T. Audiology

Our focus in this text started with physics. This led us into many engineering applications in electronics. After looking at the technological developments in sound reproduction and electronic synthesizers, we turned to biology. Then we examined the psychology of perception. This chapter takes us into an area related to medicine.

Audiograms

Audiograms are medical records of an ear's ability to hear sound. The study of hearing loss is called *audiology*. It is a fairly recent field of study. It originated after World War II to assess the hearing losses of war veterans. The government provides disability payments for veterans that suffer injuries, many of which severely curtail employment opportunities. The coordinated effort to study the science of hearing loss led to the use of the word audiology in 1946.

Table T-1 lists the ranges for human hearing in terms of sound level and pitch. As we have studied, these features rely mainly on the amplitude and frequency of the sound respectively. Since the timbre is a result of overtone frequencies, testing amplitude (sound level) and frequency for sine waves suffices.

Table T-1. Hearing Ranges: Sound Level and Frequency.

Characteristic	Range	Typical Problem Regions
Sound Level (β)	$0 \leq \beta \leq$ "140 dB"	Outer and Middle Ear
Frequency (f)	20 Hz $\leq f \leq$ 20,000 Hz	Inner Ear

Quotations appear with 140 dB in Table T-1 because this limit is not relevant in testing. You are tested for the lower limit. If you can hear levels near 0 dB, you can hear louder sounds. With frequency, things are different. The different frequencies need to be tested.

Hearing impairment can result from problems in each of the three regions of the ear. Problems in the outer and middle ear tend to affect all frequencies. There can be blockage in the ear canal or damage to the bones in the middle ear. Problems in the inner ear can be selective, effecting some frequencies and not others. Perhaps only one region along the basilar membrane is not functioning properly. One suffers loss in hearing those frequencies corresponding to the problem area. The result is that some frequencies are not heard unless they are loud. If an appreciable percentage of the basilar membrane is not working properly, sounds lose clarity. Doctors can remove obstructions such as wax in the outer ear. Operations can often repair the middle ear. However, difficulties in the inner ear are hard to correct. Hearing aids that amplify everything do not really help.

Data from testing frequency for hearing thresholds can be easily plotted on a two-dimensional graph. One axis is chosen for frequency, the horizontal. The other axis, the vertical, is chosen for the sound level of the hearing threshold. See Fig. T-1 for a grid ready for data. The frequencies tested do not include the entire range of human hearing. The focus is on frequencies present in speech. Speech falls mostly between 250 Hz and 4000 Hz. The intent of hearing-loss assessment is to determine whether an individual can function in society without a "hearing challenge." Therefore typical testing is restricted to the frequency range 125 Hz to 8000 Hz (See Fig. T-1).

The limits of the usual hearing test correspond to an extra octave on each side of the range for most speech. Hearing loss in this range can present one with difficulties in communication. The audiogram is a diagnostic record for this range. If you can pass the test everywhere up to 8000 Hz, you pass. Of course you may have a serious loss at 10,000 Hz and beyond. But for practical purposes you can understand speech and you are judged to be satisfactory. This was the government's original concern in measuring the hearing of veterans. If you are a veteran, the question is can you understand speech? Communication is crucial for employment. The government doesn't care if you can't fully appreciate the richness of the high notes in the Sibelius *Violin Concerto* because you miss out on some of the overtones.

The audiogram is a card on which the response measurements are recorded in a grid similar to Fig. T-1. The frequencies jump by octaves. Pure tones (sine waves) are presented to the ear. The softest sound level heard at each of the main frequencies is noted. Since the ear is not uniformly sensitive to all frequencies, bass tones are boosted to compensate. Normal thresholds are then 0 dB for each of the tested frequencies.

Fig. T-1. Audiogram Grid.

