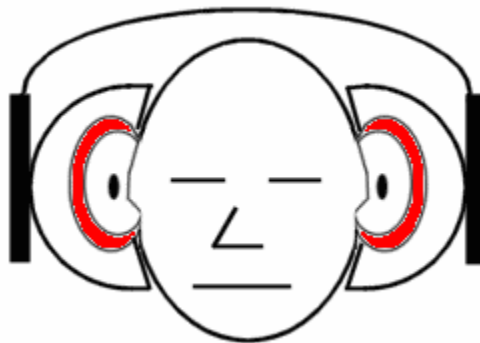


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Preventing Hearing Damage When Listening With Headphones

(A HeadWize Headphone Guide)



Hearing damage from headphones is probably more common than from loudspeakers, because many people exploit the acoustic isolation by listening at higher volumes. Moreover, the risk of hearing damage from headphones is higher than with loudspeakers, even at comparable volumes, due to the close coupling of the transducers to the ears. One of the benefits of headphone listening is the ability to detect musical details. Any hearing damage would have substantial impact on that experience. This article takes a look at the process of human hearing and offers guidelines for safe listening. (The information given here does not substitute for medical expertise. Readers should consult a physician for a diagnosis of hearing damage.)

THE ANATOMY OF HEARING LOSS

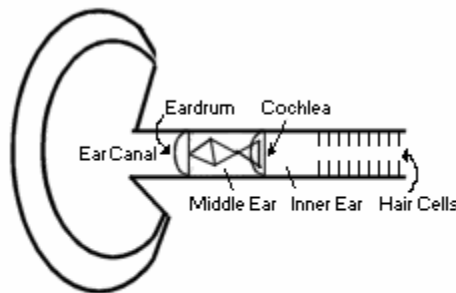


Figure 1: Simplified View of Ear Structure

The simplified view of the human ear in figure 1 identifies the basic mechanisms of human

hearing. Sound travels down the ear canal and causes the eardrum to vibrate. Inside the middle ear, a bone attached to the eardrum vibrates with the eardrum and propagates sound waves through the middle ear by way of two other ear bones, which amplify the sound. The third ear bone vibrates against the cochlea of the inner ear. The cochlea is filled with fluid and is lined with frequency-sensitive hair cells that convert vibrations into electrical signals going to the brain. The cells that respond to high frequencies are located in the outer cochlea, and those for the low frequencies follow behind.

90 dbA	8 hrs
92 dbA	6 hrs
95 dbA	4 hrs
97 dbA	3 hrs
100 dbA	2 hrs
102 dbA	1.5 hrs
105 dbA	1 hr
110 dbA	0.5 hr
115 dbA	0.25 hr or less

Note: When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Figure 2: OSHA Regulation 1910.95 - Occupational noise exposure

As seen in the OSHA Noise Exposure table in figure 2, the louder the sound, the less time it takes for damage to occur. OSHA limits noise exposure levels in the work environment to about 90dB for an 8-hour period, but permits exposure to higher levels for short periods. Many experts believe that the OSHA numbers are too high for hearing safety. EU countries have very strict laws about noise exposure. For example, U.K. employers must take action at two levels of noise exposure: 85dB and 90dB. At 85dB, employers must offer hearing protection and hearing education to employees. At 90dB or higher, employees MUST wear earplugs, and the employer MUST try to reduce the ambient noise level.

60 dB	Everyday conversation, ringing telephone.
70 dB	Restaurant.
80 dB	Heavy city traffic, alarm clock at 2 feet, factory noise, vacuum cleaner, garbage disposal.
90 dB	Subway trains, motorcycle, workshop tools, lawn mower.
100 dB	Chain saw, pneumatic drill.
110 dB	Dance club.

120 dB	Rock concert speaker sound, sandblasting, thunderclap.
130 dB	Jet take off, gunfire.

Figure 3: Decibel levels of common sounds.

Most people are exposed to dangerous noise levels on a daily basis (figure 3), but usually for far less time that it would take for hearing damage to occur. The harmful effects can be cumulative, so long-term exposure to short periods of loud noise can produce hearing loss years later.

