Hearing Loss

A Primer for the Performing Arts

Douglas T. Owens, DA

Noise-induced hearing loss (NIHL) is a major health problem that affects an estimated 16.1% of American adults, but for musicians, the onset of noise-induced, or any type of hearing loss, can be a career-changing event. The potential for dangerous sound pressure levels in musical environments has been documented in numerous studies, with exposures in both short and long durations shown to be harmful. Yet, in theory, NIHL is completely preventable. This review discusses basic information concerning the hearing mechanism and NIHL, audiometry, standards, protective strategies, and terminology. It aims to provide a general understanding of these processes as they relate to musicians and other performing artists. *Med Probl Perform Art* 2008;23:147–154.

Noise-induced hearing loss (NIHL) is a condition that has gained attention over the years. Anyone is susceptible to NIHL, and its onset can force changes in previous noise exposure habits. For musicians, any type of hearing loss is potentially career-changing, and at the very least, it is a rude awakening into the loud environment in which we live and work. Yet, in theory, NIHL is completely preventable.

It is clear that NIHL continues to be a major health issue in society. Based on 2003-04 data from the National Health and Nutrition Examination Survey,[1] it is estimated that 16.1% (29 million) of American adults between the ages of 20 and 69 exhibit hearing loss within the speech frequencies. For this study, Agrawal, Platz, and Niparko[1] defined the speech frequency hearing test as "a pure-tone mean of 25 dB or higher at 0.5, 1, 2, and 4 kHz in either ear." In addition, subjects were given hearing examinations at the high frequencies, with "a pure-tone mean of 25 dB or higher at 3, 4, and 6 kHz in one or both ears." From this, 8.5% of adults 20 to 29 years of age and 17% of adults between 30 and 39 years of age were found to exhibit high-frequency hearing loss.[1] The potential for NIHL exists, as any hearing loss exhibited between 3 and 6 kHz is considered to be noise-induced.

In its 1998 "Healthstyles" survey involving 2,681 American adults, the National Institute for Occupational Safety and Health (NIOSH) concluded that Americans do not have their hearing checked on a regular basis and are not aware of the potential for hazardous noise in the home.[2] NIOSH defines NIHL as follows[3]:

> NIHL is caused by exposure to sound levels or durations that damage the hair cells of the cochlea. Initially, the noise exposure may cause a temporary threshold shift—that is, a decrease in hearing sensitivity that typically returns to its former level within a few minutes to a few hours. Repeated exposures lead to a permanent threshold shift, which is an irreversible sensorineural hearing loss.[3]

The American Medical Association[4] adds:

> Hearing impairment associated with noise exposure can occur at any age, including early infancy, and is often characterized by difficulty in understanding speech and the potentially troublesome symptom, tinnitus (i.e., ringing in the ears). Very loud sounds of short duration, such as an explosion or gunfire, can produce immediate, severe, and permanent loss of hearing. Longer exposure to less-intense but still hazardous sounds, commonly encountered in the workplace or in certain leisure-time activities, exacts a gradual toll on hearing sensitivity, initially without the victim's awareness.[4]

Exposure to music at dangerous sound pressure levels has the potential to be equally hazardous, both in short and longer durations. For the musician, the onset of noise-induced or any type of hearing loss can be a career-changing event. The potential for dangerous sound pressure levels in musical environments has been documented in numerous studies. Among the studies, Axlesson and Lindgren[5] studied the hearing of classical musicians; Cutietta, Millin, and Royse[6] investigated NIHL among high school band directors; Cutietta, Klich, Royse, and Rainbolt[7] and Harding and

Editor's Note: With Dr. Owens' paper, MPPA inaugurates an occasional series of review articles on common performing arts medicine topics. Under the editorship of Dr. William Dawson, this series will provide current information directed principally to primary healthcare providers, therapists, and educators.

Dr. Owens is Assistant Professor of Music Education and Coordinator of Music Education Student Teaching, at the University of Southern Maine, Gorham, Maine.

The author declares no conflicts of interest associated with the subject of this paper.

Address correspondence and reprint requests to: Douglas T. Owens, DA, Assistant Professor, Music Education, University of Southern Maine, 37 College Avenue, Gorham, ME 04038. Tel (207) 780-5260; fax (207) 780-5527; email dowens@usm.maine.edu.