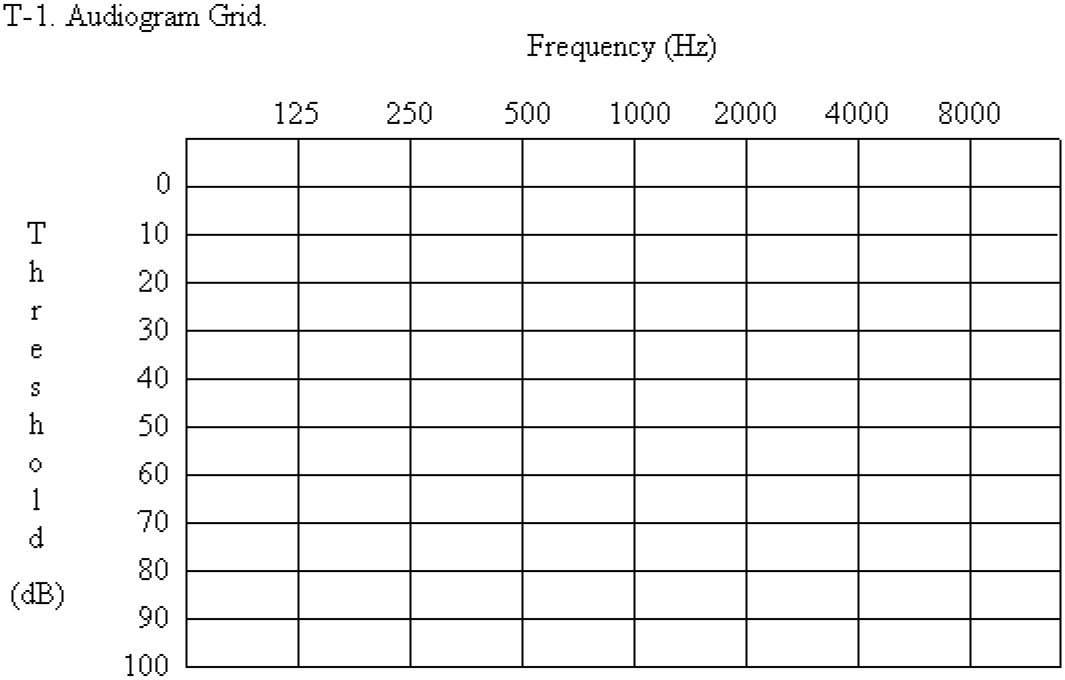
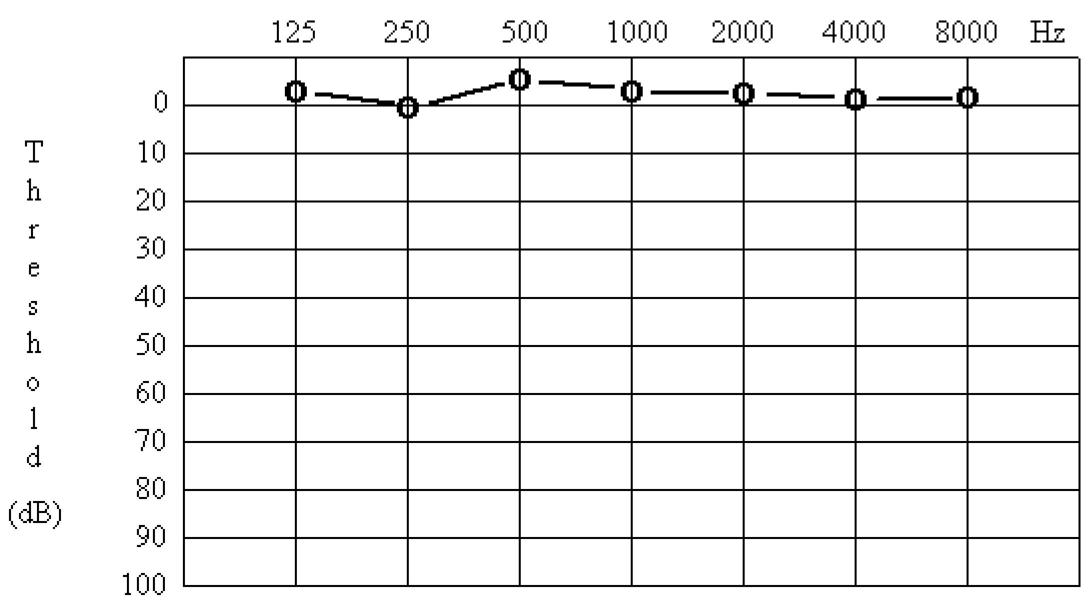


Fig. T-2 depicts an audiogram for a normal ear. The measured thresholds are connected by straight lines. The ear hears as low as 0 dB for the frequencies across the spectrum. In fact, this particular ear exceeds the normal a little. Younger people may be able to score better than 0 dB for many of the frequencies. The zero reference is a statistical average. Some people have better hearing than the average. A "–3 dB" means that an ear can hear a sound softer than the drop of a pin on a soft cushion. The minus 3 signifies half the intensity. We might approximate this by dropping half a pin or a smaller pin. A "–5 dB" is even better.

