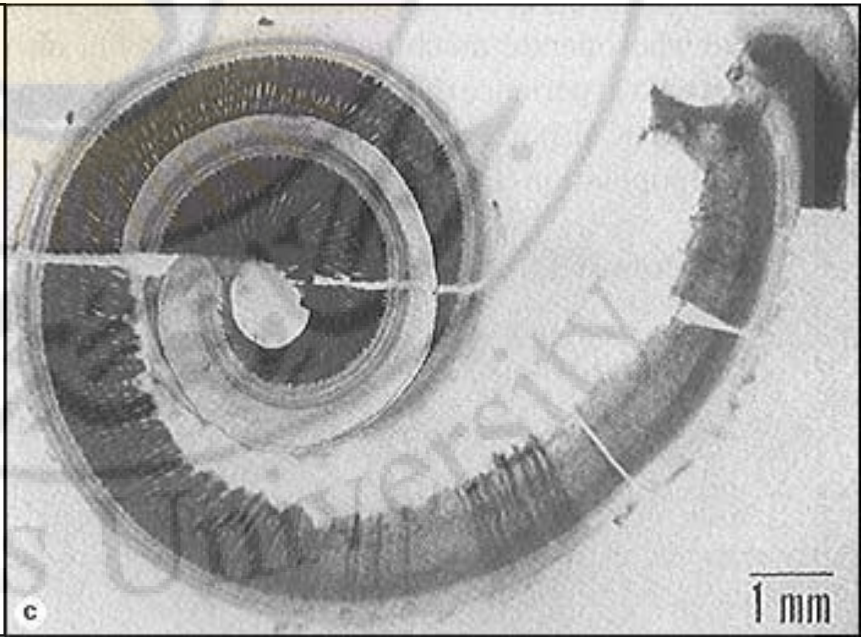


Severe Hearing Loss: Loss of discrete preservation of frequency specific input to the auditory system. . .more muddled, overlapped signals sent to central auditory system

Dead Regions in the Cochlea

- Hearing impairment is often associated with damage to the hair cells in the cochlea. Sometimes there may be complete loss of function of **inner hair cells (IHCs)** over a certain region of the cochlea; this is called a “dead region”. If the IHCs are nonfunctional in a certain region, the **primary auditory neurons** innervating that region will play little or no role in perception.

Cochlea from a 25-year-old man who had been exposed to gunshots. The dark lines show auditory neurons. There are no neurons coming from the basal part of the cochlea, indicating a dead region.



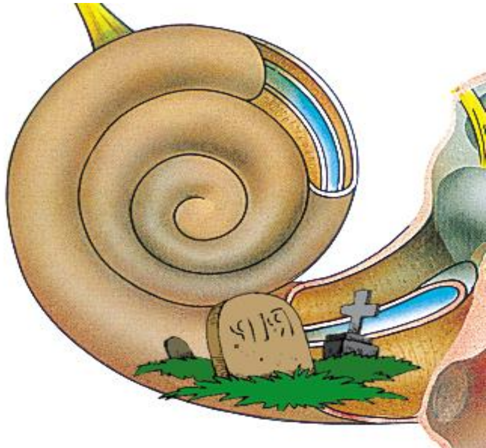
Cochlear Dead Regions

Dead regions are locations within the cochlea without functioning inner hair cells (IHCs) and/or auditory neurons.

Other terms include "lacunae", "holes in hearing," and "dead zones"

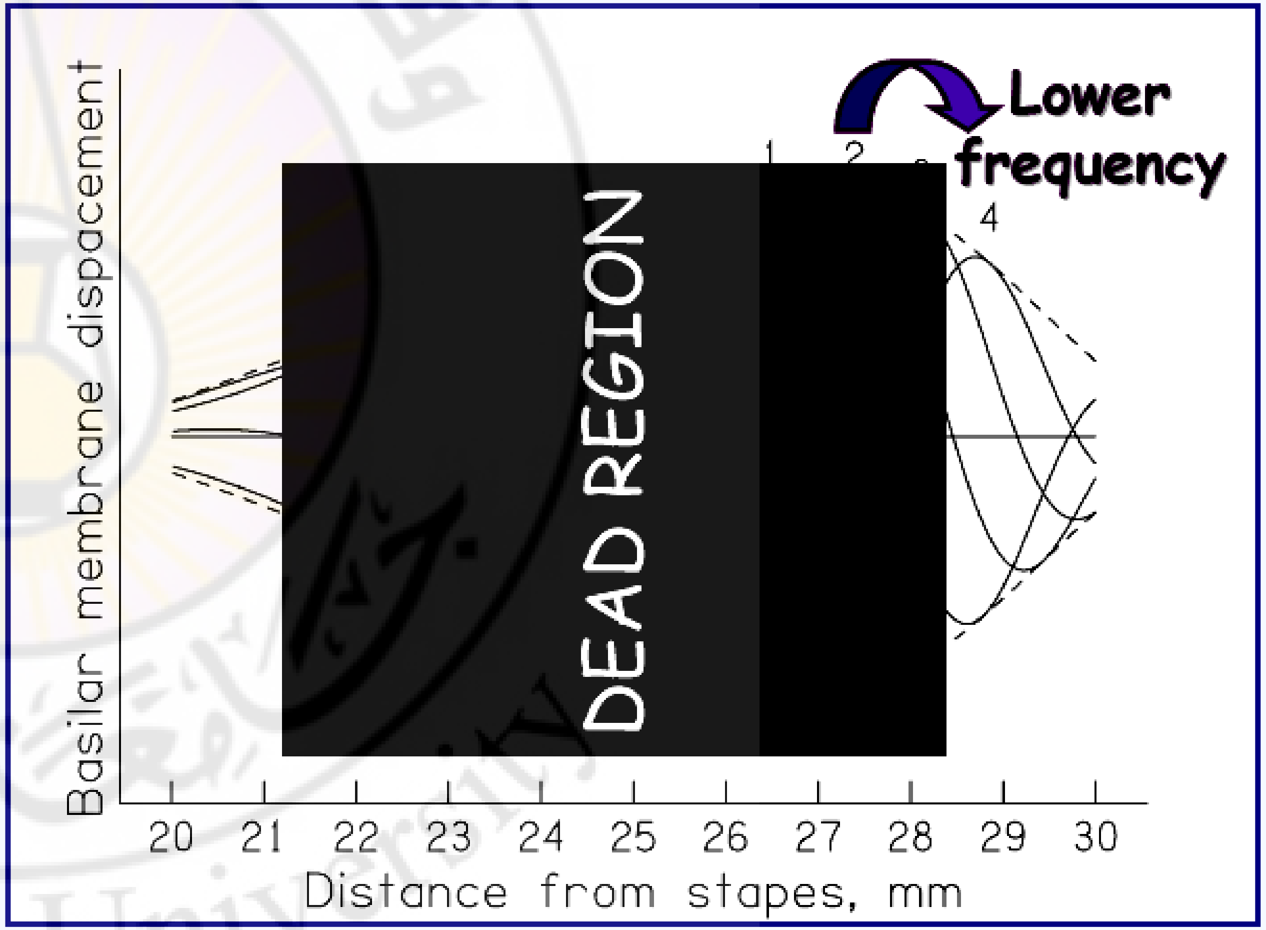
Ways of characterizing a dead region

- One way of characterizing a dead region is in terms of the **place in the cochlea** that is dead. For example, one might refer to a *basal dead region* or an *apical dead region*.
- An alternative definition is in terms of the **range of characteristic frequencies (CFs)** of the IHCs or neurons that would normally be associated with that region. Say, for example, that the IHCs are non-functioning over a region of the basilar membrane where the IHCs and neurons normally have CFs in the range 4000 to 10000 Hz. One might then describe this as a dead region extending from 4000 to 10000 Hz.
- In a more precise way, a dead region is defined in terms of the CFs of the IHCs and/or neurons immediately adjacent to the dead region. This definition is appropriate even if the CFs of the IHCs and neurons are shifted from “normal” values.



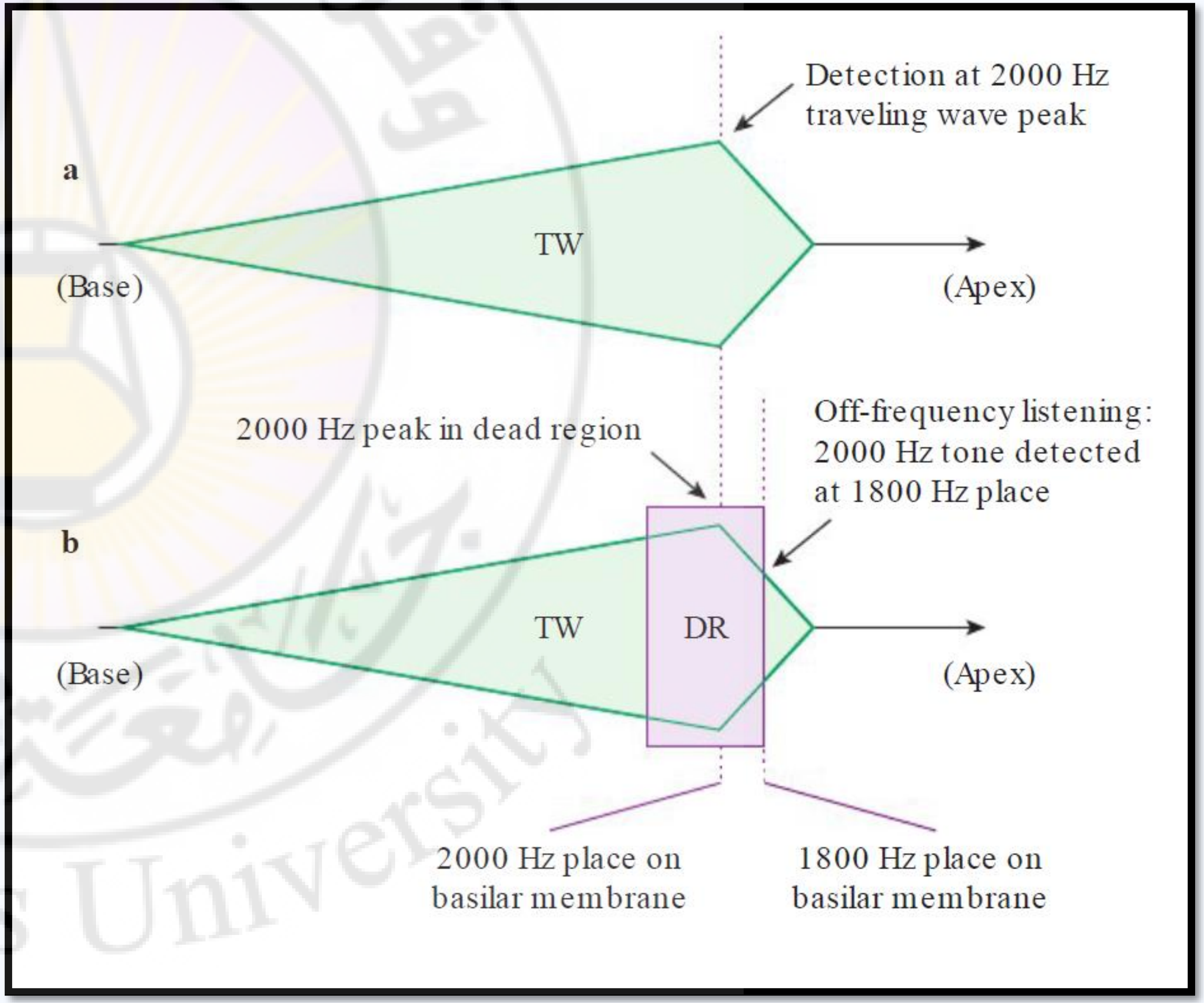
Off-frequency listening

- Basilar-membrane vibration in a dead region is not detected via the neurons directly innervating that region. We would expect there to be no response to a test tone that activates such a dead region.
- Yet it is still possible for the patient to detect it due to **off-frequency listening** which means that part of the vibration pattern caused by the test tone is picked up by functioning IHCs at nearby locations along the basilar membrane. this corresponds to downward spread of excitation.



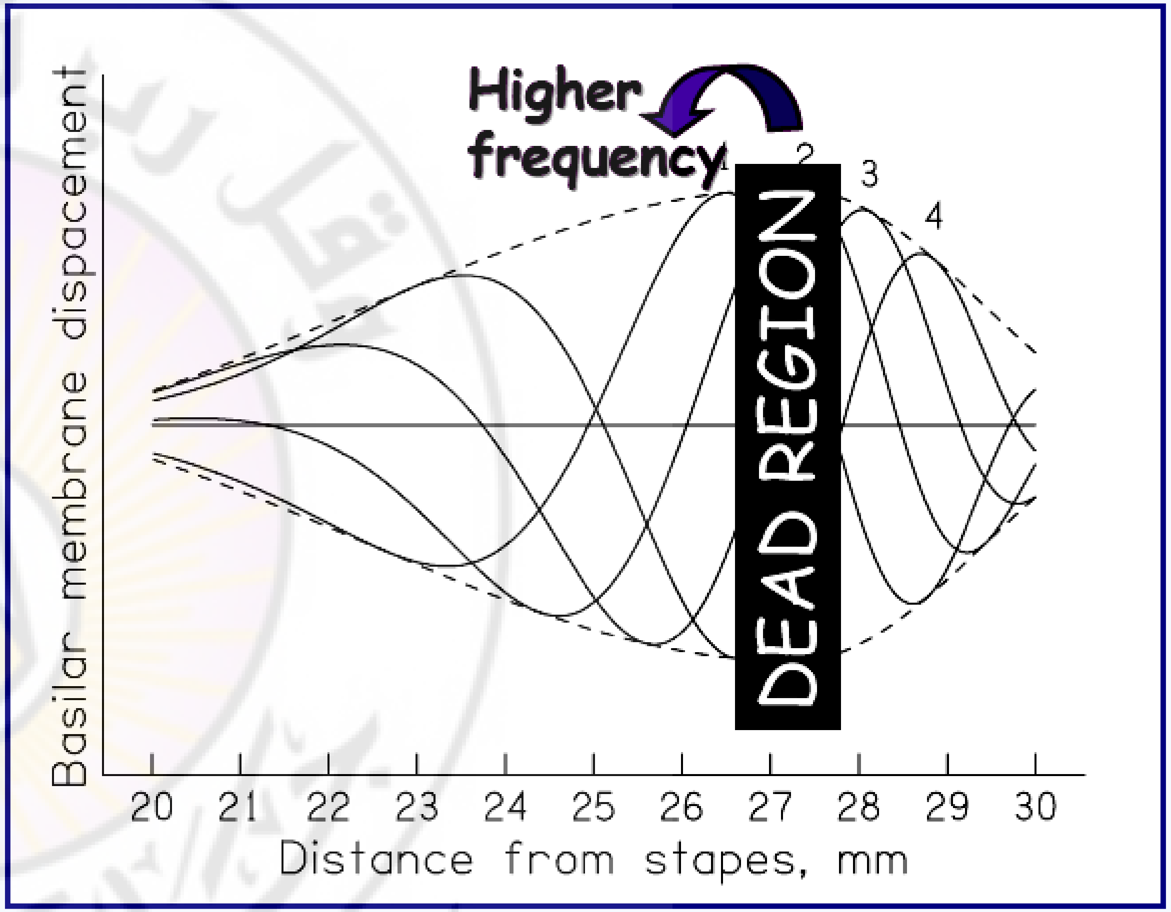
Off-frequency listening

- For example, a patient with a dead zone at the 2000 Hz place might still respond to a 2000 Hz test tone if part of its excitation pattern activates healthy IHCs at the 1800 Hz location.



- Similarly, if there are no functioning IHCs at an apical region of the cochlea, a low-frequency sound may be detected via neurons that are tuned to higher frequencies, i.e. via **upward spread of excitation.**

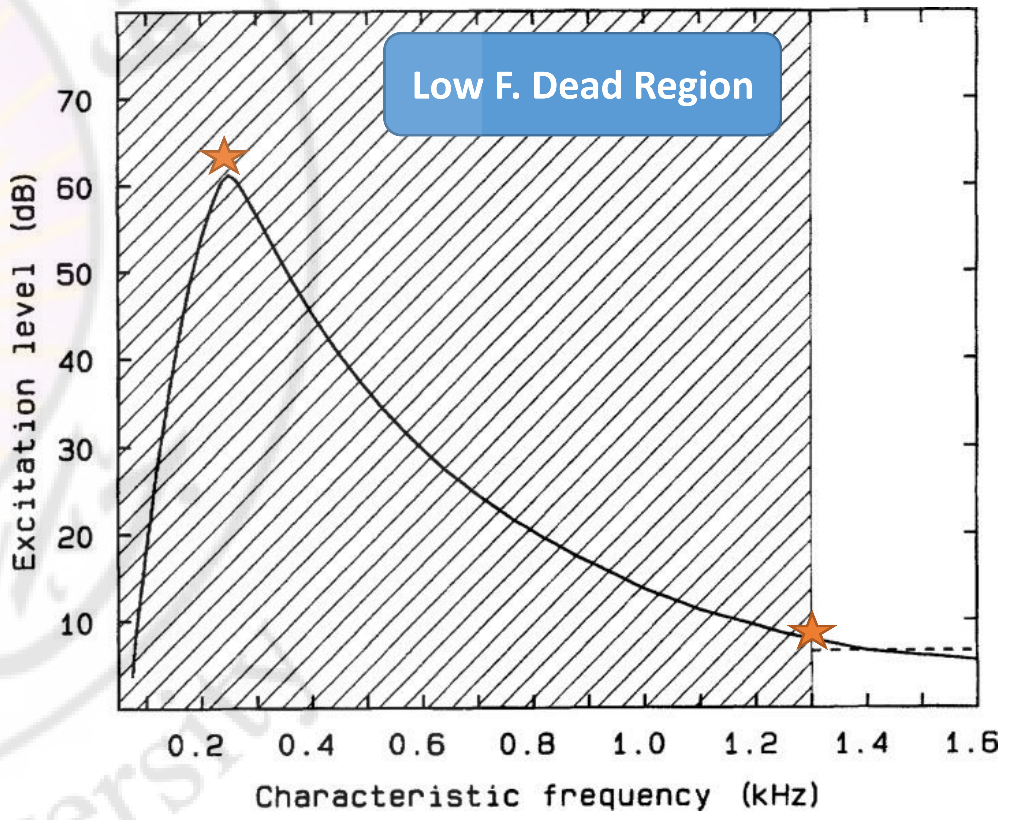
- Because of this possibility, the "true" hearing loss at a given frequency may be greater than suggested by the audiometric threshold at that frequency.



Detection of a tone of a particular frequency via IHCs and neurons with CFs different from that of the tone, is often called **"off-frequency listening"** or **"off-place listening"**.

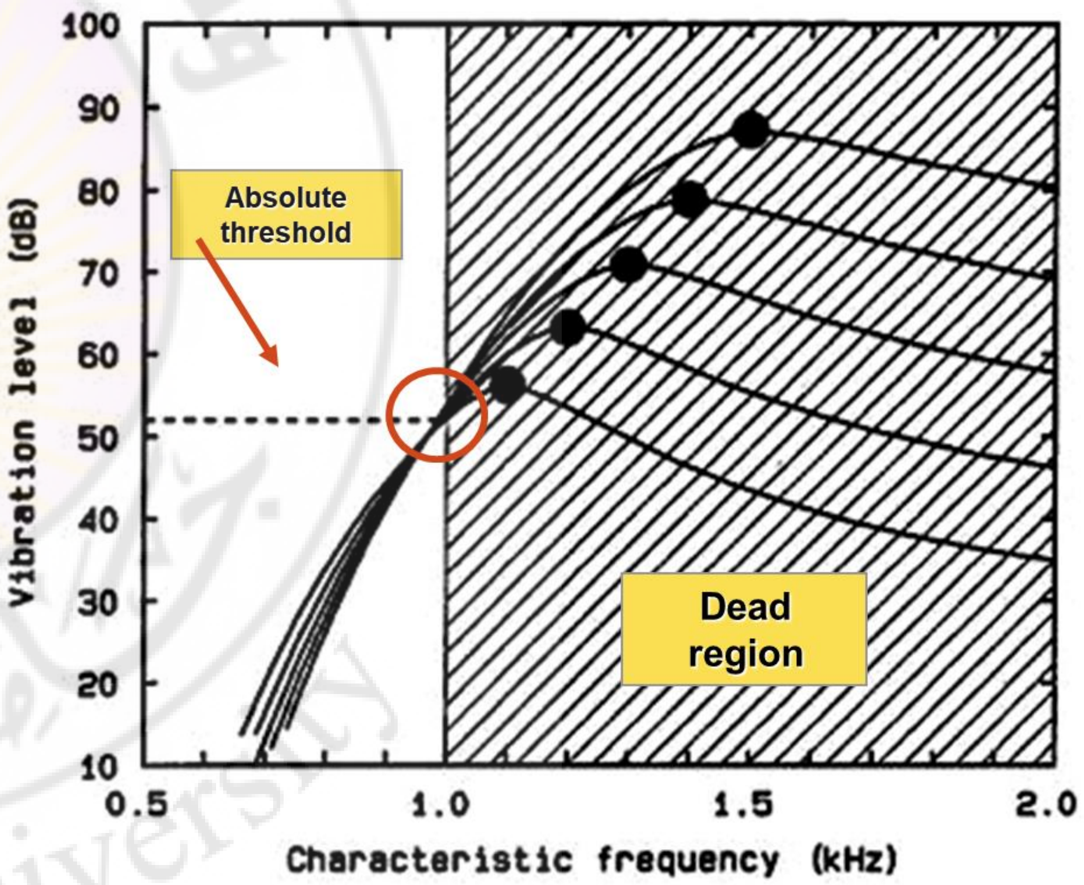
Effect of Dead Regions on the Audiogram

- The solid curve shows the **"excitation pattern"** that might be evoked by a low-frequency (250 Hz) tone in an ear with a low-frequency dead region, with normal hearing at medium and high frequencies.
- The dead region is indicated by the shaded area.
- The low-frequency tone is not detected via neurons innervating the apical region of the cochlea, as the IHCs in that region are dead. However, the tone will become audible when it produces sufficient excitation in the region of normal hearing.
- **In this example, the 250-Hz tone needs to be presented at about 60 dB to produce detectable excitation just outside the edge of the dead region (CFs just above 1.3 kHz).**



Effect of Dead Regions on the Audiogram

- A hypothetical ear with a 50-dB hearing loss at low frequencies, and a dead region extending from 1 kHz upwards (indicated by the shaded area).
- Each of the curves represents the excitation pattern for a tone with frequency falling in the dead region; the frequencies used are 1.1, 1.2, 1.3, 1.4 and 1.5 kHz.
- It is assumed that this tone is detected because of the downward spread of excitation.
- To be detectable the excitation must fall above the horizontal dashed line, whose position is determined by the absolute threshold for frequencies below the dead region.



Effect of Dead Regions on the Audiogram

- The following features in the audiogram can be taken as strong hints that a dead region may be present:
  - A hearing loss more than 90 dB at high frequencies or 75–80 dB at low frequencies.
  - A hearing loss of 40–50 dB at low frequencies with near-normal hearing at medium and high frequencies (perhaps indicating a low-frequency dead region).
  - A hearing loss greater than 50 dB at low frequencies with somewhat less hearing loss at higher frequencies (also perhaps indicating a low-frequency dead region).
  - A hearing loss increasing rapidly (more than 50 dB/octave) with increasing frequency (perhaps indicating a high-frequency dead region).

Beyond the Audiogram

- It is difficult to determine from the audiogram alone whether or not there is a dead region.

- It is even more difficult to define the extent of any dead region that might be present.

- Hence, special techniques may be used to identify dead regions when they are suspected.

Identification of DR

I. **Threshold Equalizing Noise (TEN) test:**

   A. **TEN (SPL)** Moore, et al. 2000

   B. **TEN (HL)** Moore, et al. 2004

II. **Psychophysical tuning curve (PTCs):**

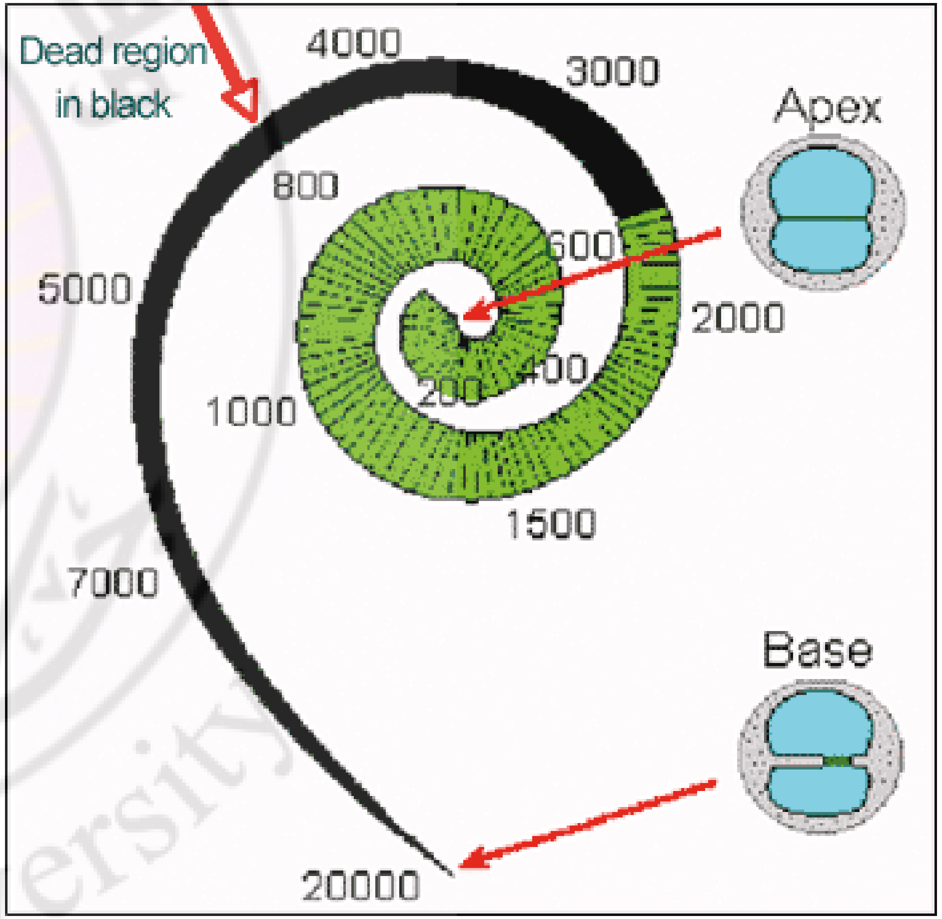
   A. **Classical method** Kluk and Moore, 2005

   B. **Fast method** Sek, et al. 2005

III. **Electrophysiological Tuning Curve (ETCs)** **Kluk, John, Picton, Moore 2007-8**

Diagnosing Dead Regions in the Cochlea

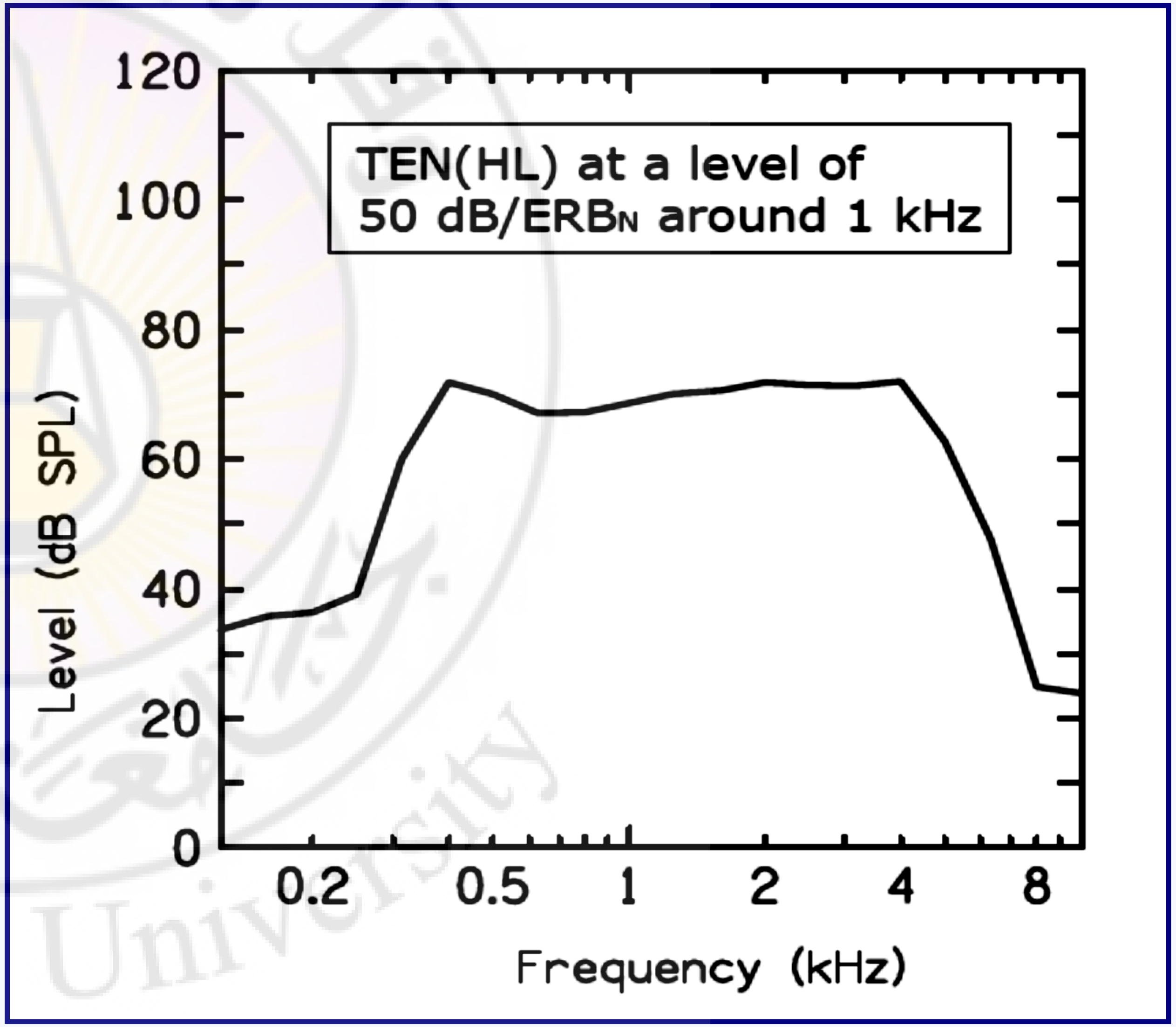
- The TEN(HL) test for diagnosing dead regions was designed to be quick and easy to administer and hence suitable for use in clinical practice.
- The development and validation of the first version of the test are described in Moore et al (2000).
- The test involves measuring the threshold for detecting a puretone presented in a background noise called **threshold-equalizing noise (or TEN).**



TEN(HL)

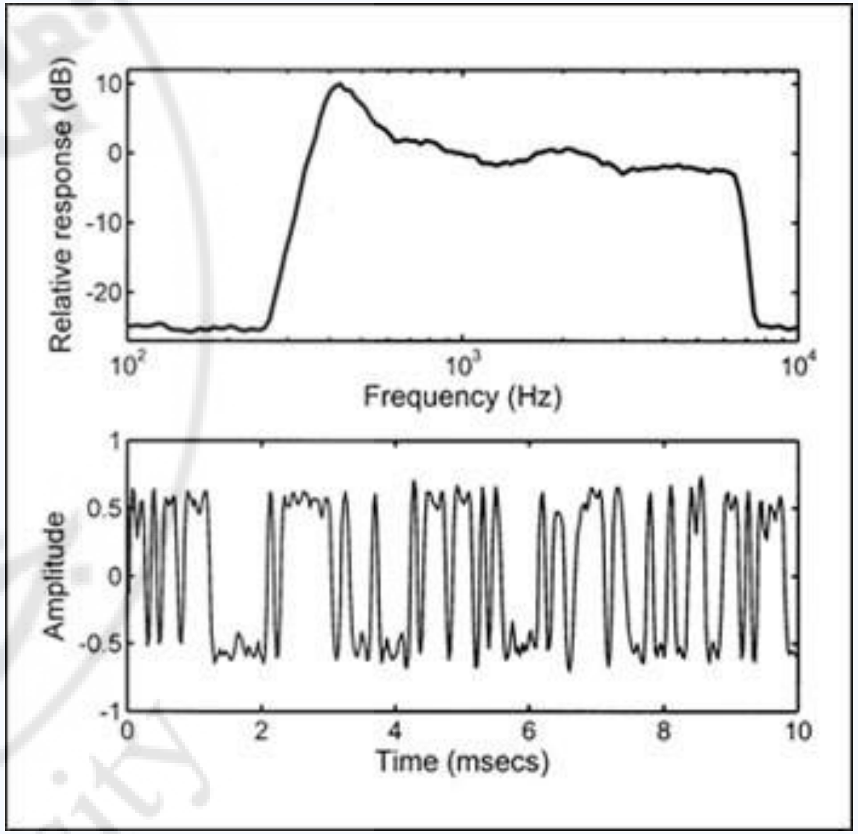
- Threshold-equalizing noise is a masking noise designed to produce the same masked thresholds at all frequencies (i.e., an 80 dB TEN level should produce an 80 dB masked threshold at every frequency tested).

