Hearing Safety

Some basic principles & information

The louder the sound, the shorter the maximum duration of exposure for safe hearing

Even very short (instantaneous) bursts of extremely loud sound can damage your hearing, and may be too short for you to consciously perceive the full loudness

Repeated hearing system abuse can/will lead to permanent changes & damage

Occupational noise exposure is regulated by the US Department of Labor, Occupational Safety and Health Administration (OSHA)
http://www.osha.gov/SLTC/noisehearingconservation/standards.html

There are two primary forms of hearing loss

Conducive hearing loss
- Caused by damage to or malfunction of the ear's physical mechanism in the outer or middle ear (physical trauma, illness, congenital, etc.)
- Often can be corrected or mitigated by surgery or hearing aids

Sensorineural hearing loss
- Caused by damage or malfunction of nerves in the inner ear (over-exposure to loud sounds, illness, congenital, etc.)
- Can sometimes be mitigated with hearing aids

These two forms can occur simultaneously

Some ideas to keep in mind

Almost all forms of hearing loss that are attributable to over-exposure can be prevented

Most forms of hearing loss that are caused by over-exposure are not naturally regenerating – they are permanent, not self-healing

Hearing protectors are available in a wide variety of forms and prices

Further Reading

See the included articles *Hearing Protection for the Critical Listener* and *The Nature of Hearing and Hearing Loss* from *Soundscape, The Journal of Acoustic Ecology*, Vol. 6 No. 1.

$$D = [C_1/T_1 + C_2/T_2 + ... + C_n/T_n] \times 100$$

where

C_n = total time of exposure at a specified noise level, and
T_n = exposure duration for which noise at this level becomes hazardous.

The daily dose can be converted into an 8-hr TWA according to the following formula (or as shown in Table 1–2):

$$\text{TWA} = 10.0 \times \text{Log}(D/100) + 85$$

Table 1–1. Combinations of noise exposure levels and durations that no worker exposure shall equal or exceed

Exposure level, *L* (dBA)	Duration, *T*			Exposure level, *L* (dBA)	Duration, *T*		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	—	106	—	3	45
81	20	10	—	107	—	2	59
82	16	—	—	108	—	2	22
83	12	42	—	109	—	1	53
84	10	5	—	110	—	1	29
85	8	—	—	111	—	1	11
86	6	21	—	112	—	—	56
87	5	2	—	113	—	—	45
88	4	—	—	114	—	—	35
89	3	10	—	115	—	—	28
90	2	31	—	116	—	—	22
91	2	—	—	117	—	—	18
92	1	35	—	118	—	—	14
93	1	16	—	119	—	—	11
94	1	—	—	120	—	—	9
95	—	47	37	121	—	—	7
96	—	37	48	122	—	—	6
97	—	30	—	123	—	—	4
98	—	23	49	124	—	—	3
99	—	18	59	125	—	—	3
100	—	15	—	126	—	—	2
101	—	11	54	127	—	—	1
102	—	9	27	128	—	—	1
103	—	7	30	129	—	—	1
104	—	5	57	130–140	—	—	<1
105	—	4	43	—	—	—	—

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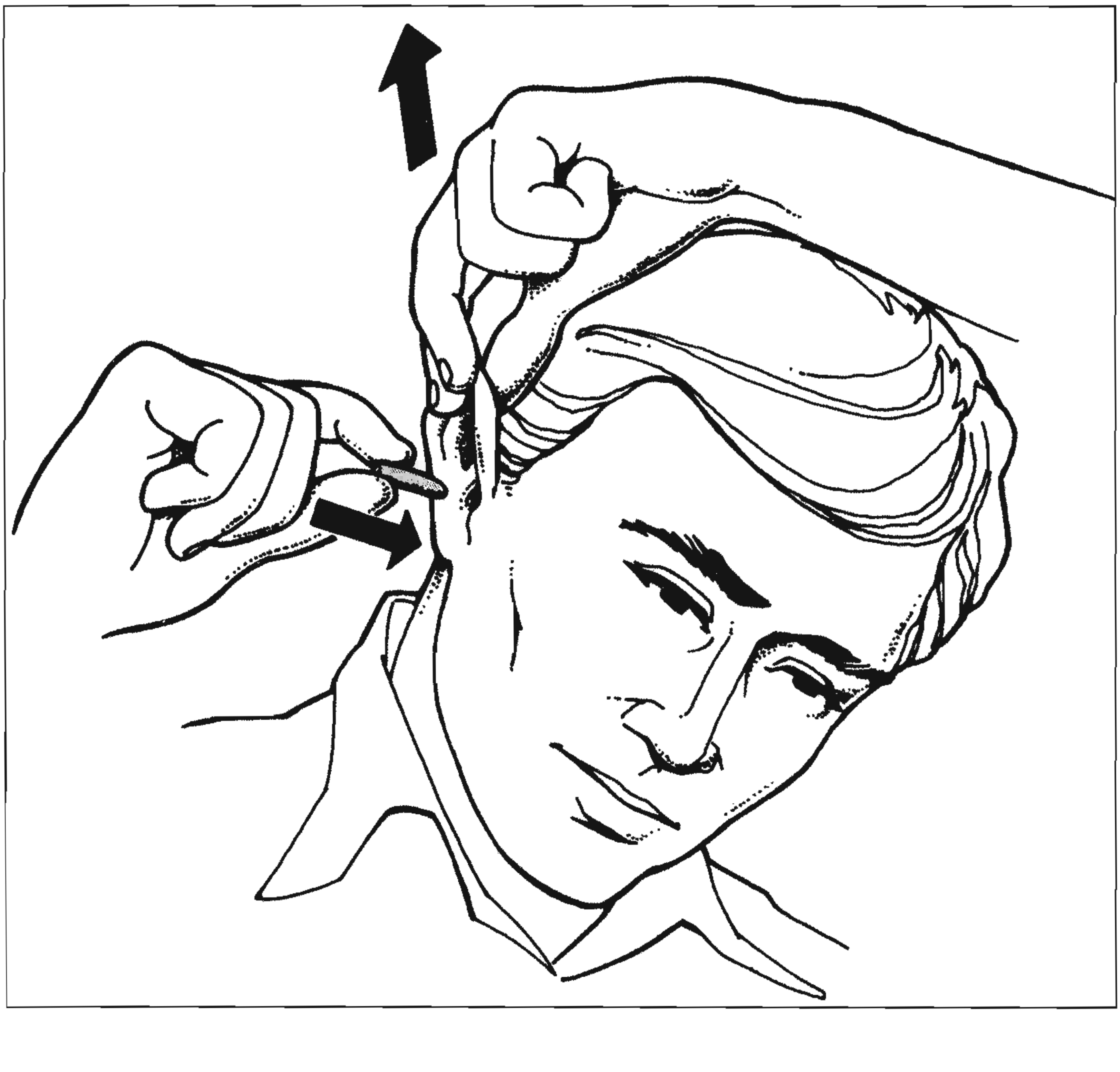
Hearing Loss



The Journal of Acoustic Ecology

Hearing Protection For The Critical Listener

By Elliott H. Berger, M.S.

