PURE TONE AUDIOMETRY

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Pure tone audiometry is the standard behavioral assessment of an individual's hearing. The results of pure tone audiometry are recorded on a chart or form called an audiogram. In most cases a pure tone audiogram is easy to obtain and provides information about peripheral hearing acuity across the frequencies used in speech. It allows for a quick view of how well, or how poorly, an individual can hear specific frequencies and for a comparison of one ear to the other. In the presence of a hearing loss, the pure tone audiogram often allows a clinician to make some inferences which, when viewed in conjunction with the patient's case history, can help lead to a diagnosis or determine the likely etiology of the hearing loss. The following is a summary of how a pure tone audiogram is obtained and interpreted.

PURE TONES

1. Frequency

A pure tone is a tone having a single specific frequency. The frequency of the tone is determined by the rate or speed at which the sound source vibrates. Frequency is measured in Hertz (Hz; named after German physicist Heinrich Hertz) or, less commonly, cycles per second (CPS). Hz and CPS are synonymous; thus a 500 Hz tone means that the transducer, or sound source, is vibrating 500 times per second. A 4000 Hz tone results from the transducer vibrating at a higher rate: 4000 times per second. The 4000 Hz tone has a *higher frequency* than the 500 Hz tone. The term "pitch" is often used interchangeably with frequency. While this is generally acceptable, "frequency" is a scientific term to describe a specific aspect of a signal, while "pitch" is a more subjective term to describe sound quality.

2. Intensity

Intensity is defined as the amount of energy transmitted per second over an area of one square meter (Speaks text). For our purposes, the intensity of the pure tone is the loudness of the tone. Again, as with "frequency vs. pitch" there is a difference between the objective "intensity" and subjective "loudness," but in terms of understanding the process of pure tone audiometry, it is acceptable to think of intensity as synonymous with loudness.

Sound intensity is measured in decibels (dB). There are several dB scales used for different applications; most common in audiometry are the dB HL (hearing level) scale, the dB SPL (sound pressure level) scale, and the dB SL (sensation level) scale. By far the most common dB scale used in audiology, and the standard scale used on a pure tone audiogram, is the dB HL scale. This scale is referenced to the average hearing of young adults. “0 dB HL” means the average threshold of audibility of these young, normally-hearing adults. This is different than “0 dB SPL”, which means that no sound pressure is present. Sounds at very low pressure levels are inaudible to human ears; thus, for example, a 5 dB SPL sound would be inaudible to even the most acute human hearing, while a 5 dB HL sound would be audible, though very soft, to a person with very good hearing. In general, 0 dB HL is equal to about 10 to 15 dB SPL; this varies across different frequencies. Finally, the dB SL scale is referenced to an individual’s threshold of audibility for the signal in question. If a person’s threshold for a 1000 Hz pure tone is 20 dB HL and a 1000 Hz tone of 60 dB HL is presented, that tone is termed as 40 dB SL, as it is 40 dB louder than the individual’s threshold. The dB SL scale is infrequently used for pure tone audiometry but is somewhat more common in speech audiometry.

The use of different dB scales can obviously lead to some confusion. There are in fact additional dB scales not described above; the others have acoustical engineering applications and are unlikely to be used or referenced for audiometric testing. It is important to always note which dB scale is being used (i.e. HL, SL, SPL). Again, the most common scale used in audiometric testing is the dB HL scale, and it is this scale which is represented on the standard pure tone audiogram. Those trained to measure signals in dB are generally very careful to specify which dB scale they are referencing. If, in a narrative report, the dB scale is not specified, the information should be viewed cautiously.

PURE TONE AUDIOMETRY

Pure tone audiometry is the use of pure tones to assess an individual’s hearing. The results of this testing are plotted on the audiogram. Pure tones are generated by an audiometer and presented to the patient via headphones or, in some cases, through loudspeakers. The audiometer allows the audiologist to select the type of stimulus (in this case pure tones), the frequency of the tones, the intensity of the tones, the transducer through which the stimuli are presented, and a number of other test parameters. Transducers include supra-aural air conduction earphones, circumaural air conduction earphones, insert air conduction earphones, bone conduction headphone, and loudspeakers (known as “sound field”). The standard transducer for pure tone audiometry is the supra-aural air conduction earphones (TDH-39 or TDH-50). Anytime any degree of hearing loss is measured through these earphones, bone conduction pure tone audiometry must be performed.

Air conduction audiometry

An air conducted signal is defined as a sound wave traveling through air; this is the means by which humans typically hear most sounds. Air conduction audiometric thresholds are reflective of a person’s hearing for air conducted sounds; that is, most of what we hear on a daily basis. This mode of signal presentation assesses the entire auditory system: the outer ear, ear canal, tympanic membrane, middle ear system, cochlea, auditory nerve, auditory brainstem, and auditory cortex. A deficit in one or more of these areas may result in a measurable hearing loss when testing via air conduction. Thus, when a hearing loss is measured during air conduction testing, further tests become necessary to determine which part(s) of the auditory system are dysfunctional.