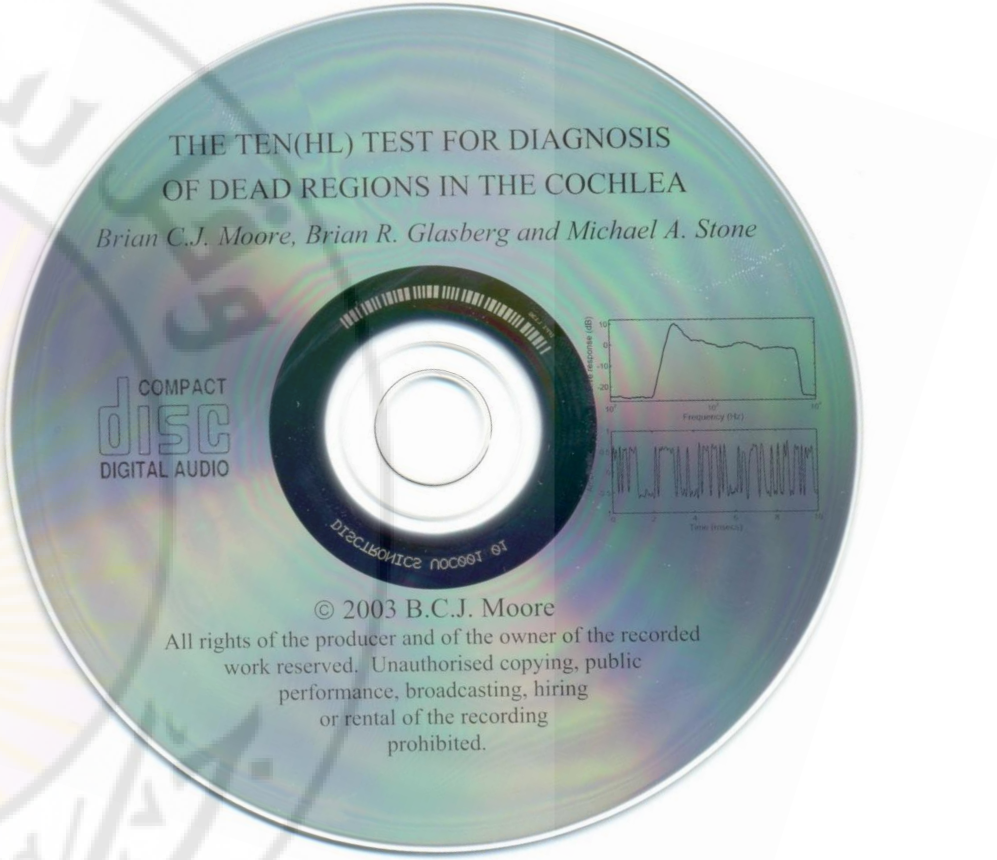
- The test originally used sound pressure levels (TENSPL), but it now uses hearing level **(HL)** measurements in 2 dB steps at audiometric frequencies between **500 and 4000 Hz**.



TEN(HL)

- A problem with this first version of the TEN test was that the clinician had to measure absolute thresholds (audiometric thresholds) twice—once using the tones generated by the audiometer, with level specified in dBHL, and once using the tones from the CD, with level specified in dBSPL. This was inconvenient for the clinician.
- To overcome this problem, a second version of the TEN test was developed in which the noise was designed to give equal masked thresholds in dBHL for all frequencies from 500 to 4000 Hz for normally hearing people.
- This version is called the “TEN(HL)” test. As all calibrations were in dBHL, absolute thresholds could be measured either using the tones generated by the audiometer, or using the test tones from the CD; the results were expected to be very similar.
- This version of the TEN(HL) test can only be used with specific (TDH39, TDH49, and TDH50) headphones.





Until recently, the TEN(HL) test for diagnosing dead regions in the cochlea could only be conducted by use of a compact disc player connected to an audiometer. Now, the test has been implemented within the many stand-alone and PC-based audiometers (**GSI** audiostar Pro, Affinity2.0 and Equinox2.0 (version 2.0.4) made by **Interacoustics**)

Implementation of the Test in Audiometers

- Possible frequencies for the test tone are 500, 750, 1000, 1500, 2000, 3000, and 4000 Hz.
- Initially, the TEN is turned off while the appropriate level is selected. Some useful rules for selecting the level of the TEN are as follows:

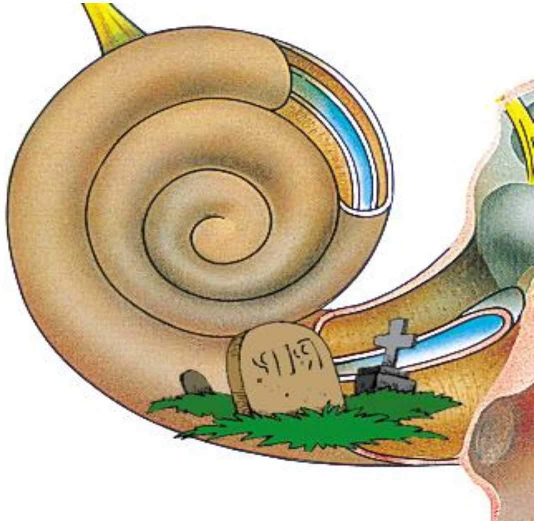
➢ For frequencies where the hearing loss is less than or equal to 60 dBHL, set the TEN level to 70 dBHL. This is not unpleasantly loud for most people, and it leads to a definitive result.

➢ When the hearing loss is 70 dBHL or more at a given frequency, set the TEN level 10 dB above the audiometric threshold at that frequency. For example, if the audiometric threshold is 75 dBHL, set the TEN level to 85 dBHL.

➢ If the TEN is found to be unpleasantly loud, or if the maximum TEN level of 90 dBHL is reached, then the TEN level can be set equal to the audiometric threshold. This should still give a definitive result.

Implementation of the Test in Audiometers

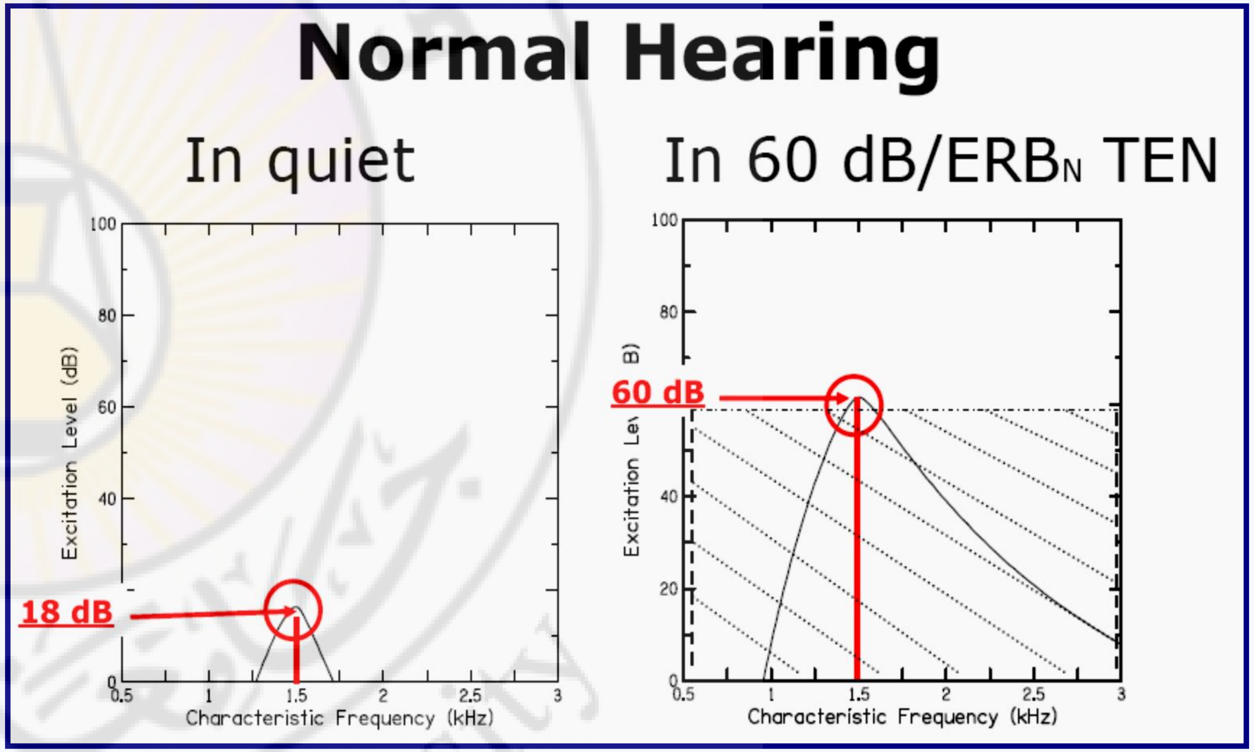
- It may be difficult or impossible to apply the TEN(HL) test when the hearing loss at the test frequency is 90 dBHL or more, although it is quite likely that a dead region would be present with such a severe hearing loss.
- The threshold for detecting a test signal in the TEN is determined using the same procedure as would be used for manual audiometry, except that a step size in level of 2 dB should be used when the tone is in the region of the detection threshold; larger steps can be used initially, to find the approximate threshold. The use of small steps makes the outcome more precise, and reduces the incidence of false positives.
- Once the threshold has been measured for a given test frequency, the appropriate TEN level is set for the next test frequency, and the process is repeated.



Test Procedure

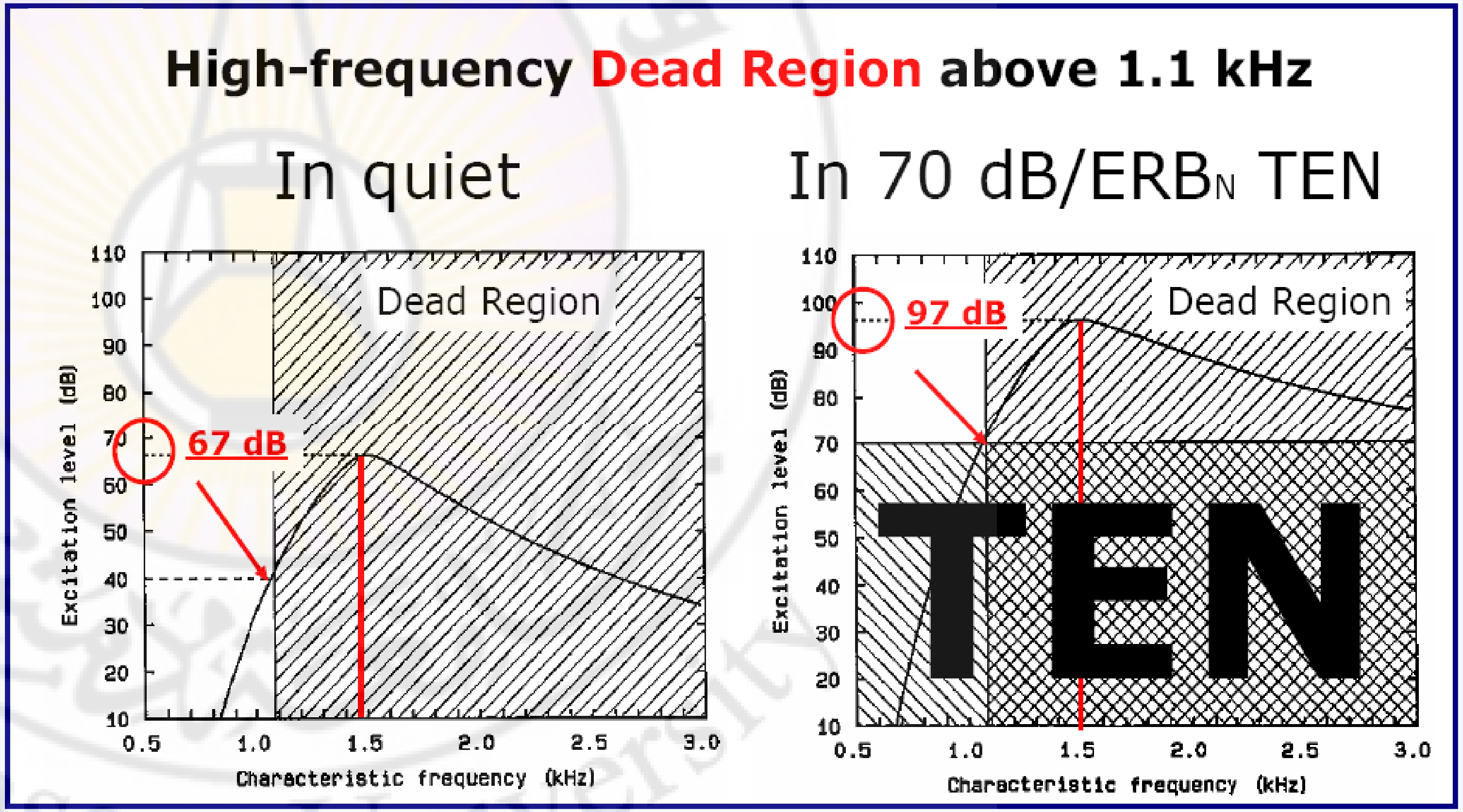
- Testing involves obtaining unmasked thresholds for the test tones followed by masked thresholds using the TEN.
- **Note**: the TEN test is performed **ipsilaterally**, meaning that the tone and the noise are presented in the **same ear**.

- **If the test tone is *not* in a dead region, then the masked threshold will be about equal to the TEN level, or *less than* 10 dB above it .**



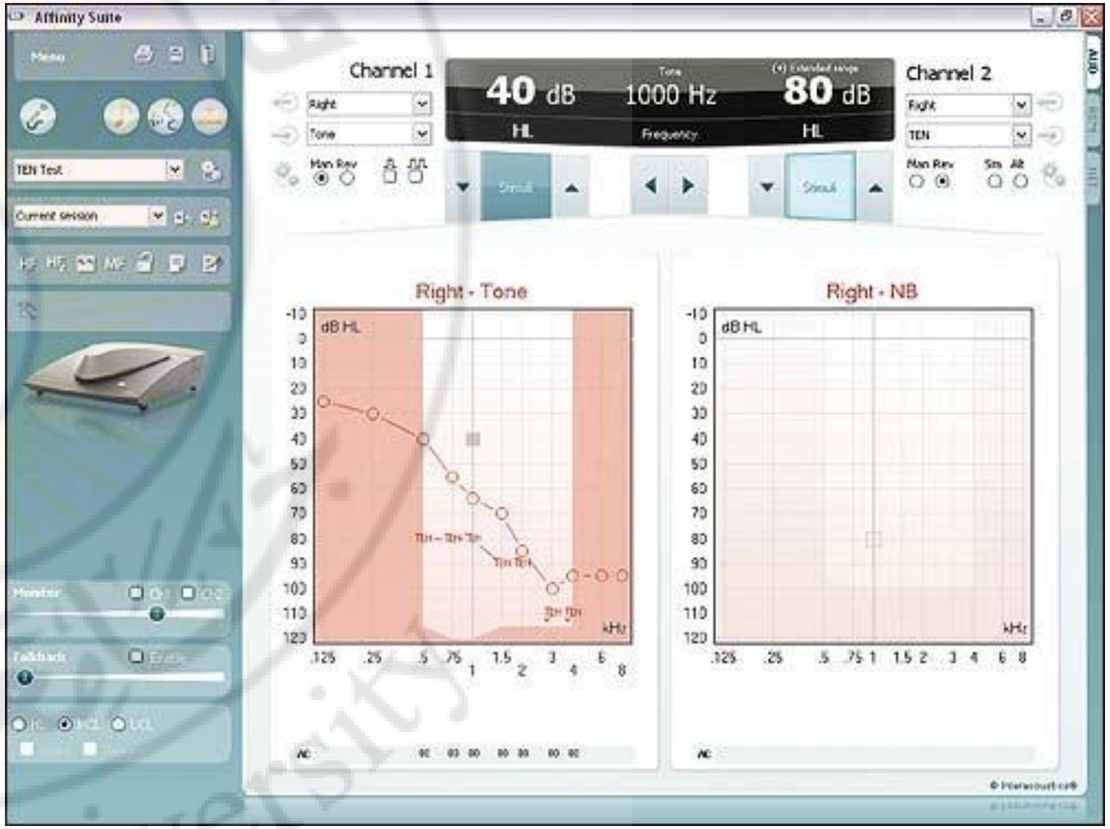
Test Procedure

- If the test tone *is* in a dead region, then the masked threshold will be *at least* 10 dB higher than the TEN level.



Criteria for diagnosing a dead region

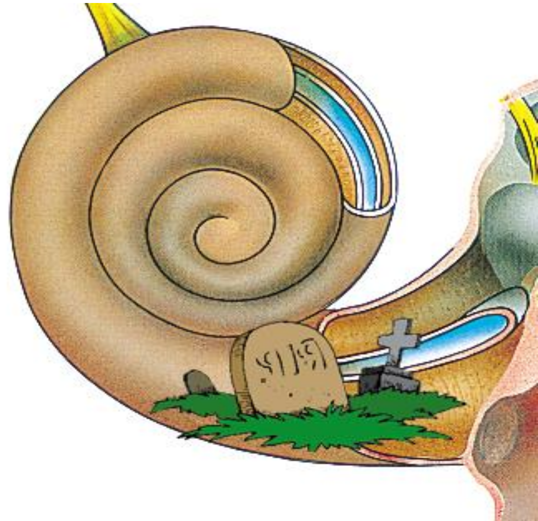
1. **The threshold of the test tone in the TEN is 10 dB or more above the TEN level.**
2. **The threshold of the test tone in the TEN is 10 dB or more above the audiometric (absolute) threshold.**



- If the TEN level is selected as described earlier, then criterion #2 will automatically be satisfied when criterion #1 is satisfied.

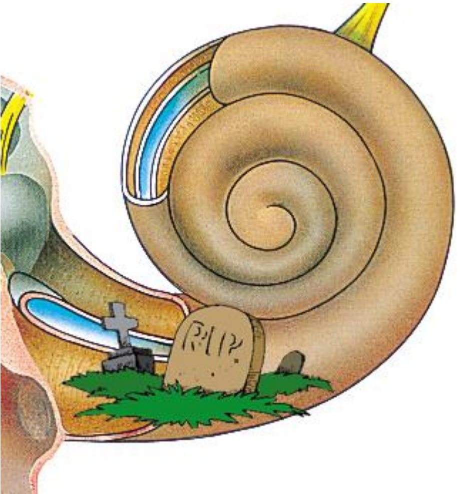
Notes:

- It typically takes about 4 minutes per ear to perform the TEN(HL) test for all test frequencies.
- In practice, it is usually not necessary to conduct the TEN(HL) test for frequencies where the hearing loss is 50 dB or less. For example, if a patient has a typical sloping hearing loss, with relatively good hearing at low frequencies and poor hearing at high frequencies, it is only necessary to conduct the test for the medium and high frequencies.
- However, if the patient has an unusually shaped audiogram, such as a localized mid-frequency loss, it may be worth conducting the TEN(HL) test even when the loss is mild.



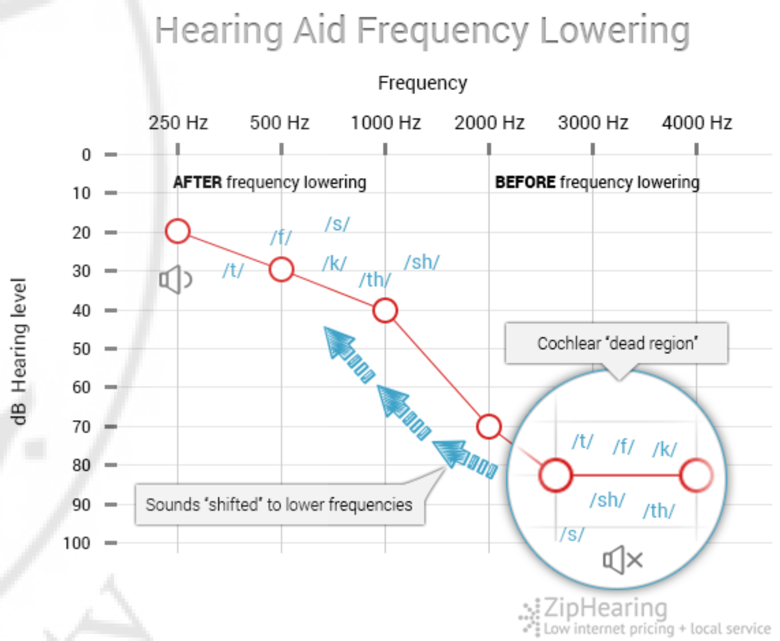
Importance of diagnosing DRs

- Help counsel the patient and manage expectations regarding the potential benefit of hearing aids
- Helps on choice of type of hearing aid
- Can help determine if a patient would be a good candidate for cochlear implants
    - Patient might do better with an implant when there are extensive dead regions
    - Helps determine insertion depth



High Frequency Dead Regions

- For patients with high frequency dead regions, there may be some benefit in applying amplification for frequencies **up to about 1.7fe**.
- For example, if a patient has a dead region that starts at 1000 Hz and extends upwards from there, there may be some benefit in amplifying frequencies up to 1700 Hz.
- However, there will probably be no benefit of applying amplification for frequencies above this point. Trying to achieve sufficient gain for frequencies above 1700 Hz might lead to problems with distortion and acoustic feedback.
- For a patient with an extensive high frequency dead region, a hearing aid incorporating frequency transposition or frequency compression might be a viable option.



Low Frequency Dead Regions

- Examples of etiologies that are known to be associated with low-frequency dead regions are Mondini dysplasia, vascular disruption and the advanced stages of Ménière's disease.

- For people with low frequency dead regions, as can occur for example in cases of Ménière’s syndrome, there appears to be some benefit in amplifying frequencies above 0.57fe, but not in amplifying frequencies below 0.57fe.

- Amplification of frequencies below 0.57fe can actually lead to reduced speech intelligibility.

Restricted Areas of Cochlear Function

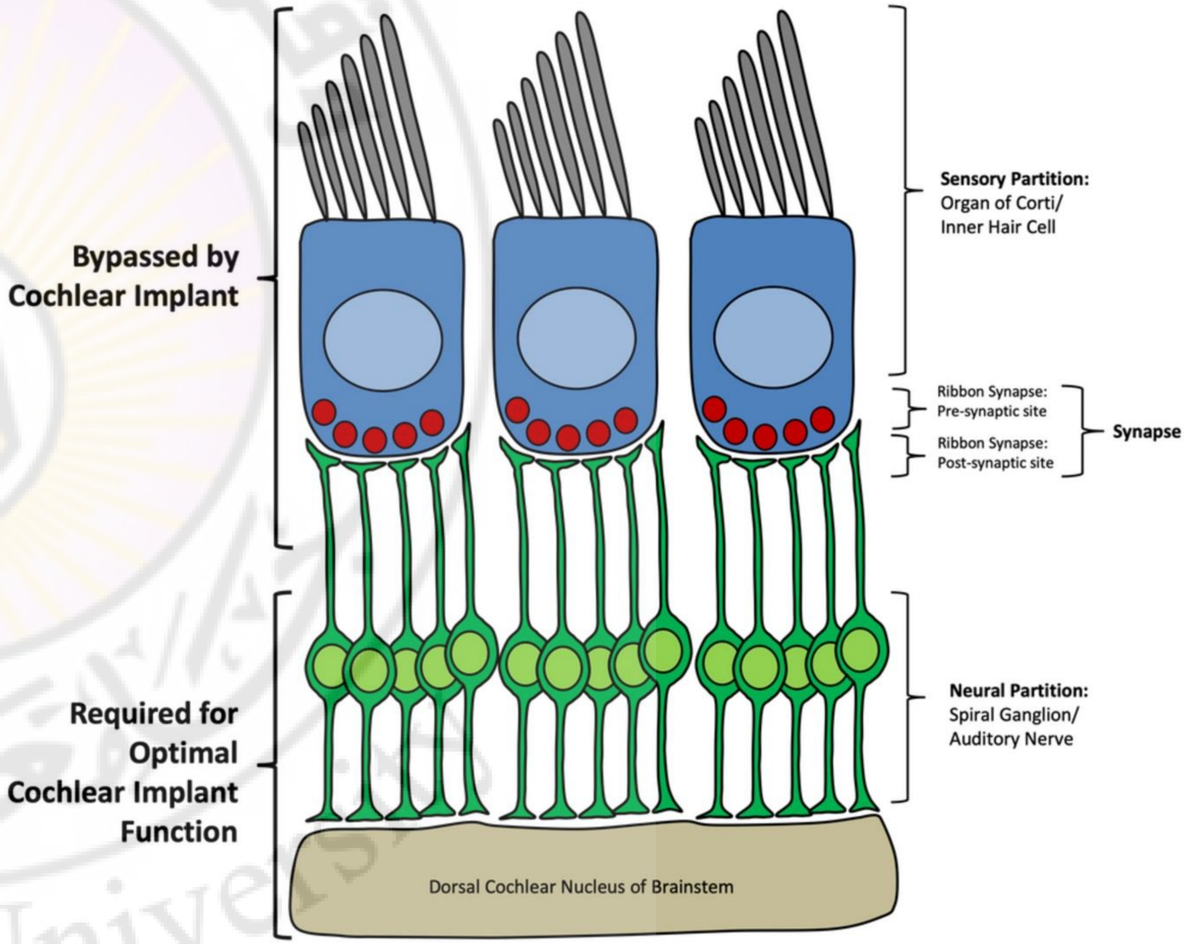
- In rare cases, the audiogram may have the form of an **inverted V** in which hearing is relatively good over a small frequency range, and poor at all remaining high and low frequencies.
- This can indicate a restricted functioning region in the cochlea, with extensive dead regions below and above it.
- However, it is not safe to make a diagnosis of dead regions based solely on an inverted V-shaped audiogram. A test such as the TEN(HL) test is needed for a firm diagnosis.
- For a patient who does have a restricted functioning region—with dead regions above and below the functioning region—the most effective amplification strategy may be to amplify over a limited frequency range around the functioning region.

Assessing Potential Usefulness of Implants or Hybrids

- The TEN(HL) test may also be relevant for patients who are being considered for a **cochlear implant**.
- A patient with very extensive dead regions would be likely to do better with a cochlear implant than with a hearing aid (or aids).
- The test may also be useful for patients considering a combination of a cochlear implant and a hearing aid. Such patients typically have a dead region in the parts of the cochlea that normally respond to medium and high frequencies, but have some functional hearing at lower frequencies.
- It may be useful to determine the edge frequency (fe) of any dead region. This may be relevant to choosing the most appropriate insertion depth of the electrode array, and to the way that frequencies in the input signal are mapped to acoustic and electric stimulation.

Auditory neuropathy

- Patients with auditory neuropathy sometimes have high thresholds for detecting the test tone in the TEN, meeting the TEN(HL) test criteria for diagnosis of a dead region even for frequencies where their audiometric thresholds are near normal.
- This does not necessarily indicate that they have extensive dead regions, although they may have only patchy survival of IHCs.



Central problems

- Patients may also have high thresholds for detecting the test tone in the TEN as a result of central problems (eg, brain injury) in auditory areas resulting from trauma or a stroke.
- These high thresholds may result from poor “detection efficiency” rather than from dead regions.
- Nevertheless, high thresholds in the TEN are likely in all cases to be associated with a poor ability to understand speech when background sounds are present.

3. Tests for Non-organic hearing loss

Nonorganic hearing loss

- The exaggerated hearing loss which is not due to an organic cause, is called a **nonorganic hearing loss**.
- Nonorganic hearing losses are also known as **functional** or **exaggerated hearing losses**, or **pseudohypacusis**, and these terms are used interchangeably.

Some Points

- Not all patients with exaggerated hearing losses actually have normal hearing. In fact, most adults with functional impairments have at least some degree of underlying organic hearing loss.
- clinical experience suggests that it is more common bilaterally
- Because functional losses do not have an organic basis they must be due either to **psychogenic** causes or to **malingering** or **feigning**.
- Malingering may be motivated by financial or other benefits that the patient associates with a hearing loss.

- Nonorganic hearing loss tends to occur in **children** who fail hearing screening tests at school, but it has also been reported following incidents of head trauma and in some cases of child abuse.

Some Points…

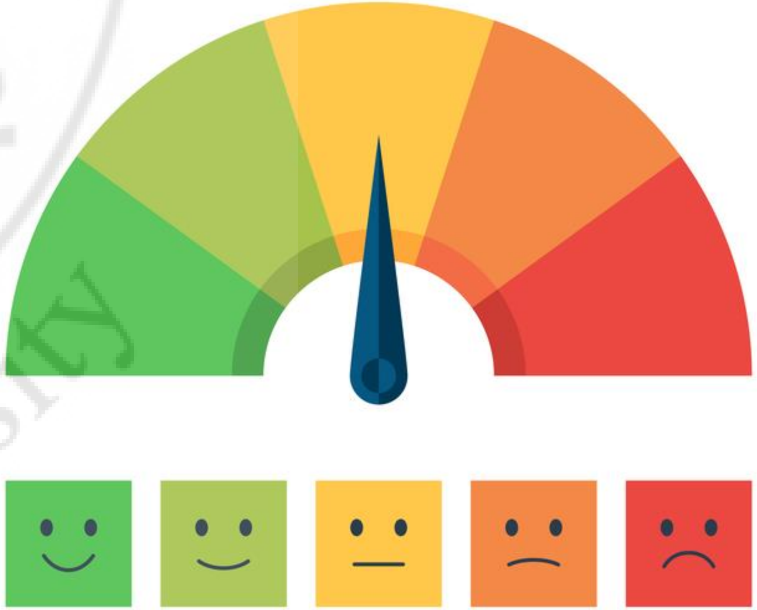
- The first factors that raise the index of suspicion for a possible nonorganic hearing loss involve real world considerations about **who referred the patient** and why the evaluation is being done, rather than his clinical behavior or complaints.
- These include referrals made by attorneys, insurance companies, or compensation boards.
- Also included are referrals that are in any way related to legal issues, accidents, employment and/or work environment issues, or any form of claim that deals with any kind of pension or compensation.

Behavioral Manifestations of Nonorganic Hearing Loss

- Many of these patients exaggerate the behaviors and complaints that they associate with people who have real hearing problems.
- Examples include leaning forward, turning the head to favor the “better side,” cupping a hand over one ear to make sounds louder, and obviously gazing at the talker’s mouth to demonstrate a reliance on lipreading.
- Some patients talk loudly in an exaggerated effort to hear their own voices.
- Functional patients may also constantly ask for repetition and clarification, or even insist on having things written for them.
- One might observe the patient conversing effortlessly with others in the waiting room even though his audiometric thresholds would make this impossible. Few adult feigners make this mistake when the clinician is present unless they are caught off guard. However, it is not uncommon for children with nonorganic hearing loss to carry on a conversation in an informal setting but not in a test situation.

Indicators of Nonorganic Hearing Loss

- Lack of False Alarm Responses
- Threshold Variability
- Absence of a Shadow Curve
- Atypical Speech Audiometry Responses
- SRT-PTA Discrepancy
- Audiogram Configuration

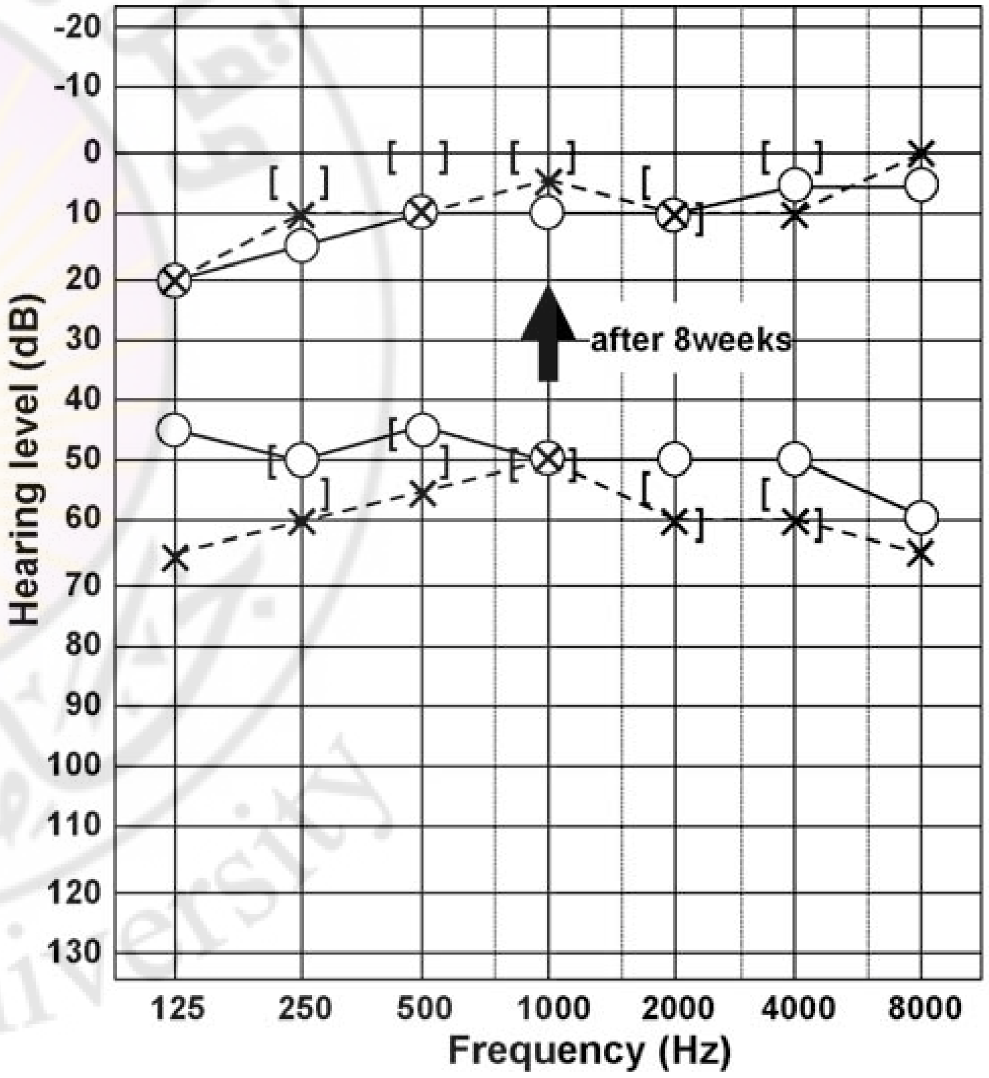


Lack of False Alarm Responses

- Almost all patients who have normal hearing and organically based hearing losses will occasionally respond even though no tone has been presented.
- These responses that are made during the silent periods between tone presentations are called **false positive responses** or **false alarms**; and demonstrate that the patient is highly motivated to hear every possible signal, no matter how faint it might be.
- Pure tone testing should include 1-minute “silent periods,” during which no stimuli are presented, as a check for false alarms.
- One should consider the possibility of nonorganic hearing loss if the patient does not produce any false alarms, especially during these rather long silent intervals.

