6 Uniform Hearing Protection for Musicians

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INTRODUCTION

Use of hearing protection by musicians and music industry professionals can dramatically reduce auditory risk; however, standard hearing protectors are generally unacceptable because they provide too much attenuation and they alter the frequency response, making music sound muddy and unclear. Flat-response moderate attenuation earplugs, available in custom and noncustom styles, are the preferred choice for amateur and professional musicians. This chapter discusses the design and rationale of flat attenuation earplugs and provides techniques for fitting and troubleshooting them.

SCOPE OF THE PROBLEM

Decades of data have demonstrated that exposure to loud sound for sustained periods of time can cause noise induced hearing loss, and exposure to loud music is no exception. Chasin (1996) reported that most professional musicians will eventually develop music induced hearing loss, and Royster et al. (1991) found that over half of symphony orchestra musicians had audiometric profiles consistent with noise induced hearing damage. In addition to hearing loss, excessive sound exposures can cause tinnitus, diplacusis (abnormal pitch perception), and hyperacusis, any of which can be debilitating and career threatening to those employed in the music industry. Audio engineers, recording engineers, sound crews, managers, disc jockeys, and music educators, as well as music students, are all exposed to high sound levels and all face a real risk of incurring permanent auditory damage. Typical sound levels that musicians are exposed to can be found in Chapter 1.

> **KEY POINT**
>
> In addition to hearing loss, excessive sound exposures can cause tinnitus, diplacusis, and hyperacusis, any of which can be debilitating and career threatening to those employed in the music industry.

DAMAGE RISK CRITERIA

Damage risk criteria are based on industrial noise, and whereas the music spectrum is quite different, damage risk criteria remain the best guidelines we have at present to estimate auditory risk and the need for hearing protection for music exposures. Two standards exist in the United States: Occupational Safety and Health Administration (OSHA) Occupational Noise Standard (OSHA, 1983) and National Institute for Occupational Safety and Health (NIOSH) Criteria for a Recommended Standard (NIOSH, 1998).

OSHA

When deciding which standard to use, it is important to keep in mind that the differences in these standards have a significant impact on auditory risk. The more liberal OSHA standard provides for a permissible exposure limit (PEL) of 90 dBA for 8 hours per day, 5 days per week, for a working lifetime of 40 years. OSHA uses a 5 dB time-intensity tradeoff; that is, for every 5 dB increase in noise level, the allowable exposure time is reduced by half (Table 6-1). The OSHA standard reflects a compromise between risk reduction and cost implementation for an industrial workforce, and the higher exposure limits result in a greater number of individuals incurring significant hearing loss.

KEY POINT

The OSHA standard uses a 5 dB exchange rate and reflects a compromise between risk reduction and cost implementation for an industrial workforce.

NIOSH

In contrast, the NIOSH criteria have a PEL of 85 dBA for 8 hours per day (5 dB less than the OSHA standard) with a 3 dB time-intensity tradeoff: for every 3 dB increase in noise level, the allowable exposure time is reduced by half. The NIOSH standard is based on scientific data, with an emphasis on hearing loss prevention. The choice of which standard to use impacts the risk of material hearing impairment; with a 40-year (working lifetime) exposure, the OSHA standard results in 25% excess risk for developing a material hearing impairment, whereas the NIOSH criteria result in 8% excess risk (NIOSH, 1998). As reported by Suter (2006), the vast majority of nations around the world use an 8-hour PEL of 85 dB with a 3 dB exchange rate, and in 2007 the Interna-

Table 6–1. Allowable daily exposures (OSHA and NIOSH)

	Noise level dBA							
	85	*88*	*90*	*92*	*94*	*95*	*97*	*100*
OSHA	16		8	6		4	3	2
NIOSH	8	4			1	3/4	1/2	1/4

Note. Adapted and used with permission from Etymotic Research, Inc.

tional Safety Equipment Association petitioned OSHA to adopt an 85 dBA PEL with a 3 dB exchange rate. It remains to be seen if OSHA will embark on the lengthy process of changing the noise standard.

> **KEY POINT**
>
> The NIOSH standard uses a 3 dB exchange rate and is based on scientific data, with an emphasis on hearing loss prevention.

Noise Dose

Because music levels vary widely, it is difficult to predict an individual's true exposure over time. However, a measure of noise dose (a measure integrating sound levels over time) provides a more accurate estimate of risk. Both the OSHA standard and the NIOSH criteria are based on noise dose, which is expressed as a percentage of the daily maximum permissible exposure. Using the NIOSH criteria, a 100% dose is equivalent to an 85 dBA time-weighted average for 8 hours (or 88 dBA for 4 hours, 91 dBA for 2 hours, and so on). See Table 6-2.