The general procedure for air conduction pure tone audiometry is as follows:

The patient is instructed to listen carefully for a beeping sound (pure tone) and when he or she hears a sound, even if it is very soft, to raise his or her hand (in some test settings the patient is given a button to push in lieu of hand raising). The earphones are placed on the ears and checked for secure and proper fit. The audiologist then begins to present pure tones of one frequency to the patient, initially at an intensity level that it is assumed they can hear quite well. After the patient demonstrates a good understanding of the task, the intensity (loudness) of the tone is decreased in 10 to 15 dB steps and the tone is presented again. This is continued, with tones being presented for one to two seconds, until the patient no longer responds. The intensity is then raised in 5 dB steps until the patient responds, decreased again and increased again in 5 dB steps until the patient responds. Thus, the patient will have responded three times at this lowest audible intensity: once while the intensity was being decreased, twice while it was being increased. This lowest audible intensity is defined as the patient's threshold for the particular frequency and is marked as such on the audiogram (see "audiometric symbols"). This method is described as the "modified Hughson-Westlake ascending-descending paradigm" (Katz text, pg. 101). This routine is repeated for all test frequencies in one ear, then again in the other ear. This procedure will establish an air conduction pure tone threshold curve for each ear. If there is any degree of hearing loss measured at any frequency in either ear, bone conduction pure tone testing must be performed. In some cases, based on signs or symptoms, bone conduction testing will be performed even with normal air conduction thresholds.

Bone conduction audiometry

Bone conduction pure tone testing stimulates the cochlea directly, bypassing the outer and middle ear. This type of testing is used to determine whether a hearing loss measured via air conduction is reflective of a cochlear/neural deficit or an outer or middle ear dysfunction. Ideally, an outer ear problem would be visualized using otoscopy, so bone conduction is primarily used to distinguish between middle ear- and inner ear-related hearing losses. If bone conduction pure tone thresholds agree with air conduction thresholds, the loss is determined to be related to the cochlea or higher neural processes and is termed "sensorineural." If, on the other hand, bone conduction thresholds are better than air conduction thresholds, a conductive component is present: the cochlea, when stimulated directly, responds at lower intensities (i.e."better") than when it is stimulated via the outer and middle ear, meaning something in the outer or middle ear is reducing the sound intensity that is reaching the cochlea. A difference between air conduction and bone conduction thresholds is referred to as an "air-bone gap." If bone conduction thresholds are normal in the presence of abnormal air conduction thresholds, this is termed a "conductive" hearing loss. If bone conduction thresholds indicate a hearing loss but one which is less severe than is indicated by air conduction thresholds, the loss is termed a “mixed” hearing loss: there is both a sensorineural component and a conductive component to a mixed hearing loss.

Bone conduction pure tone audiometry is performed using the same modified Hughson-Westlake method as in air conduction audiometry but the tones are presented via a bone conduction headset. This is comprised of a bone oscillator affixed to a metal band which can be worn over the head in a similar fashion as standard headphones. The bone oscillator is typically placed on the mastoid process or, in some cases, in the middle of the forehead.

Because sound waves are propagated much more quickly and efficiently through a solid (such as bone) than through a gas (such as air), the presentation of a bone-conducted signal to any point on the head will stimulate the ear in which cochlear hearing is better. Thus, if the bone oscillator is placed on the left mastoid but the patient has better cochlear hearing in the right ear, the signal will be heard in the right ear. This phenomenon is termed “crossover” or, conversely, there is no “inter-aural attenuation.” If bone conduction testing is to be performed and there is a significant difference in hearing between the ears, it is necessary to use a masking noise in the non-test ear. A brief overview of masking follows.

Clincial Masking

It is obviously important to be sure that a signal presented to the test ear (the ear which is desired to be tested) is perceived by the test ear and that that perception results in the behavioral response (hand raise). At certain intensity levels, the signal presented to the test ear will cross over and be heard in the non-test ear. The inter-aural attenuation rate, or the intensity difference at which a sound will be heard in the non-test ear, is approximately 40 dB for air conduction signals presented through circumaural earphones, approximately 65 dB for air conduction signals presented through insert earphones, and 0 dB for bone conduction signals (Katz text, pg 117-128).   Thus, if there is asymmetry between the ears which exceeds these levels, masking must be presented to the non-test ear to assure that the behavioral responses are reflective of hearing in the test ear.

Most commonly, the masking noise used for pure tone audiometry is narrow-band noise; that is, a broad-band white noise passed through an electronic filter so it has a narrow frequency band response, generally the same frequency as the pure tone being presented to the test ear. This masking signal is presented via air conduction, either circumaural phones or insert phones, to the non-test ear.