60-70 dB	normal piano practice
70 dB	fortissimo singer 3 ft. away
75-85 dB	chamber music in small auditorium
84-103 dB	violin
85-111 dB	flute
85-114 dB	trombone
106 dB	timpani & bass drum rolls
120 - 137 dB	symphonic music peak
150 dB	rock music peak

Figure 4: Decibel levels of musical noise.

As seen in figure 4, musical instruments have the same potential to induce hearing damage as jackhammers and chainsaws. Musicians and concert-goers who fail to use hearing protection may be subjecting themselves to acoustic trauma on a regular basis. Interestingly, there are studies indicating that hearing damage may be less severe, if the individual considers the sound to be "pleasant music" as opposed to noise. Nevertheless, prolonged exposure to high volume sounds, whether music or noise, can and does result in hearing damage.

NOISE-INDUCED HEARING DAMAGE

Two types of hearing damage can result from exposure to loud noise: sensorineural hearing loss and tinnitus. Sensorineural hearing loss happens in the inner ear when high energy sound waves, rippling through ear fluid, overstimulate and kill hair cells. When hair cells for a band of frequencies are destroyed, those frequencies are no longer heard. In addition to being at the frontline of the cochlear sensor array, the high frequency hair cells are also the most sensitive. It is not surprising, then, that noise-induced hearing loss typically begins with the high frequencies in the 3kHz-6kHz range. Cochlear implants may improve hearing function in those cases, where the auditory nerve cells (that connect to the hair cells) are still intact.

If loud noise only damages the hair cells beyond their capacity to heal completely, then either hearing at certain frequencies will be diminished and/or the listener will suffer tinnitus, when the damaged cells fire continuously even though there is no real sound. Tinnitus is typically described as a persistent, loud buzz in the head at the frequency of the hearing damage. For some tinnitus sufferers, the buzz is very loud - 90dB or more -

and can compromise the quality of life, not to mention completely ruin all ability to enjoy music. Diminished hearing can be corrected to a degree with hearing aids. Tinnitus is currently not curable, but there are treatments and devices to minimize its impact on the sufferer.

SOUND PERCEPTION IN HEADPHONES VS. LOUDSPEAKERS

In loudspeaker reproduction, sounds must travel several feet before reaching the listener's ears. By the time they arrive, a portion of the high frequencies have been absorbed by the air. Low frequencies are not absorbed as much, but they are more felt through bone conduction than actually heard. With headphones, the ears hear all frequencies without any attenuation, because the transducers are literally pressed against them. Thus, when listening to headphones at the same effective volume level as loudspeakers, headphones may still transmit louder high frequencies that are more likely to cause hearing damage.

Another hearing phenomenon that seems to be more noticeable with headphones is a decreasing sensitivity to sound levels over time, as the ears adapt to loud sounds. The listener perceives a gradual drop in loudness even though the volume control setting hasn't changed. The acoustic isolation of headphones tends to highlight this dulling effect. It is all too easy for headphone listeners to turn up the volume to the point where hearing is at risk. Interestingly, most people find it difficult to distinguish between 85dB and 100dB SPLs, despite that the latter is more injurious to hearing. Therefore, it is important to avoid listening fatigue by resting the ears in silence after long sessions with headphones and to fight the temptation to turn up the volume.

Personal stereos are another source of hearing damage risk. Using those open-air lightweight ("Walkman-style") headphones that come with portable stereos, listeners can enjoy music on the go - and often have the volume levels cranked up to drown out traffic and other outdoor noises. In a recent study of noise exposure from portable stereos ([Airo et al.](#)), listeners in a quiet laboratory setting were comfortable with headphones set at an average volume of 69 dB. Once outside where the mean noise level was 65 dB, the average volume went up to 82 dB, with some levels as high as 95 dB. The study concluded that "[s]ome hearing loss risk would be expected when [portable stereos] are used in noisy conditions at work or among traffic, and therefore avoiding continuous use of [portable stereos] in noisy conditions is recommended." (See [SETTING SAFE HEADPHONE VOLUME LEVELS](#) below for tips on safe listening in high noise environments.)