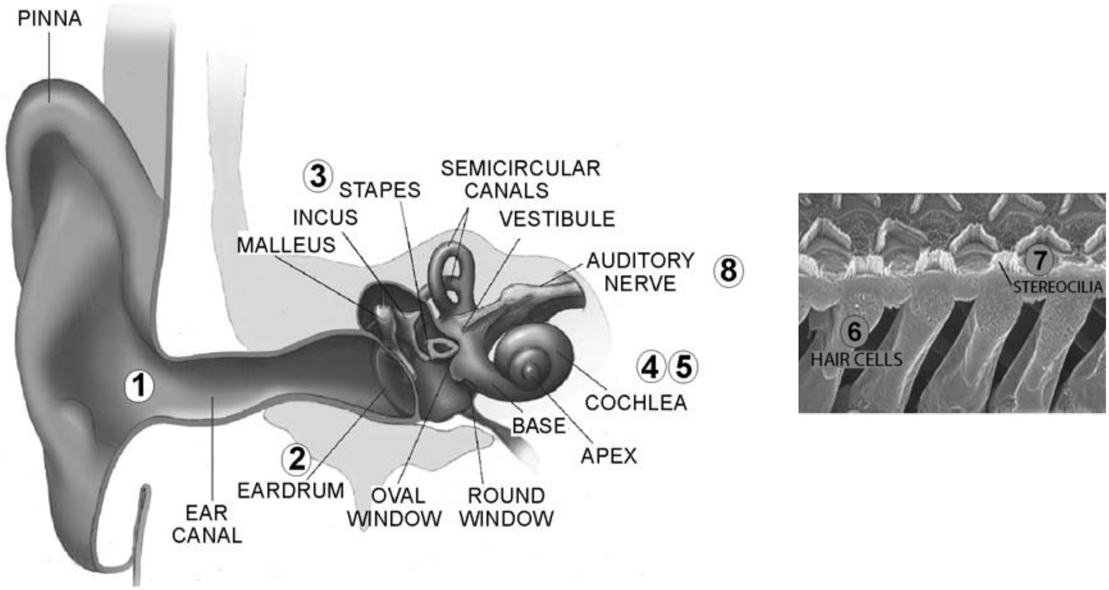

FIGURE 1. Structures of the ear and the sound pathway. Hearing depends on a series of events that change sound waves in the air into electrical signals that the auditory nerve carries to the brain.

1. Sound waves enter the outer ear, or pinna, and travel through the ear canal to the eardrum.
2. The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear: the malleus, incus, and stapes.
3. These three bones amplify the sound and send the vibrations to the snail-shaped cochlea, or inner ear.
4. The cochlea is a fluid-filled organ with an elastic membrane that runs down its length and divides the cochlea into upper and lower parts. This "basilar" membrane serves as the base, or ground floor, on which key hearing structures sit.
5. Vibrations cause the fluid inside the cochlea to ripple, and a traveling wave forms along the basilar membrane.
6. Hair cells—sensory cells in the organ of Corti sitting on top of the membrane [*inset*]—"ride the wave." This motion causes bristly structures on top of the hair cells to bump against an overlying membrane and deflect to one side.
7. As the bristles, or stereocilia, move, pore-like channels on their surface open up. This allows certain neurochemicals, such as glutamate and GABA,[15,16] to rush in to generate an electrical signal.
8. The auditory nerve carries the signal to the brain, which translates it into a "sound" that we recognize and understand.

Adapted from the NICD Fact Sheet: Noise Induced Hearing Loss. Bethesda, National Institute on Deafness and Other Communication Disorders, 1997–2007.[13]

Owens[8] studied hearing loss among music educators; Henoch and Chesky[9] measured the sound pressure levels from within a university jazz ensemble; and Owens[10] and Royer[11] measured the sound pressure levels in school band rooms.

The purpose of this paper is to provide information regarding the hearing mechanism and NIHL. Included is information concerning the anatomy and physiology of the ear, pathophysiology of NIHL, testing methods, tinnitus, standards, protective strategies and terminology, that is intended to provide a basic understanding of this condition for performing arts medicine practitioners.

ANATOMY AND PHYSIOLOGY OF THE EAR

The ear is a complex mechanism that continues to be researched. It has three major sections: the outer ear, middle ear, and inner ear. In addition, various pathways exist connecting the ear to the brain. Sataloff and Sataloff[12] describe the ear and these pathways as follows:

The outer ear has two parts: (a) the "trumpet-shaped" apparatus on the side of the head called the auricle or pinna, and (b) the tube leading from the auricle into the temporal bone called the external auditory canal. This opening is called the meatus. The tympanic membrane, or eardrum, stretches across the inner end of the external ear canal separating the outer ear from the middle ear.

The middle ear is a tiny cavity in the temporal bone. The three auditory ossicles, malleus (hammer), incus (anvil), and stapes (stirrup), form a bony bridge from the external ear to the inner ear. The bony bridge is held in place by muscles and ligaments. The middle ear chamber is filled with air and opens into the throat through the eustachian tube. The eustachian tube helps to equalize pressure on both sides of the eardrum.

The inner ear is a fluid-filled chamber divided into two parts: (a) the vestibular labyrinth, which functions as a part of the body's balance mechanism, and (b) the cochlea, which contains the hearing-sensing nerve. Within the cochlea is the organ of Corti, which contains thousands of minute, sensory, hairlike cells. The organ of Corti functions as the switchboard of the auditory system. The eighth cranial or acoustic nerve leads from the inner ear to the brain, serving as the pathway for the impulses the brain will interpret as sound.[12]

