

Recently, I've been trying to organize some of the columns and articles I've written over the past ten years. As I was looking through them, it became apparent that I've neglected to

discuss what is perhaps the most important hearing dimension of all, **the simple audiogram.**

In reality, however, the "simple" audiogram, and particularly its implications, is not quite so simple. Even though just about everybody who receives a hearing aid has his or her hearing tested with a pure-tone audiometer, not everybody receives a comprehensive explanation of exactly what the results mean and what the implications are for them.

And even for those who do, at a time when prospective hearing aid purchasers are being inundated with new information, anxious

about the test results, and worried about the cost involved, much of this explanation will be forgotten or misconstrued by the time several weeks have passed. I know that I'm often bemused when I hear what some people recount to me what they think their audiologist told them about their audiogram and its implications. I'm sure this was not what they were told, but it is what they remember. And in this context, that is the only relevant consideration.

For audiologists, the audiogram is such a basic dimension and so self-evident that its explanation, after the thousandth time, is often unconsciously truncated and simplified. They may go through it by rote memory, unaware that their client simply isn't getting it. For people who may not even have heard of a pure-tone audiometer before they stepped into the audiologist's office, this is a quite understandable. To expect them to fully understand how the pattern of their hearing loss impacts upon their listening behavior is not very realistic.

Yet, in spite of the recent advances made in diagnostic audiological

evaluations, and they are truly impressive, the information and insights provided by the simple audiogram can still provide the most pertinent information to explain the behavioral implications of a hearing loss.

Perhaps the most important insight of all is an appreciation of how specific audiograms impact upon the perception of certain speech sounds. Without including speech in the equation, it is simply not possible to intelligibly discuss the audiogram. This, after all, is the signal we are most interested in hearing (not to minimize the specific needs of certain groups of people for other types of sounds, such as musicians).

### **Figure One Audiogram — The "Speech Banana"**

The audiogram of a fairly typical audiogram can be seen in Figure 1. (My thanks to Brad Ingrao for creating these figures for me.) Let's first go through the fundamentals. Frequency (or pitch) is depicted on the horizontal axis, from low frequencies on the left (250 Hz) to high frequencies on the right (8,000 Hz). For some specific purposes, it may be useful to test 125 Hz as well as some frequencies higher than 8,000 Hz (for example, a progressive hearing loss above 8,000 Hz can occur with certain type of ototoxic medications).

The amount of hearing loss is shown on the vertical axis with the higher numbers indicating a greater degree of hearing loss. A symbol on this axis (red circle for the right ear and blue cross for the left) is a measure of the person's hearing threshold at this frequency; i.e., the loudness (intensity) point where sound is just audible.

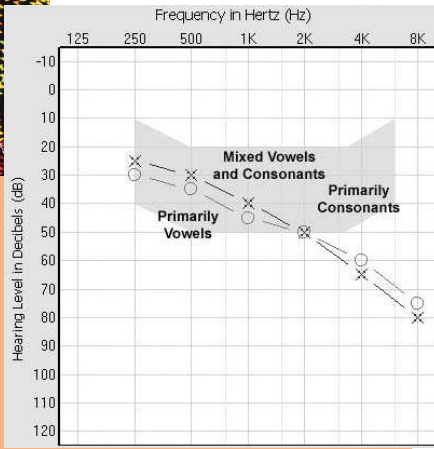
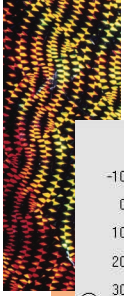
Thresholds from zero to 15 dB are considered to be within the normal hearing range. After that point, people will usually begin to display some communication difficulties because of the elevated hearing thresholds. The higher the number, the greater the impact of the hearing loss (referring only to the unaided condition).

**The 100 dB point should not be confused with a 100 percent hearing loss, that is a total lack of hearing.**

# The Audiogram: Explanation and Significance

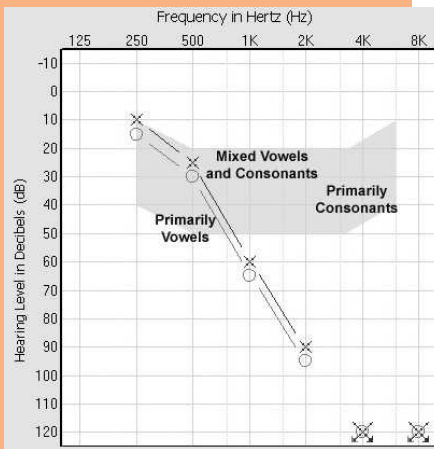
By Mark Ross

*The information and insights provided by the simple audiogram can still provide the most pertinent information to explain the behavioral implications of a hearing loss. Here is a clear explanation of how to understand your audiogram.*



