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Pure Tone Audiometry
An overview

PRODUCT INSIGHTS

Among the wide range of hearing assessments, pure tone audiometry remains the most widely used and universally recognized method. Its simplicity, reliability, and standardized protocol make it an essential tool in every audiology practice.

WHAT IS THE HEARING THRESHOLD?

In audiology, the hearing threshold represents the minimum intensity of a sound that evokes an auditory response. More precisely, the audiometric threshold is defined as the lowest level at which a patient can detect a sound at least 50% of the time.

Pure tone audiometry determines this threshold across different frequencies using pure tones generated by the audiometer. Results are expressed in decibels (dB), but specifically in dB HL (Hearing Level) rather than dB SPL (Sound Pressure Level).

Unlike dB SPL, which reflects the physical intensity of sound, dB HL incorporates correction factors so that a person with normal hearing, tested under ideal conditions, will register a threshold of 0 dB HL at each frequency. These correction factors vary depending on the frequency and the type of transducer used, and are defined by international standards (EN ISO 389-1, 389-2, 389-3, 389-4, 389-5, and 389-7).

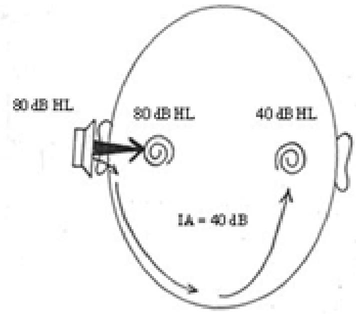
MASKING

When a test signal is presented to one ear, it can also stimulate the cochlea of the opposite ear through sound transmission via the skull bones. This phenomenon is known as cross-hearing. In situations where **cross-hearin**g may occur, a **masking signal** must be introduced.

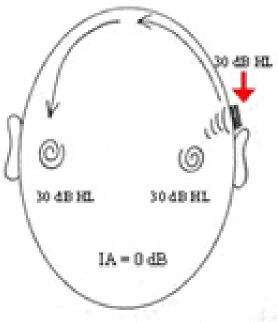
Masking works by raising the threshold of the **non-test ear** through the presentation of an appropriate masking signal — typically a narrowband noise (NBN) centered on the frequency being tested — at a controlled level. This ensures that the non-test ear does not detect the test stimulus, preventing false-positive responses that would compromise threshold accuracy.

The unit of measure for NBN is **dB EM (Effective Masking)**. Unlike dB HL, dB EM is defined so that, at a given frequency (e.g., 1 kHz), a masking noise set at 20 dB EM will make inaudible any tone of the same frequency presented at or below 20 dB HL.

A key concept in determining the appropriate masking strategy is **interaural attenuation (IA)** — the reduction in signal intensity as sound presented to one ear is transmitted by bone conduction to the opposite ear.



Interaural attenuation with AC



Interaural attenuation with BC

For air-conducted signals, the level of interaural attenuation (IA) varies with frequency, the type of transducer used (supra-aural headphones or insert earphones), and to some extent, individual patient differences.

For headphones, reference values are provided in the table below, adapted from:

Goldstein B.A., Newman C.W. (1994). *Clinical Masking: A Decision-Making Process*. In J. Katz (Ed.), *Handbook of Clinical Audiology*.

Frequency (Hz)	*125*	*250*	*500*	*1000*	*2000*	*4000*	*8000*
IA (dB)	35	40	40	40	45	50	50

With insert earphones, interaural attenuation (IA) is much higher (typically above 70 dB). By contrast, for bone-conducted signals, IA is close to 0 dB. This means it is never possible to be certain which cochlea is being stimulated by a bone-conduction tone, regardless of vibrator placement — cross-hearing is always a potential factor in bone conduction testing.

Once IA is understood, potential cases of cross-hearing can be identified using the following formula, which indicates when masking becomes necessary:

ACTE – IA ≥ BCNTE

where:

- **ACTE** = Air Conduction threshold for the Test Ear
- **IA** = Interaural Attenuation
- **BCNTE** = Bone Conduction threshold for the Non-Test (contralateral) Ear

Just as with test tones, masking noise itself can be transmitted via bone conduction to the test ear if its intensity is too high. When the masking noise not only masks the non-test ear but also affects the test ear, the effect is called **overmasking**.

