First A Word About Sound

Sound is a mechanical disturbance propagated through elastic media –
Definition paraphrased from classroom discussion (10/22/02, Cornell University)

In order to hear, our ears make use of two important features of sound:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>measured in Hertz</th>
<th>Allows for differentiation of pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sound Pressure Level</strong></td>
<td>measured in decibels</td>
<td>Allows for differentiation of intensity</td>
</tr>
</tbody>
</table>

High pitches are represented as high frequencies and low pitches are represented as low frequencies. The following images show a graphical representation of a high and low-pitched sound. Note the difference in frequency.

*High-pitched sound = higher frequency*

*Low-pitched sound = lower frequency*
Musical sound is just one of three different types of sounds

The sound produced by vibration of a tuning fork is nearly a pure tone, as seen below. Note the sinusoidal representation.

![Graph of a musical sound showing a pure tone as a regular wave of a single frequency.](image1)

Musical instruments produce complex sounds that are a combination of the fundamental frequency (the lowest frequency) and the overtones. Each instrument produces a sound with a different combination of overtones; the difference between these sounds is called *timbre*. The following image shows a graph of a musical sound. Note the complex and periodic nature.

![Graph of a musical sound showing a complex periodic nature.](image2)

*Musical tone = composed of fundamental frequency and harmonic characteristics*

The third type of sound is noise, in which there is no normal frequency.
How We Hear

The healthy ear processes sound frequencies ranging from 20 Hz to 20,000 Hz. It detects sounds as soft as .0002 dynes/cm**2 (0 DB HL) and can tolerate sounds a million times more intense (200 dynes/cm**2 or 120 DB HL). Sound frequencies between 500 and 4000 Hz include the frequencies most important for speech.

Normal hearing: sound waves are first collected in our outer ear (called the auricle or pinna), pass through our ear canal and cause our eardrum to vibrate. These vibrations are in turn transmitted to our inner ear by the bones of our middle ear. Our inner ear plays a vital role in the transformation of these mechanical vibrations into electrical impulses, or signals, which can be recognized and decoded by our brain. When the vibrations reach the cochlea through movement of the bones in the middle ear, the fluid within it begins to move, resulting in back and forth motion of tiny hairs (sensory receptors) lining the cochlea. This motion results in the hair cells sending a signal along the auditory nerve to the brain. Our brain receives these impulses in its hearing centers and interprets them as a type of sound.

Anatomy

The most important structures involved in hearing are shown on the figure below. The outer ear (pinna or auricle) may provide a modest (10db) amplification of sounds at the upper range of speech processing frequencies. The middle ear, bounded by the eardrum (1) and the bony labyrinth, provides an additional 20-30 Db of mechanical amplification by coupling the large eardrum (tympanic membrane) to the oval window into the fluid filled inner ear. The 20 to 30 db of amplification is approximately the difference in sound intensity between a whisper and normal conversation.
Figure: The outer ear consists of the auricle (unlabelled), the external auditory canal, and the lateral surface of the tympanic membrane (TM). The middle ear includes the medial surface of the eardrum, the ossicular chain, the eustachian tube, and the tympanic segment of the facial nerve. The inner ear includes the auditory-vestibular nerve, the cochlea and the vestibular system (semicircular canals). The auditory nerve, also called the cochlear nerve, transmits sound to the brain.

Early Warnings of hearing loss

- Do people "mumble"?
- Do you frequently say "what?" or "Huh?"
- DO you misunderstand names and numbers?
- DO you like the TV/radio volume louder?
- Do you have trouble hearing in noisy rooms?

Overview of causes of hearing loss

There are three "pure" types of hearing loss encountered commonly in clinical practice: sensorineural, conductive, and central. A fourth type, denoted "mixed", is simply a combination of sensorineural and conductive.
Disorders of the middle ear are generally responsible for conductive losses. Disorders of the cochlea or cochlear nerve for sensorineural hearing loss, and disorders of the brainstem or brain account for central hearing loss.