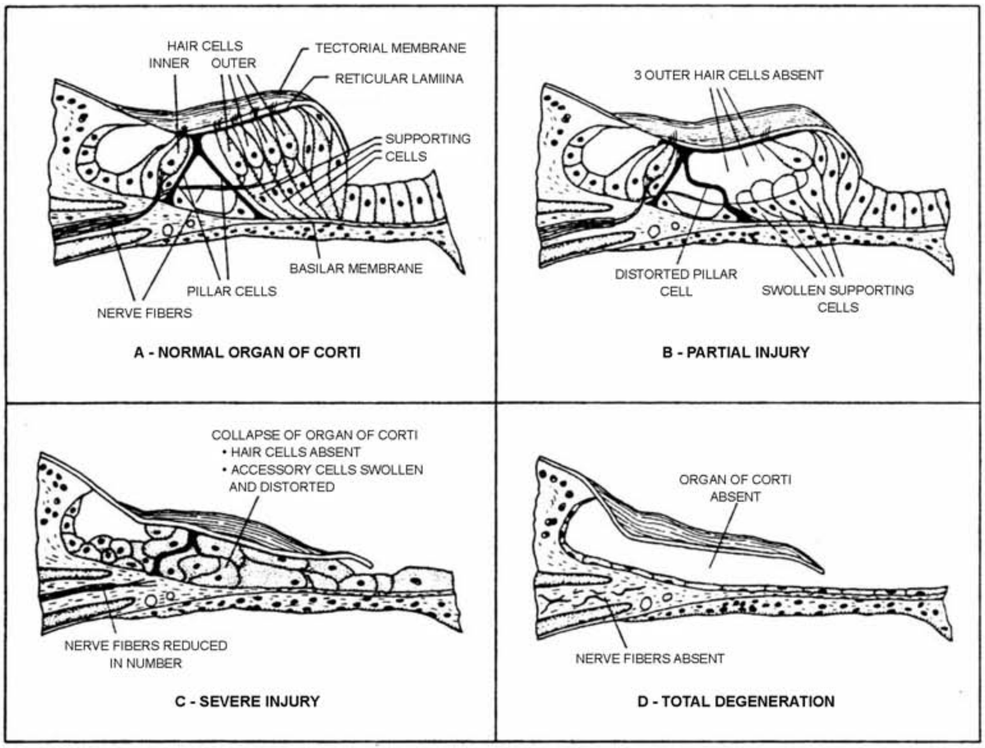

FIGURE 2. The human organ of Corti, showing the progression of noise-induced injury. Panel A shows the normal state, with increasing degrees of noise-induced permanent injury shown in panels B, C, and D. Reprinted from Miller JD: Effects of noise on people. *J Acoustical Soc Am* 1974;*56*(3):729-764; with permission, ©1974, Acoustical Society of America.[17]

Figure 1 shows the structures of the ear and explains their involvement in the hearing process.[13]

Chasin[14] states the following regarding sound transduction, the changing of sound waves into nerve impulses, in the inner ear:

> The structure of sound transduction in the cochlea is similar to that of a piano keyboard: low-frequency sounds are transduced on one end while the higher frequency sounds are transduced from the other end. Specifically, in the cochlea, high-frequency sounds are transduced by those hair cells nearer to the stapes footplate of the middle ear, while those that transduce the lower-frequency sounds are found in the innermost turns of this snail-shaped organ.[14]

As said, hair cells near the base of the cochlea detect higher-pitched sounds, such as a cell phone ringing. Those nearer the apex, or centermost point, detect lower-pitched sounds, such as a large dog barking.

As the hair cells vibrate, the motion causes bristly structures, called stereocilia, located atop the hair cells' surface, to bump against an overlying membrane and deflect. Pore-like channels on the stereocilia's surface open to allow neurochemicals to enter and generate an electrical signal.

One of the neurochemicals presumed to be involved in sound perception is the neurotransmitter glutamate. Nordang and colleagues[15] report that "glutamate is the afferent transmitter between the cochlea inner ear hair cells and afferent neurons, hitherto visualized only in the cochlea of animal species." Glutamate helps transmit the auditory signal from receptors in the cochlea toward the brain. In addition, Meza[16] reports that γ-aminobutyric acid (GABA) may act as both an afferent neurotransmitter and an efferent neurotransmitter, carrying signals to and from the brain, respectively.

PATHOPHYSIOLOGY OF HEARING LOSS

Miller[17] states that high levels of noise exposure can cause damaging physical changes in the inner ear, which contribute to hearing problems. He describes the stages of hearing loss as caused by excessive noise exposure (Figure 2):

> Excessive exposure to noise can result in the destruction of hair cells and collapse or total destruction of sections of the organ of Corti. In addition, auditory neurons may degenerate. . . . The injury illustrated in Panel B [see Figure 2] includes absence of three outer hair cells, distortion of a pillar cell, and swelling of the supporting cells. In Panel C, there is a complete collapse of the organ of Corti with the absence of hair cells, distortion of the accessory structures, and a reduction in the number of nerve fibers. This section of the organ of Corti is almost certainly without auditory function. The injury in Panel D is obvious; there is complete degeneration of the organ of Corti.[17]

With excessive noise exposure comes the potential destruction of the hair cells. These cells do not regenerate, resulting in permanent hearing loss.

