The great irony of being a musician is that the sound produced—the very essence of the musical experience—represents a long-term health risk to the artist. This overview examines the lack of sufficient evidence-based studies on this at-risk population, which is particularly important in light of the low level of compliance to hearing-loss prevention programs among musicians. The review explores the number of musicians at risk, the five most common types of hearing loss affecting them, and the necessary components of a hearing-loss prevention program, including measurement, education, and acoustic modifications to the work environment. Hearing protection devices designed specifically for performing musicians are explored in depth, including the proper use of spectrum-neutral high-fidelity earplugs with in-ear monitoring systems as tools to control sound levels without detracting from the quality of musical performance.

The risk of hearing loss as a result of exposure to unsafe loudness levels in the music industry has been well documented. Despite a few conflicting studies on the issue of what is now referred to as music-induced hearing loss (MIHL), most investigators have agreed that there is a risk of MIHL for both acoustic and amplified instruments.1–4

The purpose of this review is not to argue whether or not live music is responsible for damage to the hearing mechanism of countless performers; rather, it is to investigate the research regarding MIHL beyond the debate of its actual existence. This review discusses the number of people who may be at risk, other types of hearing disorders caused by overexposure in addition to or besides actual loss of hearing, the types of preventative tools and prevention strategies that are currently being employed, and the lack of evidence-based research demonstrating the success of these strategies.

MUSCNIANS AT RISK

The subject of MIHL presents many challenges. For instance, there has been a surprising scarcity of research on strategies for hearing loss prevention and its effectiveness, especially considering the potential size of the population that may be at risk. While there is no accurate measurement of the number of at-risk musicians, one source available for the number of musicians is the US Census. The following are the total numbers for the occupation category “musicians and composers” as published by the US Census Bureau5 from 1930 to 2001.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>165,182</td>
</tr>
<tr>
<td>1983</td>
<td>155,000</td>
</tr>
<tr>
<td>1990</td>
<td>138,330</td>
</tr>
<tr>
<td>2001</td>
<td>161,000</td>
</tr>
</tbody>
</table>

In 2006, the US Department of Labor6 estimated that 264,000 musicians worked full time, part time, or were self-employed with 68,000 of them music directors/composers and 98,000 were musicians, singers, and related professions (musical instrument repairers and tuners, producers/directors, teachers, and actors). The 2007 sales report of the National Association of Music Merchants (NAMM), whose membership includes those who manufacture and sell musical instruments of all kinds, was $7.5 billion in new instrument sales.7 Sales of new music equipment in the US topped $7.4 billion in 2008, while 3 million new guitars were sold in 2006, about half of which (1.5 million) were electric with a corresponding 1.2 million guitar amplifiers sold in the same year. NAMM sales figures for other potentially loud instruments for 2007 include: power amplifiers for live concert sound reinforcement (600,000) and powered mixers (190,000), as well as almost 2 million drums, 650,000 cymbals, 3 million percussion instruments, 140,000 brass instruments, 241 million headphones/earphones, and 49 million single loudspeakers.7

These numbers indicate that the scope of MIHL may reach far beyond the 264,000 musicians identified by the US Department of Labor, which alone merits attention. Sales figures for new instruments suggest the number of musicians at risk could be much higher, and studies suggest that they should be taking precautions to protect their valuable hearing whether they are full time or part-time, professional or amateur musicians.

DEFINITION OF HEARING DAMAGE

Hearing disorders can manifest themselves in different ways. Kahari et al.8 identified five different hearing disorders caused...
by high sound levels of music: hearing loss, distortion, tinnitus (a conscious perception of sound in the absence of external sound), hyperacusis (decreased sound tolerance), and diplacusis (one pitch is heard as two or an inability to match pitch). Other than hearing loss, reports of tinnitus and decreased sound tolerance are higher than reports of diplacusis and distortion,\(^8\) and these are discussed in more detail here.

The American Tinnitus Association estimates that 50 million Americans may experience prolonged tinnitus, while tinnitus interferes with daily activities for up to 12 million Americans.\(^9\) Tinnitus has several causes. Diseases such as otosclerosis, Ménière’s disease, cardiovascular disease, otitis media, vestibular schwannoma, hyper- and hypothyroidism, and mechanical abnormalities in the jaw and neck, along with certain medications, can all result in some form of tinnitus.\(^10\)

In addition to these possible causes, exposure to loud music is an additional source of tinnitus for many performers. According to the National Institute on Deafness and Other Communication Disorders,\(^11\) anywhere from <1% to 10% of males and from 1% to 8.6% of females in the general population have reported chronic tinnitus, depending on age. Conversely, Latinen\(^12\) reported that 37% of the classical musicians he studied from five major orchestras reported temporary tinnitus. In addition, 18% of men and 15% of women reported chronic tinnitus, a significantly higher percentage than in the non-musician population.

