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Noise Exposure and Hearing Disorders

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Exposure to unwanted sounds, or noise, is a common on-the-job occurrence. An unfortunate consequence is work-related hearing loss, a condition which has been listed as one of the most prevalent occupational health concerns in the United States for more than 25 years.¹ Hearing loss can be a seriously disabling condition due to the integral role of hearing in human communication. Hearing-impaired individuals often avoid situations in which communication is difficult, rather than risking a misunderstanding and potentially embarrassing mistakes. This tendency leads to isolation, difficulties at work, and possibly adverse psychological consequences. The following scenarios illustrate difficulties associated with noise-induced hearing loss (NIHL):

- Going to restaurants, parties, or other social gatherings becomes a chore, since background noise or music makes conversation difficult, if not impossible.
- Watching television requires the volume to be set very loud, making it irritating or annoying for the rest of the family to be in the same room.
- Working in noisy environments can make communication difficult and increase the risk of workplace injuries due to an inability

- to hear environmental sounds and warning signals. 33
- Dealing with tinnitus (the perception of sound in the absence of external acoustic stimuli) becomes an unexpected consequence for some, who expected a hearing loss to result in silence, not an ever-present ringing in their ears. 34

Greater awareness and improved noise-control strategies are needed for the prevention of these hearing disorders. 35

PROPERTIES OF SOUND 44

Sound results from oscillations in pressure in any “elastic” medium, such as air, water, and solids, that effectively couples the sound source with the ear. When transmitted through air, sound is usually described in terms of variations in pressure that alternate above and below the ambient atmospheric pressure. The characteristics of a particular sound depend on the rate at which the sound source vibrates, the amplitude of the vibration, and the properties of the conducting medium. Frequency is an objective description of the rate at which complete cycles of high- and low-pressure regions are produced by a sound source, and it is measured in Hertz (Hz). Subjectively, frequency is often referred to



1 as “pitch,” although there is not an exact corre-
 2 lation between the two terms. Normal human
 3 ears respond to a very wide frequency range,
 4 approximately from 20 to 20,000 Hz.

5 A normal healthy human ear is also capable of
 6 detecting a remarkable range of sound levels.
 7 When the term *level* is used in acoustics, decibel
 8 notation is implied. By definition, the decibel
 9 (dB) is a dimensionless unit, related to the loga-
 10 rithm of the ratio of a measured quantity to a
 11 reference quantity. Decibel notation can cause
 12 confusion because it is often associated with dif-
 13 ferent reference quantities. Acoustic intensity,
 14 acoustic power, hearing thresholds, electric volt-
 15 age, electric current, electric power, and sound
 16 pressure level may all be expressed in decibels,
 17 each having a different reference. The decibel
 18 has no meaning unless a reference quantity is
 19 specified, or the reference quantity is understood
 20 from the context in which it is being used. Sound
 21 pressure levels (SPLs) as high as those produced
 22 by jet engines (120 dB or greater) are found in
 23 some work areas, whereas sound levels approach-
 24 ing the threshold of hearing (approximately
 25 0 dB) are used for audiometric testing.

26 ASSESSMENT OF NOISE EXPOSURE

27 The terms *noise* and *sound* are often used inter-
 28 changeably; however, sound is normally used to
 29 describe useful communication or pleasant
 30 audible signals, such as music, whereas noise is
 31 frequently considered as unpleasant or unwanted
 32 sound. Four major factors contribute to the
 33 occurrence of negative noise effects: (a) the
 34 overall noise level, (b) the frequency content,
 35 (c) the duration of exposure, and (d) the suscep-
 36 tibility of the individual.

37 There is a wide variety of measurement instru-
 38 mentation for conducting noise-exposure assess-
 39 ments. Careful consideration of the objectives of
 40 the measurement must be made prior to equip-
 41 ment selection. Sound-level meters and noise
 42 dosimeters are the instruments that are used
 43 most often. In all circumstances, accurate sound-
 44 level measurements require a well-trained oper-
 45 ator and calibrated instruments.

46 A basic sound-level meter consists of a micro-
 47 phone that converts air pressure variations
 48 into an electrical signal, an amplifier/filter, an

49 exponential time-averaging circuit, a device to
 50 determine the logarithm of the signal, and some
 51 type of output display. Some sound-level meters
 52 provide only the basic functions, while others
 53 are equipped with a very wide range of features,
 54 including integration for dose and impulse noise
 55 measurement capabilities.

56 General-purpose sound-level meters are nor-
 57 mally equipped with two filters or frequency-
 58 weighting networks, designated by the letters
 59 A and C. Other frequency-weighting networks,
 60 such as B and D, have been developed, but they
 61 are not used for industrial noise measurements.
 62 Most sound-level meters also will have a linear
 63 or flat response setting, which does not apply
 64 any correction values—that is, it weights all fre-
 65 quencies equally. The particular weighting net-
 66 work used must always be indicated when
 67 sound-level readings are obtained. The A, B, and
 68 C weighting curves approximate the response
 69 characteristics of the human ear at various sound
 70 levels, and, in the earliest sound-level meters,
 71 they could be easily produced with a few
 72 common electronic components. Empirically,
 73 the A-weighting has been found to give a good
 74 estimation of the risk potential for hearing
 75 damage from exposure to continuous noise. It is
 76 the weighting network used for occupational
 77 noise exposure measurements.

78 A noise dosimeter consists of a miniature
 79 microphone connected to a small microprocessor-
 80 based sound-level meter, which stores the noise
 81 data. The microphone is positioned at the top of
 82 a worker’s shoulder, and the sound-level meter
 83 hardware unit is clipped to the wearer’s belt or
 84 placed in a pocket. Noise dosimeters continu-
 85 ously measure sound levels obtained near a
 86 worker’s ear, then provide an average value for
 87 the exposure throughout the individual’s work
 88 day. A dosimeter is essentially identical to any
 89 other sound-level meter, with the addition of an
 90 integrating function that keeps track of the noise
 91 level as well as the accumulated exposure time.
 92 Dosimeters make it convenient to measure and
 93 assess a person’s noise exposures, by eliminating
 94 the need for the surveyor to follow a worker
 95 throughout the work day with a sound-level
 96 meter and a stopwatch to assess the worker’s
 97 exact amount of exposure to different noise
 98 levels. Many instruments can continuously log
 99 or store noise exposure levels at 1-minute, 99

1 10-second, or even 1-second intervals. This noise
 2 exposure history information can be saved and
 3 analyzed in many ways to help pinpoint periods
 4 of high noise levels or other significant occur-
 5 rences during a work shift.
 6 A worker’s daily noise dose can be expressed
 7 as a percentage, with 100% constituting the limit
 8 of acceptable exposure. A noise dose is usually
 9 converted into an 8-hour time-weighted average
 10 (TWA). A TWA is a single value for noise level
 11 obtained by averaging all of the different sound
 12 levels that a worker is exposed to during the
 13 work day and normalizing that average to
 14 8 hours. The TWA represents that constant noise
 15 level in dBA that has the same severity over
 16 8 hours as the exposure to the actual noise in a
 17 work day.

