Prevention of Hearing Loss from Noise Exposure

Brian J. Fligor, Sc.D., Children's Hospital Boston, Harvard Medical School, Boston, MA

Click here to download "Your Guide to Prevention of Hearing Loss From Noise"

Introduction

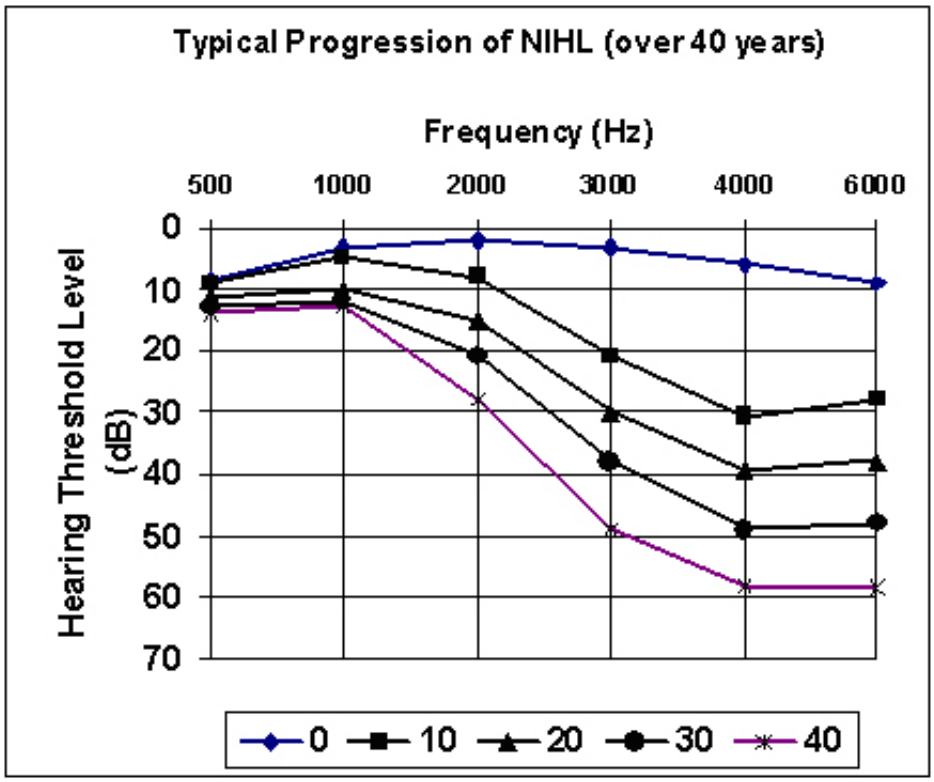
Noise is one of the most common causes of hearing loss, and one of the most common occupational illnesses in the United States. A single shot from a large caliber firearm, experienced at close range, may permanently damage your hearing in an instant. Repeated exposures to loud machinery may, over an extended period of time, present serious risks to human hearing. According to the National Institute on Deafness and Other Communication Disorders (NIDCD):

- 10 million Americans have already suffered irreversible hearing damage from noise
- 30 to 50 million more are exposed to dangerous noise levels each day.

Why has this problem become so widespread? Unfortunately, the effects of noise are often underestimated because the damage takes place so gradually, loud noises have become so common in our culture, and (although traumatizing to the parts of the body responsible for hearing) there are no externally-visible physical changes (like bleeding). As a result, people have traditionally not appreciated the serious impact of noise-induced hearing loss (NIHL) on their daily living until they're frustrated by a permanent communication problem or ongoing ringing in their ears. Perhaps a bit too late, they then become passionate about "hearing conservation" in order to save the hearing they still possess. Doesn't it make more sense, though, to emphasize "HEARING LOSS PREVENTION", while you still have good hearing sensitivity? This document will summarize how excessive noise can damage the hearing system, factors that influence this damage, and actions that you can take to prevent hearing loss.