Temporary threshold shift (TTS) and permanent threshold shift (PTS) are common occurrences among persons who have regular exposure to high decibel (dB) levels. Seidman[18] states that temporary threshold shift is a temporary loss of hearing following overexposure to sound. Permanent threshold shift refers to any hearing loss that is lasting, and it is found in persons experiencing extended exposure to loud sounds. Alberti[19] further explains the relationship between temporary threshold shift, permanent threshold shift and NIHL:

> If TTS occurs day after day, the recovery becomes less complete and a permanent threshold shift (PTS) occurs, because with persistent exposure to such sounds some hair cells do not recover. First to fail permanently are the outer hair cells in the basilar part of the cochlea, in the area which responds to 4 kHz and the adjacent areas of 3 and 6 kHz. This is where the ear is most sensitive, in part because of the harmonic amplification of the ear canal and in part because of an absolute sensitivity. Once hair cells degenerate they do not recover and a permanent hearing loss develops.
>
> Classically therefore, following noise exposure, hearing loss is shown as an audiometric notch [a pattern of hearing loss shown on an audiogram], usually maximal at 4 kHz but may also be based anywhere between 3 and 6 kHz. With higher noise exposure for longer periods, the loss extends into adjacent frequencies. If the sound is sufficiently intense, it produces a much more severe
>
> TTS which may go on to a more rapidly produced PTS. There is a critical point where moderate TTS changes to longer-term TTS, which correlates well with anatomical damage to the outer hair cells, a process of damage and scarring or repair. The threshold for TTS is somewhere between 78 and 85 dB, and the point where it changes from mid-term to long-term is about 140 dB. The spectrum of the sound and the length of exposure are critical.[19]

According to Howard and Angus,[20] a loss of hearing acuity at 4 kHz (4000 Hz) is the typical sign of NIHL, as the ear is most sensitive at that frequency. As noted earlier, Alberti[19] has stated that this sensitivity is "due to the harmonic amplification of the ear canal and in part because of an absolute sensitivity." Howard and Angus[20] refer to the hearing loss pattern known as the *audiometric notch*, stating that the pattern is demonstrative of hearing loss due to noise rather than age.

Melnick[21] notes that hearing loss due to noise exposure begins at 4 kHz, and increases from the 3 to 6 kHz range with additional noise exposure. Melnick states that the hearing loss becomes evident when the comprehension of normal speech becomes difficult.

Tinnitus

One symptom commonly associated with NIHL is tinnitus. While tinnitus can have multiple causes other than noise, including many diseases and medications, it may be common among musicians, in whom it may occur as a manifestation of NIHL.

Tinnitus is a constant, internally generated noise caused by multiple factors, including excessive exposure to noise. The American Tinnitus Association describes tinnitus simply as "the perception of sound in the ears or head where no external source is present." [22] Lockwood, Salvi, and Burkard[23] define the common type of tinnitus as the erroneous perception of a sound that is externally nonexistent. It is believed that the production of internal noise is caused by damage to the inner ear hair cells, although, as Howard and Angus[20] state, the potential exists for those with tinnitus to be additionally susceptible to hearing damage caused by excessive exposure to noise.

In an investigation of the prevalence of tinnitus in college students, Zeigler[24] found that college music majors experienced tinnitus more frequently than students with other majors. He found that musicians performing on all instrumental families experienced problems with tinnitus, with percussionists and vocalists reporting the most difficulty. In addition, Zeigler noted (in 1997) the lack of hearing protection used by students when in situations that could cause exposure to high levels of noise. College music majors should be aware of the potential for hearing loss in the profession and that the length of their exposure to high sound pressure levels could affect their hearing and, ultimately, their career.

TESTING METHODS

A comprehensive hearing examination is necessary in order to attribute hearing loss to noise. As Chasin[14] states, "A full hearing assessment including pure tone, immittance, otoacoustic emission, and speech audiometry is recommended in order to rule out any nonmusic, medically related concerns." In addition, musicians present a wide range of rehearsal and performance styles and types, making the assessment of each musician a very specific event. Sataloff and Sataloff[25] also emphasize the importance of a comprehensive examination: "When hearing loss is classified, the point at which the auditory pathway has broken down is localized, and it is determined whether the patient's healing loss is conductive, sensorineural, central, functional, or a mixture of these."

The hearing exam should be completed in an audiometric booth. The booth reduces any ambient noise to a minimum to meet industry standards. In order to assess hearing, the audiometer will generate pure tones at frequencies between 250 and 8000 Hz (0.25 to 8 kHz). Sataloff and Sataloff[26] suggest the following:

> The tester is to determine the subject's threshold at the specific frequencies in the following order: 1000, 2000, 3000, 4000, 6000, 8000, 1000 (repeat), 500 and 250 Hz. The 1000-Hz tone is tested first because usually this is the easiest one for which to establish a definitive threshold. The threshold at 1000 Hz is confirmed by repeating it, to help confirm test accuracy and because the subject who has not previously had an audiogram may not have recognized the tone as such the first time.[26]

HEARING PROTECTION STANDARDS

Hearing protection standards exist in order to better inform us of the limits of exposure to noise. The standards of the National Institute of Occupational Safety and Health

TABLE 1. Sound Exposure Duration: NIOSH and OSHA Standards

Duration of Exposure (*hrs*)	Sound Pressure Level, in dBA	
	NIOSH[28]	OSHA[29]
8	85	90
6	–	92
4	88	95
3	–	97
2	91	100
1.5	–	102
1	94	105
0.5	97	110
0.25	100	115
0.125	103	–

Data from Table 1-1, NIOSH[28] and OSHA occupational noise exposure standard 29 CFR 1910.95[b], Table G-16.[29]