18 **NOISE-INDUCED HEARING LOSS**

19 The Bureau of Labor Statistics has identified
 20 noise-induced hearing loss (NIHL) as a leading
 21 work-related condition.¹ The reported preva-
 22 lence of work-related hearing loss varies consid-
 23 erably among occupational groups. With 10 or
 24 more years of noise exposure, it is estimated that
 25 8% of the workers exposed to 85 dBA, 22% of
 26 the workers exposed to 90 dBA, 38% of the
 27 workers exposed to 95 dBA, and 44% of those
 28 exposed to 100 dBA will develop hearing
 29 impairment.² Noise-induced hearing loss is esti-
 30 mated to be among the most common causes of
 31 acquired hearing loss. The National Institutes of
 32 Health estimates that approximately one-third
 33 of all hearing losses can be attributed, at least in
 34 part, to noise exposure.³

35 Noise-induced hearing loss is a specific condi-
 36 tion with established symptoms and objective
 37 findings. The following features characterize
 38 cases of NIHL:

- 39 1. Irreversible sensorineural (nerve-type)
 40 hearing loss that cannot be corrected by
 41 conventional medical or surgical proce-
 42 dures, with damage mainly to the cells in
 43 the peripheral auditory organ, which are
 44 responsible for transforming the sound
 45 waves into neural signals.
- 46 2. A history of long-term exposure to noise
 47 levels—exposure to continuous noise

- 48 levels greater than 85 dBA for 8 hours a
 49 day, or exposure to impact/impulse noise
 50 with peaks over 140 dB.
- 51 3. Hearing loss that has developed gradually
 52 over a period of years, most rapidly during
 53 the first 6 to 10 years of exposure—
 54 with the rate of loss decreasing as hearing
 55 thresholds increase, in contrast to age-
 56 related hearing loss.
- 57 4. Usually starting in the high frequencies
 58 (high-pitched sounds), with most affected
 59 persons showing a loss or “notch” in sensi-
 60 tivity at 4,000 Hz. (If high-level noise expo-
 61 sures continue, the loss of hearing generally
 62 spreads to adjacent frequencies above and
 63 below 4,000 Hz.)
- 64 5. An initial hearing loss that may be tempo-
 65 rary, after which the original hearing sensi-
 66 tivity is usually restored within a matter of
 67 hours. (However, in some cases temporary
 68 losses may last for days or weeks. Perma-
 69 nent losses result when these temporary
 70 losses do not recover completely.)
- 71 6. Reduced word recognition ability that
 72 is consistent with the degree of high-
 73 frequency hearing loss.
- 74 7. No progression if the person is removed
 75 from noise exposure.

76 Hearing loss resulting from hazardous long-
 77 term exposure to noise progresses in a fairly
 78 well-established, recognizable pattern. Noise-
 79 induced hearing loss at the frequencies maxi-
 80 mally affected (4,000 and 6,000 Hz) shows a
 81 rapid increase over the first 10 years of exposure;
 82 the development of the hearing loss then slows
 83 and tends to plateau. Hearing loss at frequencies
 84 below 4,000 Hz develops at a slower rate, but
 85 continuously throughout the entire exposure
 86 period.

87 Noise-induced hearing loss has a gradual
 88 onset, and the affected individual might be
 89 unaware of any change until significant damage
 90 has occurred. Remedial behaviors, such as turn-
 91 ing up the radio or television volume or blaming
 92 others for not speaking clearly, may conceal ini-
 93 tial hearing difficulties. The affected person may
 94 be unaware of any hearing problem even when
 95 the hearing test indicates decreased hearing abil-
 96 ity. In some cases, damage may occur instanta-
 97 neously, depending upon the noise characteristics

1 and exposure circumstances. These cases are
 2 usually referred to as “acoustic trauma.” Gener-
 3 ally, impulsive or impact noises are most likely
 4 to produce significant losses within short expo-
 5 sure periods, and steady-state continuous noises
 6 are responsible for impairments that develop
 7 over a long period of time.

8 Traditionally the mechanism underlying
 9 NIHL has been explained as physical trauma
 10 causing damage to the cochlea, which contains
 11 hair cells responsible for transforming the sound
 12 waves into neural signals that are transmitted to
 13 the auditory nerve and ultimately to the brain
 14 (Fig. 21-1). Hair cells are attached to the basilar
 15 membrane, and the stereocilia are in contact
 16 with the tectorial membrane. Sound waves lead
 17 the basilar membrane to vibrate up and down.
 18 The vibration creates a shearing force between
 19 the basilar membrane and the tectorial mem-
 20 brane, causing the hair-cell stereocilia to bend
 21 back and forth. This leads to internal changes
 22 within the hair cells that create electrical signals.
 23 Auditory nerve fibers rest below the hair cells
 24 and pass these signals on to the brain. Therefore,
 25 hair cells respond to sounds by bending of the
 26 stereocilia.^{4,5}

27 The most common morphological finding in
 28 NIHL is degeneration of the hair cells (mainly
 29 the outer rows), which are thought to be the
 30 most vulnerable structures of the organ of Corti.
 31 The damage of inner hair cells and especially
 32 outer hair cells is described as a disarrangement
 33 of hairs, fusion of stereocilia, formation of giant
 34 hairs that exceed the normal stereocilia in length

and thickness, and deformation of cuticular 35
 plates. The loss of the outer hair cells induces 36
 retrograde degeneration of the efferent fibers, 37
 but it has little effect on the afferent cochlear 38
 neurons. Therefore, if there were damage to the 39
 outer hair cells alone, the lesion would be less 40
 obvious—since only rather extensive damage to 41
 the inner hair cells causes substantial degenera- 42
 tion of the afferent nerve fibers. 43

44 Recently, metabolic processes involving oxi-
 45 dative stress have been shown to contribute to
 NIHL. The generation of reactive oxygen species, 46
 or free radicals, has been associated with cellular 47
 injury in different organ systems. Free radicals 48
 produce cell damage by binding to macromole- 49
 cules and producing lipid peroxidation—a basic 50
 mechanism of toxicity that is thought to be part 51
 of the mechanism of acquired hearing loss. Med- 52
 ical treatments, such as antioxidants, are being 53
 sought to prevent or minimize hair cell damage. 54

OTHER EFFECTS OF NOISE EXPOSURE 55

56 Exposure to excessive levels of noise is not
 57 restricted to the work environment, and the
 effects of noise exposure are not restricted solely 58
 to decreased hearing. Noise from power tools, 59
 powered lawn maintenance equipment, farm 60
 equipment, and shooting hobbies (such as skeet, 61
 targets, and hunting) or other recreational activ- 62
 ities, such as attending music concerts, riding 63
 in motorboats, and watching automobile or 64
 motorcycle races, are examples of potentially 65