Noise-induced hearing loss

Every day, we enjoy sounds: from nature sounds, to music, to a good conversation with a friend or loved one. Stop for a moment and think of your *favorite* sound. Is it the rain, or ocean waves, or a child's laughter? Now, imagine permanently losing the ability to hear your favorite sound… slowly. That would be tragic. When an individual is exposed at work or at home to harmful sounds – sounds that are too loud for too long a time - sensitive structures of the inner ear can be damaged, causing noise-induced hearing loss (NIHL). NIHL is a hearing disorder characterized by a gradual, progressive loss of high frequency hearing sensitivity over time, as a result of exposure to excessive noise levels. The Figure below illustrates this typical progression, in which the pattern of NIHL usually shows a "notch" that is most often seen at or near 4000 Hz. In later stages, the hearing loss may spread to frequencies that are more critical to understanding human speech *(in the range of 500-3000 Hz)*. NIHL usually occurs in both ears. However, the hearing loss may not necessarily occur equally between the left and right ears when the exposure conditions favor one side of the head. A common example of "asymmetric" NIHL is from shooting a rifle or shotgun (a right-handed shooter often has poorer hearing in the left ear, which is closer to the muzzle than the right ear). It is even possible to see a hearing loss in only one ear, as can happen in acoustic trauma, when a loud blast affects the ear nearest the explosion.



Progression of hearing loss following exposure to loud noise (95 dBA, averaged across the work day. Data show hearing loss for white males at ages 20, 30, 40, 50 and 60 years with 0 - 40 years of exposure, respectively). (ANSI 3.44-1996)

Tinnitus and noise exposure

Another condition that is often part of NIHL is tinnitus (pronounced “TIN-i-tus” or “tin-EYE-tus”). This is a condition described as the perception of sound (often buzzing, ringing, or hissing) in the absence of any external stimulus (that is, there is no sound others hear but the tinnitus sufferer does). This essentially takes away the opportunity for the person to experience quiet, and can be very distressing.

Some 30 million adults suffer from persistent tinnitus (it can also affect children). For some people the problem is severe enough that it impacts their everyday life. Tinnitus affects people differently. The most common areas in which tinnitus has a direct influence are:

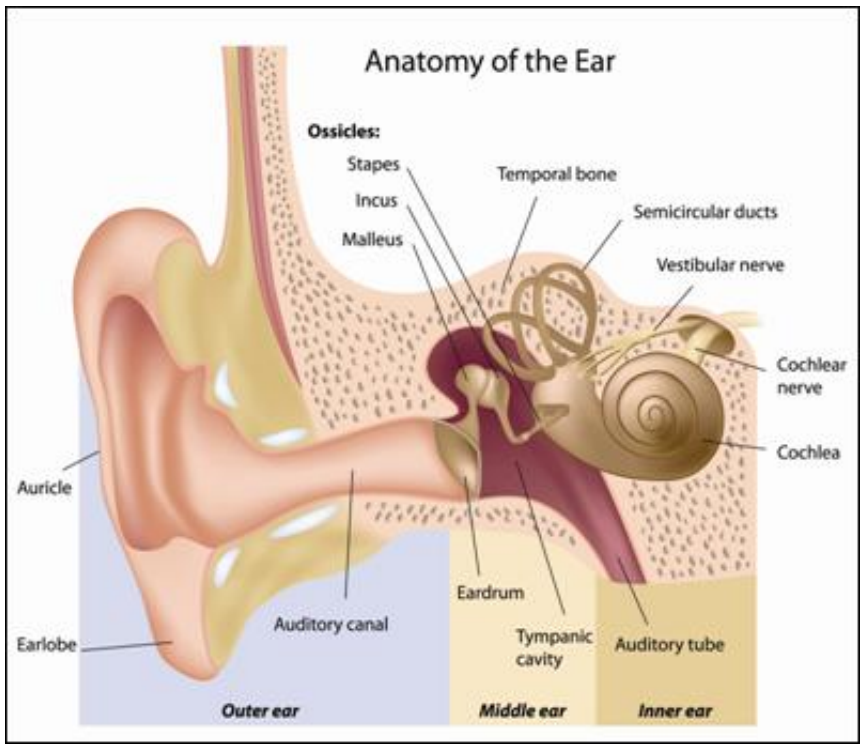
- **Thoughts and emotions.** Some are annoyed, bothered, depressed, anxious or angry about their tinnitus. They think and focus on their tinnitus often.
- **Hearing.** In some, the sound of the tinnitus competes with or masks speech or environmental sound perception.
- **Sleep.** Many tinnitus sufferers report that their tinnitus interferes with them getting to sleep. It can also make it more difficult to get back to sleep when they wake up in the middle of the night.
- **Concentration.** Some tinnitus sufferers report that they have difficulty focusing on a task because of their tinnitus. This might include reading a book or the newspaper.