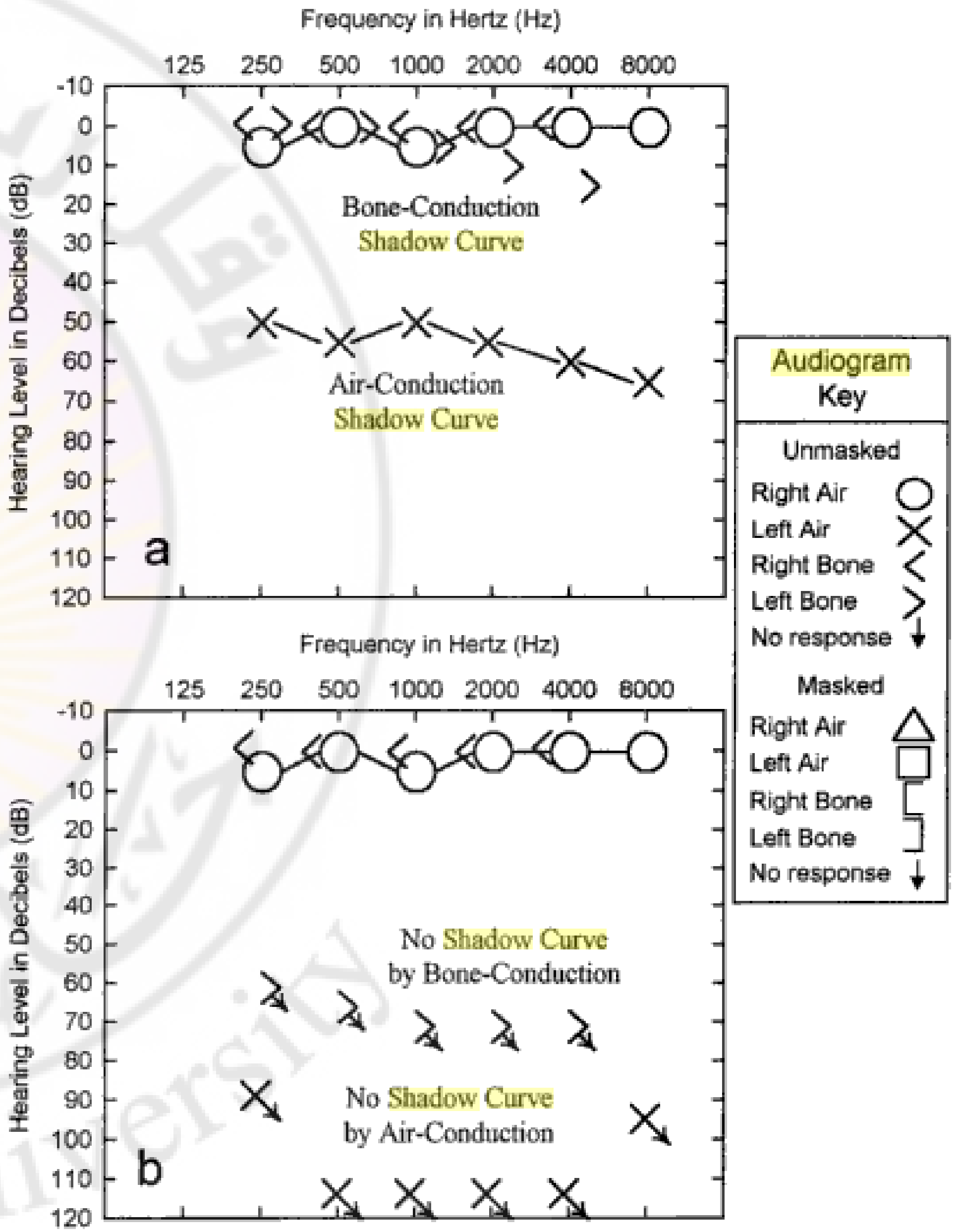
Threshold Variability

- Pure tone thresholds are usually repeatable within a range of ±5 dB, and test-retest reliability is certainly expected to be within ± 10 dB.
- Thresholds that vary by **15 dB or more** from test to retest are associated with a nonorganic hearing loss.
- On the other hand, good test-retest reliability does not rule out a nonorganic hearing loss because many functional patients are able to produce thresholds that are quite reliable.



Absence of a Shadow Curve

- The absence of a shadow curve for air-conduction is a strong indicator of nonorganic hearing loss when there is a unilateral (or asymmetrical) hearing loss so large that it must result in cross-hearing of the signals being presented to the poorer ear.
- In addition, because there is little interaural attenuation for bone-conduction, the absence of a shadow curve for bone-conduction is a very strong sign of pseudohypacusis.

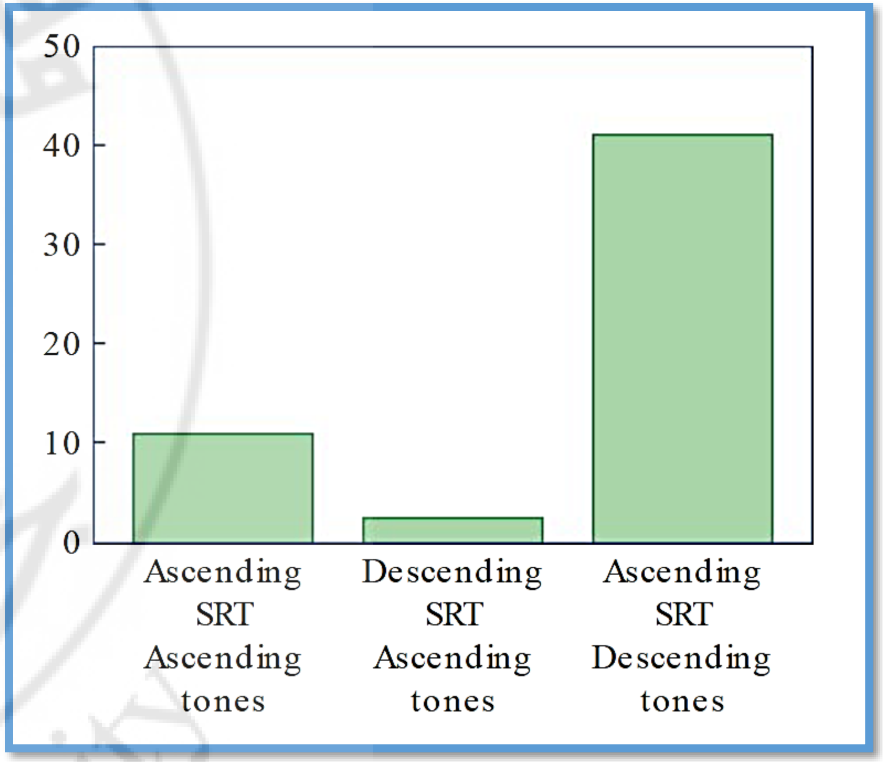


Atypical Speech Audiometry Responses

- They often miss spondee words previously repeated correctly at lower hearing levels.
- They also give many half-word responses to the spondee words (e.g., “cow” for “cowboy,” or “well” for “farewell”), and even monosyllabic word responses that are unrelated to the spondee that was presented (e.g., “ball” for “armchair”).
- Functional patients may also obtain higher than expected speech recognition scores when tested at low sensation levels (SLs) relative to their admitted thresholds. This suggests a nonorganic hearing loss because high speech recognition scores are not expected until the presentation level reaches ~ 30 dB SL or even higher.

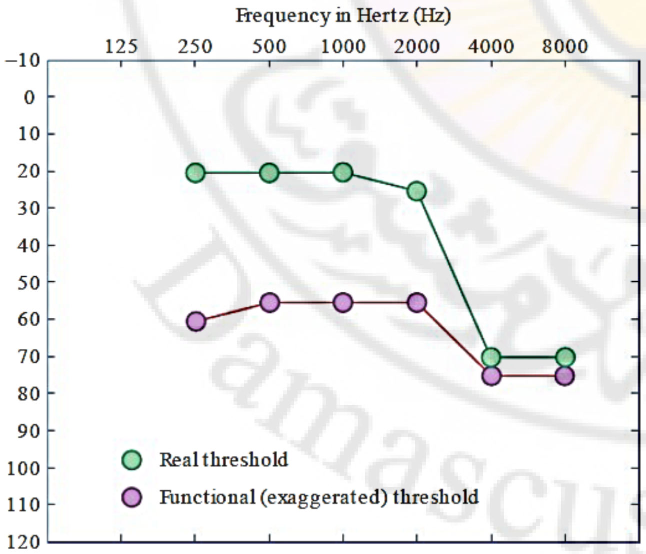
SRT-PTA Discrepancy

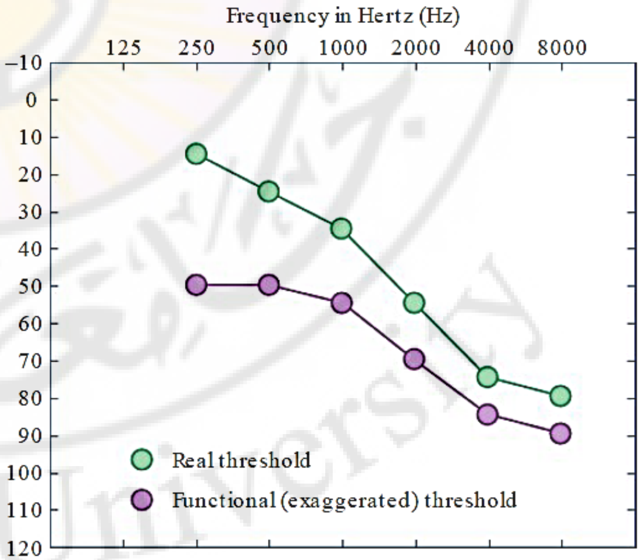
- The pure tone average (PTA) of the 500, 1000, and 2000 Hz thresholds and the SRT normally agree within reasonable limits.
- SRT is often better (lower) than the PTA in patients with functional losses.
- An **SRT-PTA discrepancy** (or **PTA-SRT discrepancy**) **of 12 dB or more** is considered to indicate a nonorganic hearing loss.
- One must be mindful of the shape of the audiogram when making the SRT-PTA comparison.



Audiogram Configuration

- The classical literature described nonorganic hearing loss as “saucer-shaped” or “ flat,” but it has been shown that no particular audiometric configurations are characteristic of functional losses.
- On the other hand, the *functional components* of exaggerated audiograms are related to the configuration of the *underlying, organic thresholds.*



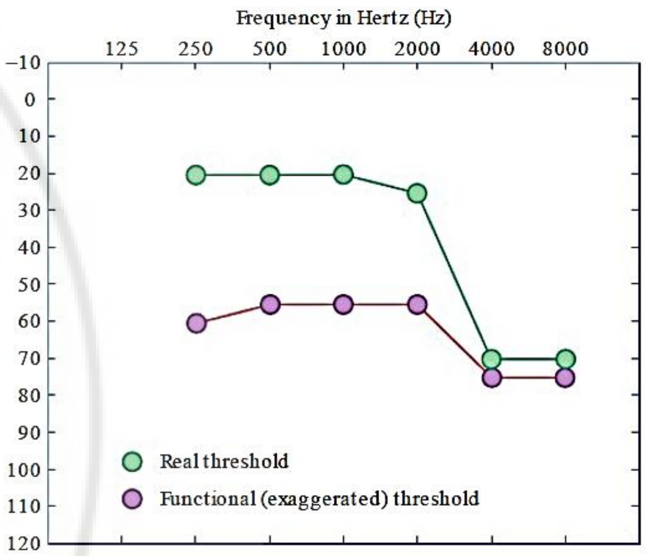


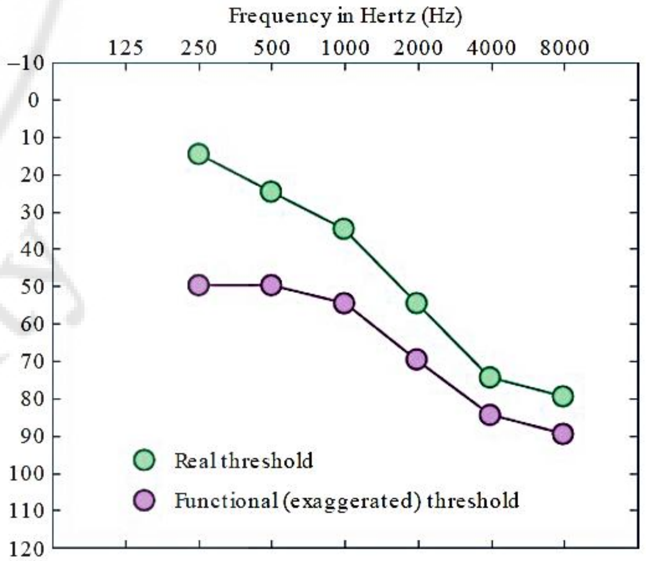
Audiogram Configuration

- Patients with functional impairments use an internalized reference level or "anchor" that has a certain loudness level; they will not respond to a test tone (or other test stimulus) until its loudness level reaches that of the anchor within an ear.

- Functional components are smaller at the frequencies where the actual losses are worse and larger at the frequencies where the real thresholds are better because loudness recruitment is related to the degree of hearing loss.

- As a result, the majority of functional components tend to be wider at lower frequencies and narrower at higher frequencies simply because high-frequency losses are so common.





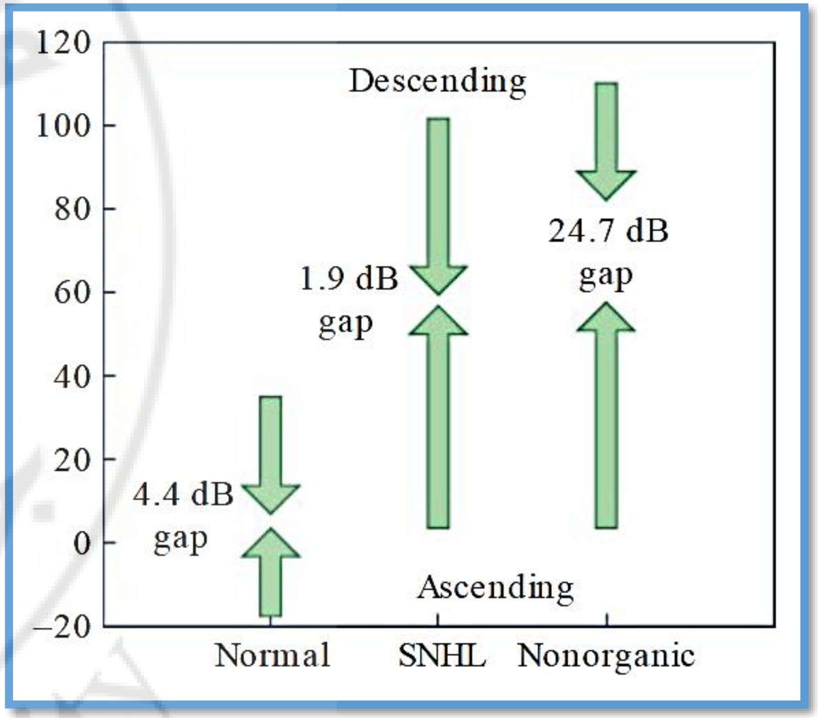
Tests for Nonorganic Hearing Loss

Behavioral Tests

Physiological Tests

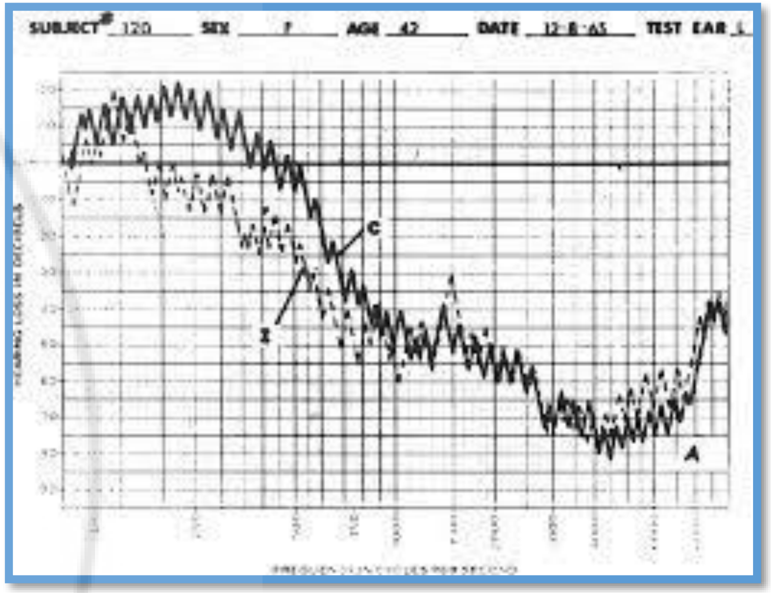
Ascending-Descending Gap Tests

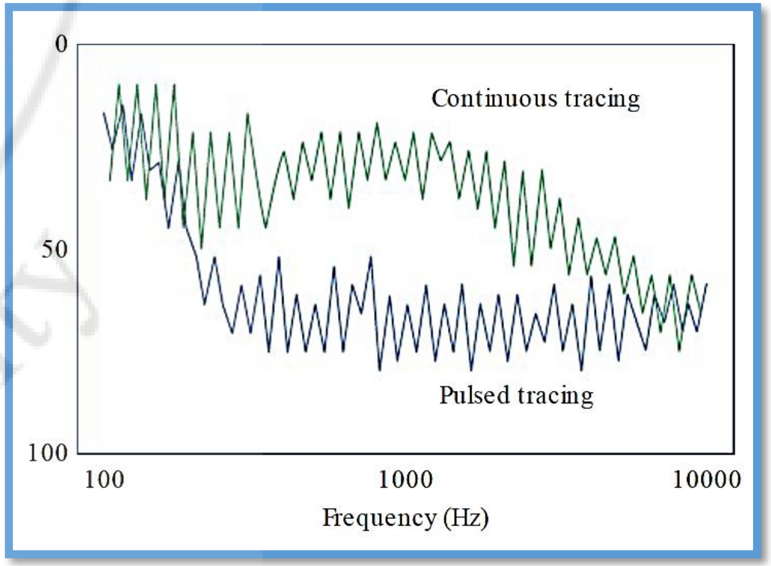
- One way to help identify patients with functional losses is to use techniques that cause their exaggerated thresholds to be even more variable.
- This can be done by testing the threshold for the same tone separately with an ascending approach and with a descending approach.
- The difference between these two thresholds is usually called the **ascending-descending gap**, and the testing itself can be done by either manual or Bekesy audiometry.
- When Bekesy audiometry is used, the method is known as Bekesy Ascending-Descending Gap Evaluation (BADGE).
- The ascending-descending gap is narrow for real thresholds and wide for exaggerated hearing losses.



Bekesy Audiometry

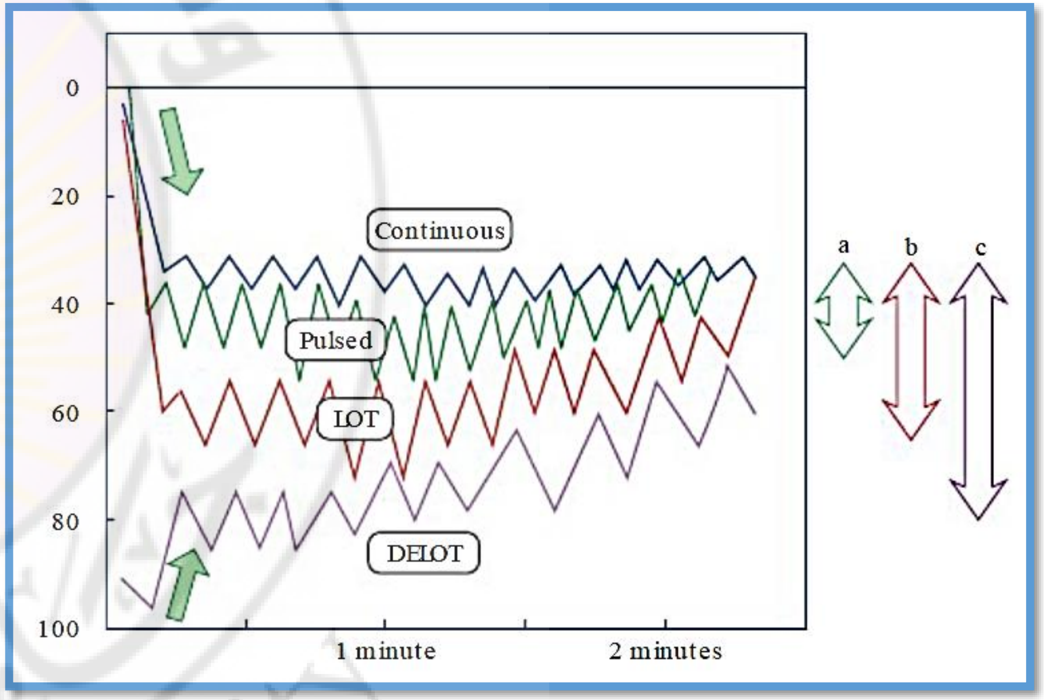
- The type V Bekesy audiogram is associated with functional (or nonorganic) hearing loss.
- Unlike other Bekesy audiograms, functional patients’ pulsed tracings are tracked below the continuous tracings.
- It appears that this pattern is due to the effects of **loudness memory** as the functional patient attempts to keep the continuous and pulsed tones at a targeted loudness above his real thresholds.
- The pulsed tone needed more intensity than the continuous tone to reach the same recalled loudness.





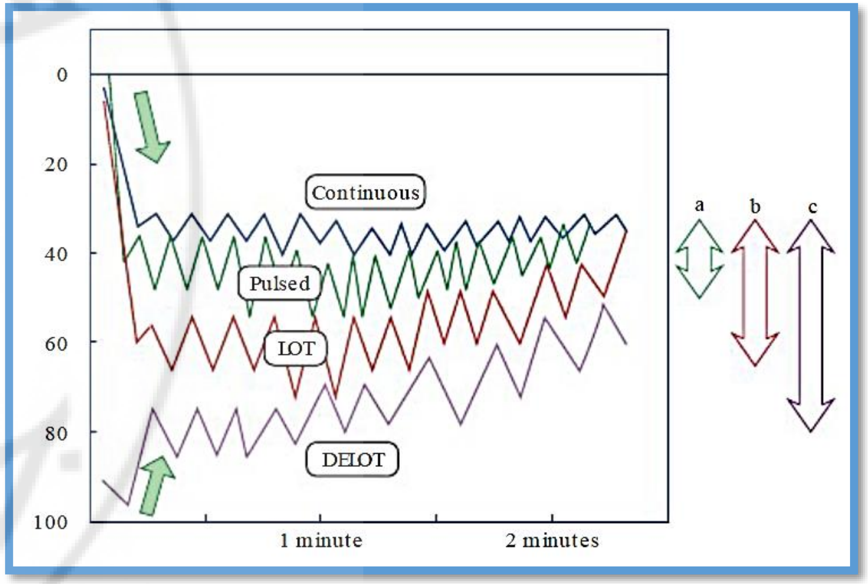
Bekesy Lengthened Off -Time (LOT) test

- Conventional Bekesy audiometry uses pulsed tones that are *on* and *off* for equal amounts of time (200 ms *on* and 200 ms *off*).
- The **Lengthened Off -Time (LOT) test** uses Bekesy audiometry in which the pulsed tones have an *off -time* that is lengthened from 200 to 800 ms.
- In addition, the LOT test uses fixed-frequency rather than sweep frequency tracings.
- The LOT test increases the degree to which the pulsed tracing falls below the continuous tracing in functional patients, thereby improving the identification of functional impairments with the type V Bekesy pattern.



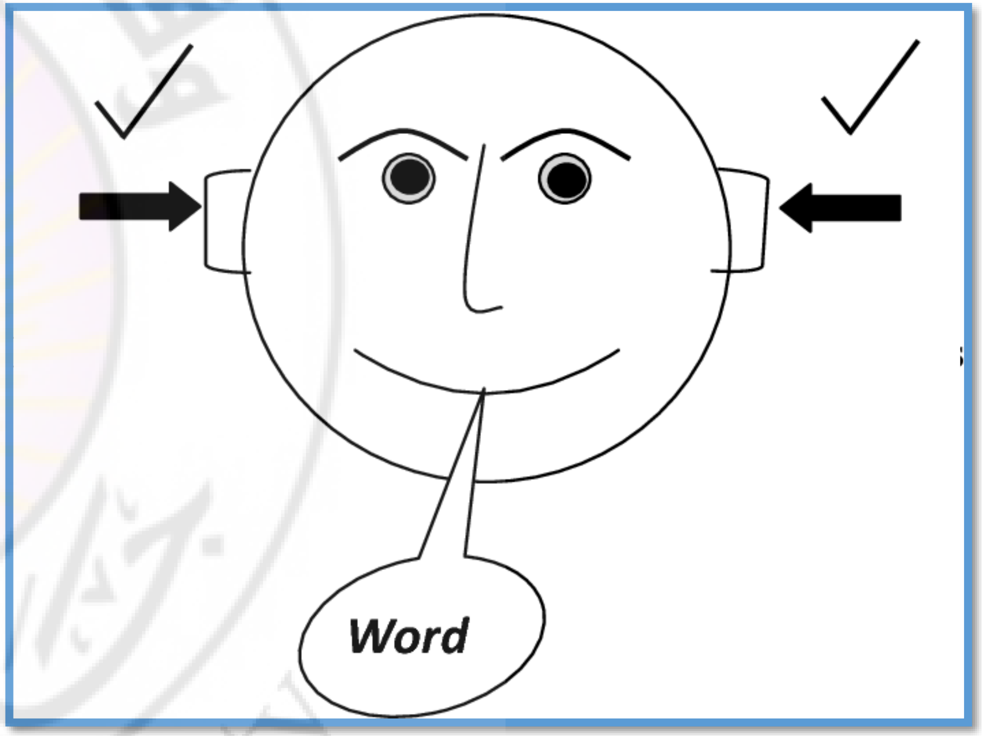
Bekesy Descending-LOT (DELOT) test

- **DELOT test** combines the LOT with the BADGE.
- The DELOT test begins with the same ascending continuous and 200 ms *on*/800 ms *off* pulsed tracings that are used in the LOT test.
- It then adds a *third* 200 ms *on*/800 ms *off* pulsed tracing that begins 25 dB above the worst (highest) threshold found on the LOT test.
- This will be a descending tracing because it starts from above the patient's apparent threshold.
- Functional patients tend to produce DELOT tracings that fall below the LOT tracing on the Bekesy audiogram (i.e., at higher hearing levels).
- This widens the gap between the continuous and pulsed tracings, making the type V pattern even clearer.



Stenger Test

- A tone presented from the right earphone is heard in the right ear, and a tone presented from the left earphone is heard in the left ear.
- However, a tone presented from both earphones is heard as a single, fused image that seems to be located somewhere in the head. This phenomenon is called **binaural fusion**.
- The image is heard in the middle of the head if the tone has the same sensation level in both ears. This is a **midline lateralization**.
- Small differences in the SLs at the two ears will cause the tone to be perceived toward the side with the higher sensation level, that is, it will be lateralized to the right or to the left . This situation is called the **Stenger phenomenon (effect).**



Stenger Test

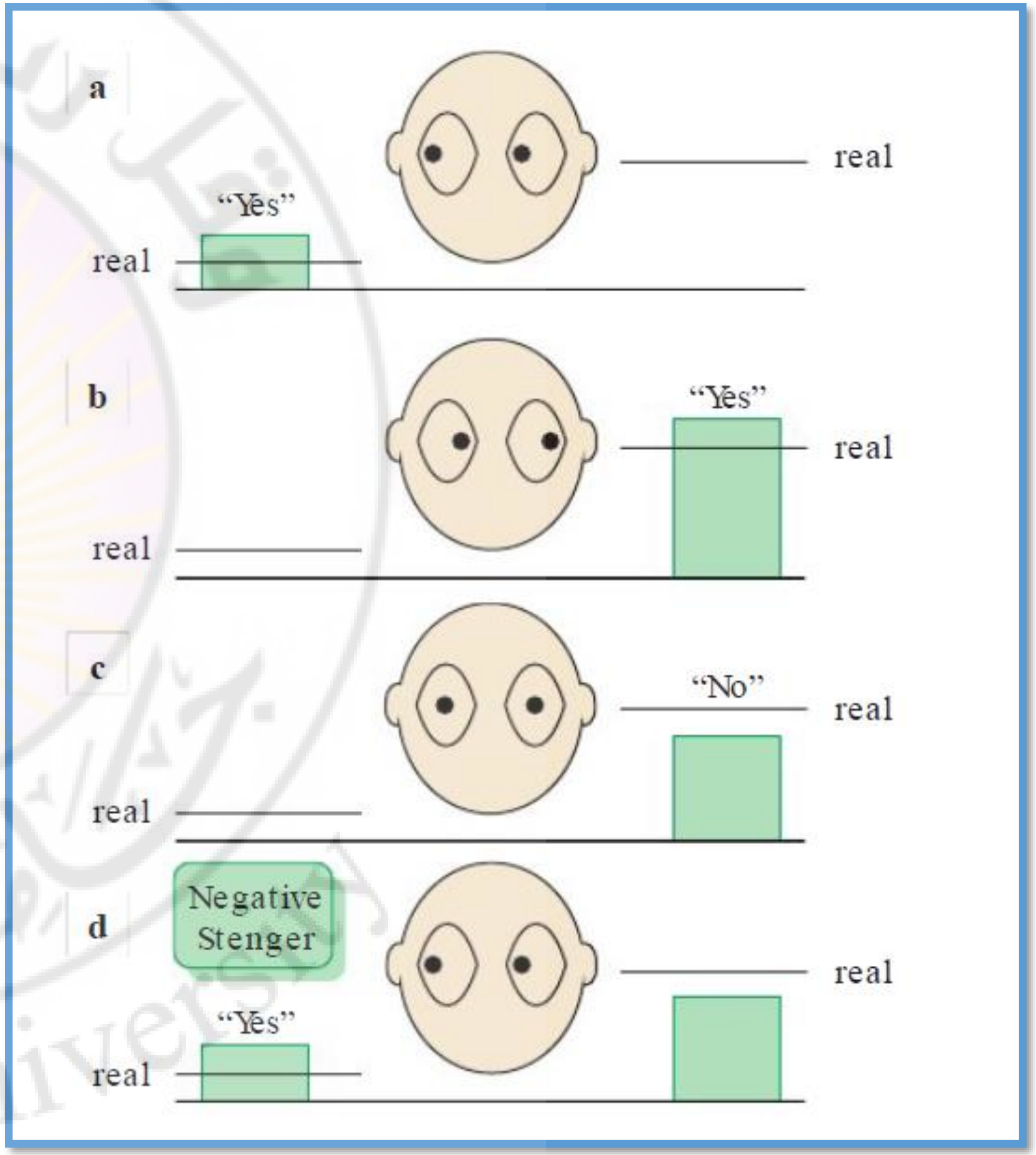
- The **Stenger test** makes use of the Stenger effect in a clinical test for ***unilateral*** **functional hearing loss**.
- The Stenger test can be used to identify a unilateral nonorganic hearing loss, and to also estimate the patient's real thresholds in that ear.
- It is called the **pure tone Stenger test** when testing is done with pure tones, and the **speech Stenger test** when spondee words are used as the stimuli.
- There must be a unilateral or asymmetrical hearing loss in which the two ears differ by *at least 30 dB* (preferably ≥ 40 dB) at each frequency where the pure tone Stenger test is performed.
- The speech Stenger test requires a similar difference between the two SRTs.

Stenger Test: Negative results

- Negative Stenger test results for a patient with a real unilateral hearing loss. “Real” represents a true, organically based threshold.

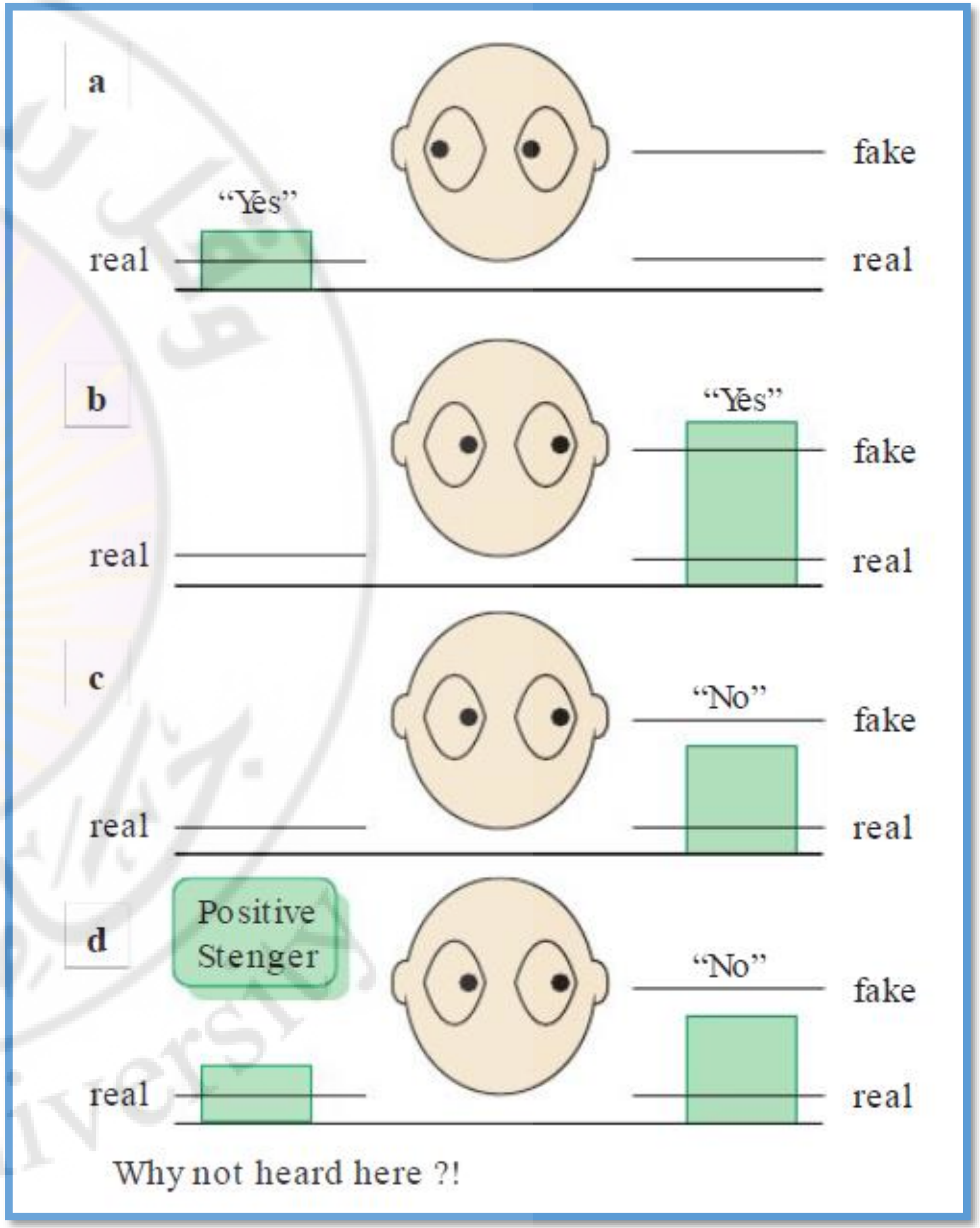
- Two tones are presented simultaneously in panel (d). One of them is 10 dB *above* the better ear’s threshold, jus, and the other one is 10 dB *below* the poor ear’s threshold.

- The patient responds (“yes”) because she can hear the tone in her better, right ear. She is not influenced by the below-threshold 40 dB tone in her left ear because she cannot hear it.