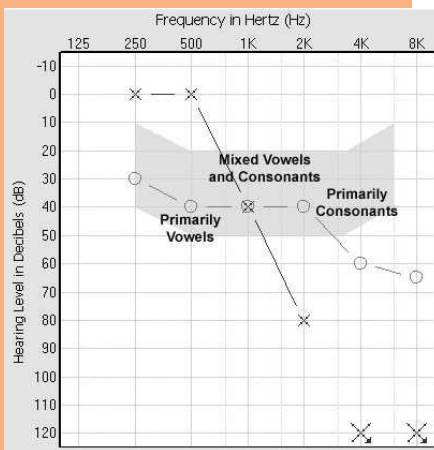
**Figure One Audiogram:  
The "Speech Banana"**

A fairly typical audiometric pattern for older people.



**Figure 2 Audiogram:  
The "Ski Slope"**

A severe-to-profound high-frequency hearing loss ("ski-slope" curve).



**Figure 3 Audiogram:  
Behavioral Implications  
of Hearing Loss**

Two very different ears with the same pure-tone average.

Hearing sensations do continue past this point, with some audiometers extending this vertical range to 120 dB. In short, the audiogram is a chart of a person's hearing loss, frequency by frequency.

Now note the shaded area extending across the audiogram (the so-called "speech banana"). This is a general, but static, representation of the acoustical speech energy across frequency. Some speech sounds, such as vowels, are predominantly composed of low frequency energy, with less of their power in the higher frequencies. Other speech sounds, in particular the voiceless consonants, are the reverse. They have most of their energy in the high frequencies and less in the lower frequencies.

Only the shaded area of the speech banana above the threshold curve is audible; portions below will not be perceived. In spite of portrayals to the contrary on some charts, no speech sound can be pinpointed to a specific point on the audiogram; all of them spread their energy somewhat along some segment of the frequency spectrum.

In addition to their energy locations on the frequency axis, speech sounds also vary in intensity. Some are naturally weaker (like the voiceless /th/ sound, the weakest sound in the English language) and some are naturally more intense (like the vowel /aw/, the strongest). When these are spoken in a normal fashion, as in the word "thaw" there is a 30 dB intensity range between the two phonemes. The intensity of all other speech sounds in the English language fall within these bounds (note, however, that this does not take into consideration inflected speech, which will move the entire speech banana up and down).

As already noted, the speech banana is a *static* representation of speech sounds. In reality, however, conversational speech is a dynamic and time-varying event, with one speech sound (phoneme) following another in a rapid succession.

The specific acoustical composition of speech sounds is partially shaped by the preceding and following sounds in an utterance. These specific effects, such as the unique modifications in vowels made by different pre-

ceding and following consonants, are actually secondary cues that can be helpful for understanding speech.

Indeed, the ability to take advantage of these cues may help explain why some people seem to understand speech much better than one would predict on the basis of their audiogram. Still, there are certain anchor locations for all speech sounds, as displayed on the speech banana, and these can offer valuable insights in understanding the effects of differing hearing losses.

Looking at the audiogram again, and relating it to the speech banana, it is apparent that a person with this hearing loss will hear more of the lower frequency speech sounds than the higher ones. Indeed, some of the higher frequency sounds, such as the /s/ sound (the most frequently used phoneme in the English language) will barely be heard at all. Will this person be able to understand normal speech without a hearing aid? Yes, but only with some difficulty and then only if the talker is close by and raises his or her voice slightly.

There are, unfortunately, many people with audiograms similar to this who do not, for one reason or another, wear hearing aids. One often sees this type of audiogram in older people whose hearing loss just "crept up" on them and who are still not fully aware of the difficulty they are causing themselves, their family and friends.

Conversing with such individuals is a strain on everyone's part. Often, they'll complain that they can "hear" the talker but cannot "understand" what is being said. This is, indeed, a very frequent complaint. Looking at the audiogram, we can understand somewhat why this should occur: they are not hearing the full range of high frequencies where many of the consonants have their predominant energy. And we know from many years of research, that consonants contribute more to the understanding of speech than vowels. Without a hearing aid, this person would be hearing primarily low frequency vowels energy and some part of the voiced consonants, but little or no portions of the crucial voiceless con-

sonant sounds (such as /s/, /t/, and /k/).