This is analogous to some people having better vision than normal. The normal acuity is 20/20. You see at 20 ft what you should see at 20 feet. But some people can see at 20 ft what normal people see at 15 ft. They are better. Their vision is given the rating 20/15. A few people can see at 20 ft what normal folks see at 10 ft. Their vision is 20/10. As an example, it is said that baseball great Babe Ruth could read a far license plate when his friends couldn't determine the color of the plate.

Hearing thresholds may be a little better than 0 dB or a little worse. As long as the threshold is near 0 dB, we consider the response normal. Some consider 20/25 vision normal. These people need to be at 20 ft in order to read letters they should be able to discern at 25 ft. However, this is very close to normal. A vision of 20/30 may still be good enough to pass a driver's test without needing glasses. Similarly, someone's typical hearing thresholds may be +5 dB for some frequencies; other people may score around –5 dB. We might say that at +5 dB one has a slight loss just as we might say that a person with vision of 20/25 or 20/30 has a slight visual-acuity impairment (without glasses). It is easy to correct for the common forms of visual impairment by prescribing glasses since the difficulty lies with all frequencies of light, the image. It is more difficult with the ear since some frequencies may be fine, others not.

Fig. T-2. Audiogram of a Normal Ear.



Hearing Loss

Fig. T-3 below shows some degrees of hearing losses. A slight loss indicates that sound levels need to be louder than 0 dB to be heard, but not greater than 10 dB. For example, a 5-dB threshold indicates a slight loss. A mild loss requires sound levels to be near 15 dB to be heard. A threshold near 25 dB denotes a moderate loss.

Fig. T-3. Degrees of Hearing Loss.

A threshold of 30 dB across the audio spectrum indicates that any sounds below 30 dB cannot be heard. This means that an individual with a 30-dB threshold cannot hear at all the drop of a pin on a soft cushion (0 dB), breathing (10 dB), a gentle breeze (20 dB), or a faint whisper (a little less than 30 dB). The whisper at 30 dB is barely audible. The hearer is not able to understand the whispered message. It is too faint to make out phrases and sentences.

Table T-2 indicates how a person with a 30-dB threshold (across all frequencies) hears. We simply call 30 dB our new threshold. The hard-of-hearing person hears 30 dB as the average person hears 0 dB. The hard-of-hearing person hears 40 dB as 10 dB and so on.

The descriptions for slight, mild, and moderate losses refer to the general population. In settings where there are severe hard-of-hearing individuals, all of the above impairments are considered virtually normal. Schools for the deaf and hard-of-hearing can have individuals with hearing thresholds of 100 dB.

Table. T-2. Hearer's Perceptions with 30-dB Threshold Compared to Normal Perceptions.

dB	Normal Perception	Hearer with 30-dB Threshold
0	Drop of a Pin on a Soft Cushion	Not Heard.
10	Breathing	Not Heard
20	Gentle Breeze	Not Heard
30	Whisper	Drop of a Pin on a Soft Cushion
40	Quiet Office	Heard as Breathing
60	Conversation	Heard as a Whisper
90	Nearby Subway Train	Heard as Conversation
120	Rock Band	Heard as Nearby Subway Train

Fig. T-4 gives a rough sketch of a possible audiogram for Beethoven as he was going deaf during his adult years. Beethoven turned 30 in 1800 and around this time realized he was going deaf. Beethoven's uniformly high threshold (low line on audiogram) could have been due to the onset of a middle-ear problem. Middle-ear disorders can often be corrected today through drugs or surgery. Beethoven’s case is still being debated today. Eventually, Beethoven's audiogram dropped lower and lower. His genius allowed him to continue composing music after he was profoundly deaf! For example, he composed his famous *Ninth Symphony* afterwards. He completed this monumental work in 1824. The last movement incorporates a choir. Here Beethoven sets Schiller's *Ode to Joy* to music.