Table 6–2. Exposure levels and durations equivalent to a 100% noise dose based on the NIOSH criteria

Level (dBA)	*Duration*	*Dose %*
79	24	75
82	16	100
85	8	100
88	4	100
91	2	100
94	1	100
97	30 min	100
100	15 min	100
103	7.5 min	100
106	3.75 min	100

Note. For durations exceeding those shown, the resulting dose is larger; for example, a 91 dB exposure for 4 hours would be twice the daily limit (200% dose); 91 dB for 8 hours would be four times the daily limit (400% dose), and so on.

LIMITATIONS OF CONVENTIONAL EARPLUGS

Musicians need protection from excessive sound levels to prevent auditory injury, but they also need to hear, and hear well, while they play. Traditional earplugs are problematic for those in the music industry for three major reasons: unbalanced attenuation (too much high frequency attenuation); too much overall attenuation; and excessive occlusion effect.

Unbalanced Attenuation

Inserting an earplug into the ear removes the ear's natural resonant peak, which is approximately 17 dB at 2700 Hz in the average ear. When combined with the earplug's attenuation characteristics, this results in a net treble deficiency of 15 to 20 dB (Killion, 1993), causing music and voices to sound muffled. Most musical instruments have a significant amount of energy above 1000 Hz, with harmonics that are more intense than the fundamental (Chasin, 1996). Earplugs with too much high frequency attenuation destroy the tonal balance, which can result in mishearing or overplaying to compensate for the lack of high frequency sound heard through the earplugs. Overplaying, in turn, can cause other music-related injuries (e.g., wrist strain or injury in drummers).

Too Much Overall Attenuation

Standard hearing protectors often provide too much attenuation for those in the music industry: deeply inserted foam earplugs can provide 30 to 40 dB of sound reduction when far less may be needed to adequately protect hearing. Excessive attenuation can result in mishearing or overplaying, and in this case musicians often forego the use of hearing protection in an effort to hear the music better.

Occlusion Effect

Occlusion effect is an increase in sound pressure level at the eardrum in the occluded ear compared to the open ear for sounds generated by the user (e.g., vocalist, brass, or woodwinds). When a musician sings or blows into the mouthpiece of an instrument, sound is conducted via the jaw to the bone surrounding the inner one third of the ear canal. When earplugs provide a shallow seal (outer two thirds of the ear canal) the result is elevated sound pressure levels behind the earplug, which may put the musician at risk for overexposure.

> **KEY POINT**
>
> Traditional earplugs are problematic for those in the music industry because of unbalanced attenuation, too much overall attenuation, and excessive occlusion effect.

DESIGN AND RATIONALE FOR HIGH FIDELITY EARPLUGS

High fidelity earplugs reproduce sound as it is normally heard, but at a lower intensity, preserving the tonal balance of the music while reducing sound levels at the ear. Musicians Earplugs™ (Killion, DeVilbiss, & Stewart, 1988) were the first and are still the only custom high fidelity earplugs in the world. Musicians Earplugs consist of a deeply-fitted custom earmold combined with a patented attenuator button. As shown in Figure 6–1, the volume of air in the earmold bore acts as an acoustic mass, whereas the diaphragm in the attenuator button acts as an acoustic compliance. The combination of the two produces a resonance at approximately 2700 Hz (as in the average normal ear) resulting in a smooth, flat attenuation across frequency (Killion et al., 1988; Figure 6–2).

Shown another way, Musicians Earplugs preserve the tonal balance of the music, as can be seen in Figure 6–3. The overall level is reduced equally across

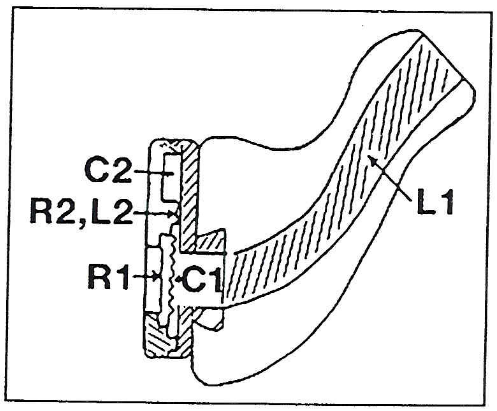


Figure 6–1. Line diagram of ER-15 Musicians Earplug. C = compliance; R = resistance; L = inductance.