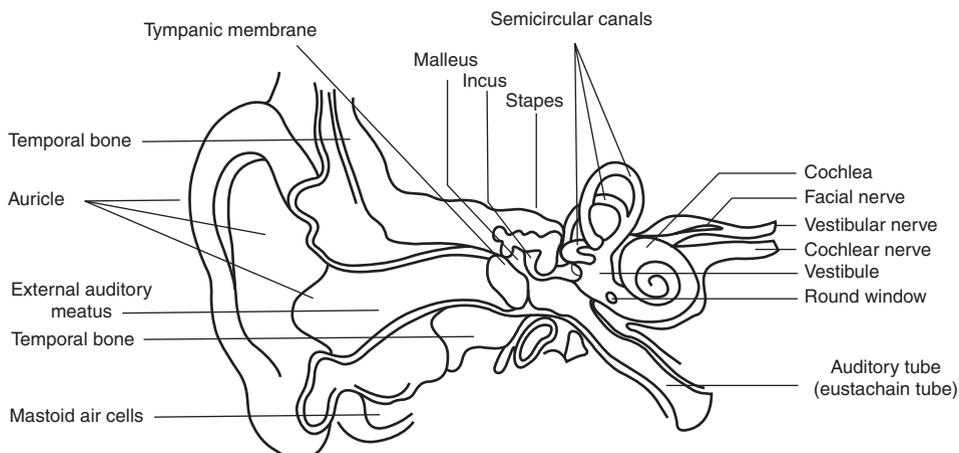


Figure 21-1. Schematic drawing of the ear.



1 hazardous nonoccupational sources of noise.
 2 Additionally, excessive noise exposure is associ-
 3 ated with hypertension, ischemic heart disease,
 4 respiratory disorders, annoyance, sleep distur-
 5 bance, and decreased school performance. Noise
 6 can also disrupt communication. Some studies
 7 have suggested an association between accidents
 8 and both occupational noise exposure and/or
 9 hearing loss.^{6,7}

46 susceptibility, including age, gender, race, blood
 47 pressure, and use of certain medications.
 48 A common scientific opinion is that hearing loss
 49 due to noise exposure should not continue to
 50 progress if the person is removed from noise
 51 exposure. There is, however, limited knowledge
 52 about how noise impairment is influenced by, or
 53 interacts with, age-related hearing impairment.
 54 The effects of noise and age are challenging to
 55 differentiate, but they seem to be additive.
 56 Hearing acuity may decline with aging, but a
 57 healthy person who has not been exposed to
 58 ototraumatic or ototoxic agents may have
 59 normal hearing acuity even after age 65. The
 60 median hearing level across the frequencies of
 61 1,000, 2,000, 3,000, and 4,000 Hz for 60-year-
 62 olds not exposed to noise is 17 dB HL for males
 63 and 12 dB HL for females.¹¹ Young animals are
 64 probably more susceptible to the effects of noise.
 65 Mice that had been exposed to noise at different
 66 ages between 4 and 124 weeks demonstrate dif-
 67 ferences in their sensitivity to noise exposure;
 68 mice exposed to noise when they are young
 69 suffer greater hearing impairment, compared to
 70 elderly mice.¹² When young mice age, they have
 71 been found to have an age-related hearing loss
 72 that is more severe than mice of the same age
 73 who have not been exposed to noise, suggesting
 74 that noise exposure makes mice more sensitive
 75 to age-related hearing impairment.

10 **THE IMPACT OF HEARING DISORDERS**

11 Consequences of hearing disorders range from
 12 slight to seriously debilitating. At work, a hear-
 13 ing loss can increase difficulties associated with
 14 the use of hearing protectors, causing interfer-
 15 ence with verbal communication and detection
 16 of warning signals. In addition, the earnings of
 17 workers with severe hearing loss are estimated to
 18 be 50% to 70% of those than their peers without
 19 hearing impairment.⁸

20 Hearing loss can have a severe impact on social
 21 interaction and family life. Hearing disabilities
 22 may have a negative effect on self-image, causing
 23 a perception of oneself as abnormal, prematurely
 24 old, or as a burden because affected individuals
 25 often ask others to repeat what they say. There
 26 are several barriers to seeking help and using
 27 hearing aids, including cost, pride, denial of a
 28 problem, and the stigma attached to deafness.
 29 People with hearing difficulties will often try to
 30 downplay or conceal its seriousness to minimize
 31 the risk of being marginalized, and they may
 32 avoid seeking help. People with untreated hear-
 33 ing loss are more likely to report depression and
 34 anxiety, and they are less likely to participate in
 35 social activities compared to those who wear
 36 hearing aids.⁹ Unfortunately, less than 20% of
 37 the estimated 28 million U.S. residents who
 38 could benefit from hearing devices own them,
 39 and less than 20% of physicians include hearing
 40 testing in regular physical examinations.¹⁰

76 Gender and race seem also to be associated
 77 with susceptibility to NIHL. White males have
 78 the highest rates of noise-induced hearing loss,
 79 and African American females the lowest.

80 Certain nonacoustic factors in the workplace,
 81 which may directly affect hearing or interact
 82 with noise, are considered possible contributors
 83 to variability in individual susceptibility to
 84 NIHL.¹³ For example, workers with vibration-
 85 induced white finger (VWF) syndrome have a
 86 higher rate of hearing loss than workers exposed
 87 to similar noise levels, but not to vibration.¹⁴ It is
 88 not known if whole-body vibration enhances
 89 risk for hearing loss.

41 **INFLUENCE OF OTHER FACTORS ON**
42 **HEARING LOSS**

43 The incidence and degree of hearing loss
 44 vary greatly among groups, partly due to endog-
 45 enous factors or individual attributes that affect

Hearing Loss from Chemical
Exposures

90
91
92 Since noise is present in most occupational
 93 settings, the hearing disorders observed among
 94 workers are often attributed to noise exposure



1 alone, without considering the effects of other
2 agents. The terms “occupational” and “work-
3 related” hearing loss have been used synony-
4 mously for NIHL, although this is not always
5 correct, since chemical agents have also been
6 implicated in hearing loss. In several settings,
7 noise coexists with other factors that are poten-
8 tially dangerous for hearing, so caution should be
9 taken before identifying a hearing loss simply as
10 noise induced. Moreover, when one considers the
11 possibility that other environmental and occupa-
12 tional factors can affect hearing, current hearing
13 loss prevention initiatives need to be reexamined.

14 Sensorineural hearing loss is increased in
15 noise-exposed workers who are also exposed to
16 certain chemicals, due to their effects on the
17 auditory system or brain. For example, some
18 metals, solvents, polychlorinated biphenyls
19 (PCBs), pesticides, and asphyxiants (such as
20 carbon monoxide) adversely affect the auditory
21 system, even in the absence of excessive noise.¹⁵
22 If workers are exposed to these chemicals at suf-
23 ficiently high concentrations, their hearing may
24 be impaired, even in the absence of exposure to
25 loud noise. Work activities that involve exposure
26 to these agents, often in combination with noise,
27 include manufacturing of metal, leather, and
28 petroleum products; painting; printing; wood-
29 working; construction; furniture making;
30 fueling vehicles and aircraft; degreasing; and
31 firefighting. In addition, hearing loss may occur
32 following consumption of water or fish contam-
33 inated with these chemicals.