Determining the specific intensity level at which to present the masking noise represents one of the more technically challenging areas of performing pure tone audiometric testing. The intensity level must be sufficient to mask the test signal in the non-test ear but not so intense that it effects the perception of the signal in the test ear. This masking level will be dependent upon a number of variables including the means of transduction of the test signal (i.e. air conduction or bone conduction); the air conduction thresholds of the test and non-test ears; and the bone conduction threshold of the better ear.

More specific information on clinical masking is beyond the purview of this writing. As a general rule, masking needs to be applied anytime the level of interaural attenuation for a particular transducer is exceeded: 40 dB for circumaural earphones, 65 dB for insert earphones, or 0 dB (that is, *any degree of asymmetry*) for bone conduction headphones.

Soundfield Audiometric Testing

In some cases, particularly with infants and young children or with some cognitively delayed adult individuals, the use of earphones is not possible, generally because a patient will not tolerate the headphones for any length of time. As with many behavioral tests of children, the window of opportunity for obtaining information is very narrow, and forcing earphones upon a child often closes this window very rapidly. In these cases, the stimuli are presented through loudspeakers and the testing is described as being performed "in (the) soundfield." It is important to recognize that soundfield audiometric testing is *not ear-specific*. That is, thresholds obtained by presenting the stimulus via loudspeakers will be heard by the better-hearing ear, should one ear hear better than the other. For example, an individual may have normal hearing in one ear and a mild to moderate hearing loss in the other ear. When tested in soundfield this individual will hear and respond to pure tones presented at 20 dB HL or lower. A unilateral hearing loss *cannot be assessed using soundfield testing.* While this is a significant limitation of soundfield testing, it is viewed as an acceptable compromise in the case of a patient who will not wear earphones. In other words, information about one ear is better than no information.

Visual Reinforcement Audiometry

Visual reinforcement audiometry (VRA) or conditioned operant response (COR) audiometry is another audiometric method used with special populations such as children or cognitively challenged individuals. In these cases, a "raise your hand when you hear the beep" response cannot be reliably elicited. Rather, a visual reinforcement is initially coupled with the auditory stimulus. This visual reinforcement (VR) is generally a toy housed within a smoked glass box located at 90 degrees to the right and the left of the patient. This toy will usually light up and move and make some noise itself (the classic example is the monkey banging cymbals together) and is controlled by the tester. When the stimulus tone is initially presented (either via earphone or via loudspeaker), the VR is simultaneously activated. Over two or three trials, the patient will ideally begin to associate the sound with the light-up toy. The stimulus is then presented by itself and the VR is activated only when the patient turns his/her head to look for the toy. Thus, the head-turn becomes the response indicating that the stimulus sound was heard. This test method usually requires that the patient be distracted with toys or similar stimuli between stimuli presentation so that they don't simply stare at the smoked glass box waiting for it to light up. In some clinics, a second tester may sit in the test area with the patient, facing the patient, using toys or gestures to keep the patient's attention at mid-line.

PURE TONE AUDIOGRAM

An audiogram is a graphic representation of an individual's hearing. Frequency, measured in Hertz (Hz), is plotted on the abscissa, generally from 250 Hz (0.25 kHz) up to 8000 Hz (8 kHz). The audiogram will represent each frequency octave starting at 250 Hz. An octave is a doubling of frequency, so the standard audiogram will include 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. In many cases, especially when a large difference is measured between two octave frequencies, the inter-octaves will also be tested, including 750 Hz, 1500 Hz, 3000 Hz, and 6000 Hz.