Even more potentially debilitating to a musician’s career is decreased sound tolerance. There is no generally accepted term for decreased sound tolerance, although hyperacusis and phonophobia are used most frequently. Hyperacusis is defined as abnormal acuteness of hearing characterized by intolerance for ordinary sound levels. Hyperacusis can develop into phonophobia, which is described as an overwhelming fear of sound. Hyperacusis can be very problematic for performing musicians in that it not only interferes with loudness judgments, but it also can be a major source of physical discomfort and may interfere with daily life.

Hyperacusis, loss of frequency resolution (hearing loss), tinnitus, diplacusis, and distortion can result in compromised music perception and cognition, making it very difficult for those affected to continue working or practice music, which decreases the overall quality of daily life.

In 2003, Kaharit et al.\(^8\) assessed hearing and the incidence of hearing disorders in 139 rock/jazz musicians. Other purposes of the study were:

1. To correlate the high-frequency pure-tone average (HFPTA) values with reference population,\(^\text{13}\) taking age and sex into consideration;
2. To assess the incidence of other hearing disorders, such as tinnitus, hyperacusis, distortion, and diplacusis, in rock/jazz musicians and make comparisons with age-appropriate reference populations;\(^\text{14}\)
3. To assess the influence of low and high levels of weekly exposure to sound on pure-tone hearing thresholds in rock/jazz musicians; and
4. To report sound level measurements made on a random selection of musical performances.

The researchers’ initial hypothesis was that rock/jazz musicians do not have a higher proportion of hearing disorders than nonmusicians; however, the results of their study indicated otherwise:\(^8\)

Hearing disorders were found in 74% of 139 rock/jazz musicians. Hearing loss, tinnitus, and hyperacusis were the most common hearing disorders, and occurred significantly more often among rock/jazz musicians than in different reference populations. Hyperacusis and a combination of tinnitus and hyperacusis were significantly more common among women than among men, and hearing loss and the combination of hearing loss and tinnitus were significantly more common among men than among women. Men displayed slightly but significantly elevated hearing thresholds in the left ear as compared to the right.

The study concludes:

A high proportion of the rock/jazz musicians (74%) studied here do have hearing disorders, and more than 50% of the musicians had very distressing combinations of hearing disorders. Our initial hypothesis that rock/jazz musicians do not have a higher proportion of hearing disorders than nonmusicians must be rejected.

Kahari et al.\(^8\) further suggested that hearing problems such as tinnitus, hyperacusis, distortion, and/or diplacusis, in addition to hearing loss, are underestimated and should be defined as hearing disorders, and in the future they should be reported together with hearing loss. Perhaps the acronym should change from MIHL (music-induced hearing loss) to MIHD (music-induced hearing disorders) to reflect these important yet often unaccounted for abnormalities?

**PROTECTIVE STRATEGIES**

There are five components to any hearing loss prevention program:

1. sound level survey
2. audiometric monitoring
3. education and motivation
4. reducing level of exposure through environmental controls
5. hearing protection devices

**Sound Level Measurements and Audiometric Evaluation**

Sound level surveys for musicians present unique challenges. Unlike hearing loss prevention (HLP) in industrial settings in the United States, where company and worker participation in these five components is government mandated and regulated by the Occupational Safety and Health Administration (OSHA), HLP in the music industry is left totally to the individual, and participation is strictly on a voluntary basis. This alone may be one of the reasons there is an apparent lack of research on musicians and hearing disorders. Also complicating the matter is the fact that guidelines for safe exposure developed and refined by NIOSH and OSHA are for noise exposure.
Owens\textsuperscript{14} detailed the differences between NIOSH and OSHA standards and also provided an analysis of sound levels from select orchestral instruments. His conclusion was:

Musicians require high levels of hearing accuracy for their work. Standards specific to the needs of musicians should be developed. Lacking specific standards at this point, the NIOSH standards are good guidelines for musicians to follow.

There is no guideline specifically designed for music exposure. Consequently, hearing professionals have no other choice than to use these well-established guidelines for noise.

Sound surveys indicated that orchestral musicians were exposed to levels ranging from 83 dB to 97 dBA $L_{eq}$\textsuperscript{2,16} Kahari et al.\textsuperscript{5} measured musical $L_{Aeq}$ ranging from 91.4 dBA to as high as 115 dBA for rock/jazz musicians. ($L_{eq}$ is best described as the average sound level over a given period of measurement, and $L_{Aeq}$ is the A-weighted $L_{eq}$.) Phillips and Mace\textsuperscript{6} took sound level measurements in music practice rooms at a university school of music and recorded averages of 87 to 95 dBA, reporting that 45\% of the students exceeded the allowable exposure level.