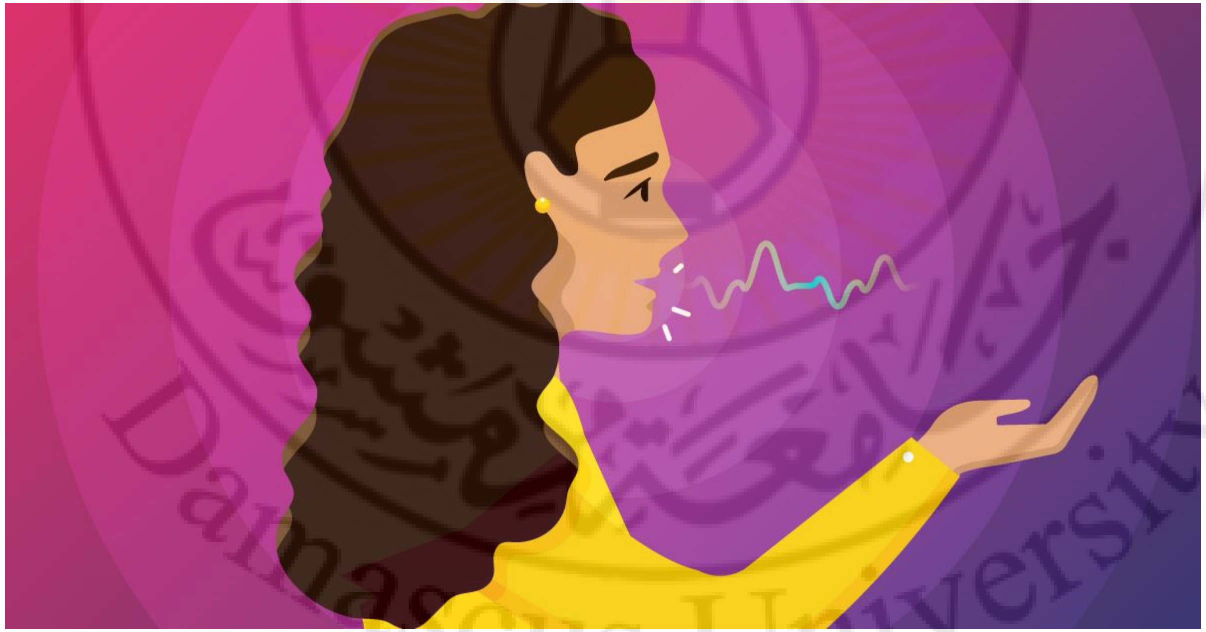
Stenger Test: Positive results

- Positive Stenger test results for a patient with a nonorganic unilateral hearing loss. “Real” represents a true, organically based threshold; “fake” indicates the exaggerated voluntary threshold.
- Two tones are presented simultaneously; one *is 10 dB above the better ear’s threshold,* and the other one is *10 dB below the poor ear’s threshold.* A patient with a real loss would not hear the below-threshold tone in the left ear, and would thus respond to the above-threshold tone in the right ear.
- However, in functional patient, the fused image of these two tones is heard only in the left ear and therefore, he refuses to respond.
- If the hearing loss in his left ear were real, he still would hear the above threshold tone in the right ear!



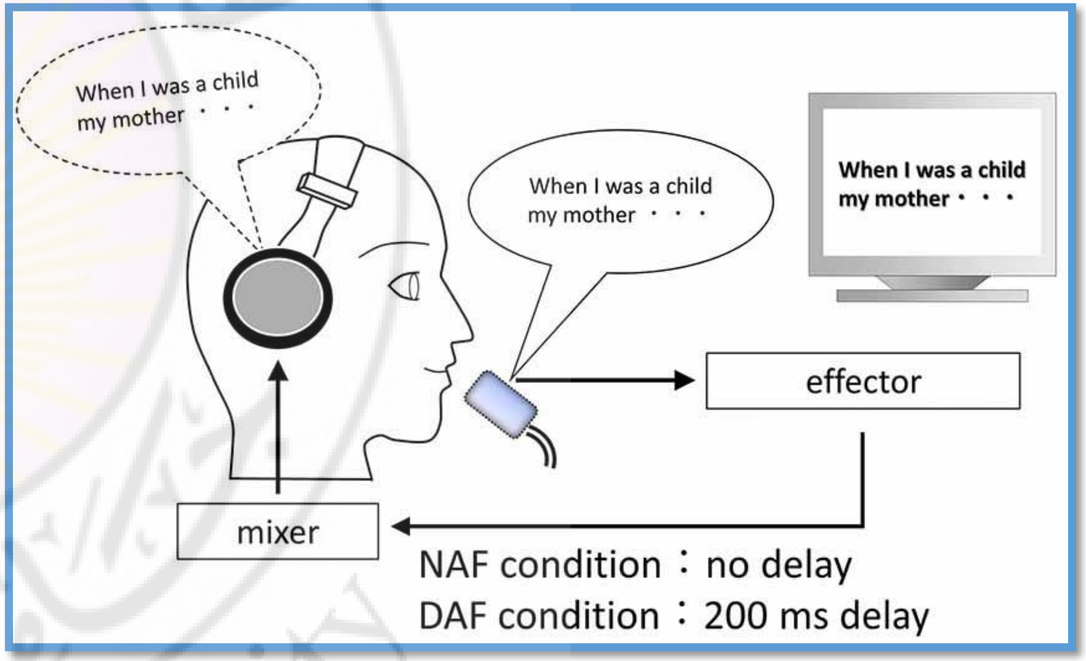
Speech Stenger Test

- The speech Stenger test is done in the same way as the pure tone Stenger, except spondee words are used instead of pure tones, and the test is done at sensation levels relative to the SRTs of the two ears.



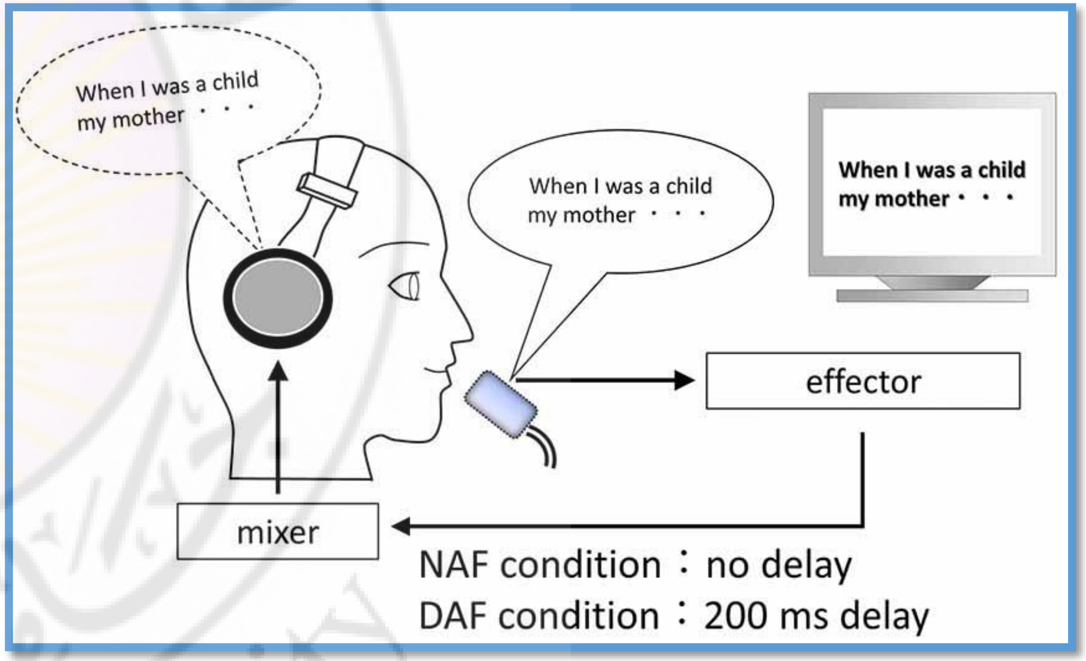
Delayed Auditory Feedback Tests (DAF)

- People expect to hear what they are saying simultaneously as they are talking.
- If a person speaks into a microphone and hears himself through earphones, then it is possible to insert a time delay between when he says something and when he hears it.
- This phenomenon is called **delayed auditory feedback (DAF)** or **delayed side tone for speech**, and it causes disruptions of the talker's speech production in terms of such characteristics as rate, fluency, intensity, and vocal quality.



Delayed Auditory Feedback Tests (DAF)

- It is a simple matter to apply DAF for speech as a test for nonorganic hearing loss.
- The patient is asked to read a passage. His speech is picked up by a microphone, subjected to a time delay of ~180 ms, and then directed to his earphones.
- **Pseudohypacusis is indicated if the patient's speech production can be disrupted by DAF at hearing levels below the patient's SRT.**



Lombard Reflex Test

- The **Lombard reflex** or **effect** is the elevation of vocal effort that occurs when talking in the presence of noise.
- A Lombard effect can only be caused by a noise that can be heard. If a noise that is below her voluntary thresholds can induce a patient to raise her speaking level, then her hearing must actually be better than admitted.
- The patient is asked to read a passage, during which the clinician monitors the level of the patient’s speech on the VU meter of the audiometer.
- Noise is introduced into both of the patient’s earphones and its intensity is raised while the audiologist watches the VU meter (and listens) for changes in the patient’s vocal level.
- An exaggerated hearing loss is suspected if the patient’s speech level is raised by a noise that is lower than the patient’s admitted thresholds.

Low level PB words Test

Sensation Level	Word Recognition Score (%)
5	25
10	50
20	75
28	88
32	92
40	100

Switching Speech Test or Varying Intensity Story Test (VIST)

- A passage, or a series of questions, is presented to the patient with the speech being switched back and forth between the patient's right and left earphones, so each ear gets only part of the information.
- The presentation levels are above the threshold of the "good" ear and below the admitted threshold of the "bad" ear.
- A functional loss is revealed by the ensuing confusion and/or how the patient recounts the story or answers the questions.
- Tests of this type are not recommended because they rely on a very cumbersome approach just to identify a unilateral nonorganic hearing loss, and it is not surprising that they are rarely if ever used.
- علی رضا به آبادی اطراف شهر رفت تا پدر، مادرش را ببیند.
- R R+L R+L R L L R+L R+L R L R+L R+L

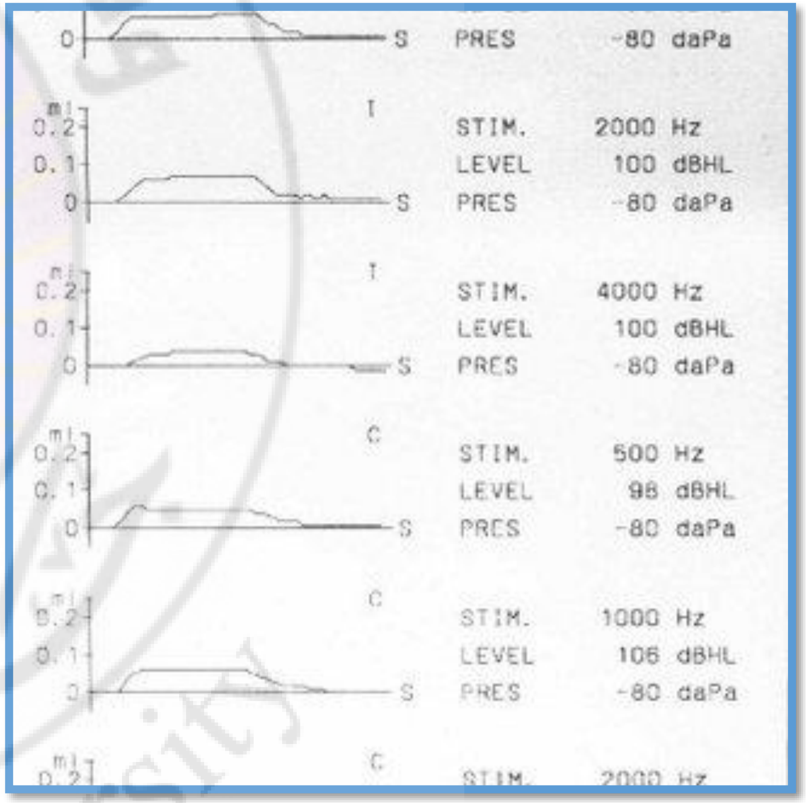
Yes – No Test

Physiological Tests

- **Electrodermal (Psychogalvanic Skin Response) Audiometry**
- **Acoustic Reflex**
- **Otoacoustic Emissions**
- **Auditory Evoked Potentials**
  - **ABR**
  - **ASSR**
  - **EcochG**
  - **Cortical Responses**

Acoustic reflex thresholds (ARTs)

- A functional impairment is suspected when an ART occurs at or below the patient's hearing threshold, or at an atypically low level even though it exceeds the hearing threshold.



دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی ایران

Behavioral Tests for Audiological Diagnosis

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4. Tinnitus: assessment and management

Tinnitus

- Definition
- Classification
- Epidemiology
- Causes
- Mechanisms
- Impacts
- Assessment
- Management

Tinnitus: Definition

- **Tinnitus** is the abnormal perception of sounds in the ears or the head for which there is no external stimulus.
- With prevalence ranging from 10% to 15%, tinnitus is a **common** disorder.
- Tinnitus is typically associated with a wide variety of sensorineural and conductive hearing losses, but it also occurs when hearing is within normal limits.
- The sensations are often described as ringing in the ears, head noises, or ear noises, and the sounds are variously characterized as tonal, ringing, buzzing, rushing, roaring, hissing, chirping, pulsing, humming, etc.

tin·ni·tus

[*"TIN-it-us"*, *"tin - NITE - us"*]

Presentation

- Ringing
- Hissing
- Static
- Buzzing
- Waterfall
- Crickets/ Cicadas

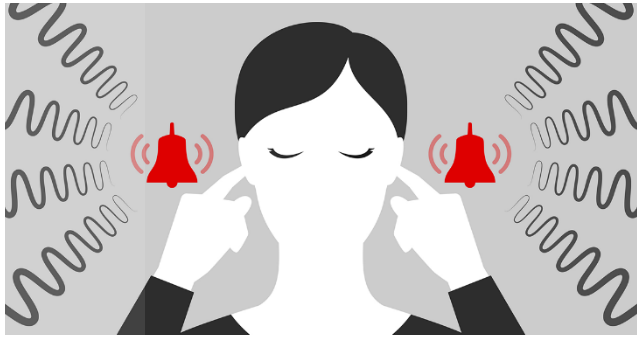
Tinnitus: Definition

Term	Definition
Tinnitus	The perception of sound when there is no external source of the sound
Primary tinnitus	Tinnitus that is idiopathic[a] and may or may not be associated with sensorineural hearing loss
Secondary tinnitus	Tinnitus that is associated with a specific underlying cause (other than sensorineural hearing loss) or an identifiable organic condition
Recent onset tinnitus	Less than 6 months in duration (as reported by the patient)
Persistent tinnitus	6 months or longer in duration
Bothersome tinnitus	Distressed patient, affected quality of life[b] and/or functional health status; patient is seeking active therapy and management strategies to alleviate tinnitus
Nonbothersome tinnitus	Tinnitus that does not have a significant effect on a patient's quality of life but may result in curiosity of the cause or concern about the natural history and how it might progress or change

Tinnitus: Classification

- ***Objective (Somatosounds) tinnitus***
  - Can be audible by an examiner using a stethoscope or ear canal microphone.
  - **Somatosounds** that reflect the perception of internally generated sounds from joints, muscles, turbulent blood flow, or, rarely, otoacoustic emissions.
  - Objective tinnitus usually has a pulsatile or rhythmic quality.
  - Is less common

- ***Subjective tinnitus*** is not audible to an examiner.



Subjective Tinnitus

- **Most commonly related to**
  - Sensorineural hearing loss (SNHL)
  - Acoustic trauma
  - Presbycusis
- **Less commonly the result of**
  - Conductive hearing loss,
  - Endolymphatic hydrops,
  - Cerebellopontine angle tumors
- An identifiable original source is not clear in most patients with **chronic tinnitus**.
- Of all cases of tinnitus presented, 80% are subjective in nature; those are the ones on which we focus for acoustic therapy treatments.

Box 151-2. SUBJECTIVE TINNITUS SUBTYPES

Pattern of hearing loss
- Noise-induced hearing loss
- Presbycusis
- Unilateral
- High-frequency hearing loss
- Outer hair cell dysfunction

Somatic tinnitus
- Temporomandibular joint dysfunction
- Cervical dysfunction
- Gaze evoked
- Cutaneous evoked
- General somatosensory modulated

Typewriter tinnitus
Exacerbated by sleep or rest
Musical/complex
Associated affective disorder
Intrusive (versus habituated)

Objective Tinnitus

- Objective tinnitus tends to be associated with sources involving, for example, the vascular system, Eustachian tube, temporomandibular joint, and/or muscular activity.
- As a result, **medical assessment** is an important step in the assessment of the patient with tinnitus.
- Of all cases of tinnitus presented, **20%** are objective in nature (even less in some reports).

Box 151-1. OBJECTIVE TINNITUS SUBTYPES

Pulsatile

Synchronous with Pulse

Arterial etiologies
- Arteriovenous fistula or malformation
- Paraganglioma (glomus tympanicum or jugulare)
- Carotid artery stenosis
- Other atherosclerotic disease (subclavian, external carotid)
- Arterial dissection (carotid, vertebral)
- Persistent stapedial artery
- Intratympanic carotid artery
- Vascular compression of cranial nerve VIII
- Increased cardiac output (pregnancy, thyrotoxicosis)
- Intraosseous (Paget disease, otosclerosis)

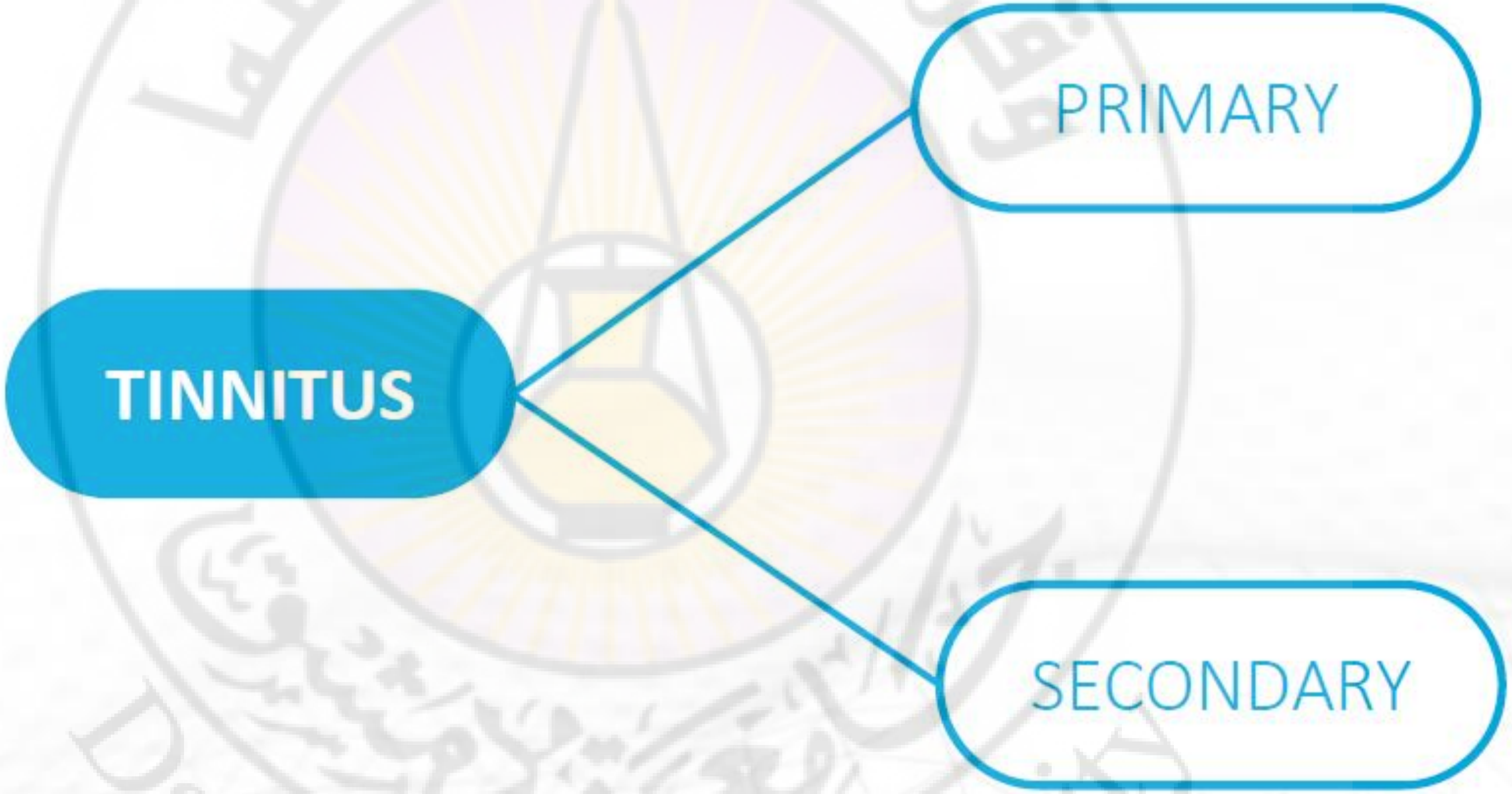
Venous etiologies
- Pseudotumor cerebri
- Venous hum
- Sigmoid sinus and jugular bulb anomalies

Asynchronous with Pulse

Palatal myoclonus
Tensor tympani or stapedius muscle myoclonus

Nonpulsatile

Spontaneous otoacoustic emission
Patulous eustachian tube

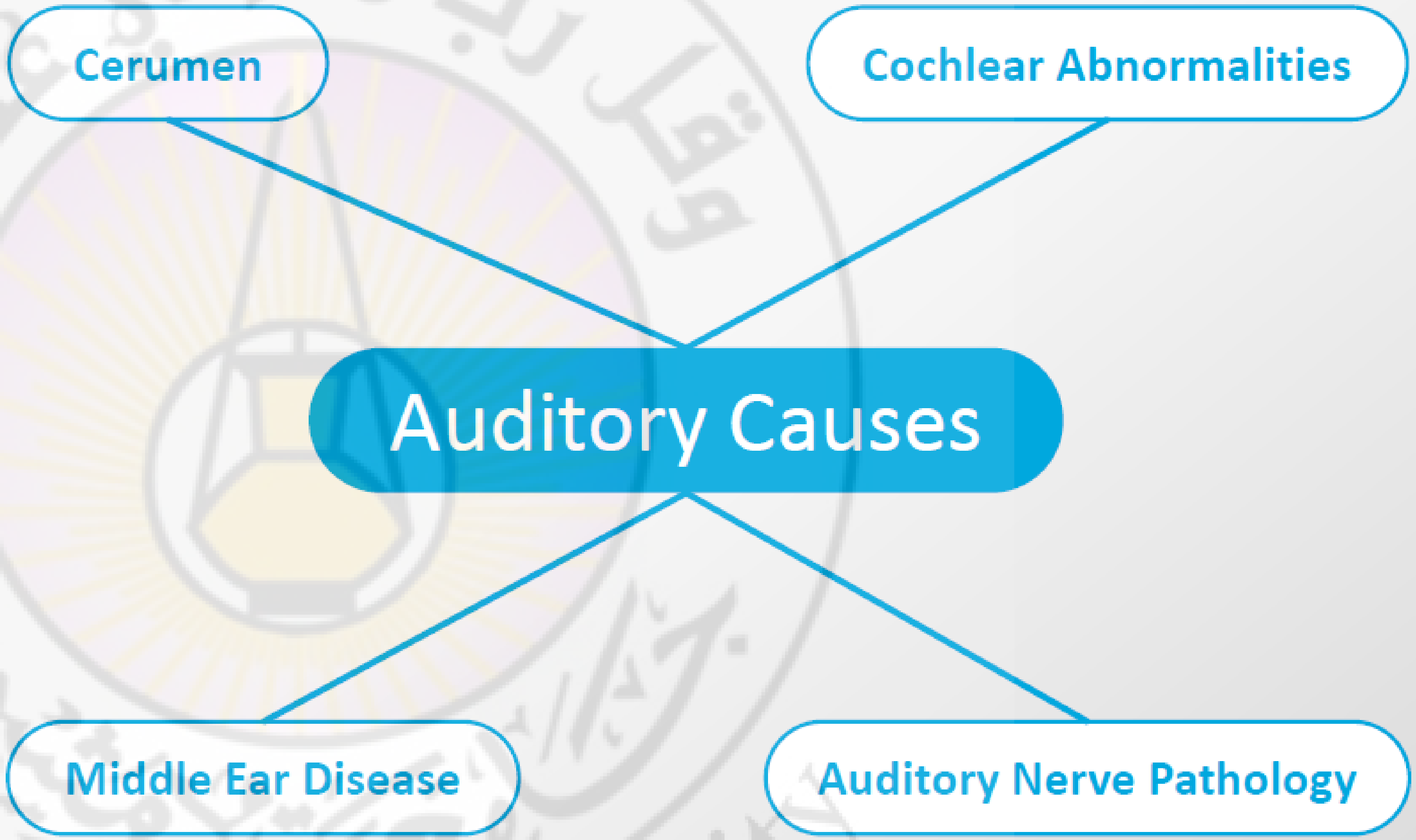

TINNITUS
PRIMARY
SECONDARY


TINNITUS
PRIMARY
SECONDARY

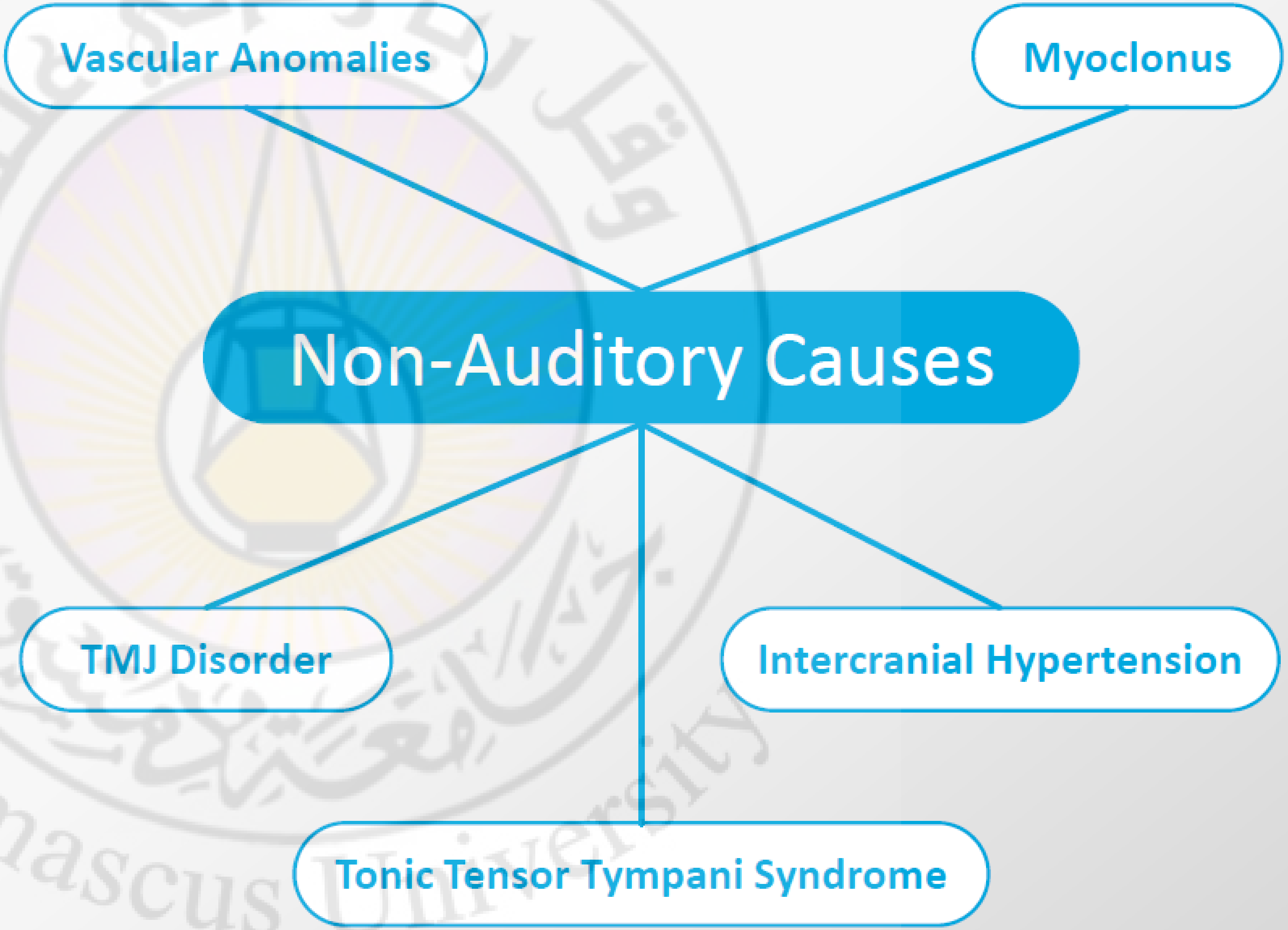
Secondary Tinnitus

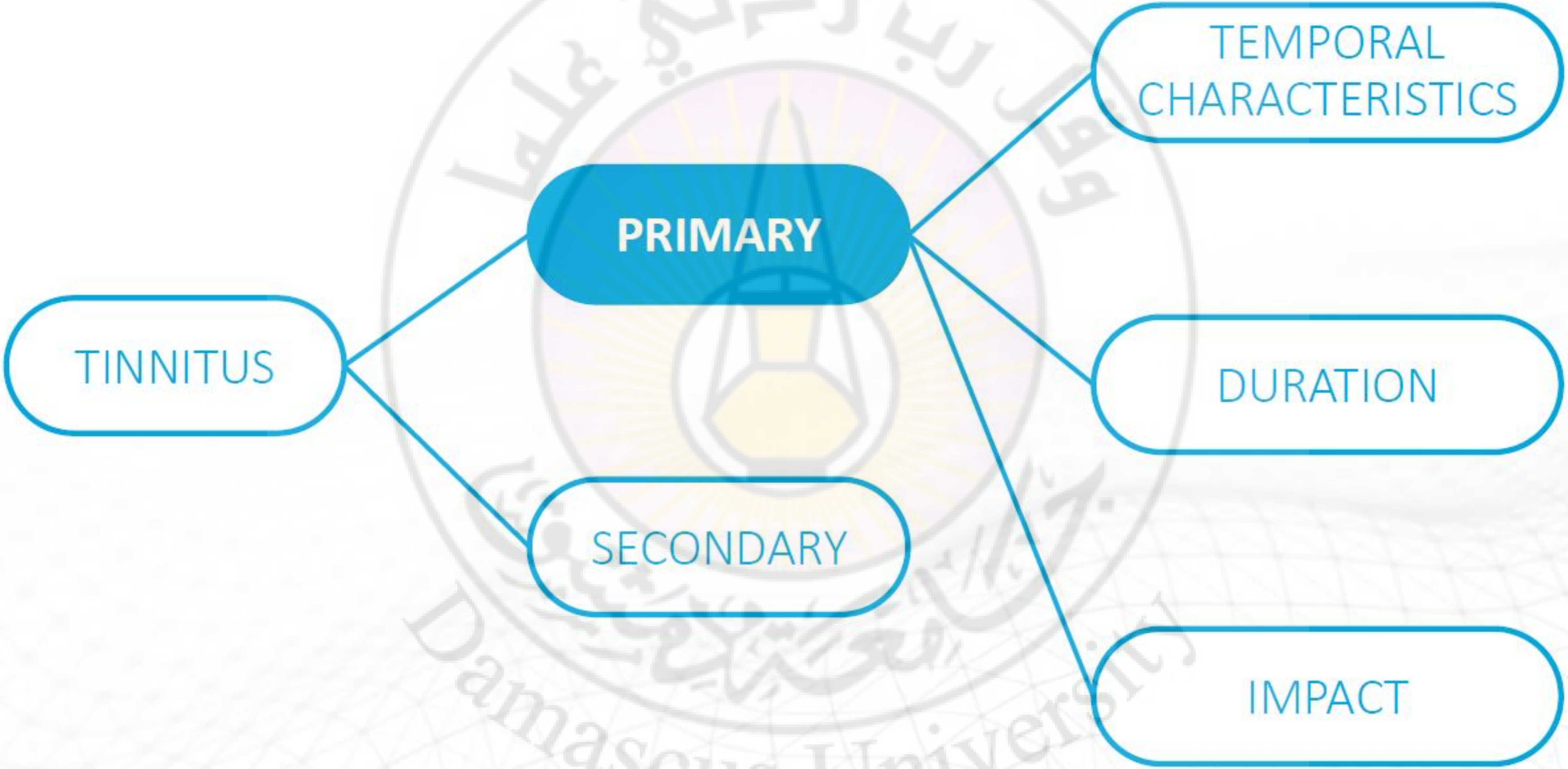
- Tinnitus associated with an underlying cause that is not sensorineural hearing loss
- Cause can be auditory or non-auditory
- Most common is pulsatile tinnitus
- Most treatable type of tinnitus

Secondary Tinnitus



Secondary Tinnitus




TINNITUS
PRIMARY
SECONDARY
TEMPORAL CHARACTERISTICS
DURATION
IMPACT

Primary Tinnitus

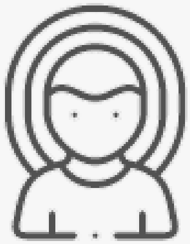
- Tinnitus that occurs from an unknown source
  - May or may not be associated with Sensorineural Hearing Loss
- Can be further characterized
  - Temporal Characteristics
  - Duration
  - Impact

Primary Tinnitus

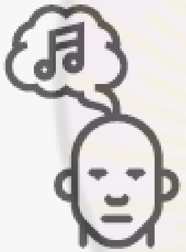
TEMPORAL CHARACTERISTICS	DURATION	IMPACT
Spontaneous	Recent	Non-Bothersome
Temporary	Persistent	Bothersome
Occasional		
Intermittent		
Constant		

Tinnitus must be distinguished from other phantom auditory perceptions and perceived sound intolerances.

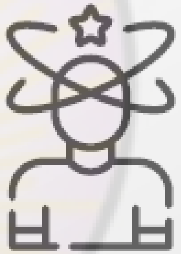
Phantom Auditory Perceptions



Auditory Hallucinations



Musical Ear Syndrome



Auditory Imagination

Tinnitus

Tinnitus: Epidemiology (US)

- 50 Million in the US have experienced tinnitus
- 1 in 12 adolescents have experienced tinnitus
- 1 in 10 adults have experienced tinnitus
- 20 Million seek medical attention
- 2 Million debilitated by tinnitus
- 9% of women and 5.5% of men with severe tinnitus attempted suicide!