I don't want to give the impression that the perception of vowels is unimportant — on the contrary, it is and can be very important — only that by not actually hearing some of the consonants, people with hearing loss have to struggle to fill in the acoustical gaps they produce in the stream of speech. Those individuals with superior linguistic skills would perform this task better than those with lesser skills. Often, people with this type of loss are not aware of the sounds that they don't hear. They define what they do hear as "normal" — as it is, *for them*.

In truth, they may be hanging on to speech comprehension with their finger tips; any further distortion in the speech signal, such as someone talking rapidly or in a foreign accent, or in the presence of noise and reverberation, and they lose it. And this audiogram depicts only a gradual high-frequency hearing loss; were this person's audiogram something like the one shown in Figure 2, problems with speech perception would be even more severe.

## Figure 2 Audiogram — The "Ski Slope"

This audiogram in Figure 2 is often described as a "ski-slope" hearing loss. Somebody with this type of hearing loss actually hears better at 250 Hz than the one whose audiogram is shown in Figure 1, but much worse at 1,000 Hz and higher. Looking at the speech banana, it is apparent that while a great deal of low frequency vowel energy will be perceived, practically no high-frequency consonants would be.

An individual with this audiogram would have even more difficulty in understanding speech than the one whose audiogram is shown in Figure 1. These people depend upon whatever low frequency energy they do receive for comprehending speech. The presence of noise and reverberation (not exactly an uncommon occurrence in our society!) would have a disproportionate effect on them, since it would mask the only speech energy they are able to receive.

Complaints of "hearing" but not "understanding" would occur even more frequently. Without a hearing

aid (and even with one) this person needs to depend upon visual cues (speechreading) to supplement the information received through hearing. Some people, because of their superior ability to utilize some of the secondary cues in a speech signal referred to above, or their superior linguistic ability, may do better than these comments would suggest. But there are limits to even the keenest brain and the most developed auditory integration ability; at some point, people do need to detect speech energy in order to understand a spoken message. And this person is missing just too much of the speech signal to expect easy communication in any oral exchange.

It is usual to describe the extent of a hearing loss with verbal labels. Thus, someone may be described as having mild, moderate, severe or profound hearing loss, or some combination of terms ("mild to moderate" or "severe to profound"). This is an easy and shorthand way of labeling the severity of a hearing loss. While there is merit and often necessity to this practice, there is also the danger of oversimplification. Or perhaps someone's hear-

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ing loss is described by employing a single figure (derived usually from averaging the hearing losses at 500 Hz, 1,000 Hz, and 2000 Hz). The numbers themselves then serve as the basis for the verbal label that is applied. For example people with an average 40 dB hearing loss are considered to have just a moderate hearing loss. But such a shorthand label does not reflect the pattern of a hearing loss, a pattern, as we have seen, that may lead to more insights into the behavioral implications of a hearing loss. For example, consider the audiograms shown in Figure 3.

### Figure 3 — Behavioral Implications of Hearing Loss

The average hearing loss is the same for both ears in the audiogram shown in Figure 3. In the left ear, the hearing thresholds at 500 Hz, 1,000 Hz, and 2,000 Hz are 0 dB, 40 dB, and 80 dB respectively. Their average is 40 dB. In the right ear, the hearing loss at each of the three frequencies is the same, also resulting in an average of 40 dB.

But it should be apparent, just from a visual inspection, that these two ears would perceive speech quite differently. Quite clearly this example demonstrates that the shorthand description of a hearing loss with a number or a verbal label can be quite deceptive.

What I have often found useful in explaining the need to understand the audiogram is commenting that it is possible for someone to be completely deaf and have completely normal hearing *in the same ear* at the same time. Looking at this audiogram, we can state that this person has perfectly normal hearing in the left ear, but this is only true at 250 Hz and 500 Hz.

Or one could assert that he is completely deaf in the left ear, as again indeed he is (but only at 4,000 Hz and higher). Both statements are correct and both describe the left ear of this person. All it would take to resolve this verbal conundrum would be an understanding of what the audiogram actually signifies (degree of hearing loss across frequency).

These three examples **do not** illustrate the full variety of possible audiograms. In a room full of people with

hearing loss, it is doubtful that any two would exhibit exactly the same audiogram for both their ears. There would be differences in degree of hearing loss at the different frequencies as well as divergences between the ears. People with bilaterally **symmetrical** hearing losses (that is, with similar hearing losses in both ears) may have quite different auditory experiences than people with bilaterally **asymmetrical** hearing losses.