(NIOSH)[27,28] are more protective than the Occupational Health and Safety Administration (OSHA) standards.[29] Health effects depend on exposure limit and duration. The NIOSH maximum daily exposure level is 85 dBA over an 8-hr period. A 3-dB exchange rate is used by NIOSH, which reduces the maximum allowable exposure time to high sound pressure levels.[27] The exchange rate is the relationship between the intensity of the noise and the dose received; if the intensity of an exposure increases by 3 dB, the dose doubles.[30]

The NIOSH and OSHA standards are presented in Table 1.[28,29]

As stated, NIOSH has set the maximum allowable daily exposure limit of 85 dBA (A-weighted) over an 8-hr period. Common sounds in relation to the 85-dB level include the following:

Whispered conversation, quiet library: 30 dB
Normal conversation: 60-70 dB
Heavy city traffic: 85 dB
Hair dryer, power lawn mower: 90 dB
Power drill: 98 dB
Personal music player at maximum level: 105 dB
Chain saw, amplified rock concert: 110 dB
Ambulance siren: 120 dB
Jet engine at takeoff, gun shot: 140 dB[31,32]

As a comparison to the sound pressure levels produced by common activities, Folprechtova and Miksovska[33] measured the sound pressure levels of selected orchestral musical instruments. They found that sound pressure levels ranged from 75 dBA for the bass to 114 dBA for the trombone. Chamber concerts typically produce 70 to 92 dBA, whereas symphony orchestras record up to 100 dB, with peaks at 120 to 137 dB.[34] The selected instruments and their decibel levels are described in Table 2.

For the purposes of comparison, the OSHA standards for noise exposure are listed in Table 1.[29] The OSHA standard is an industrial standard, which was "developed for the protection of workers in industrial settings when exposed to industrial noise."[35] This standard, along with its 5-dB exchange rate, was developed in part to account for the any exposure to noise that was not continuous. According to NIOSH, "The rule makes no distinction between continuous and noncontinuous noise, and it will permit comparatively long exposures to continuous noise at higher sound levels than would be allowed by the 3-dB rule."[35] In addition, the standard implies that some recovery from temporary threshold shifts during any interruptions from noise exposure may be possible, which is a potentially dangerous assumption.

TABLE 2. Selected Musical Instruments and Their Decibel Levels, in dBA

Violin	84–103	Cello	84–92
Bass	75–83	Piccolo	95–112
Flute	85–111	Clarinet	92–103
French horn	90–106	Oboe	80–94
Trombone	85–114	Xylophone	90–92

Data from Folprechtova and Miksovska.[33]

All persons, including musicians, would benefit from the more-protective NIOSH standards. Musicians require high levels of hearing accuracy for their work. Standards specific to the needs of musicians should be developed.[10,36] Lacking specific standards at this point, the NIOSH standards are good guidelines for musicians to follow.

PROTECTIVE STRATEGIES FOR MUSICIANS

Noise-induced hearing loss is in theory completely preventable. For musicians who are proactive about their hearing protection, the following information is prudent to a future of good hearing health:

- Musicians should have a comprehensive baseline audiometric threshold hearing examination conducted by an audiologist. According to the American College of Occupational and Environmental Medicine,[36] if the hearing loss is due to noise, it will be revealed at 3, 4, or 6 kHz. Repeat hearing examinations should be conducted regularly, especially if exposure habits change to louder environments.
- At the examination, musicians should ask to be fitted for custom ear molds with removable filters for effective sound pressure reduction. Each ear mold contains a filter that reduces the level of exposure by 9, 15, or 25 dB, depending on the model of filter selected. Multiple types of filters can be purchased and are interchangeable for use in various acoustical environments. For the best protection, the noise exposure levels should be determined in order to select the appropriate filters.
- Musicians should be familiar with, and adhere to, the NIOSH standards.[28] Noise at or above 85 dB can cause damage to the ears. Rehearsal and performance rooms where the resulting sound pressure levels are at or above 85 dB require monitoring of exposure time and/or hearing protection.

APPENDIX: TERMINOLOGY

Audiogram: A graph showing hearing (threshold) level as a function of frequency.[38(p2.2)]

Baseline audiogram: A valid audiogram against which subsequent audiograms are compared to determine if hearing thresholds have changed. The baseline audiogram is preceded by a quiet period so as to obtain the best estimate of the person's hearing at that time.[30(p1)]

Decibel (dB): The unit used to express the intensity of sound. The decibel measurement originated in the telephone industry and was named after telephone inventor Alexander Graham Bell. The original unit, the *bel*, is too large for most common applications, and so the *deci-bel*, or one-tenth of a *bel*, was adopted.

The decibel scale is a logarithmic scale in which 0 dB approximates the threshold of hearing in the mid-frequencies for young adults and in which the threshold of discomfort is between 85 and 95 dB SPL (sound pressure level) and the threshold of pain is between 120 and 140 dB SPL.[30(p2)] dBA is the sound intensity level determined with the A-weighted measurement scale [see *weighted measurements*], which is weighted toward the mid-frequencies corresponding to human hearing with less sensitivity to very high and very low frequencies.