34 Exposure to solvents was implicated as a caus-
35 ative factor for hearing loss in a 20-year longitu-
36 dinal study in a company where 23% of workers
37 in the chemical division had compensable hear-
38 ing loss, compared to 5% to 8% of company
39 workers not exposed to chemicals. This effect
40 was found despite the lower noise levels in the
41 chemical division (80 to 90 dBA, compared to
42 95 to 100 dBA elsewhere).¹⁶ Solvents, which can
43 reach the inner ear via the blood, may cause
44 damage to some structures and functions of the
45 inner ear. The onset latency, site of lesion, injury
46 mechanism, and extent of ototoxic damage from
47 these toxins vary due to risk factors such as the
48 type of chemical, interactions with other agents,
49 and exposure level and duration.

50 Hearing loss from ototoxicity is bilaterally
51 symmetrical and often irreversible. Similar to

the effect of noise exposure, a high-frequency 52
“notch” on the audiogram is often present fol- 53
lowing long-term exposure to ototoxic chemi- 54
cals, although a wider range of frequencies may 55
be affected, from 2,000 to 8,000 Hz.^{15,17} 56

Ototoxicity of chemicals had been overlooked 57
for a long time because (a) workers exposed to 58
ototoxic chemicals are often also exposed to 59
loud noise, and (b) audiograms do not identify 60
the cause of hearing loss. (See Box 21-1.) Conse- 61
quently, it is difficult to perform a differential 62
diagnosis of hearing impairment and assign 63
causation. The nature and severity of ototoxic 64
damage vary according to type of chemical, 65
chemical interactions, and level, duration, and 66
pathway exposure—as well as exposure to exces- 67
sive noise. The National Institute for Occupa- 68
tional Safety and Health (NIOSH) recommends 69
that hearing-loss prevention programs consider 70
chemical exposures when monitoring for haz- 71
ards, assessing hearing, and controlling expo- 72
sures.^{18,19} Since 1998, the American Conference 73
of Governmental Industrial Hygienists (ACGIH) 74
has recommended audiograms for workers 75
exposed to toluene, lead, manganese, or n-butyl 76
alcohol.²⁰ 77

TINNITUS 78

Tinnitus is a condition often associated with 79
many forms of hearing loss. It is usually described 80
as “ringing in the ears,” but other forms of sound 81
have been reported, such as buzzing, pulsing, 82
hissing, knocking, roaring, whooshing, chirping, 83
whistling, and clicking. Tinnitus can be continu- 84
ous or intermittent—lasting for minutes to a few 85
hours at a time. It can be a minor annoyance 86
or a serious and nearly intolerable condition. 87
In severe cases, it may interfere with daily activi- 88
ties and sleep. Tinnitus is associated with noise 89
exposure frequently, and also with more than 90
200 medications as well as dietary, nutritional, 91
hormonal, immunological, and stress factors. 92
(See Box 21-2.) 93

Although the reported prevalence of work- 94
related tinnitus ranges from 17% to 60% of 95
cases among noise-exposed workers,^{21,22} it has 96
attracted relatively little interest. For example, 97
only 13 U.S. states and the United Kingdom, 98
Canada, Australia, Germany, Denmark, and 99

Box 21-1. Case of Hearing Loss Following Noise and Chemical Exposures

A 41-year-old man came to the occupational medicine clinic for his annual physical examination. He worked in a company that made specialized paints. His job in the paint-mixing rooms was to open and mix the contents of large barrels of solvents, including xylene, toluene, and methyl ethyl ketone in a specified manner, with intermittent use of a loud mixing machine. He did not wear hearing protection because the 8-hour time-weighted average (TWA) of noise exposure during the previous year was 84 dBA. The ventilation in the mixing room had not always been optimal, causing a usually strong solvent smell. He also noted that he often spilled small amounts of solvents on his hands and arms, after which he wiped himself with a rag. He has noted that his hearing had been getting worse, and he was concerned about going deaf. He had no major medical problems and no family history of significant hearing loss.

His physical examination was normal, except for some defatting of his fingertips and apparent hearing difficulty. His audiogram showed a significant hearing loss at high frequencies bilaterally (Fig. 21-2). Compared to his baseline audiogram with the company, he has lost more than 10 dB (as an average over 2,000, 3,000, and 4,000 Hz), and he also had an absolute loss greater than 25 dB at these frequencies. (Therefore, his loss was potentially recordable under the Occupational Safety and Health Administration [OSHA] recordkeeping standards, if it was thought to be due to workplace exposures.) A full audiological evaluation revealed that his hearing loss was sensorineural, and there was no other medical explanation for it.

The physician who evaluated him was faced with several questions concerning this worker:

1. Given that noise exposure, as measured during the previous year, was not excessive, what were possible explanations for the worker's degree of hearing loss?
2. Should his hearing loss be considered a work-related medical condition?
3. What further steps are warranted in evaluating this worker's hearing loss and preventing further hearing loss?

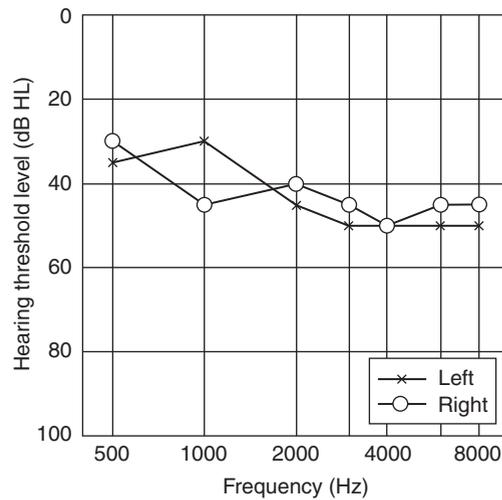


Figure 21-2. Audiogram of a 41-year-old man who works in paint manufacturing.

This man had been exposed to intermittent noise at work. His noise exposure, as an 8-hour TWA, was below the OSHA action level, but peak exposures from the mixing machine may have been high enough to cause hearing loss over time, even with the 8-hour TWA being less than 85 dBA.

In addition, this worker had simultaneously been exposed to a variety of organic solvents, including xylene and toluene, which are neurotoxic and ototoxic. These solvent exposures in this relatively young man may be (a) potentiating the adverse effects of noise on cochlear hair-cell function and survival, and/or (b) having a direct independent ototoxic effect. It was necessary to reduce his exposures to both noise and solvents to preserve his hearing.