Fig. T-4. Hypothetical Audiogram for Beethoven in His 30s (early 1800s).

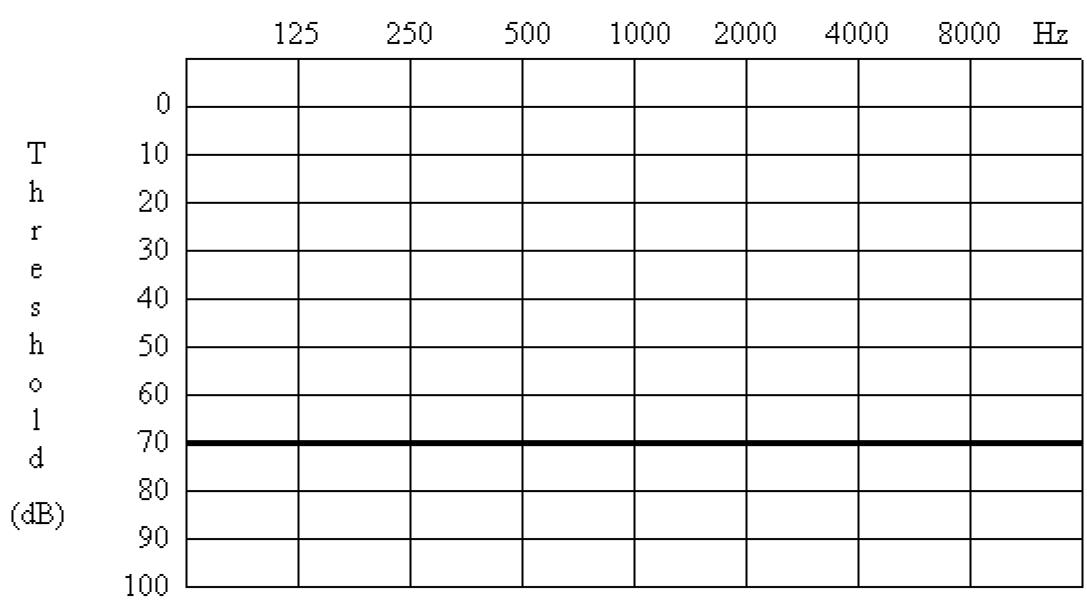


Fig. T-5 illustrates the audiogram for a rock musician. Rock music is usually played at sound levels harmful to the ear. Rock music is often 120 dB. On stage it can be 140 dB. We can actually feel inside us sound levels at about 120 dB and above. The left ear ("X" in Fig. T-5) of our rock musician is worse than the right ear ("O") because of the proximity of the speaker to that ear during practice and performance in the particular band. Loss typically begins at the high frequencies. A relevant factor may be the fact that the hair cilia responding to high frequencies are close to the oval window, the entry point for the sound. We also know from the Fletcher-Munson curves that the ear is more sensitive at the high-frequency end.

Fig. T-5. Audiogram of Rock Musician (Left Ear "X", Right Ear "O").