The maximum masking intensity before overmasking occurs (Mmax) is defined as:

Mmax = IA + BCTE

Accordingly, overmasking occurs when the effective masking level presented to the non-test ear (EMLNTE) meets the following condition:

EMLNTE ≥ IA + BCTE + 5

AIR CONDUCTION AUDIOMETRY

When performing audiometry with air-conducted signals, the standard procedure is to use pure tones, either continuous or pulsed. The clinician must then decide whether masking is necessary and, if so, determine the appropriate masking level.

For reliable results, testing should always be carried out in a suitably quiet environment — ideally in a sound-treated booth. The maximum permissible ambient noise levels are defined in EN ISO 8253-1, which ensures that test conditions are consistent and dependable.

Once the patient has been fitted with headphones, the test is conducted according to the procedure outlined in EN ISO 8253-1.

1. <u>Instructions to the Patient</u>

Instruct the patient to press the response button (or raise a hand) whenever they hear a sound, and to release the button (or lower the hand) when the sound is no longer audible.

2. <u>Presentation and Interruption of Test Tones</u>

Each test tone should be presented for 1–2 seconds. When the patient responds, the interval between successive tones must vary, but should never be shorter than the duration of the tone itself.

3. Initial Familiarization

Before threshold determination, the patient must be familiarized with the task by presenting a signal at a level sufficient to elicit a clear response. This ensures the patient understands the procedure and can respond consistently.

A recommended familiarization method is:

1. Present a 1000 Hz tone at an easily audible level (e.g., 40 dB HL for a normal-hearing subject).
2. Decrease the tone level in 20 dB steps until no response occurs.
3. Increase the level in 10 dB steps until a response is obtained.
4. Present the tone again at the same level.

If responses are consistent, familiarization is complete. If not, repeat the procedure. After a second failed attempt, re-explain the instructions.

Note: In cases of profound hearing loss, these procedures may not be applicable.

4. Estimation of Hearing Threshold (Ascending Method)

- Begin testing with the ear the patient perceives as better.
- Test frequencies in this order: 1000, 2000, 4000, 8000, 500, 250 Hz (include half-octaves if needed).

Procedure:

1. Present the first test tone at 10 dB below the lowest response level observed during familiarization. If no response, increase in 5 dB steps until a response occurs.

2. After a response, lower the level by 10 dB steps until there is no response, then restart the ascending sequence. Continue until the patient responds at the same level three times across a maximum of five ascending runs.

o Short method: acceptable if at least two consistent responses occur at the same level across three ascending runs.

3. Move to the next frequency, starting at a level expected to be audible, and repeat.

4. Retest at 1000 Hz.

o If the second measurement is within 5 dB of the first, proceed with the other ear.

o If there is an improvement of ~10 dB or more, repeat the entire frequency sequence until results stabilize within a 5 dB difference.

5. Continue until testing is completed on both ears.

BONE CONDUCTION AUDIOMETRY

Bone conduction audiometry is essential for distinguishing between conductive and sensorineural hearing loss, but it always requires careful masking because interaural attenuation (IA) for bone conduction is close to 0 dB. As a result, the non-test ear must be masked at all levels to obtain accurate thresholds.

Follow the steps below to establish the threshold:

1. Position the bone vibrator on the patient's mastoid, as close as possible to the concha without touching it. Place the masking headphone over the non-test ear. The unused headphone should be positioned forward of the test ear, leaving the cavity exposed. Ensure that the headbands of the two transducers do not interfere with each other.

2. Begin testing with the ear the patient perceives as better, starting at 1000 Hz.

3. Establish the initial threshold without masking, using the shortened ascending method described previously.

o Note: this preliminary result cannot be considered a true bone-conduction threshold due to the possibility of an occlusion effect (see next section).

4. Activate the masking noise and determine the correct masking level — and thus the hearing threshold — using the Plateau method (described in the following section).

5. Test the remaining frequencies in the same sequence as for air-conduction audiometry. Continue

until both ears have been tested.