- 1 Sweden provide workers' compensation for
- 2 tinnitus.²²
- 3 It is likely that there are several mechanisms
- 4 that cause tinnitus. It likely results from increases
- 5 in the spontaneous neural activity in the audi-
- 6 tory system. The first relay of the primary
- 7 auditory pathway is in the cochlear nuclei in the
- 8 brainstem, which tend to develop hyperactivity
- 9 that might be relayed to higher levels in the
- 10 brain. Alternatively, heightened activity of some
- 11 descending pathway or other central mechanism
- 12 might explain this hyperactivity.

GOVERNMENTAL REGULATIONS

13

Federal, state, and local governments set and 14
 enforce noise standards for aircraft, airports, 15
 interstate motor carriers, railroads, medium- 16
 and heavy-duty trucks, motorcycles, mopeds, 17
 and many commercial, industrial, and residen- 18
 tial activities. 19

The Environmental Protection Agency (EPA) 20
 coordinated all federal noise-control activities 21
 until 1983. Responsibility of regulating noise was 22
 then transferred to state and local governments. 23

Box 21-2. Case of Noise-Induced Hearing Loss and Tinnitus

A 55-year-old dockworker with tinnitus was evaluated. His job involved working in the hold of freighters, loading and unloading cargo, including steel girders and rods and crates of frozen produce. From a cab, he also operated a loading crane several hours a day. He reported exposure to frequent impact noise from metal striking metal. He noted that, when operating the crane, he had to shout to be able to communicate to a co-worker nearby. He did not wear hearing protection, saying that he needed to hear sounds (such as that of the overhead crane when he was loading), and to shout communication when he was operating the crane. For 1 or 2 hours a day, he operated a forklift in a refrigerated warehouse, where noise from the refrigeration units was so loud that he had to shout to communicate with a co-worker at arm's length. He did not wear hearing protection when he drove the forklift because of the need to hear warning signals and communication from co-workers.

This worker reported that he first noticed tinnitus 15 years before, when his ears rang for several hours after noisy work shifts. Gradually, it became more frequent; by the time of this evaluation, it interfered with his hearing when there was background noise. He reported that many times his hearing decreased after a work shift, and then improved the following day. He also noticed that when he started his car in the morning, the radio seemed excessively loud because he had left the volume turned up the night before.

Recently, he had argued with his wife about the television volume. When she reduced the volume to a level that she preferred, he had difficulty hearing what people were saying, so he increased it. He also had noticed that talking on the phone was difficult for him if there was background noise, and that having a conversation in a bar was also increasingly difficult. He admitted that his friends had kidded him about being "in need of a hearing aid," and that the thought of having a hearing loss had led him to feel depressed.

On physical exam, his blood pressure was 140/88 and he had normal external auditory canals and tympanic membranes. His audiogram is illustrated in Figure 21-3.

This case illustrates many of the clinical aspects of noise-induced hearing loss. The worker reported exposure to occupational noise at or above 85 dBA as indicated by the "shout test." In addition to sources of steady-state noise, such as refrigerator fans and crane motors, he was also exposed to impact noise, including crashes of metal on metal. In addition, he gave a history of recurrent temporary threshold shifts after work shifts, with loss of hearing acuity and tinnitus that improved overnight. Over the years, however, such temporary changes had progressed to permanent hearing loss and tinnitus.

While the symmetric nature of his hearing loss and the "notch" at high frequencies on his audiograms all pointed to the diagnosis of noise-induced hearing loss, he needed to be referred for a full audiological evaluation for other

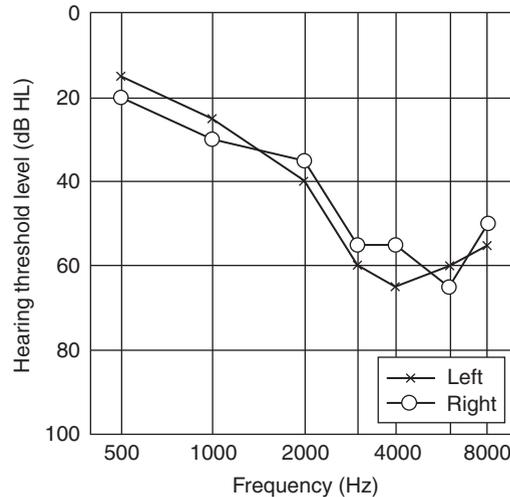


Figure 21-3. Audiogram of a 55-year-old dock worker, illustrative of noise-induced hearing loss.

audiological disorders, such as otosclerosis. He may have also been a candidate for a trial of amplification and for tinnitus treatment.

He needed to protect his hearing if he wished to remain in a noisy area. While noise reduction through engineering controls would have been the ideal way to reduce his exposure, adequate noise reduction may have been difficult, due to the nature of his work. Therefore, hearing protection may have been necessary. Standard earplugs that preferentially attenuate at higher frequencies may have worsened his problem of discriminating speech. Therefore, a "flat-attenuation" earplug may have been more appropriate for him, given his preexisting high-frequency loss.

Another occupational issue facing this man is whether he could safely operate a forklift with his degree of hearing loss. His hearing, with and without amplification, could have been compared to any internal company policies for mobile-equipment operators and to applicable Department of Transportation guidelines. A workplace accommodation for him could have been his having a radio-communication headset that could also provide hearing protection, to allow him both to protect his hearing and to communicate with others while operating the crane.

Finally, his hearing level according to American Academy of Otolaryngology criteria indicated that he had a degree of hearing impairment, which, more likely than not, was due to his occupational noise exposure—although his audiogram also suggested an element of hearing loss due to aging. His history of not wearing hearing protection was not a reason to deny him workers' compensation for his hearing loss.

1 Although the EPA no longer plays a prominent
2 role in regulating noise, its past standards and
3 regulations remain in effect, and other federal
4 agencies continue to set and enforce noise
5 standards for sources within their regulatory
6 jurisdiction.

7 Workers in general industry who are exposed
8 to noise levels above 85 dBA are required by the
9 Occupational Safety and Health Administration
10 (OSHA) to be in a hearing conservation pro-
11 gram, which includes noise measurement, noise
12 control, periodic audiometric testing, hearing
13 protection, worker education, and record keep-
14 ing. Twenty-four states, Puerto Rico, and the
15 U.S. Virgin Islands have OSHA-approved state
16 plans and have adopted their own standards and
17 enforcement policies. Most of these state stan-
18 dards are identical to those of federal OSHA.
19 However, some states have adopted different
20 standards or may have different enforcement
21 policies. Most health and safety regulations are
22 designed to keep damage risk within “acceptable
23 limits”—that is, some people are likely to incur a
24 hearing loss even when exposed to less than the
25 maximum daily amount of noise specified in a
26 regulation.

27 In the construction industry, noise exposures
28 are required to be evaluated and controlled, and
29 hearing protectors must be offered when expo-
30 sures exceed 85 dBA. Apart from exposure limits,
31 there is no mandatory hearing conservation
32 program for construction workers. However,
33 construction workers may choose to follow the
34 criteria outlined in “Hearing Loss Prevention
35 for Construction and Demolition Workers,”
36 developed by the American National Standards
37 Institute. This standard, which helps employers
38 prevent occupational hearing loss among
39 construction and demolition workers with
40 potential exposures to continuous, intermittent,
41 or impulse noise of 85 dBA and or higher, was
42 approved by the American National Standards
43 Institute (ANSI) and the American Society of
44 Safety Engineers in 2007.