Hearing is one of our most important senses; the one, it can be argued, without which our lives are most impacted (Gasaway, 1996). For critical listeners and acoustic ecologists, hearing has special significance. Since relatively modest changes may effect our aural perceptions and the enjoyment we derive from the aesthetic and professional aspects of audition we should exercise special care in the protection of our ears. It is truly regrettable that about 10 million Americans, and countless others worldwide, experience hearing loss that is at least partially attributable to noise exposure, since hearing loss due to noise (with the exception of unexpected explosive sounds) is virtually entirely preventable through the use of hearing protection devices (HPDs).

Hearing protection can sometimes be achieved through common-sense actions that will reduce our exposure to noise, either by decreasing the level or the duration of the exposure (i.e., our cumulative noise dose). For example, excessively loud sound from personal music systems is something we can control. At other times, either due to occupational exposures (noisy jobs), or recreational activities (shooting, woodworking, snowmobiling, flying light aircraft, attending concerts, public events, etc.), our only viable choice may be to purposely exclude sound from our ears. Though our fingers can do this quite effectively, functioning as the equivalent to a 25-dB HPD,[1] a preferred alternative is a bona fide personal hearing protection device, generally an earplug or earmuff, or as an alternative, a semi-insert (earplug or pod-like tips on a lightweight spring-loaded band).

Hearing conservationists normally recommend that HPDs be worn whenever sound levels regularly exceed 85 dBA for extended periods. Such levels are generally present if you feel the need to shout in order to be heard by a normal hearing person who is only about 3 feet away. To familiarize yourself with sound levels see the accompanying article in this issue on hearing loss, or visit www.e-a-r.com/pdf/hearingcons/T88_34NoiseLevels.xls to download a file with hundreds of representative sound levels.

Today, more than ever, there are a wide variety of hearing protectors available in both consumer and professional markets. Following are a few ideas that may help you choose and use those devices most effectively.

1. HEARING PROTECTORS MUST BE COMFORTABLE AND WELL FITTED. You should try different brands and types to find what is best for you. Be sure to carefully read the instructions and practice proper insertion. Two of the most common consumer complaints I receive about foam earplugs are "they don't block enough sound," and "they don't stay in." Nine times out of ten the reason is incorrect fitting. The goal is a proper, very tight and crease-free roll down (thinner than a pencil), accompanied by a pinna pull to facilitate full insertion well into the earcanal (see Figure 1). This takes practice. Without it, you will still get protection, but the fit is not as comfortable or secure, the noise attenuation not as great, and the occlusion effect more annoying (see Item 7 below). An in-depth brochure called *Tips and Tools for Fitting and Using E•A•R ® Foam Earplugs*, applicable to all brands and types of roll-down foam earplugs, is available at www.e-a-r.com/pdf/hearingcons/tipstools.pdf.

Figure 1—Illustration of the correct method of pulling the pinna (outer ear) by reaching over the head with the opposite hand to the ear being fitted.

Other types of HPDs also require correct use. See E•A•RLog 19 for numerous suggestions on fitting a broad range of products: http://e-a-r.com/hearingconservation/earlog_main.cfm.

2. DON'T GET HUNG UP ON THE NOISE REDUCTION RATING (NRR), the US. government-mandated noise protection factor that must appear on the packaging for all HPDs.[2] It is based on optimized laboratory-based tests that, in practice, represent what only a few of the most motivated and best-trained users can achieve. During the test the devices are worn for only brief periods, comfort is irrelevant, and, especially for earplugs, most users will rarely achieve the test results in practice. Unfortunately NRRs don't even necessarily rank order products in an appropriate manner. This means that small differences in NRRs, less than 4 or 5 dB, should definitely be ignored. The more rigorous you are about fitting, the closer your achieved protection will approach the

NRR, which is intended to indicate the approximate reduction in decibels (dB) of the overall sound level that the device can provide to those wearing the device in an optimal manner.

Your best bet is to simply use the NRR as an indicator that a product was designed for and tested for noise reduction. As a rough guide you can presume that devices with NRR of 29 and greater are among those providing the highest possible protection, and those with NRRs of 16 and lower provide modest protection. The lower values of protection are often quite sufficient (and even preferred) for common recreational exposures, other than shooting or the loudest of rock concerts.