Although the recommended NIOSH regulations are more protective than OSHA regulations for those working in noisy environments, some music styles make it difficult to comply with the NIOSH standard. In these cases, it is recommended that the performer attempt to comply with the OSHA standard. Although the risk of developing MIHD is 8\% using the NIOSH standard, 25\% using the OSHA guideline, 18 even more essential for musicians. Without a baseline test and repeat testing, individuals have no way of determining if the preventative measures are effective. A baseline hearing test should be as routine as visiting the dentist.

### Education

Educating musicians on the risks involved with their particular work environment, informing them of appropriate prevention strategies, and recommending periodic hearing evaluations are essential to the success of any HLP program.

The effectiveness of a hearing loss prevention program within a college music school may be dependent on attitudes of the students. Chesky et al.\textsuperscript{19} assessed the attitudes of music majors toward noise and compared them to those of students not majoring in music. Results showed that music majors have a healthier attitude toward sound compared to students not majoring in music and that music majors may be more likely than other students to respond to and benefit from a hearing loss prevention program. Their conclusion:

Considering that music majors would be more likely than non-music majors to practice hearing conservation, schools of music should support healthy attitudes through the establishment of hearing conservation programs similar to those in other areas (e.g., hunting, industry, military, etc.).

### Acoustic Modifications to the Work Environment

Environmental changes to the rehearsal or performance space can help to reduce risk of MIHD. Chasin\textsuperscript{20} reviewed instrument-specific environmental modifications, such as adding baffles or risers, to help orchestral musicians. He suggested the following:

1. Speaker/amplifier enclosures should be elevated.
2. Treble brass instruments should be on risers (or at least not on the playing plane of other musicians downwind).
3. The orchestra/band should be set back from the edge of the stage, allowing the higher frequency instruments and voices that reflect off the stage floor to better reach the audience.
4. Treble stringed instruments should be away from overhangs since high frequencies are easily absorbed by acoustically treated surfaces.
5. The use of baffles.
6. Changing the location of certain instruments.

### HEARING PROTECTION DEVICES

Unfortunately, in professional life, most musicians do not have the opportunity or the time to modify the acoustics of a wedding hall, nightclub, or large arena. Often these rooms are reverberant with tight quarters in the performance areas. Aware of the potential danger and unable to modify the performance area acoustics, the use of hearing protection devices may be the only practical choice a musician has to reduce the risk of MIHD. The most commonly used devices are custom-fitted earplugs with flat attenuation and in-ear monitoring systems.

Ear plugs made for nonmusical purposes are a poor choice for musicians because they alter the frequency response of the music and usually provide too much attenuation of high pitches for music performance.\textsuperscript{4} In 1989, Etymotic Research, Inc., introduced earplugs that reduce sound levels with little change to pitch, spectral resolution, or overall balance.\textsuperscript{22} The custom-fitted ER Series high-fidelity earplugs were developed specifically as hearing protectors for musicians who were unable to use traditional ear plugs. The musician is able to select between three interchangeable filters which provide 9, 15, or 25 dB of sound reduction (Figure 1). The best attenuator is the one that provides the minimum compromise to sound quality but still meets OSHA or NIOSH guidelines. The ER20 is a one-size-fits-all style with 20 dB of attenuation and mainly intended for concert attendees or musicians on a strict budget.

Although the ER Series of ear plugs overcomes some of the limitations of traditional hearing protection, it appears that usage levels among musicians are still far from ideal. In his study, Latinen\textsuperscript{12} surveyed 134 men and 62 women from five different orchestras. He found that 94\% of the respondents were concerned about their hearing to some degree, 31\% reported some hearing loss, 37\% reported tinnitus, and 43\% reported hyperacusis, yet only 6\% of the musicians always used hearing protector devices (HPDs). Hearing protectors were used more often among musicians having ear symptoms (20\%) than those reporting no symptoms (6\%).
Latinen proposes that education about typical hearing disorders and how to deal with them might lead to increased usage of HPDs.

Zander et al. found similar results of low usage on a survey of 429 musicians from classical symphony and opera orchestras. He calls for more audiological studies that can optimize and further develop hearing protectors. In this study, the most important factor for the musicians was the sonority of their own instruments, but they see it as the aspect least featured in current hearing protectors. Although ER Series hearing protectors have been evaluated as “the least poor,” only 16% of those surveyed used them.

Cheskey et al., in a 2009 study, assessed the attitudes of 323 college music students regarding the comfort, ability to communicate in a musical environment, and ability to play music using the generic ER20 ear plugs. Although most subjects liked the ER20s, they were not willing to use them while playing their instruments. Unfortunately, the study did not evaluate the more commonly recommended and used ER custom plugs. Would the results have been similar using a deep-seated, custom-fitted plug with 9 dB of attenuation?