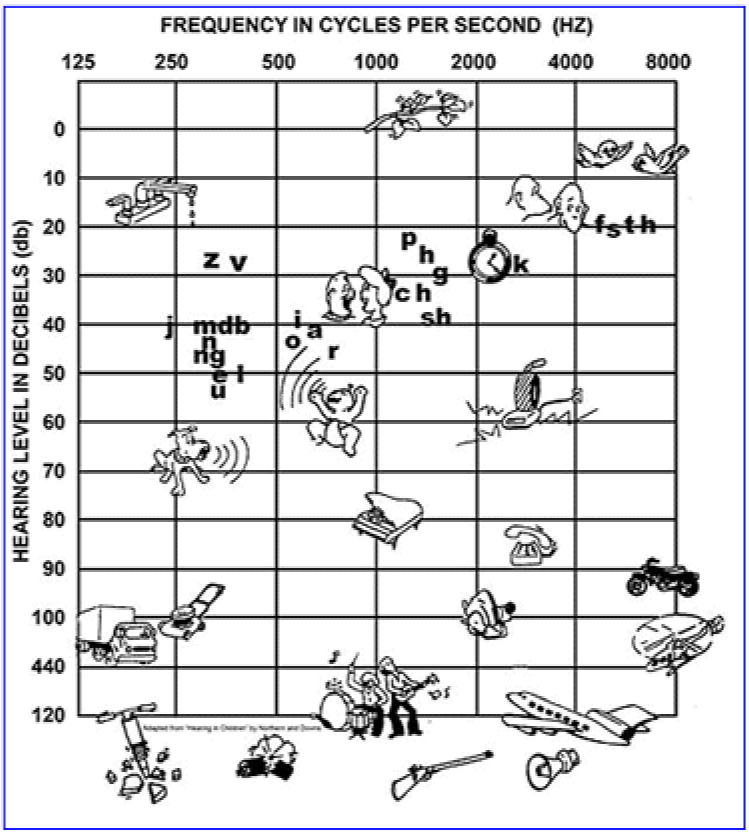

Figure 1: This is an audiogram with some familiar environmental sounds pictured. A clinical audiogram would not have the cartoons but would have similar representation of frequency (in HZ) and intensity (in dB).

On the ordinate of the audiogram is the intensity level, plotted in decibels hearing level (dB HL). Audiograms generally are arranged with lower intensities represented at the top and higher intensities represented at the bottom, increasing in 5 dB steps. Audiograms usually represent a range from -10 dB HL to 100 or 120 dB HL. Normal hearing is considered to be 20 dB HL or better, mild hearing loss from 20 to 40 dB HL, moderate hearing loss from 40 to 60 dB HL, severe hearing loss from 60 to 80 dB HL, and profound hearing loss at 80 dB HL or worse. Very often an individual's threshold curve will transcend two or more of these intensity regions and would be termed, for example, a "mild to severe (sensorineural, conductive, or mixed) hearing loss."

Audiometric Symbols

See Figure 1 (need to find a "figure 1," probably a YHB audiogram scanned)

When a pure tone threshold is determined, the threshold is recorded on the audiogram using a variety of symbols. These symbols are generally universal, but most audiograms have a key or legend which should be referenced if there is any confusion. The symbol is placed on the audiogram coordinate (frequency and intensity) which corresponds with the measured threshold.

Unmasked air conduction thresholds are represented as an "O" for the right ear and an "X" for the left ear.

Masked air conduction thresholds are represented as a triangle for the right ear and a square for the left ear.

Unmasked bone conduction thresholds are represented as a "<" for the right ear and a ">" for the left ear.

Masked bone conduction thresholds are represented as a "[" for the right ear and a "]" for the left ear.

If no threshold can be obtained at the limits of the audiometer (90 to 120 dB HL, depending upon the stimulus frequency and the transducer) for a particular test frequency (as in the case of profound hearing loss at that frequency), the above symbols are used with an arrow pointing downwards from the symbol.

A threshold obtained in soundfield is represented by an "S"; this is not an ear-specific finding, as outlined above.

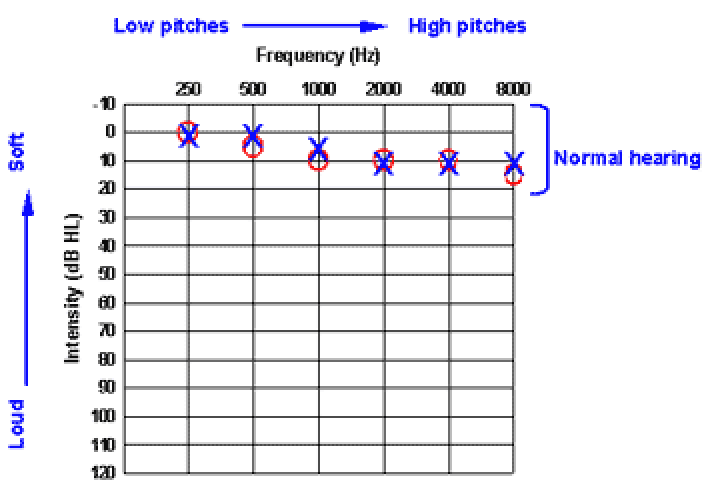

Figure 2: A clinical audiogram with symbols indicating a patient with normal hearing in both ears

CONCLUSIONS

Pure tone audiometric testing provides an excellent overview of an individual's ability to hear and respond to sounds. The pure tone audiogram is widely accepted as the gold standard assessment of peripheral auditory function. Though on its face pure tone audiometry is easy to perform, as reviewed above there are many potential challenges to obtaining reliable pure tone thresholds. Audiometric screening can be performed by most anyone with an understanding of the basic principles outlined above; a comprehensive audiometric evaluation needs to be performed by an audiologist with training and skill with the nuances only alluded to in the preceding text. Additionally, pure tone thresholds reflect an individual's ability to hear "beeping" sounds. Clearly, the ability to hear *and comprehend* complex sounds, such as speech needs to be more specifically tested. A review of speech audiometry can be found in the accompanying narrative.