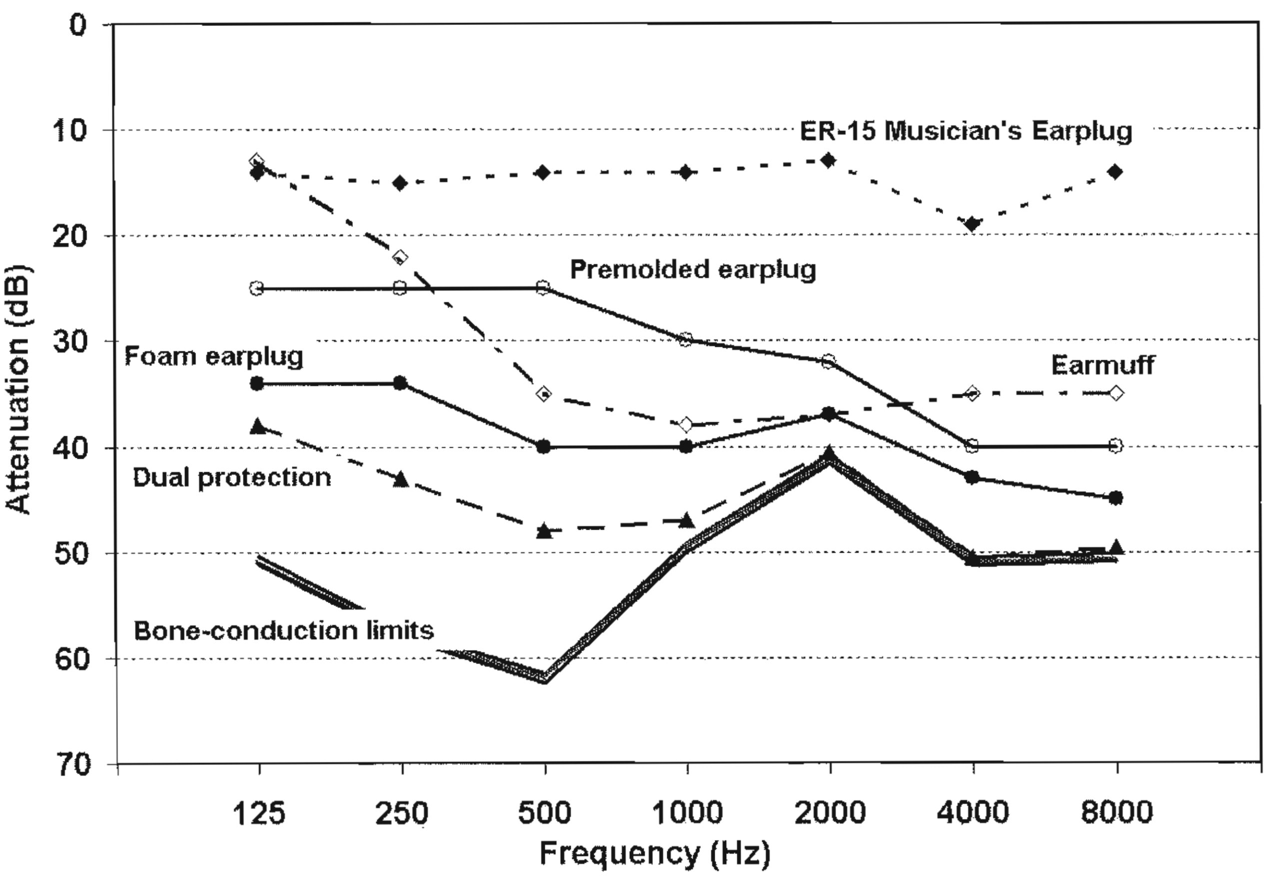
3. NO HEARING PROTECTOR WILL BLOCK ALL SOUND. Sometimes users are worried that they won't hear anything at all; other times they are worried that the device won't be protective enough. Figure 2 provides an indication of the amount of noise reduction (also called "attenuation"), on average, that well-fitted hearing protectors will provide. To achieve these values you *must* read the instructions for fitting and use and be sure the device is scrupulously inserted in the earcanal or placed over the ears to fully seal against sound. Devices providing the 30- to 40-dB of protection shown in the figure will make it sound as though you are in the room adjacent to the sound source, with a solid-core door tightly shut and sealed around its perimeter.

The bone-conduction limits, also illustrated in Figure 2, represent the noise reduction that can be achieved if the earcanal is perfectly sealed and blocked so that no sound can traverse that route to the inner ear. Even in this case, sound vibrates and to some extent (as indicated in Figure 2) passes through the bone and tissues of the skull, bypassing the hearing protector. Normally, HPDs are not worn well enough to provide noise reduction that approaches these limits; so much sound comes through the hearing protector that the small amount filtering through the bone-conduction paths is inconsequential. However, these limits are reached in the case of a deeply fitted earplug worn together with a well-positioned earmuff (dual protection), at which point the small amount of vibration transmitted by bone conduction becomes the most important contributor to what is heard.

When wearing well-fitted dual protection, a person with normal hearing will have difficulty even detecting the presence of speech delivered at a normal level from 3 feet away. Typically, dual protection is recommended for extreme noise levels in excess of 100 dBA where communication is not essential and is difficult regardless of whether or not hearing protection is worn.

4. THE CHOICE BETWEEN AN EARPLUG AND AN EARMUFF IS GENERALLY ONE OF PERSONAL PREFERENCE or ergonomics, as both types, when well fitted, can block sounds similarly. However, the better earplugs typically outperform the better earmuffs at the lower frequencies, which are those below approximately 250 Hz (see Figure 2), or in musical terms, middle C on the piano. Earplugs are of course more portable and less conspicuous to use in public places. Earmuffs are easier to put on and take off for short-term exposures, and for those who are averse to the idea of putting something in their ears, a more desirable solution. Semi-inserts are a compromise between the two, usually not as protective as plugs, but easier to don and doff, and convenient to store around the neck when not in use. The key is to use something that you like and fits your lifestyle. A variety of HPDs are shown in Figure 3.

Figure 2—Attenuation (noise reduction) for various hearing protectors as compared to the bone conduction limits (see text). Notice the tendency for most products to be more effective in blocking high-frequency sound, which makes them sound muffled.



5. THERE ARE MANY BASIC STYLES OF EARPLUGS. In the consumer market, those products that I am often asked about include roll-down foam (the foam is rolled into a tiny cylinder and inserted in the earcanal where it expands in place), premolded rubber-like plugs (usually with multiple flanges or sealing rings), formable wax or silicone slugs (the slug is pressed into the entrance of the earcanal), and custom-molded plugs (wherein a liquid with the consistency of thick honey is injected into the ear to make a custom-shaped device). Although all can work and block sound, there are a few things to keep in mind.