Wearing headphones (especially the Walkman-style) during exercise is also dangerous to hearing. Aerobic exercise diverts blood from the ears to the limbs, and leaves the inner ear more vulnerable to damage from loud sound. A Swedish study estimated that the risk of hearing loss is doubled when listening to headphones at high volume during aerobic exercise. The study recommends limiting headphone use during exercise to one-half hour per day at half volume. (See [SETTING SAFE HEADPHONE VOLUME LEVELS](#) below for more tips on safe listening in high noise exercise environments.)

SYMPTOMS OF HEARING DAMAGE

Hearing damage from excessive noise exposure is not always permanent. Even if one's hearing has been subjected to major acoustic shock, quick medical intervention may minimize the trauma. On the other hand, hearing damage can also be gradual, cumulative and without obvious warning signs. A hearing test and a medical examination are the only way to truly diagnose hearing damage. However, the following symptoms are serious enough to warrant an appointment with the ear doctor:

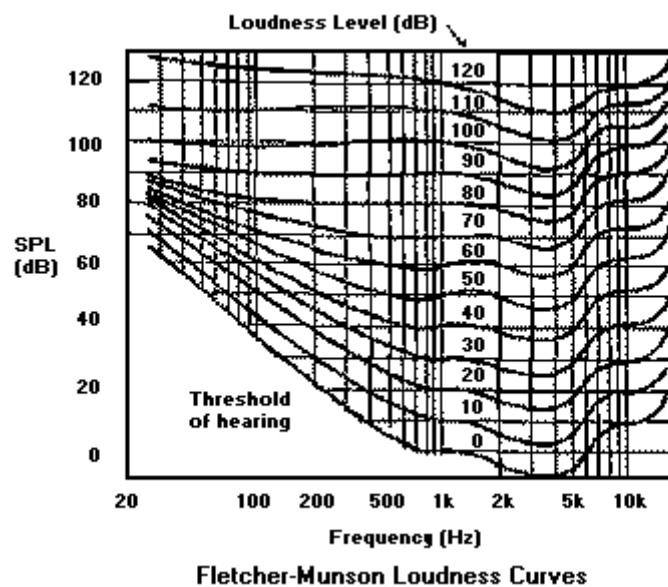
- Ringing or buzzing in the ears
- Difficulty in understanding speech.
- Slight muffling of sounds
- Difficulty understanding speech in noisy places or places with poor acoustics

After exposure to loud music, the listener may experience "threshold shifting," when low-level sounds are no longer as audible as they were. Lee Ranaldo (Sonic Youth) suggests the following procedure to test hearing after attending a loud concert or listening to loud music:

[S]et the volume of your radio to a level where you can barely hear the words. A talk show works best, as sometimes it is hard to understand lyrics in music. After [listening to loud music], turn on the radio to the same setting. Can you still hear and understand the words? If not, you're experiencing a form of short term hearing loss called temporary threshold shift. When this happens too many times, the damage can become permanent.

More severe symptoms of hearing damage can include acute or chronic dizziness, pain, discomfort, and drainage from the ears. In the case of severe acoustic trauma, an immediate visit to an ear doctor or the Emergency Room of a hospital is in order. There are medications that when given in time may minimize hearing loss.

SETTING SAFE HEADPHONE VOLUME LEVELS



The Fletcher-Munson loudness curves (shown above) indicate that low-level listening may not be as satisfying because perception of loudness is not linear, but is dependent on frequency and volume. The curves are flattest when the SPL is at the threshold of pain. Tone controls can rebalance sound to have the same pleasing amplitude spectrum at lower listening levels. The most accurate loudness compensation would dynamically adjust to both frequency and volume. Such dynamic filters are not widely available to consumers. Still, a small amount of equalization (treble and bass boost) can restore naturalness to the sound of headphones, so that listening at safe levels is appealing (or at least, not unappealing).

The table in figure 1 lists the maximum safe exposure times at various noise levels, but headphones do not come with built-in SPL meters to help the listener determine whether the volume is too high. Also, audio professionals may need to set the gain of the headphone amplifier high to hear low-level details clearly, but then are overwhelmed when the music swells or explodes in crescendos. Therefore, methods for setting safe headphone volume levels depend on how the headphones are being used.