Data from the 1999-2004 National Health and Nutrition Examination Survey, conducted by the Centers for Disease Control and Prevention (US)

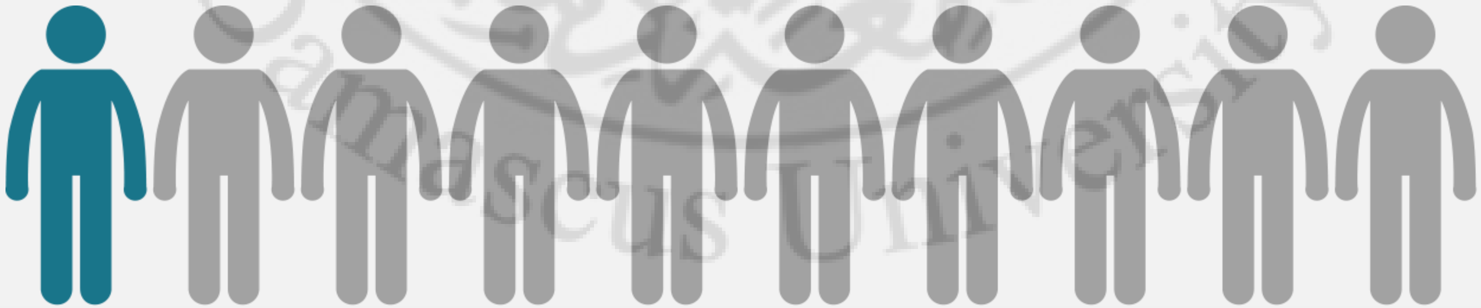
Tinnitus: Epidemiology (UK)

- 10% of adults experienced prolonged spontaneous tinnitus.
- 5% of adults tinnitus is reported to be moderately or severely annoying.
- 1% of the adult population, tinnitus has a severe effect on quality of life.
- The incidence indicate that 7% of the UK adult population have consulted their doctor about tinnitus.
- 2.5% have attended a hospital with regard to tinnitus.
- Up to one-third of **children** experience occasional tinnitus, and in approximately 10% tinnitus has been bothersome.

Baguley, 2002

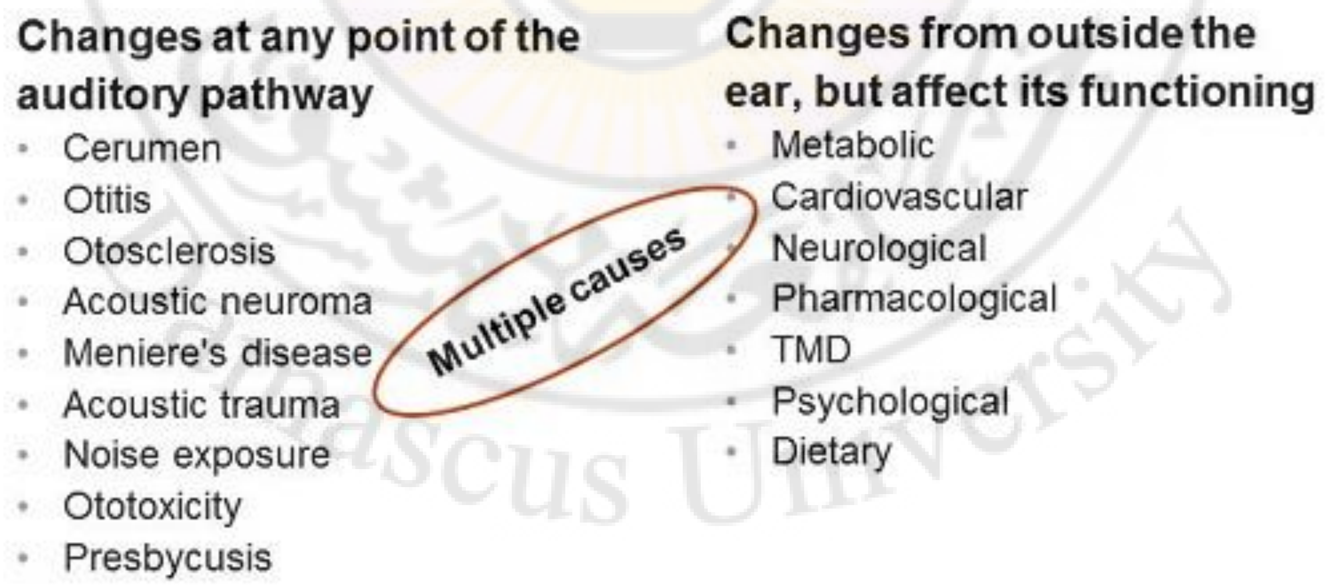
Tinnitus: Epidemiology

Results of epidemiological studies show similar prevalence not only in other European countries, the USA, and Japan, but also in low-income and middle-income countries in Africa and Asia, which indicates that the perception of phantom sounds is a **global burden**. Because of demographic developments and an increase in professional and leisure noise exposure, tinnitus prevalence is expected to **continue to increase**.



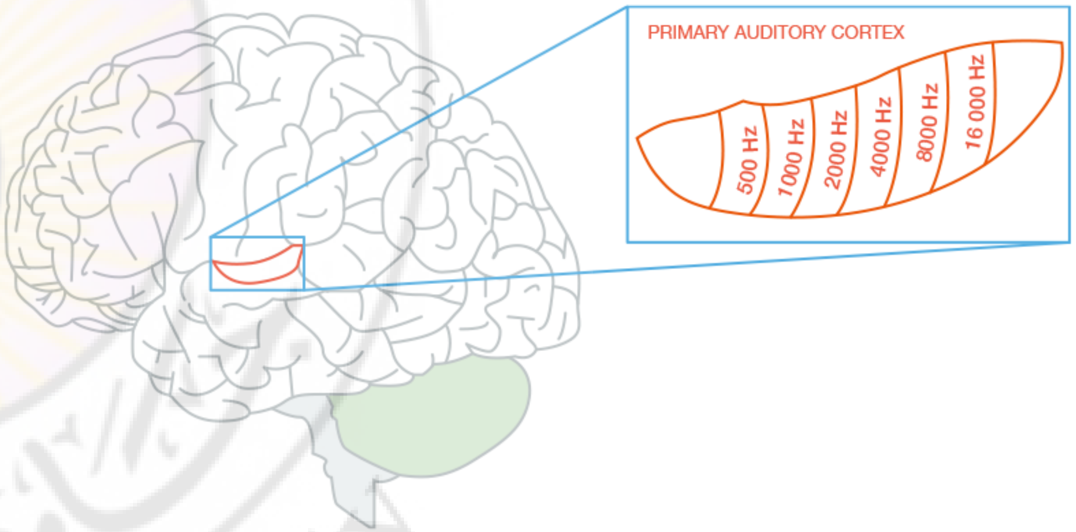
Tinnitus: Causes

- There are **over 200 causes** identified for subjective tinnitus. We may be familiar with many of those factors that occur along the auditory pathway; however, we may not feel as familiar with changes from outside of the ear that contribute to or exacerbate tinnitus in one way or another.
- Some of those disorders can be metabolic, cardiovascular, neurologic, pharmacological, temporomandibular, psychological, or dietary.



Tinnitus: Causes

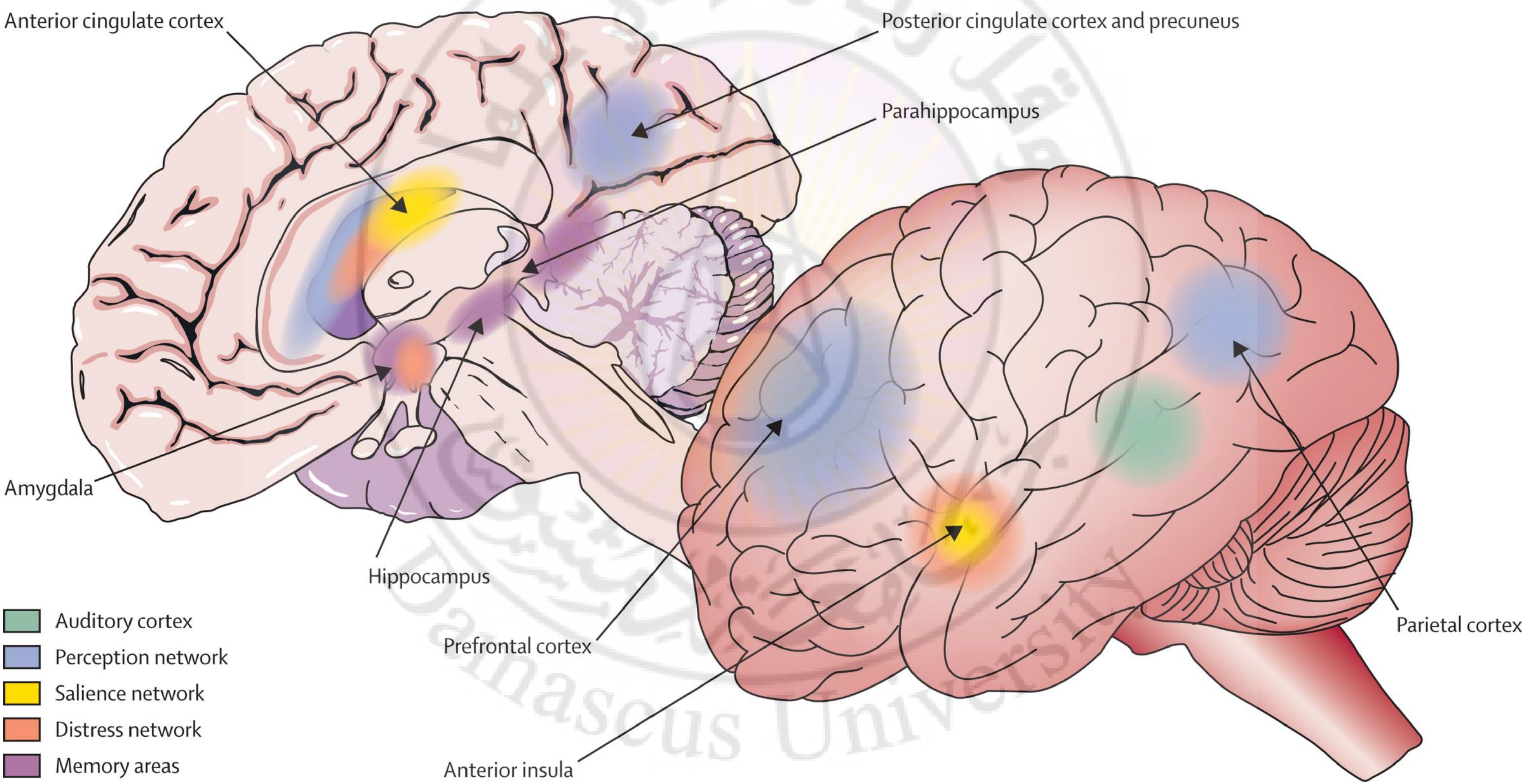
- The generators of tinnitus were originally thought to be focused on the **inner ear** itself and the **auditory nerve**.
- Our current view of tinnitus has changed somewhat; we are now viewing the mechanisms of tinnitus generators as **more central to the auditory system**.
- The main factor is still damage to the inner ear, leading to a deafferentation of the central auditory cortex. This deafferentation can lead to alterations in the central plasticity resulting from the changing the balance of the excitatory and inhibitory reaction of the nerve.



Tinnitus: Causes

- We are finding now that there are some areas of the **central auditory cortex** that are affected when a patient has the symptom of tinnitus.
- Functional MRI studies of the auditory cortex and the auditory pathway can show areas that are lit up in a patient with tinnitus as opposed to in a patient that does not have tinnitus.
- This has led to this change in our perspective in that tinnitus is more central than we had originally thought.

Brain networks involved in phantom perception



Known Causes of Tinnitus

Hearing Loss

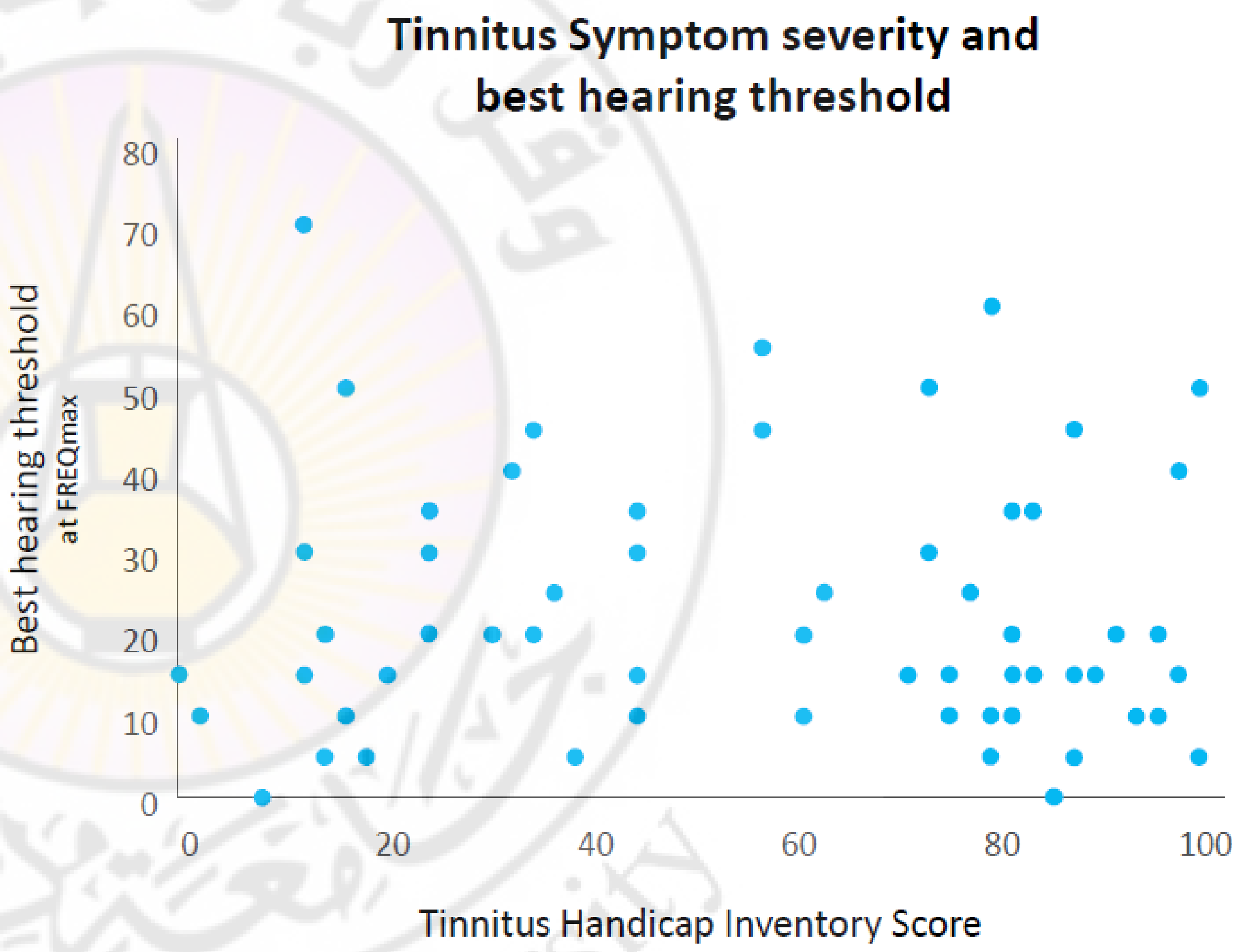
- **90%** of chronic tinnitus sufferers have some sort of hearing loss
  - Most common with SNHL
  - Secondary tinnitus associated with CHL

Noise Exposure

- Hair cell damage
- Biochemical changes in cochlea
- Damage to auditory nerve/CNS

Tinnitus and Hearing Loss

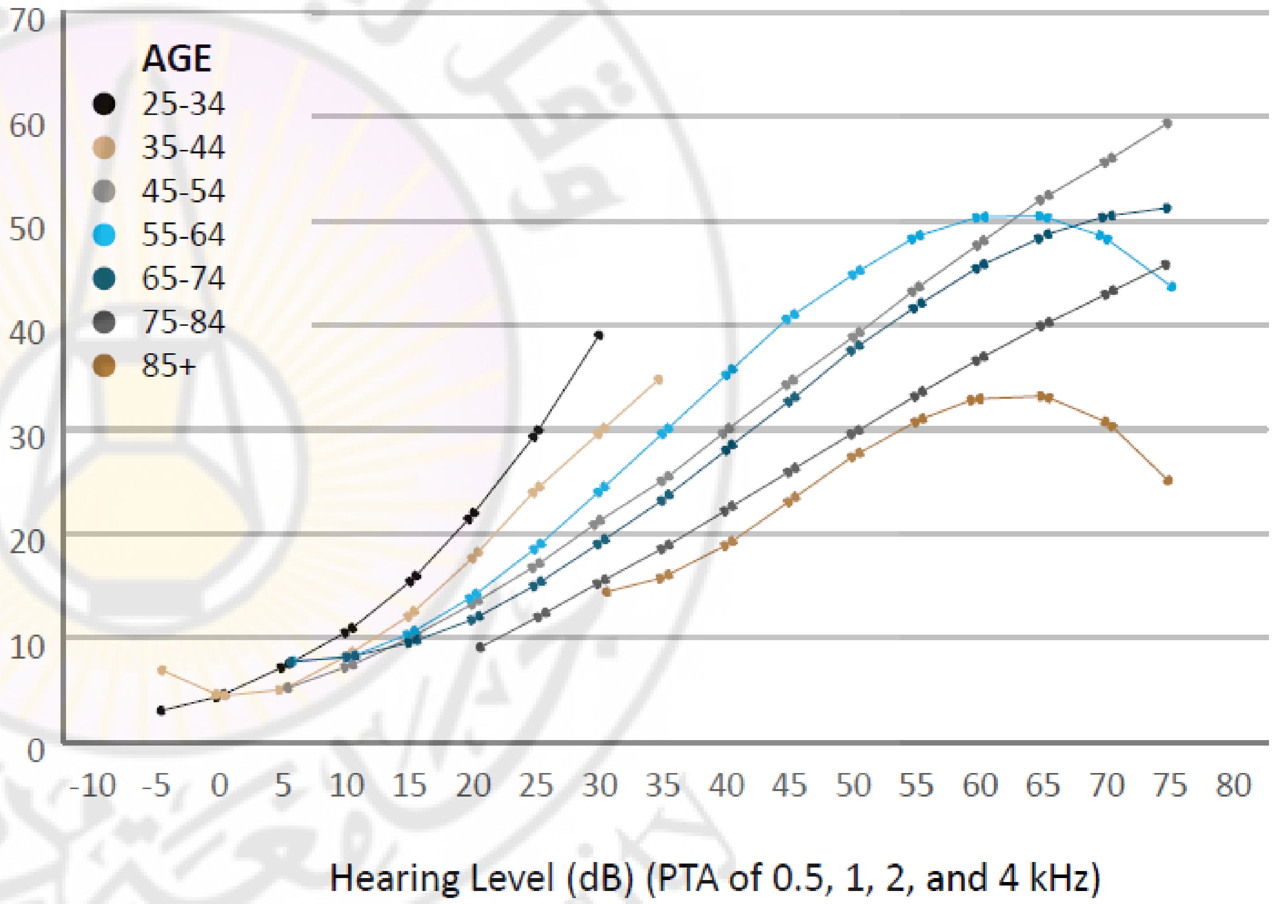
No correlation between tinnitus severity and hearing threshold



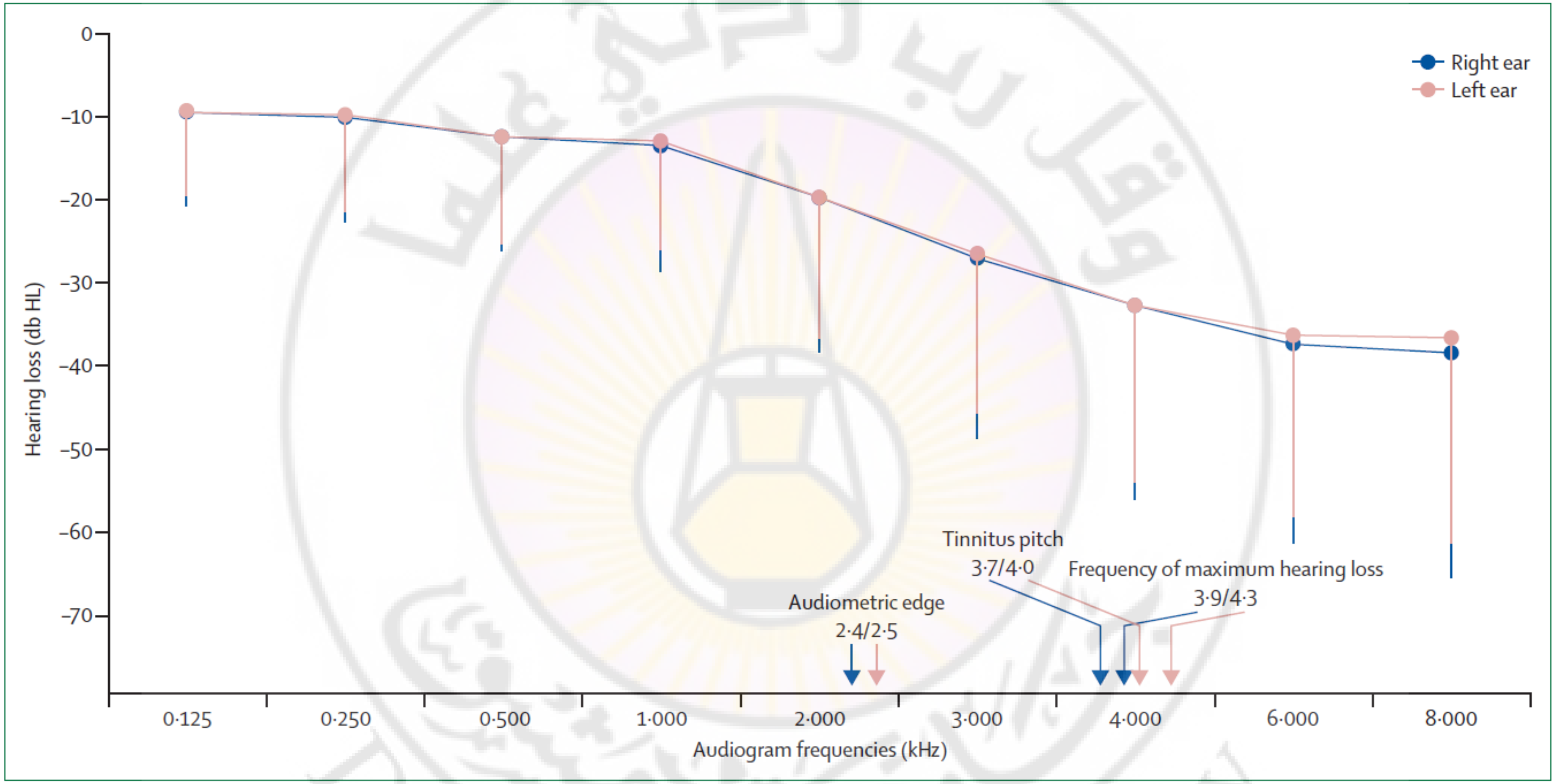
Tsai, Cheung, and Sweetow, Laryngoscope, 2012

Tinnitus and Hearing Loss

For all age categories, as hearing loss increases, the prevalence of tinnitus increases



Borchgrevink et al., 2001



Hearing loss in patients with tinnitus and the association with tinnitus pitch

Risk Factors for Tinnitus

- Thyroid issues
- Drugs and medications
- Ear infections
- Acoustic Neuroma
- Otosclerosis
- Cardiovascular disease
- Noise exposure
- Sudden hearing loss
- Meniere's disease
- Head or neck trauma

Causes

Cardiovascular Disease

- Restriction of blood flow in the blood vessels
- Heart Disease
- Coronary Artery Disease
- Hypertension
- Malformation of blood vessels

Causes

Medications

500+ prescription and OTC drugs, supplements associated with tinnitus

- Salicylate Analgesics (Aspirin)
- Antibiotics (Amoxicillin, Azithromycin, etc.)
- Painkillers (Oxycodone, Morphine, etc.)
- Cancer Drugs (Cisplatin, Carboplatin, etc.)
- Diuretics (Lasix)
- Cardiac Medications (Statins, ACE Inhibitors, etc.)
- Antimalarials (Quinine, Hydroxychloroquine, etc.)

Causes

Head and Neck Injury

- Skull fracture, whiplash, blow to face/head, TMJ/jaw related problems
- Report onset shortly after injury/trauma

Causes

Auditory Related

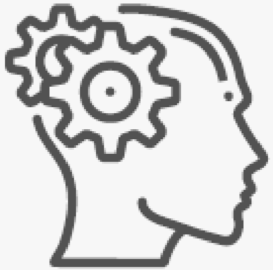
- Ear Infections
- Noise Exposure
- Meniere's Disease
- Otosclerosis
- Sudden Hearing Loss
- Acoustic Neuroma

Possible Risk Factors for Tinnitus

- Alcohol usage
- Health status
- Anxiety
- Depression
- Genetics
- Geographic region
- Smoking
- Lyme Disease
- Obesity
- Low weight

There are many **causes** of tinnitus, and as a result, there are likely many different mechanisms of tinnitus.

Mechanisms of Tinnitus



Theories of Causality

The Neurophysiological Model of Tinnitus

The Neural Synchrony Model

Theory of Causality

- Perception of tinnitus likely involves the auditory pathway and its interaction with other brain systems
- Current view is that all tinnitus originates in the central auditory system.

The Neurophysiological Model of Tinnitus

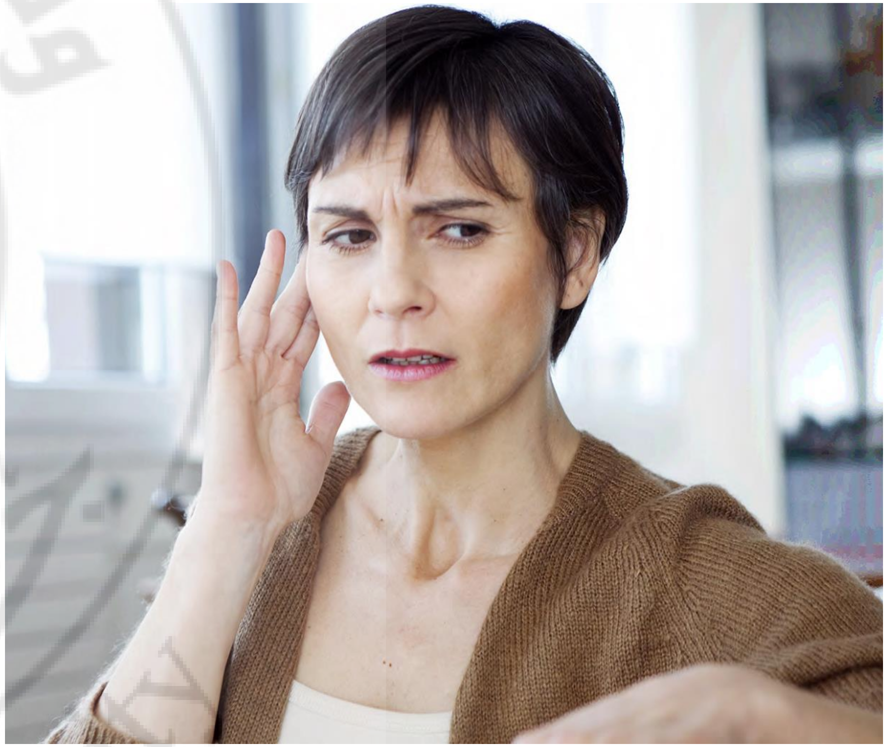
- Tinnitus results from the abnormal processing of a signal generated in the auditory system.
- This may result in 'feedback', whereby the annoyance created by the tinnitus causes the individual to focus increasingly on the noise, which in turn exacerbates the annoyance and so a 'vicious cycle' develops.

Neural Synchrony Model

- Irregular neural activity develops in regions of the primary auditory cortex that have been affected by hearing loss
- Increase neural firing in the regions affected by hearing loss are the cause of tinnitus.
  - The regions affected by hearing loss are "disconnected" from the brain.

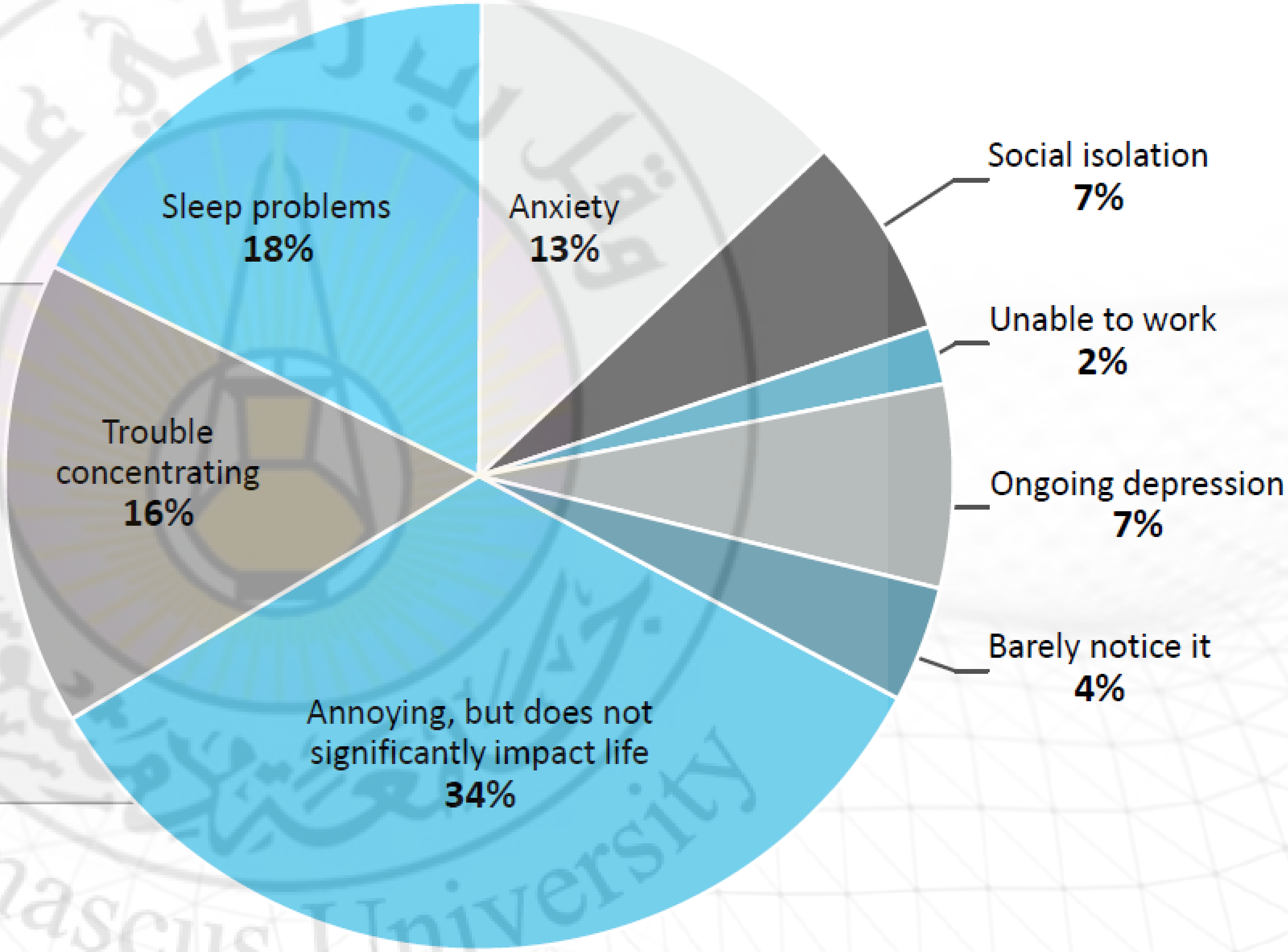
Tinnitus: Impacts

- The repercussions of tinnitus can affect different areas of a patient's life, and significant tinnitus may affect the **quality of life** in different manners.
- The patient can have disruptions in their **sleep**.
- They may have difficulty **concentrating**.
- They can have difficulty in their **emotional balance** and **well-being.**
- Some patients will change their **social activities** due to the fact that they are experiencing tinnitus. They may pull away from others.
- They may try to **avoid noise** because it worsens their perception of the tinnitus; they may change their lives in general as a result.