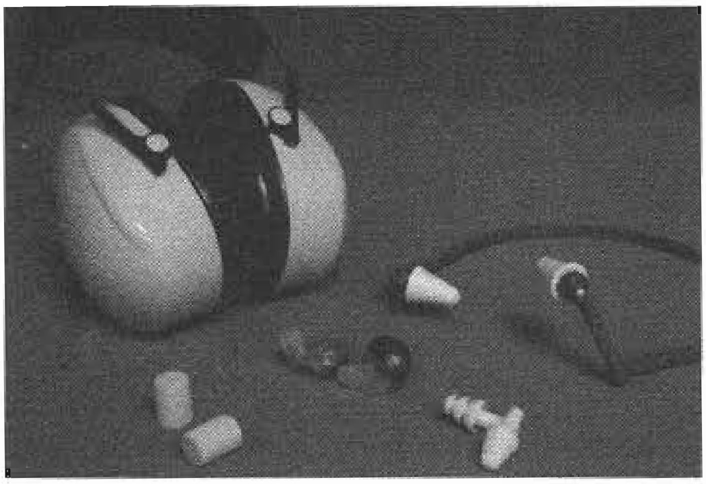


Figure 3—Representative hearing protectors (clockwise from lower left): foam earplugs, earmuffs, semi-insert device, premolded earplugs, (center) custom earmolds with ER-15 acoustic feature.

Foam plugs, as noted above, require some skill to insert properly. However, they are forgiving and even when not inserted optimally will provide a reasonable noise-blocking seal, though one that is not as secure or effective as otherwise could be achieved. Overall, they tend to be the most comfortable and effective style of earplug, providing protection equivalent to high-attenuation earmuffs. Premolded plugs can also seal well, but as a group tend to be somewhat less comfortable and protective. Unlike foam plugs that can be inserted very deeply with little discomfort, deeper and more protective fittings of premolded earplugs tend to be less acceptable. Formable plugs made of wax or silicone can only seal at the entrance of the canal. This limits the noise exclusion they can provide, primarily in the low frequencies, and also creates a large occlusion effect as discussed in Item 7, below. Custom earmolds, which can be among the most comfortable of earplugs, are more expensive, and contrary to intuition are not normally the most protective. Taking a good impression and making a well-fitting mold requires training, skill, and attention to detail. Even when well fitted, custom earmolds can easily break or lose their seal since they lack the dynamic accommodation of foam plugs or the flexible flanges of premolded earplugs.

6. WHEN WORN IN MODERATE NOISE HPDs WILL MAKE TINNITUS (A RINGING, BUZZING, OR HUMMING IN YOUR EARS) MORE APPARENT for those who already experience it, since the ambient noise that normally partially masks the tinnitus will be substantially eliminated by the noise reduction of the HPD. However, in higher noise levels enough sound will usually penetrate the hearing protector to provide a degree of masking or covering up of the tinnitus. Use of the HPD will help keep the noise from worsening the tinnitus, and once the protector is removed the masking provided by ambient sounds will immediately return.

7. WHENEVER YOU PROPERLY FIT AN EARPLUG OR EARMUFF YOU WILL EXPERIENCE THE OCCLUSION EFFECT (OE). This effect, which increases the efficiency with which body-conducted sounds are transmitted to the inner ear, causes a change in the perception of one's voice and body sounds. They become fuller, boomier, hollow-sounding, and muffled. The OE is easily demonstrated by sealing your earcanals with your thumbs while reading this sentence aloud. The OE is both a nuisance to HPD wearers, that can be minimized by proper selection and fitting (deeper-seated plugs reduce the OE), and an aid to wearers to use as a fit test; its presence indicates a proper seal. See E•A•RLog 19 for more information (http://e-a-r.com/hearingconservation/earlog_main.cfm).

8. MANY NOISE EXPOSURES ONLY REQUIRE 10 DB OF NOISE REDUCTION, SO DON'T OVERPROTECT with high-attenuation products unless you simply prefer the extra quieting they provide and won't be troubled by the greater degree of isolation they will create between you and the sounds around you. An excellent, but expensive, moderate-attenuation product I often wear is the ER-15 Musicians Earplug™ (cost in excess of US $120/pair, see www.etymotic.com/ for availability information for the US and worldwide). This custom molded earplug requires two trips to an audiologist to create and fit, but in return provides a comfortable, truly high-fidelity hearing protector that blocks sounds equally, regardless of their pitch, avoiding the muffling effect so common with conventional products (see Figure 2).

An alternative, much less costly one-sized product (from about US $12/pair), with nearly equivalent sound quality can be purchased off the shelf—Professional Musician E•A•R® Plugs www.aosafety.com/hbc/music.htm (and for international availability see www.e-a-r.info), also sold as ER-20 High Fidelity Earplugs (www.etymotic.com). Like the ER-15 these plugs avoid excessive protection and are ideal for music exposures and many public entertainment events.

9. MANY POTENTIAL HPD USERS ASK ABOUT "HIGH-TECHNOLOGY" SOLUTIONS SUCH AS EARMUFFS THAT INCORPORATE ACTIVE NOISE REDUCTION (ANR; sometimes also called noise cancellation). This method takes sound picked up underneath the earmuff cup and processes it so that it can be reintroduced via a small earphone to cancel the incoming sound. The applications are limited and only effective for low-frequency sound below about 400 Hz, such as the loud rumbling engine noise inside a light aircraft.

Another application for ANR is in earmuffs designed to provide an earphone-listening experience while reducing nuisance noise. Such devices are useful for travel applications such as in commercial aircraft when you want to listen to music or the movie soundtrack while at the same time reducing the perception of the noise in the cabin (see www.bose.com and www.peltoracoustics.com for representative products). However, for good noise protection, consumer ANR devices offer little that can't be achieved with a conventional and much less costly passive (non-electronic) device. So if you are comfortable wearing an earplug, an effective alternative is to use insert earphones (like the ER-6 Isolator™ earphones by www.etymotic.com) that passively block sound and, like their ANR counterparts, include the ability to accept an electronic input to reproduce music or other audio information.

10. LISTEN TO YOUR EARS TO MAKE SURE YOU ARE GETTING THE PROTECTION YOU NEED. If, immediately following a noise exposure you experience increased tinnitus, or for those blessed with normally quiet ears, you experience the onset of tinnitus, the noise was too loud for your ears. Regular exposures of that nature will likely lead to hearing loss and permanent or increased

tinnitus. Another, post-exposure effect that indicates inadequate protection is if your hearing seems dulled or your ears feel full after an exposure. Again, the indication is that the exposure was too great and there is potential for permanent effects. In such cases you should re-check how well you fitted your hearing protection, and/or consider using a more protective product, and if you still experience noise aftereffects, reduce the severity, duration, or repetition of your exposures.