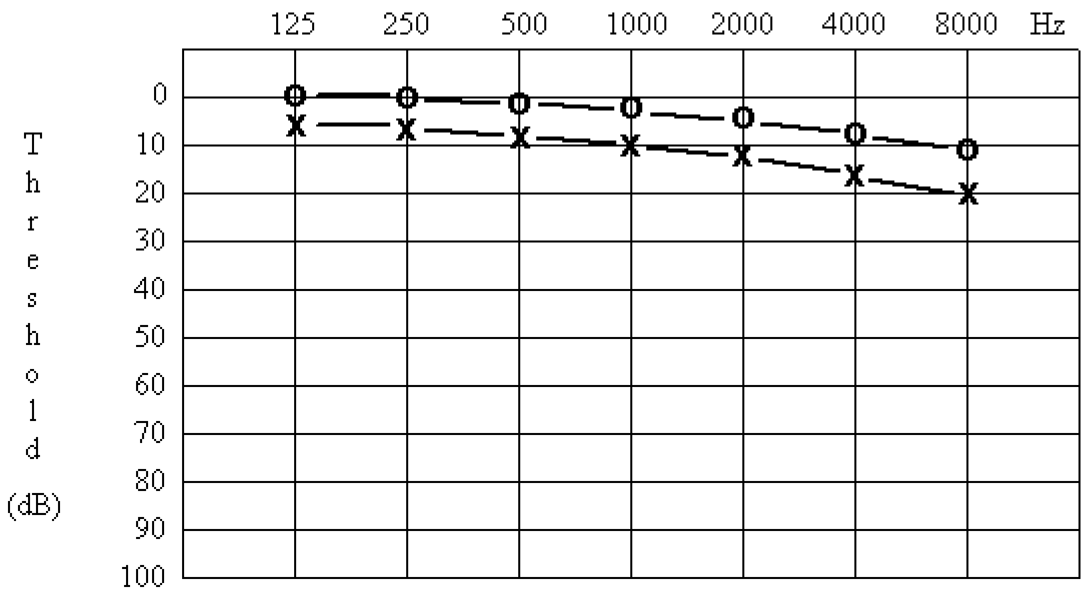
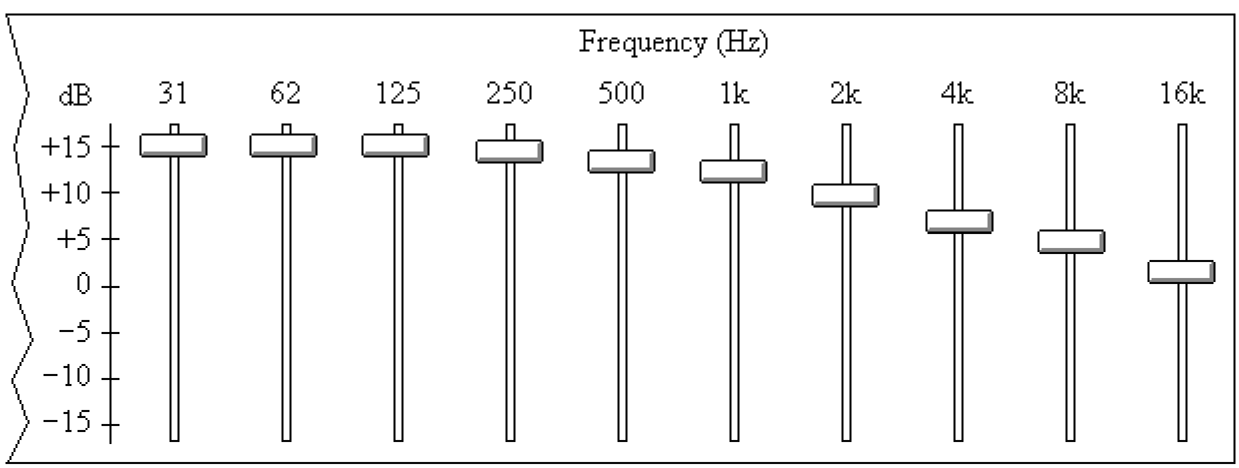


Fig. T-6. Using a Frequency Equalizer to Simulate Hearing Loss.



Cutaway of Equalizer (Right Channel).