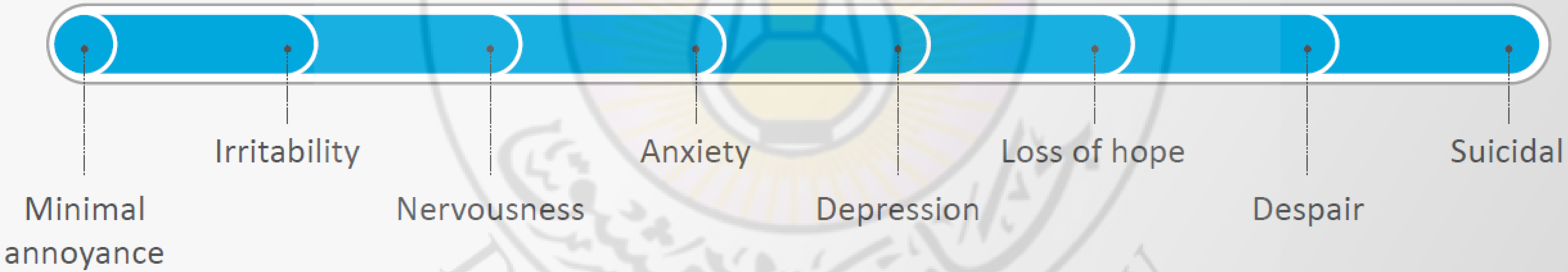


Quality of life impacts

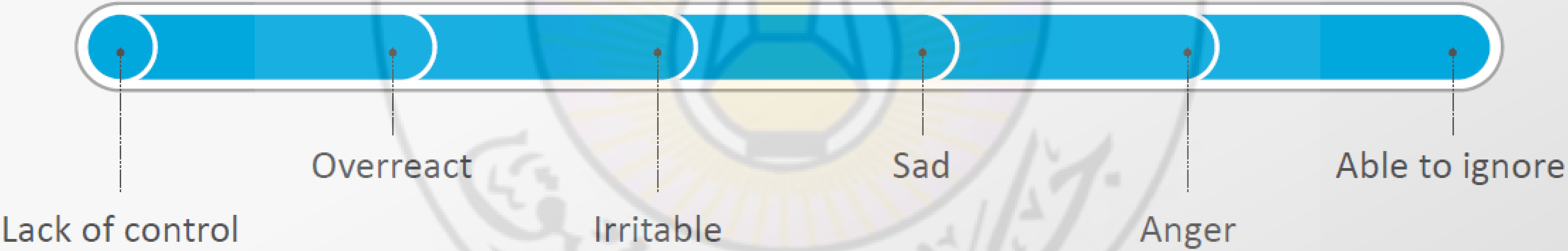
- Thoughts and Emotions
- Sleep
- Concentration
- Socialization
- Physical Health
- Economic well-being



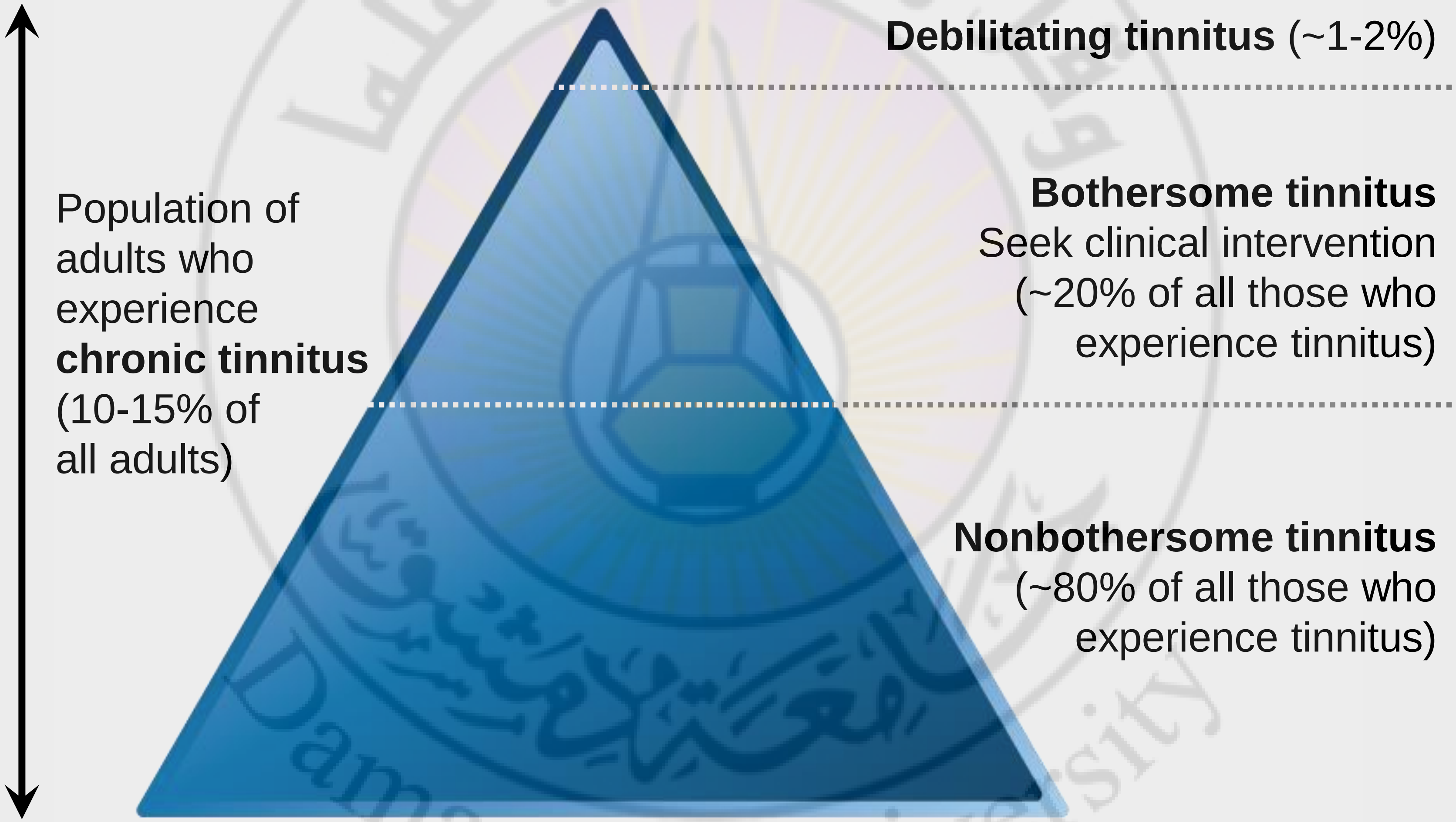
Thoughts and Emotions



Reactions to Tinnitus



Severity of tinnitus



Why Are Some More Bothered Than Others?

- Research shows that there is no difference in psychoacoustic characterization of tinnitus when comparing groups of people who experience tinnitus and those who suffer from it.
- The **reaction** to tinnitus creates the distress, not the tinnitus itself.

Cycle of distress (Vicious Cycle)

دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی ایران

Behavioral Tests for Audiological Diagnosis

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

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Mechanisms of Tinnitus

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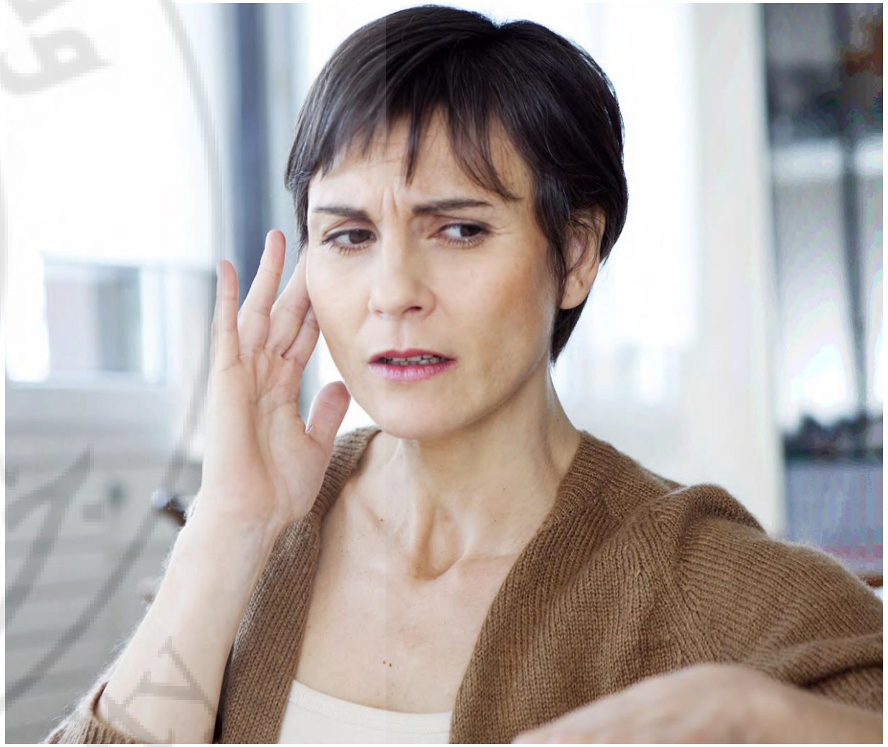

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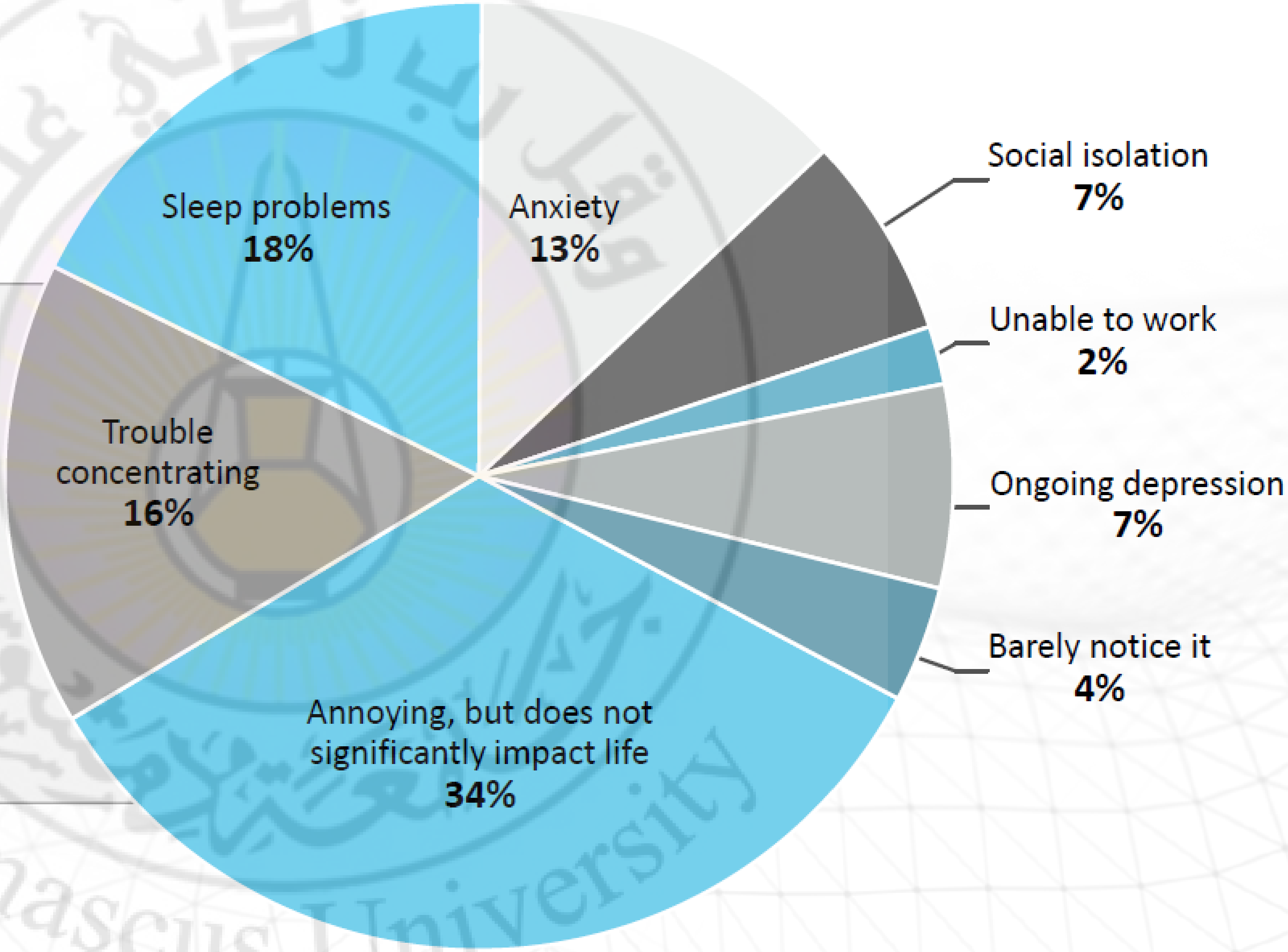

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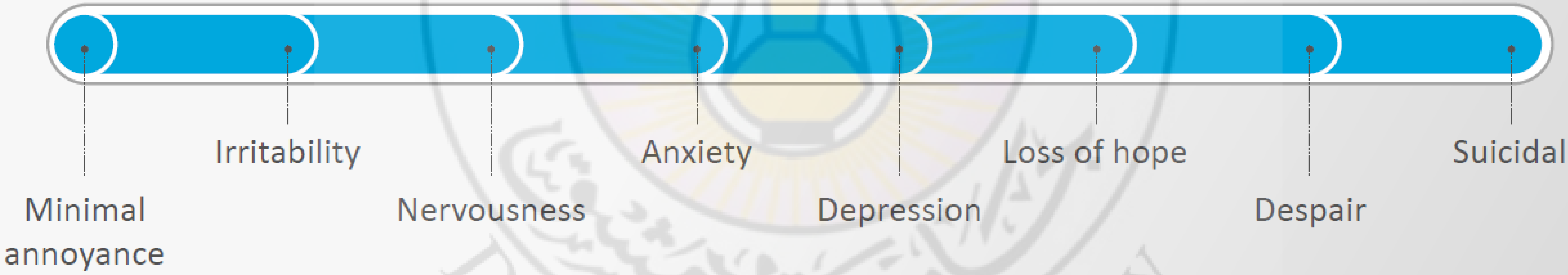

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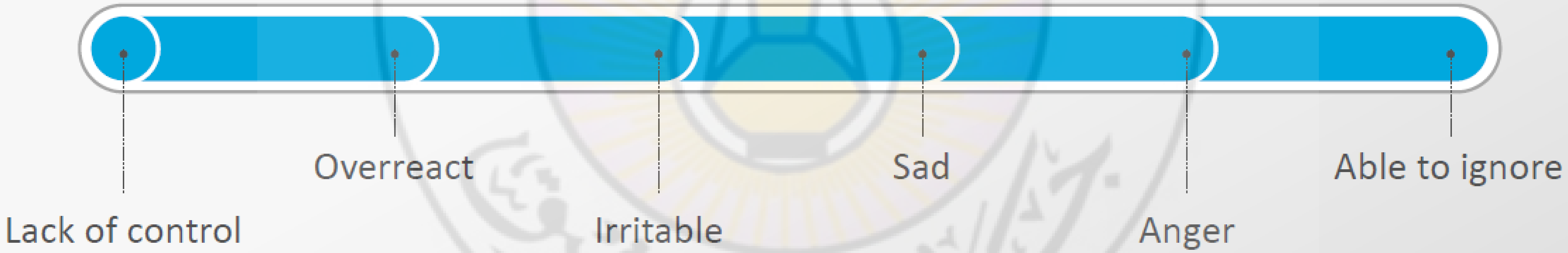

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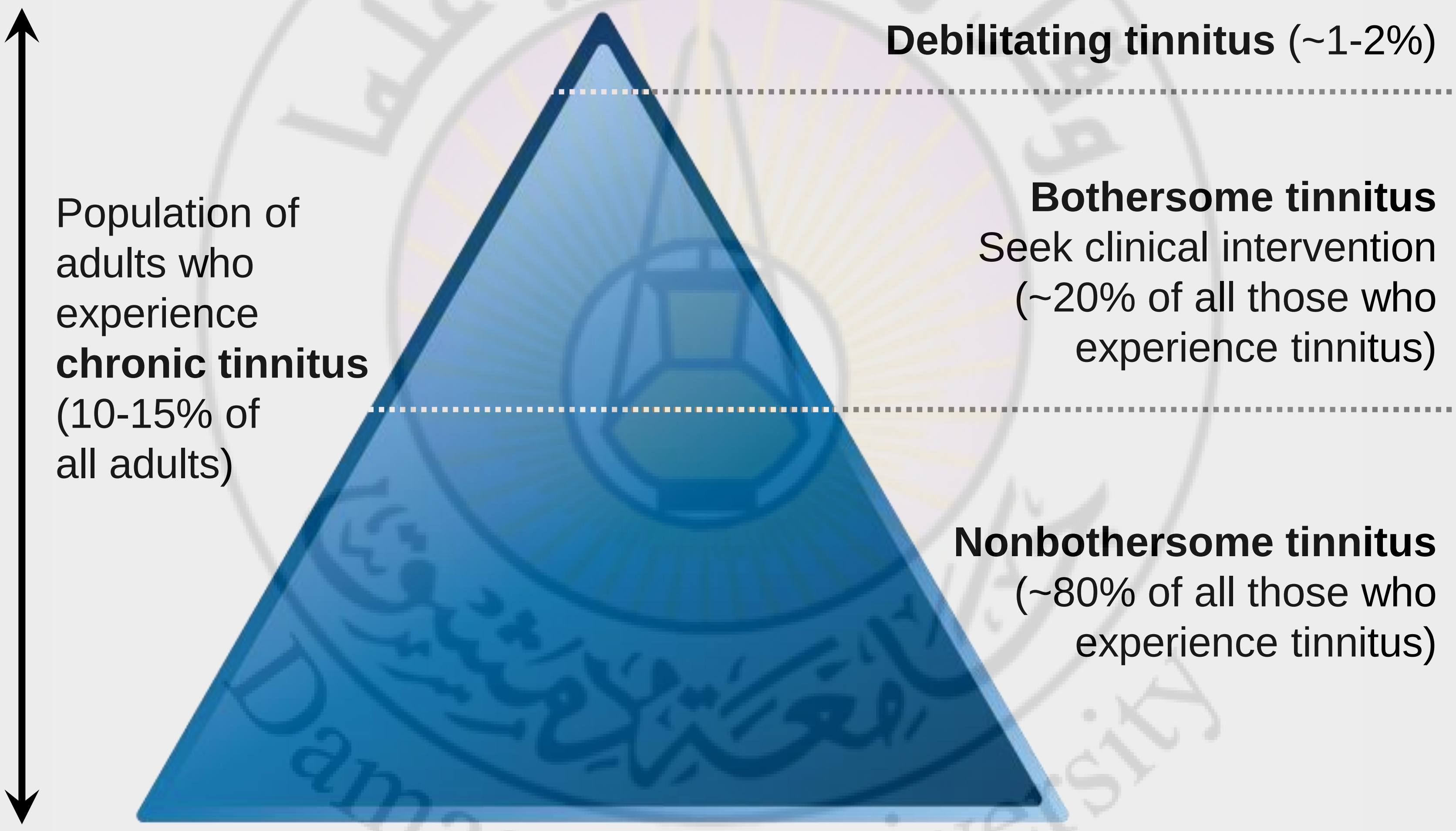

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Cycle of distress (Vicious Cycle)

Tinnitus: Assessment

- Tinnitus can be a symptom of various underlying pathologies and be accompanied by many different comorbidities. Therefore, an integrated multidisciplinary approach is needed for comprehensive tinnitus diagnosis.

➢ **Self-Assessment (assessment of tinnitus severity)**

➢ **Case History**

➢ **Clinical ear examination**

➢ **Audiological Assessment**

Assessment of tinnitus severity

- Patient's perception regarding their tinnitus and hearing problems.
- Many different questionnaires/surveys available:

➢ **Tinnitus & Hearing Survey (THS)**

➢ **Tinnitus Functional Index (TFI)**

➢ **Tinnitus Handicap Inventory (THI)**

➢ **Tinnitus Reaction Questionnaire (TRQ)**

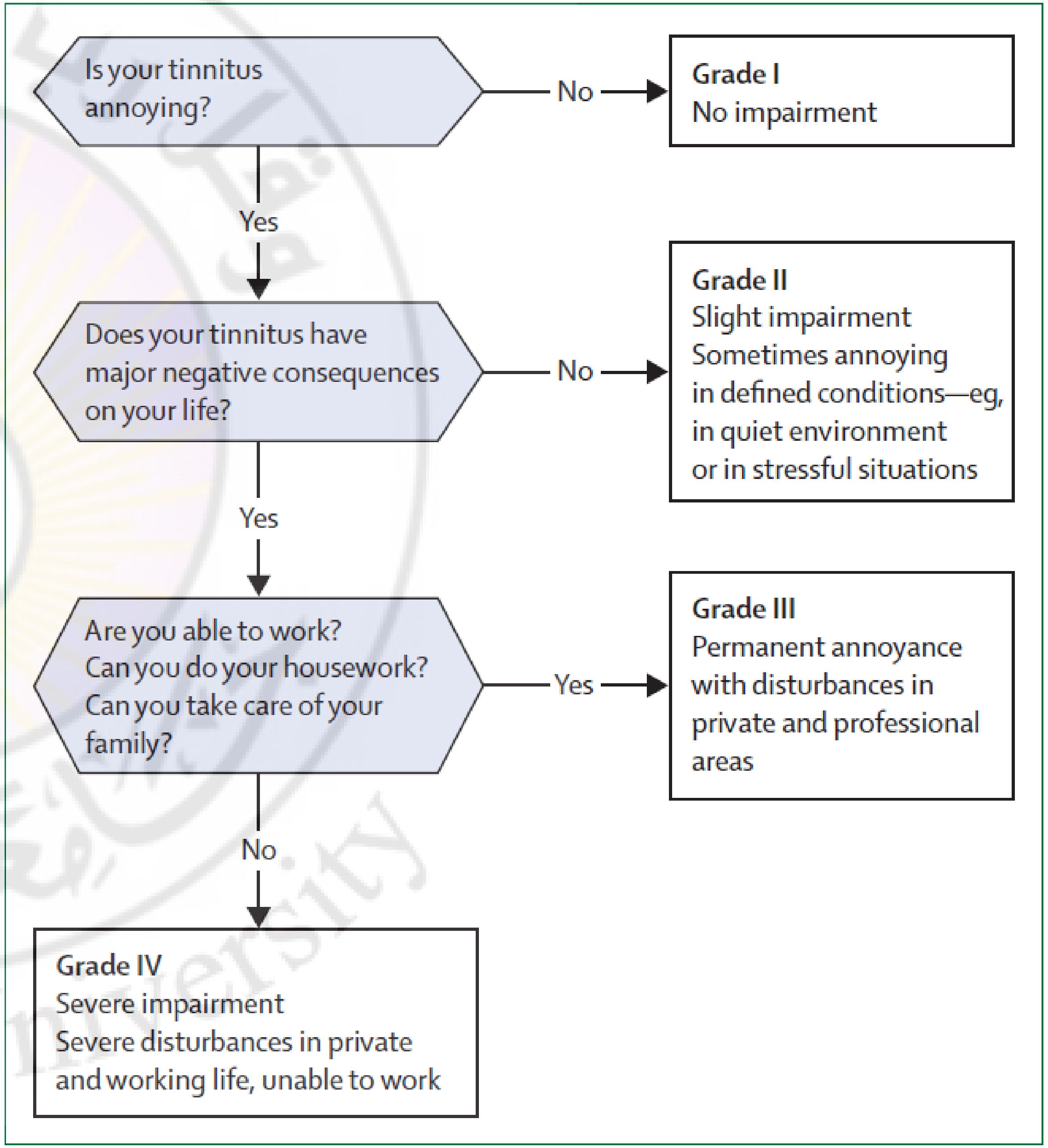
➢ **Tinnitus Handicap Questionnaire (THQ)**

➢ **Tinnitus Severity Index (TSI)**

➢ **Beck Depression Inventory**

➢ **Spuelberger State-Trait Anxiety Inventory**

➢ **Primary Care PTSD Screen**



Client ID: 0000004 Questionnaire date: 12/11/2015 Tester: ABC Page: 1 / 3

Date of birth: 1984-05-17 Name: Tinnitus, Tricia

TINNITUS FUNCTIONAL INDEX

Please read each question below carefully. To answer a question, select ONE of the numbers that is listed for that question.

I Over the PAST WEEK...

1. What percentage of your time awake were you consciously **AWARE OF** your tinnitus?

   Never aware ► 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100% ◄ *Allways aware*

2. How **STRONG** or **LOUD** was your tinnitus?

   Not at all strong or loud ► 0 1 2 3 4 5 (6) 7 8 9 10 ◄ *Extremely strong or loud*

3. What percentage of your time awake were you **ANNOYED** by your tinnitus?

   None of the time ► 0% 10% 20% 30% 40% 50% 60% (70%) 80% 90% 100% ◄ *All of the time*

SC Over the PAST WEEK...

4. Did you feel **IN CONTROL** in regard to your tinnitus?

   Very much in control ► 0 1 2 3 4 5 6 7 8 9 (10) ◄ *Never in control*

5. How easy was it for you to **COPE** with your tinnitus?

   Very easy to cope ► 0 1 2 3 4 5 6 (7) 8 9 10 ◄ *Impossible to cope*

6. How easy was it for you to **IGNORE** your tinnitus?

   Very easy to ignore ► 0 1 2 3 4 5 6 7 8 9 (10) ◄ *Impossible to ignore*

Case History

Relevant items in the case histories of patients with tinnitus:

- **Background**
  - Age and sex
  - Family history of tinnitus (parent, sibling, children)
- **Tinnitus history**
  - **Duration**
  - **Initial onset**: gradual or abrupt? Associated events? Hearing change, acoustic trauma, otitis media, head trauma, whiplash, dental treatment, stress, other?
  - **Pattern:** pulsatile? Intermittent or constant? Fluctuant or non-fluctuant? Other?
  - **Site:** right ear? Left ear? Both ears (symmetrical)? Inside head?
  - **Loudness:** scale 1–100. At worst and at best?
  - **Quality of the sound:** pure tone or noise? Uncertain or polyphonic?
  - **Pitch:** very high, high, medium, low?
  - Proportion of awake time aware of tinnitus
  - Proportion of awake time annoyed by tinnitus
  - Previous tinnitus treatments (no, some, or many)

Case History

Relevant items in the case histories of patients with tinnitus:

Modifying influences

- Natural masking? Music, everyday sounds, other sounds?
- Aggravated by loud noise?
- Altered by head and neck movement or touching of head or upper limbs?
- Effect of nocturnal sleep and daytime nap on tinnitus?
- Effect of stress?
- Effect of medications?

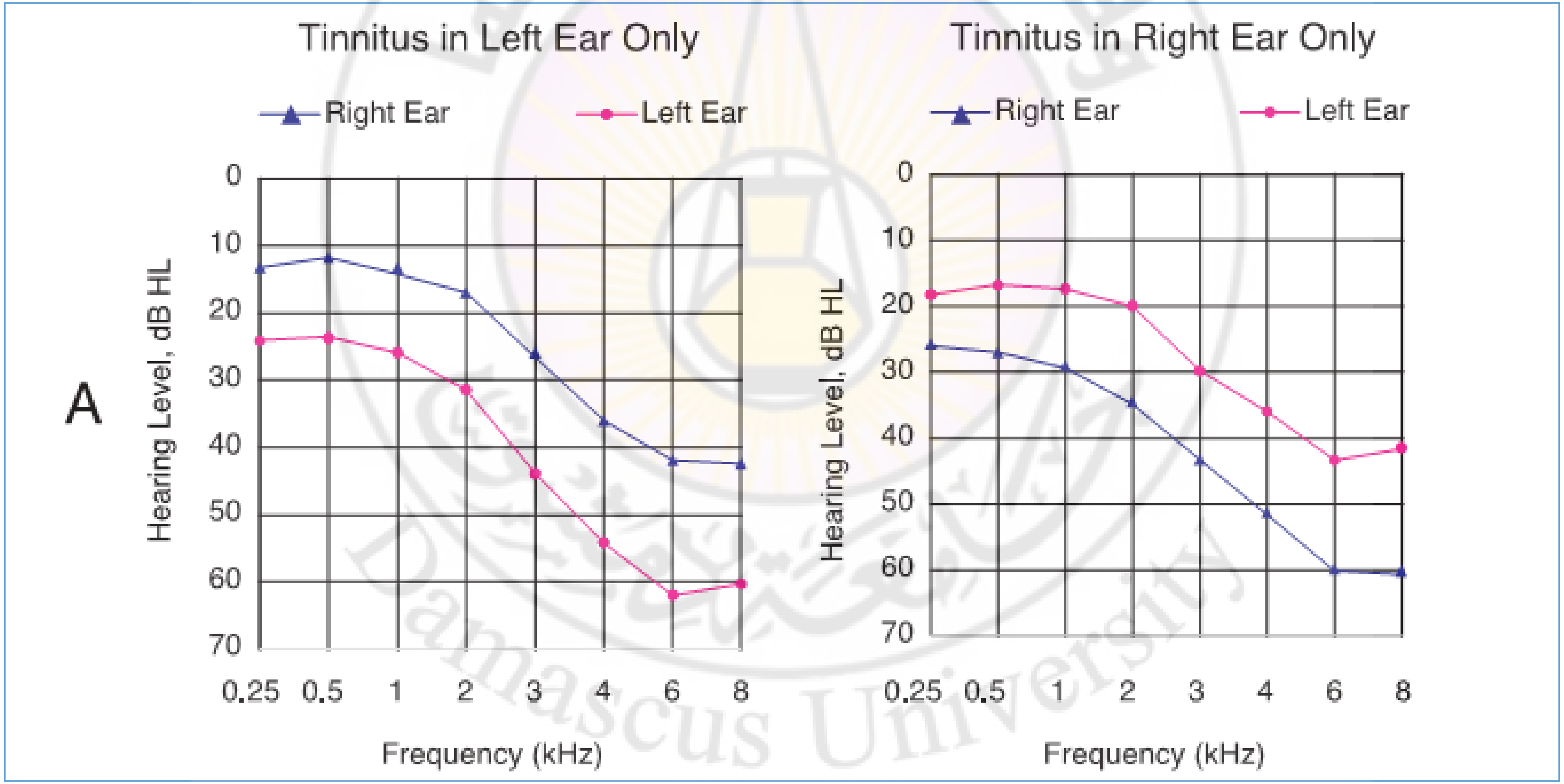
Related conditions

- Hearing impairment? Otalgia? Otorrhea?
- Hearing aids (no, left ear, right ear, or both ears; effect on tinnitus)?
- Noise annoyance or intolerance? Noise-induced pain? Hyperacusis?
- Vertigo or dizziness?
- Temporomandibular disorder?
- Neck pain?
- Other pain syndromes?
- Under treatment for psychiatric disorder?

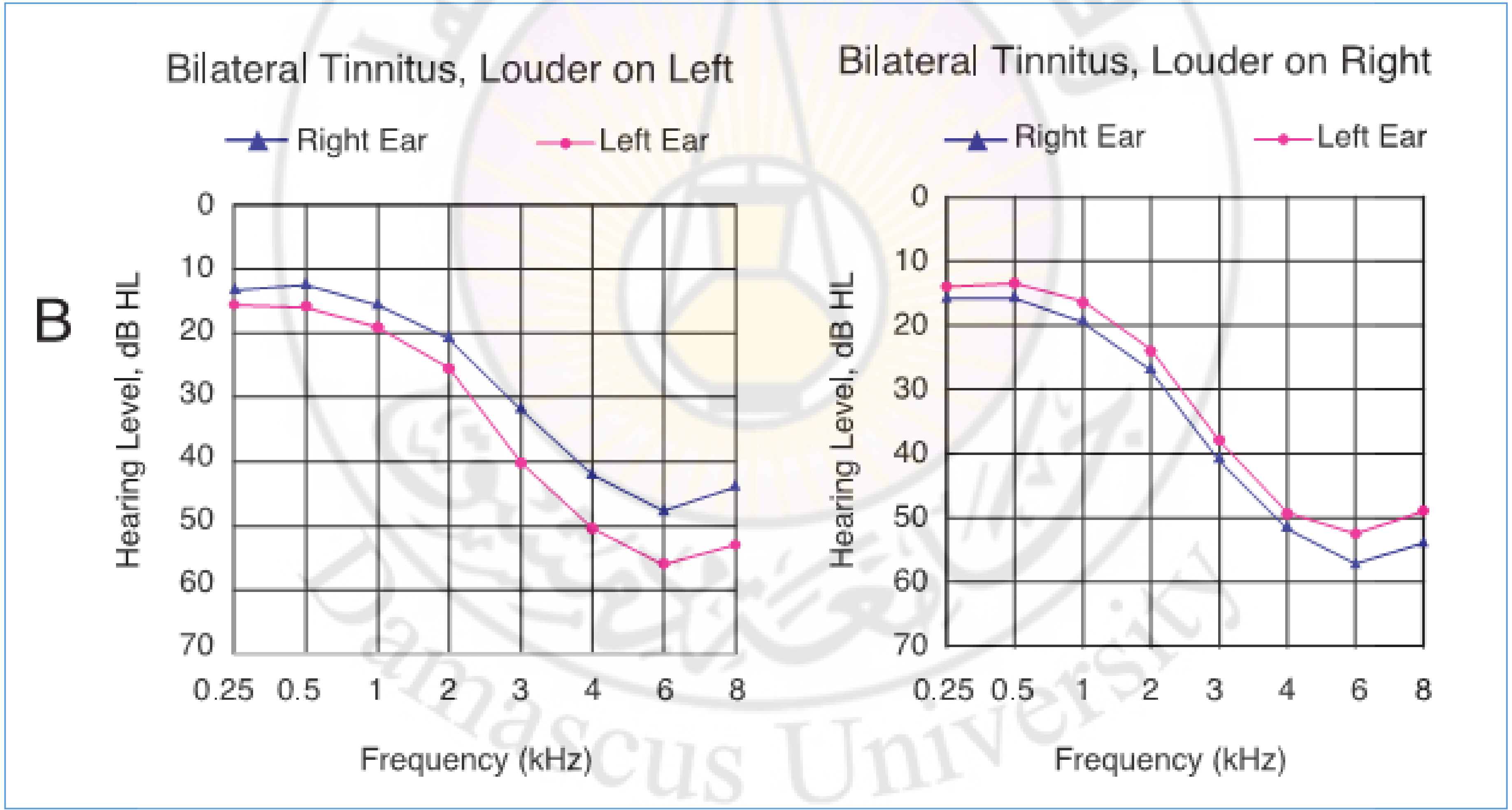
Sound features of tinnitus

TINNITUS CRITERIA	POSSIBLE FEATURES
Onset	Sudden, gradual
Pattern	Pulsatile, intermittent, constant, fluctuating
Site	Right or left ear, both ears, within head
Loudness	Wide range, varying over time
Quality	Pure tone, noise, polyphonic
Pitch	Very high, high, medium, low

Tinnitus Localization



…Tinnitus Localization



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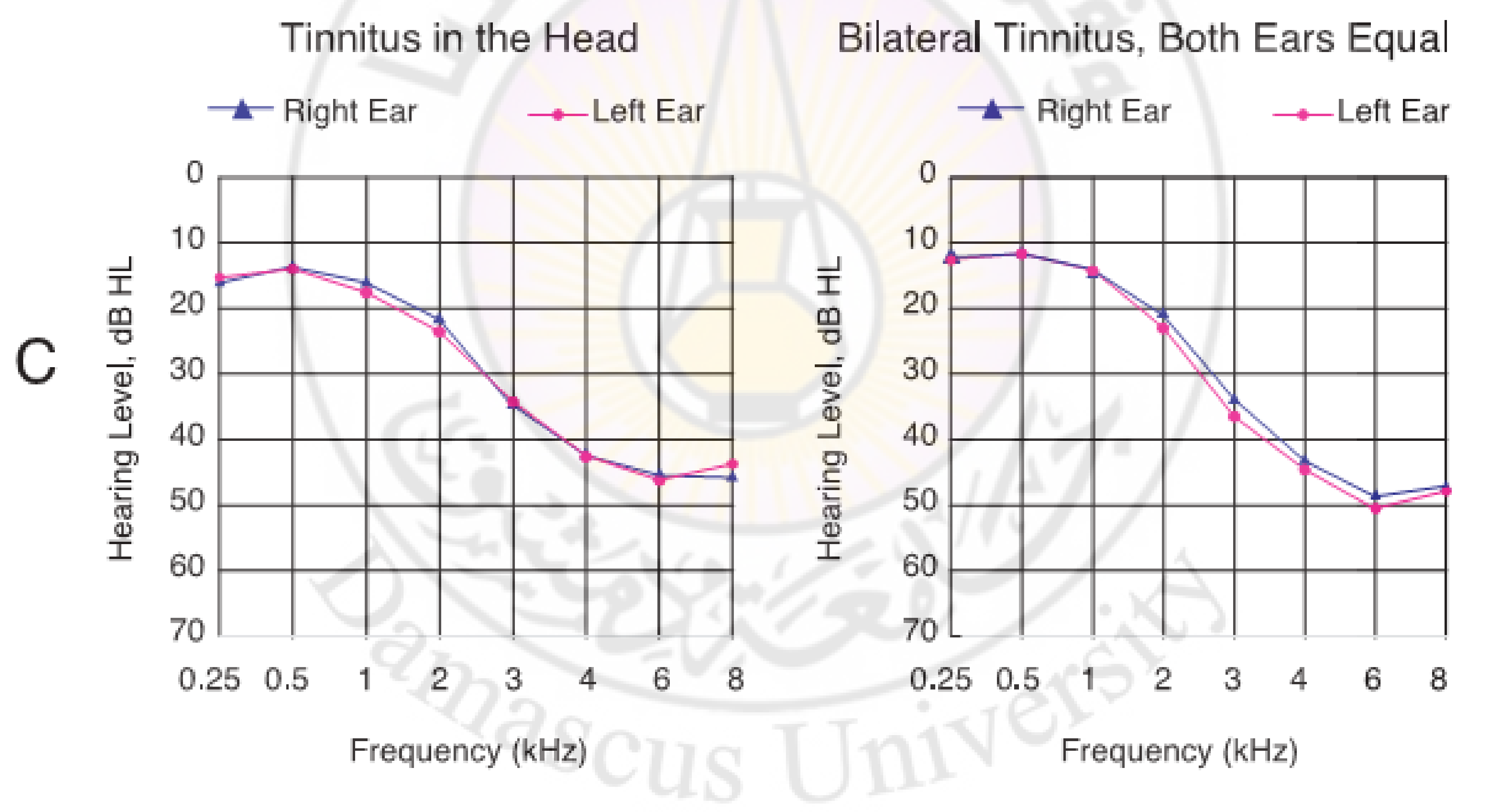


Case History

- Further diagnostic steps are advised if the findings of case history indicate **acute tinnitus,** a potentially dangerous underlying condition (e.g., carotid dissection), a possible causal treatment option, or relevant subjective impairment.
- **Immediate action** is necessary in tinnitus with sudden, acute hearing loss; in acute post-traumatic tinnitus; and in cases with concomitant suicidal tendencies.
- It is specifically important to the tinnitus sufferer to evaluate their **state of mind**. Patients may come in very emotionally distressed by their tinnitus, occasionally with suicidal intent. It is a moral imperative for the clinician to assess the patient for the risk of self-harm during the clinical visit.
- Additional exacerbating conditions such as poor sleep quality and significant situational stress (such as work environment or familial strife) should be asked.