Little research has been performed on other factors that might result in the decision for or against hearing protection. There is also an absence of evidence-based data that demonstrate the effectiveness of using custom HPDs in the musical performance, and therefore none can be presented here. This article hopes to incite more research in this important area.

In-Ear Monitoring

In larger arenas, musicians need to hear themselves on stage over myriad competing sound sources. The development of personal in-ear monitors was driven by the need to provide an onstage listening experience that surpassed the limitations of traditional loudspeaker systems.

The public address system, crowd noise, onstage amplifiers, and escalating volume levels from other performers trying to hear themselves all add to the difficulty of hearing one’s own instrument or voice during a live performance. The solution has been to place wedgeshaped loudspeakers on stage facing the musicians, pointed at the musicians’ knees so they do not block sight lines for the audience. With the ever-increasing size of venues and stages, more loudspeakers are needed to provide sound to all areas of the concert venue. As a result, the performers are forced to increase the volume of their monitor loudspeakers to hear over the competing sound sources, and they are exposed to ear-shattering sound levels.

Because the objective of onstage monitor systems is to allow the performers to hear themselves, presenting the monitor mix through smaller speakers at or in the ear is an attempt to address the shortcomings of speakers placed on stage. Bands using in-ear monitoring systems can remove all or most floor monitors from the stage, reducing onstage volume levels significantly. The goal of successful personal monitor use is to provide a full-bandwidth stereo mix to the performer on stage while acoustically blocking out the competing sound sources so that in-ear sound levels can be reduced.

A personal in-ear monitoring system consists of a belt-pack amplifier that is either hard-wired or wireless and a set of earphones with tiny loudspeakers (Figures 2 and 3). The best fit, comfort, and sound quality come from custom-molded earpieces. Custom personal monitors that are not vented and fit with a tight acoustic seal can provide 25 dB or more of attenuation. Personal monitors are not hearing protection devices by design. Because they are amplifier driven and their output level is controlled by the musician, personal monitors can produce sound levels commensurate with on stage floor monitors, leaving ample room for misuse.

Federman and Ricketts studied first-time users of personal monitors and found that preferred listening levels for floor and in-ear monitors were only ~0.6 dB different, suggesting that musicians were not protecting their hearing simply by using in-ear monitors. When asked to reduce floor and in-ear monitor levels to a minimum acceptable listening level, the subjects were only able to turn down the floor monitors 0.6 dB to reach minimally acceptable levels. The same subjects were able to minimally accept reduced volume levels by 6 dB using personal monitors, demonstrating their potential efficacy. This study suggests that personal monitors themselves do not protect hearing—it is the behavior while using them that can reduce sound levels and offer protection.

Given the fact that personal monitors are capable of producing damaging sound levels and that most musicians will turn them to the volume they are accustomed to, the performer must be directed toward safe usage, either through probe-mic

FIGURE 1. Etymotic ER series custom ear plug (Sensaphonics, Chicago, IL; used with permission).

FIGURE 2. Custom personal monitors (Sensaphonics, Chicago, IL; used with permission).
measurements taken during a sound check or rehearsal or from manufacturers-specific sound level measurement devices. From these readings, musicians can be directed to safe levels using time-weighted averages. Regardless, musicians should monitor their hearing status on a regular basis to ensure that the personal monitors are used at a safe listening level.

CONCLUSION

Musicians depend on good hearing to optimize their careers, yet compliance with HLP recommendations is poor. This inequity is alarming, especially considering the underestimated size of this population. If other types of hearing disorders caused by overexposure besides actual loss of hearing are considered, it appears that almost 75% of career musicians could be affected. Despite an increased awareness about the possible risks and innovations in HPDs specifically designed for musicians, such as high-fidelity ear plugs and personal monitors, only a small percentage of musicians use these devices in rehearsals or performances to protect their hearing. What are the reasons? Why do some musicians reject utilizing ER series plugs while others refuse to play without them?

The lack of evidence-based research demonstrating the success of HPDs and strategies is surprising. The lack of research about music and hearing in general is startling. This is a wake up call to all the stakeholders in HLP for musicians to initiate much needed research. Should there be a damage risk criteria developed specifically for music? What is the long term success of a well-designed and observed HLP program? Where is the evidence-based data demonstrating the effectiveness of HLP devices?

The common thread for most researchers is a call for increased education on the dangers of loud music and its effects on musical careers. Educational campaigns should start at the elementary school level and continue all the way through college music programs. HLP programs should focus on helping musicians understand the risk of music-induced hearing loss, on environmental and equipment changes that can reduce risk, on the pros and cons of HPDs, and on the consequences of not preserving one’s hearing.

REFERENCES

9. American Tinnitus Association: FAQ’s about tinnitus [webpage]. Portland, OR: ATA; 2009. Available at: http://www.ata.org/about-tinnitus/patient-faq1#How many people have tinnitus...