11. NOT ONLY DO HPDs PROTECT YOUR EARS, BUT THEY CAN BE FUN AND USEFUL TOO. Want to hear a new sound? Take a shower while wearing earplugs. Not only will you keep your earcanals dry, but the impact of the water pouring upon your scalp will make interesting sounds in your ears due to the occlusion effect. Do you need to hear distortion in audio equipment at high sound levels? Listen through earplugs. If you audition at very high levels (over 100 dB) your inner ear sends a distorted signal to the brain. This should be no surprise. Those levels cause hearing damage so it makes sense that your ear is being overstressed when that is happening. Reducing the level with earplugs lessens the distortion in your hearing mechanism so that you can better hear the true performance of the sound system.

Or perhaps you want to "cleanse" your auditory palate to enjoy the next listening experience. Nature recordist, Gordon Hempton, who says earplugs should be as common as aspirin, shared with me the following. He occasionally takes an earplug-break during his field recording sessions even though he is often listening to extremely subtle and quiet sounds, in order to re-equilibrate his ears prior to his next listen, much as you would savor a taste of sorbet between courses at a fine meal.

Other types of artists may "need" hearing protection too. In 1981 Robert Hamon, a performance artist, created a video/sound installation entitled *Archangel, An Opera*, sponsored by the Western Front gallery in Vancouver. In this case there were no performers, only an audience full of participants; the subject being the personal experiences of those in attendance. The presentation was set in a four-court tennis bubble.

Guests arrived in soft-soled shoes and were handed yellow foam earplugs, a flashlight, and a glass of champagne. The installation included five video monitors displaying views of the constellations, hundreds of silver metal paper clips lying on a large felt-covered vibrating silver tray that was mounted on three red and white battery-powered electric toothbrushes, and 40 frogs with torsos wrapped in silver tinsel garlands distributed throughout the bubble. The audience was instructed to insert the plugs, and turn on their flashlights while sipping the champagne. The occlusion-effect enhanced sensation of bubbles popping within their mouths sounded like wild applause as their flashlight beams danced across the dome while they wandered about experiencing the space.

Concluding Remarks

Once you have selected a hearing protection device and learned to wear it properly, the key is to have it available when needed. Since you can't always predict when you will be exposed to noise, keep your HPDs handy, just like you might carry a pair of sunglasses. Obviously this type of application dictates earplugs instead of earmuffs due to their portability. I find foam plugs are small, lightweight, and easy to store in jacket or pants pockets or a travel bag, and if lost the cost for replacement is trivial. However, many times they are more protective than I require, so I like to also have available one of the low-attenuation "high-fidelity" protectors such as a Musicians earplug. My goal is to assure that I always have handy the protection I need, when I need it.

So there you have it—my best tips for selecting, using, and enjoying your hearing protection. Remember, life can be loud—be prepared.

Endnotes

1 Did you ever need immediate and brief hearing protection with only one hand free? Reach over your head with your free hand to use a finger to block the opposite ear while lifting the shoulder of that same arm to press against and seal the ear that it naturally contacts.

2 Other countries also specify noise reduction factors for hearing protection, numbers like the Single Number Rating (SNR) and Sound Level Conversion (SLC), but they are based on more realistic testing procedures. Though still optimistic, they better reflect what can be achieved in practice.

References

Gasaway, D. C. (1996). "To Prevent Noise-Induced Hearing Loss—Aim Between the Ears," Spectrum Suppl. 1(13) p. 28.

For additional information on noise and hearing protection visit www.e-a-r.com/hearingconservation for reprints, FAQs, audio presentations, current news, and links.

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The Nature Of Hearing And Hearing Loss

I wonder about the trees/Why do we wish to bear/Forever the noise of these/More than any other noise/So close to our dwelling place... From *The Sound of Trees* by Robert Frost

By Kathryn H. Arehart, Ph.D.

If a tree falls in a forest and no one is there to hear it, does it make a sound? The answer to this question depends on the way in which we define sound. An objective definition of sound relates to a physical characterization of pressure waves traveling through the air. A subjective definition relates to the human perception of the physical disturbance caused by the sound source.

Soundscapes may contain many different sounds: in addition to the sound of trees, there may be also be the sounds of distant thunder, a mountain quail and a running stream. As Plomp points out,

> When we say that we hear one or another "sound" we refer to our ability to identify the various percepts one to one with their sources. Implicitly, such usage also indicates that although the vibrations produced by the various sound sources are superimposed seemingly inextricably in the air, the ear is able to disentangle these vibrations so faithfully that we are not aware of the fact that they were ever mixed. [Plomp, 2002, *The Intelligent Ear*, page 1]

This disentanglement typically occurs without our awareness except when something interferes with the natural process. This interference can be competing vibrations (e.g., an airplane flying over a natural soundscape) or it can be due to a problem within the auditory system itself. The purpose of this article is to describe the nature of human hearing and how hearing loss can disrupt the ability to listen within a soundscape.

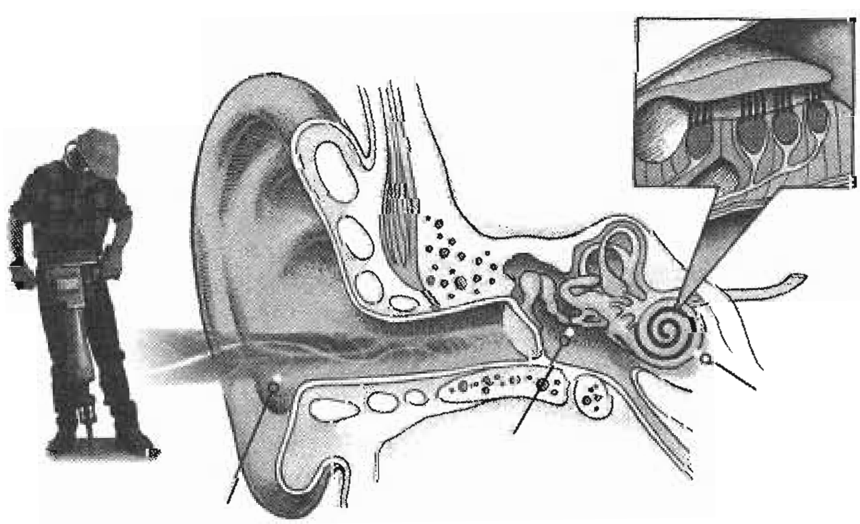
Nature of Hearing

Hearing involves a complex process in which the auditory system changes sound vibration from the environment into neural impulses that the brain perceives as sound. As shown in Figure 1, the ear has three major parts. The outer ear consists of the pinna (which is the part of the ear that is visible) and the outer ear canal. The eardrum separates the outer ear from the middle ear. The middle ear is an air-filled space that contains the ossicles, which are three small bones called the malleus, incus and stapes. The stapes interfaces with a membrane called the oval window, which forms a boundary between the middle ear and the inner ear. The inner

Figure 1—How We Hear

Healthy inner-ear nerves (hair cells) are the key to good hearing. Although some die off naturally as you age, many more are killed early if your ears aren't protected from harmful noise.