For more information on tinnitus and treatment:

- See the Better Hearing Institute's *Your Guide to Tinnitus*
- Visit the American Tinnitus Association website at www.ata.org.

How do we hear and the impact of noise?

While earlier we have explained the mechanisms of hearing, it would be useful to review these principles in terms of how noise can lead to permanent hearing damage. Our hearing system is designed to detect and process sounds



over a remarkably wide range of levels. One can appreciate that early humans with better hearing could hear a predator or enemy trying to sneak up on them and "get the jump on them" and so have the greatest opportunity to survive and have offspring with good hearing. Modern industrialization, with combustion engines, pneumatic pumps, and repetitive loud machine noise wouldn't have existed early in human development, and so the ear would not have been tuned to develop to be able to tolerate these very recent high sound levels.

Acoustic signals enter the auditory system through the outer ear, funneled by the pinna (the external part of the ear that we can see) and external ear canal. This funneling causes a "resonance" (like that created when you blow across the top of a glass bottle) which boosts energy in high frequencies, about 2000 Hertz (heard as a high pitch). The energy then reaches the eardrum and is transmitted through the middle ear by vibrating three tiny bones, called the ossicles. The eardrum and ossicles amplify the vibrations and carry them to the inner ear (specifically, the "cochlea"), which is a fluid-filled chamber locked inside the skull. These vibrations through the middle ear can be dampened when loud sounds cause a contraction of two tiny muscles attached to the middle ear bones, but this action is not fast enough to offer protection from sudden bangs and cannot be sustained during long exposures.

Inside the cochlea are very specialized sensory cells, called "hair cells" which are responsible for our remarkable ability to detect very soft sound and tolerate reasonably loud sound. We are born with a full complement of cells (about 17,000); if these cells are damaged, they are not replaced with new cells. So, when a hair cell dies, it is gone for good. Vibration from the middle ear to the inner ear causes motion in the inner ear fluid. This motion stimulates the top portion of the hair cells, which results in chemical changes that produce nerve impulses. These nerve impulses are carried along the hearing nerve to the brain, where they are interpreted as sound. The brain uses the incoming nerve impulses in an elegant interpretation of *which, when* and *how many* hair cells are stimulated. The hearing sensitivity of young children, with no hearing damage, allows them to detect very soft sounds across a range of approximately 8-9 octaves.

Noise "ages" hearing

Noise damages hearing in a manner not dissimilar to the effects of aging. In some ways, age-related hearing loss (presbycusis) is "lifetime wear and tear" on hearing. Noise serves to speed up the "wear and tear" process. When the hearing system is exposed to excessive noise, mechanical and metabolic changes can occur from this stress. Scientific research, based on studies of industrial workers, as well as lab studies of humans and animals, have investigated the effects of noise on hearing. This work has determined that, after excessive noise has stimulated cells in the inner ear, chemical processes occur that can exceed the cells' tolerance, damaging their structure and function.

When sound is sufficient to cause hearing loss, most often there is a temporary loss of hearing sensitivity, known as temporary threshold shift (TTS). You likely have experienced this after attending a loud concert or working with loud tools or machinery. If the ear is given time to rest (typically 16 to 48 hours of relative quiet) the TTS recovers back to baseline hearing. With repeated occurrence, this TTS does not recover, and instead becomes a permanent threshold shift. How quickly this happens varies from one person to the next, and depends on how high was the offending sound exposure.