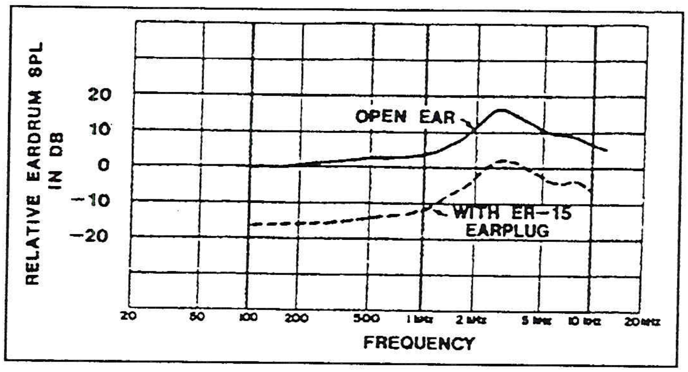


Figure 6–2. Expected eardrum SPL in diffuse (random incidence) sound field with ear open vs. ear occluded with ER-15 earplug. *Note.* From "An Earplug with Uniform 15-dB Attenuation," by M. C. Killion, E. DeVilbiss, & J. Stewart, 1988, *Hear Journal*, *41*(4), pp. 14–17. Used with permission.

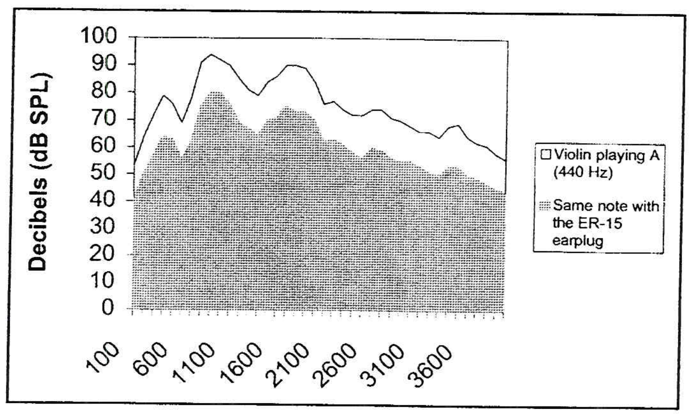


Figure 6–3. Musicians Earplugs preserve the tonal balance of the music. The overall level is reduced equally across the frequency range, thereby maintaining the spectral "shape."

the frequency range, thereby maintaining the "shape" of the music.

> **KEY POINT**
>
> High fidelity earplugs such as the ER-15 reproduce sound as it is normally heard, but at a lower intensity, preserving the tonal balance of the music while reducing sound levels at the ear.

GUIDELINES FOR CHOOSING ATTENUATORS

The interchangeable attenuator buttons are available in three values: 9, 15, and 25 dB, and Musicians Earplugs using these attenuators are referred to as the ER-9, ER-15, and ER-25. The optimal attenuator is the one that provides the minimum amount of attenuation that will reduce sound exposures to a safe level. As mentioned previously, too much attenuation can cause problems for musicians. Fortunately, the actual amount of attenuation needed is often less than one might expect, as Table 6–3 illustrates.

The ER-15 has the flattest frequency response, and is useful for most musical applications, whereas the ER-25 is recommended only for higher sound exposures (e.g., drummers, marching band drumlines, rock musicians, amplified music, and those located in front of the brass section). The ER-9 provides 9 dB of attenuation in the low frequencies and 14 to 15 dB of attenuation in the high frequencies and is often appropriate for solo practice and other situations in which less than 15 dB of protection is needed (e.g., viola players). Musicians often require at least two sets of attenuators (such as ER-15 and ER-25), which are interchangeable depending on the exposure level; this sometimes means using a different attenuator in each ear. Table 6–4 summarizes these recommendations for various music instrument categories.

Deeply-sealed earplugs are necessary to reduce the occlusion effect; thus, Musicians Earplugs should be long enough to seal deeply in the bony portion of the ear canal (Killion, 2003; Killion et al., 1988). On occasion, a bit of occlusion is desirable (e.g., for vocalists as an aid in self-monitoring), and if needed, this can be achieved with a slightly shorter plug that seals less deeply in the ear canal.