HOW MASKING IS APPLIED

Whenever cross-hearing is a concern, masking noise must be delivered to the non-test ear through headphones or dedicated insert earphones.

The most widely used method for determining the appropriate masking level is the Plateau Technique, first described by J.D. Hood in 1960. This involves gradually increasing the masking noise to the non-test ear until a plateau is reached — a range of masking levels across which the threshold of the test ear remains unchanged. Reaching this plateau indicates that undermasking (insufficient masking to prevent cross-hearing) and overmasking (masking that also affects the test ear) have both been avoided.

Steps of the Plateau Technique:

1. Determine the threshold of the test ear without masking.

2. Introduce masking noise at an initial level of 10 dB above the air conduction threshold of the non-test ear (for bone conduction, see note below). This starting level generally avoids overmasking.

3. Recheck the threshold of the test ear.

   o If the threshold is unchanged, increase the masking noise in 5 dB (or 10 dB) steps, checking the threshold each time.

   o If the threshold remains unchanged across three successive 5 dB increases (or two successive 10 dB increases), the plateau has been reached, and the masked threshold can be recorded.

   o If the threshold changes, undermasking has occurred and the procedure must be repeated starting from the new threshold.

Note on Bone Conduction:

When testing via bone conduction, the initial masking level must be adjusted for the occlusion effect (OE) caused by the headphone covering the non-test ear. The OE raises bone conduction thresholds in the low frequencies: by +15 dB at 250 Hz and 500 Hz, and by +10 dB at 1000 Hz. Therefore, the initial masking level should be:

- AC threshold of the non-test ear + 25 dB at 250 Hz and 500 Hz
- AC threshold of the non-test ear + 20 dB at 1000 Hz

UCL AUDIOMETRY

The UCL (Uncomfortable Loudness Level) test identifies the intensity at which sounds become intolerable for the patient. This measurement is essential for defining the upper limit of the patient's hearing range. Clinically, it is particularly valuable for:

- Hearing aid fitting, ensuring amplification remains within a comfortable dynamic range.
- Detecting recruitment, the abnormal rapid growth of loudness often associated with sensorineural hearing loss.

HF AUDIOMETRY

High-frequency (HF) audiometry extends threshold testing beyond the conventional range, allowing assessment of hearing between 8 kHz and 20 kHz (up to 16 kHz in free-field conditions).

Measuring thresholds in this region is especially useful for detecting early signs of hearing damage related to noise exposure or ototoxic drug treatments, as these conditions typically affect the higher frequencies before the lower ones.

HF testing can be conducted via air conduction using dedicated high-frequency transducers, or in free field.

From a clinical perspective, the procedure and controls are essentially the same as in standard pure tone audiometry, with the main difference being that the audiogram is extended to display the high-frequency range.

It is worth noting that the very highest test frequencies (18 kHz and 20 kHz) are available in air conduction only if enabled in the device settings. Since no international normative data exist for these frequencies, results are expressed in dB SPL rather than dB HL.

MULTIFREQUENCY AUDIOMETRY

Multifrequency audiometry extends pure tone testing by allowing threshold determination at intermediate points between the standard audiometric frequencies. This provides a more detailed frequency resolution compared to traditional audiometry and can be useful in specific diagnostic or research contexts.

Different audiometers on the market implement this function in different ways.

At Inventis, multifrequency testing is designed around the 11 standard frequencies of conventional audiometry (125 Hz – 8 kHz). For each central frequency, it is possible to explore additional frequencies both below and above, with the spacing defined in fractions of an octave (e.g., 1/3, 1/6, 1/12, or 1/24 octave). This approach ensures a resolution that is finer at lower frequencies and proportionally broader at higher ones.

Alternative systems may adopt a different logic, such as using fixed steps in Hz (for example, 10 Hz increments) to provide a uniform resolution across the entire spectrum. While this solution is more common in psychoacoustic research, the octave-based approach is generally favored in clinical practice, where it offers both efficiency and sufficient precision for routine diagnostics.

In addition, the test can typically be carried out with fine intensity steps (commonly 1 or 5 dB). Some configurations also include intermediate increments (e.g., 2 dB) to further refine threshold determination, although this is less frequently required in daily practice.

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