While earlier we have explained the mechanisms of hearing, it would be useful to review these principles in terms of

how noise can lead to permanent hearing loss damage. Our hearing system is designed to detect and process sounds over a wide range of levels, but probably not for the extremely loud noises that occur in our modern world. Acoustic signals enter through the outer ear, funneled by the pinna (the external part of the ear that we can see) and external ear canal. This funneling causes a "resonance" (like that created when you blow across the top of a glass bottle) which boosts energy in high frequencies, about 2000 Hertz (heard as a high pitch). The energy then reaches the middle ear where it causes the eardrum to vibrate three tiny bones, called the ossicles, in the middle ear. The eardrum and ossicles amplify the vibrations and carry them to the inner ear or cochlea, which is a fluid-filled chamber locked inside the inner ear. These vibrations can be dampened when loud sounds cause a contraction of two tiny muscles attached to the middle ear bones, but this action is not fast enough to offer protection from sudden bangs and cannot be sustained during long exposures. The vibrations move through the fluid in the cochlea, which contains about 20,000 sense cells of hearing, called the hair cells. Movements in the fluid stimulate the top portion of the hair cells, which causes chemical changes that produce nerve impulses. These nerve impulses are carried along the hearing nerve to the brain, where they are interpreted as sound. The brain uses the incoming nerve impulses in an elegant interpretation of which, when and how many hair cells are stimulated. The hearing sensitivity of young children, with no hearing damage, allows them to detect very soft sounds across a range of approximately 8-9 octaves.

Loud explosions (that peak for a few milliseconds at levels greater than 130-140 dB) may cause immediate hearing loss (this is called “acoustic trauma”). More often, however, hearing loss is caused by repeated exposure to noise above 85 dBA over long periods. The risk of noise-induced hearing loss depends on both the intensity and duration of the exposure. As intensity increases, the length of time for which the exposure is “safe” decreases. As a result, someone exposed to 85dBA (often produced by gas-engine lawn mowers) for 8 hours may be equally at risk for noise exposure after using a chain saw (producing 110dBA) for only a few minutes.

For typical long term exposure to high level sound that results in permanent hearing loss, a cascade of chemical events occurs when the cell is metabolically “overloaded” and the cell undergoes a process known as “apoptosis.” The cell that is damaged beyond its ability to recover literally fragments and the pieces of the cell are ejected into the fluid of the cochlea. Cells around the now missing hair cell serve as “scar tissue” to maintain the structural integrity of the system, but these supporting cells do not contribute to the active process of hearing. This damage results in sensorineural hearing loss and, often, tinnitus.

What are the symptoms of NIHL?

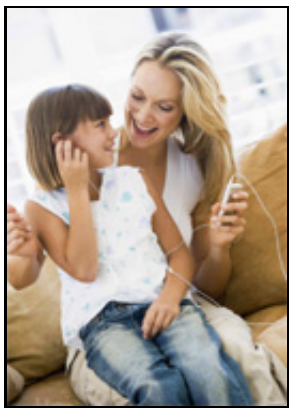
NIHL develops gradually so that people may lose a significant amount of hearing before becoming aware of its presence. During the early stages, sufferers often report having to turn up the volume on the TV or have difficulty understanding speech in groups or in the presence of background noise. As the hearing loss worsens, it becomes difficult to understand normal conversation even in quiet, one-on-one situations. The individual may not be aware of the high frequency hearing loss, but it can be detected with a hearing test. In fact, early identification is important in order to recognize the presence of NIHL and then take steps to prevent further hearing loss.

Some of the warning signs of the presence of, or exposure to, hazardous levels of noise are as follows:

- You can’t hear someone talking three feet away
- You have a feeling of “fullness” in your ears after leaving a noisy area
- You hear ringing or buzzing (tinnitus) in your ears immediately after exposure to noise
- You suddenly have difficulty understanding speech after exposure to noise; you can hear people talking but you have difficulty understanding them.