Courtesy, E. Berger, Aearo Co.



Hair cells within the cochlea of the inner ear respond to vibrations by generating nerve (electrical) impulses. The brain interprets these as sound.

The outer ear collects and funnels sound waves along the earcanal to the eardrum

The middle ear contains a chain of three tiny bones, called ossicles, which link the eardrum to the inner ear. When sound waves strike the eardrum, the ossicles conduct the vibrations to the cochlea in the inner ear.

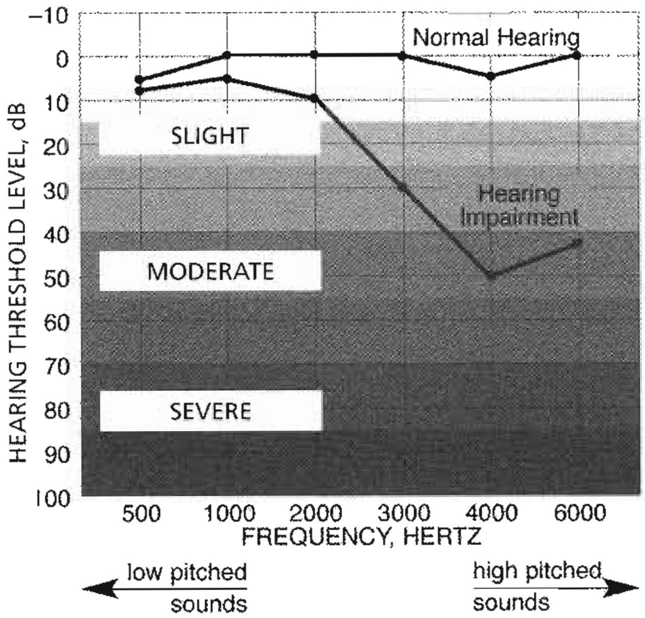


Fig 2—Degrees of hearing loss with audiometric profiles representative of normal and impaired hearing.

Courtesy, E. Berger, Aearo Co.

ear is fluid filled and consists of the sensory organs for hearing (the cochlea) and for balance (the semicircular canals). Within the cochlea are rows of hair cells. The hair cells communicate with nerve fibers in the hearing nerve, that in turn connect to the auditory cortex in the brain by way of the central auditory nervous system.

The outer and middle ears are the *conductive* part of hearing. The outer ear collects sounds from the environment. When sound waves travel through the ear canal and strike the eardrum, the sound waves cause the vibrations to be transmitted through the chain of ossicles and transferred to the fluids of the cochlea. The cochlea and hearing nerve are called the *sensorineural* part of hearing. The cochlea transduces sound vibrations into neural impulses that are sent along the hearing nerve up to the auditory cortex in the brain. The cochlear hair cells are an essential part of this transduction process. As the stapes pushes and pulls on the oval window, it causes the fluid within the cochlea to move. This fluid movement causes the hair cells to bend and release neurotransmitters, which in turn causes the hearing nerve fibers to fire. The cochlea is organized with a frequency map, such that higher frequencies are processed closest to the middle ear and lower frequencies are processed at the end furthest from the middle ear. This frequency-by-place organization plays an important role in the ear's ability to distinguish different frequencies. Finally, the brain uses the complex neural code coming from the auditory periphery to interpret the soundscape.

The interpretation of the soundscape involves several layers of complexity. The simplest layer is the *detection* of sound. That is, is sound present? A second layer of processing is *resolution*. That is, can specific characteristics of one sound source be perceptually separated from another sound source? When listening in a soundscape, spatial resolution allows us to discern that two sounds are coming from different locations. Frequency resolution refers to our ability to distinguish two or more frequencies in a complex sound. Temporal resolution refers to our ability to perceive changes that occur in sounds over time. A third layer of processing is the identification of sounds in the auditory environment (e.g., naming different instruments playing in an orchestra or identifying the several bird calls present in one scene).

Nature of Hearing Loss

Hearing loss can impact both the detection and resolution of sound. The effects of a particular hearing loss will depend on three characteristics, including the *degree* of the loss, the *configuration* of the loss and the *type* of the loss.

Figure 2 shows an audiogram, which is one way to quantify hearing loss in terms of a person's ability to detect sound. Along the horizontal axis is the frequency of the sound, which is described in terms of the number of cycles per second or Hertz. (Middle C on the piano corresponds to 256 Hz). While the human auditory system is sensitive to frequencies ranging from 20 Hz to 20,000 Hz, normally only the frequencies from 250 to 8000 Hz are tested in a hearing evaluation.

The vertical axis shows the volume or the level of the sound using a scale called the decibel (dB) Hearing Level scale. During a hearing test, an audiologist establishes the softest level at which someone can just detect a pure tone of a particular frequency. These levels are called the *threshold of hearing* and are plotted on the audiogram.

Question: Why do the test frequencies in the audiogram chart in Figure 2 only extend up to 6000 Hz?

Answer: Because of testing and calibration problems at higher frequencies, audiometric testing generally only extends to 6 or 8 kHz, even though young, normal-hearing adults can hear sounds out to 16 to 20 kHz. Today there are earphones and test systems that do extend hearing testing to 16 kHz, but there are no normative data or official standards against which one could make comparisons. When testing is done at those frequencies it often uses the individual as a baseline against which future comparisons are made, as in the case of monitoring hearing that might be changing in a patient who is being administered a cancer treatment that includes ototoxic drugs. One should also consider that few if any natural or musical sounds contain fundamental and important energy above 10 kHz, so that hearing losses at those high frequencies are not only difficult to measure but also difficult to detect by the person experiencing them.