Dosimeter: When applied to noise, an instrument that measures sound levels over a specified interval, stores the measures, and calculates the sound as a function of sound level and sound duration. The results are described in terms of dose, time-weighted average, and (perhaps) other parameters such as peak level, equivalent sound level, sound exposure level, etc.[30(p2)]

Equal-energy rule: The relationship between sound level and sound duration based on a 3-dB exchange rate: i.e., the sound energy resulting from doubling or halving a noise exposure's duration is equivalent to increasing or decreasing the sound level by 3-dB, respectively.[30(p2)]

Exchange rate: The relationship between intensity and dose. NIOSH recommends a 3-dB exchange rate; thus, if the intensity of an exposure increases by 3 dB, the dose doubles. OSHA uses a 5-dB exchange rate, the U.S. Navy uses a 4-dB exchange rate, and the U.S. Army and Air Force use a 3-dB exchange rate. Note that the equal-energy rule is based on a 3-dB exchange rate.[30(p2)]

Frequency: The rate of repetition of a periodic event. Sound in air consists of a series of compressions and rarefactions due to air particles set into motion by a vibrating source. The frequency of a sound wave is determined by the number of times per second a given molecule of air vibrates about its neutral position. The greater the number of complete vibrations (called cycles), the higher the frequency. The unit of frequency is the hertz (Hz).[39(p4)]

Frequency range: Most sound sources, except for pure tones, contain energy over a wide range of frequencies. For measurement, analysis, and specification of sound, the frequency range is divided into sections (called *bands*). One common standard division is into 10 octave bands identified by their center frequencies: 0.0315, 0.063, 0.125, 0.25, 0.5, 1, 2, 4, 8 and 16 kHz. An octave band in sound analysis represents a frequency ratio of 2:1.[39(p4)]

Hertz (Hz): The unit measurement for audio frequencies. The frequency range for human hearing lies between 20 Hz and ~20,000 Hz (0.002 to 20 kHz). The sensitivity of the human ear drops off sharply below about 0.5 kHz and above 4 kHz.[30(p3)]

Loudness: The subjective attribute of a sound characterized along a continuum from "soft" to "loud." Although a subjective attribute, loudness relates primarily to sound pressure level and, to a lesser extent, on the frequency characteristics and duration of the sound.[30(p3)]

Noise: 1) Any disagreeable or undesired sound or other disturbance; an unwanted sound. By extension, any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device.
2) Sound of a general random nature, the spectrum of which does not exhibit clearly defined frequency components.[38(p2.9)]

Noise dose: Noise exposure expressed as a percentage of the allowable daily exposure. For OSHA, a 100% dose would equal an 8-hr exposure to a continuous 90-dBA noise; a 50% dose would equal an 8-hr exposure to an 85-dB(A noise or a 4-hr exposure to a 90-dBA noise. If 85-dBA is the maximum permissible level, then an 8-hr exposure to a continuous 85-dBA noise would equal a 100% dose. According to NIOSH standards, if a 3-dB exchange rate is used in conjunction with an 85-dBA maximum permissible level, a 50% dose would equal a 2-hr exposure to 88 dBA or an 8-hr exposure to 82 dBA.[30(p3)]

Noise-induced hearing loss (NIHL): A sensorineural hearing loss that is attributed to noise and for which no other etiology can be determined.

Presbycusis: The gradual increase in hearing loss that is attributable to the effects of aging and not related to medical causes or noise exposure.[30(p4)]

Sensorineural hearing loss: A hearing loss resulting from damage to the inner ear, from any source.[30(p4)]

Sound level meter: A device that measures sound and provides a readout of the resulting measurement. Some provide only A-weighted measurements [see *weighted measurements*], but others provide A- and C-weighted measurements and some can provide weighted, linear, and octave (or narrower) band measurements. Some sound level meters are also capable of providing time-integrated measurements.[30(p4)]

Sound pressure level (SPL): The level, in dB, of acoustic pressure waves. Sound pressure is the dynamic variation of the static pressure of air and is measured in force per unit area. Sound pressure is normally represented on a logarithmic amplitude scale, which gives a better relationship to the human perception of hearing. Typical values on this open-ended scale are a sound level of 0 dB, which is the average threshold of human hearing, 60 to 70 dB for normal conversation, 110 dB for an extremely loud concert, and 150 dB for the noise of a rocket takeoff or a jet engine at close range.

SPLs can be measured with various weighting filters whose characteristics approximate the sensitivity of the ear at various frequencies and levels based on the Fletcher-Munson curves. Most commonly used is the "A-weighting," which is most sensitive in the mid-frequencies. Other, less common weightings are B, C, and D [see *weighted measurements*].