IMPORTANCE OF IMPRESSION TECHNIQUE

Because Musicians Earplugs are a custom product, they're ultimately only as good as the professional who fits them and the

Table 6–3. Limits of permissible exposure based on NIOSH

Level (dBA)	% Dose per Hour	% Dose 8 Hours	Time (Hours) to Reach 100% Dose: No EP	ER-9	ER-15	ER-25	ER-20
85	<25 (12.5)	100	8	24	24	24	24
88	25	200	4	24	24	24	24
91	50	400	2	16	24	24	24
94	100	800	1	8	24	24	24
97	200	1600	30 min	4	16	24	24
100	400	3200	15 min	2	8	24	22 (est.)
103	800	6400	7.5 min	1	4	24	14 (est.)
106	1600	12,800	3.8 min	30 min	2	20 (est.)	7 (est.)
109	3200	25,600	1.9 min	15 min	1	10 (est.)	3.5 (est.)

Note. Based on "Criteria for a Recommended Standard: Occupational Noise Exposure—Revised Criteria," by the National Institute for Occupational Safety and Health, 1998, Department of Health and Human Services (NIOSH) Publication No. 98-126.

Table 6–4. Recommended custom earplugs for various musical instrument categories. In some cases there is more than one possible fitting.

Instrument Category	*ER-9*	*ER-15*	*ER-25*	*Potential Harmful Sounds*
Small strings	✓	✓		Own/other instruments
Large strings	✓	✓		Brass
Woodwinds		✓		Brass, percussion
Brass		✓	✓	Other brass
Flutes		✓		Percussion
Percussion			✓	Own/other percussion
Vocalists	✓	✓		Speakers/monitors
Acoustic guitar	✓	✓		Percussion/speakers
Amplified instruments		✓	✓	Speakers/monitors
Marching bands		✓		Multiple sources
Music teachers		✓		Multiple sources
Recording engineers		✓		Speakers/monitors
Sound crews		✓		Speakers/monitors

earmold lab that makes them. Long impressions (past the second bend of the ear canal) are required so earmold laboratories can make earmolds that seal in the bony portion of the ear canal. Musicians may require extra reassurance while long impressions are taken. Whenever possible, musicians should play their instrument while the impressions are curing so that all normal mouth, jaw, and body movements (which affect the shape of the ear canal) are accounted for in the finished impressions (Santucci, personal communication, February 16, 2007). Impressions should have no gaps, and should extend past the second bend of the ear canal. Even experienced clinicians redo impressions, because properly fitting Musicians Earplugs cannot be made from inadequate impressions. Seal issues can often be resolved by taking impressions using a high viscosity silicone (Pirzanski, 2006). The musician should hold her mouth open while the silicone is injected, and then make normal movements (as in playing the instrument) while the impression is curing.

EARMOLD CONSTRUCTION

The sole manufacturer of attenuators for Musicians Earplugs is Etymotic Research, Inc. Earmold laboratories are held to rigorous standards of construction, so that earplugs made by any lab in the world should provide the same flat attenuation in the ear. Etymotic Research and its European affiliate conduct regular site visits to ensure uniform manufacturing practices. Labs use the same fundamental principles to determine sound bore dimensions and canal length, which produce flat attenuation when the buttons are attached to the custom earmolds. This is accomplished in part by measuring the correct volume of air in the finished mold with an acoustic mass meter. Certification is awarded to a lab when all criteria are met.

ORDERING OPTIONS

Earmolds for Musicians Earplugs are available in silicone or vinyl, with silicone having the advantage of significantly less shrinkage over time (Dillon, 2001). Typically one set of attenuator buttons is supplied with the earmolds, but additional attenuators can be ordered from the earmold lab at the time of the original order or at a later date. Attenuator buttons are available in clear, beige, red, or blue, and can be partially countersunk or completely countersunk into the earmolds (Figure 6-4).

FITTING MUSICIANS EARPLUGS

Musicians Earplugs should be fitted as part of a hearing loss prevention program that includes comprehensive baseline audiological testing and ongoing monitoring. Earplugs reduce sound levels at the ear only if a seal is achieved and they are worn consistently. Audiological monitoring provides the evidence needed to determine if the hearing loss prevention program is working. Musicians Earplugs require a professional fitting and orientation that includes verification of earmold fit and instruction on use and care of the earplugs. Earplugs should not cause discomfort or soreness, although a modified wearing schedule may be necessary at first for plugs that seal deeply. As with most earmolds, Musicians Earplugs can be washed with mild soap and water (after removing attenuator buttons). Vinyl molds will eventually shrink and harden over time, whereas silicone molds remain more stable (Dillon, 2001).