45 Also in 2007, the Federal Railroad Adminis-
46 tration issued a final rule entitled “Occupational
47 Noise Exposure for Railroad Operating Employ-
48 ees,” which requires railroads to conduct noise
49 monitoring and implement a hearing conserva-
50 tion program for employees whose exposure
51 to cab noise equals or exceeds an 8-hour TWA of

85 dBA. There is no hearing-loss prevention 52
regulation for workers in agriculture, despite 53
their high prevalence of hearing loss, or for 54
workers in the service and public sectors. 55

Separate from the Occupational Noise Expo- 56
sure Standard, OSHA’s current recordkeeping 57
rule significantly altered the criteria for docu- 58
menting what constitutes a reportable hearing 59
threshold shift. Work-related hearing loss in 60
either ear is recordable when both of the follow- 61
ing occur: 62

1. An average shift in hearing threshold of 63
10 dB or greater at 2,000, 3,000, and 4,000 Hz, 64
relative to the audiometric baseline (called 65
a standard threshold shift, or STS) 66
2. The average hearing level in the same ear 67
is 25 dB or greater at 2,000, 3,000, and 68
4,000 Hz. 69

After the recording criteria were revised in 2004, 70
it was anticipated that the number of recordable 71
hearing loss cases would increase in most states,²³ 72
possibly leading to improvements in hearing 73
conservation and noise-control programs. While 74
the revision of the recording criteria has led to 75
some improvement the management of hearing 76
conservation programs, it has not had the 77
expected effects. From 2004 through 2007, 78
about 25,000 cases of recordable hearing shift 79
were reported annually to the Bureau of Labor 80
Statistics. 81

82 **STRATEGIES FOR IMPROVING** 83 **HEARING-LOSS PREVENTION IN THE** 84 **WORKPLACE**

The National Occupational Research Agenda 85
(NORA) is a partnership program developed to 86
stimulate innovative research and improved 87
workplace practices. Established in 1996, NORA 88
has become a research framework for NIOSH 89
and the United States. After diverse parties col- 90
laborate to identify the most critical issues in 91
workplace safety and health, they work together 92
to develop goals and objectives for addressing 93
these needs. Participation in NORA is broad, 94
including stakeholders from universities, large 95
and small businesses, professional societies, 96
government agencies, and worker organizations. 97

1 In 2006, the program entered its second decade
 2 with a new sector-based structure to improve
 3 the translation of research into practice in work-
 4 places. Within NORA, noise and hearing loss
 5 comprise a cross-sector area because noise and
 6 hearing loss affect almost all industrial sectors.
 7 Based on extensive experience in hearing
 8 conservation, NIOSH has published *Preventing*
 9 *Occupational Hearing Loss—A Practical Guide*.¹⁸
 10 This guide presents attributes of successful hear-
 11 ing-loss prevention programs and identifies
 12 responsibilities of management, those who
 13 implement hearing-loss prevention programs,
 14 and workers affected by noise exposure.

15 **Controlling Hazardous Exposures**

16 Initial steps of hearing-loss prevention programs
 17 are hazard assessment and control. Required
 18 noise measurements serve as the basis for assess-
 19 ing noise-control alternatives. If employees'
 20 daily noise exposures are controlled to levels
 21 below a TWA of 85 dBA, a hearing conservation
 22 program is not legally required.

23 Exposure at the NIOSH recommended expo-
 24 sure limit (REL) for occupational noise (85 dBA
 25 TWA)¹⁹ for 40 years increases the risk of NIHL
 26 by 8%—considerably lower than the 25%
 27 increased risk at the current OSHA and Mine
 28 Safety and Health Administration (MSHA) PEL
 29 of 90 dBA TWA.

30 NIOSH previously recommended a 5 dB
 31 exchange rate for halving the exposure time
 32 when calculating TWAs—that is, starting at the
 33 85 dBA REL for an 8-hour period, for each 5 dB
 34 increase in exposure, the permissible exposure
 35 time was to be halved. However, since 1998,
 36 NIOSH has recommended a 3 dB exchange rate,
 37 which is more firmly supported by scientific
 38 evidence.¹⁹ The 5 dB exchange rate is still used
 39 by OSHA and MSHA.

40 Whenever there is hazardous noise in a work-
 41 place, measures should be taken to reduce noise
 42 levels as much as possible to protect exposed
 43 workers and to monitor the effectiveness of
 44 intervention. The most effective way to prevent
 45 NIHL is to remove the noise source from the
 46 workplace, such as by engineering controls, or to
 47 remove the worker from exposure to hazardous
 48 noise.²⁴

Unfortunately, hearing protection devices 49
 (HPDs) are often adopted in lieu of controlling 50
 noise exposure. While relatively inexpensive and 51
 easy to use, providing HPDs to control noise 52
 exposure is often problematic (Fig. 21-4). In 53
 order to achieve the desired noise attenuation, 54
 workers must wear HPDs consistently during 55
 exposure to noise levels greater than 85 dBA. 56
 Workers often find it difficult to do so because 57
 HPDs can be uncomfortable and interfere with 58
 communication. Consequently, use of HPDs is 59
 inconsistent and varies widely. They are usually 60
 purchased on the basis of minimum cost and 61
 maximum attenuation, often leading to use of 62
 uncomfortable devices that overprotect. New 63
 electronic hearing protection devices are avail- 64
 able that not only protect at appropriate levels 65
 but also facilitate communication. Recommen- 66
 dations to increase the use of HPDs include 67
 identifying devices that offer adequate attenua- 68
 tion and provide workers with better comfort. 69

The original rating system developed by the 70
 EPA to measure HPD attenuation is recognized 71
 as obsolete. Laboratory-derived attenuation 72
 values have been shown to fail to predict how 73
 HPDs function in the workplace. Therefore, 74
 OSHA has instructed its compliance officers to 75
 derate the labeled noise-reduction rating (NRR) 76
 of HPDs by 50% when enforcing the OSHA 77
 Occupational Noise Exposure Standard. NIOSH 78
 recommends derating by subtracting from the 79
 NRR 25% for earmuffs, 50% for formable ear- 80
 plugs, and 70% for all other earplugs. This *vari-* 81
able derating scheme, as opposed to OSHA's 82
fixed derating scheme, distinguishes among the 83
 performance of different types of HPDs. Con- 84
 sensus standards have been developed with new 85
 strategies for a more accurate determination 86
 of HPD attenuation provided in the field. The 87
 latest standards incorporate the variance of both 88
 (a) the fit of the protector among test subjects, 89
 and (b) the variance of the HPD's performance 90
 over a wide range of noise spectra. These criteria 91
 have formed the basis of a proposed revision of 92
 EPA's Product Noise Labeling regulation.^{25,26} 93
 The proposed regulation provides guidance 94
 for evaluating and labeling passive HPDs, active 95
 noise-reduction devices, and impulsive noise- 96
 reduction devices, such as sound restoration (or 97
 nonlinear) acoustic protectors.²⁷ 98