SPL in dB is defined as:

$$SPL = 20 \log_{10}(p/p_{ref})$$

where p = the actual sound pressure, and p_{ref} = is the reference sound pressure (20 μPa), which roughly corresponds to the threshold of human hearing.[40(p1)]

Threshold of hearing: The minimum SPL of a specified sound that is capable of evoking an auditory sensation for a given listener. Also called *threshold of audibility*. For measurement, other sources of sound reaching the ears should be negligible, and the general conditions of measurement must be specified (e.g., listening with one or two ears, in the free field, or with earphones).[38(p2.16)]

Threshold of pain: The minimum SPL of a specified sound that will produce a sensation of definite pain in the ear of a given listener—typically 120 to 140 dB SPL.[30]

Threshold shift: Two types of changes in hearing sensitivity which may be encountered by audiometric monitoring programs: *permanent threshold shift* (PTS) and *temporary threshold shifts* (TTS). As the names imply, any change in hearing sensitivity that is persistent is considered a PTS. Persistence may be assumed if the change is observed on a 30-day follow-up examination. A TTS, or temporary worsening in hearing sensitivity such as that caused by exposure to loud noise, may persist for 14 hrs (or longer if the exposure duration exceeds 12 to 16 hrs). Hearing professionals need to recognize that not all threshold shifts represent decreased sensitivity, and not all TTS and PTS are due to noise exposure. When a PTS can be attributable to noise exposure, it may be referred to as a *noise-induced permanent threshold shift* (NIPTS).[30(p4)]

Time-weighted average (TWA): A value, expressed in dB(A), that is computed so that the resulting average is equivalent to an exposure resulting from a constant noise level over an 8-hr period.[30(p4)]

Weighted measurements: Two weighting curves are commonly applied to measures of sound levels to account for the way the ear perceives the "loudness" of sounds: *A-weighting* is a measurement scale that approximates the "loudness" of tones relative to a 40-dB SPL, 1-kHz reference tone. A-weighting has the advantage of being correlated with annoyance measures and is most responsive to the mid-frequencies of 0.5 to 4 kHz. In comparison, *C-weighting* approximates the "loudness" of tones relative to a 90-dB SPL, 1-kHz reference tone. C-weighting has the advantage of providing a relatively "flat" measurement scale that includes very low frequencies.[30(p4-5)]

- Noise exposure can be monitored in the rehearsal and performance environment with an inexpensive digital sound pressure meter.
- Everyone should be aware of noise levels while using personal music players, car and home audio systems, power tools, lawn equipment, snow blowers, etc.

We live and work in loud environments. It is important to be aware of the environment at all times and make adjustments where necessary. Awareness of the acoustical characteristics of the performance and rehearsal environment and the musician's location in any ensemble is especially important and necessary for good hearing health.

REFERENCES

1. Y, Platz E, Niparko J: Prevalence of hearing loss and differences by demographic characteristics among US adults. Arch Intern Med 2008; 168(14):1522-1530.
2. National Institute of Occupational Safety and Health: Noise-induced hearing loss—Attitudes and behaviors of U.S. adults [webpage]. Atlanta, NIOSH/CDC, Nov 1998. Available from http://www.cdc.gov/niosh/topics/noise/abouthlp/nihlattitude.html; accessed Aug 21, 2008.
3. National Institute of Occupational Safety and Health: Criteria for a Recommended Standard: Occupational Noise Exposure. Cincinnati, NIOSH/CDC, NIOSH, June 1998. Publ no. 98-126. Available from http://www.cdc.gov/niosh/docs/98-126/chap2.html#22; accessed Aug 21, 2008.
4. Noise and hearing loss [consensus conference]. JAMA 1990; 263(23): 3185. Available from Academic Search Premier, Ipswich, MA; accessed Aug 19, 2008.
5. Axlesson A, Lindgren F: Hearing in classical musicians. Acta Otolaryngol Suppl 1981; 377:3-74.
6. Cutietta RA, Millin J, Royse D: Noise induced hearing loss among school band directors. Bull Council Res Music Educ 1989;101:41-49.
7. Cutietta RA, Klich RJ, Royse D, Rainbolt H: The incidence of noise-induced hearing loss among music teachers. J Res Mus Educ 1994; 42(4):318-330.
8. Harding RA, Owens DT: Colorado music educators hearing threshold project. In: Proceedings of the Hawaii International Conference on Arts and Humanities, Honolulu, HI, Jan 8-11, 2004.