VERIFICATION OF PERFORMANCE

The attenuation of Musicians Earplugs can be measured using standard real-ear measurement protocols (measuring insertion loss rather than insertion gain). Real-ear measures can also be used to assess the degree of occlusion effect and the results of any corrective actions. Techniques for these measures are described by Chasin (1996, 1998), Revit (1992,

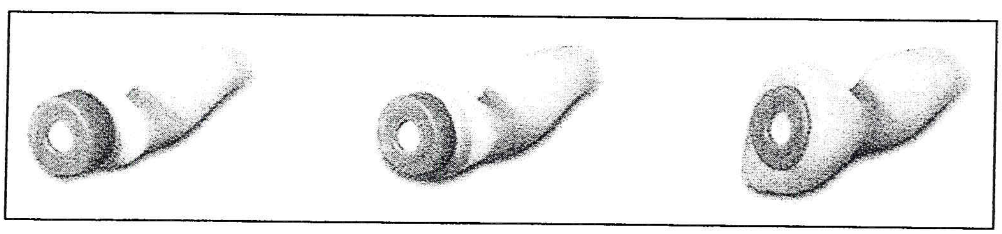


Figure 6–4. Custom Musicians Earplugs with attenuators placed. Standard, partially countersunk, and countersunk.

2000), and Mueller et al. (1992). The most common fitting issue encountered is reduced low frequency attenuation (unbalanced attenuation) caused by a leak in the earmold fit. When this occurs, the earmolds should be remade from new impressions. An occlusion effect of 20 dB is significant and should also be addressed by having the earmolds remade. Fit problems can often be successfully addressed by using a high viscosity silicone impression material and an open-jaw impression technique (Pirzanski, 2006). Every ear is unique and in some cases the geometry of the user's ear canals will impact the response of the finished product. Narrow ear canals can be particularly problematic; if the earmolds are long enough to seal in the bony portion of the ear canal, the bore diameter may not be wide enough to provide the high frequency boost needed to overcome insertion loss. Shortening the earmolds allows for a wider bore and better high frequency response but may increase the occlusion effect (which may not be an issue if the musician isn't a vocalist or horn player). The needs of each user must be taken into account in this situation.

NON-CUSTOM EARPLUGS FOR MUSICIANS

Shortly after the introduction of Musicians Earplugs, Etymotic Research and Aearo Corporation jointly developed and patented the ER-20™, a low cost, ready-fit, high fidelity earplug. The ER-20s use a tuned resonator and acoustic resistor (Figure 6–5) to provide an almost-flat 20 dB of sound reduction across frequency.

As with custom Musicians Earplugs, the optimal response with ER-20s (flat

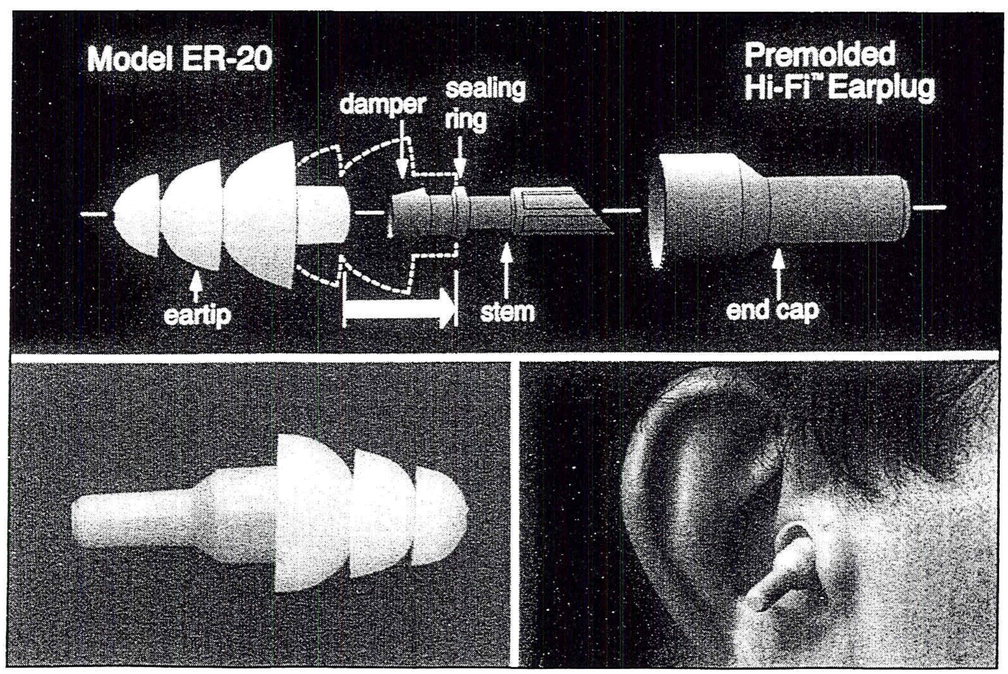


Figure 6–5. Construction of ER-20 earplug.