Indoors in a quiet listening environment: According to the [Airo](#) study, listeners in a quiet room set headphone volumes at an average of 69 dB, a little less than the average sound level in a restaurant. With open-air headphones, the ability to hear normal conversation through the headphones is a good indicator that the volume level is safe. Because closed-ear headphones acoustically isolate the listener, normal conversation may not be audible when wearing these types of headphones. Instead, a safe volume level may be set by moving one earcup off and comparing the level in other earcup with that of normal conversation.

Outdoors on a busy street: The average sound level on a busy street is about 80 dB. In the [Airo](#) study, when the outdoor noise was a mere 65 dB, listeners raised headphone volume levels to over 80 dB. Therefore, on a busy street, levels would likely have to be dangerously high to drown out ambient noise - especially if open-air headphones are used. While the Airo study recommends not using headphones in such noisy conditions, if the listener insists on musical accompaniment outdoors, closed-ear headphones and canalphones that substantially attenuate ambient noise may allow for safer listening volumes.

Two other options for safer outdoor listening involve using ear protectors and ear plugs. Although a bit bulky, wearing ear protectors over earbuds or other small phones can provide a quiet listening environment. A less cumbersome alternative is to put on headphones after inserting foam ear plugs (the kind with at least 30dB of even attenuation across the audio spectrum). This setup may allow a higher headphone volume to mask outdoor noise but still maintain a safer listening level inside the ears. Neither of these options will provide adequate protection if the headphone volume is set too high.



Performers onstage: Although performers onstage can monitor with closed-ear headphones, they are usually too cumbersome for performers who move around. (Open-air phones have no acoustic isolation and are rarely used in a live performance, unless the performer must hear ambient sounds.) Instead, in-ear monitoring systems offer both acoustic isolation and mobility without the need for floor monitor (wedge) and sidefill loudspeakers. In-ear monitors are usually canalphones attached a wireless receiver unit worn by the performer. For the best acoustic isolation, the earpieces should be custom-molded for each performer's ears (a temporary solution is to expand the earpiece to fit snugly with a small amount of moldable earplug compound - check with the earphone manufacturer first about any precautions).

An audio limiter to set the maximum level for the canalphone is essential, since

amplified transient noise could result in severe acoustic trauma. When ambient noise levels are very high, no headphone or canalphone may offer enough acoustic isolation for safe listening. Whether closed-ear or in-ear headphones are used, an audiologist can measure the SPLs from inside a performer's ears with the help of a tiny probe to determine safe listening levels.

In recording studios: Audio engineers tend to run headphones at higher levels to hear details. Closed-ear headphones and canalphones are the best choice for monitoring at setting safe listening levels, as they block ambient sounds. Console operators rarely monitor with open-air headphones (especially in noisy environments), because of bass leakage and poor acoustic isolation. Musicians will also hear more clearly and safely with closed-ear phones. Vocalists prefer open-air phones to be able to hear their own voices when singing and may listen most safely with open-air phones when in isolation.

An audio limiter for each musician is a good idea, even in the studio (however, engineers may need to hear musical dynamics accurately). In any case, musicians can set their own listening levels with remote volume controls. The better distribution systems allow musicians to individually control their mix as well as the volume. A custom mix allows a musician to listen at a lower level by masking out sounds that have minimal impact on their performance. For more information about using headphones in professional settings, see [The Art of Monitoring and Mixing With Headphones](#).



Anyone who listens to loud music or is exposed to loud noise on a regular basis should test hearing periodically, because hearing loss can be cumulative, very gradual and virtually symptomless. In cases of temporary hearing loss, such tests can ensure that there has been adequate recovery time. While headphones can damage hearing if played too loudly, they are also a good means of testing hearing. Any of the test CDs for evaluating loudspeakers and headphones will have a series of test tones that span the audio spectrum. An impromptu listen of these tones can help determine the range of a person's hearing. A more detailed assessment requires a CD designed for testing hearing. Audiometric CDs, such as Audio-CD from [Digital Recordings](#), are accurate enough to measure trends in a person's hearing.

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Addendum

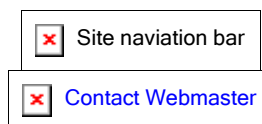
12/16/98: Expanded discussion of safer options for outdoor listening and added discussion of hearing damage risk from listening to headphones during exercise.

3/25/01: Added new information on musicians and hearing loss and noise-induced hearing loss.

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