9. Henoch MA, Chesky K: Sound exposure levels experienced by a college jazz band ensemble: comparison with OSHA risk criteria. Med Probl Perform Art 2000;15(1):51-56.
10. Owens D: Sound pressure levels experienced by the high school band director. Med Probl Perform Art 2004;19(3):109.
11. Royer RD: Sound pressure levels and frequencies generated in secondary public school band rooms [dissertation]. Dissert Abst Int 1995;57(10):6187. UMI no. 9710324.
12. Sataloff RT, Sataloff J: Occupational Hearing Loss. New York, Marcel Dekker, 1987.
13. Noise-induced hearing loss [NIDCD fact sheet]. Bethesda, National Institute of Deafness and Other Communication Disorders, Apr 2007. NIH publ no. 97-4233. Available from http://www.nidcd.nih.gov/health/hearing/noise.asp; accessed Aug 21, 2008.
14. Chasin M: Musicians and the Prevention of Hearing Loss. San Diego, Singular Publishing Group, 1996.
15. Nordang L, Oestreicher E, Arnold W, Anniko M: Glutamate is the afferent neurotransmitter in the human cochlea. Acta Otolaryngol 2000;120(3):359-362. Available from Academic Search Premier, Ipswich, MA; accessed Oct 14, 2008.
16. Meza G: Modalities of GABA and glutamate neurotransmission in the vertebrate inner ear vestibule. Neurochem Res 2008;33(8):1634-1642. Available from Academic Search Premier, Ipswich, MA; accessed Oct 14, 2008.
17. Miller JD: Effects of noise on people. J Acoust Soc Amer 1974; 56(3):729-764.
18. Seidman MD: Noise-induced hearing loss (NIHL). Volta Rev 1999;101(1):29-39.
19. Alberti PW: The pathophysiology of the ear. In: Goelzer B. Hansen CH, Sehrndt GA, eds: Occupational Exposure to Noise: Evaluation, Prevention and Control. Geneva, Federal Institute for Occupational Safety and Health, World Health Organization, 2001. Available from www.who.int/occupational_health/ publications/noise3.pdf; accessed Aug 20, 2008.
20. Howard DM, Angus J: Acoustics and Psychoacoustics, 2nd ed. Oxford, Focal Press, 2001.
21. Melnick W: Hearing loss from noise exposure. In: Harris CM, ed: Handbook of Acoustical Measurements and Noise Control. New York, McGraw-Hill, 1991, pp 18.1-18.19.
22. About tinnitus [webpage]. Portland, American Tinnitus Association, 2007. Available from http://www.ata.org/abouttinnitus/index.php; accessed Sep 21, 2008.
23. Lockwood AH, Salvi RJ, Burkard RF: Tinnitus and the performer. Med Probl Perform Art 2001;16(4):133-135.
24. Zeigler MC: An investigation of the prevalence of tinnitus in college music majors and nonmusic majors [dissertation]. Dissert Abst Int 1997;58(06):2128. UMI no. 9735829. [check vs MPPA paper]
25. Sataloff RT, Sataloff J: Hearing loss in musicians. In: Sataloff RT, Brandfonbrener A, Lederman R, eds: Textbook of Performing Arts Medicine. New York, Raven Press, 1991.
26. Sataloff RT, Sataloff J: Hearing Loss, 4th ed. New York, Taylor and Francis, 2005.
27. National Institute of Occupational Safety and Health: Criteria for a Recommended Standard: Occupational Noise Exposure. Cincinnati, NIOSH/CDC, NIOSH, June 1998. Publ no. 98-126. Available from http://www.cdc.gov/niosh/docs/98-126/chap1.html; accessed Aug 21, 2008.
28. National Institute of Occupational Safety and Health: Recommended exposure limit. In: Criteria for a Recommended Standard: Occupational Noise Exposure. Cincinnati, NIOSH/CDC, NIOSH, June 1998. Publ no. 98-126. Available from http://www.cdc.gov/niosh/docs/98-126/chap1.html#11; accessed Aug 21, 2008.
29. Occupational Health and Safety Administration: Occupational noise exposure, standard 1910.95. Washington, DC, OSHA,1983. Available from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=9735&p_table=STANDARDS; accessed Aug 21, 2008.
30. National Institute for Occupational Safety and Health: Appendix F: common to hearing loss prevention. Available from http://www.cdc.gov/niosh/96-110v.html; accessed Aug 21, 2008.
31. National Institute of Occupational Safety and Health: Noise and hearing loss prevention: NIOSH sound meter [webpage]. Atlanta, NIOSH/CDC, NIOSH. Available from http://www.cdc.gov/niosh/topics/noise/abouthlp/noisemeter_html/hp0a.html; accessed Oct 14, 2008.
32. NIDCD: How loud is too loud? [webpage]. Bethesda, National Institute on Deafness and Other Communication Disorders, Apr 2008. Available at: http://www.nidcd.nih.gov/health/hearing/ruler.asp; accessed Oct 30, 2008.
33. Folprechtova A, Miksovska O: The acoustic conditions in a symphony orchestra. Procov Lek 1976;28:1-2.
34. Chasin M: Hearing aids for musicians. Hearing Rev 2006; 13(3):18-27. Available from http://www.hearingreview.com/issues/articles/2006-03_2.asp.
35. National Institute of Occupational Safety and Health: Exchange rate: In: Criteria for a Recommended Standard: Occupational Noise Exposure. Cincinnati, NIOSH/CDC, NIOSH, June 1998. Publ no. 98-126. Available from http://www.cdc.gov/niosh/docs/98-126/chap3.html#33; accessed Oct 14, 2008.
36. Henoch MA, Chesky K: Thoughts to ponder—the sound of music: is it hazardous to your hearing? Int Trombone Assoc J 1999;27(1):18.
37. American College of Occupational and Environmental Medicine: Policies and Position Statements: Noise-induced hearing loss. Elk Grove Village, IL, ACOEM, 2002. Available from http://www.acoem.org/guidelines.aspx?id=846 <http://www.acoem.org/guidelines.aspx?id%20=846>; accessed Nov 13, 2008.
38. Harris CM: Definitions, abbreviations, and symbols. In Harris CM, ed: Handbook of Acoustical Measurements and Noise Control. New York, McGraw-Hill, 1991, pp 2.1-2.23.
39. Egan MD: Architectural Acoustics. New York, McGraw-Hill, 1988.
40. Sound pressure level [webpage]. National Instruments Measurement Encyclopedia, Sep 6, 2006. Available from http://zone.ni.com/devzone/cda/tut/p/id/1877; accessed Aug 21, 2008.