Case History

- The next step in the hierarchical diagnostic algorithm is differentiation between pulsatile and non-pulsatile tinnitus.
- In **pulsatile tinnitus**, the sound perception is heartbeat-synchronous and neurovascular examination is necessary. Diseases such as arteriovenous malformation, sinus venous thrombosis, benign intracranial hypertension, and high jugular bulb could be causes of pulsatile tinnitus.
- **Non-pulsatile tinnitus** is much more common than pulsatile tinnitus and should be differentiated according to duration, concomitant symptoms, and causal factors.

Case History

- In **acute tinnitus** accompanied by **sudden hearing loss**, diagnostic and therapeutic procedures will focus on the acute hearing loss and should not be postponed.
- **Paroxysmal tinnitus** can be a symptom of auditory nerve compression, superior canal dehiscence syndrome, Menière's disease, palatal myoclonus, migraine, or epilepsy. For differential diagnosis, MRI, auditory evoked potentials, vestibular tests, and electroencephalography could be indicated.

Case History

- **Constant non-pulsatile** tinnitus can be accompanied by conductive or sensorineural hearing loss.
- Conductive hearing loss can be caused by otosclerosis, different forms of otitis, or eustachian tube dysfunction.
- In sensorineural hearing loss, further diagnostic procedures are indicated to identify the exact cause, including MRI and otoacoustic emissions for assessment of outer hair cell function.
- Tinnitus occurring together **with vertigo** is indicative of pathological abnormalities, such as Menière's disease, superior canal dehiscence, or damage to the vestibulocochlear system, and needs detailed assessment of vestibular function.

Case History

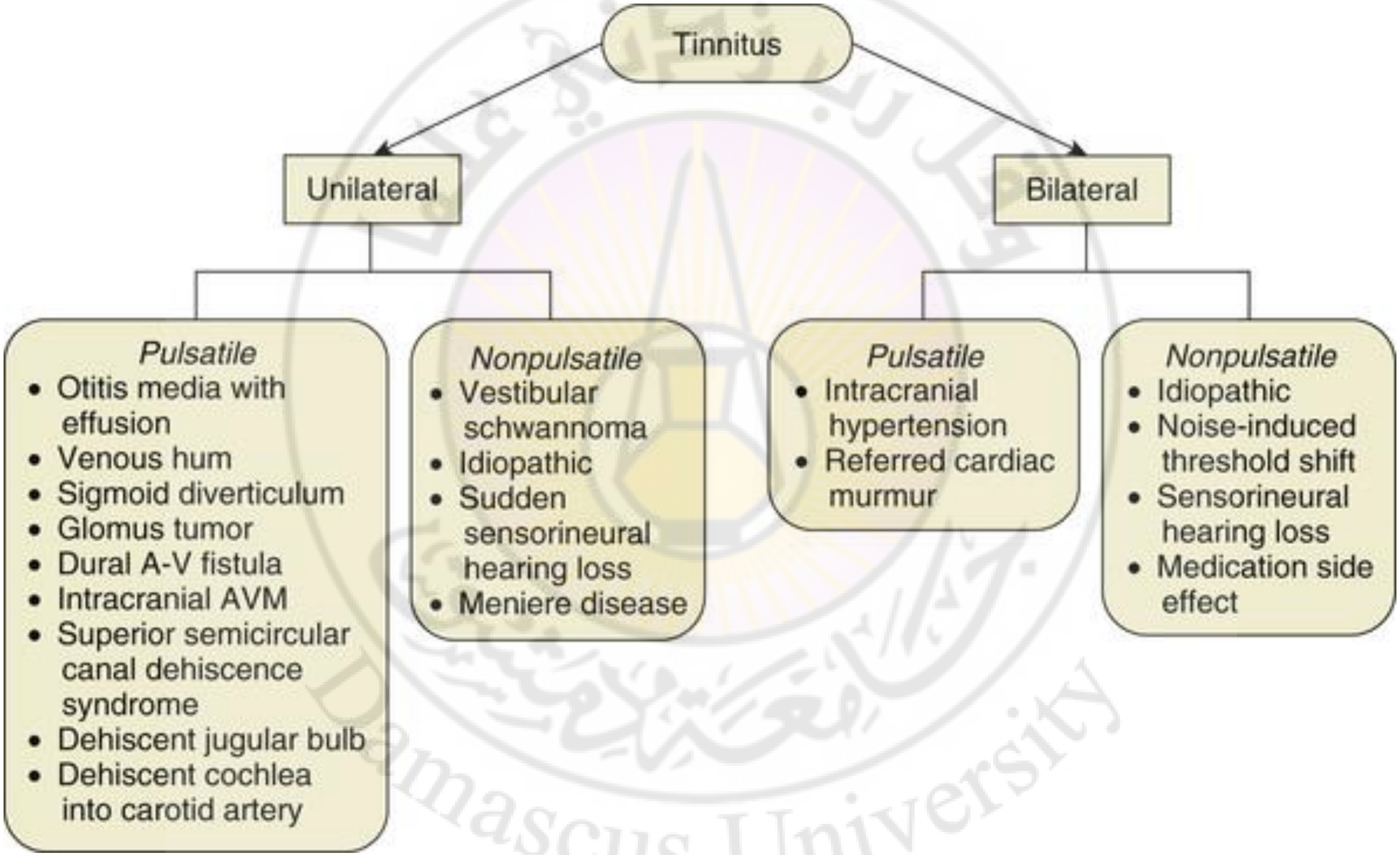
- **Neurologic symptoms** should be obtained, such as headaches, vision changes, and cranial nerve (CN) changes, as well as symptoms of **stroke** such as aphasia and face/body weakness now or in the past.
- If tinnitus occurs together with **headache**, space-occupying lesions, benign intracranial hypertension, disorders of CSF circulation, and craniocervical anomalies should be excluded by MRI.
- In cases of lateralized headache together with tinnitus on the same side and with a similar time course, trigemino-autonomal headache syndromes should be considered and, if confirmed, specifically treated.

Case History

- Co-occurring **psychiatric disorders**, such as depression, anxiety, and insomnia, should also be investigated and specifically treated if present, because they play a major part in tinnitus-related impairment of quality of life.
- **Hyperacusis** and **phonophobia** frequently occur together with tinnitus and are sometimes indicative of an anxiety disorder.
- Immediate referral to a psychiatrist is necessary when a patient reports acute suicidal ideation.
- When tinnitus is associated with **neck** or **temporomandibular** dysfunction or pain, these systems should be examined in detail by experienced dentists and physiotherapists.

Case History

- Specific diagnostic tests are advised if tinnitus begins or worsens within 3 months of a **traumatic event**.
- Traumatic events can cause tinnitus in different ways. The indication for further diagnostic procedures depends on the trauma mechanism; noise, ear, head, neck, or emotional trauma, or a combination thereof (eg, in blast injuries) should be considered.
- In cases of **post-traumatic pulsatile tinnitus**, immediate diagnostic investigations for vascular pathological changes (especially carotid dissection) is mandatory.


Tinnitus
Unilateral
Bilateral
Pulsatile
• Otitis media with effusion
• Venous hum
• Sigmoid diverticulum
• Glomus tumor
• Dural A-V fistula
• Intracranial AVM
• Superior semicircular canal dehiscence syndrome
• Dehiscent jugular bulb
• Dehiscent cochlea into carotid artery
Nonpulsatile
• Vestibular schwannoma
• Idiopathic
• Sudden sensorineural hearing loss
• Meniere disease
Pulsatile
• Intracranial hypertension
• Referred cardiac murmur
Nonpulsatile
• Idiopathic
• Noise-induced threshold shift
• Sensorineural hearing loss
• Medication side effect

Audiological Assessment

- **Otoscopy**
- **Audiometric Thresholds (Air & Bone) & HF Audiometry**
- **Speech testing**
- **Tympanometry & Acoustic Reflex**
  - Acoustic Reflexes and LDL/CLs should be done only if the patient does not have loudness level issues. These tests may exacerbate the tinnitus of the patient.
- **OAEs**
  - HF Audiometry and OAEs may be useful for diagnosing those with "normal" hearing sensitivity.
- **Tinnitus Loudness & Pitch Matching**
- **Minimum masking level (MML) & Residual Inhibition (RI)**
- **MCLs**
- **UCLs/LDLs** (only if a sound tolerance problem is reported)

Otoscopic Exam

- **Otoscopy** is performed routinely prior to placing earphones for testing. Clinicians should be aware that **cerumen** can be a cause of *tinnitus* — even a small amount of cerumen on the tympanic membrane can create a mass effect and a mild high-frequency conductive hearing loss that might be assumed to be sensorineural if bone conduction testing is not done.
- Bone conduction testing is therefore essential whenever cerumen is identified as a potential cause of tinnitus.
- Patients should be referred as necessary for cerumen removal (ideally by an otolaryngologist). Some audiologists are trained and competent in performing cerumen removal.

Pure-Tone Thresholds

- **Pulsed tones** are often recommended for use when evaluating pure-tone thresholds in tinnitus patients. The use of pulsed tones may assist some patients in distinguishing between the tones and the tinnitus.
- When testing thresholds, it is important to introduce to the patient the concept of **high- and low-pitched** sounds.
- Also, patients should be asked to identify any tones that sound **"really close" to the tinnitus**. Addressing these issues during pure-tone testing will help to prepare the patient for the subsequent tasks of tinnitus loudness and pitch matching.

Tinnitus Psychoacoustic Assessment

- **Pitch matching**
- **Loudness matching**
- **Minimum masking level (MML)**
- **Residual Inhibition (RI)**

Tinnitus Loudness and Pitch Matching

- Most patients are capable of selecting the loudness and pitch of a pure tone that provides an approximate match with the loudness and pitch of their tinnitus.
- Repeated loudness matches are usually reliable within a few decibels. Repeated pitch matches, however, can often differ by an octave or more. Some patients will match their tinnitus to narrowband noise [NBN] or BBN
- **Objective:**
- Using a clinical audiometer, determine the frequency (in hertz) and loudness (record both as dB HL and dB SL) of a tone or noise that is closest in pitch and loudness to the patient’s most bothersome tinnitus.

Combined Loudness- and Pitch-Matching Procedure

1. Identify ‘‘Tinnitus Ear’’ and ‘‘Stimulus Ear’’

- To perform tinnitus matching, the patient must distinguish clearly between the tinnitus perception and the external auditory stimulus. This is accomplished most readily if the stimulus in one ear is compared with the tinnitus in the contralateral ear.
- Prior to testing, the **‘‘tinnitus ear’’** and the **‘‘stimulus ear’’** are identified. The ear with the loudest or most prominent tinnitus (the ‘‘most bothersome’’ tinnitus) is considered the tinnitus ear, and the contralateral ear is the stimulus ear.
- Selection of ears is arbitrary if the patient’s tinnitus is symmetrical, and if the stimulus ear has normal sensory perception.
- Concerns of **binaural diplacusis** (perceiving the same auditory stimulus differently between ears) would indicate that ipsilateral matching is necessary. Binaural diplacusis would be suspected when hearing thresholds are grossly asymmetrical or when there is reported distortion. In these cases, **monaural ipsilateral testing** is recommended.

Combined Loudness- and Pitch-Matching Procedure

2. Ensure That Patient Understands ‘‘Loudness’’ and ‘‘Pitch’’

- Patients often confuse pitch and loudness when matching tones to their tinnitus. Prior to testing, the audiologist should review these terms with the patient and instruct as necessary.
- Helpful examples include a piano keyboard or men’s versus women’s voices for pitch, and volume on a radio for loudness.
- Pitch and loudness can be demonstrated by presenting tones with the audiometer.

Combined Loudness- and Pitch-Matching Procedure

3. Pitch Matching Using an Audiometer

- The objective is to determine the frequency of a pure tone that patients perceive to be closest to the pitch of their tinnitus. The procedure starts by presenting a pure tone at a frequency well below the perceived tinnitus pitch, so that patients can easily tell the difference in pitch between the tone and the tinnitus.
- About 90% of patients will select a frequency of 2000 Hz or higher as a pitch match, so 1000 Hz is a good starting frequency. This frequency may be described to the patient as a **''mid-pitched tone''** to provide a reference.
- Tones of different frequencies are then presented in **octave intervals** to gradually approach and identify the octave frequency that is closest to the perceived tinnitus pitch. **Inter-octave tones** are then presented to more closely identify the tinnitus frequency.
- The pitch-matched tone is then compared with tones an octave higher and an octave lower, to ensure that the patient has not made the common mistake of **''octave confusion''.**

	Comparison tones	Tone judged most like tinnitus
Trial 1	1 kHz vs 2 kHz	2 kHz
Trial 2	2 kHz vs 3 kHz	3 kHz
Trial 3	3 kHz vs 4 kHz	4 kHz
Trial 4	4 kHz vs 5 kHz	4 kHz
Trial 5	4 kHz vs 4.5 kHz	4 kHz
Trial 6	4 kHz vs 4.25 kHz	4.25 kHz
Trial 7	4.12 kHz vs 4.25 kHz	4.12 kHz
Trial 8	4.12 kHz vs 4.18 kHz	4.12 kHz
Trial 9	4.12 kHz vs 4.125 kHz	4.125 kHz

Pitch Matching

Combined Loudness- and Pitch-Matching Procedure

4. Loudness Matching Using an Audiometer

- The objective is to determine the level of the pitch-matched tone that matches the patient's perceived tinnitus loudness.
- Following a final pitch match, the threshold of the pitch-matched tone is obtained to the closest 1 dB. The tone is then raised in 1-dB steps to determine the loudness match (recorded in both dB HL and dB SL) at the pitch-match frequency.
- Patients can become confused between matching for loudness versus matching for pitch. Test results can be confounded if such confusion occurs. While presenting tones for pitch matching, it is therefore important that all tones are presented at levels that approximate the patient's perceived tinnitus loudness. These levels will generally be **10–20 dB SL** at frequencies where hearing is within normal limits, and **5–10 dB SL (or less)** where hearing thresholds are significantly elevated.

	Comparison tones	Tone judged most like tinnitus
Trial 1	55 dB vs 60 dB	60 dB
Trial 2	60 dB vs 65 dB	65 dB
Trial 3	65 dB vs 70 dB	65 dB
Trial 4	65 vs 68 dB	65 dB
Trial 5	65 vs 66	65 dB

Loudness Matching

Combined Loudness- and Pitch-Matching Procedure

5. Start Testing

- Testing starts by presenting a 1000-Hz tone at 10–20 dB SL. Ask the patient, ‘‘Is the tinnitus louder or softer than the tone?’’ Adjust the level accordingly before proceeding with pitch matching. Then ask, ‘‘Is the tinnitus higher pitched or lower pitched than the tone?’’
- Repeat the above procedure at adjacent octave frequencies, **maintaining output levels** that approximate the tinnitus loudness (instruct the patient to report any tones that are substantially louder or softer than the tinnitus).
- When an octave frequency is identified as a ‘‘close match’’ to the tinnitus, continue testing at adjacent inter-octave frequencies.
- After that, **octave-confusion testing** is performed. The pitch-matched tone should be presented in alternation with a tone an octave above, then an octave below (assuming such octaves are available). The match using this procedure is the final, octave-confirmed pitch match. A further possibility is that the clinician might want to alternate the pitch-matched tone with a **warble** (frequency modulated) tone at the same frequency. Some patients will choose the warble tone as a better match.

Combined Loudness- and Pitch-Matching Procedure

5. Testing continue….

- The next objective is to obtain a precise **loudness match at the pitch-match frequency**. The loudness match will be measured to the closest 1 dB.
- The loudness match should also be reported in **dB SL**; thus, a hearing threshold must be obtained to the nearest 1 dB. To obtain a threshold with 1-dB resolution, first find the threshold in the usual manner (i.e., down 10, up 5). Then, starting 5 dB below the threshold, increase the level in 1-dB steps until the patient hears the tone. Confirm that threshold at least once.
- After obtaining a threshold at that frequency, the level of the tone should be raised to some level that is definitely below the perceived tinnitus loudness.
- **Instruct the patient**, ''For each tone that I present, please tell me whether the tone should be made louder or softer to be the same loudness as your tinnitus.'' Adjust the tone in 1-dB steps until the patient reports a loudness match. Record the loudness match in **dB SL and dB HL**.

Combined Loudness- and Pitch-Matching Procedure

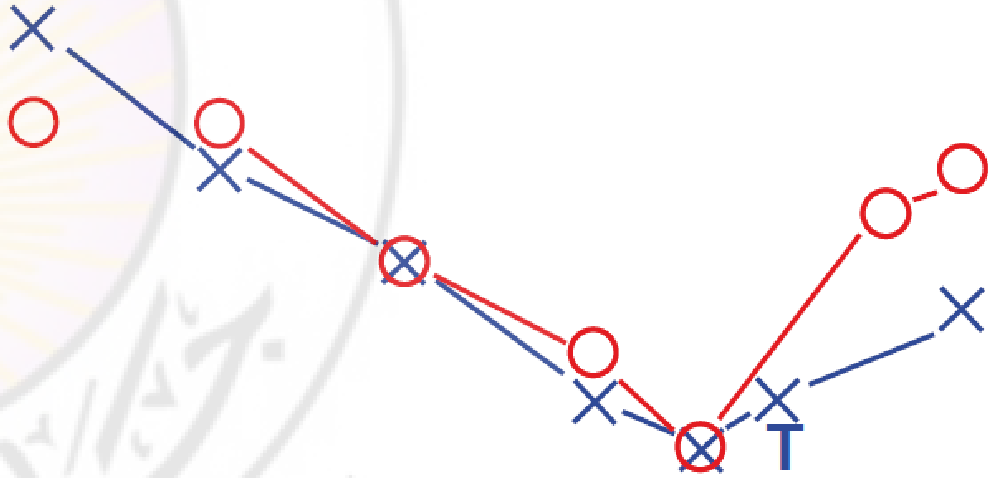
6. Determine Whether the Tinnitus Sounds More Like a Tone or More Like Noise

- The tone that was matched in pitch and loudness to the tinnitus is compared with NBN at the same frequency and same (approximate) loudness. One of these stimuli is presented for a few seconds, followed by the other for a few seconds. Ask the patient, ‘‘Which of these sounds most like your tinnitus?’’ If the tone is selected, no further testing is necessary.
- If the NBN is chosen by the patient, the next task is to determine whether the tinnitus sounds more like **NBN or BBN**. The NBN is presented for a few seconds followed by BBN (white or speech noise) for a few seconds. Both stimuli should be presented at levels that approximate the patient’s tinnitus loudness.
- Most audiometers have the capability of presenting both speech and white noise, and each should be presented to the patient for the final decision.
- When the patient selects the best match, a hearing threshold and tinnitus loudness match are obtained for the selected stimulus. The threshold and loudness match are made in 1-dB steps, and the loudness match is recorded in dB HL and dB SL.

Combined Loudness- and Pitch-Matching Procedure

7. Plot the Tinnitus Match on the Audiogram

- The stimulus that is best matched to the tinnitus (pure tone, NBN, or BBN) is plotted on the patient's audiogram for counseling purposes (to objectify the tinnitus and to illustrate that the tinnitus loudness is ''only a few decibels above the hearing threshold'').
- If the match is to a **tone**, then a **single point (T)** is plotted, representing the frequency and decibel level of the tone.
- If the matching stimulus is **NBN**, a **short horizontal line** is made at the decibel level. If the match is to **BBN**, the **horizontal line is made correspondingly wider**.



Minimum masking level (MML)

- **Objective:** Using an audiometer, determine the lowest level of *Tone, NBN or BBN* (in dB HL and dB SL) that renders a patient's tinnitus inaudible (completely ''masks'' the tinnitus). That level is the **MML**.
- P. J. Jastreboff and Jastreboff (2001): MML is actually a process of **''suppression''** of neural activity (not Masking)
- The patient is given a noise band or tone for about 1-2 seconds at a low level and asked if he hears his own tinnitus. This level is changed until the tinnitus is just masked. This is completed for all the frequencies, 250 to 8KHz. The resulting curves are then classified according to **Feldman's system**.
- As the level of the external sound is raised, at some point the sound of the tinnitus will start to change—the tinnitus is reduced in loudness, or its characteristic quality (or timbre) is altered in some way. This is the point at which **partial masking** begins, which is also the beginning of **''mixing'' or ''blending''** of the tinnitus and the external sound.
- As the external sound is made louder, the tinnitus perception continues to change until the tinnitus can no longer be heard. This is the level of **complete masking**, or **complete suppression**.

There are **six types of curves** in the **Feldman's system**.

Type 1, Convergence, the patient's threshold curve and masking curve will slope together from low to high frequencies. They will meet at the frequency of the tinnitus and all frequencies above that.

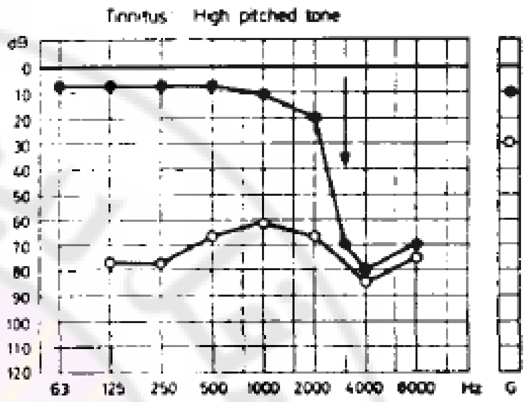
Type 2, Divergence, the threshold and masking curves slope further apart from low to high frequencies.

Type 3, Congruence, the threshold and masking curves almost overlap each other for all frequencies. This type of tinnitus can be masked by any noise just above the threshold of the tinnitus.

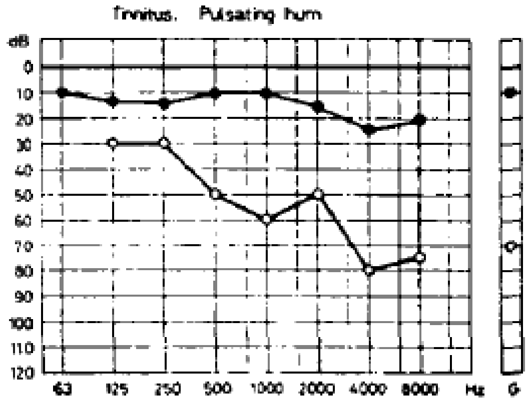
Type 4, Distance, the masking curve follows the threshold curve, but is at least 20dB above the threshold.

Type 4a, Distance is the same as type 4, but the tinnitus can only be masked by pure tones.

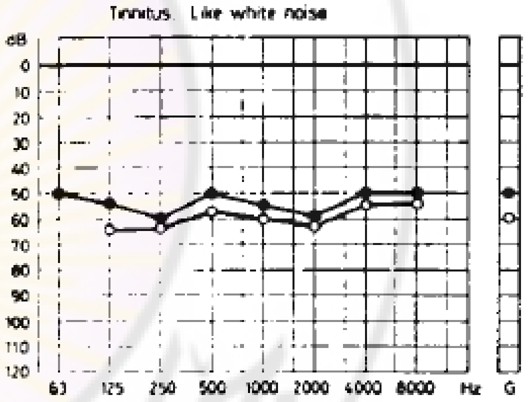
Type 5, persistence, is found when no sound at any level can mask tinnitus. This usually happens when the patient has a severe to profound hearing loss, but occasionally it occurs with those with moderate hearing loss.



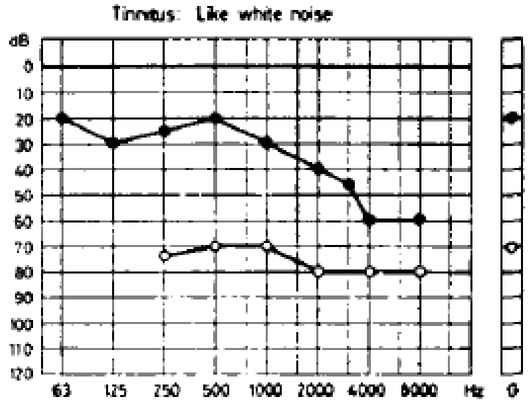
Type 1, Convergence



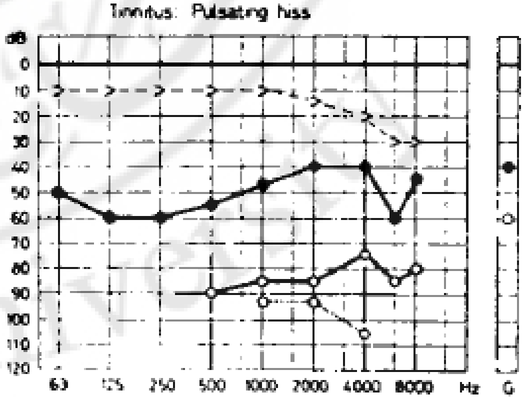
Type 2, Divergence



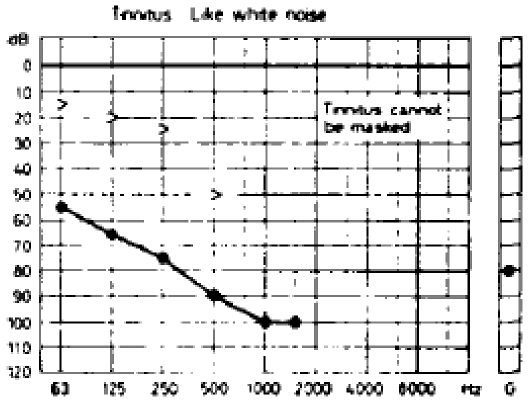
Type 3, Congruence



Type 4, Distance



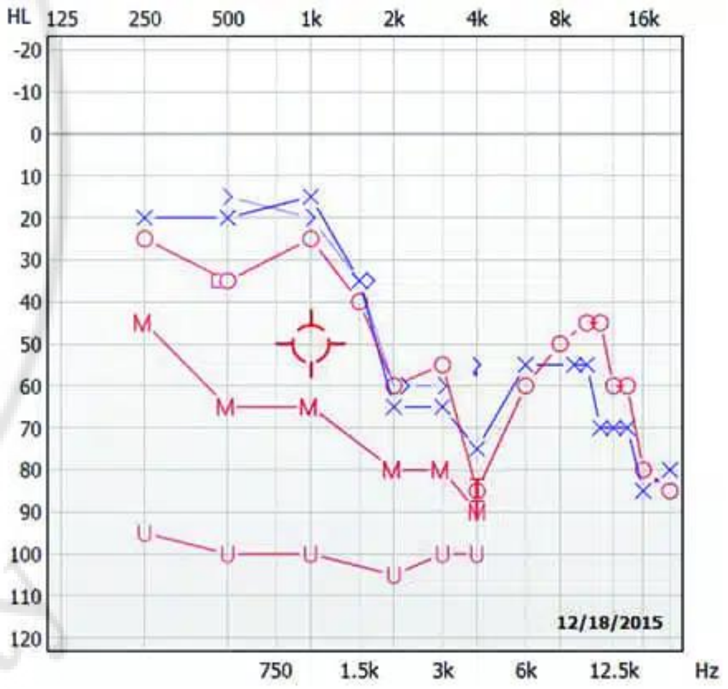
Type 4a, Distance



Type 5, persistence

Minimum masking level (MML): Implications for treatment

- After the minimal masking curves have been established, the audiologist can determine whether **masking** is a good choice for treatment.
- If a patient exhibits a **convergence** curve, this indicates good candidacy for acoustic masking.
- A **divergence** curve shows poor but possible acoustical masking.
- Since **congruence** can be masked by any sound, a patient with this curve will be a good candidate for any type of masker.
- The patient with a **distance** curve may not be able to tolerate acoustical masking because of the level of masking required to mask the tinnitus.
- Finally, the patient with a **persistence** curve is also not a candidate for acoustical masking.
- Patients with higher MMLs (e.g., exceeding 10 dB SL) may need to use a greater amount of environmental sound as therapy or may benefit from an approach that more closely approximates TRT rather than masking.



Residual Inhibition (RI)

- The **purpose** of testing for residual inhibition is to determine whether the use of tinnitus maskers would be a viable treatment course.
- Residual inhibition is defined as the temporary suppression and/or disappearance of tinnitus following a period of masking. recommended measurement procedure is to present the sound that has been identified at the pitch match at a level corresponding to the **MML + 10 dB for 1 minute**. The stimulus is the same as used for the MML measurement. Then the post-masking effects are classified into four categories.

1) Positive-Complete RI (CRI), where the tinnitus is completely absent for more than one minute

2) Positive-Partial RI (PRI), where the tinnitus is still present but softer at a lower perceived level than before for more than one minute. The *quality* may have changed as well.

3) Negative RI (NRI) where there is no reported change in the tinnitus;

4) Rebound, where the tinnitus is actually louder after the masking stimulus is presented. Rebound, would be a contraindication to maskers. For these cases, the time it takes the sound to return to its original level (Recurrence Time) is recorded.

Tinnitus Evaluation Form

Tinnitus Evaluation

12/18/2015, 11:48 AM	New	Right	Binaural	Left
Pitch Matching		T 4000 Hz		
Loudness Matching		T 5 SL		
Hearing Threshold		• 85 HL		
Masking Noise Threshold		85 HL		
Minimum Masking Level (MML)		0 SL (85 HL)		
Maskability		Complete		
Residual Inhibition		1 m 19 s		
Inhibition Characteristic		Partial		

Note: T = high pitched "beep"

Loudness Discomfort Levels (LDLs)

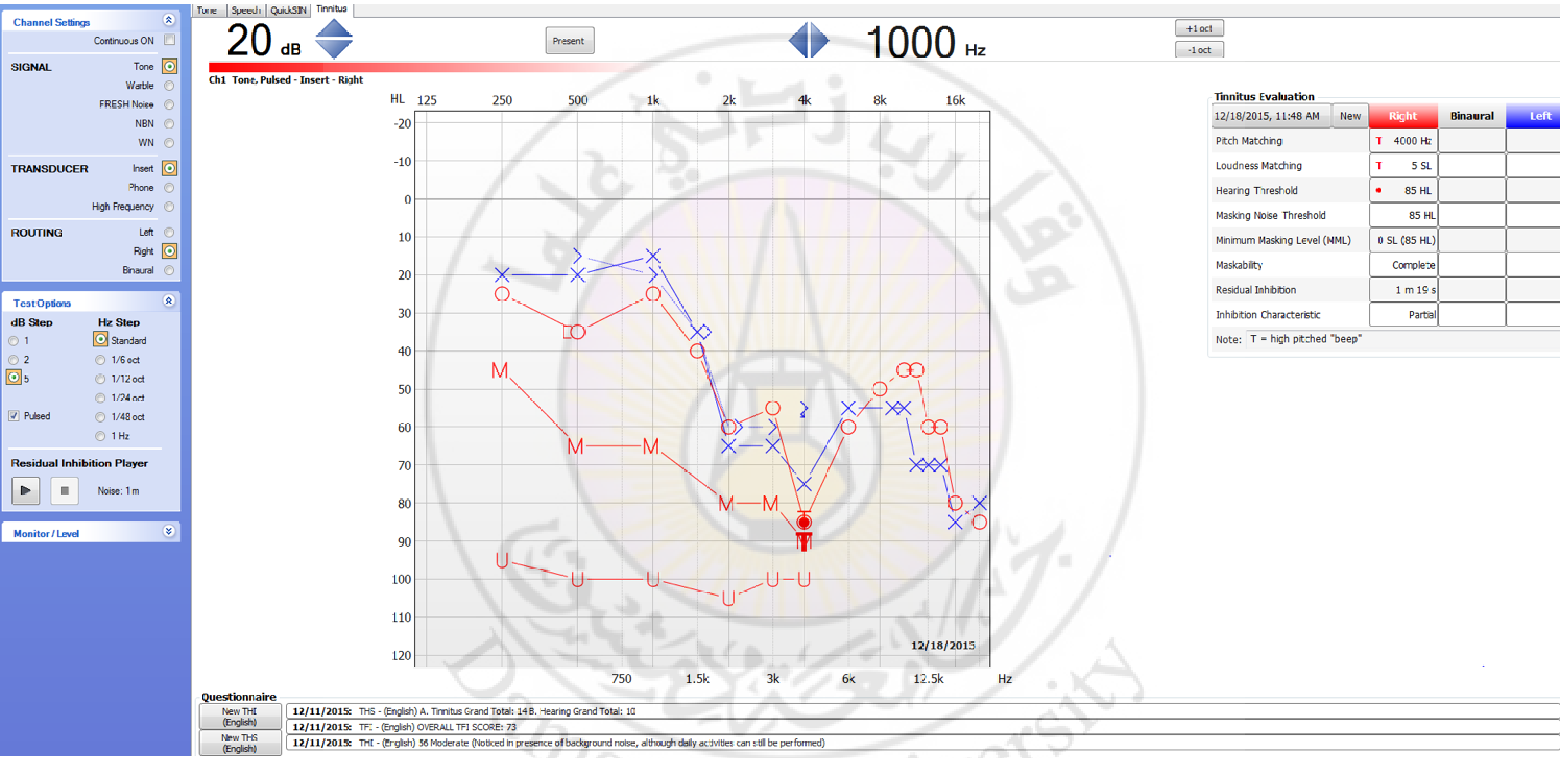
- For tinnitus patients who report a sound tolerance problem, LDLs should be measured as part of the initial assessment. If a patient does not report a problem with sound tolerance, then determining LDLs is not necessary.