attenuation with little occlusion effect) is achieved when the earplugs seal deeply in the ear canals. Whereas the ER-20s fit most average size ears, they're too large for some adult ears and many children's ears. The ER-20 earplug shown in Figure 6–6a seals the ear, although not deeply. More importantly, the user reported it was uncomfortable and thus unlikely to be worn consistently. In 2006, Etymotic Research released BabyBlues™ earplugs, which provide the same 20 dB of flat attenuation as the ER-20s but have smaller eartips to fit smaller-than-average-size ear canals. The BabyBlues earplug shown in Figure 6–6b provides a deeper seal, and the same user reported it was comfortable for long periods of time.

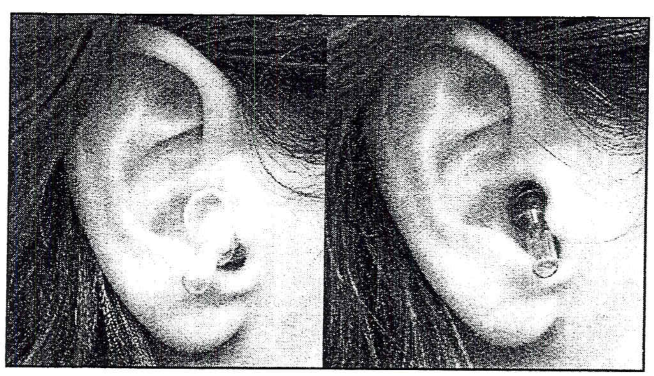
KEY POINT

The noncustom ER-20s use a tuned resonator and acoustic resistor to provide an almost-flat 20 dB of sound reduction across frequency.

The ER-20s and BabyBlues provide a high fidelity, low cost option so anyone can benefit from flat attenuation hearing protection. These earplugs are used by thousands of music educators and students in the United States. The most successful programs require the use of hearing protection for students exposed to damaging sound levels in school-based and school-sponsored activities (Palmer, 2007). These earplugs are also useful as a backup for anyone who uses custom Musicians Earplugs.

NOISE REDUCTION RATING (NRR)

The U.S. EPA requires manufacturers to print a noise reduction rating (NRR) on all noncustom earplugs. The required formula used to determine NRR includes an adjustment for individual variability and for those persons who do not wear ear protection as instructed. Many investigators have found no consistent rank order correlation between the real-world NRRs and labeled NRRs (Berger, 1999). NRR is computed from laboratory data that are not representative of the values attained in the real world by actual users. The NRR for the ER-20s is 12 dB, but clinical measurements of properly inserted ER-20s



A B

Figure 6–6. (**A**) ER-20 (**B**) BabyBlues.

indicate they provide almost equal sound reduction (20 dB) at all frequencies (E-A-RCAL, 1992).

SUMMARY

Musicians and music industry professionals are at significant risk of developing permanent auditory damage from high sound levels. Suggested exposure limits in the United States are based on two standards: Occupational Safety and Health Administration (OSHA) Occupational Noise Standard (OSHA, 1983) and National Institute for Occupational Safety and Health (NIOSH) Criteria for a Recommended Standard (NIOSH, 1998). The OSHA standard uses a 5 dB exchange rate that predicts less potential damage for a given exposure than does the NIOSH standard, which uses the 3 dB exchange rate. The 3 dB exchange rate is based on solid scientific studies. Both the OSHA and the NIOSH standards are based on noise dose, which is expressed as a percentage of the daily maximum permissible exposure.

Traditional earplugs are problematic for those in the music industry because of unbalanced attenuation, too much overall attenuation, and excessive occlusion effect. Custom Musician Earplugs (ER-9, ER-15, and ER-25) provide uniform attenuation, and when used properly minimize the risk for future hearing loss while still allowing the musician to be able to hear and monitor music. Noncustom versions (ER-20 and BabyBlues) provide a low cost, ready-fit option appropriate for all music enthusiasts.

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