Normal-hearing young adults can perceive sounds that extend across a wide range of levels ranging from sounds that are at threshold (0 dB HL) to sounds that are intolerably loud (120 dB HL). This range of levels is called the *dynamic range of hearing*. Thresholds less than 15 dB HL are considered normal hearing, so any thresholds that fall in the unshaded portion of the audiogram are considered normal. If a person has thresholds which are 15 dB HL or greater, they are considered to have a hearing loss. A hearing evaluation often includes determination of a listener's tolerance for loud sounds (level at which sounds become uncomfortably loud). For many people with hearing loss, this level will be similar to or even lower than the tolerance of someone with normal hearing (at or below 120 dB HL). Therefore, individuals with hearing loss often have a reduced dynamic range (e.g., from thresholds of 40 dB HL to intolerably loud at 110 dB HL).

The *degree* of hearing loss (see Figure 2) refers to the amount of hearing loss and is described in terms of being slight (15—25 dB HL), mild (25—40 dB HL), moderate (45—55 dB HL), moderately severe (55—70 dB HL), severe (70—85 dB HL) and profound (greater than 85 dB HL).

The *configuration* of hearing loss tells us how hearing loss changes across the frequency range. Hearing loss can occur at all frequencies or at just some frequencies. The "hearing impairment" line on the audiogram illustrates a configuration with normal hearing in the low frequencies and sloping downward to a moderate hearing loss in the higher frequencies. A person with this configuration of hearing loss will not be able to detect any sounds that are at frequencies and levels in the region above the "hearing-impairment line." This hearing loss will impact a person's ability to hear some but not all speech sounds. Consider, for example, the word "Sue." Sounds like the /s/ are called fricatives and mostly consist of higher-frequency sounds that are low level (below about 40 dB HL). In contrast, vowel sounds have most of their energy in the lower frequencies and are often more moderate in level. Thus, the person with this configuration of hearing loss might be able to hear the vowel sound but not be able to detect the fricative. In contrast to the sloping configuration shown here, a hearing loss might also have a flat configuration, such that the thresholds are the same across the entire frequency range.

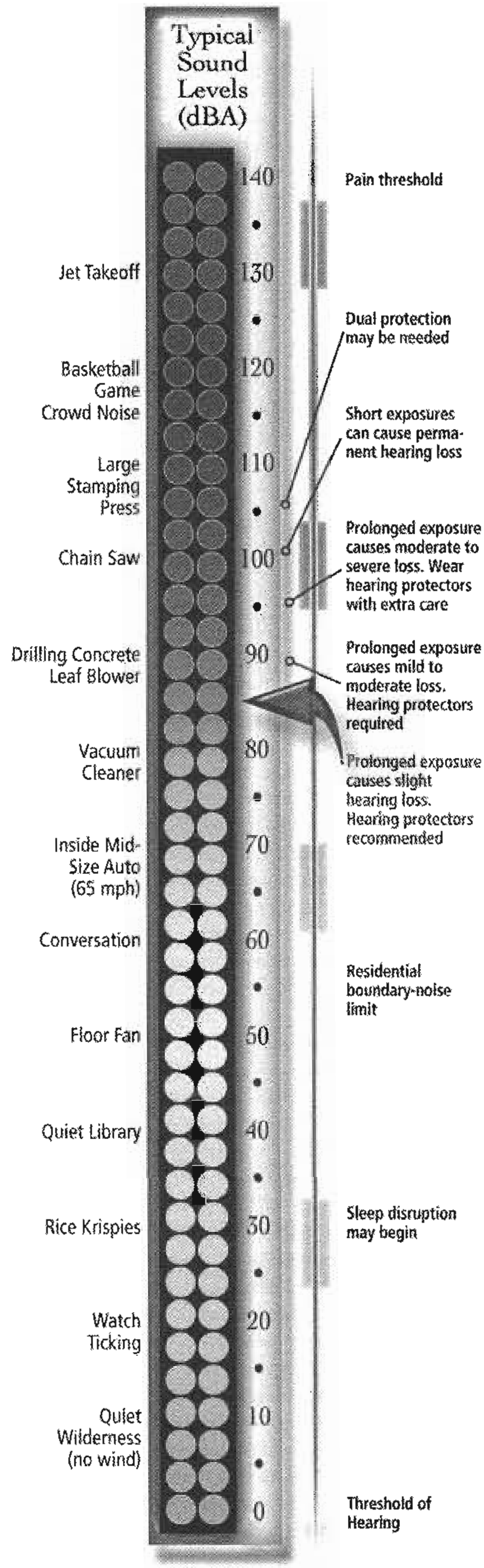
Question: What is the threshold of auditory pain and why is it variously shown as 120, 130 or 140 dBA?

Answer: Although some may think of auditory pain as an extreme discomfort in the hearing of a sound, which is certainly true of sounds above 110 dB and approaching 120 dB, auditory physiologists have defined it differently. It is the point at which a physical, i.e tactile sensation is felt in the middle ear, as opposed to a sound being sensed or heard in the inner ear. The definitive research on this topic was done in the US Air Force in the 1950s by von Gierke and his associates. It involved test signals such as speech, pure tones, and jet-engine noise. This painful and dangerous research is rare, especially today, because of human-subject review board concerns. The values found in that early work were 140 dB. For more information please see Von Gierke et al. (1953). "Aural Pain Produced by Sound," *Benox Report—An Exploratory Study of the Biological Effects of Noise*, ONR Project NR 144079, Univ. of Chicago, p. 29—36.

The *type* of hearing loss describes the place within the auditory system that the hearing problem occurs. There are three types of hearing loss: conductive, sensorineural and mixed. A *conductive* hearing loss affects the conduction of sound through the outer ear and/or through the middle ear. A conductive hearing loss causes an attenuation of the sound volume reaching the inner ear due to a problem in the effective transmission of the sound. Therefore, it will primarily affect a listener's ability to detect sounds. The degree of hearing loss resulting from a conductive loss will usually be in the slight to moderate range. Examples of conditions that cause a conductive hearing loss include the following: earwax (cerumen) that becomes impacted in the outer ear canal; a foreign object (e.g., a bead) trapped in the ear canal; an infection (such as "swimmer's ear") in the ear canal; a rupture (hole) in the eardrum; fluid in the middle ear due to an ear infection; and a break or discontinuity in the chain of ossicles. A conductive hearing loss is often successfully resolved with surgical or medical treatment. For example, antibiotics might help resolve a temporary hearing loss due to an ear infection in the middle ear or surgical repair of an ossicular break might restore efficient conduction of sound through the middle ear.