**Sensorineural Hearing Loss**

*Sensorineural hearing loss* (SNHL) accounts for about 90% of all hearing loss. This is sometimes also called "nerve deafness", although the term is not entirely accurate, leaving out disorders of the hair-cells of the inner ear. It is found in 23% of population older than 65 years of age. The term "sensorineural" is used to indicate that there is either a cochlear or an eighth nerve lesion. The diagnosis of a sensorineural pattern hearing loss is made through audiometry, which shows a significant hearing loss without the "air-bone gap" that is characteristic of conductive hearing disturbances. In other words, air conduction is equal to bone conduction.

Common causes include old age, where the hearing pattern is often called presbycusis (see following section), *Menieres disease*, *ototoxic medications* (such as high-dose aspirin or certain strong diuretics), *immune disorders*, and noise exposure (see following section). Trauma (inner ear concussion) can cause both temporary and permanent hearing loss. Diabetes is associated with gradually progressive bilateral high-frequency SNHL. Pathological studies suggest that it is due to microangiopathic involvement of inner ear blood vessels and subsequent stria vascularis atrophy and hair cell loss (Fukushima et al, 2004)

13-20% of those with meningitis develop hearing loss (Dichgans et al, 1999; Wellman et al, 2003). Postmeningitic hearing loss can be due to lesions of the cochlea, brainstem and higher auditory pathways, but usually is related to suppurative labyrinthitis (cochlear).

There are many causes of sensorineural hearing loss that are extremely rare. Tumors in general are a very rare cause of sensorineural hearing loss. Examples are *acoustic neuroma* and *glomus tumor*. Hyperviscosity syndromes such as *Von Waldenstroms macroglobulinemia* are another rare cause. Superficial siderosis, due to CNS bleeding, can cause a slowly progressive sensorineural hearing loss as well as cerebellar or vestibular disturbances. *Kawasacki's disease* is a rare cause of hearing loss in children. Radiation to the ear is often associated with a chronic, progressive hearing deterioration (Wang et al, 2004).

**References for sensorineural hearing loss:**

- Fukushima H and others. The effects of type I diabetes mellitus on the cochlear structure and vascularture in human temporal bones. The National Temporal Bone Registry, Summer 2004 issue, Volume 12, #1
Noise is a common cause of hearing loss in the US. Twenty-five percent of the US work force is regularly exposed to potentially damaging noise (Suter and von Gierke, 1987). Because of occupational risk of noise induced hearing loss, there are government standards regulating allowable noise exposure. People working before the mid 1960's may have been exposed to higher levels of noise where there were no laws in the USA mandating use of devices to protect hearing. An example of an audiogram showing noise induced hearing loss is shown below. There is a clear "notch" at 3000 hz, with better hearing at both lower and higher frequencies.

Noise can also cause a reversible hearing loss, called a temporary threshold shift. This typically occurs in individuals who are exposed to gunfire or firecrackers, and hearing in their ears after the event (tinnitus). Non-occupational noise are also regularly encountered during recreational activities and are a source of premature hearing reduction. Peak noise levels, in DB, are provided in the following table taken from Smith et al, 1999).

<table>
<thead>
<tr>
<th>NOISE</th>
<th>LEVEL</th>
</tr>
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<tbody>
<tr>
<td>Firecracker</td>
<td>180</td>
</tr>
<tr>
<td>Gunshot</td>
<td>167</td>
</tr>
<tr>
<td>Car Stereo</td>
<td>154</td>
</tr>
<tr>
<td>Children's toys</td>
<td>150</td>
</tr>
<tr>
<td>Sporting events</td>
<td>127</td>
</tr>
<tr>
<td>Rock Concert</td>
<td>120</td>
</tr>
<tr>
<td>Health Club</td>
<td>120</td>
</tr>
<tr>
<td>Motorboats</td>
<td>115</td>
</tr>
<tr>
<td>Video Arcade</td>
<td>110</td>
</tr>
<tr>
<td>Snowmobile</td>
<td>99</td>
</tr>
<tr>
<td>Movie</td>
<td>94</td>
</tr>
</tbody>
</table>

Hearing loss and tinnitus (usually temporary), can also be associated with high doses of aspirin or other otoxic drugs such as the nonsteroidal anti-inflammatory drugs.