Preventing noise-induced hearing loss

NIHL is almost entirely preventable. Although hearing normally declines with age, the average, healthy, non-noise-exposed person can have essentially normal hearing at least up to age 60. Individuals vary in their susceptibility to hearing loss. While research has shown some trends, there currently is no reliable way to identify which particular individuals may be most susceptible to NIHL. To protect themselves when exposed to hazardous noise, everyone should take these precautions:



- Know which noises can cause damage (those above 85 decibels), including jet engines, lawn mowers, motorcycles, chainsaws, powerboats, and personal listening devices (like MP3 players). If you have to raise your voice to shout over the noise to be heard by someone within an arm's length away, the noise is probably in this range. More formal noise measurements can be made (and are required in most industries), to determine risks from noise exposures. The noise thermometer below shows you the relative risk associated with certain noisy environments.
- If possible, try to reduce noise at the source. Sometimes, replacing mufflers, keeping equipment in good maintenance, or placing the machine inside an enclosure can shield a person from the risks of NIHL. When purchasing new tools and yard equipment, consider their noise outputs before buying units with ineffective mufflers.
- Personal listening devices (like MP3 players with earphones) can also present risks to hearing if used at too high a volume for too long. Consider using earphones that block out background noise to help you moderate your listening level, and give yourself listening breaks if you do choose to listen loud. Some devices exist on the market which limit the volume that can be output by the MP3 player, virtually making them kid-proof.
- Wear hearing protection devices (HPDs) such as earplugs or earmuffs, when involved in loud activities (at work or when involved in noisy recreational activities). When properly selected and used, HPDs can be powerful tools for preventing NIHL. HPDs are required by law to be labeled with a Noise Reduction Rating (NRR) that is based on performance obtained under ideal laboratory conditions. Usually, people obtain far less protection than the labeled rating because they don't wear the devices correctly or neglect to wear them during the entire period of the noise exposure. It must be emphasized that the best hearing protector is not the one with the highest NRR, but the one that people will consistently wear whenever exposed to loud noise. There is no single protector that will fit everyone, be universally comfortable, and be appropriate in every environment. What follows are some typical HPD options, as well as some special-purpose options, that you may consider.

click on noise thermometer to enlarge

Disposable plugs are placed inside the ear canal to block out noise. They are commonly made of expandable foam. One size fits most everyone. They roll up into a thin cylinder for insertion. Once they're inside your ear canal, they expand to form a good seal. Keep the plugs as clean as possible by inserting them with clean hands. Always inspect

them before reinsertion. If they are damaged or dirty, throw them away.

Sound isolating earphones with universal-fit ear tips. These earphones provide considerable sound isolation to most people, therefore the volume on MP3 players may be set lower. Noise cancelling headphones are also available which do a great job of cancelling steady state noise such as on an airplane. These devices require little maintenance. The ear tips may be cleaned as needed; if they become brittle simply replace.

Reusable plugs are preformed to fit the ear. They are usually made of a flexible rubber or silicon. They may be flanged or cone-shaped and are often joined by a cord so that they're not easily lost. Reusable plugs can be worn safely for months, depending on the type. They should be replaced as soon as they become hard, torn, or deformed. Inspect and clean them often with warm soapy water. Rinse well. Store them in the case supplied by the manufacturer.

Earmuff stereo headphones. The soft plastic cushions, filled with foam or liquid, should form a good seal against noise. If you wear glasses with wide temples, you may want to choose another type of protector. If you're exposed to very loud noise, you can wear earmuffs and plugs together. Wipe the cushions clean with a damp rag when they become soiled. Check the cushions often, and replace them if they're stiff, worn, cut, or torn. Do not modify your muffs in any way.

Special purpose headsets. When communication is required with hearing protection, special-purpose earmuffs may help you understand speech from co-workers or those transmitting signals to you by radio. Advances in active noise reduction may be effective in reducing low frequency noises that can interfere with speech. Care of special-purpose earmuffs also requires that the internal electronics are maintained.