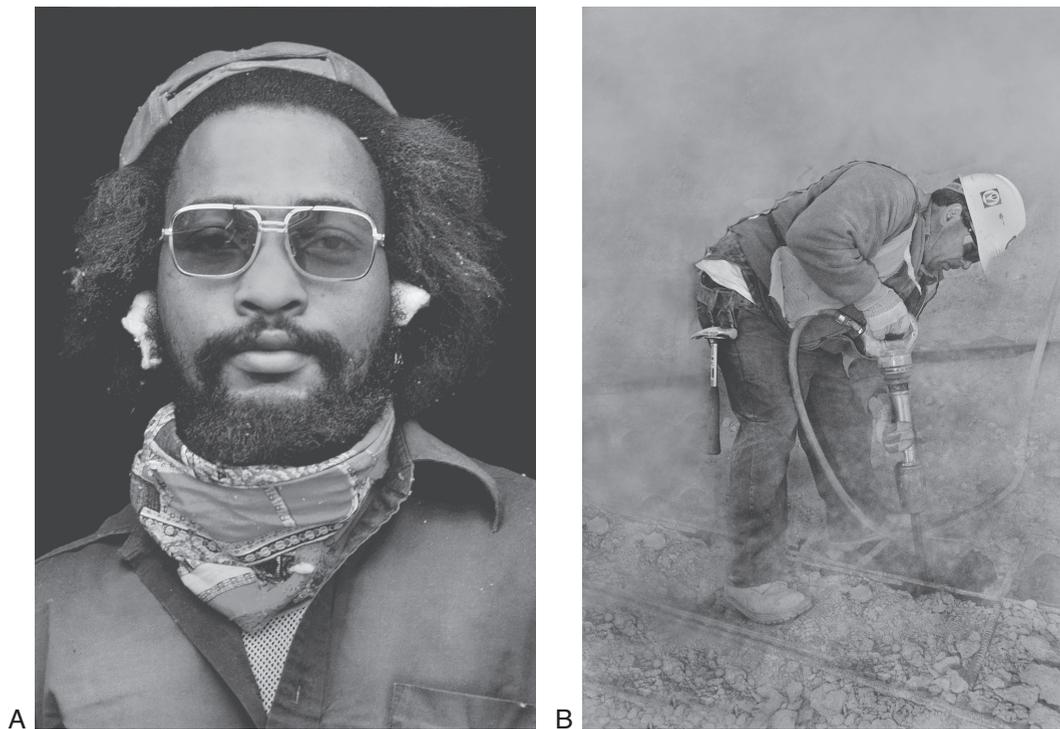


Figure 21-4. Improper and proper hearing protection: (A) Cotton earplugs are ineffective in protecting a worker from loud noise. (B) This jackhammer operator is appropriately wearing earplugs. (Photographs by Earl Dotter.)

1 Inclusion Criteria for Hearing-Loss 2 Prevention Programs

3 Federal regulations consider only noise as a risk
4 factor for hearing loss. Preventive strategies that
5 are used to protect workers from noise exposure
6 will not protect workers from incurring a hear-
7 ing loss due to chemical exposure. When oto-
8 toxic chemicals are present in the workplace,
9 hearing loss prevention measures may be needed
10 even where noise exposure does not exceed
11 85 dBA.

12 ACGIH advises workers exposed to ototoxins
13 to receive periodic audiograms.²⁰ The U.S. Army
14 requires that hearing conservation programs
15 consider ototoxic chemical exposures, especially
16 when noise exposure does not exceed permissi-
17 ble or recommended limits.²⁸ Annual audio-
18 grams are recommended for workers whose
19 airborne exposures are at 50% of the most strin-
20 gent occupational exposure limits for toluene,
21 xylene, *n*-hexane, organic tin, carbon disulfide,

mercury, organic lead, hydrogen cyanide, diesel 22
fuel, kerosene, jet fuel, organophosphate 23
pesticides, or chemical-warfare nerve agents— 24
regardless of the noise level. This 50% level, 25
while somewhat arbitrary, ensures data collec- 26
tion from exposure situations below occupa- 27
tional exposure limits. Annual audiograms also 28
are recommended when dermal exposures to 29
these agents result in a systemic dose equivalent 30
to 50% or more of the occupational exposure 31
limit. For workers participating in hearing con- 32
servation programs because of excessive noise, 33
reviewers of audiometric data should be alert to 34
possible additive, potentiating, or synergistic 35
effects between noise and ototoxic chemicals, 36
and should, if necessary, initiate reduction of 37
exposure to the noise and/or the chemicals. 38

Audiometric Monitoring 39

Audiograms indicate a person's hearing thresh- 40
old. Results are given in decibels, which indicate 41

1 the intensity or loudness a sound has to be for
 2 the person to detect it. Thresholds below 25 dB
 3 HL are considered normal. NIOSH suggests that
 4 (a) monitoring audiometry be conducted on
 5 noise-exposed workers late in, or at the end of,
 6 their daily work shifts; and (b) audiometry be
 7 repeated immediately after any monitoring
 8 audiogram indicates a significant threshold
 9 shift.¹⁹ Before conducting retests, workers should
 10 be instructed and earphones refitted. Those
 11 who employ this retest strategy will find a
 12 significant reduction in the number of workers
 13 called back for a confirmation audiogram—
 14 because if the retest audiogram does not show
 15 the same shift as the initial audiogram, the retest
 16 audiogram becomes the test of record.

17 By testing workers during their work shifts, one
 18 may identify temporary threshold shifts (TTSs).
 19 Although the relationship between permanent
 20 threshold shifts and TTSs is not completely under-
 21 stood, workers with a TTS are being overexposed
 22 to noise. Discovering a TTS and taking action to
 23 prevent its recurrence will help protect workers
 24 from permanent hearing damage. If annual mon-
 25 itoring audiograms are performed before or at the
 26 beginning of work shifts, TTSs from noise expo-
 27 sure on the previous work shifts will have resolved
 28 so that any threshold shifts observed will repre-
 29 sent permanent shifts in hearing.

30 Audiometry should be conducted again within
 31 30 days of any monitoring or retest audiogram
 32 that continues to show a significant threshold
 33 shift. A minimum of 12 hours of quiet should
 34 precede the confirmation audiogram to deter-
 35 mine whether the shift is a TTS or a permanent
 36 threshold shift. Hearing protectors should not
 37 be considered as a substitute for a quiet work
 38 environment.¹⁹

39 The OSHA criterion for the standard thresh-
 40 old shift (a change of 10 dB or more in the aver-
 41 age of hearing thresholds at 2,000, 3,000, and
 42 4,000 Hz) may not be the ideal method to iden-
 43 tify and prevent permanent NIHL. NIOSH rec-
 44 ommends a better criterion for the calculation of
 45 significant threshold shift: an increase of 15 dB
 46 in the hearing threshold level at any of the test
 47 frequencies in either ear (at 500, 1,000, 2,000,
 48 3,000, 4,000, and 6,000 Hz), as determined by
 49 two consecutive audiometric tests.¹⁹ This alter-
 50 native criterion has both high sensitivity and
 51 high specificity.