While most people exhibit a gradually sloping hearing loss across frequency (such as in Figure 1), some people have audiograms that are very atypical. This would include people with rising thresholds with frequency as well as those with perfectly normal hearing at the very low and high frequencies, but with moderately or severe hearing losses in the mid frequencies. The varieties are almost (but not quite) endless and many of these differences have behavioral implications. One has to look at the curve and not just some average figure or verbal label.

It is also true that some people with very similar audiograms “hear” quite differently. While an audiogram can help explain much of the auditory behavior of a person, it does not explain it all. We know that there are other dimensions to auditory experiences that cannot be explained by the audiogram. Still, the audiogram is a good place to begin when trying to understand someone’s speech perception problems. Hearing losses greater than about 70 dB may produce qualitatively different effects than losses less than this.

The reason for this phenomenon is that more severe hearing losses usually involve different structures within the cochlea (i.e., more inner hair cell damage) and that these different structures will impact upon the cochlea’s ability to separate incoming speech sounds into their various frequency components. A hearing loss may also involve central auditory pathways and these, too, may affect speech perception quite severely. Nevertheless, in spite of all these caveats, the audiogram is still the most fundamental auditory dimension of all.

There is another dimension of hearing loss that is sometimes also includ-

ed on an audiogram and that is the **discomfort threshold**. (But whether included or not, it is a dimension that every hearing aid dispenser has to take into consideration when fitting a hearing aid.) This is the loudest sound that an individual is willing to tolerate. When measured with tones across frequencies and compared to the hearing thresholds (i.e., the audiogram) at these same frequencies, the difference between them is the usable “listening area.” (It is also referred to as the “dynamic range.”) It is the auditory area — the “target” — within which a hearing aid is expected to provide amplified sound. Sounds delivered by the hearing aid below the threshold of hearing would not be audible; those exceeding the threshold of discomfort would not be tolerated (the hearing aid user would either turn the volume control down or simply remove the hearing aid).

The dilemma of the threshold of discomfort for people with hearing loss is that it is often the same as that observed with normally hearing individuals (perhaps 90 dB or so across frequency). But because their threshold of hearing is elevated, but not their threshold of discomfort, this means that people with hearing loss generally have a reduced listening area (or narrow dynamic range).

For example, if someone’s thresholds at 1,000 Hz were 50 dB and their threshold of discomfort were 90 dB, their dynamic range would be 40 dB at this frequency. This is an adequate listening space within which to deliver amplified speech sounds. If, however, the loss were 75 dB and the tolerance level at 95 dB, then the resulting dynamic range would only be 20 dB. In this instance, it would be more of a challenge to package sound within this more restricted dynamic range (this is where advanced technology can be very helpful, as in hearing aids with fast acting automatic gain control circuits).

Finally, it is important for people to be familiar with the details of their audiogram so that they can track any changes with time. Hearing loss, particularly adult onset hearing losses, may get gradually worse. (Anybody

experiencing rapid changes in their auditory thresholds should check with an otolaryngologist as soon as possible.) After a while, these changes will likely have behavioral implications that may require reprogramming one's hearing aid (if only a few frequencies are involved) or changing to another hearing aid if the deterioration extends across frequency.

It is a good idea for people to keep copies of all the audiometric tests administered to them so that comparisons can be made (and to be sure that they are dated correctly).

In brief, the audiogram is perhaps the most important indicator of one's hearing function, the particulars of which everybody who has a hearing loss should be aware of.



Mark Ross, Ph.D., is an audiologist and associate at the Rehabilitation Engineering Research Center (RERC) at Gallaudet University in Washington, D.C. He dates his emergence into the field of audiology to the time he attended the Army Aural Rehabilitation program as a patient in 1952. He received his doctoral degree from Stanford University and taught at the University of Connecticut and worked as a clinical audiologist at the Newington Children's Hospital. Dr. Ross is the former director of research and training at the League for the Hard of Hearing and has served on the boards of SHHH and the International Federation of Hard of Hearing People. He has written a regular column on developments in research and technology in the Journal since 1990. He and his wife, Helen, live in Storrs, Connecticut.

To find more Dr. Ross articles on technology for consumers, go to:  
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"This article is supported in part by GRANT #H133E030006 from the U.S.

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