Musicians Earplugs™ are sleeves that fit in the ear canal and a removable filter to change between different levels of attenuation: 9 dB, 15 dB, or 25 dB. Musicians and music enthusiasts may prefer to use a type of earplug that is designed to match the ear's natural response, making sound quieter but not distorted. Filters in these Musicians EarplugsTM use a diaphragm that reduces noise levels relatively equally across all frequencies. These filters can be placed in pre-formed or custom-made earplugs. While these earplugs may be washed with water and mild soap, the filter should never be exposed to water. Remove the filter before such washing. Molds should be replaced when discolored, cracked, or obviously hardened. Never use alcohol or solvents to clean the sleeves.

Custom in-ear monitor, made of a silicone material. The benefit is a consistently comfortable fit and excellent sound isolation. Musicians can also use custom in-ear monitors to hear themselves rather than through the floor "wedge" loudspeaker monitors. This results in lower levels on stage and if the earpiece is tightly sealed to the ear without venting, it **can** serve as a hearing protection device. Used inappropriately, however, it can be turned up to dangerous levels. A variation for the normal consumer can be obtained from hearing health professionals for simply listening to MP3 players; the devices can be made of silicone or acrylic (although silicone seals in the ear better and most often provides better sound isolation). Keep the sound ports that fit in the ear canal clear of earwax and use a "wax loop" tool to remove wax. Do not get these wet and do not use alcohol or solvents to clean the earpieces. Wipe them with a tissue and store them in a cool, dry place between use. Consider using a desiccant (moisture absorber) container if you sweat a lot during performance.

Preventing noise-induced hearing loss

- If you're exposed to hazardous noise on the job, your employer may already be providing annual hearing tests to identify any change in hearing that might indicate under-protection from the noise. Occupations particularly at risk for hearing loss due to exposure to noise are as follows:
  - Firefighters
  - Police officers
  - Factory workers
  - Miners
  - Farmers
  - Construction workers
  - Military personnel
  - Heavy industry workers
  - Musicians
  - Entertainment industry professionals
  - Office staff in crowded buildings

Conclusions

- If you are aware of some of the symptoms of NIHL (like ringing ears or muffled speech), seek a hearing test from a qualified hearing health professional. Although noise exposures are hazardous, other medical causes for hearing loss should be ruled out by a qualified health care provider, using data from your hearing test and your history.
- Be alert to hazardous noise. Since prevention is so critical, make sure that your family (especially children), friends, and colleagues are aware of the hazards of noise. Although animal research with drug therapies and

the physiology of the hearing system may eventually lead to the development of treatment strategies to reduce NIHL, the most fundamental recommendation is the best. **One-third of permanent hearing loss is preventable with proper hearing loss prevention strategies**.

PROTECT THE HEARING THAT YOU HAVE NOW!

References

ANSI (1996). American National Standard: Determination of occupational noise exposure and estimation of noise-induced hearing impairment. New York: American National Standards Institute, Inc., ANSI S3.44-1996.

National Institutes of Health (1990). Noise and Hearing Loss. NIH Consensus Development Conference Consensus Statement 1990, Jan 22-24; 8 (1).

National Institute for Occupational Safety and Health (1998). Revised Criteria for a recommended standard - Occupational noise exposure, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 98-126.

National Institute on Deafness and Other Communication Disorders (1999). Noise-Induced Hearing Loss. NIH Pub. No. 97-4233.

Occupational Safety and Health Administration (1983). Occupational Noise Exposure Standard. 29 CFR Chapter XVII, Part 1910.95.

NIDCD, Statistics and Epidemiology of Hearing Loss. http://www.nidcd.nih.gov/health/statistics/quick.htm accessed December 1, 2009.

Kopke RD, Jackson RL, Coleman JK, Liu J, Bielefeld EC, and Balough BJ. (2007) NAC for noise: from bench top to the clinic. Hearing Research 226(1-2): 114-25.

Yost W. (1994) Fundamentals of Hearing: An Introduction (3rd ed.). San Diego: Academic Press, Inc.

Photos courtesy of, and used with permission:

Sight and hearing www.soundandhearing.org: Noise Thermometer

Etymotic Research: Musician ear plugs, noise canceling earbuds

Sensaphonics: in-ear monitor

Tinnitus photo: Auricle Ink Publishers, Inc, Sedona, AZ.