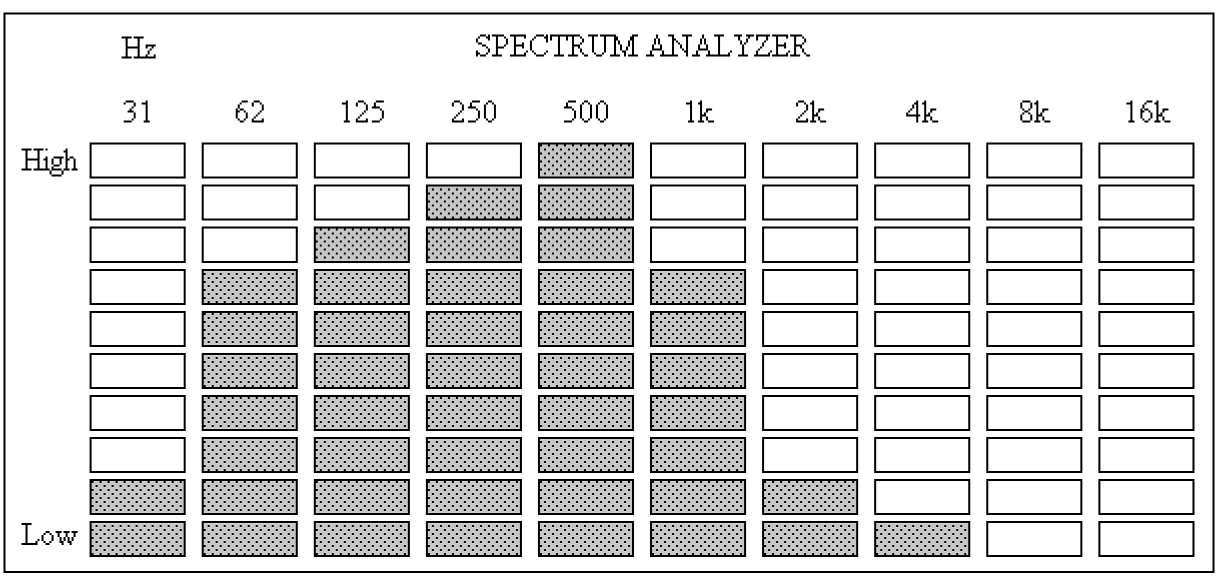
In Fig. T-6 we employ a frequency equalizer to simulate hearing loss. We studied equalizers in an earlier chapter. The equalizer is a signal-processing unit that consists of an array of active filters. The equalizer in Fig. T-6 is a 10-band frequency equalizer. The cutaway illustrates the right channel. Rather than use the equalizer to "equalize" frequencies for our specific listening environment, we use the processing unit to "unequalize" frequencies in this example.

The frequency equalizer in Fig. T-6 allows for boosting frequency bands up to +15 dB or filtering them down to –15 dB. We can set all the bands up to +15 dB. We then lower the master volume control to compensate. Now we have the choice of knocking any frequency band down to –15 dB, which is 30 dB lower than the +15 setting. Therefore, we can achieve up to a 30-dB loss. We arrange the slider controls to imitate the audiogram of our rock musician. This simulates the hearing loss.

The better frequency equalizers like our 10-band equalizer in Fig. T-6 have spectrum analyzer displays (see Fig. T-7). The spectrum analyzer is usually located in the center of the front panel. It displays with rapidly moving lights the current frequency distribution of the sound we are hearing. The sound typically changes constantly as we hear speech or music. The analyzer displays the amount we hear in each frequency band from moment to moment. A snapshot of the spectrum analyzer display appears in Fig. T-7. Note the absence of activity at the higher-frequency end of the spectrum. This is a result of our setting of the slider bars in Fig. T-6. The analyzer in Fig. T-7 reflects what a person with a hearing loss hears.

With specialized laboratory filters we can simulate more severe hearing losses. Our commercial stereo equalizer gives us control of 30 dB for the frequency bands. This is more than satisfactory for the usual use of an equalizer - to make the adjustments necessary in accommodating room acoustics.

Fig. T-7. Spectrum Anaylzer on Frequency Equalizer.



Damage to the inner ear is usually permanent. Once the hair cilia are destroyed, they cannot recover. One should always take precautions when around nearby loud sound levels. It is advisable to wear ear protection when working with power equipment such as weed eaters, lawn mowers, and power saws. You should not expose yourself to sound levels near 80 dB and above for long periods of time. Note that a rock band playing at 120 dB is 10,000 times more intense in terms of energy than an 80-dB sound. Or to look at it another way, a rock band cranking away at 120 dB is equivalent to ten thousand other bands playing at 80 dB. How do we know this from the way the decibel scale works? Before we conclude this chapter we discuss two more common forms of hearing loss.

1. Presbycusis (prez-bee-KUE-sis). *Presbycusis* is the natural hearing loss at high frequencies that accompanies age. A child may be able to hear 20,000 Hz and beyond. The young adult at age 20 (assuming no loss due to exposure to loud sounds) may hear 18,000 Hz and beyond. Then after a decade, this may drop to 15,000 Hz. In later years, it may dip to 12,000 Hz or 10,000 Hz. However, all may still pass the hearing test since that examines only to 8,000 Hz.