Musicians and the prevention of hearing loss:

Musical instruments can generate considerable sound and thus can also cause hearing loss. The most damaging type of sounds is in the high-frequencies. Violins and violas can be sufficiently loud to cause permanent hearing loss. This is typically worse in the left ear which is nearer the instrument. Unlike other instruments, the ability to hear the high-frequency harmonics is crucial to these musicians. Mutes can be used while practicing to reduce long term exposure. (Karlsson, Lundquist et al. 1983; Ostri, Eller et al. 1989; Royster, Royster et al. 1991; Sataloff 1991; Palin 1994; Teie 1998; Obeling and Poulsen 1999; Hoppmann 2001; Kahari, Axelsson et al. 2001). In a study of rock/Jazz musicians, almost 3/4 had a hearing disorder, with hearing loss, hyperacusis and tinnitus being the most common maladies. (Kaharit, Zachau et al. 2003)

There are a number of strategies that can be used to reduce the chance of noise injury from other instrumentalists. Musicians ear plugs are generally "flat" so that bass and treble notes are not relatively favored, thus distorting perception. Nevertheless, a"vented" ear plug can be used to tune the ear cavity to low frequencies, which are less damaging. Drummers should use musicians ear plugs, such as the ER-25. Guitarists and vocalists can use the less attenuating ER-15. Too much ear protection can result in overplaying and not enough protection can result in hearing loss.

Plexiglass baffles can be used to reduce the noise from other instruments. These are particularly relevant for drummer's high-hat cymbals. Drums and brass can be particularly a problem. Ear monitors are small in-the-ear devices that look like hearing aids, that can be used to electronically protect hearing, while allowing the musicians to hear themselves. Acoustic monitors are stethoscope like devices that block sound from other in the group, but allow the instrumentalist to hear their own instrument.

Loudspeakers produce both high and low frequency sounds. High frequencies tend to emanate in almost a straight line, while low frequencies are present in nearly all directions. Thus, standing besides a high-frequency source may provide some protection. Humming just prior to, and through a loud noise such as a cymbal crash or rim shot may provide some protection. Small protective muscles in the ear contract naturally when we sing or hum, and thus humming may protect from other noises.

Presbycusis

*Presbycusis* is defined as hearing loss associated with degenerative changes of aging. Presbycusis is the most common type of hearing loss in the United States. This type of hearing loss is typically gradual, bilateral, and characterized by difficulty hearing high frequencies.

There are four types: *sensory presbycusis* is caused by loss of sensory elements in the basal end (high-frequency end) of the cochlea with preservation of neurons. These patients have symmetrical, high-frequency sensorineural hearing loss (as shown below). Pathology shows loss of hair cells. *Neural presbycusis* is caused by loss of cochlear neurons. These patients have poorer discrimination than patients with sensory presbycusis. *Striatal presbycusis* is caused by loss of the stria vascularis with aging. Patients have a flat or slightly sloping hearing loss with good speech discrimination. Mixed presbycusis is also possible. A final type is *cochlear conductive presbycusis*. This is a sensorineural hearing loss caused by thickening of the basilar membrane caused by deposition of basophilic substance. This diagnosis is made on postmortem. (Harris, 1998). An example of presbycusis is shown below. Presbycusis can be inherited -- a recent study suggested that heritability of medium and low frequencies was .38 and .31 (DeStefano et al, 2003). More information about presbycusis is found [here](#). Statistical data from the US vital statistics can be found [here](#).

**References for Presbycusis**