A *sensorineural* hearing loss is due to a problem in the cochlea and/or the hearing nerve. Whereas a conductive loss primarily affects the detection of sound, a sensorineural hearing loss will affect both the detection and the resolution of sound. The impact of the sensorineural hearing loss on detection will be evident on the audiogram. The degree of impairment resulting from sensorineural hearing loss can range from slight to profound. Such

Fig 3—Representative sound levels together with indications of safe vs. hazardous exposures. Courtesy, E. Berger, Aearo Co.



hearing loss can also introduce distortions that affect a person's ability to resolve sounds. This degraded resolution is not evident on the audiogram, but is evident in a person's ability to effectively hear in complex auditory environments. Often, someone with a sensorineural hearing loss will report greater difficulty hearing in noisy environments. The person's ability to resolve or perceptually separate different sounds (e.g., the speech from the competing background noise) becomes more difficult. Sensorineural hearing losses are usually permanent and not curable through medical treatment. Hearing aids are a common prescription for a person with a sensorineural hearing loss.

Question: I am surprised that the chart of sound levels indicates that a crowd at a basket ball game reaches nearly 120 dBA, which is more than 10-dB louder than a chain saw.

Answer: Surprising though it may be, values that high are easily (though not always) reached when over 10,000 screaming fans get pumped up in a large reverberant indoor arena. And though chain saws are loud indeed, and certainly require the use of hearing protection, they fall short of crowd noise when the fans are fanatically excited. Both crowd noise and chain saws are potentially hazardous sounds depending upon the duration and regularity of the exposures. For a listing of estimates of noise levels for about 1,000 different sources see www.e-a-r.com/pdf/hearingcons/T88_34NoiseLevels.xls

Examples of conditions that can cause a sensorineural hearing loss include hereditary hearing loss, medications that are toxic to the cochlea, viruses, head trauma, tumors, aging and most commonly, exposure to noise. The gradual hearing decline associated with aging is called presbycusis, mainly affecting higher-pitched sounds. Unlike the loss in Figure 2 that indicates a recovery at the highest test frequency, presbycusic losses are monotonic, showing increasing loss with increasing frequency. According to the National Institutes of Health, presbycusis affects approximately 35 percent of adults between 65 and 75 years of age and up to 50 percent of adults who are older than 75.

Sensorineural hearing loss is often due to damage to the cochlear hair cells. For example, exposure to intense noise can result in the death of hair cells in specific regions of the cochlea. As illustrated in Figure 3, the amount of noise that can cause hearing loss depends on both its level and duration. Damage to hair cells can occur due to repeated exposure to moderate-level sounds or due to a single exposure to a very intense sound. The damage may also be temporary (called a *temporary threshold shift*, or TTS) that will recover typically within minutes or hours, or permanent (called a *permanent threshold shift*, or PTS). One might notice for example, a dullness in the listening experience due to a TTS after a day of work in a noisy environment, or subsequent to a lengthy airplane ride or time spent in other loud forms of transport, or from a too-loud listening session to one's favorite music or at a concert, etc. Though this may well recover by the next morning, if one repeatedly experiences TTSs, it is likely that with time they will become permanent. One strategy for avoiding noise-induced hearing loss is to be sure to allow the ears time for recovery before the next hazardous exposure.

The National Institute of Health estimates that noise is a primary factor in the hearing loss of about one third of the 28 million Americans with hearing loss. Hearing loss due to noise can happen at any age and often is accompanied by tinnitus (see accompanying tinnitus article by Martin et al.). Except for exposures to unexpected blasts/explosions, hearing loss due to noise is almost completely avoidable. Education about hazardous sound levels is an important first step in its prevention. A helpful strategy is to monitor sound levels in your listening environment with an inexpensive sound level meter (e.g., Radio Shack sound level meter model 33—4050 costs about $40).

A *mixed* hearing loss occurs when a person has both a conductive and a sensorineural hearing loss at the same time. For example, a person with a noise-induced hearing loss may also have a chronic ear infection, resulting in a mixed hearing loss. Finally, a hearing loss can occur in one ear (unilateral) or in both ears (bilateral). In a bilateral hearing loss, the hearing loss can be similar in both ears (symmetrical) or different in each ear (asymmetrical).

Listening in the soundscape with a hearing loss can affect a person's ability to both detect faint sounds as well as to clearly resolve the frequencies, the location and/or the duration of the sounds in the auditory environment. The soft and subtle whisper of a light breeze through the trees may be one of the first sounds that we loose and with that—if we concur with Robert Frost's words at the beginning of this article—a profound sense of connectedness to nature. Persons who are concerned about their hearing might consult with a hearing health care professional. Otolaryngologists are physicians and surgeons who specialize in diseases of the ear, nose, throat, head and neck. Audiologists are trained to evaluate hearing loss and other disorders, including tinnitus and balance disorders. They also provide non-medical rehabilitation for persons with hearing loss, including the fitting of hearing aids and assistive listening devices.

Resources regarding hearing loss

The websites of the American Academy of Audiology (www.audiology.org) and the American Speech—Language—Hearing Association (www.asha.org) have helpful information regarding hearing and hearing loss, including screening questionnaires that can assist in determining if you might have a hearing loss or need a hearing test. The National Institutes of Health has helpful health information on many problems that cause hearing loss, www.nidcd.nih.gov.

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"A British study among 23 DJs indicated that many DJs, themselves, suffer from the loud music. Seventeen in 23 said they experienced some degree of tinnitus, and 16 reported that they had suffered from temporary hearing loss. Three DJs suffered from permanent noise induced hearing loss (NIHL) after years of excessive noise exposure at work. On average, the 23 DJs worked for 1 hour and 53 minutes without a break with noise levels of 105 dB." Read More: www.youth.hear-it.org/page.dsp?page=2978