- The threshold level of discomfort for a sound defines that sound's LDL. The LDL should reflect the level just below physical discomfort and not just fear that the sound is going to get too loud.

- Clinical LDL testing can be done using pure tones, speech stimuli **(UCL)**, and BBN. Using pure tones, LDLs can be obtained at **various audiometric frequencies (between 1 and 8 kHz)**, establishing the upper limit of the auditory dynamic range for each frequency tested.

- **Patients are instructed**, ''You will listen to different tones. Each tone will be made slightly louder in steps. Tell me when the loudness of the tone would be **OK for 3 seconds**, but would not be OK for more than 3 seconds.'' The objective is to identify the level for each frequency at which any further increase would cause discomfort.

- Because patients are often inconsistent when providing repeated LDLs within a test session, it is advisable to measure each LDL twice.



Screenshot from Madsen Astera2 Tinnitus Module

دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی ایران

Behavioral Tests for Audiological Diagnosis

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Iran University of Medical Sciences
Rehabilitation Research Center
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Tinnitus Psychoacoustic Assessment

- **Pitch matching**
- **Loudness matching**
- **Minimum masking level (MML)**
- **Residual Inhibition (RI)**

Tinnitus Loudness and Pitch Matching

- Most patients are capable of selecting the loudness and pitch of a pure tone that provides an approximate match with the loudness and pitch of their tinnitus.
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1. Identify ‘‘Tinnitus Ear’’ and ‘‘Stimulus Ear’’

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Combined Loudness- and Pitch-Matching Procedure

2. Ensure That Patient Understands "Loudness" and "Pitch"

- Patients often confuse pitch and loudness when matching tones to their tinnitus. Prior to testing, the audiologist should review these terms with the patient and instruct as necessary.
- Helpful examples include a piano keyboard or men's versus women's voices for pitch, and volume on a radio for loudness.
- Pitch and loudness can be demonstrated by presenting tones with the audiometer.

Combined Loudness- and Pitch-Matching Procedure

3. Pitch Matching Using an Audiometer

- The objective is to determine the frequency of a pure tone that patients perceive to be closest to the pitch of their tinnitus. The procedure starts by presenting a pure tone at a frequency well below the perceived tinnitus pitch, so that patients can easily tell the difference in pitch between the tone and the tinnitus.
- About 90% of patients will select a frequency of 2000 Hz or higher as a pitch match, so 1000 Hz is a good starting frequency. This frequency may be described to the patient as a **''mid-pitched tone''** to provide a reference.
- Tones of different frequencies are then presented in **octave intervals** to gradually approach and identify the octave frequency that is closest to the perceived tinnitus pitch. **Inter-octave tones** are then presented to more closely identify the tinnitus frequency.
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Trial 8	4.12 kHz vs 4.18 kHz	4.12 kHz
Trial 9	4.12 kHz vs 4.125 kHz	4.125 kHz

Pitch Matching

Combined Loudness- and Pitch-Matching Procedure

4. Loudness Matching Using an Audiometer

- The objective is to determine the level of the pitch-matched tone that matches the patient's perceived tinnitus loudness.
- Following a final pitch match, the threshold of the pitch-matched tone is obtained to the closest 1 dB. The tone is then raised in 1-dB steps to determine the loudness match (recorded in both dB HL and dB SL) at the pitch-match frequency.
- Patients can become confused between matching for loudness versus matching for pitch. Test results can be confounded if such confusion occurs. While presenting tones for pitch matching, it is therefore important that all tones are presented at levels that approximate the patient's perceived tinnitus loudness. These levels will generally be **10–20 dB SL** at frequencies where hearing is within normal limits, and **5–10 dB SL (or less)** where hearing thresholds are significantly elevated.

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Trial 5	65 vs 66	65 dB

Loudness Matching

Combined Loudness- and Pitch-Matching Procedure

5. Start Testing

- Testing starts by presenting a 1000-Hz tone at 10–20 dB SL. Ask the patient, ‘‘Is the tinnitus louder or softer than the tone?’’ Adjust the level accordingly before proceeding with pitch matching. Then ask, ‘‘Is the tinnitus higher pitched or lower pitched than the tone?’’
- Repeat the above procedure at adjacent octave frequencies, **maintaining output levels** that approximate the tinnitus loudness (instruct the patient to report any tones that are substantially louder or softer than the tinnitus).
- When an octave frequency is identified as a ‘‘close match’’ to the tinnitus, continue testing at adjacent inter-octave frequencies.
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Combined Loudness- and Pitch-Matching Procedure

5. Testing continue….

- The next objective is to obtain a precise **loudness match at the pitch-match frequency**. The loudness match will be measured to the closest 1 dB.
- The loudness match should also be reported in dB SL; thus, a hearing threshold must be obtained to the nearest 1 dB. To obtain a threshold with 1-dB resolution, first find the threshold in the usual manner (i.e., down 10, up 5). Then, starting 5 dB below the threshold, increase the level in 1-dB steps until the patient hears the tone. Confirm that threshold at least once.
- After obtaining a threshold at that frequency, the level of the tone should be raised to some level that is definitely below the perceived tinnitus loudness.
- **Instruct the patient**, ''For each tone that I present, please tell me whether the tone should be made louder or softer to be the same loudness as your tinnitus.'' Adjust the tone in 1-dB steps until the patient reports a loudness match. Record the loudness match in dB SL and dB HL.

Combined Loudness- and Pitch-Matching Procedure

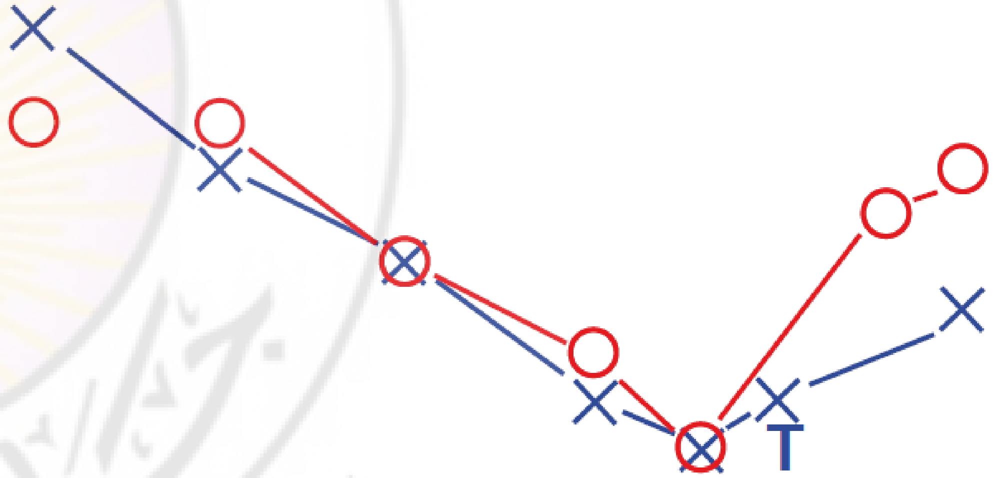
6. Determine Whether the Tinnitus Sounds More Like a Tone or More Like Noise

- The tone that was matched in pitch and loudness to the tinnitus is compared with NBN at the same frequency and same (approximate) loudness. One of these stimuli is presented for a few seconds, followed by the other for a few seconds. Ask the patient, ''Which of these sounds most like your tinnitus?'' If the tone is selected, no further testing is necessary.
- If the NBN is chosen by the patient, the next task is to determine whether the tinnitus sounds more like **NBN or BBN**. The NBN is presented for a few seconds followed by BBN (white or speech noise) for a few seconds. Both stimuli should be presented at levels that approximate the patient's tinnitus loudness.
- Most audiometers have the capability of presenting both speech and white noise, and each should be presented to the patient for the final decision.
- When the patient selects the best match, a hearing threshold and tinnitus loudness match are obtained for the selected stimulus. The threshold and loudness match are made in 1-dB steps, and the loudness match is recorded in dB HL and dB SL.

Combined Loudness- and Pitch-Matching Procedure

7. Plot the Tinnitus Match on the Audiogram

- The stimulus that is best matched to the tinnitus (pure tone, NBN, or BBN) is plotted on the patient's audiogram for counseling purposes (to objectify the tinnitus and to illustrate that the tinnitus loudness is ''only a few decibels above the hearing threshold'').
- If the match is to a **tone**, then a **single point (T)** is plotted, representing the frequency and decibel level of the tone.
- If the matching stimulus is **NBN**, a **short horizontal line** is made at the decibel level. If the match is to **BBN**, the **horizontal line is made correspondingly wider**.



Minimum masking level (MML)

- **Objective:** Using an audiometer, determine the lowest level of *Tone, NBN or BBN* (in dB HL and dB SL) that renders a patient's tinnitus inaudible (completely ''masks'' the tinnitus). That level is the **MML**.
- P. J. Jastreboff and Jastreboff (2001): MML is actually a process of **''suppression''** of neural activity (not Masking)
- The patient is given a noise band or tone for about 1-2 seconds at a low level and asked if he hears his own tinnitus. This level is changed until the tinnitus is just masked. This is completed for all the frequencies, 250 to 8KHz. The resulting curves are then classified according to **Feldman's system**.
- As the level of the external sound is raised, at some point the sound of the tinnitus will start to change—the tinnitus is reduced in loudness, or its characteristic quality (or timbre) is altered in some way. This is the point at which **partial masking** begins, which is also the beginning of **''mixing'' or ''blending''** of the tinnitus and the external sound.
- As the external sound is made louder, the tinnitus perception continues to change until the tinnitus can no longer be heard. This is the level of **complete masking**, or **complete suppression**.

There are six types of curves in the Feldman's system.

Type 1, Convergence, the patient's threshold curve and masking curve will slope together from low to high frequencies. They will meet at the frequency of the tinnitus and all frequencies above that.

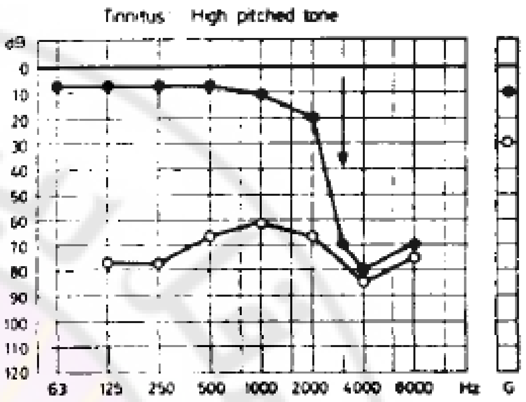
Type 2, Divergence, the threshold and masking curves slope further apart from low to high frequencies.

Type 3, Congruence, the threshold and masking curves almost overlap each other for all frequencies. This type of tinnitus can be masked by any noise just above the threshold of the tinnitus.

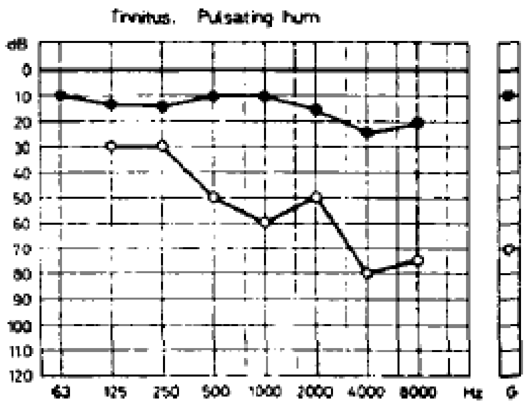
Type 4, Distance, the masking curve follows the threshold curve, but is at least 20dB above the threshold.

Type 4a, Distance is the same as type 4, but the tinnitus can only be masked by pure tones.

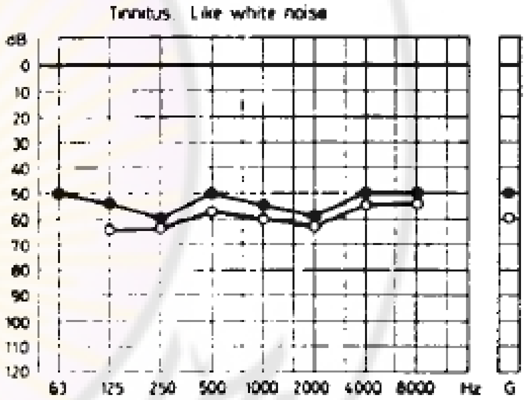
Type 5, persistence, is found when no sound at any level can mask tinnitus. This usually happens when the patient has a severe to profound hearing loss, but occasionally it occurs with those with moderate hearing loss.



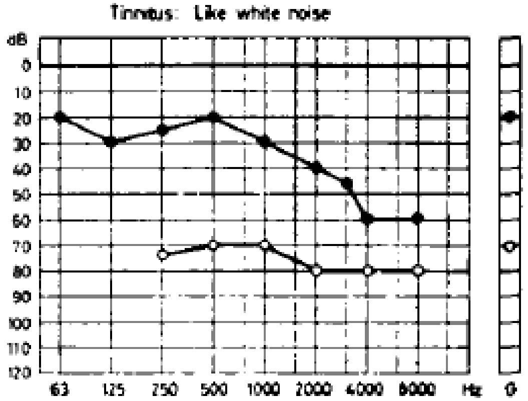
Type 1, Convergence



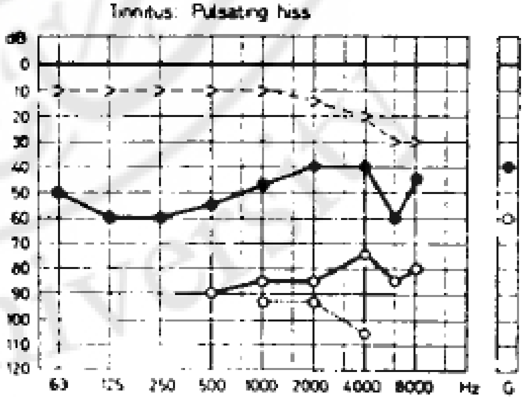
Type 2, Divergence



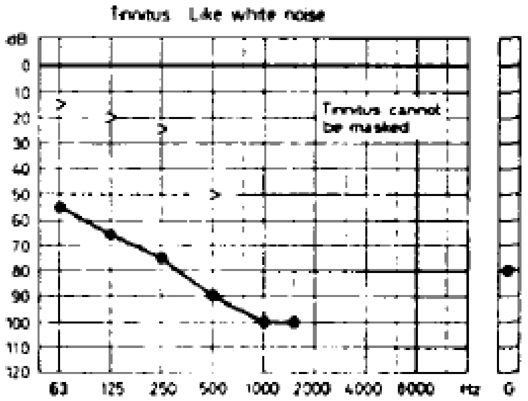
Type 3, Congruence



Type 4, Distance



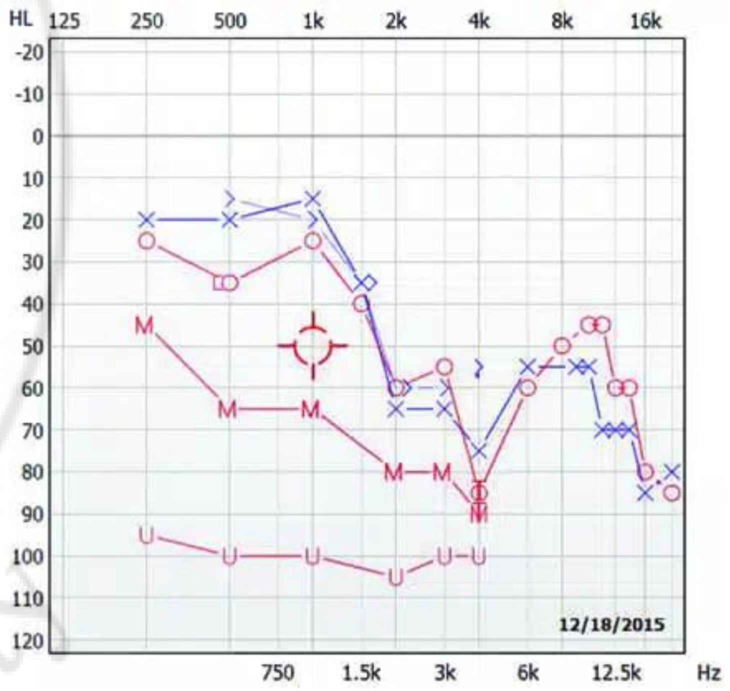
Type 4a, Distance



Type 5, persistence

Minimum masking level (MML): Implications for treatment

- After the minimal masking curves have been established, the audiologist can determine whether masking is a good choice for treatment.
- If a patient exhibits a convergence curve, this indicates good candidacy for acoustic masking.
- A divergence curve shows poor but possible acoustical masking.
- Since congruence can be masked by any sound, a patient with this curve will be a good candidate for any type of masker.
- The patient with a distance curve may not be able to tolerate acoustical masking because of the level of masking required to mask the tinnitus.
- Finally, the patient with a persistence curve is also not a candidate for acoustical masking.
- Patients with higher MMLs (e.g., exceeding 10 dB SL) may need to use a greater amount of environmental sound as therapy or may benefit from an approach that more closely approximates TRT rather than masking.



Residual Inhibition (RI)

- The **purpose** of testing for residual inhibition is to determine whether the use of tinnitus maskers would be a viable treatment course.
- Residual inhibition is defined as the temporary suppression and/or disappearance of tinnitus following a period of masking. recommended measurement procedure is to present the sound that has been identified at the pitch match at a level corresponding to the **MML + 10 dB for 1 minute**. The stimulus is the same as used for the MML measurement. Then the post-masking effects are classified into four categories.

1) Positive-Complete RI (CRI), where the tinnitus is completely absent for more than one minute

2) Positive-Partial RI (PRI), where the tinnitus is still present but softer at a lower perceived level than before for more than one minute. The *quality* may have changed as well.

3) Negative RI (NRI) where there is no reported change in the tinnitus;

4) Rebound, where the tinnitus is actually louder after the masking stimulus is presented. Rebound, would be a contraindication to maskers. For these cases, the time it takes the sound to return to its original level (Recurrence Time) is recorded.

Tinnitus Evaluation Form

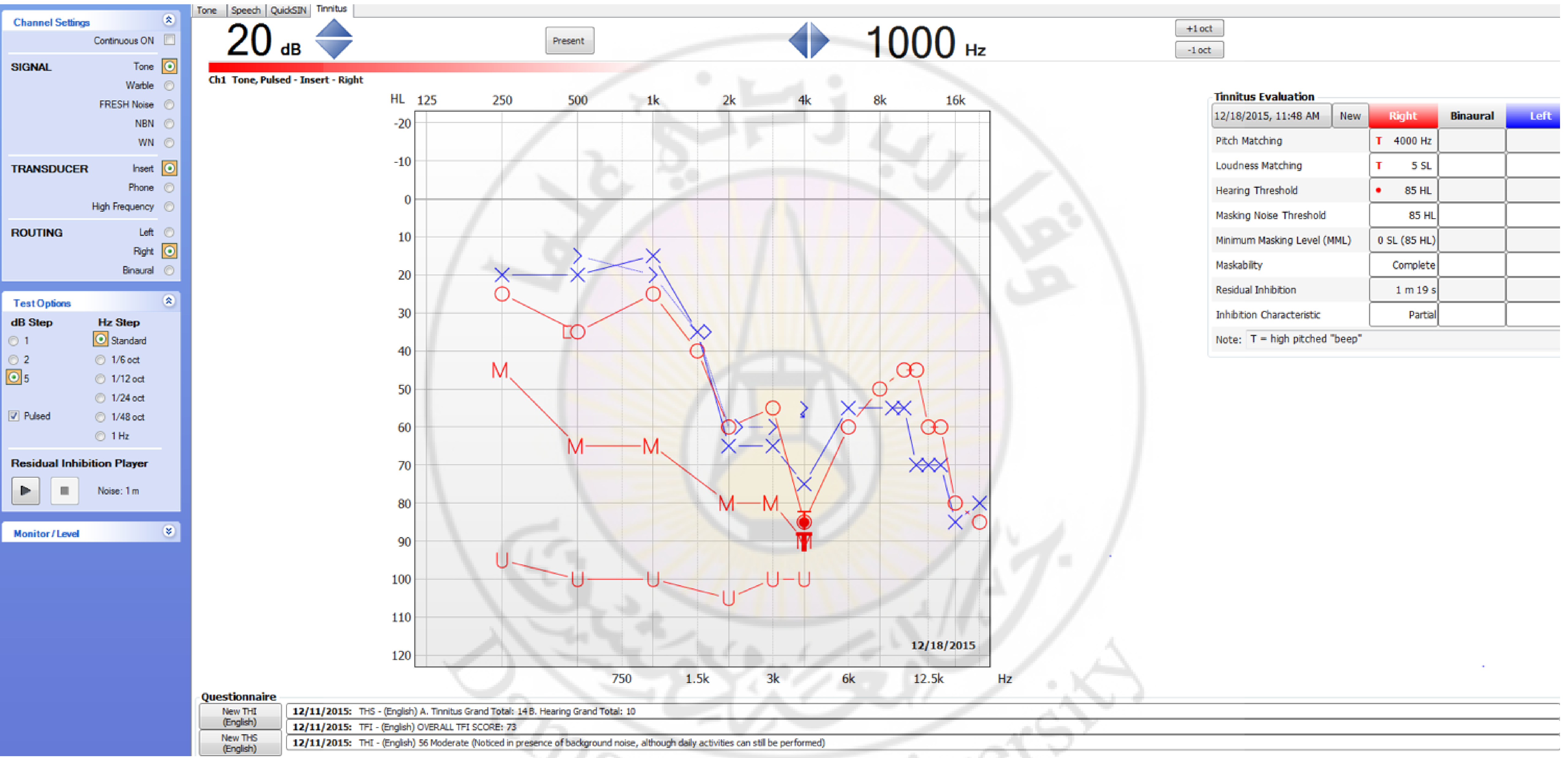
Tinnitus Evaluation

12/18/2015, 11:48 AM	New	Right	Binaural	Left
Pitch Matching		T 4000 Hz		
Loudness Matching		T 5 SL		
Hearing Threshold		• 85 HL		
Masking Noise Threshold		85 HL		
Minimum Masking Level (MML)		0 SL (85 HL)		
Maskability		Complete		
Residual Inhibition		1 m 19 s		
Inhibition Characteristic		Partial		

Note: T = high pitched "beep"

Loudness Discomfort Levels (LDLs)

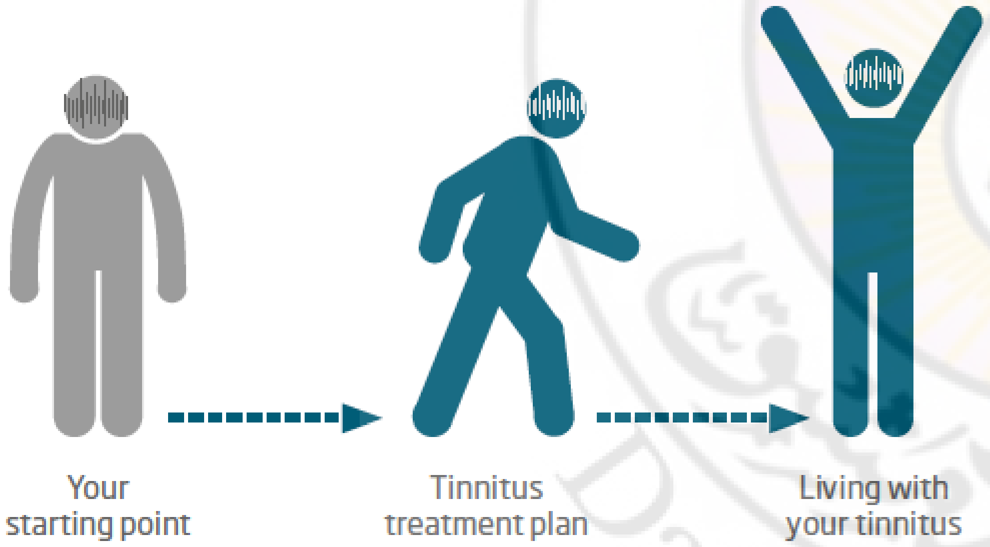
- For tinnitus patients who report a sound tolerance problem, LDLs should be measured as part of the initial assessment. If a patient does not report a problem with sound tolerance, then determining LDLs is not necessary.
- The threshold level of discomfort for a sound defines that sound's LDL. The LDL should reflect the level just below physical discomfort and not just fear that the sound is going to get too loud.
- Clinical LDL testing can be done using pure tones, speech stimuli **(UCL)**, and BBN. Using pure tones, LDLs can be obtained at **various audiometric frequencies (between 1 and 8 kHz)**, establishing the upper limit of the auditory dynamic range for each frequency tested.
- **Patients are instructed**, ''You will listen to different tones. Each tone will be made slightly louder in steps. Tell me when the loudness of the tone would be **OK for 3 seconds**, but would not be OK for more than 3 seconds.'' The objective is to identify the level for each frequency at which any further increase would cause discomfort.
- Because patients are often inconsistent when providing repeated LDLs within a test session, it is advisable to measure each LDL twice.

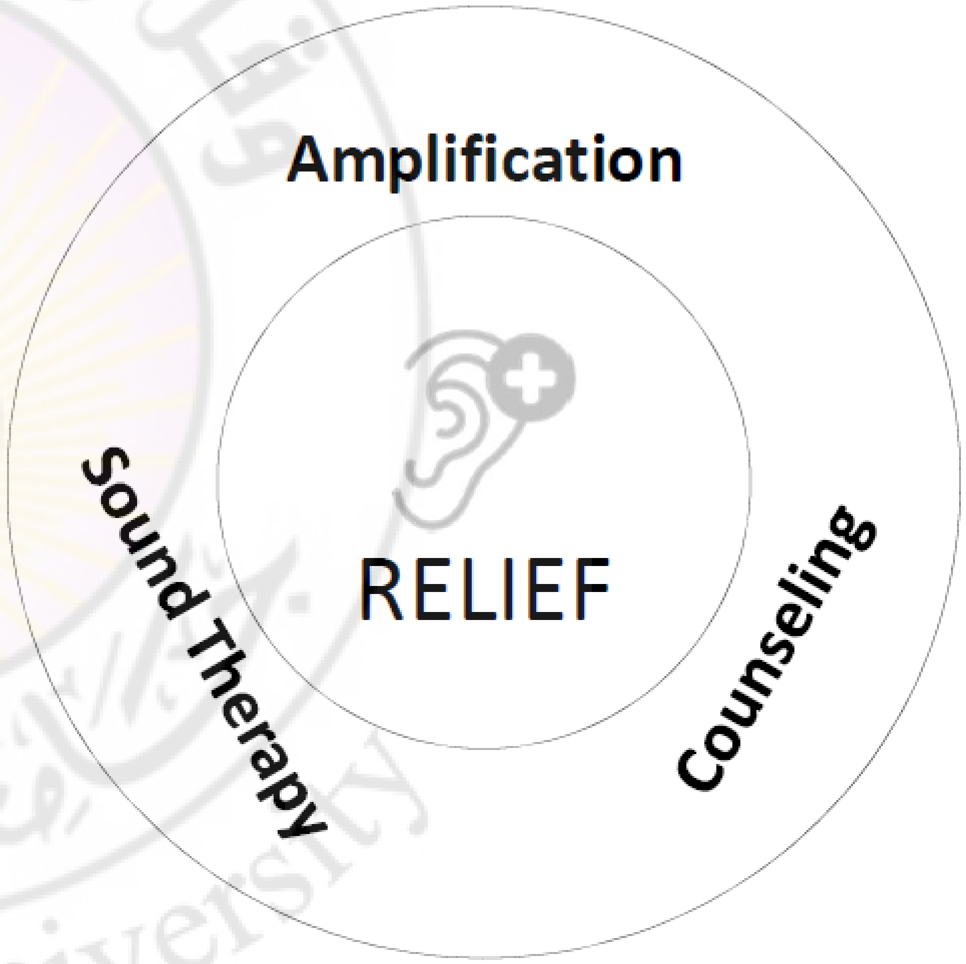


Screenshot from Madsen Astera2 Tinnitus Module

Tinnitus: Management

There is no cure, but it can be managed!





Never tell a patient there is nothing that can be done to help with their tinnitus.

There are options to help the patient with their tinnitus!

Counseling and Treatment

- Explain what tinnitus is and why it may be happening
- Discuss different options for treatment
- Create goals for treatment
  - Lessen impact of tinnitus on daily life

Hearing Technology

It can help reduce the awareness and disturbance and manage tinnitus symptoms

Sound Therapy

Tinnitus sound therapy uses a process known as **habituation** to retrain the way the brain interprets tinnitus.

myNoise

Oticon Tinnitus Sound

Relax Melodies

Resound Relief

Simply Noise

Starkey Relax

Whist Tinnitus Relief

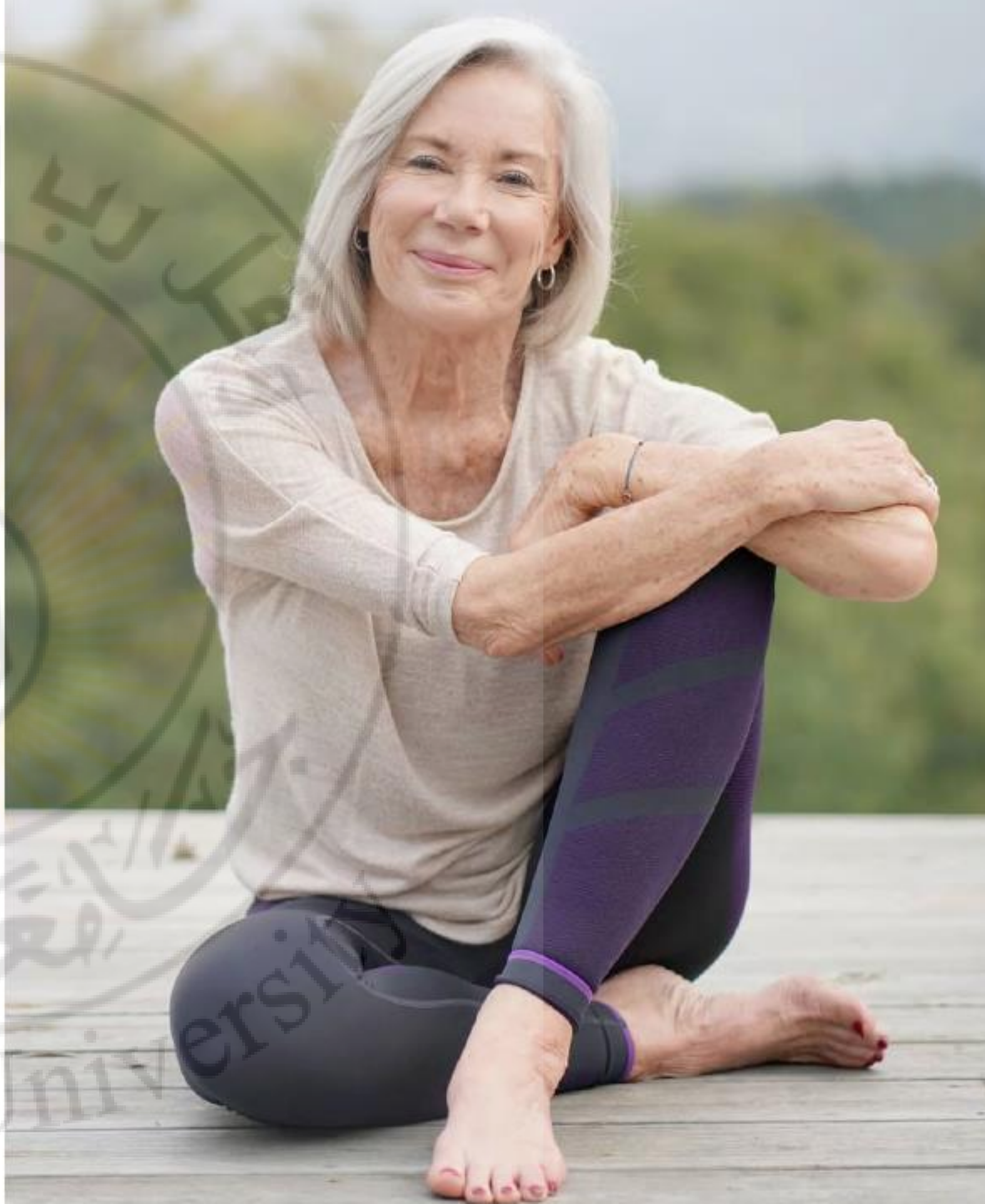
White Noise Lite

Lifestyle Changes

- Quit Smoking
- Diet Change
- Getting a better night's rest
- Relaxation
- Exercise

Relaxation/Meditation

- Relaxing
- Meditation
- Diet



Well-Known Protocols

- Tinnitus Retraining Therapy
  Dr. Pawell Jastreboff

- Progressive Tinnitus Management
  National Center for Rehabilitative Auditory Research

- Tinnitus Activities Treatment
  Dr. Richard Tyler at the University of Iowa

Support Groups

- In-person
- Virtual

Tinnitus Resources

American Tinnitus Association
www.ata.org

Tinnitus Research Initiative
www.tinnitusresearch.net

National Center for Rehabilitative Auditory Research (NCRAR)
www.ncrar.research.va.gov/Education/Documents/TinnitusDocuments

American Academy of Audiology
www.audiology.org

Tinnitus Retraining Therapy
www.tinnitus-pjj.com

University of Iowa Tinnitus & Hyperacusis Research
www.medicine.uiowa.edu/oto/research/tinnitus-and-hyperacusis

Questions?