It is interesting to conjecture how much of our normal hearing loss is due to aging versus our exposure to higher levels of noise that accompany an industrialized society. One study found that older people at age 70 in a third-world country had hearing as good as the average 30-year-old in an industrialized society. This study suggests the importance of factors other than age.

2. Tinnitus (tin-NIGH-tis). *Tinnitus* is an internal perception of sound when there is no sound present at all. It is sometimes referred to as a ringing or a buzzing tone. Tinnitus can be caused by infections or medication. However, the most serious form is due to damaged hair cilia in a narrow frequency band. A sudden loud exposure such as a gunshot can destroy some hair cilia and damage neighboring ones that partially recover. Fig. T-8 shows an audiogram for localized destruction of hair cilia.

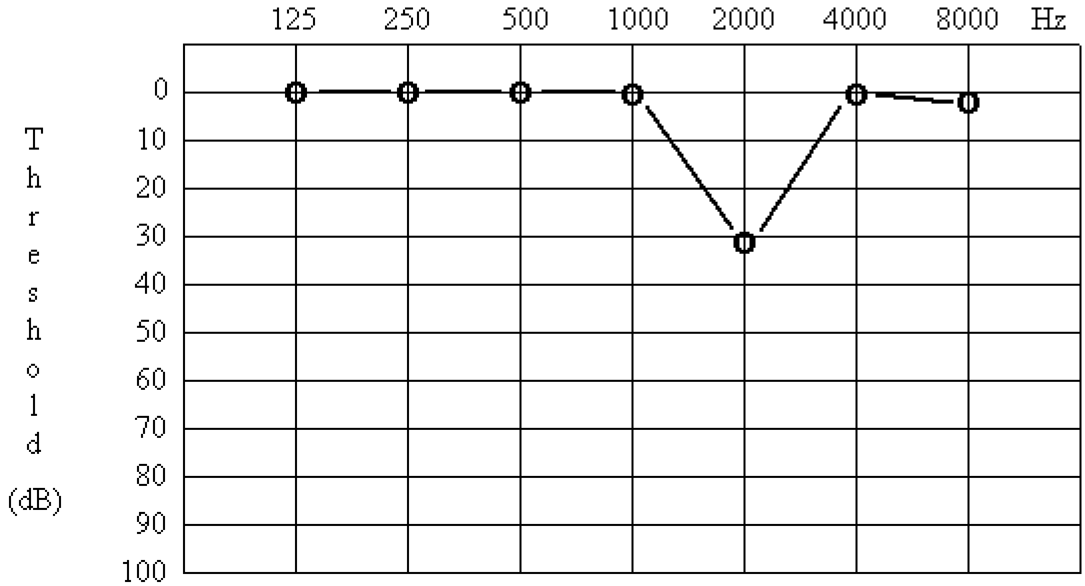
The ear described in Fig. T-8 tested normal for all frequencies except 2000 Hz. There is damage in this vicinity. The strange thing about the ear-brain system is that a person with the audiogram in Fig. T-8 may permanently hear a tone or ringing of frequencies in this region. The ear can't detect these frequencies. Yet there is an ever-present internal sensation of these. When it is quiet externally, the ringing is most noticed. These individuals have to learn to bear with this sound. They also have to learn to sleep with it.

The dip in the audiogram of Fig. T-8 is called the *acoustic trauma notch*. Perhaps the ear hears an explosion at close range. The sound is intense. Most of the hair cilia recover but a small group does not. They are permanently out of commission. The audiogram then shows the acoustic trauma notch. The individual may hear a ringing with a pitch or pitches corresponding to the damaged hair cilia along the basilar membrane.

3. Conductive Loss. When an individual has a *conductive hearing loss*, the audiogram shows a problem across the entire frequency spectrum like the audiogram in Fig. T-4.

4. Sensory Neural. A *sensory neural hearing loss* is one that involves damage to hair cells in the inner ear. This damage can involve a region of the hair cells. In the frequency regions where there is no damage, the individual will hear normally and the audiogram level will be up near 0 dB. See the audiograms in T-5 and T-8.

Fig. T-8. Audiogram (Notched) for an Ear with Tinnitus Caused by Destroyed Hair Cilia.



--- End of Chapter T ---