Age Correction

52

53 Although many people experience a decrease in
 54 hearing acuity with age, others do not. It is not
 55 possible to predict who will and who will not
 56 develop hearing loss with aging. The median
 57 hearing loss attributable to aging for a given age
 58 group cannot be generalized to all individuals in
 59 that age group. Thus, when calculating signifi-
 60 cant threshold shifts, age-correcting hearing
 61 thresholds will overestimate the expected hear-
 62 ing loss for some people and underestimate it
 63 for others.

64 Unfortunately, the adjustment of audiometric
 65 thresholds for aging has become a common
 66 practice in workers' compensation litigation.
 67 In this application, age corrections reduce the
 68 amount of hearing loss attributable to noise
 69 exposure, with a consequent reduction in the
 70 amount of compensation paid to workers for
 71 hearing loss.

72 Age-correcting audiograms obtained in an
 73 occupational hearing-loss prevention program
 74 is not recommended.¹⁹ The purpose of the pro-
 75 gram is to prevent hearing loss. If an audiogram
 76 is age corrected, regardless of the source of the
 77 correction values, the time required for a signifi-
 78 cant threshold shift to be identified will be pro-
 79 longed. Delaying the identification of a worker
 80 with a significant threshold shift is counterpro-
 81 ductive to all other hearing conservation efforts.

Accommodating Workers with Hearing Loss

82

83

84 After a confirmation audiogram that indicates a
 85 permanent threshold shift, NIOSH recommends
 86 a written notification to the worker and a refer-
 87 ral to the audiometric manager or professional
 88 supervisor for review and determination of
 89 probable etiology. This referral should explore
 90 all possible causes in addition to occupational
 91 noise, including ototoxic chemicals, age-related
 92 hearing loss, familial hearing loss, nonoccupa-
 93 tional noise exposure, and medical conditions.¹⁹

94 Workers with a threshold shift due to causes
 95 other than noise should be counseled by audio-
 96 metric managers and referred to their physicians
 97 for evaluation and possible treatment. Appro-
 98 priate actions should be planned for workers
 99 showing a threshold shift that is determined by

1 the audiometric manager to be due likely to
 2 occupational noise. At a minimum, these actions
 3 should include reinstruction and refitting of
 4 hearing protectors, additional training in worker
 5 responsibilities for effective hearing-loss preven-
 6 tion, and/or reassignment to a quieter work area.
 7 The professional supervisor should be responsi-
 8 ble for identifying whatever changes may be
 9 necessary, and for ensuring that they are imple-
 10 mented. According to OSHA's Hearing Conser-
 11 vation Amendment, the professional supervisor
 12 of the audiometric testing component of a hear-
 13 ing conservation program must be a licensed or
 14 certified audiologist or otolaryngologist, or other
 15 physician.

16 The main factors that enable workers with
 17 hearing loss to continue working are ability to
 18 cope with the hearing loss, support from man-
 19 agement and co-workers, adequate work condi-
 20 tions, psychological support from patient
 21 organizations as well as family members and
 22 friends, support from medical professionals and
 23 programs, and financial and other benefits.²⁹
 24 A set of guidelines can be used by health profes-
 25 sionals for managing the work-related condi-
 26 tions. Important to workers with hearing loss is
 27 knowledge about and availability of better hear-
 28 ing protectors and hearing aids, alternative
 29 means of obtaining and financing hearing aids,
 30 self-acceptance, a quiet work environment,
 31 determination and persistence to ask for needed
 32 accommodations at work, education of co-
 33 workers about hearing loss, and opportunities to
 34 communicate information and experiences with
 35 other affected workers.

36 **Accommodating Workers** 37 **with Tinnitus**

38 Several standardized scales exist to evaluate in
 39 the interference of tinnitus on the quality of life.
 40 Most of them are short and easy to administer.
 41 Their use can offer valuable information on how
 42 to accommodate workers that suffer from tin-
 43 nitus.³⁰ Most important in managing workers
 44 with tinnitus is to refer them to otolaryngolo-
 45 gists or otologists (ear specialists), who will try
 46 to determine its cause by evaluating the auditory
 47 system, measuring blood pressure and kidney
 48 function, and assessing diet, allergies, and medi-
 49 cations. Specialists determine treatment, which

may include maskers (electronic devices the size 50
 of a hearing aids that use sound to make tinnitus 51
 less noticeable), support and counseling, sur- 52
 gery, drug therapy (such as tricyclic antidepres- 53
 sants), diet, psychotherapy, electrical/magnetic 54
 stimulation, acupuncture, biofeedback, and 55
 hypnosis. They also should explain to patients 56
 the pathophysiology of their tinnitus, make rec- 57
 ommendations for hearing aids when appropri- 58
 ate, and provide periodic monitoring.³¹ 59

60 **ACKNOWLEDGMENT**

This chapter is dedicated to the memory of 61
 Dr. Derek E. Dunn. 62

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- Noise and hearing conservation are addressed in this standard, which is applicable to general industry in*

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2	<i>exposure, audiometric testing, hearing protection,</i>		
3	<i>employee training, and record keeping.</i>		
4	Cochlea.org. Available at: http://www.cochlea.org		
5	<i>An educational Web site sponsored by several</i>		
6	<i>institutions and companies. It contains sections</i>		
7	<i>describing the anatomy, physiology, and pathophys-</i>		
8	<i>iology of the auditory system.</i>		
9	American Tinnitus Association. Available at: http://		
10	www.ata.org		
11	<i>The American Tinnitus Association (ATA) pro-</i>		
12	<i>motes tinnitus awareness, prevention, and treat-</i>		
13	<i>ment. It offers information on prevention programs</i>		
14	<i>in schools, urges governmental and private organi-</i>		
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16	<i>research, and facilitates self-help groups.</i>		
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		<i>Hearing Conservation Manual covers all facets of</i>	22
		<i>developing a successful hearing-loss prevention pro-</i>	23
		<i>gram. The manual is designed as a reference text</i>	24
		<i>used during Occupational Hearing Conservationist</i>	25
		<i>training courses, and it is an excellent resource for</i>	26
		<i>practicing professionals.</i>	27
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		<i>This Web site contains a fact sheet regarding oto-</i>	33
		<i>toxic chemical exposures and guidelines for hearing</i>	34
		<i>conservation developed by the U.S. Army.</i>	35
		<hr/>	
		<i>The findings and conclusions in this chapter are</i>	36
		<i>those of the authors and do not necessarily repre-</i>	37
		<i>sent the views of the National Institute for Occu-</i>	38
		<i>pational Safety and Health.</i>	39